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Alternative Stormwater Management: Low Impact Development

Instructor: Cory L. Horton, P.E.

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Low-Impact Development Design Strategies

An Integrated Design Approach

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Prepared by:

Prince George's County, Maryland

Department of Environmental Resources

Programs and Planning Division

June 1999

Low-Impact Development:
An Integrated Design Approach

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Prepared by:
Prince George's County, Maryland
Department of Environmental Resource
Programs and Planning Division
9400 Peppercorn Place
Largo, Maryland 20774

Wayne K. Curry
County Executive

Prince George's County
Department of Environmental Resources

Samuel E. Wynkoop, Jr.
Director

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Preface

Low-impact development (LID) is a radically different approach to conventional stormwater management. It is our belief that LID represents a significant advancement in the state of the art in stormwater management. LID enhances our ability to protect surface and ground water quality, maintain the integrity of aquatic living resources and ecosystems, and preserve the physical integrity of receiving streams. Prince George's County, Maryland's Department of Environmental Resources has pioneered several new tools and practices in this field, which strive to achieve good environmental designs that also make good economic sense. The purpose of this manual is to share some of our experiences, and show how LID can be applied on a national level.

The LID principles outlined in these pages were developed over the last three years specifically to address runoff issues associated with new residential, commercial, and industrial suburban development. Prince George's County, which borders Washington, DC, is rich with natural streams, many of which support game fish. Preserving these attributes in the face of increasing development pressure was the challenge, which led to the development of LID techniques.

We describe how LID can achieve stormwater control through the creation of a hydrologically functional landscape that mimics the natural hydrologic regime. This objective is accomplished by:

- Minimizing stormwater impacts to the extent practicable. Techniques presented include reducing imperviousness, conserving natural resources and ecosystems, maintaining natural drainage courses, reducing use of pipes, and minimizing clearing and grading.

- Providing runoff storage measures dispersed uniformly throughout a site's landscape with the use of a variety of detention, retention, and runoff practices.

- Maintaining predevelopment time of concentration by strategically routing flows to maintain travel time and control the discharge.

- Implementing effective public education programs to encourage property owners to use pollution prevention measures and maintain the on-lot hydrologically functional landscape management practices.

LID offers an innovative approach to urban stormwater management—one that does not rely on the conventional end-of-pipe or in-the-pipe structural methods but instead uniformly or strategically integrates stormwater controls throughout the urban landscape.

We wish to thank the US Environmental Protection Agency for their encouragement and support of this document. In particular, Robert Goo and Rod Frederick of EPA's Office of Water, Nonpoint Source Control Branch. I would also like to acknowledge the contributions of the many highly dedicated professionals who contributed to the development of LID technology, especially Dr. Mow-Soung Cheng and Derek Winogradoff of Prince George's County and the Tetra Tech project team led by Dr. Mohammed Lahlou and including: Dr. Leslie Shoemaker, Michael Clar, Steve Roy, Jennifer Smith, Neil Weinstein, and Kambiz Agazi.

It is my hope that the release of this manual will stimulate a national debate on this promising form of stormwater management. We are currently developing new LID principles and practices directly applicable to such issues as urban retrofit, combined sewer overflow, and highway design. This manual represents only the beginning of a new paradigm in stormwater management. I hope that you will take up the challenge and work with us to further develop LID practices.

Larry Coffman, Director
Programs and Planning Division
Department of Environmental Resources
Prince George's County, Maryland

Chapter 1
Introduction

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Chapter 1

Introduction

Figure 1-1. Parking lot bioretention area

The low-impact development (LID) approach combines a hydrologically functional site design with pollution prevention measures to compensate for land development impacts on hydrology and water quality. As shown in Figure 1-1, a parking lot bioretention area, LID techniques not only can function to control site hydrology, but also can be aesthetically pleasing.

In This Chapter…

Low-Impact Development Goals

The primary goal of Low Impact Development methods is to mimic the predevelopment site hydrology by using site design techniques that store, infiltrate, evaporate, and detain runoff. Use of these techniques helps to reduce off-site runoff and ensure adequate groundwater recharge. Since every aspect of site development affects the hydrologic response of the site, LID control techniques focus mainly on site hydrology.

There is a wide array of impact reduction and site design techniques that allow the site planner/engineer to create stormwater control mechanisms that function in a manner similar to that of natural control mechanisms. If LID techniques can be used for a particular site, the net result will be to more closely mimic the watershed's natural hydrologic functions or the water balance between runoff, infiltration, storage, groundwater recharge, and evapotranspiration. With the LID approach, receiving waters may experience fewer negative impacts in the volume, frequency, and quality of runoff, so as to maintain base flows and more closely approximate predevelopment runoff conditions.

The goals of low-impact development are discussed and demonstrated throughout the manual. The list below highlights some of the main goals and principles of LID:

- Provide an improved technology for environmental protection of receiving waters.
- Provide economic incentives that encourage environmentally sensitive development.
- Develop the full potential of environmentally sensitive site planning and design.
- Encourage public education and participation in environmental protection.
- Help build communities based on environmental stewardship.
- Reduce construction and maintenance costs of the stormwater infrastructure.
- Introduce new concepts, technologies, and objectives for stormwater management such as micromanagement and multifunctional landscape features (bioretention areas, swales, and conservation areas); mimic or replicate hydrologic functions; and maintain the ecological/biological integrity of receiving streams.

- Encourage flexibility in regulations that allows innovative engineering and site planning to promote "smart growth" principles.

- Encourage debate on the economic, environmental, and technical viability and applicability of current stormwater practices and alternative approaches.

LID is a comprehensive technology-based approach to managing urban stormwater. Stormwater is managed in small, cost-effective landscape features located on each lot rather than being conveyed and managed in large, costly pond facilities located at the bottom of drainage areas. The source control concept is quite different from conventional treatment (pipe and pond stormwater management site design). Hydrologic functions such as infiltration, frequency and volume of discharges, and groundwater recharge can be maintained with the use of reduced impervious surfaces, functional grading, open channel sections, disconnection of hydrologic flowpaths, and the use of bioretention/filtration landscape areas. LID also incorporates multifunctional site design elements into the stormwater management plan. Such alternative stormwater management practices as on-lot microstorage, functional landscaping, open drainage swales, reduced imperviousness, flatter grades, increased runoff travel time, and depression storage can be integrated into a multifunctional site design (Figure 1-2).

Specific LID controls called Integrated Management Practices (IMPs) can reduce runoff by integrating stormwater controls throughout the site in many small, discrete units. IMPs are distributed in a small portion of each lot, near the source of impacts, virtually eliminating the need for a centralized best management practice (BMP) facility such as a stormwater management pond. By this process, a developed site can be designed as an integral part of the environment maintaining predevelopment hydrologic functions through the careful use of LID control measures. IMPs are defined and described in Chapter 4, Low-Impact Development Integrated Management Practices.

LID designs can also significantly reduce development costs through smart site design by:

- Reducing impervious surfaces (roadways), curb, and gutters

- Decreasing the use of storm drain piping, inlet structures, and

- Eliminating or decreasing the size of large stormwater ponds.

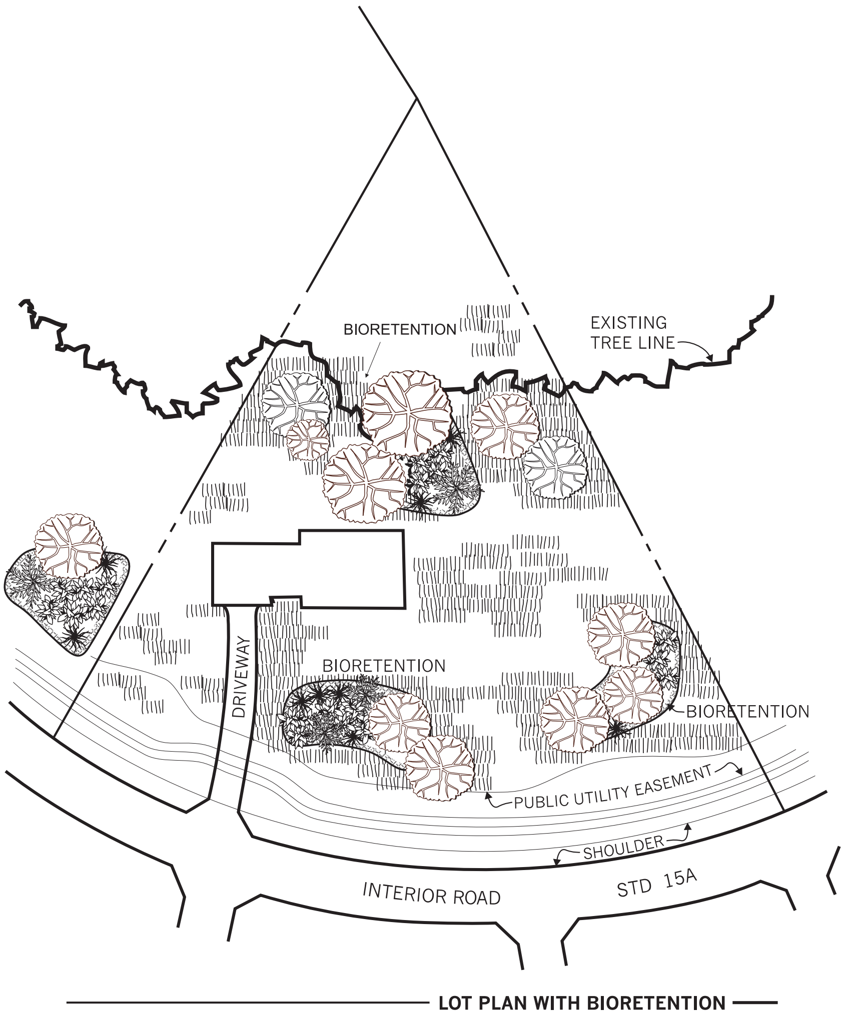


Figure 1-2

Residential lot with LID features

In some instances, greater lot yield can be obtained using LID techniques, increasing returns to developers. Reducing site development infrastructure can also reduce associated project bonding and maintenance costs.

Comparing Conventional Stormwater Management Site Design With Lid Site Design

One paradigm has typically dominated site planning and engineering—"Stormwater runoff is undesirable and must be removed from the site as quickly as possible to achieve good drainage." Current site development techniques result in the creation of an extremely efficient stormwater runoff conveyance system. Every feature of a conventionally developed site is carefully planned to quickly convey runoff to a centrally located management device, usually at the end of a pipe system. Roadways, roofs, gutters, downspouts, driveways, curbs, pipes, drainage swales, parking, and grading are all typically designed to dispose of the runoff in a rapid fashion. The magnitude of hydrologic changes (increases in volume, frequency, and rate of discharge) are amplified as natural storage is lost, the amount of impervious surfaces is increased, the time of concentration is decreased, runoff travel times are decreased, and the degree of hydraulic connection is increased. Typical conventional site design results in developments devoid of natural features that decrease travel times and that detain or infiltrate runoff. Lack of these features often adversely affects the ecosystem.

In contrast, the principal goal of low-impact development is to ensure maximum protection of the ecological integrity of the receiving waters by maintaining the watershed's hydrologic regime. This goal is accomplished by creatively designing hydrologic functions into the site design with the intent of replicating the predevelopment hydrology and thus having a significant positive effect on stream stability, habitat structure, base flows, and water quality. It is well documented that some conventional stormwater control measures can effectively remove pollutants from runoff. Water quality, however, is only one of several factors that affect aquatic biota or the ecological integrity of receiving streams. Fish macroinvertebrate surveys have demonstrated that good water quality is not the only determinant of biological integrity. In fact, the poor condition of the biological communities is usually attributed to poor habitat structure (cover, substrate, or sedimentation) or hydrology (inadequate base flow, thermal fluxes, or flashy hydrology). A conclusion that can be drawn from these studies and from direct experience is that perhaps stormwater pond technology is limited in its ability to protect the watershed and cannot reproduce predevelopment hydrological functions. With this in mind, LID can be a way to bridge this gap in protecting aquatic biota and provide good water quality as well. This manual was developed to provide a reference and a model for practitioners to use in experimenting with and applying LID techniques across the nation.

How to Use This Manual

Low-impact development allows the site planner/engineer to use a wide array of simple, cost-effective techniques that focus on site-level hydrologic control. This manual describes those techniques and provides examples and descriptions of how they work. It does not discuss detailed site planning techniques for the conservation of natural resources (trees, wetlands, streams, floodplains, steep slopes, critical areas, etc.). Such site features/constraints are typically addressed as part of existing county, state, and federal regulations. Compliance with the existing regulations is the starting point for defining the building envelope and the use of LID techniques. Once the basic building envelope has been defined, LID techniques may provide significant economic incentives to improve environmental protection and expand upon the conservation of natural resources areas. The manual has been formatted in a manner that allows the designer to incorporate LID into a specific building envelope in a logical step-by-step approach.

For ease of use and understanding, this document has been divided into six chapters and appendices. A glossary is provided at the end of the document. Figure 1-3 summarizes the major components of the LID approach.

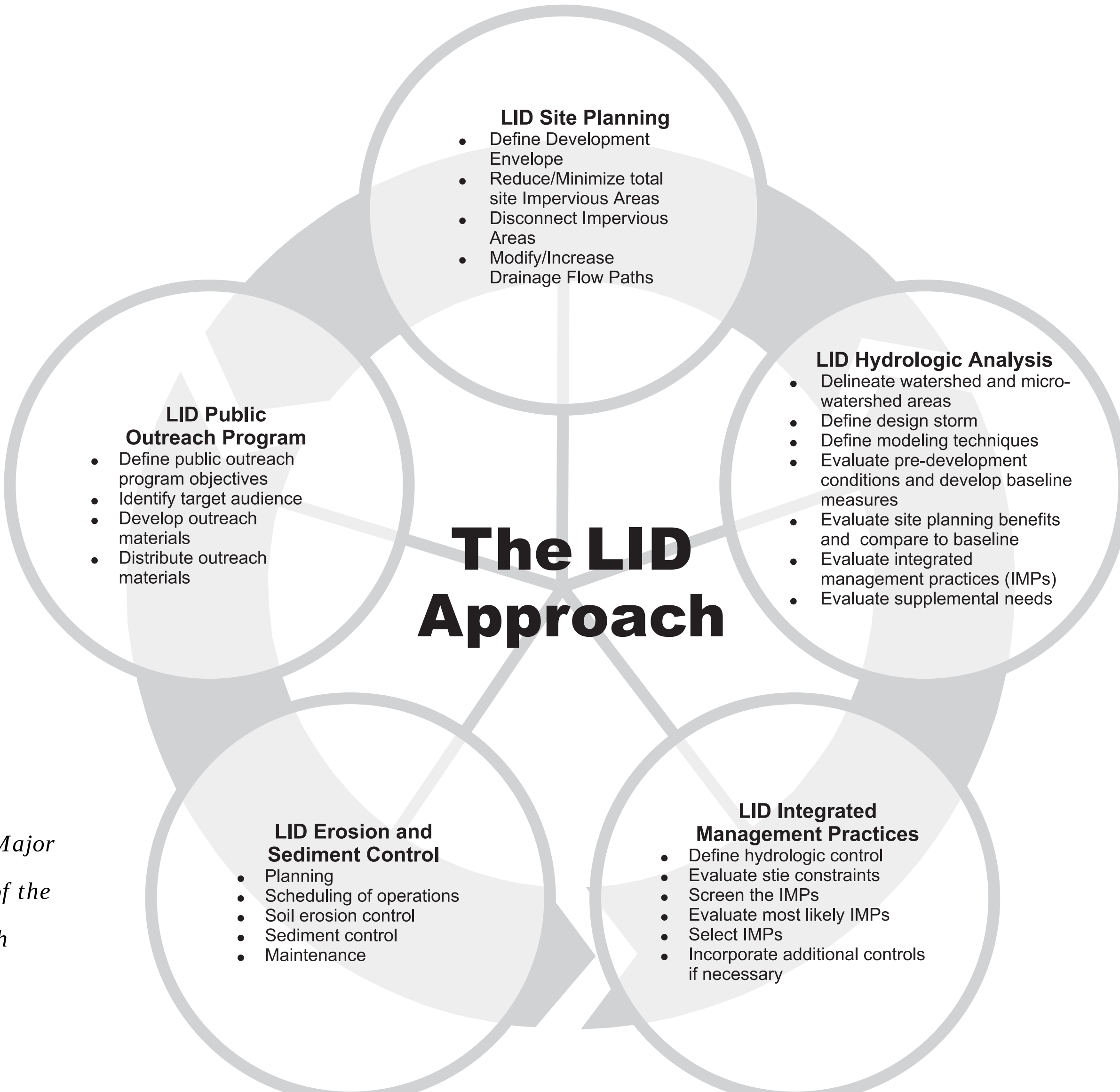


Figure 1-3. Major components of the LID approach

Chapter 1. Introduction

Chapter 2. Low-Impact Development Site Planning. The site design philosophy and site planning techniques are described and illustrated in this chapter.

Chapter 3. Low-Impact Development Hydrologic Analysis. This chapter provides an overview and general description of the key hydrologic principles involved in low-impact development, and provides guidance on the hydrologic analysis required for the design of LID sites.

Chapter 4. Low-Impact Development Integrated Management Practices. Selection criteria and descriptions for specific LID IMPs are provided along with fact sheets on IMPs.

Chapter 5. Erosion and Sediment Control Considerations for Low-Impact Development. Erosion and sediment control and LID principles are closely interrelated since LID technology can result in improved erosion and sediment control. Chapter 5 addresses that relationship.

Chapter 6. Low-Impact Development Public Outreach Program. Chapter 6 explains why LID approaches require the education of homeowners, landowners, developers, and regulators and offers suggestions for conducting a successful public outreach program.

Appendix A. Example LID Hydrologic Computation

Appendix B. Sample Maintenance Covenant

Glossary.

Chapter 2
Low-Impact Development Site Planning

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Chapter 2

Low-Impact Development Site Planning

Introduction

Site planning strategies and techniques provide the means to achieve stormwater management goals and objectives; facilitate the development of site plans that are adapted to natural topographic constraints; maintain lot yield; maintain site hydrologic functions; and provide for aesthetically pleasing, and often less expensive stormwater management controls. Hydrologic goals and objectives should be incorporated into the site planning process as early as possible.

The goal of LID site planning is to allow for full development of the property while maintaining the essential site hydrologic functions. This goal is accomplished in a series of incremental steps, which are presented in this chapter. These steps include first minimizing the hydrologic impacts created by the site development through site design and then providing controls to mitigate or restore the unavoidable disturbances to the hydrologic regime. The hydrologic disturbances are mitigated with the use of an at-source control approach, in contrast to the currently used end-of-pipe control approach. The newer approach results in the creation of hydrologically functional landscapes that preserve and maintain the essential hydrologic functions of the development site and the local watershed.

Lot Yield

The total number of buildable lots within the development

In This Chapter…

Fundamental LID Site Planning Concepts

A few fundamental concepts that define the essence of low-impact development technology must be integrated into the site planning process to achieve a successful and workable plan. These concepts are so simple that they tend to be overlooked, but their importance cannot be overemphasized. These fundamental concepts include:

- Using hydrology as the integrating framework
- Thinking micromanagement
- Controlling stormwater at the source
- Using simplistic, nonstructural methods
- Creating a multifunctional landscape

These fundamental concepts are defined in the following sections.

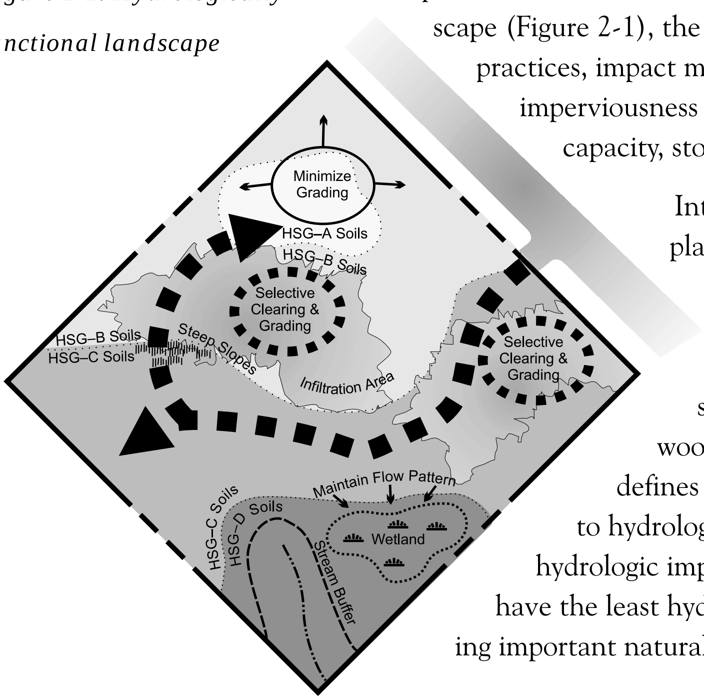
Hydrology

The movement of water into and across the site

Concept 1 - Using Hydrology as the Integrating Framework

In LID technology, the traditional approach to site drainage is reversed to mimic the natural drainage functions. Instead of rapidly and efficiently draining the site, low-impact development relies on various planning tools and control practices to preserve the natural hydrologic functions of the site. Planners may begin by asking, "What are the essential predevelopment hydrologic functions of the site, and how can these essential functions be maintained while allowing full use of the site?" The application of low-impact development techniques results in the creation of a hydrologically functional landscape (Figure 2-1), the use of distributed micromanagement practices, impact minimization, and reduced effective imperviousness allowing maintenance of infiltration capacity, storage, and longer time of concentration.

Figure 2-1. Hydrologically functional landscape



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

Potential site development and layout schemes are then evaluated to reduce, minimize, and disconnect the total impervious area at the site. Further analysis is then conducted on the unavoidable impervious areas to minimize directly connected impervious surfaces. Bioretention areas, increased flow paths, infiltration devices, drainage swales, retention areas, and many other practices can be used to control and break up these impervious areas. The end result is an integrated hydrologically functional site plan that maintains the predevelopment hydrology in addition to improving aesthetic values and providing recreational resources by adding additional landscape features.

Development envelope

The total site areas that affect the hydrology (i.e., lots to be developed, streams, buffers, floodplains, wetlands, slopes, soils, and woodlands.

Concept 2 - Thinking Micromanagement

The key to making the LID concept work is to think small. This requires a change in perspective or approach with respect to the size of the area being controlled (i.e., microsubsheds), the size of the control practice (microtechniques), siting locations of controls, and the size and frequency of storms that are controlled. Micromanagement techniques implemented on small sub catchments, or on residential lots, as well as common areas, allow for a distributed control of stormwater throughout the entire site. This offers significant opportunities for maintaining the site's key hydrologic functions including infiltration, depression storage, and interception, as well as a reduction in the time of concentration. These micromanagement techniques are referred to as integrated management practices (IMPs).

Interception

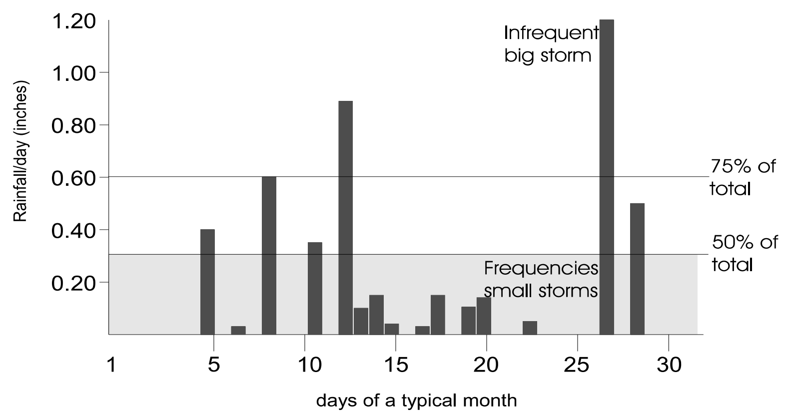
Water trapped on vegetation before reaching the ground

Figure 2-2 presents a typical month's rainfall in the San Francisco Bay area, showing how small storms plus the first increment of the bigger storms account for half of the total rainfall volume. These small storms, because of their frequency and cumulative impacts, make the largest contribution to total annual runoff volume and have the greatest impact on water quality and receiving water hydrology.

Other advantages of micromanagement techniques include the following:

- Provide a much greater range of control practices that can be used and adapted to site conditions.
- Allow use of control practices that can provide volume control and maintain predevelopment groundwater

Figure 2-2. Frequency of small storms at San Francisco International Airport (Source: BASMAA, 1997)



Depression storage

Small, water-holding pockets on the land surface

recharge functions, thereby compensating for significant alterations of infiltration capacity.

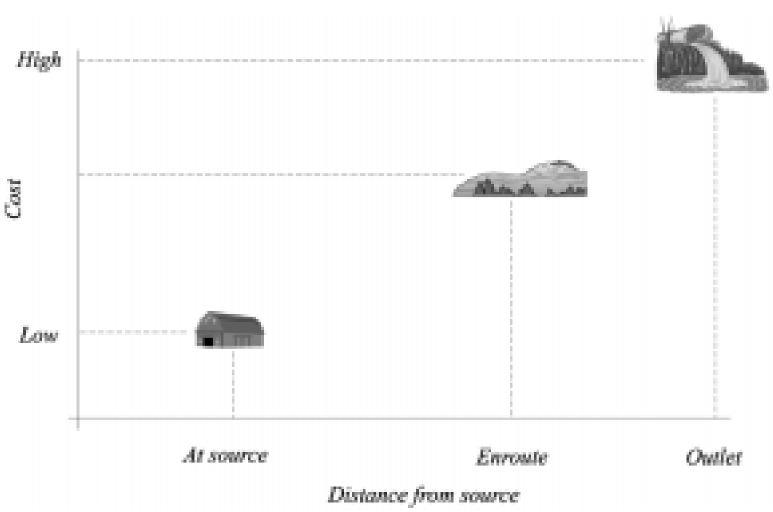
- Allow on-lot control practices to be integrated into the landscape, impervious surfaces, and natural features of the site.
- Reduce site development and long-term maintenance costs through cost-effective designs and citizen participation and acceptance.

Concept 3 - Controlling Stormwater at the Source

The key to restoring the predevelopment hydrologic functions is to first minimize and then mitigate the hydrologic impacts of land use activities closer to the source of generation. Natural hydrologic functions such as interception, depression storage, and infiltration are evenly distributed throughout an undeveloped site. Trying to control or restore these functions using an end-of-pipe stormwater management approach is difficult, if not impossible. Therefore, compensation or restoration of these hydrologic functions should be implemented as close as possible to the point or source, where the impact or disturbance is generated. This is referred to as a distributed, at-source control strategy and is accomplished using micromanagement techniques throughout the site. The distributed control strategy is one of the building blocks of low-impact development.

The cost benefits of this approach can be substantial. Typically, the most economical and simplistic stormwater management strategies are achieved by controlling runoff at the source. Conveyance system and control or treatment structure costs increase with distance from the source (Figure 2-3).

Figure 2-3. Relative cost as a function of distance from source (Source: BASMAA, 1997)



Concept 4 - Utilization of Simplistic, Nonstructural Methods

Traditionally, most stormwater management has focused on large end-of-pipe systems and there has been a tendency to overlook the consideration of small simple solutions. These simple solutions or systems have the potential to be more effective in preserving the hydrologic functions of the landscape and they can offer significant advantages over conventional engineered facilities such as ponds or concrete conveyances. In some cases LID techniques will need to be combined with traditional stormwater controls.

The use of LID techniques can decrease the use of typical engineering materials such as steel and concrete. By using materials such as native plants, soil and gravel these systems can be more easily integrated into the landscape and appear to be much more natural than engineered systems. The "natural" characteristics may also increase homeowner acceptance and willingness to adopt and maintain such systems.

Small, distributed, microcontrol systems also offer a major technical advantage: one or more of the systems can fail without undermining the overall integrity of the site control strategy.

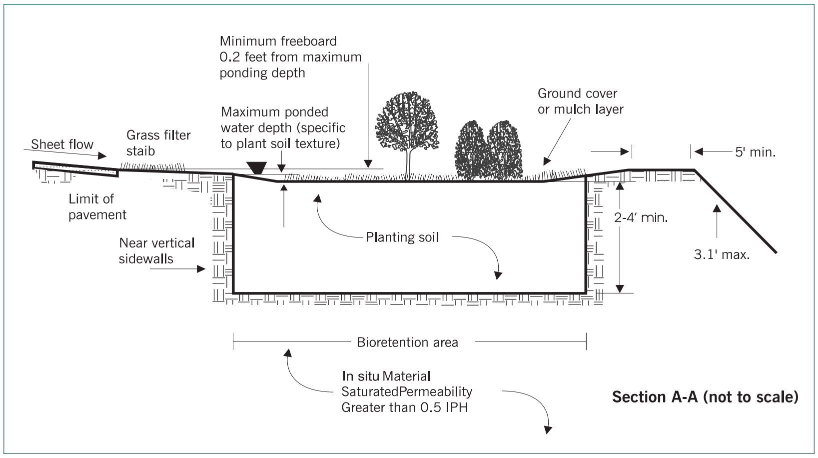
These smaller facilities tend to feature shallow basin depths and gentle side slopes, which also reduce safety concerns. The integration of these facilities into the landscape throughout the site offers more opportunities to mimic the natural hydrologic functions, and add aesthetic value. The adoption of these landscape features by the general public and individual property owners can result in significant maintenance and upkeep savings to the homeowners association, municipality or other management entity.

Concept 5 - Creating a Multifunctional Landscape and Infrastructure

LID offers an innovative alternative approach to urban stormwater management that uniformly or strategically integrates stormwater controls into multifunctional landscape features where runoff can be micromanaged and controlled at the sources. With LID, every urban landscape or infrastructure feature (roof, streets, parking, sidewalks, and green space) can be designed to be multifunctional, incorporating detention, retention, filtration, or runoff use.

Figure 2-4.

Bioretention cell



The bioretention cell in Figure 2-4 is perhaps the best example of a multifunctional practice and illustrates a number of functions. First the tree canopy provides interception and ecological, hydrologic, and habitat functions. The 6-inch storage area provides detention of runoff. The organic litter/mulch provides pollutant removal and water storage. The planting bed soil provides infiltration of runoff, removal of pollutants through numerous processes, groundwater recharge, and evapotranspiration through the plant material.

The opportunities, effectiveness, and benefits for control of runoff through numerous small-scale multifunctional landscape features have not been fully explored. To apply LID to any land use is simply a matter of developing numerous ways to creatively prevent, retain, detain, use, and treat runoff within multifunctional landscape features unique to that land use.

Table 2-1 Steps in LID Site Planning Process

Step 1	Identify Applicable Zoning, Land Use, Subdivision and Other Local Regulations
Step 2	Define Development Envelope
Step 3	Use Drainage/Hydrology as a Design Element
Step 4	Reduce/Minimize Total Site Impervious Areas
Step 5	Integrate Preliminary Site Layout Plan
Step 6	Minimize Directly Connected Impervious Areas
Step 7	Modify/Increase Drainage Flow Paths
Step 8	Compare Pre and Post Development Hydrology
Step 9	Complete LID Site Plan

The LID Site Planning Process

Site planning is a well-established process consisting of several elements. The incorporation of LID concepts into this process introduces a number of new considerations to better mimic the predevelopment hydrology and create a hydrologically functional landscape. These concepts include considering hydrology as a design focus, minimizing imperviousness, disconnecting impervious surfaces, increasing flow paths, and defining and siting micromanagement controls. Table 2-1 provides a summary of the steps involved in integrating the LID technology into the site planning process. These steps are described below.

Zoning ordinances

Land use controls at the county or municipal level designed to regulate density, types, and extent of development

Identify Applicable Zoning, Land Use, Subdivision, and Other Local Regulations

The planning process of a local governmental entity (county, district, borough, municipality, etc.)–zoning ordinances and comprehensive planning–provides a framework to establish a functional and visual relationship between growth and urbanization. Zoning ordinances predesignate the use and physical character of a developed geographic area to meet urban design goals. Common zoning components are summarized in Table 2-2. The zoning requirements are intended to regulate the density and geometry of development, specifying roadway widths and parking and drainage requirements, and define natural resource protection areas.

Table 2-2 Common Zoning Components

Zoning Requirement	Purpose
Land use restriction	Separate residential, commercial and industrial uses and/or specify the percentage mix of these uses
Lot Layout Requirement	
Equal-sized or similarly shaped lots	Provide consistency among residential use or districts
Minimum lot sizes	Provide consistency among residential uses or districts
Frontage requirements	Provide additional distinction among residential zones; access
Fixed setbacks for front, back, and side yards	Provide additional distinction among residential and side yards provide consistency among residential zones; control coverage by buildings.
Road Layout Requirements	
Road width	Ensure vehicular and pedestrian safety and avoid rights-of-way public facility burdens
Road turnarounds	Prevent undue fire safety hazards; provide adequate fire safety vehicular access.
Sidewalks and pedestrian walkways	Ensure vehicular and pedestrian safety and avoid access public facility burdens.
Residential and commercial development	Ensure vehicular and pedestrian safety and avoid access public facility burdens.
Common or shared facilities	Prevent environmental or safety hazards from unmaintained facilities such as shared septic systems or driveways.
Drainage and Grading	
Curbs/gutters and storm drains	Prevent undue burden of development on off-site water, streets, and buildings
Stormwater quality and quantity Structures	Prevent undue burden of development on off-site water, streets, and buildings
Grading to promote positive drainage	Prevent soil erosion problems due to drainage

Identification of existing zoning ordinances and applicable subdivision regulations is not a new concept, but rather an established element of current site planning practices. The LID site planning process recognizes that in most instances, LID approaches need to meet the local zoning requirement. However, typical conventional zoning regulations are often inflexible and restrict development options regarding certain site planning parameters. Consequently, local planning agencies that wish to optimize the environmental and economic benefits provided by the LID approach will want to consider the adoption of environmentally sensitive and flexible zoning options that facilitate the use of LID technology.

Subdivision regulations

Local land use controls specify how large land parcels are broken into smaller pieces

The LID approach employs a number of flexible zoning options to meet the environmental objectives of a site without impeding urban growth. The use of these options provides added environmental sensitivity to the zoning and subdivision process over and above what conventional zoning can achieve. Alternative zoning options, such as

Table 2-3 Alternative Zoning Options

Zoning Option	Functions Provided
Overlay District	Uses existing zoning and provides additional regulatory standard
Performance Zoning	Flexible zoning based on general goals of the site based on preservation of site functions
Incentive Zoning	Provides for give and take compromise on zoning restrictions allowing for more flexibility to provide environmental protection
Imperviousness Overlay Zoning	Subdivision layout options are based on total site imperviousness limits
Watershed-based Zoning	Uses a combination of the above principles to meet a predetermined watershed capacity or goal

those summarized in Table 2-3, include overlay districts, performance zoning, incentive zoning, impervious overlay zoning, and watershed-based zoning to allow for the introduction of innovative development, site layout, and design techniques.

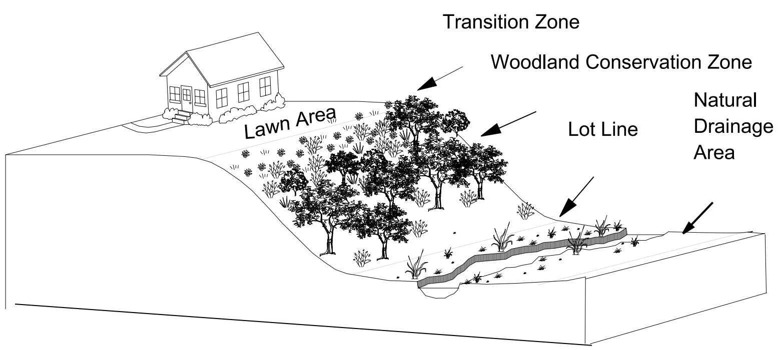
Define Development Envelope and Protected Areas

After the zoning code and subdivision regulations have been analyzed, a development envelope can be prepared for the proposed site. This is done by identifying protected areas, setbacks, easements, topographic features and existing subdrainage divides, and other site features. Site features to be protected are illustrated in Figure 2-5 and may include riparian areas such as floodplains, stream buffers, and wetlands; woodland conservation zones and important existing trees; steep slopes; and highly permeable and erosive soils. These features can be mapped in an overlay mode.

Reduce Limits of Clearing and Grading

The limits of clearing and grading refer to the site area to which development is directed. This development area will include all impervious areas such as roads, sidewalks, rooftops, and pervious areas such as graded lawn areas and open drainage systems. To minimize hydrologic impacts on existing site land cover, the area of development should be located in areas that are less sensitive to disturbance or have lower value in terms of hydrologic function (e.g., developing barren clayey soils will have less hydrologic impact than development of forested sandy soils). At a minimum, areas of development should be placed outside of sensitive area buffers such as streams, floodplains, wetlands, and steep slopes. Where practical and possible, avoid developing areas with soils which have high infiltration rates to reduce net hydrologic site impacts.

Figure 2-5. Some protected site features



Use Site Fingerprinting

Site fingerprinting (minimal disturbance techniques) can be used to further reduce the limits of clearing and grading, thereby minimizing the hydrologic impacts. Site fingerprinting includes restricting ground disturbance by identifying the smallest possible area and clearly delineating it on the site. Land-cover impacts can be reduced through minimal disturbance techniques that include the following:

Site fingerprinting

Site clearing and development using minimal disturbance of existing vegetation and soils

- Reduce paving and compaction of highly permeable soils.
- Minimizing the size of construction easements and material storage areas, and siting stockpiles within the development envelope during the construction phase of a project.
- Siting building layout and clearing and grading to avoid removal of existing trees where possible.
- Minimizing imperviousness by reducing the total area of paved surfaces.
- Delineating and flagging the smallest site disturbance area possible to minimize soil compaction on the site and restricting temporary storage of construction equipment in these areas.
- Disconnecting as much impervious area as possible to increase opportunities for infiltration and reduce water runoff flow.
- Maintaining existing topography and associated drainage divides to encourage dispersed flow paths.

Use Drainage/Hydrology as a Design Element

Site hydrology evaluation and understanding are required to create a hydrologically functional landscape. As illustrated in Figure 2-6, urbanization and increased impervious areas greatly alter

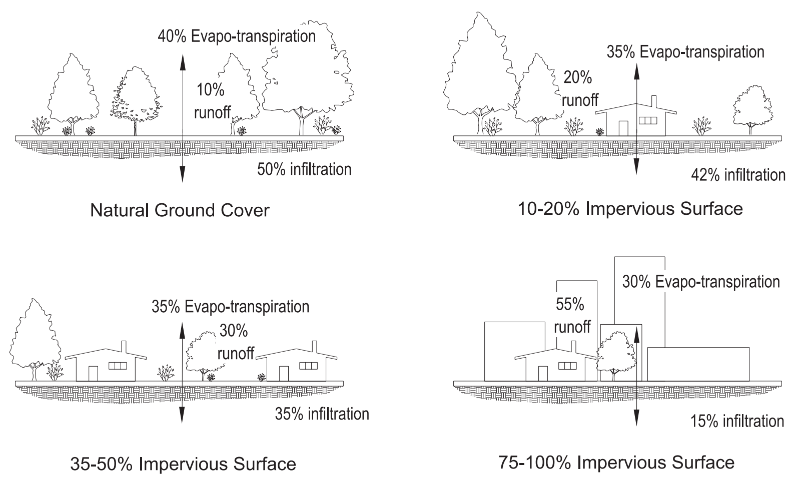


Figure 2-6. Impervious surface changes due to urbanization

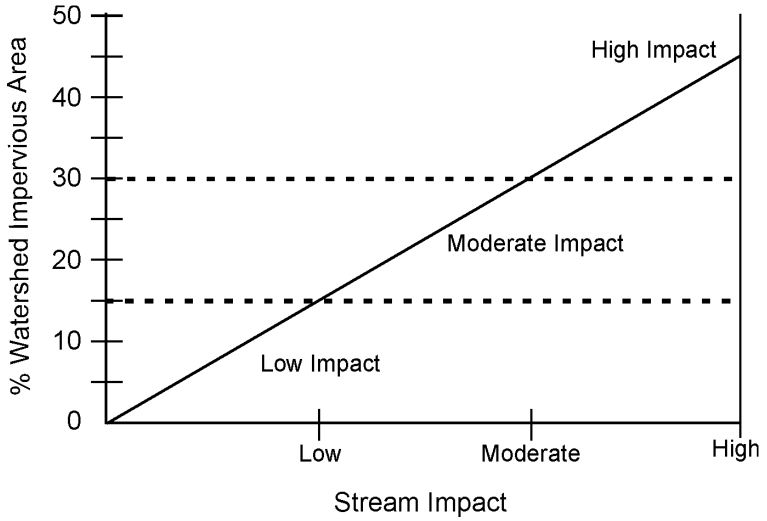


Figure 2-7. Increases in receiving stream impacts due to site imperviousness

the predevelopment hydrology (USEPA, 1993; Booth and Reinelt, 1993). This increase in impervious areas has been directly linked to increases in impacts on receiving streams (Figure 2-7) by numerous investigators (including Booth and Reinelt, 1993; Horner et al., 1994; Klein, 1979; May, 1997; Steedman 1988). To reduce these impacts created by land development, LID site planning incorporates drainage/hydrology by carefully conducting hydrologic evaluations and reviewing spatial site layout options.

Hydrologic evaluation procedures can be used to minimize the LID runoff potential and to maintain the predevelopment time of concentration. These procedures are incorporated into the LID site planning process early on to understand and take advantage of site conditions.

Spatial organization of the site layout is also important. Unlike pipe conveyance systems that hide water beneath the surface and work independently of surface topography, an open drainage system for LID can work with natural landforms and land uses to become a major design element of a site plan. The LID stormwater management drainage system can suggest pathway alignment, optimum locations for park and play areas, and potential building sites. The drainage system helps to integrate urban forms, giving the development an integral, more aesthetically pleasing relationship to the natural features of the site. Not only does the integrated site plan

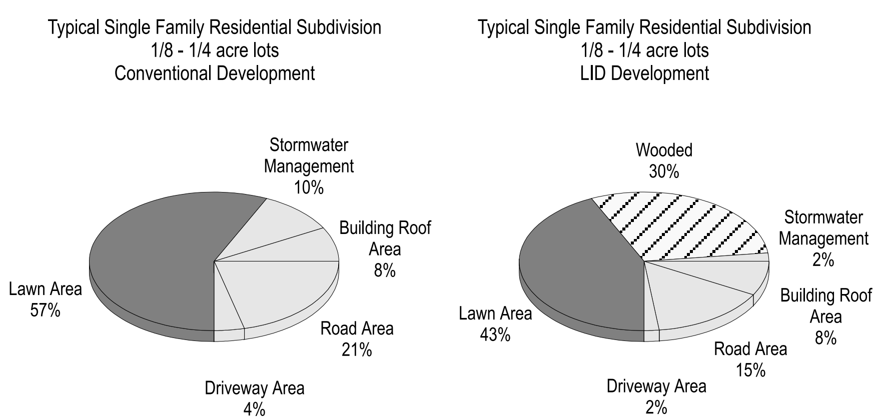


Figure 2-8. Typical imperviousness ratios for conventional and LID residential development design

complement the land, but it can also save on development costs by minimizing earthwork and construction of expensive drainage structures.

Reduce/Minimize Total Impervious Areas

After, or concurrent with, the mapping of the development envelope, the traffic pattern and road layout and preliminary lot layout are developed. The entire traffic distribution network, (roadways, sidewalks, driveways, and parking areas), are the greatest source of site imperviousness, as shown in Figure 2-8. These changes in the impervious area alter runoff and recharge values and site hydrology (Figure 2-6). For LID sites, managing the imperviousness contributed by road and parking area pavement is an important component of the site planning and design process. Methods that can be used to achieve a reduction in the total runoff volume from impervious surfaces are presented below:

Alternative Roadway Layout. Traffic or road layout can have a very significant influence on the total imperviousness and hydrology of the site plan. Figure 2-9 illustrates that the total length of pavement or imperviousness for various road layout options can vary from 20,800 linear ft for a typical gridiron layout to 15,300 linear ft for a loops and lollipops layout. Selection of an alternative road layout can result in a total site reduction in imperviousness of 26 percent.

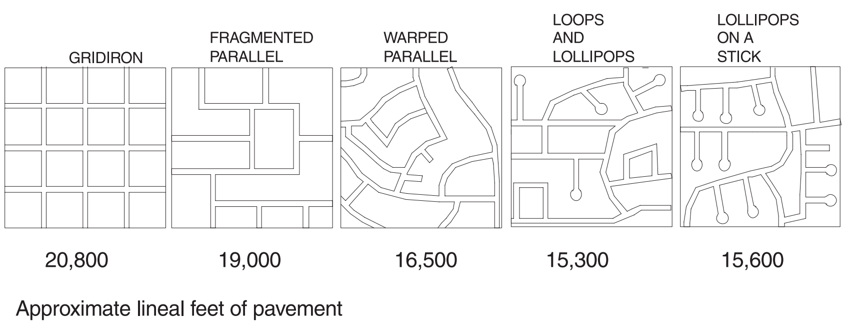
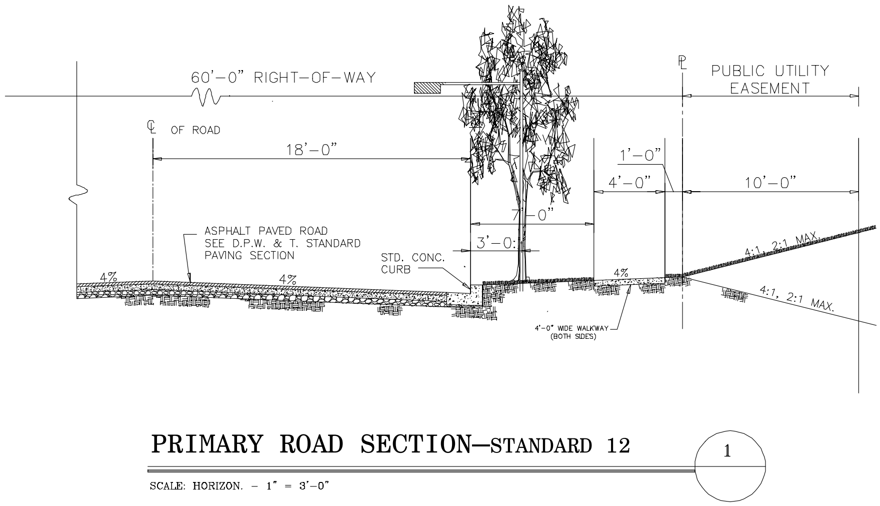


Figure 2-9. Length of pavement (imperviousness associated with various road layout options) (Adapted from ULI, 1980)

Narrow Road Sections. Reduced width road sections are an alternative that can be used to reduce total site imperviousness as well as clearing and grading impacts. Figure 2-10 shows a typical primary residential street road section and a typical rural residential street road section (Prince George's County, 1997). The right-of-way width for both sections is 60 feet. The widths of paving for the primary residential section is 36 feet wide and the section includes the use of curb and gutter. By using the rural residential road section in place of the primary residential section, the width of paving can be



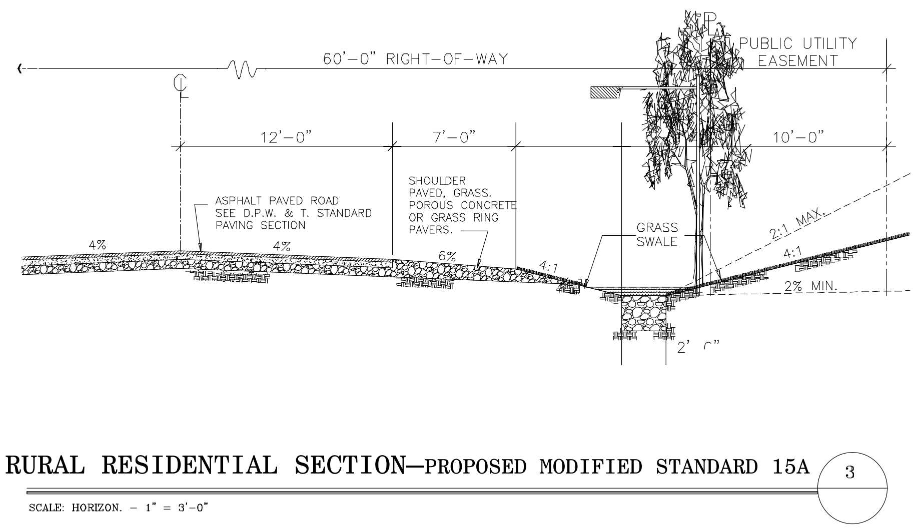


Figure 2-10. Typical road sections (Prince George's County, MD, 1997)

reduced from 36 to 24 feet, which represents a 33 percent reduction in paved width. The rural section also eliminates the use of concrete curb and gutter which reduces construction costs substantially and facilitates the use of vegetated roadside swales.

Reduced Application of Sidewalks to One Side of Primary Roads. Total site imperviousness can also be reduced by limiting sidewalks to one side of primary roads. In some cases, sidewalks or pedestrian paths can be eliminated on all other roads.

Reduced On-Street Parking. Reducing on-street parking requirements to one side, or even elimination of on-street parking altogether, has the potential to reduce road surfaces and therefore overall site imperviousness by 25 to 30 percent (Sykes, 1989). Two-sided parking requirements are often unnecessary to provide adequate parking facilities for each lot. For example, Sykes (1989) noted that allowing parking on both sides of the street provides space for 4.5 to 6.5 cars per residence.

Rooftops. Rooftops contribute to site imperviousness, and the number of lots per acre (or lot coverage) generally determines the site's rooftop impervious area. House type, shape, and size can affect rooftop imperviousness. For example, more rooftop coverage is generally required for ranch-type homes that spread out square footage over one level. With this in mind, vertical construction is favored over horizontal layouts to reduce the square footage of rooftops.

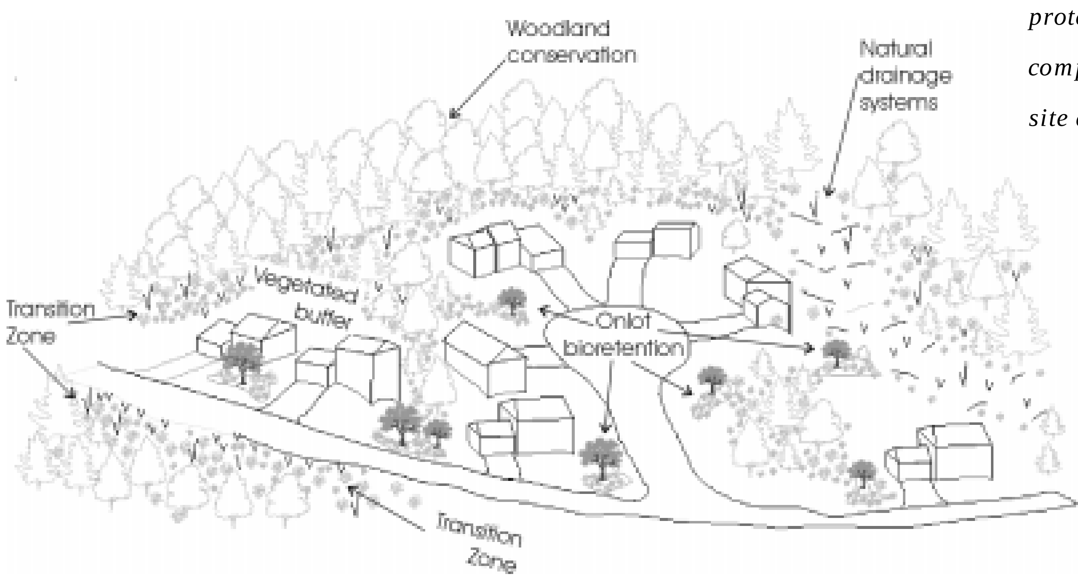
Driveways. Driveways are another element of the site plan that can be planned to reduce the total site imperviousness. Some techniques that can be used include

- Using shared driveways whenever possible, but especially in sensitive areas. This may require a subdivision waiver.
- Limiting driveway width to 9 feet (for both single and shared driveways).
- Minimizing building setbacks to reduce driveway length.
- Using driveway and parking area materials which reduce runoff and increase travel times such as pervious pavers or gravel.

Develop Integrated Preliminary Site Plan

After the development envelope has been delineated and the total site imperviousness has been minimized, an integrated prelimi-

Figure 2-11. Integrated site plan. Low-impact, environmentally sensitive development incorporates a combination of all natural resources protection options into a comprehensive, integrated site design.



integrated site plan will provide a base for conducting the hydrologic analysis to compare the pre- and postdevelopment site hydrology, and to confirm that the overall objective of creating a hydrologically functional site is being met. The procedures for conducting this analysis and fine tuning the preliminary plan to arrive at a final plan are described below. These procedures are aimed at disconnecting the unavoidable impervious areas, as well as using techniques to modify the drainage flow paths so that the postdevelopment time of concentration of stormwater runoff can be maintained as close as possible to the predevelopment conditions.

Sheet flow

Slow, shallow stormwater runoff over the land surface

Minimize Directly Connected Impervious Areas

After the total site imperviousness has been minimized and a preliminary site plan has been developed, additional environmental benefits can be achieved and hydrologic impacts reduced by disconnecting the unavoidable impervious areas as much as possible. Strategies for accomplishing this include

Open swale

Earthen channels covered with a dense growth of hardy grass

- Disconnecting roof drains and directing flows to vegetated areas.
- Directing flows from paved areas such as driveways to stabilized vegetated areas.
- Breaking up flow directions from large paved surfaces.
- Encouraging sheet flow through vegetated areas.
- Carefully locating impervious areas so that they drain to natural systems, vegetated buffers, natural resource areas, or infiltratable zones/soils.

Level spreader

A stormwater outlet designed to convert concentrated runoff to sheet flow

Modify/Increase Drainage Flow Paths

The time of concentration (Tc), in conjunction with the hydrologic site conditions, determines the peak discharge rate for a storm event. Site and infrastructure components that affect the time of concentration include

- Travel distance (flow path)
- Slope of the ground surface and/or water surface
- Surface roughness
- Channel shape, pattern, and material components

Techniques that can affect and control the Tc can be incorporated into the LID concept by managing flow and conveyance systems within the development site:

- Maximize overland sheet flow.

Table 2-4 Permissible Velocities for Vegetated Channels

No.	Cover	Slope Range (percent)	Recommended Permissible Velocity: Erosion Resistant Soils K< .3 fps	Recommended Permissible Velocity: Easily Eroded Soils K> .3 fps
1.	Bermudagrass, Midland and Coastal, Tufcote	0-5 5-10 over 10	6.0 5.0 4.0	5.0 4.0 3.0
2.	Kentucky 31 Tall Fescue, Kentucky Bluegrass	0-5 5-10 over 10	5.0 4.0 3.0	4.0 3.0 2.0
3.	Grass-legume mixture	0-5[3] 5-10	4.0 3.0	3.0 2.0
4.	Red Fesuce, Redtop, Lespedeza, sericea, Alfalfa	0-5[4]	3.5	2.5
5.	Annuals[5], Common Lespedeza Sundangrass, Small grain, Ryegrass	0-5[5]	3.0	2.0

1 Common bermudagrass is a restricted noxious weed in Maryland.
2 Soil erodibility factor (K), < = less than, > = more than.
3 Do not use on slopes teepter than 10 percent, except for vegetated side slopes in combination with stone or concrete or highly resistant vegetative center sections.
4 Do not use on slopes steeper than 5 percent except for side slopes in a combination channel as in 3 above.
5 Annuals are used on mild slopes or as temporary protection until permanent covers are established. Use on slopes steeper than 5 percent is not recommended.
6 Good, dense vegatative cover is assumed.

Source: Maryland Standards and Specifications for Soil Erosion and Sediment Control (SCS), 1983.

- Increase and lengthen flow paths.
- Lengthen and flatten site and lot slopes.
- Maximize use of open swale systems.
- Increase and augment site and lot vegetation.

Overland Sheet Flow. The site should be graded to maximize the overland sheet flow distance and to minimize disturbance of woodland along the post-development Tc flow path. This practice will increase travel times of the runoff and thus the time of concentration. Consequently, the peak discharge rate will be decreased. Flow velocity in areas that are graded to natural drainage patterns should be kept as low as possible to avoid soil erosion. Velocities in the range of 2 to 5 feet per second are generally recommend. Table 2-4 provides recommended velocities for various combinations of slopes, soils and vegetative cover (SCS, 1983). Flows can be slowed by installing a level spreader along the upland ledge of the natural drainage way buffer, or creating a flat grassy area about 30 feet wide on the upland side of the buffer where runoff can spread out. This grassy area can be incorporated into the buffer itself. It may be unnecessary to set aside additional land to create this area.

Flow Path. Increasing flow path of surface runoff increases infiltration and travel time. One of the goals of a LID site is to provide as much overland or sheet flow as allowed by local jurisdictional codes to increase the time it takes for rooftop and driveway runoff to reach open swale drainage systems. To accomplish this, the designer can direct rooftop and driveway runoff into bioretention facilities, infiltration trenches, dry wells, or cisterns that are strategically located to capture the runoff prior to its reaching the lawn. In addition, strategic lot grading can be designed to increase both the surface roughness and the travel length of the surface runoff.

Site and Lot Slopes. Constructing roads across steep sloped areas unnecessarily increases soil disturbance to a site. Good road layouts avoid placing roads on steep slopes, by designing roads to follow grades and run along ridge lines (see Figure 2-12). Steep site slopes often require increased cut and fill if roads are sited using conventional local road layout regulations. If incorporated into the initial subdivision layout process, slope can be an asset to the development. The adjacent table provides suggestions on how to incorporate slope into lot layout and road design to minimize grading and natural drainage way impacts.

Alternative road layout options use road plans that designate length of cul-de-sacs and the number of branches of side streets off collector streets based on the existing ridge lines and drainage patterns of a site:

- For areas with rolling terrain with dissected ridges use multiple short branch cul-de-sacs off collector streets.
- For flat terrain use fluid grid patterns. Interrupt grid to avoid natural drainage ways and other natural resources protection areas.

Figure 2-12. Roads placed along ridge lines preserve and utilize the natural drainage system (adapted from Sykes, 1989)

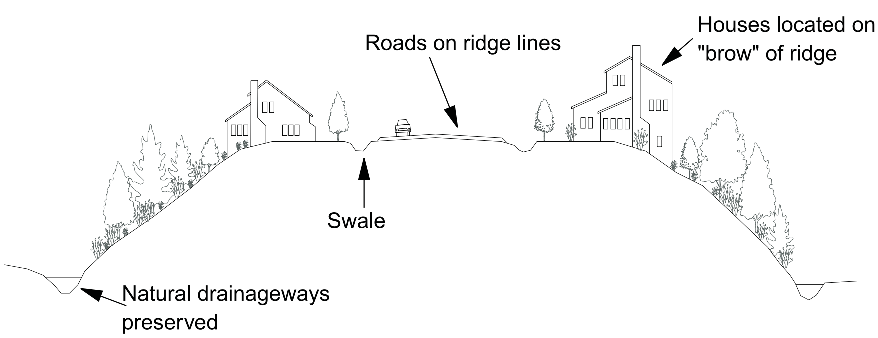


Table 2-5. Alternative Road Layouts

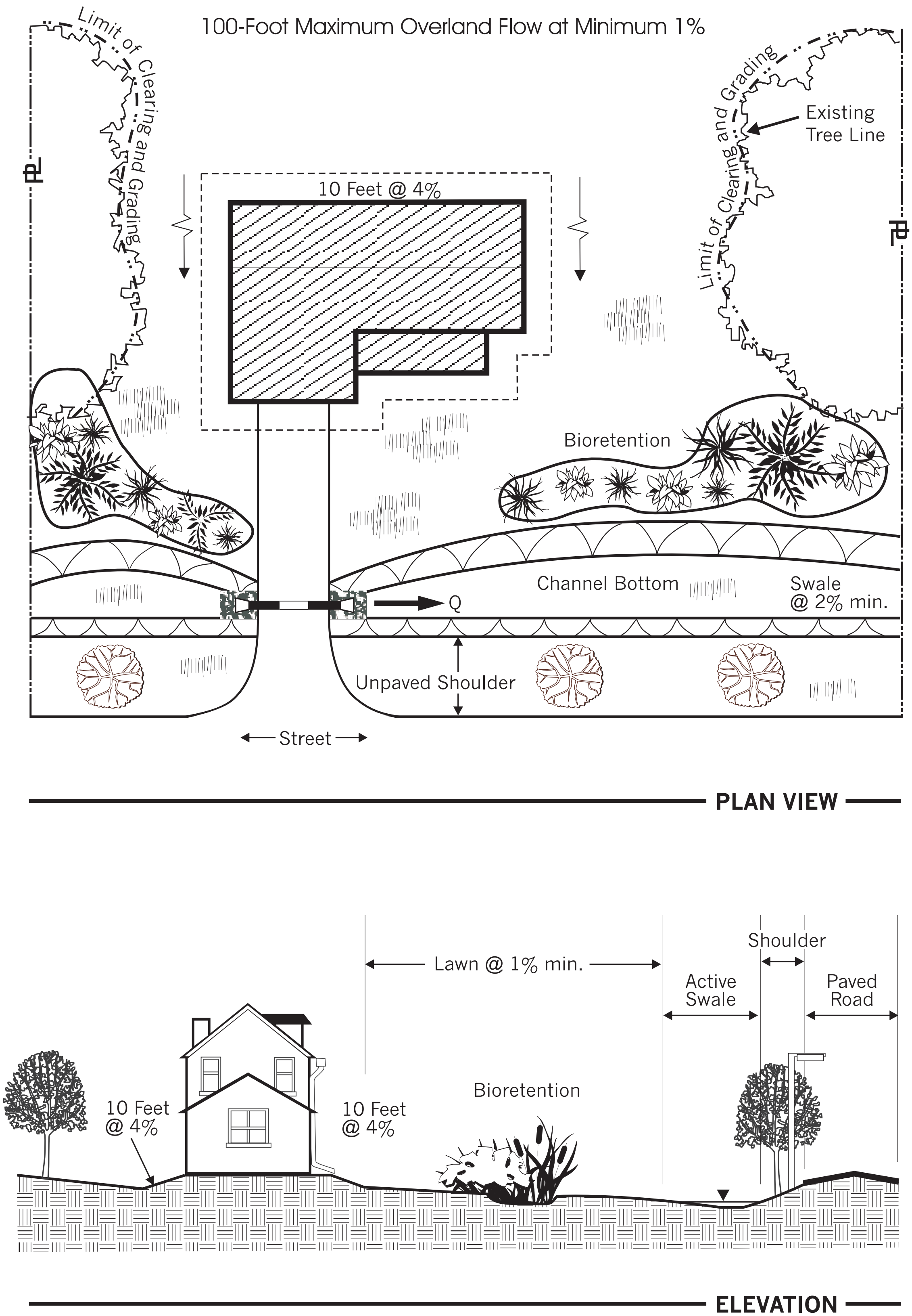
Slope of the site	Site and Road Layout options
0 to 4 %	Use with flat lots and streets parallel to the contours. Use with rambler housing units.
4 to 8 %	Use with sloped lots and streets parallel to the contours. Use split-entry or walkout housing units. Use with streets perpendicular to the contours with side-to-side split-level type housing units.
8 to 11 %	Use with sloped lots and streets perpendicular to the contours. Use with side-to-side split-level type housing units.
> 11 %	These areas are not easily used for residential lots.

Adapted from Sykes, 1989.

Figure 2-13 illustrates low-impact development site grading techniques for a site with low relief. Lot slopes are flattened to approach a minimum grade of 1 percent to increase infiltration and travel time. For residential developments, low-impact development practices should be applied to lot areas outside the building pad area as shown. The building pad area is a 10 foot perimeter around the building with a positive drainage slope of 4 percent. The designer is responsible for ensuring that the slope of the lot does not cause flooding during a 100-year event (i.e, 1-foot vertical and 25 foot horizontal distance must by provided between the 100 year overflow path and the dwelling unit). Soil compaction in the lot area should by avoided to maximize the infiltration capacity of the soil. These infiltration areas can be hydraulically connected to impervious surfaces such as rooftops and driveways to decrease travel times for these areas.

Open Swales. Wherever possible, LID designs should use multi-functional open drainage systems in lieu of more conventional storm drain systems. To alleviate flooding problems and reduce the need for conventional storm drain systems, vegetated or grassed open drainage systems should be provided as the primary means of conveying surface runoff between lots and along roadways (Figure 2-14). Lots should be graded to minimize the quantity and velocity of surface runoff within the open drainage systems. Infiltration controls and terraces can be

Figure 2-13. Low-impact development minimum lot grading and 100yr buffer requirements



used to reduce the quantity and travel time of the surface runoff as the need arises.

Figure 2-14. Vegetated swale

Site and Lot Vegetation. Revegetating graded areas, planting, or preserving existing vegetation can reduce the peak discharge rate by creating added surface roughness as well as providing for additional retention, reducing the surface water runoff volume, and increasing the travel time (Figure 2-15). Developers and engineers should connect vegetated buffer areas with existing vegetation or forested areas to gain retention/detention credit for runoff volume and peak rated reduction. This technique has the added benefit of providing habitat corridors while enhancing community aesthetics.

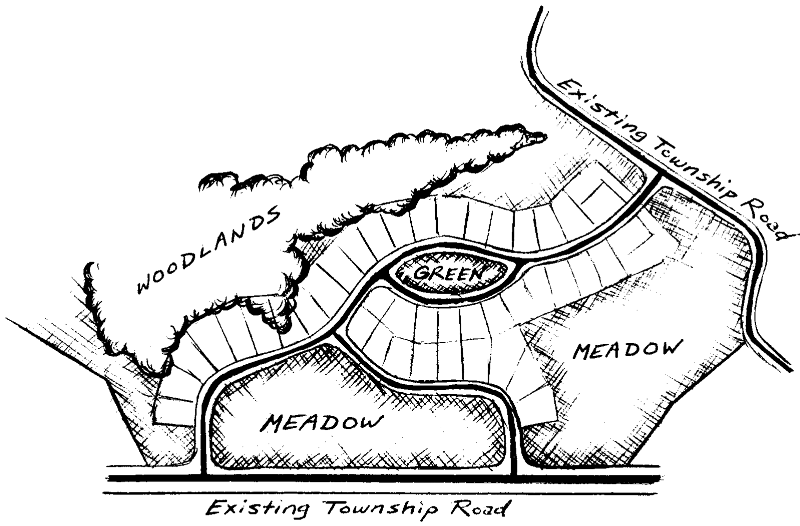
Compare Pre- and Postdevelopment Hydrology

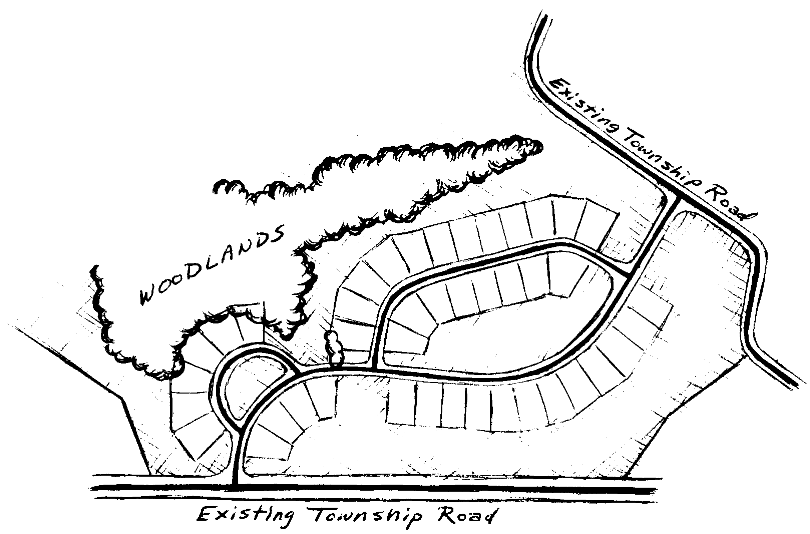
At this stage of the LID site planning process, most of the site planning work is complete. Now the designer is ready to compare the pre- and postdevelopment hydrology of the site, using the hydrologic analysis procedures presented in Chapter 3. The hydrologic analysis will quantify both the level of control that has been provided by the site planning process and the additional level of control required through the use of the integrated management practices (IMPs).

Complete LID Site Plan

Completion of the LID site plan usually involves a number of iterative design steps. Based on the results of the hydrologic evaluation, additional stormwater control requirements of the LID site are identified. These requirements will be met using IMPs distributed throughout the site. A trial-and-error iterative process is then used until all the stormwater management requirements are met. In the event the site requirements cannot be met with IMPs alone, additional stormwater controls can be provided using conventional stormwater techniques (e.g., detention ponds). Mixed use of LID measures and conventional control is referred to as a hybrid system.

Figure 2-15. Site layouts with/ without vegetation retention





Once the predevelopment hydrology objectives have been met, the designer can complete the site plan by incorporating the typical details, plan views, cross sections, profiles, and notes as required.

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Chapter 3
Low-Impact Development Hydrologic Analysis

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Chapter 3

Low-Impact Development Hydrologic Analysis

Introduction

Preserving or restoring the hydrologic functions of watersheds is a fundamental premise of the LID approach. Consideration of hydrologic principles in all phases of site development is necessary to maximize the effectiveness of planning and site design. Replication of the natural or predevelopment site hydrology not only reduces downstream stormwater impacts, but also helps control or reduce localized small-scale impacts.

The preservation of the predevelopment hydrologic regime of the site can be evaluated through consideration of the runoff volume, peak runoff rates, storm frequency and size, and water quality management. LID controls the full range of storm events, including those storm events smaller than the design storm.

This chapter reviews the basic hydrologic principles, LID hydrologic analysis concepts, methods for hydrologic evaluations, and compares conventional and LID approaches in terms of their effectiveness in controlling site hydrology.

In This Chapter…

Regional Considerations

The United States is composed of a wide range of climatic, geologic, and physiographic conditions, which result in regional provinces with widely varying combinations of these factors. Climate varies from arid regions with annual rainfall of 4 to 10 inches all the way to regions of rainforest with annual precipitation of 100 inches. Geology includes sedimentary coastal deposits through regions of piedmont, valley, and ridge provinces to mountain terrain. Elevation ranges from sea level and very low relief along the coastal areas (which include the largest concentration of major cities and population), to areas of moderate elevation and relief, such as the piedmont regions, to areas of very high elevation, such as Denver and other areas in the Rocky Mountain region.

It has been documented by EPA's Nationwide Urban Runoff Program (USEPA, 1983) that although various regions of the country display a wide range of the factors described above, they do have some things in common. Any region of the country that is subject to urban development will experience the range of hydrologic impacts previously described. The major difference between regions is likely to be the relative importance or priority ranking for any one issue. A few examples of these regional differences are described below.

A number of the rapidly developing areas of Florida, which are heavily reliant on groundwater supplies, are experiencing a serious lowering of the regional water table. This condition is due to a combination of increasing withdrawals and the loss of natural ground water recharge as the naturally occurring permeable soils are converted to impervious areas. This lowering of the water table together with the associated increase in pollutants from urban runoff may be considered the highest urban runoff priorities for these areas.

The rapidly developing areas of the Puget Sound lowlands are experiencing a rapid degradation of the physical integrity of the receiving streams in the areas that are developed (May, 1997). This degradation and the associated loss of habitat that traditionally has served as spawning grounds for a broad range of salmonids native to this area are causing great concern in this region. Consequently, the stream channel degradation associated with urban runoff may be considered the highest urban runoff priority in this area.

The solution to these two examples, and to most urban runoff control problems, is to try to mimic or maintain the predevelopment site hydrology. This is precisely the objective of low-impact development.

Overview of Key Hydrologic Principles

Hydrology is the study of water and its movement through the hydrologic cycle. Understanding how hydrologic components respond

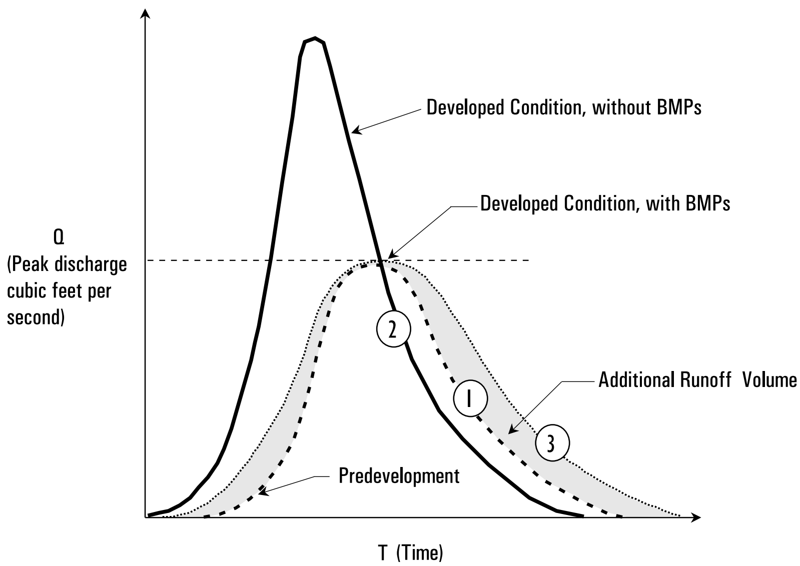


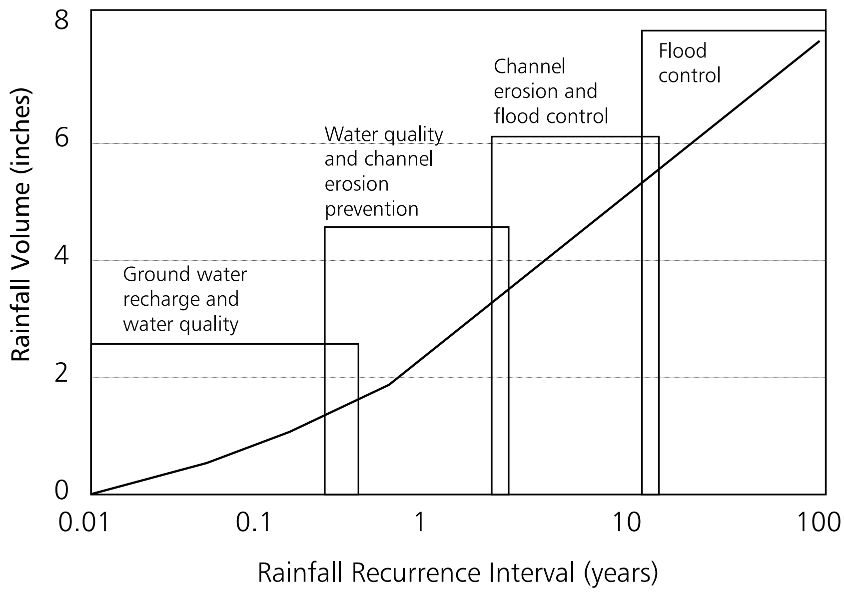
Figure 3-1. Hydrologic response of conventional BMPs

to land use changes and site development practices is the basis for developing successful watershed and stormwater management programs. One way of interpreting the hydrologic response of a system is through examination of a runoff hydrograph. A selection of typical runoff hydrographs under various land use conditions is shown in Figure 3-1.

- Hydrograph 1 represents the response to a given storm of a site in a predevelopment condition (i.e., woods, meadow). A gradual rise and fall of the peak discharge and volume define the hydrograph.
- Hydrograph 2 represents the response of a postdevelopment condition with no stormwater management BMPs. This hydrograph definition reflects a shorter time of concentration (Tc), and an increase in total site imperviousness from the predevelopment condition. The resultant hydrograph shows a decrease in the time to reach the peak runoff rate, a significant increase in the peak runoff and discharge rate and volume, and increased duration of the discharge volume.
- Hydrograph 3 represents a postdevelopment condition with conventional stormwater BMPs, such as a detention pond. Although the peak runoff rate is maintained at the predevelopment level, the hydrograph exhibits significant increases in the runoff volume and duration of runoff from the predevelopment condition, which is depicted by the shaded hydrograph area in Figure 3-1.

Key elements of the hydrologic cycle and their relationship to low-impact development technology are described below.

Figure 3-2. Relationship of the rainfall event recurrence interval and rainfall volume, and its application to stormwater management in Maryland (Source: CRC, 1996)



Precipitation and Design Storm Events. Data for precipitation, including both snow and rain, are used in site planning and stormwater design. Precipitation occurs as a series of events characterized by different rainfall amount, intensity, and duration. Although these events occur randomly, analysis of their distribution over a long period of time indicates that the frequency of occurrence of a given storm event follows a statistical pattern. This statistical analysis allows engineers and urban planners to further characterize storm events based on their frequency of occurrence or return period. Storm events of specific sizes can be identified to support evaluation of designs. Storms with 2- and 10-year return periods are commonly used for subdivision, industrial, and commercial development design.

Design storm

A specific size storm event used to plan for and design stormwater controls.

The 1- and 2-year storm events are usually selected to protect receiving channels from sedimentation and erosion. The 5- and 10-year storm events are selected to provide adequate flow conveyance design and minor flooding considerations. The 100-year event is used to define the limits of floodplains and for consideration of the impacts of major floods. Figure 3-2 provides a summary of the relationship of the rainfall event recurrence interval and rainfall volume, and its application to stormwater management in the state of Maryland.

There are numerous excellent texts and handbooks that describe the use of rainfall data to generate a "design storm" for the design of drainage systems (e.g., ASCE , 1994; Chow, 1964; SCS, 1972). For LID, a unique approach has been developed to determine the design storm based on the basic philosophy of LID (Prince George's County, MD, 1997).

Storm events commonly used for evaluation of designs differ for the various climatic regions of the United States Summaries of typical storm event characteristics (i.e., amount/intensity, duration, and return period) are provided in national maps in Technical Paper 40 (Department of Commerce, 1963). In humid regions such as the Mid-Atlantic states, the 2-year storm is approximately 3 inches of rainfall and the 10-year storm is approximately 5 inches of rainfall. The 2-year storm has a 50 percent probability of occurring in any given year, while the 10-year storm has a 10 percent probability of occurring in any given year. In dry areas, such as portions of Colorado and New Mexico, the 2-year storm is approximately 1.5 inches of rainfall and the 5-year storm is approximately 2.0 inches of rainfall.

Rainfall abstraction

The physical process of interception evaporation, transpiration, infiltration, and storage of precipitation. Represented as a depth (inches) of water over a site.

The required storage volume for peak runoff control is heavily depended on the intensity of rainfall (rainfall distribution). Since the intensity of rainfall varies considerably over geographic regions in the nation, National Resource Conservation Service (NRCS) developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from available National Weather Service (NWS) duration-frequency data and local storm data. Type IA is the least intense and type II the most intense short-duration rainfall. Figure 3-3. shows approximate geographic boundaries for these four distributions.

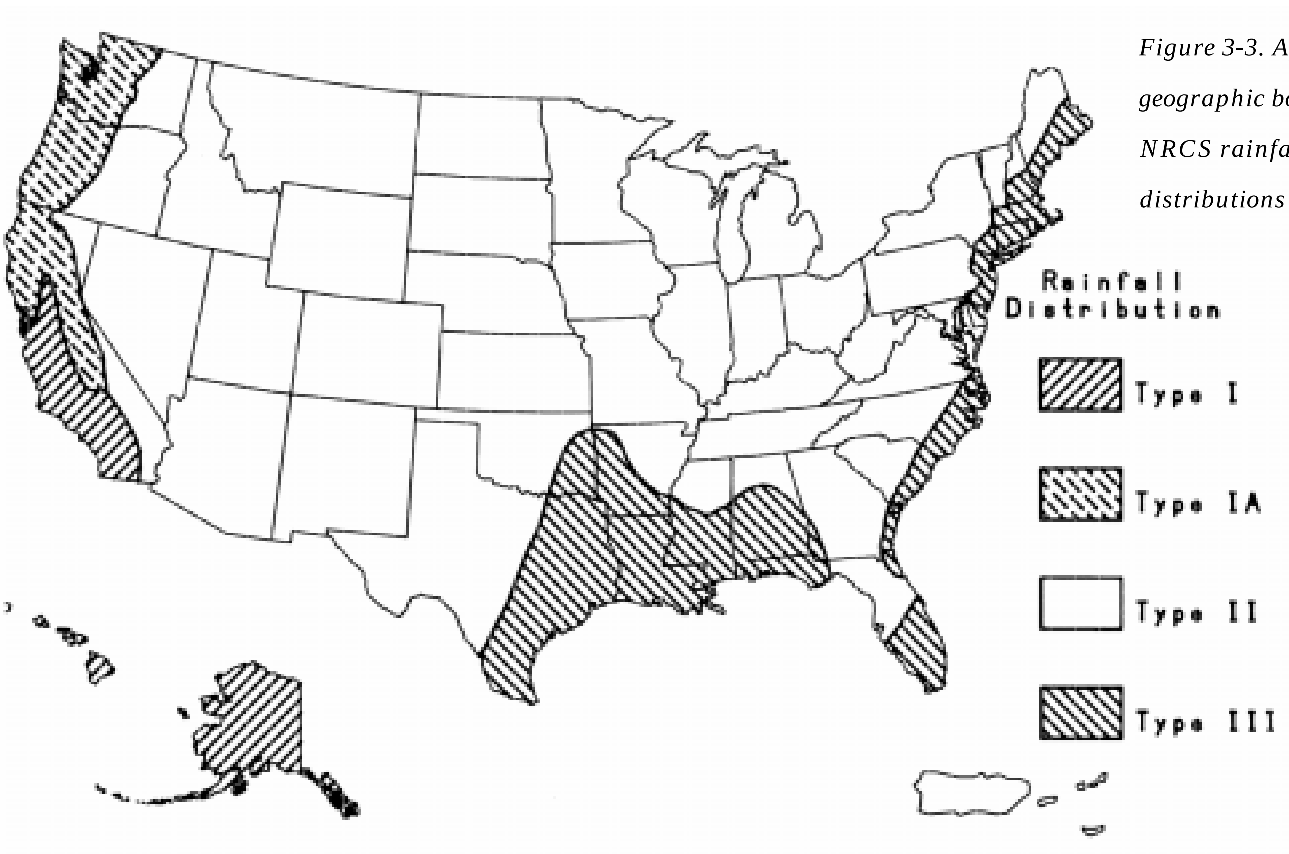


Figure 3-3. Approximate geographic boundaries for NRCS rainfall distributions

Rainfall Abstractions. Rainfall abstractions include the physical processes of interception of rainfall by vegetation, evaporation from land surfaces and the upper soil layers, transpiration by plants, infiltration of water into soil surfaces, and storage of water in surface depressions. Although these processes can be evaluated individually, simplified hydrologic modeling procedures typically consider the combined effect of the various components of rainfall abstraction.

The rainfall abstraction can be estimated as a depth of water (inches) over the total area of the site. This depth effectively represents the portion of rainfall that does not contribute to surface runoff. The portion of rainfall that is not abstracted by interception, infiltration, or depression storage is termed the excess rainfall or runoff.

The rainfall abstraction may change depending on the configuration of the site development plan. Of particular concern is the change in impervious cover. Impervious areas prevent infiltration of water into soil surfaces, effectively decreasing the rainfall abstraction and increasing the resulting runoff. Postdevelopment conditions, characterized by higher imperviousness, significantly decrease the overall rainfall abstraction, resulting not only in higher excess surface runoff volume but also a rapid accumulation of rainwater on land surfaces.

The LID approach attempts to match the predevelopment condition by compensating for losses of rainfall abstraction through maintenance of infiltration potential, evapotranspiration, and surface storage, as well as increased travel time to reduce rapid concentration of excess runoff. Several planning considerations combined with supplemental controls using LID integrated management practices (IMPs) can be used to compensate for rainfall abstraction losses and changes in runoff concentration due to site development. These practices are described in Chapters 2 and 4 of this document.

Runoff

The portion of rainfall that is not abstracted by interception, infiltration, or depression storage.

Runoff. The excess rainfall, or the portion of rainfall that is not abstracted by interception, infiltration, or depression storage, becomes surface runoff. Under natural and undeveloped conditions, surface runoff can range from 10 to 30 percent of the total annual precipitation (Figure 3-4). Depending on the level of development and the site planning methods used, the alteration of physical conditions can result in a significant increase of surface runoff to over 50 percent of the overall precipitation. In addition, enhancement of the site drainage to eliminate potential on-site flooding can also result in increases in surface runoff. Alteration in site runoff characteristics can cause an increase in the volume and frequency of runoff flows (discharge) and velocities that cause flooding, accelerated erosion, and reduced

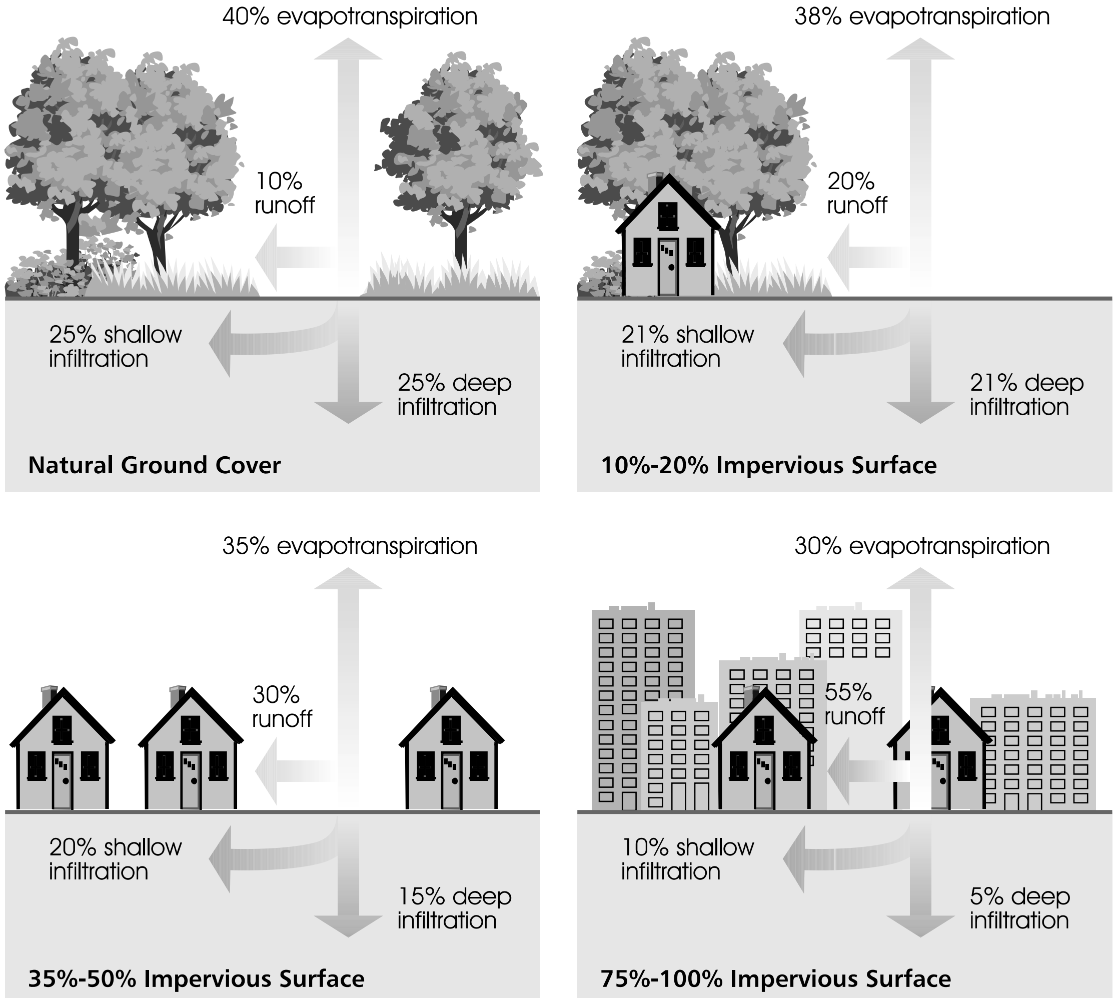


Figure 3-4. Runoff variability with increased impervious surfaces (FISRWG, 1998)

groundwater recharge and contribute to degradation of water quality and the ecological integrity of streams.

Time of Concentration. Time of concentration (Tc) is an idealized concept (Maidment, 1993) reflecting the response of a watershed to a given storm event. The Tc has been defined as the time it takes water from the most distant point (hydraulically) to reach the watershed outlet (NEH-4, SCS, 1985). Although Tc varies, it is often used as a constant. As the site imperviousness increases and the drainage pathways are altered, the contribution of land areas to excess rainfall water is likely to increase and the time to reach the downstream outlets is shortened. Traditional stormwater management approaches directed toward developing efficient drainage systems favor rapid concentration of excess water and routing it off-site through a drainage system of curbs and gutters, inlet structures, and storm drain pipes. Low-impact development relies on site planning tools and site-level management techniques to maintain the predevelopment time of concentration.

Time of concentration (Tc)

The time it takes for surface runoff to travel from the farthest point of the watershed to the outlet.

Groundwater recharge

The amount of precipitation that infiltrates into the soil and contributes to groundwater.

Groundwater Recharge. A considerable percentage of the rainfall abstraction infiltrates into the soil and contributes to groundwater recharge. Groundwater may be part of a local, intermediate, or regional water table, as illustrated in Figure 3-5. The local water table is often connected to nearby streams, providing seepage to streams during dry periods and maintaining base flow essential to the biological and habitat integrity of streams. A significant reduction or loss of groundwater recharge can lead to a lowering of the water table and a reduction of base flow in receiving streams during extended dry weather periods. Headwater streams, with small contributing drainage areas, are especially sensitive to localized changes in groundwater recharge and base flow.

Summary of Comparison Between Conventional and LID Stormwater Management Approaches

Stormwater management efforts that follow the historical design storm approach focus on two elements:

1. ***Site Drainage.*** In conventional stormwater management design, site drainage was accomplished by designing a very efficient site drainage system. Curbs, gutters, and pipes are used and carefully designed to quickly and efficiently drain any excess rainwater off the site. This approach, although it provides excellent on-site drainage, greatly alters the natural hydrologic regime of the site and provides a higher pollutant transport capacity. In addition, this approach does not address on-site water quality controls and does not consider any of the LID site planning concepts.

2. ***Off-Site Flood Control.*** The total alteration of the natural site hydrologic regime due to an efficient on-site drainage system results in a significant increase in off-site flooding potential, as

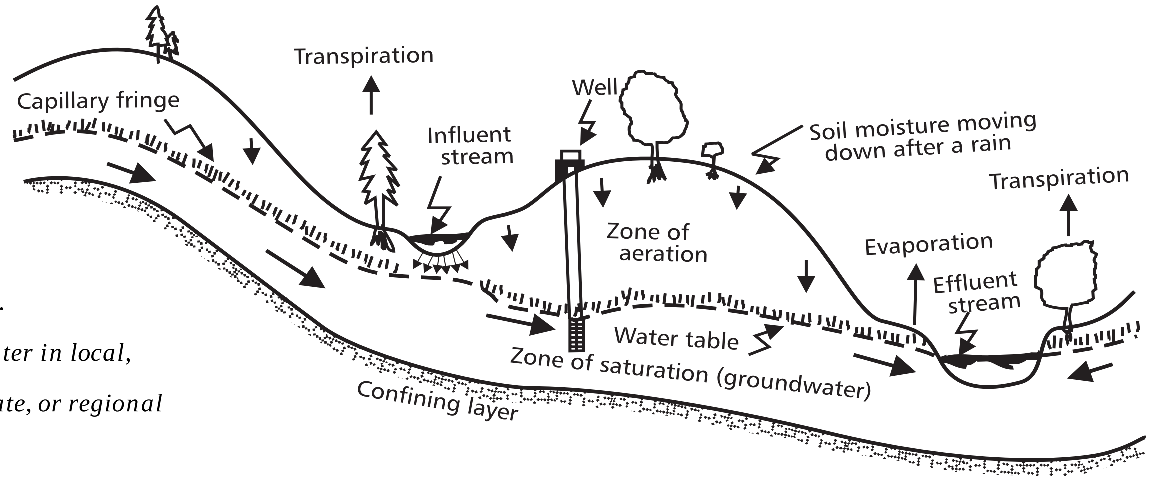


Figure 3-5. Groundwater in local, intermediate, or regional setting

well as high downstream environmental impacts associated with increased peak flows and their frequency of occurrence, higher storm flow volumes, and increased delivery of pollutant loads (EPA, 1997). The traditional approach relies on designing treatment facilities targeted mainly to control peak flows for a given storm size (i.e., 10-year storm). These facilities typically consist of large stormwater ponds, strategically placed at the low point of the site. Since environmental concerns are becoming an integral component of stormwater management, it is assumed that such facilities are providing some controls. Since these facilities are designed for peak flow control and do not control those storm events smaller than the design storm, this approach is often referred to as the "end of pipe" control approach.

Table 3-1 summarizes how conventional stormwater management and LID technology alter the hydrologic regime for on-site and off-site conditions.

Table 3-1. Comparison of Conventional and LID Stormwater Management Technologies

Hydrologic Parameter	Conventional	LID
	Onsite	
Impervious Cover	Encouraged to achieve effective drainage	Minimized to reduce impacts
Vegetation/Natural Cover	Reduced to improve efficient site drainage	Maximized to maintain predevelopment hydrology
Time of Concentration	Shortened, reduced as a by-product of drainage efficiency	Maximized and increased to approximate predevelopment conditions
Runoff Volume	Large increases in runoff volume not controlled	Controlled to predevelopment conditions
Peak Discharge	Controlled to predevelopment design storm (2 year)	Controlled to predevelopment conditions for all storms
Runoff frequency	Greatly increased, especially for Small, frequent storms	Controlled to predevelopment conditions for all storms
Runoff duration	Increased for all storms, because volume is not controlled	Controlled to predevelopment conditions
Rainfall Abstractions (Interception, Infiltration, Depression Storage)	Large reduction in all elements	Maintained to predevelopment conditions
Groundwater Recharge	Reduction in recharge	Maintained to predevelopment conditions
	Offsite	
Water Quality	Reduction in pollutant loadings but limited control for storm events that are less than design discharge	Improved pollutant loading reductions, Full control for storm events that are less than design discharge
Receiving Streams	Severe impacts documented- Channel erosion and degradation Sediment deposition Reduced base flow Habitat suitability decreased, or eliminated	Stream ecology maintained to predevelopment
Downstream Flooding	Peak discharge control reduces flooding immediately below control structure, but can increase flooding downstream through cumulative impacts and superpositioning of hydrographs	Controlled to predevelopment conditions

LID Hydrologic Considerations

In a LID system the fundamental hydrologic processes are considered throughout the site planning process. An understanding of the dynamics and interrelationships in the hydrologic cycle is used as a guide to preserving the predevelopment hydrology.

LID hydrologic considerations

Runoff volume control

Peak runoff rate control

Flow frequency/ duration control

Water quality control

The preservation of the predevelopment hydrology is evaluated by comparison of pre- and postdevelopment conditions. The comparison is facilitated by consideration of four fundamental measures-runoff volume control, peak runoff rate control, flow frequency/duration control, and water quality control. These four evaluation measures are discussed further below.

Runoff Volume Control. As the imperviousness of the site is increased, the runoff volume for a given storm increases. The ratio of the corresponding runoff volume (in inches) to the total rainfall event (in inches) is called the runoff coefficient. The typical site runoff coefficient can be maintained at the predevelopment level by compensating for the loss of abstraction (interception, infiltration, depression storage) through both site planning and design considerations.

Peak Runoff Rate Control. Low-impact development is designed to maintain the predevelopment peak runoff discharge for all the storms smaller than the selected design storm events. Use of site planning tools (see Chapter 2) and preferred management practices (Chapter 4) may control the peak runoff rate as well as the runoff volume. If additional controls are required to reach the predevelopment peak runoff rate, additional IMPs and supplemental management techniques might be needed.

Flow Frequency/Duration Control. Since low-impact development is designed to emulate the predevelopment hydrologic regime through both volume and peak runoff rate controls, the flow frequency and duration for the postdevelopment conditions should be almost identical to those for the predevelopment conditions (see Figure 3-6). The potential impacts on the sediment and erosion and stream habitat quality at downstream reaches can then be minimized.

Water Quality Control. Low-impact development is designed to provide water quality treatment control for at least the first half-inch of runoff from impervious areas using retention practices. In most LID applications, the use of distributed control and retention throughout the site will result in much higher levels of water quality treatment control for a number of reasons. First the runoff volume controlled will usually exceed the first half-inch of runoff, and frequently exceed two inches of runoff volume, thereby treating a much greater volume of

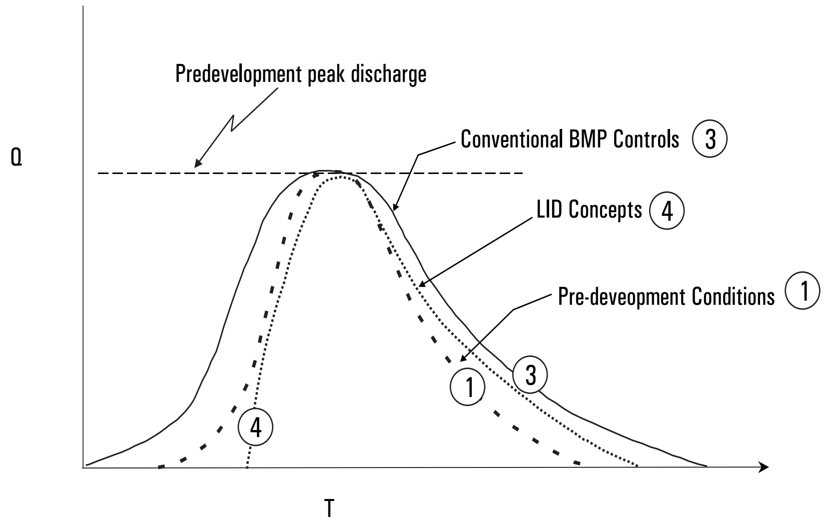


Figure 3-6. Comparison of the hydrologic response of conventional BMPs and LID IMPs

annual runoff. Also, this greater volume of runoff control will usually be associated with decreases in both the time of concentration and flow velocities which results in a reduction in the pollutant transport capacity and overall pollutant loading. Low-impact development also supports pollution prevention practices by modifying human activities to reduce the introduction of pollutants into the environment.

LID hydrologic modification tools

Reduce/minimize imperviousness

Disconnect unavoidable impervious surfaces

Preserve and protect environmentally sensitive site features

Maintain time of concentration (Tc)

Mitigate for impervious surfaces with PMPs

LID Hydrologic Tools

To achieve the goal of preserving the predevelopment hydrologic regime, a variety of LID site planning tools can be employed. The following tools are used in a variety of combinations in LID design:

- Reduce/minimize imperviousness. Change in postdevelopment hydrology can be minimized by reducing impervious areas and preserving more trees and meadows to reduce the storage requirements to maintain the predevelopment runoff volume.
- Disconnect unavoidable impervious surfaces. Additional environmental benefits can be achieved and the hydrologic impacts reduced by disconnecting unavoidable impervious surfaces as much as possible.
- Preserve and protect environmentally sensitive site features. Site features to be protected and preserved can include riparian areas, floodplains, stream buffers, and wetlands; woodlands, conservation zones, and valuable trees; steep slopes; and highly permeable and erosive soils.
- Maintain time of concentration (Tc). Maintaining the predevelopment Tc minimizes the increase of the peak runoff rate

LID hydrologic evaluation steps

1. **Delineate the watershed and microwatershed areas**
2. **Define design storms**
3. **Define modeling techniques to be employed**
4. **Compile information for predevelopment conditions**
5. **Evaluate predevelopment conditions and develop baseline measures**
6. **Evaluate site planning benefits and compare with baseline**
7. **Evaluate integrated management practices (IMPs)**
8. **Evaluate supplemental needs**

after development by lengthening flow paths and reducing the length of the runoff conveyance systems.

- Mitigate for impervious surfaces with IMPs. IMPs can provide retention storage for volume and peak control, as well as water quality control, to maintain the same natural initial abstraction volume as the predevelopment condition.
- Locate the impervious areas on less pervious soil types.

LID Hydrologic Evaluation

The purpose of the hydrologic evaluation is to determine the level of control required to achieve the stormwater management goals for LID sites. The required level of control may be achieved through application of the various hydrologic tools during the site planning process, the use of IMPs, and supplemental controls. The hydrologic evaluation is performed using hydrologic modeling and analysis techniques. The output of the hydrologic analysis provides the basis for comparison with the four evaluation measures (i.e., runoff volume, peak runoff, frequency, and water quality control).

LID Hydrologic Evaluation Steps

The hydrologic evaluation can be performed using various approaches and analytical techniques. Typically hydrologic evaluation follows a series of steps resulting in defining the needs for hydrologic control and management.

Step 1. Delineate the watershed and microwatershed areas. Hydrologic evaluation requires delineation of the drainage area for the overall study area or site and the subwatersheds contributing to key portions of the site. Delineation may need to consider previously modified drainage patterns, roads, or stormwater conveyance systems.

Step 2. Determine design storm(s). The design storms considered in the analysis should be determined based on the basic LID philosophy identified (see Section A.6 on page A.21). Regulatory requirements for design storms may also be stipulated in local ordinances, and these may limit or constrain the use of LID techniques or necessitate that structural controls be employed in conjunction with LID techniques.

Step 3. Define modeling technique(s) to be employed. Data gathering and analysis will depend on the specific type of model selected. The model selected will depend on the type of watershed, complexity of the site planning considerations, familiarity of the agency with the model, and level of detail desired. Certain models use simplified estimation methods whereas others provide detailed process-based representation of hydrologic interactions.

Step 4. Compile information for predevelopment conditions. Typical information needed includes area, soils, slopes, land use, and imperviousness (connected and disconnected).

Step 5. Evaluate predevelopment conditions and develop baseline measures. The selected modeling techniques are applied to the predevelopment conditions. The results of the modeling analysis are used to develop the baseline conditions using the four evaluation measures.

Step 6. Evaluate site planning benefits and compare with baseline. The site planning tools provide the first level of mitigation of the hydrologic impacts. The modeling analysis is used to evaluate the cumulative hydrologic benefit of the site planning process in terms of the four evaluation measures. The comparison is used to identify the remaining hydrologic control needs.

Step 7. Evaluate Integrated Management Practices (IMPs). The hydrologic control needs may be addressed through the use of IMPs (described in Chapter 4). This represents the second level of mitigation of the hydrologic impacts. After IMPs are identified for the site, a second-level hydrologic evaluation that combines the controls provided by the planning techniques with the IMPs can be conducted. Results of this hydrologic evaluation are compared with the predevelopment conditions to verify that the discharge volume and peak discharge objectives have been achieved. If not, additional IMPs are located on the site to achieve the optimal condition.

Step 8. Evaluate supplemental needs. If after use of IMPs supplemental control for either volume or peak flow is still needed, selection and listing of additional management techniques should be considered. For example, where flood control or flooding problems are a key design objective, or where site conditions, such as poor soils, or high water table limits the use of IMPs, additional conventional end-of-pipe methods, such as large detention ponds or constructed wetlands, should be considered. In some cases these controls can be sized much smaller than normal due to use of LID as part of the management system. The hydrologic evaluation is used to compare the supplemental management techniques and identify the preferred solutions.

The hydrologic evaluation steps are performed using an iterative process. Numerous site planning and management configurations may need to be evaluated to identify the optimum solutions. The concept of low-impact development is to emphasize the simple and cost-effective solutions. Use of hydrologic evaluations can assist in identifying these solutions prior to detailed design and construction costs.

Prince George's County, Maryland, has developed a detailed illustration of an approach for conducting a hydrologic evaluation based on the use of the SCS TR-55 method. A summary flow chart of the hydrologic evaluation process is shown in Figure 3-7. A full description of the application process is provided in Appendix A (Prince George's County, 1997).

Hydrologic Evaluation Techniques

A variety of models are available to simulate the rainfall-runoff processes for watersheds. The selection of the appropriate modeling technique will depend on the level of detail and rigor required for the application and the amount of data available for setup and testing of the model results. Four types of simulation models are briefly summarized below.

Hydrologic evaluation techniques

HSPF
SWMM
HEC-1
TR-55/TR-20
The rational method

Hydrologic Simulation Program - FORTRAN (HSPF). The HSPF model is a comprehensive package developed and maintained by the U.S. Environmental Protection Agency for simulation of water quantity and quality from mixed land use watersheds. The model uses continuous simulation of rainfall-runoff processes to generate hydrographs, runoff flow rates, sediment yield, and pollutant washoff and transport. HSPF includes consideration of infiltration, subsurface water balance, interflow, and base flow.

Storm Water Management Model (SWMM). SWMM is an urban stormwater model developed and maintained by the U.S. Environmental Protection Agency. SWMM is applied to stormwater simulations including urban runoff, flood routing, and flooding analysis. The model provides continuous simulation, using variable timesteps, of rainfall-runoff processes and associated pollutant washoff and transport. SWMM also includes flow routing capabilities for open channels and piped systems.

HEC-1. The HEC-1 model was developed by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC). HEC-1 is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component provides simulation of a rainfall-runoff process. The result of the modeling process is the computation of streamflow hydrographs at desired

LID Hydrologic Analysis Procedure

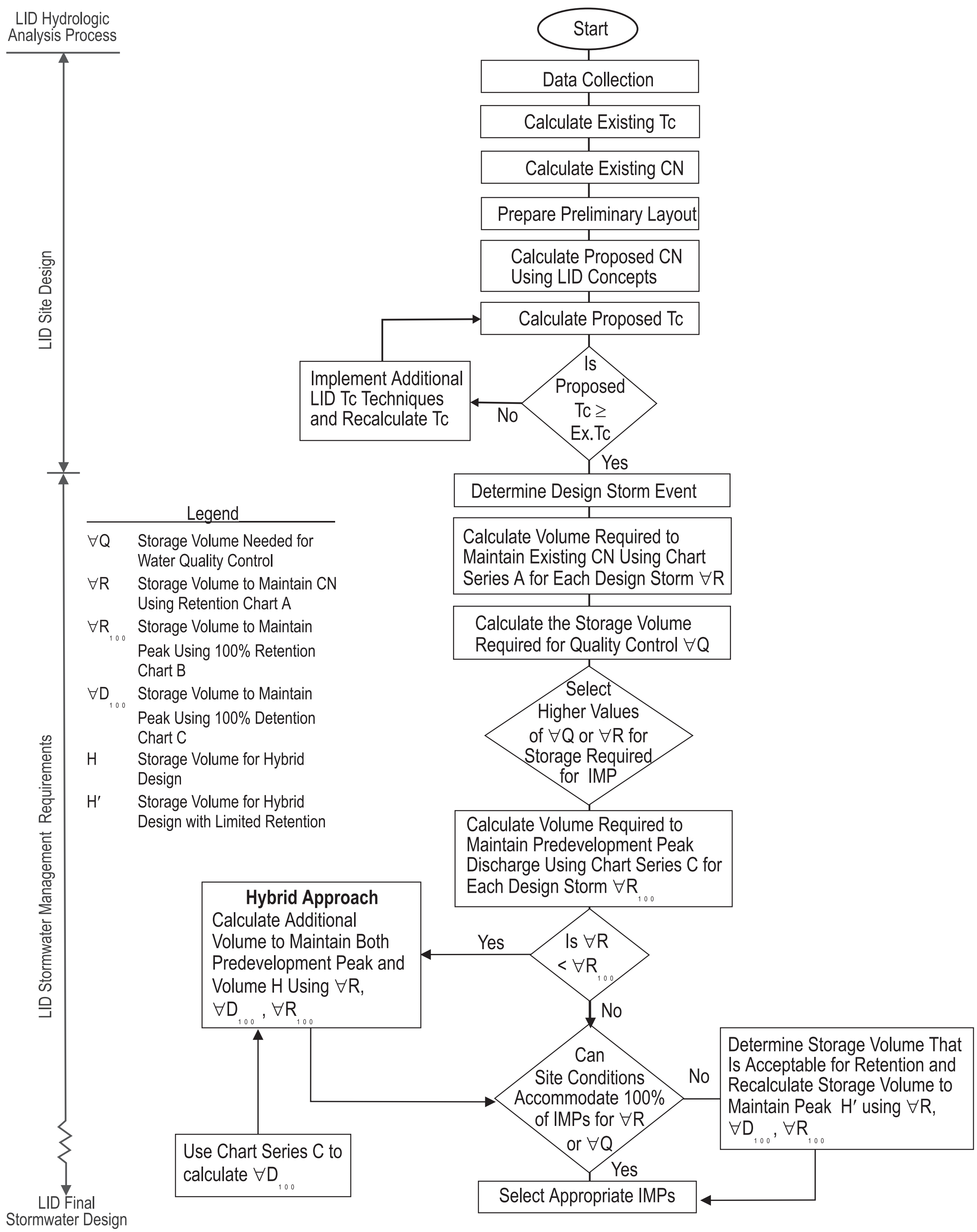


Figure 3-7. Prince George's County, Maryland, example of low-impact development analysis procedure (Prince George's County, 1997)

locations in the river basin. The depth-area option computes flood hydrographs while preserving a user-supplied precipitation depth versus area relation throughout the stream network.

TR-55/TR-20. The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), developed the TR-55/TR-20 model. TR-55 uses the runoff curve number method and unit hydrographs to convert rainfall into runoff. TR-55 and TR-20 are infiltration loss models that use the runoff curve number methods and synthetic storm flow hydrograph development to predict peak volume and flow rates for a given catchment area. The advantage of applying TR-55 and TR-20 is the convenience of tables and input parameters included for a wide range of soil and land use conditions. Also TR-55 and TR-20 models are widely used by field-level professionals.

The Rational Method. The rational method is a storm sewer evaluation method based on the rational formula (Maidment, 1993). The rational formula calculates the peak flow rate as a function of the rainfall intensity (for a specific design return period and time of concentration), the watershed area, and the runoff coefficient. The rational method is frequently used in land development applications due to its simplicity and ease of application.

Table 3-2 provides an overview of the attributes and functions of the selected models.

LID Hydrologic Illustrations

To illustrate the hydrologic analysis techniques employed by low-impact development, two examples from the Prince George's County Design Manual are discussed below (Prince George's County,

Table 3-2 Comparison of Model Attributes and Functions

Attribute	Model				
	HSPF	SWMM	TR-55/TR-20	HEC-1	Rational
Sponsoring agency	USEPA	USEPA	NRCS (SCS)	CORPS (HEC)	Method
Simulation type	Continuous	Continuous	Single event	Single event	Single event
Water quality analysis	Yes	Yes	None	None	None
Rainfall/runoff analysis	Yes	Yes	Yes	Yes	Yes
Sewer system flow routing	None	Yes	Yes	Yes	None
Dynamic flow routing equations	None	Yes	Yes	None	None
Regulators, overflow structures	None	Yes	None	None	None
Storage analysis	Yes	Yes	Yes	Yes	None
Treatment analysis	Yes	Yes	None	None	None
Data and personnel requirements	High	High	Medium	Medium	Low
Overall model complexity	High	High	Low	High	Low

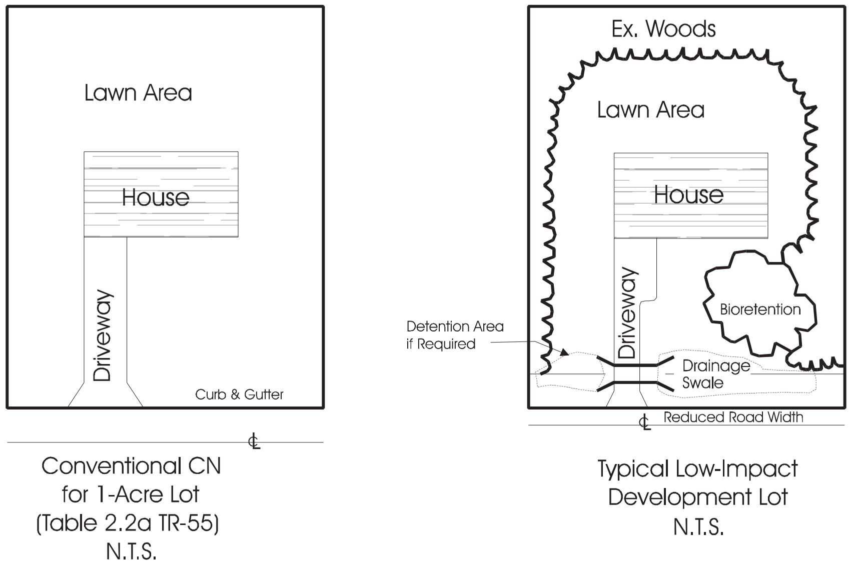


Figure 3-8. Customizing runoff CN for a low-impact development site

1997). The examples highlight the use of the LID tools in achieving the runoff volume and peak flow objectives. The first example describes the control of runoff volume and peak flow using a TR-55 application. The second example describes methods used to control the time of concentration to manage the peak flow rate.

LID Runoff Volume and Peak Flow Management

Calculation of the LID runoff potential is based on a detailed evaluation of the existing and proposed land cover so that an accurate representation of the potential for runoff can be obtained. This calculation requires the investigation of parameters associated with a low-impact development, such as the following:

- Land cover type
- Percentage and connectivity of impervious areas
- Soils type and texture
- Antecedent soil moisture conditions

Determination of LID Runoff Curve Number

The process for performing a hydrologic evaluation for a LID site is illustrated through the use of a TR-55 application example (SCS, 1986). As illustrated in Figure 3-8, customizing the curve number (CN) for a LID site allows the developer/engineer to take advantage of and get credit for a variety of LID site planning practices, which include in this case:

- Narrower driveways and roads (minimizing impervious areas)
- Maximizing tree preservation or forestation (tree planting)
- Site fingerprinting (minimal disturbance)
- Open drainage swales
- Preservation of soils with high infiltration rates (locate impervious areas on low infiltration soils)
- Location of IMPs on high-infiltration soils

Table 3-3 Comparison of Conventional and LID Land Covers

Conventional Land Covers (TR-55 assumptions)	LID Land Covers
20% impervious 80% grass	15% impervious 25% woods 60% grass

Table 3-3 shows the resulting low-impact development CN land cover compared with those of a conventional development CN, as found in Table 2.2a of TR-55 (SCS, 1986) for the example 1-acre lot.

Table 3-4 shows how LID site planning can affect components of the CN, resulting in lower CN and more infiltration.

Figure 3-9 shows how hydrologic response is altered using LID example techniques to reduce the impervious areas and the associated runoff peak volume. Hydrograph 1 is the predevelopment condition, and hydrograph 2 is the postdevelopment condition without controls. Hydrograph 5 represents the resulting postdevelopment hydrograph

Table 3-4. LID Planning Techniques to Reduce the Postdevelopment Runoff Volume

Suggested Options Affecting Curve Number	Limit use of sidewalks	Reduce road length and width	Reduce driveway length and width	Conserve natural resources areas	Minimize disturbance	Preserve infiltratable soils	Preserve natural depression areas	Use transition zones	Use vegetated swales	Preserve Vegetation
Land Cover Type				✔	✔			✔	✔	✔
Percent of Imperviousness	✔	✔	✔					✔		
Hydrologic Soils Group				✔		✔				
Hydrologic Condition				✔	✔	✔				
Disconnectivity of Impervious Area	✔	✔	✔							
Storage and Infiltration							✔			✔

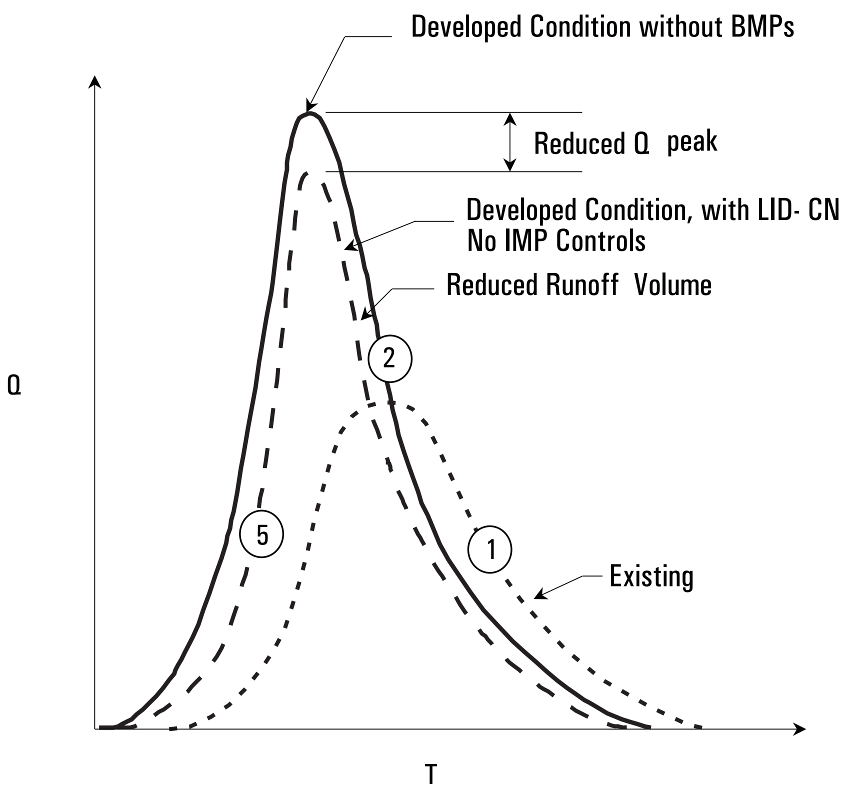


Figure 3-9. Effect of low-impact development CN on the postdevelopment hydrograph without stormwater BMPs

with a significant reduction in both postdevelopment peak rate and volume, which can be achieved by just using LID site planning techniques to reduce CN values and without the benefit of IMP.

Maintaining the Predevelopment Time of Concentration

The management of runoff volume, peak flow, and frequency requires that the postdevelopment time of concentration (Tc) be maintained close to the predevelopment Tc. The travel time (Tt) throughout individual lots and areas should be approximately the same so that the Tc is representative of the drainage. This is critical because low-impact development theory is based on a relatively homogeneous land cover and distributed IMPs. To maintain the Tc, low-impact developments use the following site planning techniques:

- Maintaining predevelopment flow path length by dispersing and redirecting flows, generally through open swales and natural drainage patterns.
- Increasing surface roughness (e.g., reserving woodlands, using vegetated swales).
- Detaining flows (e.g., open swales, rain gardens).

- Minimizing disturbance (minimizing compaction and changes to existing vegetation).
- Flattening grades in impacted areas.
- Disconnecting impervious areas (e.g., eliminating curb/gutter and redirecting downspouts).
- Connecting pervious and vegetated areas (e.g., reforestation, forestation, tree planting).

To maintain predevelopment Tc, an iterative process that analyzes different combinations of the above appropriate techniques may be required. These site planning techniques are incorporated into the hydrologic analysis computations for postdevelopment Tc to demonstrate an increase in postdevelopment Tc above conventional techniques and a corresponding reduction in peak discharge rates.

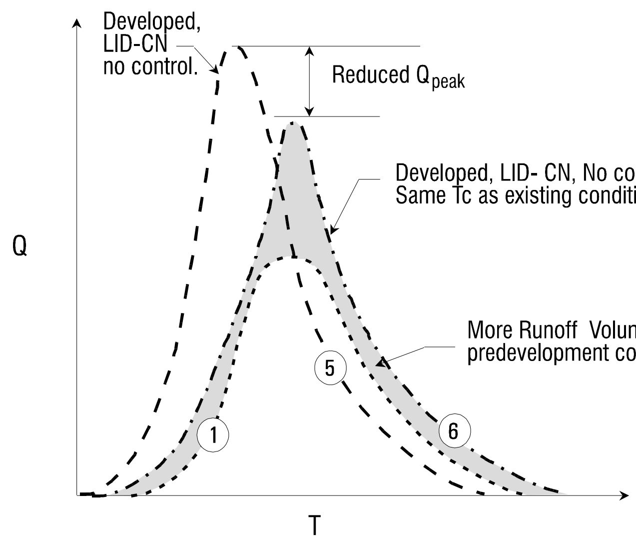


Figure 3-10. Low-impact development hydrograph that has a reduced CN and maintains the Tc without conventional stormwater controls

Figure 3-10 illustrates the hydrologic response to maintaining equal predevelopment and postdevelopment TCs. Hydrograph 1 is the predevelopment condition. Hydrograph 5, as previously described, shows the benefits of using LID techniques to reduce impervious areas and the associated runoff peak volume.

Hydrograph 6 represents the effects of using LID techniques to maintain the Tc. This effectively shifts the postpeak runoff time to that of the predevelopment condition and lowers the peak runoff rate.

Maintaining the same Tc in a small watershed can be mainly accomplished by maintaining or raising the Manning's roughness "n" for the initial overland (sheet) flow at the top of the watershed and increasing the flow path length to the most hydraulically distant point in the drainage area. After the transition to shallow concentrated flow, additional gains in Tc can be accomplished by:

- Decreasing the slope
- Increasing the flow length
- Directing the flow over pervious areas.

In LID sites, the volume of flow in closed channels (pipes) should be minimized to the greatest extent possible. Swales and open channels should be designed with the following features:

- Increase surface roughness to retard velocity.
- Maximize sheet flow conditions.
- Use a network of wider and flatter channels to avoid fast-moving channel flow.
- Increase channel flow path.
- Reduce channel gradients to decrease velocity (many local jursidictions have a minimum slope requirement of 2 percent; 1 percent may be considered on a case-by-case basis).
- The channel should flow over pervious soils whenever possible to increase infiltration so that there is a reduction of runoff to maximize infiltration capacity.

Table 3-5 identifies LID techniques and objectives to maintain the predevelopment Tc.

Detailed guidance and computational examples are provided in the Appendix A, Example LID Hydrologic Computations, which has been adapted from the Prince George's County LID Hydrologic Analysis Manual (Prince George's County, 1997).

Table 3-5. LID Techniques to Maintain the Predevelopment Time of Concentration

	Low Impact Development Technique									
Low-Impact Development Objective	On-lot bioretention	Wider and flatter swales	Maintain sheet flow	Clusters of trees and shrubs in flow path	Provide tree conservation/ transition zones	Minimize storm drain pipes	Disconnect impervious areas	Save trees	Preserve existing topography	LID drainage and infiltration zones
Minimize disturbance	✔		✔	✔	✔	✔	✔	✔	✔	
Flatten grades		✔	✔			✔			✔	✔
Reduce height of slopes						✔			✔	✔
Increase flow path (divert and redirect)		✔	✔	✔		✔	✔	✔		
Increase roughness "n"	✔		✔	✔	✔	✔	✔	✔		✔

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Chapter 4
Low-Impact Development Integrated Management

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Chapter 4

Low-Impact Development Integrated Management Practices

IMPs addressed in this chapter

- Bioretention
- Dry wells
- Filter/buffer strips
- Grassed swales
- Rain barrels
- Cisterns
- Infiltration trenches

Low-impact development technology employs microscale and distributed management techniques, called integrated management practices (IMPs), to achieve desired postdevelopment hydrologic conditions. The site planning process (Chapter 2) has identified how fundamental design techniques can be used to minimize the hydrologic effects of development. The hydrologic analysis (Chapter 3) demonstrates how to quantify the predevelopment and postdevelopment conditions under various design scenarios. This chapter presents the third step in the LID process—identifying and selecting IMPs. Detailed descriptions of the IMPs are included.

Procedures for Selection and Design of IMPs

Site planning techniques can significantly reduce the hydrologic impacts of development. Once site-planning techniques have been exercised, additional modifications are likely to be required to match the predevelopment hydrograph. Measures used to evaluate the hydrologic impact include the runoff volume and the peak flow condition. The shaded portion of Figure 3-10 illustrates the remaining "control" that might be required to meet the development hydrology goal. IMPs can be used to provide that additional hydrologic control of peak discharge and runoff volume.

LID IMPs are used to satisfy the storage volume requirements calculated in Chapter 3. They are the preferred method because

In This Chapter…

they can maintain the predevelopment runoff volume and can be integrated into the site design. The design goal is to locate IMPs at the source or lot, ideally on level ground within individual lots of the development. Management practices that are suited to low-impact development include:

- Bioretention facilities
- Dry wells
- Filter/buffer strips and other multifunctional landscape areas
- Grassed swales, bioretention swales, and wet swales
- Rain barrels
- Cisterns
- Infiltration trenches

The process for selection and design begins with the control goals identified using the hydrologic techniques described in Chapter 3. The steps identify the opportunities for supplemental controls and guide the designer through the selection and design process (Figure 4-1):

Step 1: Define hydrologic control required.

Step 2: Evaluate site constraints.

Step 3: Screen for candidate practices.

Step 4: Evaluate candidate IMPs in various configurations.

Step 5: Select preferred configuration and design.

Step 6: Supplement with conventional controls, if necessary.

Fundamental questions addressed in the IMP selection and design process

What are the goals for reduction of the volume and peak flow conditions after development?

What are site constraints for selection of IMPs?

What types of IMPs are appropriate for my site?

How many IMPs do I need to plan for?

How much will it cost to install and maintain these practices?

Will IMPs be sufficient to meet the goals and regulatory requirements?

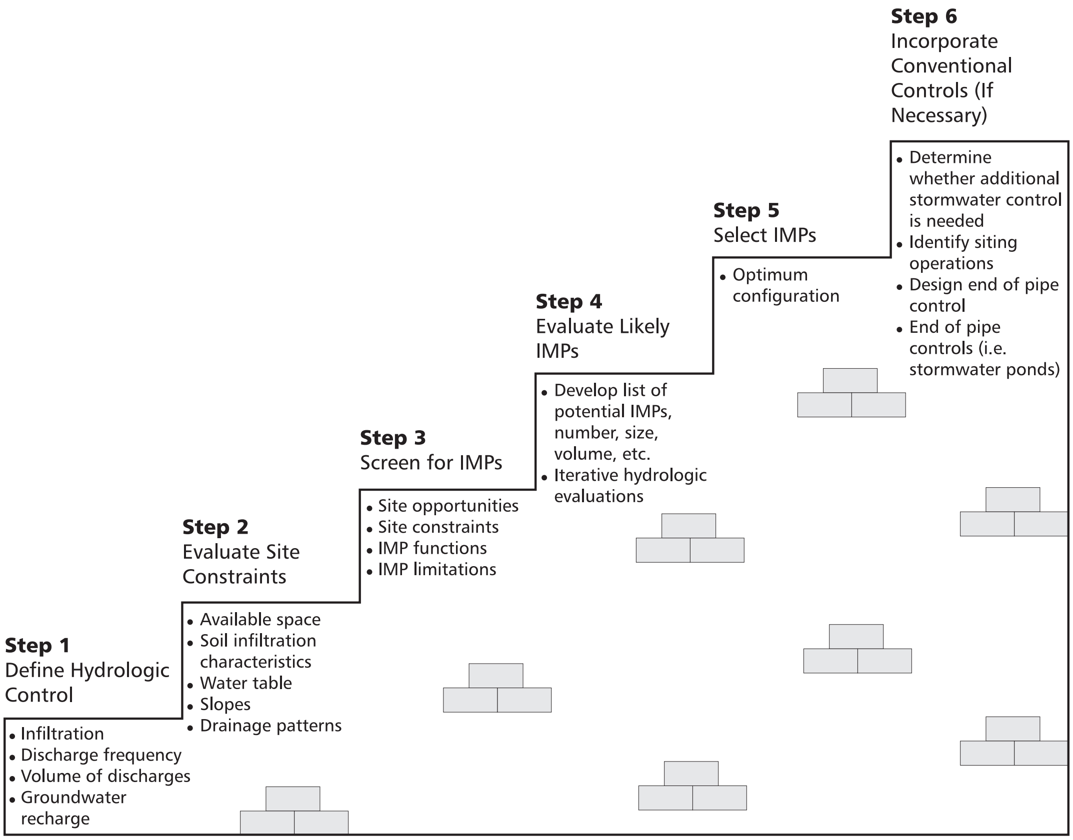


Figure 4-1. Key steps in developing stormwater plan using LID practices

Step 1: Define Hydrologic Controls Required

The goal of the LID approach is to mimic the predevelopment hydrologic regime of the site and thus maintain the predevelopment runoff volume, peak runoff rates, and frequency. These control objectives were defined and addressed, to the degree possible, through site planning techniques described in Chapter 2.

The remaining need for control must be identified based on the hydrologic goals identified in Chapter 3. This is illustrated in Figure 3-9.

Hydrologic functions such as infiltration, frequency and volume of discharges, and groundwater recharge become essential considerations when identifying and selecting IMPs. Following the procedures described in Chapter 3, the hydrologic functions can be quantified with respect to the various design parameters, which include runoff volume, peak discharge, frequency and duration of discharge, groundwater recharge, and water quality parameters. When these design parameters are quantified for predevelopment conditions, they define or quantify the hydrologic controls required for a specific site.

Step 2: Evaluate Site Opportunities and Constraints

Each site has unique characteristics and opportunities for control. The LID concept encourages innovation and creativity in the management of site planning impacts. In this step the site should be evaluated for opportunities and constraints. Opportunities are locations where physical conditions like available space, infiltration characteristics, and slopes are amenable to IMP installation. These same conditions might also constrain the use of IMPs. Table 4-1 provides a summary of potential site constraints of IMPs.

Table 4-1. Site Constraints of IMPs

	Bioretention	Dry Well	Filter/Buffer Strip	Swales: Grass, Infiltration, Wet	Rain Barrels	Cistern	Infiltration Trench
Space Required	Minimum surface area range: 50 to 200 ft^2 Minimum width: 5 to 10 ft Minimum length: 10 to 20 ft Minimum depth: 2 to 4 ft	Minimum surface area range: 8 to 20 ft^2 Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft Minimum depth: 4 to 8 ft	Minimum length of 15 to 20 ft	Bottom width: 2 ft minimum, 6 ft maximum	Not a factor	Not a factor	Minimum surface area range: 8 to 20 ft^2 Minimum width: 2 to 4 ft Minimum length: 4 to 8 ft
Soils	Permeable soils with infiltration rates > 0.27 inches/hour are recommended. Soil limitations can be overcome with use of underdrains	Permeable soils with infiltration rates > 0.27 inches/hour are recommended	Permeable soils perform better, but soils not a limitation	Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils	Not a factor	Not a factor	Permeable soils with infiltration rates > 0.52 inches/hour are recommended
Slopes	Usually not a limitation, but a design consideration	Usually not a limitation, but a design consideration. Must locate downgradient of building and foundations	Usually not a limitation, but a design consideration	Swale side slopes: 3:1 or flatter Longitudinal slope: 1.0% minimum; maximum based on permissible velocities	Usually not a limitation, but a design consideration for location of barrel outfall	Not a factor	Usually not a limitation, but a design consideration. Must locate down-gradient of buildings and foundations
Water Table/ Bedrock	2- to 4-ft clearance above water table/ bedrock recommended	2- to 4-ft clearance above water table/ bedrock recommended	Generally not a constraint	Generally not a constraint	Generally not a constraint		2- to 4-ft clearance
Proximity to build foundations	Minimum distance of 10 ft downgradient from buildings and foundations recommended	Minimum distance of 10 ft downgradient from buildings and foundations recommended	Minimum distance of 10 ft downgradient from buildings and foundations recommended	Minimum distance of 10 ft downgradient from buildings and foundations recommended	Not a factor		Minimum distance of 10 ft down-gradient from buildings and foundations recommended
Max. Depth	2- to 4-ft depth depending on soil type	6- to 10-ft depth depending on soil type	Not applicable	Not applicable	Not applicable		6- to 10-ft depth depending on soil type
Maintenance	Low requirement, property owner can include in normal site landscape maintenance	Low requirement	Low requirement, routine landscape maintenance	Low requirement, routine landscape maintenance	Low requirement		Moderate to high

Suitability Criteria/Factors

The site designer should consider or evaluate the following factors when selecting LID IMPs.

Space/Real Estate Requirements. The amount of space required for stormwater management controls is always a consideration in the selection of the appropriate control. LID IMPs, because they are integrated into and distributed throughout the site's landscape, typically do not require that a separate area be set aside and dedicated to stormwater management.

Soils. Soils and subsoil conditions are a very important consideration in every facet of LID technology, including the site planning process, the hydrologic considerations, and the selection of appropriate IMPs. The use of micromanagement practices, as well as the use of underdrains to provide positive subdrainage for bioretention practices, helps to overcome many of the traditional soil limitations for the selection and use of IMPs.

Slopes. Slope can be a limiting factor when the use of the larger traditional stormwater controls is considered. With the application of the distributed micromanagement IMPs, however, slope is seldom a limiting factor; it simply becomes a design element that is incorporated into the hydrologically functional landscape plan.

Water Table. The presence of a high water table calls for special precautions in every aspect of site planning and stormwater management. The general criterion is to provide at least 2 to 4 feet of separation between the bottom of the IMP and the top of the seasonally high water table elevation. Also, the potential for contamination should be considered, especially when urban landscape hotspots are involved.

Proximity to Foundations. Care must be taken not to locate infiltration IMPs too close to foundations of buildings and other structures. Considerations include distance, depth, and slope.

Maximum Depth. By their nature, the micromanagement practices that make up the LID IMPs do not require much depth, and thus this factor is not usually a major concern. Bioretention cells, for example, usually allow only 6 inches of ponding depth, and 2 to 4 feet of depth for the planting soil zones.

Maintenance Burden. Maintenance costs for traditional stormwater controls are significant and have become a considerable burden for local governments and communities. Maintenance costs can equal or exceed the initial construction cost. In comparison, many of the IMPs require little more than normal landscaping maintenance treatment. Additionally, this cost is typically the responsibility of the individual property owner rather than the general public. Communities are advised to retain the authority to maintain their sites if they fail to function as designed.

Suitability criteria/factors

Soils

Slopes

Water table

Proximity to foundations

Maximum depth

Maintenance burden

As previously discussed, one of the key concepts to making LID technology work is to think small with respect to the size of the area being controlled (microsubsheds) and the size of the practice (micropractices). This combination allows the designer to incorporate many of the LID practices into the landscape and to overcome potential site constraints with respect to available space, soils, slopes, and other factors in a way that would not be possible with the larger conventional methods.

Step 3: Screen for Candidate Practices

Based on the evaluation of site opportunities and constraints, a comparison with the available practices is made. IMPs that are inappropriate or infeasible for the specific site are excluded from further consideration. Screening should consider both the site constraints (Table 4-1) and the hydrologic and water quality functions identified in Table 4-2.

Table 4-2 provides an assessment of the hydrologic functions of the preferred LID management practices. Table 4-3 provides a summary of the reported water quality benefits provided by the LID IMPs.

It is important to recognize that LID stormwater management is not simply a matter of selecting from a menu of available preferred practices. Rather, it is an integrated planning and design process. The site planning process described earlier is a necessary and essential component of the LID stormwater management concept. The preferred practices by themselves might not be sufficient to restore the hydrologic functions of a site without the accompanying site planning procedures described in Chapter 2.

Table 4-2. Hydrologic Functions of LID Integrated Management Practices (IMPs)

	PMP						
Hydrologic Functions	Bio Ret	Dry Well	Filter/ Buffer	Swale Grass	Rain Barrel	Cistern	Infilt. Trench
Interception	H	N	H	M	N	N	N
Depression Storage	H	N	H	H	N	N	M
Infiltration	H	H	M	M	N	N	H
G.W. Recharge	H	H	M	M	N	N	H
Runoff Volume	H	H	M	M	L	M	H
Peak Discharge	M	L	L	M	M	M	M
Runoff Frequency	H	M	M	M	M	M	M
Water Quality	H	H	H	H	L	L	H
Base Flow	M	H	H	M	M	N	L
Stream Quality	H	H	H	M	N	L	H

H = High M = Moderate L = Low N = None

Table 4-3 Reported Pollutant Removal Efficiency of IMPs

PMP	TSS	Total P	Total N	Zinc	Lead	BOD	Bacteria
Bioretention	-	81	43	99	99	-	-
Dry Well	80-100	40-60	40-60	80-100	80-100	60-80	60-80
Infiltration Trench	80-100	40-60	40-60	80-100	80-100	60-80	60-80
Filter/Buffer Strip	20-100	0-60	0-60	20-100	20-100	0-80	-
Vegetated Swale	30-65	10-25	0-15	20-50	20-50	-	Neg.
Infiltration Swale	90	65	50	80-90	80-90	-	-
Wet Swale	80	20	40	40-70	40-70	-	-
Rain Barrel	NA	NA	NA	NA	NA	NA	NA
Cistern	NA	NA	NA	NA	NA	NA	NA

Source: CRC, 1996; Davis et al. 1997; MWCG, 1987;Urbonas & Stahre, 1993; Yousef et al., 1985; Yu et al., 1992; Yu et al., 1993.

Step 4: Evaluate Candidate IMPs in Various Configurations

After the candidate IMPs are identified, they are deployed as appropriate throughout the site and the hydrologic methods described in Chapter 3 are applied to determine whether the mix of IMPs meets the hydrologic control objectives identified in Step 1. Typically, on the first design attempt the hydrologic control objectives are not met precisely but instead are overestimated or underestimated. An iterative process might be necessary, adjusting the number and size of IMPs until the hydrologic control objectives are optimized. An example LID hydrologic computation that illustrates this procedure is provided in the Appendix.

Step 5: Select Preferred Configuration and Design

The iterative design process typically identifies a number of potential configurations and mixes of IMPs. The designer has the option to use more or fewer bioretention structures, rain barrels, cisterns, dry wells, infiltration trenches, vegetated swales, and other practices. Design factors such as space requirements, site aesthetics, and construction costs can all be factored into the decision-making process to arrive at an optimum or preferred configuration and mix of IMPs that provide the identified level of hydrologic control at a reasonable cost.

Step 6: Design Conventional Controls if Necessary

If for any reason the hydrologic control objectives developed for a given site cannot be achieved using IMPs, it might be necessary to add some conventional controls. Sometimes site constraints like low-permeability soils, the pressure of a high water table or hard rock, or very intensive land uses such as commercial or industrial sites can preclude the use of sufficient IMPs to meet the hydrologic design objectives, particularly the peak discharge criteria. In these situations it is recommended that IMPs be used to the extent possible and then that additional conventional controls such as detention or retention practices (i.e. ponds) be used to meet the remaining hydrologic design objectives. An example computation that illustrates how to determine when additional conventional controls are required is provided in the Appendix.

LID Functions Include

Groundwater recharge

Retention or detention of runoff

Pollutant settling

Aesthetic value

Multiple use

Integrated Management Practices (IMPs)

LID IMPs are designed for on-lot use. This approach integrates the lot with the natural environment and eliminates the need for large centralized parcels of land to control end-of-pipe runoff. The challenge of designing a low-impact site is that the IMPs and site design strategies must provide quantity and quality control and enhancement, including

- Groundwater recharge through infiltration of runoff into the soil.
- Retention or detention of runoff for permanent storage or for later release.
- Pollutant settling and entrapment by conveying runoff slowly through vegetated swales and buffer strips.

  In addition, LID also provides an added aesthetic value to the property, which increases a sense of community lifestyle.
- Multiple use of landscaped areas. In some cases, the on-lot or commercial hydrologic control also can satisfy local government requirements for green or vegetated buffer space.

Placing controls in series provides for the maximum on-lot stormwater runoff control (i.e., the maximum mitigation of site development impacts on the natural hydrology). This type of design control is known as a “hybrid” and is effective in reducing both volume and peak flow rate. Examples of specific IMPs are described below.

Bioretention

A practice using landscaped areas on lots to hold and infiltrate stormwater

Bioretention

Bioretention is a practice to manage and treat stormwater runoff by using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. The bioretention concept was originally developed by the Prince George’s County, Maryland, Department of Environmental Resources in the early 1990s as an alternative to traditional BMP structures (ETA, 1993). The method combines physical filtering and adsorption with biological processes. The system can include the following components, as illustrated in Figures 4-2 and 4-3: a pretreatment filter strip of grass channel inlet area, a shallow surface water ponding area, a bioretention planting area, a soil zone, an underdrain system, and an overflow outlet structure.

Figure 4-2. Bioretention area

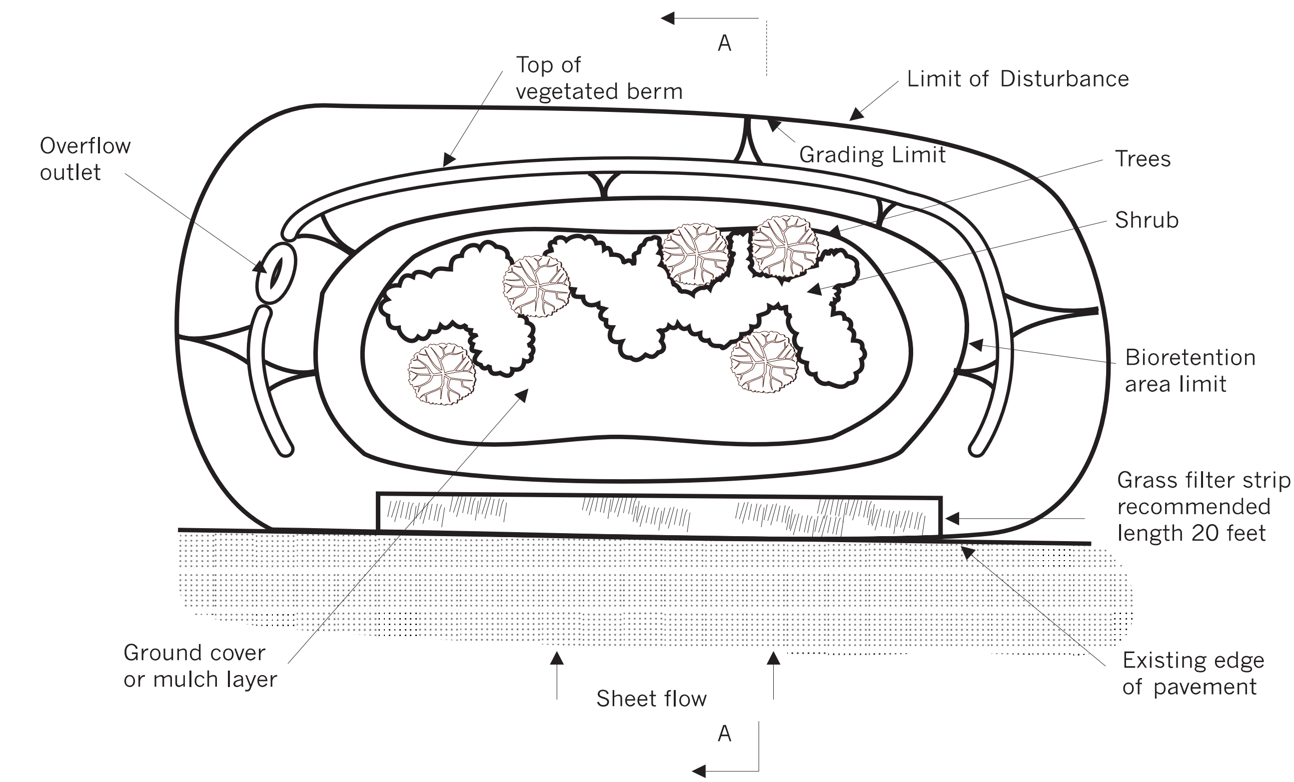
Design Considerations. The major components of the bioretention system all require careful design considerations. These major components include

- Pretreatment area (optional)
- Ponding area
- Ground cover layer
- Planting soil
- In situ soil
- Plant material
- Inlet and outlet controls
- Maintenance

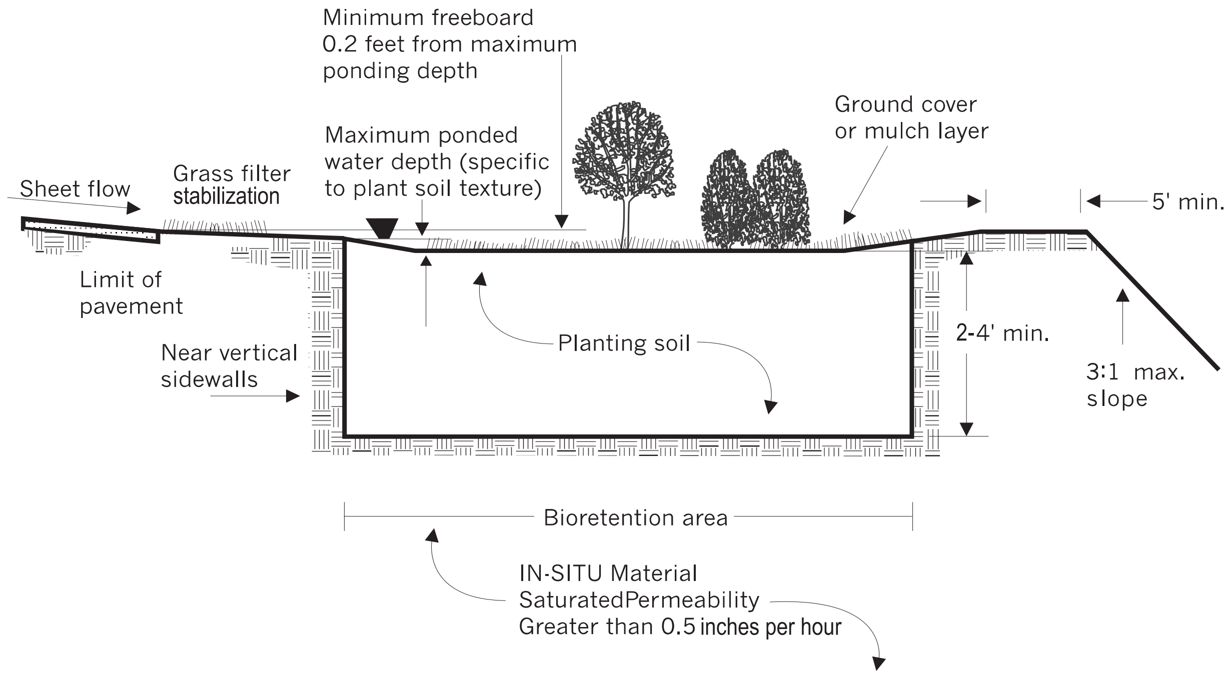
The key design consideration for these components are summarized in Table 4-4. Detailed design guidance can be obtained from the *Prince George's County Bioretention Manual* (ETA, 1993).

Table 4-4. Bioretention Design Components

Pretreatment area	Required where a significant volume of debris or suspended material is anticipated such as parking lots and commercial areas. Grass buffer strip or vegetated swale are commonly used pretreatment devices
Ponding area	Typically limited to a depth of 6 inches
Groundcover area	3 inches of mature mulch recommended
Planting soil	Depth = 4 feet Soil mixtures include sand, loamy sand, and sandy loam Clay content ≤ 10%
In-situ soil	Infiltration rate ≥ 0.5 inches/hour w/o underdrains Infiltration rate ≤ 0.5 inch/hour underdrain required
Plant materials	Native species, minimum 3 species
Inlet and outlet controls	Non erosive flow velocities (0.5 ft/sec)
Maintenance	Routine landscape maintenance
Hydrologic design	Determined by state or local agency



Plan view (not to scale)



Section A-A (not to scale)

Figure 4-3. Typical bioretention facility

Dry Wells

A dry well consists of a small excavated pit backfilled with aggregate, usually pea gravel or stone. Dry wells function as infiltration systems used to control runoff from building rooftops. Another special application of dry wells is modified catch basins, where inflow is a form of direct surface runoff. Figure 4-4 shows a typical detail of a dry well.

Dry wells provide the majority of treatment by processes related to soil infiltration, including adsorption, trapping, filtering, and bacterial degradation.

Design considerations. The key design considerations for dry wells are summarized in Table 4-5. Detailed design guidance can be obtained in *Maryland Standards and Specifications for Infiltration Practices* (MDDNR, 1984); *Maintenance of Stormwater Management Structures, a Departmental Summary* (MDE, 1986); and *Maryland Stormwater Design Manual* (MDE, 1998).

Dry Wells

Small excavated trenches backfilled with stone, designed to hold and slowly release rooftop runoff

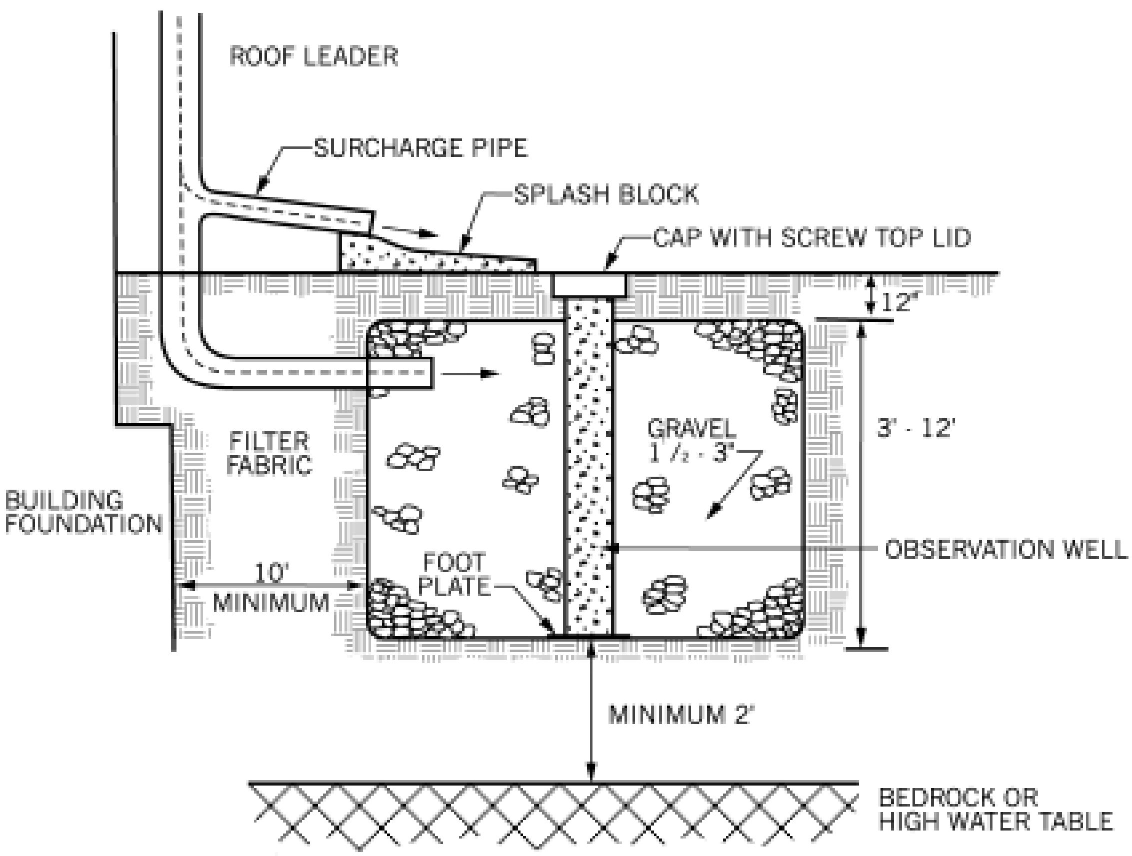


Figure 4-4. Typical dry well

Table 4-5. Dry Well Design Considerations

Design storms	Determined by local or state agencies. Guidance provided in Prince George's County LID Manual is recommended
Soil permeability	≥ 0.27 – 0.50 inches /hour
Storage time	Empty within 3 days
Backfill	Clean aggregate ≥ 11/2, ≤ 3", surrounded by engineering filter fabric
Runoff filtering	Screens should be placed on top of roof leaders, grease, oil floatable organic materials and settable solids should be removed prior to entering well
Outflow structures	Overland flow path of surface runoff exceeding the capacity of the well must be identified and evaluated. An overflow system leading to a stabilized channel or watercourse including measures to provide non-erosive flow conditions must be provided
Observation well	Must be provided, 4-inch PVC or foot place constructed flush with ground surface, cap with lock
Depth of well	3 to 12 feet
Hydrologic design	Determined by state or local agency. Maryland Design Manual is recommended
Water quality	See Table 4.3 for performance data
Maintenance	Periodic monitoring—quarterly at first and annually thereafter

Filter Strips

Bands of close-growing vegetation, usually grass, planted between pollutant source areas and a downstream receiving waterbody

Filter Strips

Filter strips are typically bands of close-growing vegetation, usually grass, planted between pollutant source areas and a downstream receiving waterbody (Figure 4-5). They also can be used as outlet or pretreatment devices for other stormwater control practices. For LID sites, a filter strip should be viewed as only one component in a stormwater management system.

Design Considerations. The key design considerations for filter strips are summarized in Table 4-6. Detailed design guidance is provided in *Maryland Standards and Specifications for Infiltration Practices* (MDDNR, 1984), *Design of Stormwater Filtering Systems*, (CRC, 1996), and *Maryland Stormwater Design Manual* (MDE, 1998).

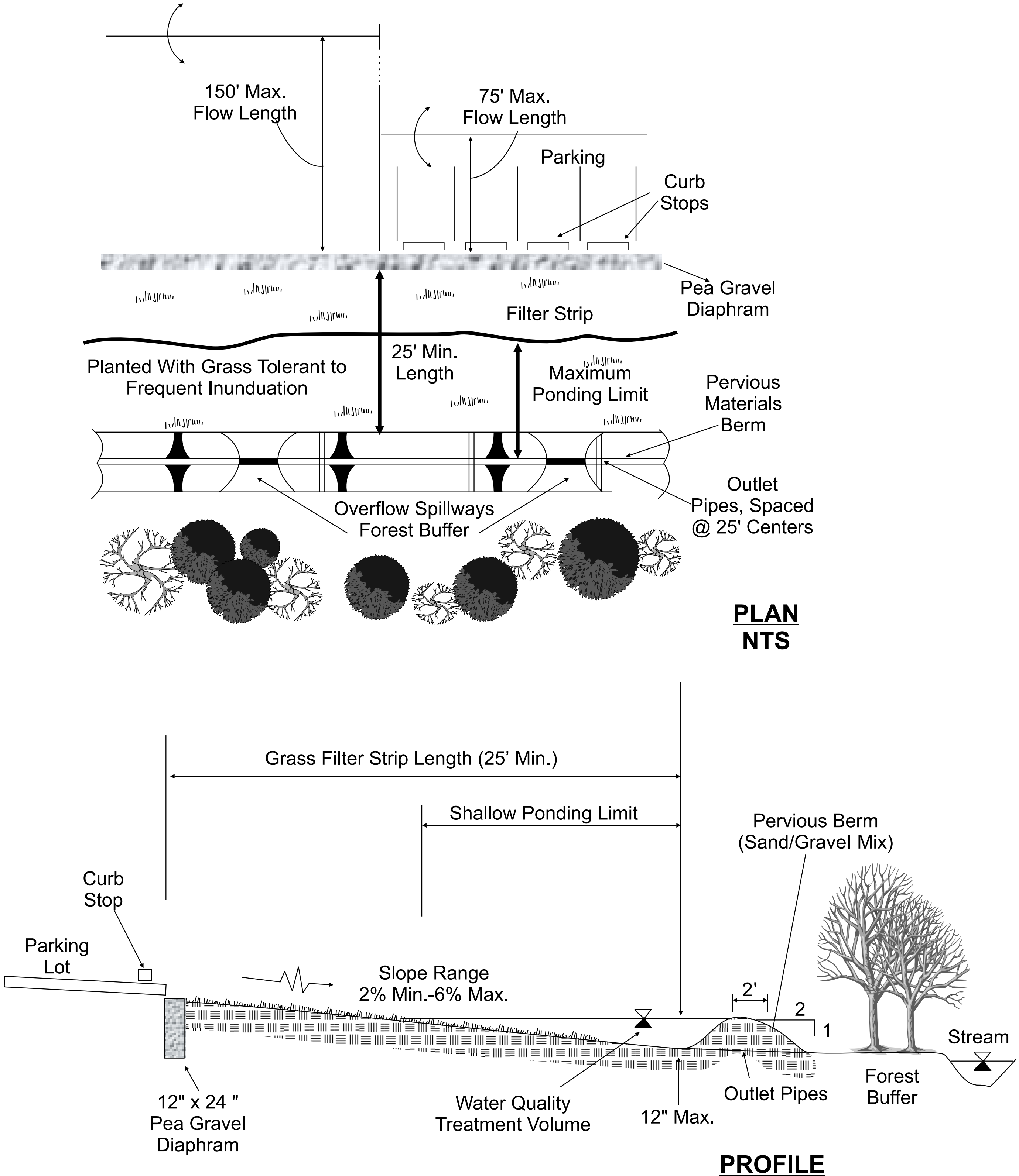


Figure 4-5. Typical filter strip (CRC, 1996).

Table 4-6. Filter Strip Design Considerations

Design storm	Determined by state or local agency. Recommended guidance in Prince George's County, Maryland, LID Manual (PGC, 1997) and Maryland Stormwater Design Manual (MDE, 1998)
Drainage area	Maximum drainage area to filter strips is limited by the overland flow limits of 150 feet for pervious surfaces and 75 feet for impervious surfaces
Slope	Minimum slope = 1.0% Maximum slope = determined by field conditions
Flow	Should be used to control overland sheet flow only. Discharge should not exceed 3.5 cubic feet per second range
Length and size	The size of the filter strip is determined by the required treatment volume. A minimum length of 20 feet is recommended
Water quality	The pollution removal effectiveness of the filter strip is summarized in Table 4.3
Maintenance	Routine landscape maintenance required

Vegetated Buffers

Vegetated buffers are strips of vegetation, either natural or planted, around sensitive areas such as waterbodies, wetlands, woodlands, or highly erodible soils. In addition to protecting sensitive areas, vegetated strips help to reduce stormwater runoff impacts by trapping sediment and sediment-bound pollutants, providing some infiltration, and slowing and dispersing stormwater flows over a wide area.

Level Spreaders

A level spreader typically is an outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope to prevent erosion. One type of level spreader is a shallow trench filled with crushed stone. The lower edge of the level spreader must be exactly level if the spreader is to work properly. Figure 4-6 shows a typical rock-filled trench level spreader detail.

Design Considerations. Sheet flow, or overland flow, is the movement of runoff in a thin layer (usually less than 1 inch in depth) over a wide surface, which begins when water ponded on the surface of the

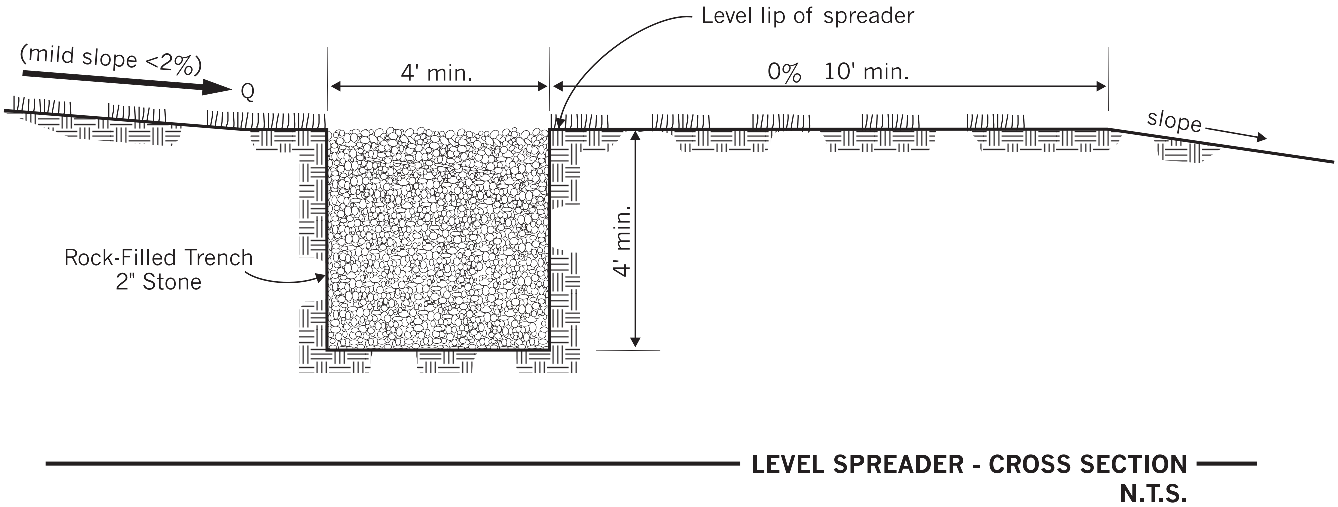
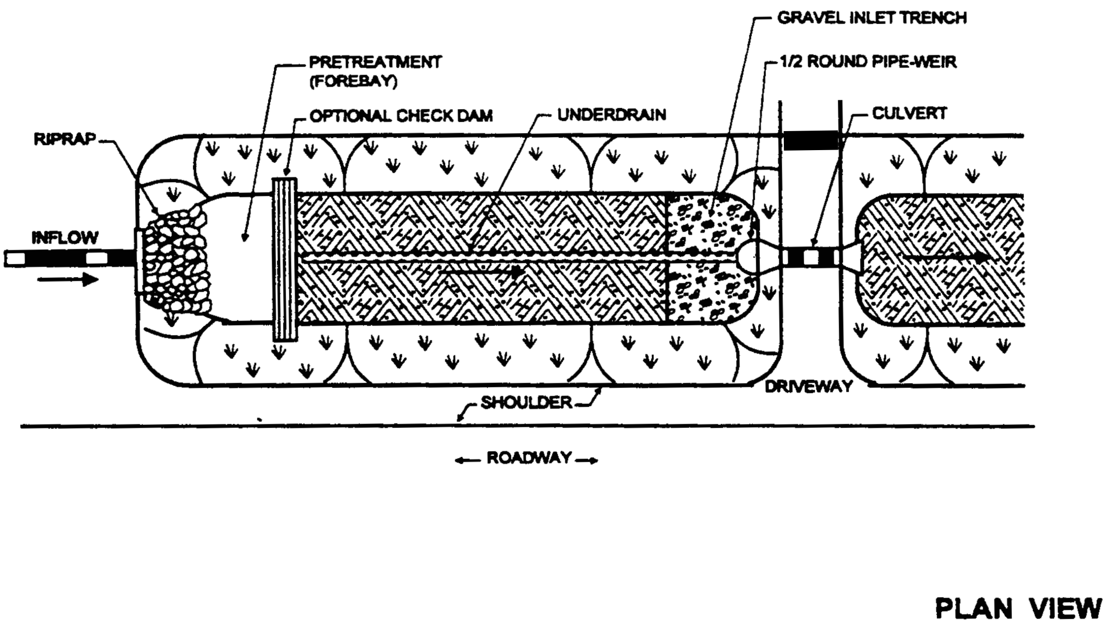


Figure 4-6. Typical rock trench level spreader

land becomes deep enough to overcome surface retention forces. Level spreaders can be used to convey sheet flow runoff from lawn areas within graded areas to bioretention facilities and transition areas.

They can also be used to deliver runoff from parking lots and other impervious areas to infiltration areas. The receiving area of the outlet must be uniformly sloped and not susceptible to erosion. Particular care must be taken to construct the outlet lip completely level in a stable, undisturbed soil to avoid formation of rilling and channeling. Erosion-resistant matting might be necessary across the outlet lip, depending on expected flows. Alternative designs to minimize erosion potential include hardened structures, stiff grass hedges, and segmenting of discharge flows into a number of smaller, adjacent spreaders. Sheet flow should be used over well-vegetated areas, particularly lawns, to achieve additional retention and increase the time of concentration.



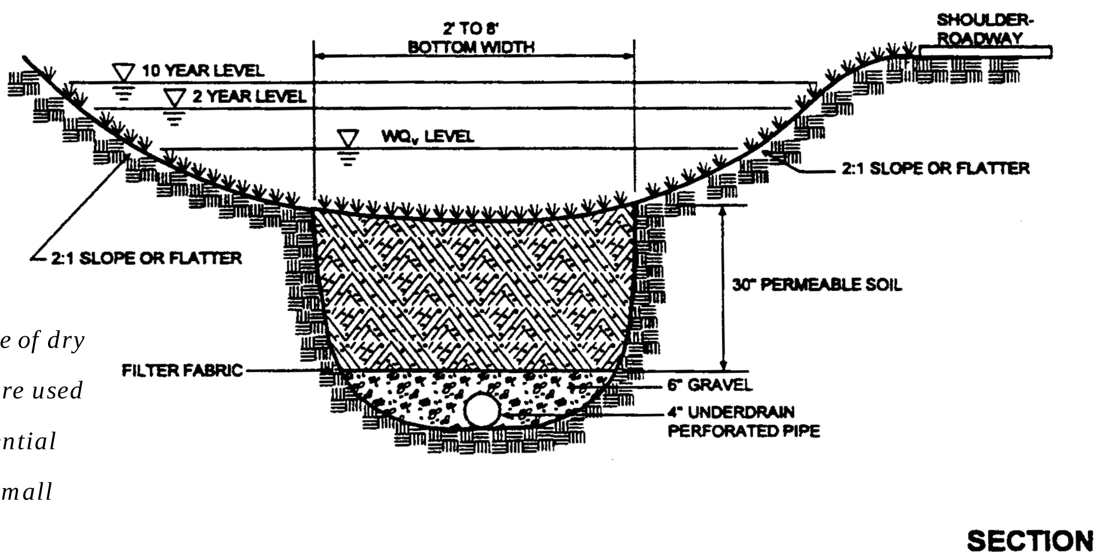
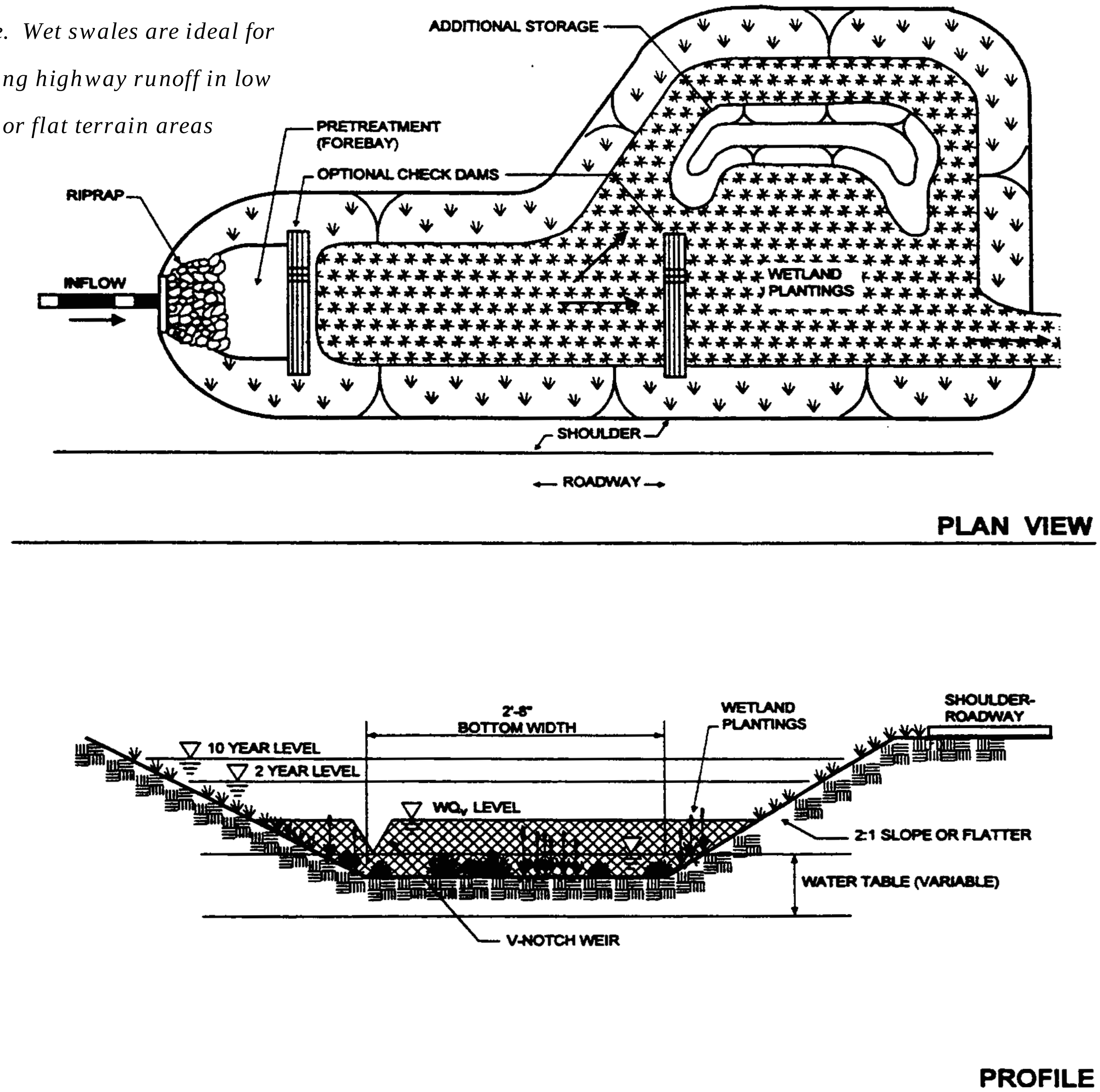


Figure 4-7. Example of dry swale. Dry swales are used at low density residential projects or for very small impervious areas

Grassed Swales

Traditionally, swale designs were simple drainage and grassed channels that primarily served to transport stormwater runoff away from roadways and rights-of-way. Today designers can design these channels to optimize their performance with respect to the various hydrologic factors. Two types of grassed swales are being used for this purpose—the dry swale, which provides both quantity (volume) and quality control by facilitating stormwater infiltration (Figure 4-7), and the wet swale, which uses residence time and natural growth to reduce

Figure 4-8. Example of wet swale. Wet swales are ideal for treating highway runoff in low lying or flat terrain areas



peak discharge and provide water quality treatment before discharge to a downstream location (Figure 4-8). The wet swale typically has water tolerant vegetation permanently growing in the retained body of water. These systems are often used on highway designs.

Design Considerations. The key design considerations for grassed swales are summarized in Table 4-7. Detailed design guidance is provided in *Maryland Standards and Specifications for Infiltration Practices* (MDDNR, 1984), *Design of Stormwater Filtering Systems* (CRC, 1996), and *Maryland Stormwater Design Manual* (MDE, 1998).

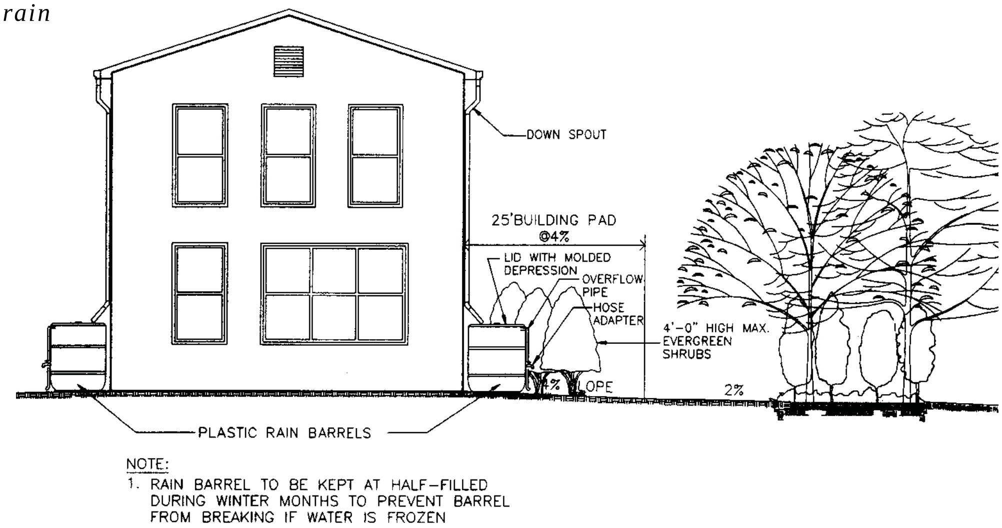
Table 4-7. Grassed Swale Design Considerations

Design Storm	Determined by state or local agency. Refer to guidance provided by the Prince George's County LID Design Manual and the Maryland Stormwater Design Manual (MDE, 1998). Local condition may necessitate adjustment of the recommendations in the guidance documents.
Channel Capacity	Swale must be sized to convey the peak discharge of the design storm
Soils	The permeability (infiltration rate) of the soils will determine whether a dry or wet swale can be used. It is recommended that soils used for dry swales have infiltration rates of 0.27 – 0.50 inches per hour.
Channel Shape	Trapezoidal or parabolic shape recommended
Bottom Width	2 foot minimum, 6 foot maximum
Side Slopes	3:1 or flatter
Channel Longitudinal Slope	1.0 % minimum, 6.0 % maximum
Flow Depth	4.0 inches for water quality treatment
Manning's n value	0.15 for water quality treatment (depth < 4") 0.15 – 0.03 for depths between 4" and 12" 0.03 minimum for depth 12"
Flow Velocity	1.0 fps for water quality treatment - 5.0 fps for 2 year storm fps for 10 year storm
Length of channel	Length necessary for 10 minute residence time
Water Quality	The pollutant removal effectiveness of grassed swales is summarized in Table 4-3
Maintenance	Routine landscape maintenance required.

Rain Barrels

Rain barrels are low-cost, effective, and easily maintainable retention devices applicable to both residential and commercial/ industrial LID sites. Rain barrels operate by retaining a predetermined volume of rooftop runoff (i.e., they provide permanent storage for a design volume); an overflow pipe provides some detention beyond the retention capacity of the rain barrel. Figure 4-9 and Figure 4-10 show

Figure 4-9. Typical rain barrel



a typical rain barrel. Rain barrels also can be used to store runoff for later reuse in lawn and garden watering

Figure 4-10. Rain barrel application to LID

Design Considerations. Rainwater from any type of roofing material can be directed to rain barrels. To be aesthetically acceptable, rain barrels can be incorporated into the lot's land-scaping plan or patio or decking design. Rain barrels placed at each corner of the front side of the house should be landscaped for visual screening. Gutters and downspouts are used to convey water from rooftops to rain barrels. Filtration screens should be used on gutters to prevent clogging of debris. Rain barrels should also be equipped with a drain spigot that has garden hose threading, suitable for connection to a drip irrigation system. An overflow outlet must be provided to bypass runoff from large storm events. Rain barrels must be designed with removable, child-resistant covers and mosquito screening on water entry holes. The size of the rain barrel is a function of the rooftop surface area that drains to the barrel, as well as the inches of rainfall to be stored. For example, one 42-gallon barrel provides 0.5 inch of runoff storage for a rooftop area of approximately 133 square feet.

Cisterns

Stormwater runoff cisterns are roof water management devices that provide retention storage volume in underground storage tanks. On-lot storage with later reuse of stormwater also provides an opportunity for water conservation and the possibility of reducing water utility costs.

Figure 4-11. Cistern. Image courtesy of Pow Plastics, Ltd., Devon, England

Design Considerations. Cisterns are applicable to residential, commercial, and industrial LID sites. Due to the size of rooftops and the amount of imperviousness of the drainage area, increased runoff volume and peak discharge rates for commercial or industrial sites may require larger-capacity cisterns. Individual cisterns can be located beneath each downspout, or storage volume can be provided in one large, common cistern. Premanufactured residential use cisterns come in sizes ranging from 100 to 1,400 gallons (Figure 4-11). Cisterns should be located for easy maintenance or replacement.

Infiltration Trenches

An infiltration trench is an excavated trench that has been back-filled with stone to form a subsurface basin. Stormwater runoff is diverted into the trench and is stored until it can be infiltrated into the soil, usually over a period of several days. Infiltration trenches are very adaptable IMPs, and the availability of many practical configurations make them ideal for small urban drainage areas (Figure 4-12). They are most effective and have a longer life cycle when some form of pretreatment is included in their design. Pretreatment may include techniques like vegetated filter strips or grassed swales (Figure 4-7). Care must be taken to avoid clogging of infiltration trenches, especially during site construction activities.

Design Considerations. The key design considerations for the infiltration trench are summarized in Table 4-8. Detailed design guidance is provided in *Maryland Standards and Specifications for Infiltration Practices* (MDDNR, 1984), *Maintenance of Stormwater Management Structures: A Departmental Summary* (MDE, 1986); and *Maryland Stormwater Design Manual* (MDE, 1998).

Figure 4-12. Median strip infiltration trench design (adapted from MWCOG, 1987).

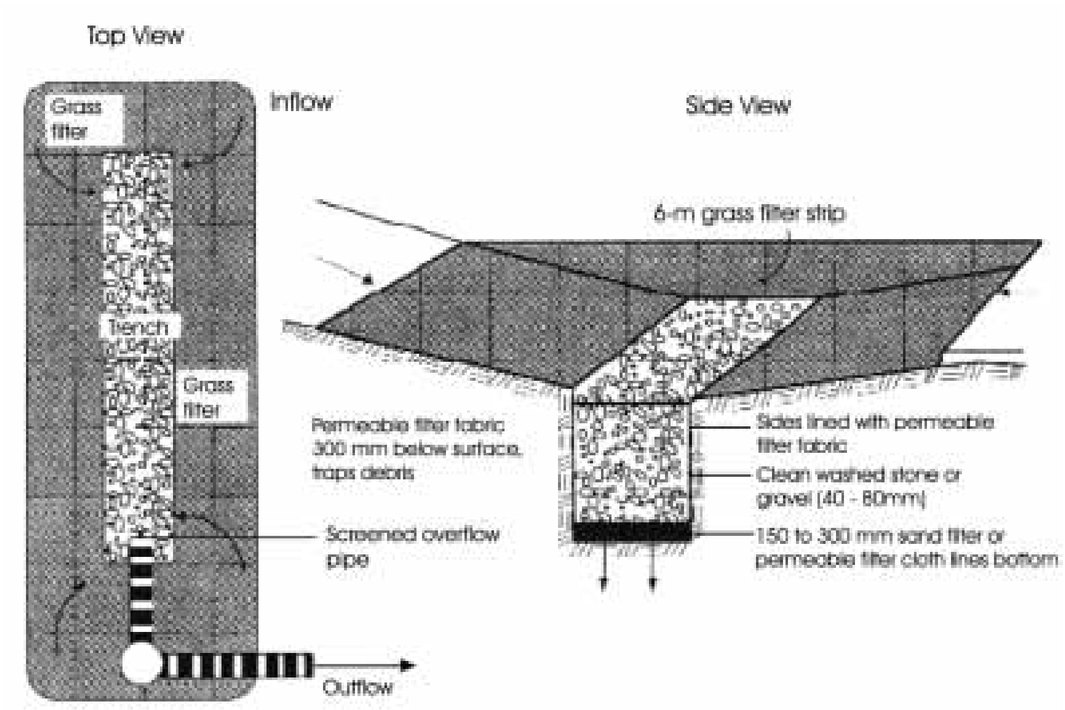


Table 4-8. Infiltration Trench Design Considerations

Design Storm	Determined by state or local agency. Guidance provided by the Prince George's County LID Design Manual and the Maryland Stormwater Design Manual is recommended. Local condition may necessitate adjustment of the recommendations in the guidance document.
Soil Permeability	> 0.27 – 0.50 inches per hour
Depth	3 – 12 feet
Storage Time	Empty within 3 days
Backfill	Clean aggregate > 11/2", < 3", surrounded by engineering filter fabric
Runoff Filtering	
Outflow Structures	Overland flow path of surface runoff exceeding the capacity of the trench must be identified and evaluated. An overflow system leading to a stabilized channel or watercourse including measures to provide non-erosive flow conditions must be provided.
Observation Well	Must be provided, 4" PVC on footplate, constructed flush with ground surface, cap with lock.
Hydrologic Design	Determined by state or local agency. Maryland Stormwater Design Manual is recommended
Water Quality	See Table 4.3 for performance data
Maintenance	Periodic monitoring; Quarterly during first year, annual thereafter.

Other Environmentally Sensitive Management Practices

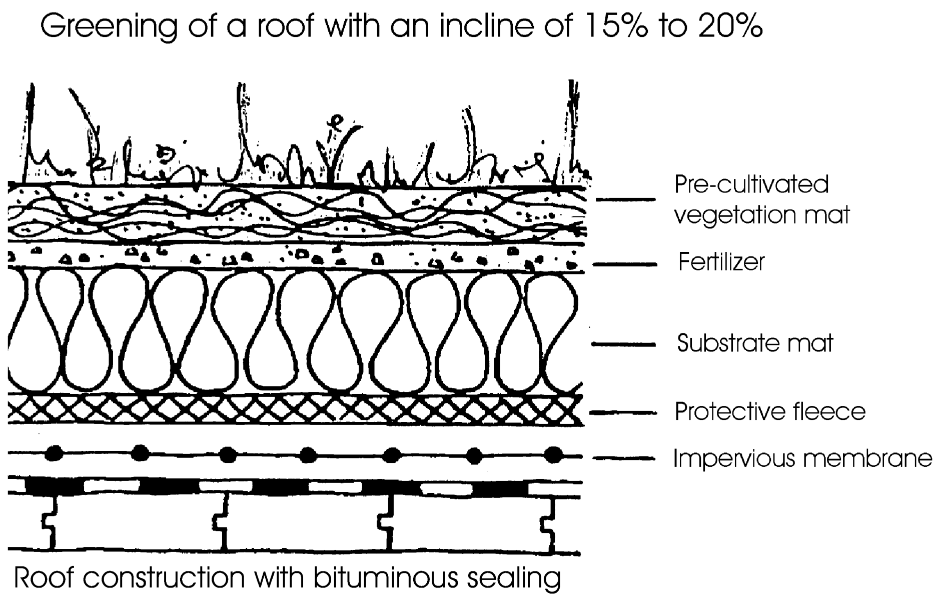
Low-Impact Development is a relatively new concept. It is anticipated that over the next few years many additional integrated management practices and improvements to the LID approach will be introduced as local agencies and designers begin to experiment with the use of the practice. A number of interesting developments are currently underway that may prove useful in future application. However the information available on these techniques is still somewhat limited.

Rooftop Greening. Rooftop greening is a technique being developed in Germany by Strodthogff & Behrens which consists of the use of pre-cultivated vegetation mats(Figure 4-13 which are reported to provide the following benefits:

- improve air quality (up to 85% of dust particles can be filtered out of the air)
- cooler air temperatures and higher humidity can be achieved through natural evaporation.
- 30-100% of annual rainfall can be stored, relieving stormdrains and feeder streams.

Figure 4-13.

Roof Greening



- Visible green roofs provide a more aesthetic landscape.

Conservation Design for Stormwater Management. Conservation design is a design approach to reduce stormwater impacts from land development and achieve multiple objectives related to land use. This approach has been jointly developed by the Delaware Department of Natural Resources and Environmental Control and Environmental Management Center of the Brandywine Conservancy.

Monitoring

Another and the final component of LID design includes the development of appropriate pre and post development monitoring protocols to document the effectiveness of individual IMPs as well at the overall LID approach. Effective stormwater monitoring, whether physical, chemical or biological is very difficult and expensive, and consequently the design of a monitoring program will have to be approached very carefully.

Providing guidance on a specific monitoring program is beyond the scope of this document. However, some general guidance can be provided.

Monitoring programs aimed at evaluating the effectiveness of a given management practice (IMP can adapt the monitoring approaches currently being used for BMPs. Table 4-9 provides a listing of parameters that should be reported with water quality data for various BMPs (Urbonas, 1995). In addition to a comprehensive discussion of

Table 4-9. Parameters to Report with Water-Quality Data for Various BMPs

Parameter (1)	Retention Pond (2)	Extended Detention Basin (3)	Wetland Basin (4)	Wetland Channel (5)	Sand Filter (6)	Oil and Sand trap (7)	Infiltration and Percolation (8)
Tributary watershed area	▼	▼	▼	▼	▼	▼	▼
Total % tributary watershed is impervious	▼	▼	▼	▼	▼	▼	▼
Percent of impervious area hyd. Connected	▼	▼	▼	▼	▼	▼	▼
Gutter, sewer, swale, ditches, in watershed	▼	▼	▼	▼	▼	▼	▼
Average storm runoff volume	▼	▼	▼	▼	▼	▼	▼
50th percentile runoff volume	▼	▼	▼	▼	▼	▼	▼
Coefficient of variation of runoff volumes	▼	▼	▼	▼	▼	▼	▼
Average daily base flow volume	▼	▼	▼	▼	▼	▼	▼
Average runoff interevent time	▼	▼	▼	▼	▼	▼	▼
50th percentile interevent time	▼	▼	▼	▼	▼	▼	▼
Coefficient of variation of runoff volumes	▼	▼	▼	▼	▼	▼	▼
Average storm duration	▼	▼	▼	▼	▼	▼	▼
50th percentile storm duration	▼	▼	▼	▼	▼	▼	▼
Coefficient of variation of storm durations	▼	▼	▼	▼	▼	▼	▼
Water temperature	▼	▼	▼	▼	▼	▼	▼
Alkalinity, hardness and pH	▼	▼	▼	▼	▼	▼	▼
Sediment setting velocity distribution, when available	▼	▼	▼	▼	▼	▼	▼
Type and frequency of maintenance	▼	▼	▼	▼	▼	▼	▼
Inlet and outlet dimensions and details	▼	▼	▼	▼	▼	▼	▼
Solar radiation, when available	▼		▼	▼			
Volume of permanent pool	▼		▼		▼	▼	
Permanent pool surface area	▼		▼		▼	▼	
Littoral zone surface area	▼						
Length of permanent pool	▼		▼		▼	▼	
Detention (or surcharge) volume	▼	▼	▼		▼	▼	▼
Detention basin's surface area	▼	▼	▼		▼	▼	▼
Length of detention basin	▼	▼	▼		▼	▼	▼
Brim-full emptying time	▼	▼	▼		▼	▼	▼
Half-brimful emptying time	▼	▼	▼		▼	▼	▼
Bottom stage volume		▼					
Bottom stage surface area		▼					
Forebay volume	▼	▼	▼		▼	▼	▼
Forebay length	▼	▼	▼		▼	▼	▼
Wetland type, rock filter present			▼	▼			
Percent of wetland surface at P 0.3 and P 0.6 depths			▼	▼			
Meadow wetland surface area			▼	▼			
Plant species and age of facility	▼	▼	▼	▼			
2-year flood peak velocity				▼		▼	
Depth high ground water or impermeable layer		▼	▼				▼

monitoring considerations is provided in the publication, ''Stormwater NPDES related Monitoring Needs'' (ASCE, 1994).

Monitoring programs aimed at an overall evaluation of LID designs will be more difficult to design, particularly where cause and effect relationships in urban ecosystems are involved. Monitoring programs will need to be tailored to each specific site's requirement, and will likely require a mix of physical, chemical, and biological considerations. Guidance for undertaking this work can be found in the following publications: 1) Stormwater NPDES Related Monitoring Needs, (ASCE, 1994: Effects of Watershed Development & Management on Aquatic Ecosytems , (SCE, 1996): and ''Urban Quality Monitoring and Assessment Approaches in Wisconsin, (Bannerman, 1998).

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Chapter 5
Erosion and Sediment Control Considerations for Low-Impact Development

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Chapter 5

Erosion and Sediment Control Considerations for Low-Impact Development

Erosion and sediment control and stormwater management are closely interrelated. The application of LID concepts and the associated emphasis on minimizing the areas disturbed, as well as breaking up drainage areas into small manageable subcatchment areas, is in total harmony with the basic principles of erosion and sediment control. The designer will find that the application of LID technology can easily result in improved erosion and sediment control without significant additional effort.

Erosion and Sediment Control Steps

The following five basic common sense steps govern the development and implementation of a sound erosion and sediment control plan for any land development activity.

Step One: Planning. Plan the operation to fit the existing site features, including topography, soils, drainage ways, and natural vegetation.

Step Two: Scheduling of Operations. Schedule grading and earthmoving operations to expose the smallest practical area of land for the shortest possible time. If possible, schedule land disturbance activities during dry seasons or periods.

Step Three: Soil Erosion Control. Apply soil erosion

Erosion and Sediment Control Steps

1. **Planning**
2. **Scheduling of operations**
3. **Soil erosion control**
4. **Sediment control**
5. **Maintenance**

In This Chapter…

prevention and control practices as a first line of defense against off-site damage.

Step Four: Sediment Control. Apply sediment control practices as a second line of defense against off-site damage.

Step Five: Maintenance. Implement a thorough maintenance program before, during, and after development is completed.

Step One

Plan the development to fit the site features:

- **topography**
- **drainage ways**
- **soils**
- **vegetation**

The following sections describe in more detail how these steps are used in controlling erosion and sedimentation in an LID setting.

Step One: Planning. The first step in controlling erosion and sediment is to plan the development to fit the site features, including; topography, soils, drainage ways, and natural vegetation. It should be observed that this step is very similar to the planning guidelines provided for low impact development in Chapters 2 and 3 of this design manual. In other words, by following the planning guidelines set forth in Chapters 2 and 3 of this manual, the site planner or designer will also be implementing the first step of erosion and sediment control. Not surprisingly, the two processes are similar. Listed below are key considerations of the planning element.

Topography. The primary considerations are slope steepness and slope length. Because of the effect of runoff, the longer and steeper the slope, the greater the erosion potential. The percent of slope can be determined from the site topography. Areas of similar steepness can be identified and grouped together to produce a slope area map. Slope gradients can be grouped into three or more general ranges of soil erodibility as presented below:

0% - 7 %	Low erosion hazard
7% - 15 %	Moderate erosion hazard
15 % or over	High erosion hazard

Within these slope gradient ranges the greater the slope length, the greater the erosion hazard. Therefore, in determining potential critical areas the site planner should be aware of excessively long slopes. As a general rule, the erosion hazard will become critical if slope lengths exceed the following values:

0% - 7 %	300 feet
7% - 15 %	150 feet
15 % or over	75 feet

Drainage ways. Natural drainage patterns that exist on the site should be identified to plan around these critical areas where water will concentrate. Where possible, natural drainage ways should be used to convey runoff over and off the site to avoid the expense and problems of constructing an artificial drainage system. These natural drainage ways should be protected with vegetative buffers whenever possible.

Man-made ditches, diversions, and waterways will become part of the erosion problem if they are not properly stabilized. Care should also be taken to be sure that increased runoff from the site will not erode or flood the existing natural drainage system.

Soils. Major soil considerations from an erosion and sediment control standpoint include erodibility, permeability, depth to water table and bedrock, and soils with special hazards including shrink/swell potential or slippage tendencies.

Soil considerations

- **Erodibility**
- **Permeability**
- **Depth**
- **Constraints**

Erodibility is a term that describes the vulnerability of a soil to erosion. The average particle size and gradation (texture), percentage of organic matter, and soil structure influence soil erodibility. The most erodible soils generally contain high proportions of silt and very fine sand. The presence of clay or organic matter tends to decrease soil erodibility. Clays are sticky and tend to bind soil particles together, which along with organic matter helps to maintain stable soil structure.

By combining the soils information with information on the topography, drainage, and vegetation on the site, the planner can determine the critically erodible and sensitive areas that should be avoided if possible during construction.

Natural Vegetation. Ground cover is the most important factor in terms of preventing erosion. Any existing vegetation that can be saved will help prevent erosion. Vegetative cover shields the soil surface from raindrop impact while the root mass holds soil particles in place. Vegetation also can “filter” sediment from runoff. Thus grass “buffer strips” can be used to remove sediment from surface runoff. Vegetation also slows the velocity of runoff and helps maintain the infiltration capacity of a soil. Trees and unique vegetation protect the soil as well as beautifying the site after construction. Where existing vegetation cannot be saved, the planner should consider staging of construction, temporary seeding, or temporary mulching.

Natural Vegetation

- **Protects soil surface**
- **Filters sediment**
- **Reduces runoff velocity**

Step Two

Expose the smallest practical area for the shortest possible time.

Step Two: Scheduling of Operations. The second erosion and sediment control step is to expose the smallest practical area of land for the shortest possible time. The reason behind this step is rather simple-1 acre of exposed land will yield less sediment than 2 acres of exposed land, and an area exposed for 3 months will yield less sediment than an area exposed for 6 months.

The clearing, grubbing and scalping of excessively large areas of land at one time is an unnecessary invitation to sediment problems. As previously described in Chapter 2, these initial earth-disturbing activities should be kept to a bare minimum. On the areas where disturbance takes place, the site designer should consider staging of construction, temporary seeding, and/or temporary mulching as a technique to reduce erosion. Staging of construction involves stabilizing one part of the site before disturbing another. In this way the entire site is not disturbed at once and the time without ground cover is minimized. Temporary seeding and mulching involves seeding or mulching areas that would otherwise lie open for long periods of time. The time of exposure is limited and therefore the erosion hazard is reduced.

Step Three

Apply soil erosion practices as a first line of defense

Step Three: Soil Erosion Control Practices. The third important principle is to apply soil erosion control practices on disturbed areas as a first line of defense against off-site damage. Control does not begin with the perimeter sediment trap or basin. It begins at the source of the sediment, the disturbed land area, and extends down to the control structure.

Soil particles become sediment when they are detached and moved from their initial resting place. This process, which is called erosion, is accomplished for the most part by the impact of falling raindrops and the energy exerted by moving water and wind, especially water. A reduction in the rate of soil erosion is achieved by controlling the vulnerability of the soil to erosion processes or the capability of moving water to detach soil particles. In humid regions this is accomplished through the use of “soil stabilization” and “runoff control practices.”

Soil stabilization practices include a variety of vegetative, chemical, and structural measures used to shield the soil from the impact of raindrops or to bind the soil in place, thus preventing it from being detached by surface runoff or wind erosion. Representative soil stabilization practices include the following:

- Vegetative stabilization, both temporary and permanent
- Topsoiling

- Erosion control mattings (Figure 5-1)
- Mulching
- Tree protection

The use of mulch to achieve temporary stabilization is gaining increased attention and recognition. Ongoing research efforts are confirming the fact that mulching is a very effective method of reducing runoff as well as removing pollutants from runoff. Table 5-1 displays types of mulches.

Figure 5-1. Erosion control mattings

Runoff control practices, in contrast, include a number of measures designed to reduce the amount of runoff generated on a construction site, prevent off-site runoff from entering the disturbed area, or slow the runoff moving through and exiting the disturbed area.

Table 5-1. Types of Mulches

Mulch	Benefits	Limitations
Chipped wood	Readily available; inexpensive; judged attractive by most	High nitrogen demand; may inhibit seedlings; may float off-site in surface runoff
Rock	May be locally available and inexpensive	Can inhibit plant growth; adds no nutrients; suppresses diverse plant community; high cost where locally unsuitable or unavailable
Straw or hay	Available and inexpensive; may add undesirable seeds	May need anchoring; may include undesirable seeds
Hydraulic mulches	Blankets soil rapidly and inexpensively	Provides only shallow-rooted grasses, but may outcompete woody vegetation
Fabric mats	Relatively durable (organic) or very durable (inorganic); works on steep slopes	High costs; suppresses most plant growth; inorganic materials harmful to wildlife
Commercial compost	Excellent soil amendment at moderate cost	Limited erosion-control effectiveness; expensive over large areas

Step Four

Apply sediment control practices as a second line of defense against off-site damage

Stormwater runoff is the principal cause of soil erosion. Stormwater runoff control is achieved through the proper use of vegetative and structural practices, and construction measures that control the location, volume and velocity of runoff. Proper stormwater handling for erosion control can be accomplished in one or a combination of the following ways:

- Reduction and detention of the runoff
  - staging operations
  - grading and shaping of soil surfaces
  - manipulation of slope length and gradient
- Interception and diversion of runoff
  - diversion berm or dike
  - reverse benches
  - drainage swales
  - vegetation buffers
- Proper handling and disposal of concentrated flow
  - vegetative swales
  - downdrain structures
  - outlet stabilization

Sediment removal is dependent upon

- **Water flow rates**
- **Length of time water is detained**
- **Size, shape and weight of sediment particles**

Step Four: Sediment Control Practices. The fourth step is to apply sediment control practices as a second line of defense against offsite damage. Even with the best erosion control plan, some sediment will be generated and controlling it is the objective of this step. Whereas erosion control practices are designed to prevent soil particles from being detached, sediment control involves using practices that prevent the detached particles from leaving the disturbed area and reaching the receiving waterways. This goal is accomplished by reducing the capacity of surface runoff to transport sediment and by containing the sediment on site.

Sediment control practices are designed to slow the flow of water by spreading, ponding, or filtering. By so doing, the capacity of the water to transport sediment is reduced, and sediment settles out of suspension. Commonly used control practices include (1) the preservation or installation of vegetated buffer areas downslope of the disturbed area to slow and filter the runoff, (2) the construction of small depressions or dikes to catch sediment (particularly coarse-textured material) as close to its point of origin as possible, and (3) the construction of sediment traps or basins at the perimeter of the disturbed area to capture additional sediment from the runoff.

The amount of sediment removed from the runoff is mostly dependent upon (1) the speed at which the water flows through the filter, trap, or basin; (2) the length of time the water is detained; and (3) the size, shape, and weight of the sediment particles.

Currently, the most frequently used approach to sediment control is simply to direct all surface runoff into a large sediment basin, which is later cleaned out and converted to a stormwater management pond. Although this approach is arguably the simplest and lowest cost method to control sediment, it often fails to address the other principles described above and thus may not represent the best way to prevent and control sediment.

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

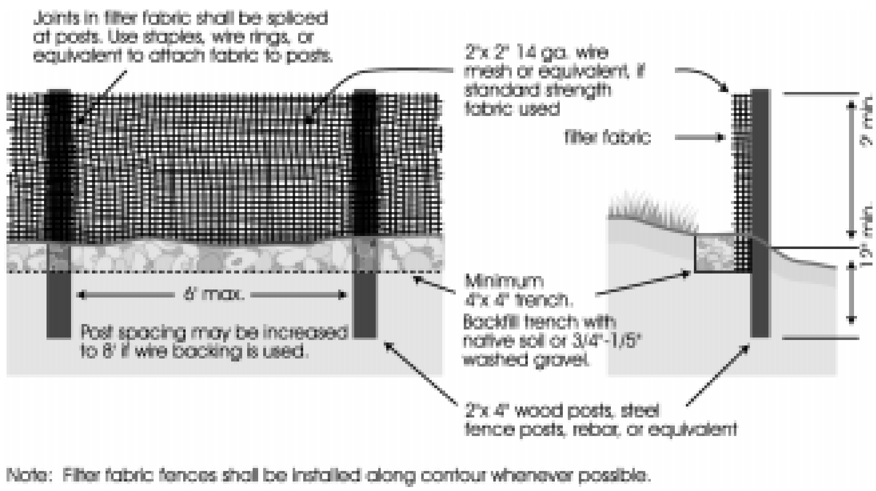

Figure 5-2. Silt fence installation guidelines

This approach will provide more opportunity to use silt fences (Figure 5-2) and small traps, such as the stone outlet trap and the rip-rap outlet trap, to control small catchment areas generally in the range of 1 to 3 acres in size. It will also allow more opportunity to integrate the use of vegetative buffers in sediment control. When bioretention practices are planned for stormwater management, they can first be used as a small temporary trap by excavating the top 2 feet of soil. Then after the site is stabilized the trap and accumulated silt can be removed and the bioretention cell can be installed. It should be noted that the bottom of the bioretention cell should be two (2) feet below the invert of sediment trap. Also, no long term controls are to be placed in use prior to completion of construction and permanent stabilization of all disturbed areas.

Step Five

Implement a thorough maintenance and follow-up operation

Step Five: Inspection and Maintenance. The final important control step is to implement a thorough inspection and maintenance program. This step is vital to the success of an erosion and sediment control program. A site cannot be controlled effectively without thorough, periodic checks of all erosion and sediment control practices.

When inspections reveal problems, modifications, repairs, cleaning, or other maintenance operations must be performed expeditiously.

Particular attention must be paid to water-handling structures such as diversions, sediment traps, grade control structures, sediment basins, and areas being revegetated. Breaches in the structures or areas being revegetated must be repaired quickly, preferably before the next rainfall.

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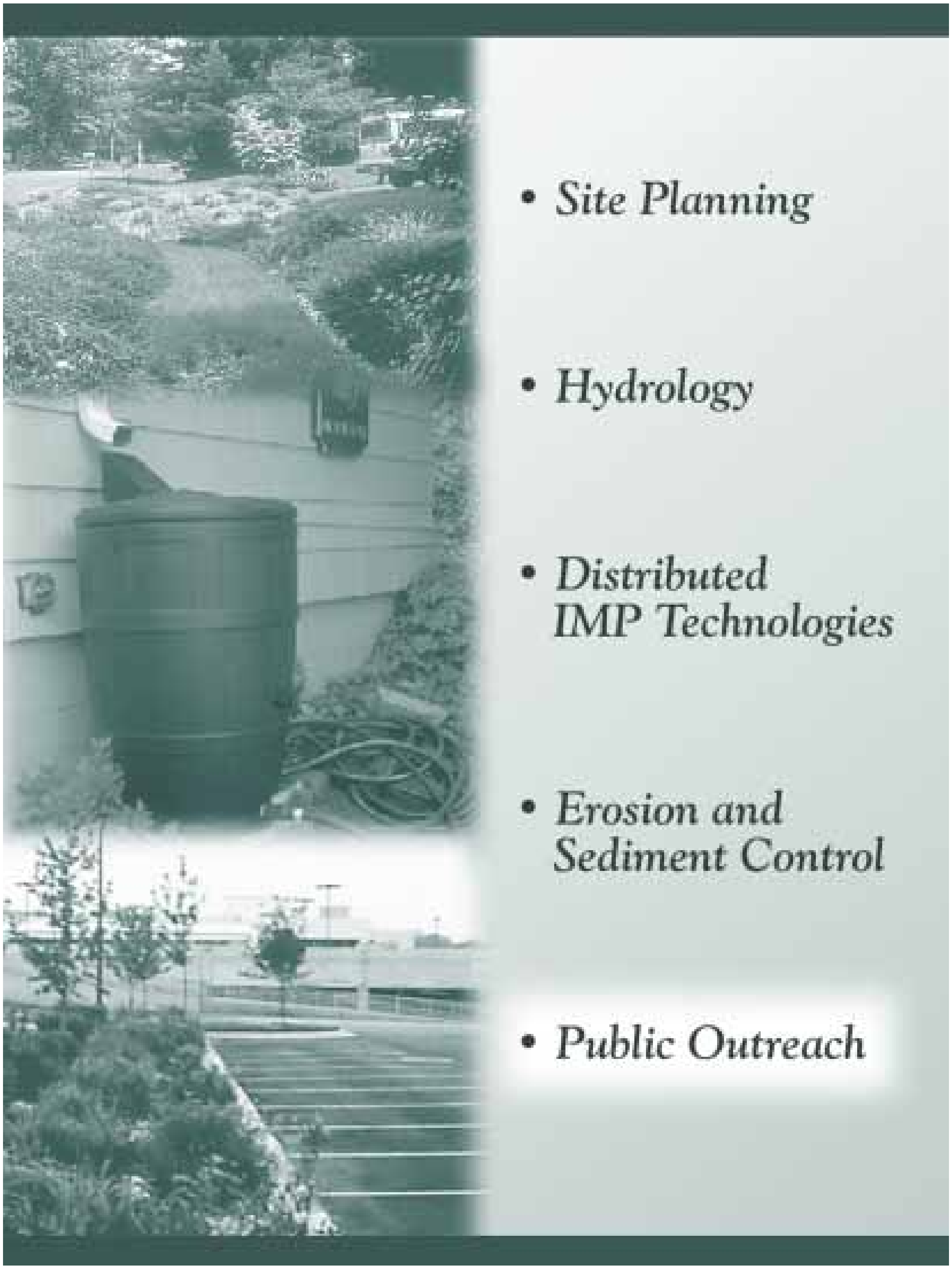
Chapter 6
Low-Impact Development Public Outreach Program



Chapter 6

Low-Impact Development Public Outreach Program

Introduction

Using LID approaches in new development can help achieve overall stormwater and pollution reduction goals. It has become more important for municipalities to be more creative in the ways they manage stormwater. LID approaches offer creative ways to control stormwater runoff, while at the same time achieving multiple development objectives. Several potential advantages include reducing the scale of maintenance costs to levels affordable by the property owner and the transfer of maintenance costs to the property owner. In addition, state and local governments may be able to decrease property acquisition costs due to a decreased need for structural stormwater controls.

A critical component to the success of LID approaches is the proper maintenance of installed IMPs by the property owners, or other designated entity. In addition information should be provided to commercial and residential property owners/managers about effective pollution prevention practices. The developer and local public agency/authority must effectively communicate the benefits of low-impact development as well as its maintenance responsibilities to potential and existing property owners. Proper maintenance practices for LID properties include maintaining vegetative buffers and removing trash and other debris from the outflow points. Property owners must also be educated about the

LID IMP Maintenance

- **Maintain vegetated buffers**
- **Remove trash and debris**

In This Chapter…

necessity of not disturbing, compacting, or eliminating IMPs. Pollution prevention practices that can support LID approaches include careful use of fertilizers on landscaped areas, parking lot sweeping, judicious mowing practices that allow the runoff to slowly percolate into the ground, and general water conservation habits. It is much more cost-efficient to prevent the pollutants from entering the stormwater than it is to remove the pollutants once they are in the system.

This chapter describes the components needed to ensure a successful low-impact development public outreach program. It is based on successful efforts by Prince George's County, Maryland.

Developing a Public Outreach Program

Effective public outreach programs for LID properties must be tailored not only for each site, but for specific audiences. One cannot develop or distribute a single brochure on maintaining IMPs to property owners. The key to effective outreach is to target a message to a specific audience and have them respond to that message. There are four key steps to follow in developing effective public outreach materials for LID properties:

- Step One: Define public outreach objectives.
- Step Two: Identify the target audiences.
- Step Three: Develop materials for those audiences.
- Step Four: Distribute outreach materials.

Each of these steps is reviewed below.

Step One: Define Public Outreach Program Objectives

The first step in developing a public outreach program is to clearly identify the objectives. Are you trying to educate a potential property owner about maintenance requirements of the IMPs on the property? Do you want to make commercial property owners aware of the potential cost savings of LID stormwater controls? The objectives identified will determine what messages are developed and how the outreach materials are distributed.

The LID education/awareness program accomplishes several objectives, including the following:

- Creating a marketing tool for developers to attract environmentally conscious buyers.

- Promoting stewardship of our natural resources by empowering citizens to take initiatives on environmental protection measures.
- Promoting more aesthetically pleasing development by creating more landscaped areas.
- Educating property owners on effective pollution prevention practices.
- Educating residential and commercial property owners on the potential cost savings of using LID approaches.
- Encouraging a greater sense of community due to the unique environmental character of LID designs.
- Ensuring proper maintenance of installed IMPs.

To help define objectives and to take advantage of the vast amount of public outreach information available, it is helpful for the developer to coordinate the public outreach program with the review agencies. This effort should begin during the site planning phase. Once the potential IMPs are identified, the developer should meet with the regulatory agency to gain an understanding of the construction and maintenance requirements of the IMPs until they are transferred to the property owner or homeowners association.

The program and planning phase will help identify the relevant target audiences to receive the outreach materials, provide the developer with existing informational materials and identify additional materials that can be developed and possible distribution mechanisms for the materials.

Step Two: Identify Target Audiences

For each LID property, whether it is residential, commercial, or industrial, there are different audiences that the developer needs to reach with public outreach information-potential buyers, new property owners, builders and construction site managers, homeowner associations and existing property owners. Specific messages must be tailored to each of these audiences based on the kind of property in question. Each of these audiences is discussed in more detail below, along with recommended messages for the audiences.

Potential Buyers

Potential buyers make up a primary target audience for outreach of LID benefits and maintenance requirements. For residential properties, the developer has the opportunity to promote the “green” aspects of low-impact development. Not only can the developer promote the extensive effort to preserve natural resources on the site, but also the measures (such as reforestation and landscaping practices) that were conducted on each lot. Those same measures will increase the aesthetic appeal, value, and habitat potential of the property. This message also works to some degree on commercial properties, by conveying the message that customers appreciate shaded areas in parking lots and the aesthetics of landscaped areas around developments.

Potential buyers must also be made aware of their individual responsibilities, as well as community responsibilities, for the upkeep and improvement of the property. For residential properties, the maintenance of on-site IMPs by the individual owner is a unique concept. Although the anticipated amount of maintenance is small, the owner must be made aware of the importance of the upkeep of plant materials and making sure that drainage structures are unimpaired. It must also be impressed on the property owners that these systems should not just be considered another part of their yard that they can freely landscape. The concept of maintenance of IMPs by the owner of commercial properties is similar to conventional developments. The difference is that instead of a large centralized facility that requires an infrequent, but large-scale, maintenance effort (e.g., mucking, mowing, reseeding, cleaning, and pumping), there may be smaller facilities distributed throughout the site. The smaller sites may require more frequent maintenance, such as trash removal and replanting, but the long-term capital costs are less.

The maintenance materials given to the potential owner at this phase do not have to be detailed, but they must clearly convey the basic requirements for the potential IMPs located on each lot and within the community/commercial property.

Builders and Site Construction Managers

Builders and site construction managers need to be made aware of planned IMPs on the property. During the construction phase, the local regulatory inspectors will verify the procedures used to protect IMP facility locations, limits of clearing and grading, and adherence to construction practices. To avoid potential problems during construction that might require extensive remedial actions to ensure the success of a IMP facility, the developer should make the builder and site construction manager aware of the appropriate phasing and construction practices. The education program should include information on clearing and grading restrictions, timing of revegetation, sedimentation removal, and maintenance after construction. Experience with bayscapes has shown that a critical element that is often neglected is follow-up care of the LID vegetation directly after installation of the system. Without proper watering and care, these systems can fail due to plant mortality.

New Property Owners

The developer, or seller, must allow the new property owner to examine and then accept any conditions that have to be met with the acquisition of the land. LID sites may require legal information and instruments to ensure that the facilities will be properly maintained. These may include easements, covenants, or homeowners' association requirements, or other applicable instruments depending on the type of development. The developer's attorney will typically develop these documents. The maintenance requirements for easements and covenants can be developed from brochures, fact sheets, and example documents, which are available from Prince George's County. A sample maintenance covenant is provided in Appendix B. The requirements and wording to be included in the documents must be approved by the local regulatory agency. The documents that are to be conveyed must be complete and detailed. They should show maintenance schedules, equipment requirements, and lists of replacement plants for vegetated IMPs.

Existing Property Owners

Once the property owner has been made aware of the proper procedures for maintenance of IMPs, it is the responsibility of the community and property owner to implement these procedures. After the initial property transfer, the developer assigns someone, either a representative of the developer or of the homeowners association, to monitor and train the new property owners on proper maintenance procedures. This will help ensure that the facilities are kept up while other units are being sold and will ensure consistent operation of the facilities. Procedures include not only maintaining vegetation and keeping structures in good condition, but also employing pollution prevention practices. Local authorities should take enforcement actions on maintenance issues only when there is a public nuisance or safety issue, or clear intent to destroy or functionally alter the LID system. The best enforcement mechanisms are the understanding of the importance of the IMP maintenance functions and that the owner has

pride in the community. It is considered advisable for local governments to have the requisite authority to take action and the mechanisms should be clearly identified before LID methods are adopted for private land owners.

Industrial and Commercial Property Owners

LID techniques are also applicable to industrial and commercial settings. Fact sheets in Chapter 4 and case studies in Chapter 5 explain LID techniques for stormwater management that can help to control and manage runoff from industrial sites including parking lots and industrial material storage areas. Local stormwater management agencies must work with commercial and industrial property owners both to retrofit existing sites with LID technologies and to incorporate LID approaches into the site planning process. In many instances, LID approaches may even save industrial and commercial property owners money by

- Requiring less land for stormwater management.
- Incorporating on-site infiltration into existing parking lot designs.
- Reducing the amount of piping and engineering required to convey stormwater.
- Lowering ongoing maintenance costs.
- Reducing the amount of grading and land disturbance when developing new sites.

Step Three: Develop Outreach Materials

Once the target audiences are identified, the appropriate materials can be developed. When identifying different target audiences it is important to consider the best formats for the audience. For example, homeowners may read a fact sheet sent to their residence about not mowing vegetative buffers, but commercial and industrial properties may benefit from a training session with accompanying materials to explain maintenance requirements for the IMPs. Many of the materials developed by Prince George's County, Maryland, to support the implementation of LID in residential settings can be modified for industrial applications.

In developing outreach materials, the developer should remember that the target audience must be shown why this information is important to them. This ties back to the objectives—cost savings, increased property values, reduction of pollutant runoff, etc.

To help the developer conduct effective outreach, local regulatory agencies can help prepare brochures, manuals, and fact sheets. Table 6-1 identifies the outreach materials developed by Prince George's County, Maryland, in support of its LID program. The table categorizes this information into critical areas, as well as showing general information on design and construction and pollution prevention. The developer may use this information directly or

Table 6-1 Educational Materials

Document	Application					
	Design and Construction	Pollution Prevention	Program Planning	Potential buyers	Settlement	Site visits
Bioretention Manual	▼					
State Infiltration Manual	▼					▼
Low-Impact Development Manual	▼		▼			▼
SWM Manual	▼		▼			▼
Bioretention Fact Sheet		▼		▼	▼	
Pollution Prevention Fact Sheet						▼
County's Pollution Laws		▼				
NPDES Fact Sheet		▼				
Bayscapes Brochure				▼	▼	▼
Car Care Brochure					▼	▼
Lawn Care Brochure					▼	▼
County Information and Service Numbers				▼	▼	▼
Household Hazardous Waste		▼		▼	▼	
Water Conservation				▼	▼	
Stream Teams				▼	▼	▼
Community Cleanup					▼	▼
Homeowners Drainage Manual				▼	▼	▼
Low-Impact Maintenance Manual					▼	▼
Reporting Pollution Prevention Fact Sheets		▼			▼	▼
Glossary of Stormwater Terms				▼		
Integrated Pest Management					▼	▼
Wildlife Habitat Improvement						
Pollution Prevention Manual						

use it as a basis for customized brochures or legal documents tailored for the specific development.

Pollution Prevention Materials

In addition to specific information regarding the maintenance requirements for LID properties, it is important to provide materials on pollution prevention practices that residential, commercial, and industrial property owners can implement to reduce the amount of pollutants going into the stormwater. Dozens of fact sheets and brochures on pollution prevention practices are available.

Basic education programs can be considered a nonstructural IMP that should be implemented for everyone. Too much pollution enters streams, rivers and lakes through carelessness or ignorance. Many people will adopt new methods or use alternative materials if they are simply informed of techniques that can reduce the impacts on receiving waters. Industry employees can learn to properly handle and store materials and dispose of industrial wastes through in-house training courses, videotape presentations, and interactive seminars. Local libraries and government agencies, such as the Cooperative Extension Service and the Industrial Extension Service, are good sources of educational materials.

Residential property owners should know the proper way to dispose of litter, yard waste, used motor oil, and other household wastes. Industries, municipalities, and homeowners can also learn how to use fertilizer and pesticides correctly to maintain their lawns and gardens without polluting nearby streams and rivers.

Step Four: Distribute Outreach Materials

There are several points in the property transfer process at which the developer can distribute outreach materials:

Construction of IMPs. Developers can provide the builder and construction site managers with outreach materials to ensure that the planned IMPs are not disturbed during the building phase.

Potential Buyers. Potential property owners can be made aware of the benefits as well as the responsibilities of owning a LID property when they first express interest in the property.

At Settlement. Educational materials outlining maintenance procedures, as well as legal instruments such as covenants and easements, can be presented at settlement.

Site Visits. Periodic site visits by the developer and/or homeowners associations and local government should be made to ensure that the IMPs are being properly maintained. Educational materials can be distributed at this time to reinforce the maintenance requirements and benefits.

Homeowner Association Meetings. Developers can make presentations and answer questions about LID maintenance requirements at homeowners association meetings. These meetings also offer a good opportunity to distribute information on pollution prevention practices.

By implementing a strong public outreach program the developer can increase the effectiveness of the IMPs installed on the property and promote LID approaches as the preferred alternative to conventional stormwater practices.

Appendices

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Appendix A

Example Low-Impact Development Hydrologic Computation*

Contents

Figures

* *Adapted from* Prince George's County, Maryland, Low Impact Development Hydrologic Analysis, 1999

Tables

Exhibits

A.1 Introduction

The Appendix provides a detailed example of an LID hydrologic computation based on the use of the SCS TR-55 hydrologic model. This example computation is adapted from the *Low-Impact Development, Hydrologic Analysis Prince George's County, Maryland* (1999).

The hydrologic analysis of low-impact development is a sequential decision-making process that can be illustrated by the flow chart shown in Figure A.1. Several iterations may occur within each step until the appropriate approach to reduce stormwater impacts is determined. The procedures for each step are described below. Supporting design charts have been developed to determine the amount of storage required to maintain the existing volume and peak runoff rates to satisfy typical storm water management requirements at different geographic areas in the nation (Types I, IA, II and III storms). A few representative examples of these charts are provided in Exhibits A, B, and C.

A.2 Data Collection

The basic information used to develop the low-impact development site plan and used to determine the runoff curve number (CN) and time of concentration (Tc) for the pre- and postdevelopment condition is the same as conventional site plan and stormwater management approaches.

A.3 Determining the LID Runoff Curve Number

The determination of the low-impact development CN requires a detailed evaluation of each land cover within the development site. This will allow the designer to take full advantage of the storage and infiltration characteristics of low-impact development site planning to maintain the CN. This approach encourages the conservation of more woodlands and the reduction of impervious area to minimize the needs of IMPs.

The steps for determining the low-impact development CN are as follows:

Step 1: Determine percentage of each land use/cover.

In conventional site development, the engineer would refer to Figure 2.2.a of TR-55 (SCS, 1986) to select the CN that represents the proposed land use of the overall development (i.e., residential, commercial) without checking the actual percentages of impervious area, grass areas, etc. Because low-impact design emphasizes minimal

Step 1:

Determine storage volume required to maintain runoff volume or CN. Use Chart Series A: Storage Volume Required to Maintain the Pre-development Runoff Volume Using Retention Storage (Example A.2)

Step 2:

Determine storage volume for water quality volume requirements. Determine storage volume required for quality control BMPs. Use larger of volumes to maintain CN (Step 1, Example A.2) or water quality volume (Example A.3).

Step 3:

Determine storage volume required to maintain predevelopment peak runoff rate using 100% retention. Use Chart Series B: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Retention.

Step 4:

Determine whether additional detention storage is required to maintain predevelopment peak runoff rate. Compare the results of Steps 1 and 2 to the results of Step 3. If the storage volume in Steps 1 and 2 is determined to be greater than that in Step 3, the site area required to maintain the predevelopment CN also controls the peak runoff rate. No additional detention storage is needed. If the site area in Step 1 is less than that in Step 3, additional detention storage is required to maintain the peak runoff rate (Example A.4).

Step 5 (use if additional detention storage is required):

Determine storage volume required to maintain predevelopment peak runoff rate using 100% detention. Use Chart Series C: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention. This volume is used in conjunction with Chart Series A and B to determine the hybrid volume in Step 6.

Step 6 (use if additional detention storage is required):

Hybrid approach. Use results from Chart Series A, B, and C to determine storage volume to maintain both the predevelopment peak runoff rate and runoff volume. Refer to Equations A.5 and A.6 as found in Example A.4.

Step 7 (use if additional detention storage is required):

Determine appropriate storage volume available for retention practices. If the storage volume available for retention practices is less than the storage determined in Step 3, recalculate the amount of BMP area required to maintain the peak runoff rate while attenuating some volume using the procedure in Example A.6 using Equations A.7 and A.8.

Figure A.1. Low-impact development analysis procedure site disturbance (tree preservation, site fingerprinting, etc.), it is possible to retain much of the pre-development land cover and CN.

Therefore, it is appropriate to analyze the site as discrete units to determine the CN. Table A.1 lists representative land cover CNs used to calculate the composite "custom" low-impact development CN.

Step 2: Calculate composite custom CN.

The initial composite CN is calculated using a weighted approach based on individual land covers *without* considering disconnectivity of the site imperviousness. This is done using Equation A.1. This weighted approach is illustrated in Example A.1.

Table A.1. Representative LID Curve Numbers

Land Use/Cover	**Curve Number for Hydrologic Soils Groups[1]**			
	A	B	C	D
Impervious Area	98	98	98	98
Grass	39	61	74	80
Woods (fair condition)	36	60	73	79
Woods (good condition)	30	55	70	77

[1]*Figure 2.2a, TR-55 (SCS, 1986).*

$$CN_c = \frac{CN_1 A_1 + CN_2 A_2 ... + CN_j A_j}{A_1 + A_2 ... + A_j} \qquad \text{Eq. A.1}$$

Where:

CN_c = composite curve number;

A_j = area of each land cover; and

CN_j = curve number for each land cover.

Overlays of SCS Hydrologic Soil Group boundaries onto homogeneous land cover areas are used to develop the low-impact development CN. What is unique about the low-impact development custom-made CN technique is the way this overlaid information is analyzed as small discrete units that represent the hydrologic condition, rather than a conventional TR-55 approach that is based on a representative national average. This is appropriate because of the emphasis on minimal disturbance and retaining site areas that have potential for high storage and infiltration. This custom-made CN technique is documented in Example A.1.

This approach provides an incentive to save more trees and maximize the use of HSG A and B soils for recharge. Careful planning can result in significant reductions in post-development runoff volume and corresponding IMP costs.

Step 3: Calculate low-impact development CN based on the connectivity of site impervious area.

When the impervious areas are less than 30 percent of the site, the percentage of the unconnected impervious areas within the watershed influences the calculation of the CN (SCS, 1986). Disconnected impervious areas are impervious areas without any direct connection to a drainage system or other impervious surface. For example, roof drains from houses could be directed onto lawn areas where sheet flow occurs, instead of to a swale or driveway. By increasing the ratio of disconnected impervious areas to impervious areas on the site, the CN and resultant runoff volume can be reduced. Equation A.2 is used to calculate the CN for sites with less than 30 percent impervious area.

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right) \times (98 - CN_p) \times (1 - 0.5R) \qquad \text{Eq. A.2}$$

where:

R = ratio of unconnected impervious area to total impervious area;

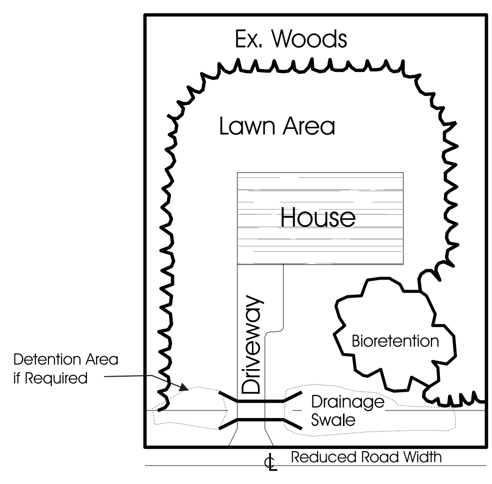
CN_c = composite CN;

CN_p = composite pervious CN; and

P_{imp} = percent of impervious site area.

Example A.1 uses steps 1 through 3 to compare the calculation of the curve number using conventional and low-impact development techniques using the percentages of land cover for a typical 1-acre residential lot from Figure A.2.

Figure A.2. Comparison of land covers between conventional and LID CNs



Conventional CN
for 1-Acre Lot
(Table 2.2a TR-55)
N.T.S.

Typical Low-Impact
Development Lot
N.T.S.

Example A.1

Detailed CN Calculation

Given:

One-acre residential lot

Conventional CN: 68 (From TR-55 Table 2.2a-Runoff curve numbers for urban areas (SCS, 1986)) Table 2.2a assumes HSG B, 20% imperviousness with a CN of 98 and 80% open space in good condition.

Custom-made LID CN: CN for individual land covers based on Table 2.2a. Assume 25% of the site will be used for reforestation/ landscaping (see Figure A.2) HSG B.

Procedure:

Step 1: Determine percentage of each land cover occurring on site and the CN associated with each land cover.

Land Use	HSG (1)	CN (2)	% of Site (3)	Land Coverage (ft^2) (4)
Impervious (Directly Connected)	B	98	5	2,178
Impervious (Unconnected)	B	98	10	4,356
Open Space (Good Condition, Graded)	B	61	60	26,136
Woods (Fair Condition)	B	55	25	10,890

Step 2: Calculate composite custom CN (using Equation A.1).

$$CN_c = \frac{98 \times 4{,}356 + 98 \times 2{,}178 + 61 \times 26{,}136 + 55 \times 10{,}890}{43{,}560}$$

$$CN_c = 65$$

Step 3: Calculate low-impact development CN based on the connectivity of the site imperviousness (using Equation A.2).

$$CN_p = \frac{61 \times 26{,}136 + 55 \times 10{,}890}{37{,}026}$$

$$CN_p = 59.2$$

$$R = \frac{10}{15}$$

$$R = 0.67$$

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right) \times (98 - CN_p) \times (1 - 0.5 \times R)$$

$$CN_c = 59.2 + \left(\frac{15}{100}\right) \times (98 - 59.2) \times (1 - 0.5 \times 0.67)$$

$$CN_c = 63.1 \text{ (use 63)}$$

LID custom CN of 63 is less than conventional CN of 68 (predevelopment CN is 55).

A.4 Development of the Time of Concentration (Tc)

The pre- and postdevelopment calculation of the Tc for low-impact development is exactly the same as that described in the TR-55 (SCS, 1986) and NEH-4 (SCS, 1985) manuals.

A.5 Low-Impact Development Stormwater Management Requirements

Once the CN and Tc are determined for the pre- and postdevelopment conditions, the stormwater management storage volume requirements can be calculated. The low-impact development objective is to maintain all the predevelopment volume, predevelopment peak runoff rate, and frequency. The required storage volume is calculated using the design charts in Exhibits A (page A-25), B (page A-27), and C (page A-29) for different geographic regions in the nation.

As stated previously, the required storage volume for peak runoff control is heavily depended on the intensity of rainfall (rainfall distribution). Since the intensity of rainfall varies considerably over geographic regions in the nation, National Resource Conservation Service (NRCS) developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from available National Weather Service (NWS) duration-frequency data and local storm data. Type IA is the least intense and type II the most intense short-duration rainfall. Figure A.3. shows approximate geographic boundaries for these four distributions.

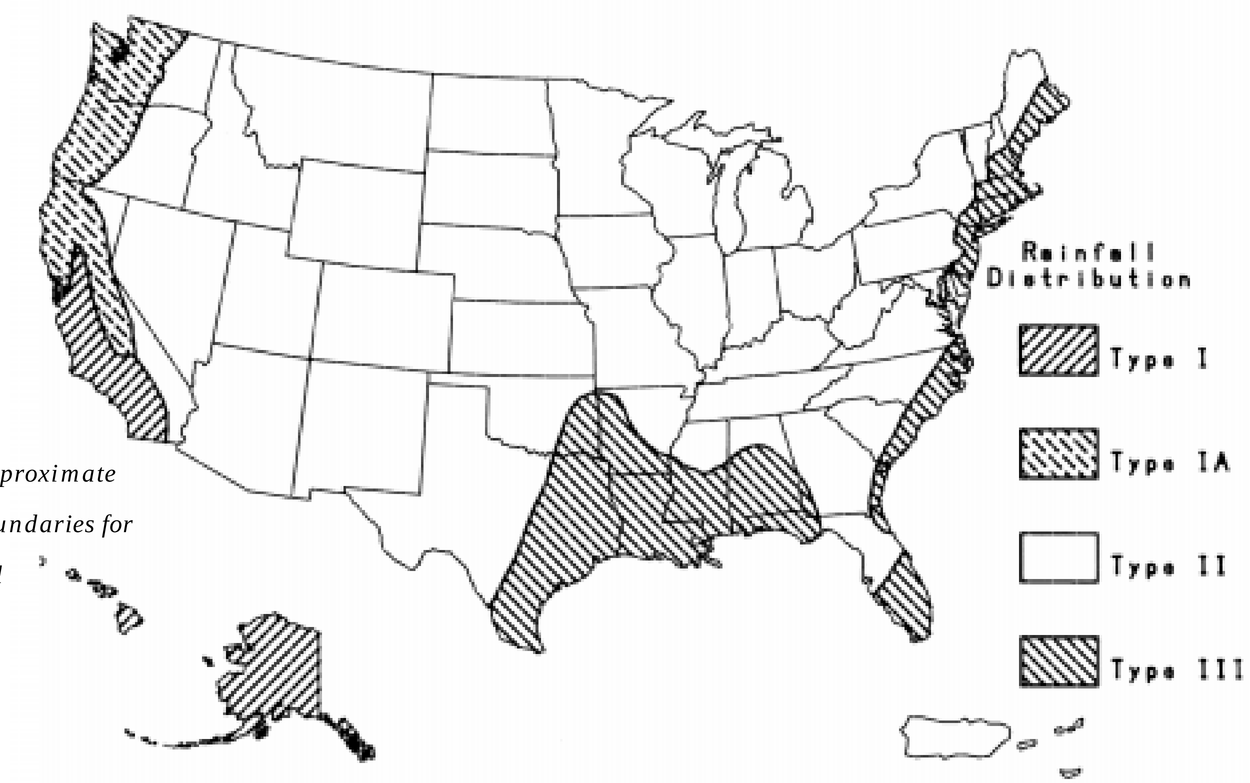


Figure A.3. Approximate geographic boundaries for NRCS rainfall distributions

The remaining low-impact development hydrologic analysis techniques are based on the premise that the post-development Tc is the same as the pre-development condition. If the post-development Tc does not equal the pre-development Tc, additional low-impact development site design techniques must be implemented to maintain the Tc.

Three series of design charts are needed to determine the storage volume required to control the increase in runoff volume and peak runoff rate using retention and detention practices. The required storages shown in these design charts are presented as a depth in hundredths of an inch (over the development site area). Equation A.3 is used to determine the volume required for IMPs.

$$\text{Volume} = (\text{depth obtained from the chart}) \times (\text{development size})/100 \qquad \text{Eq. A.3}$$

It is recommended that 6-inch depth be the maximum depth for bioretention basins used in low-impact development.

The amount, or depth, of exfiltration of the runoff by infiltration or by the process of evapotranspiration is not included in the design charts. Reducing surface area requirements through the consideration of these factors can be determined by using Equation A.4.

$$\text{Volume of site area for IMPs} = (\text{initial volume}) \times (100 - x) / 100 \qquad \text{Eq. A.4}$$

where: x = % of the storage volume infiltrated and/or reduced by evaporation or transpiration. x% should be minimal (less than 10% is considered).

Stormwater management is accomplished by selecting the appropriate IMP, or combination of IMPs, to satisfy the surface area and volume requirements calculated from using the design charts as described below. The design charts to be used to evaluate these requirements are:

- Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume Using Retention Storage (Exhibit A).
- Chart Series B: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Retention (Exhibit B).
- Chart Series C: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention (Exhibit C).

These charts are based on the following general conditions:

- The land uses for the development are relatively homogeneous throughout the site.
- The stormwater management measures are to be distributed evenly across the development, to the greatest extent possible.
- The rainfall (design storm event) is based on 1-inch increments. Use linear interpolation for determining intermediate values.

The procedure to determine the IMP requirements is outlined in Figure A.4 and described in the following sections.

Step 1: Determine storage volume required to maintain predevelopment volume or CN using retention storage.

The post-development runoff volume generated as a result of the post-development custom-made CN is compared to the predevelopment runoff volume to determine the surface area required for volume control. Use Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume using Retention Storage. The procedure for calculating the site area required for maintaining runoff volume is provided in Example A.2. It should be noted that the practical and reasonable use of the site must be considered. The IMPs should not restrict the use of the site, unless the regulatory authority decides that the sensitivity of the receiving water body requires such restrictions.

The storage area found, is for runoff volume control only; additional storage may be required for water quality control. The procedure to account for the first ½-inch of runoff from impervious areas, which is the current water quality requirement, is found in Step 2.

Step 2: Determine storage volume required for water quality control.

The surface area, expressed as a percentage of the site, is then compared to the percentage of site area required for water quality control. The volume requirement for stormwater management quality control is based on the requirement to treat the first ½ inch of runoff (approximately 1,800 cubic feet per acre) from impervious areas. This volume is translated to a percent of the site area by assuming a storage depth of 6 inches. The procedure for calculating the site area required

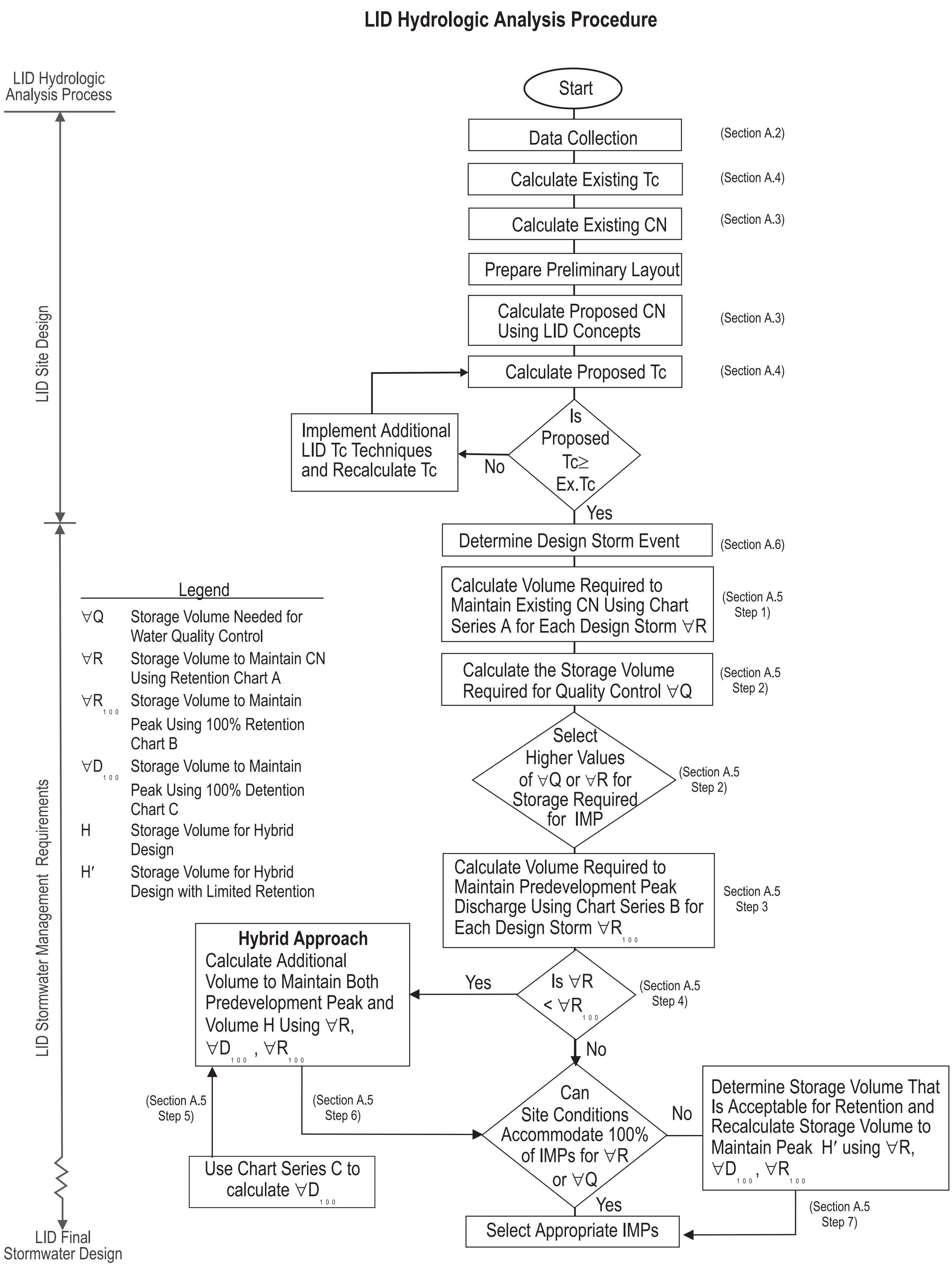


Figure A.4. Procedure to determine percentage of site area required for IMPs to maintain predevelopment runoff volume and peak runoff rate.

Example A.2

Determining Site Area Required to Maintain Volume (CN) Using Chart Series A: Storage Volume Required to Maintain the Predevelopment Runoff Volume Using Retention Storage

Given:

Site Area is 18 acres

Existing CN is 60

Proposed CN is 65

Design storm is 5 inches

Design depth of IMP is 6 inches

Solution:

Use Chart Series A: Storage Volume Required to Maintain Runoff Volume or CN.

0.35 inch of storage over the site is required to maintain the runoff volume.

Therefore: if 6-inch design depth is used, 1.1 acres (18 acres x 0.35 / 6) of IMPs distributed evenly throughout the site are required to maintain the runoff volume, or CN.

Additional Considerations:

1) Account for depths other than 6 inches:
   Site of IMP Area = 1.1 acres, if 6-inch depth is used
   Depth of IMPs = 4 inches
   Site of IMP Area = 1.1 x 6 in./4 in.
   Site of IMP Area = 1.65 acres

2) Account for infiltration and/or evapotranspiration (using Equation A.4)
   If 10% of the storage volume is infiltrated and/or reduced by evaporation and transpiration.
   Site of IMP Area = (storage volume) x (100 - X) / 100
   Site of IMP Area =1.1 x (100-10)/100

Area for IMP Storage = 1.0 acre

for quality control is provided in Example A.3. The greater number, or percent, is used as the required storage volume to maintain the CN.

From the results of Example A.3, 0.1" of storage is required for water quality using retention; from Example A.2, 0.35" of storage is required to maintain the runoff volume using retention. Since the volume required to maintain the runoff volume is larger, in this case 0.35" of storage over the site should be reserved for retention IMPs.

Step 3: Determine storage volume required to maintain peak stormwater runoff rate using 100 percent retention.

The percentage of site area or amount of storage required to maintain the predevelopment peak runoff rate is based on *Chart Series B: Percentage of Site Area Required to Maintain Predevelopment Peak Runoff Rate Using 100% Retention (Exhibit B)*. This chart is based on the relationship between storage volume, $\forall_s / \forall_r$, and discharge, Q_o / Q_i, to maintain the predevelopment peak runoff rate.

Where: *Vs* = volume of storage to maintain the predevelopment peak runoff rate using 100% retention;

Vr = postdevelopment peak runoff volume;

Qo = peak outflow discharge rate; and

Qi = peak inflow discharge rate.

Example A.3

Calculation of Volume, or Site Area, for Water Quality Control

Given:

Site area is 18 acres

Impervious area is 3.6 acres (20%)

Depth of IMP is 6 inches

Solution:

The water quality requirement is to control the first ½ inch of runoff from impervious areas *(18 acres x 20%) x 0.5in. / 18 acres* = 0.1 inch storage for water quality 0.1 inch is less than 0.35 inch (from example A.2). Therefore, use storage for runoff volume control to meet the water quality requirement.

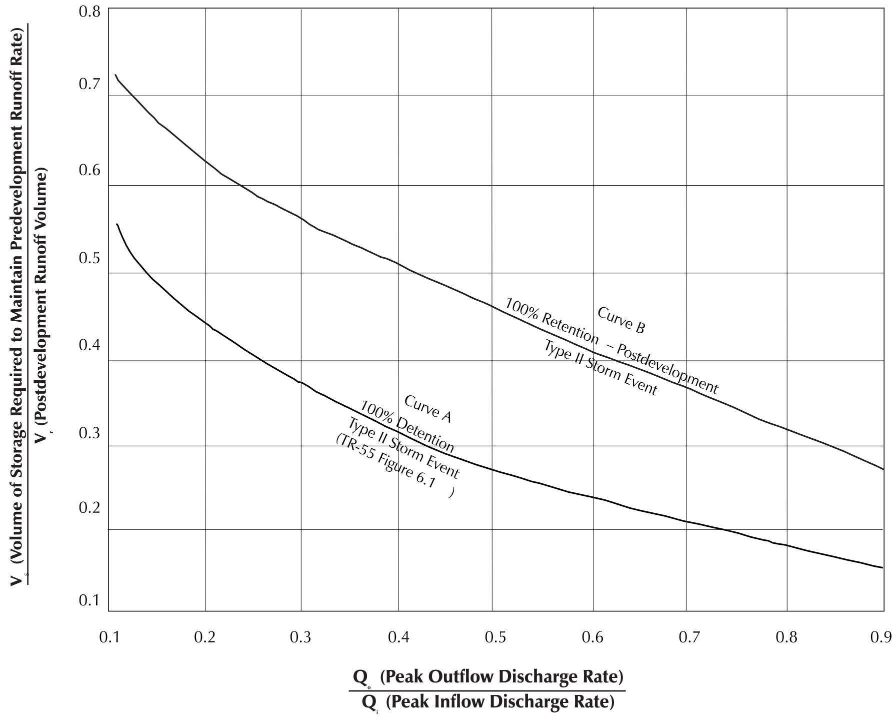


Figure A.5. Comparison of retention of storage volumes required to maintain peak runoff rate using retention and detention.

The relationship for retention storage to control the peak runoff rate is similar to the relationship for detention storage. Figure A.5 is an illustration of the comparison of the storage volume/discharge relationship for retention and detention. Curve A is the relationship of storage volume to discharge to maintain the predevelopment peak runoff rate using the detention relationship from Figure 6-1 (SCS, 1986) for a Type II 24-hour storm event. Curve B is the ratio of storage volume to discharge to maintain the predevelopment peak runoff rate using 100 percent retention. Note that the volume required to maintain the peak runoff rate using detention is less than the requirement for retention. This is graphically demonstrated in Figure A.6.

- Hydrograph 2 represents the response of a postdevelopment condition with no stormwater management IMPs. This hydrograph definition reflects a shorter time of concentration (Tc), and increase in total site imperviousness than that of the predevelopment condition. This resultant hydrograph shows a decrease in the time to reach the peak runoff and discharge rate and volume, and increased duration of the discharge volume.
- Hydrograph 8 illustrates the effect of providing additional detention storage to reduce the postdevelopment peak discharge rate to predevelopment conditions.

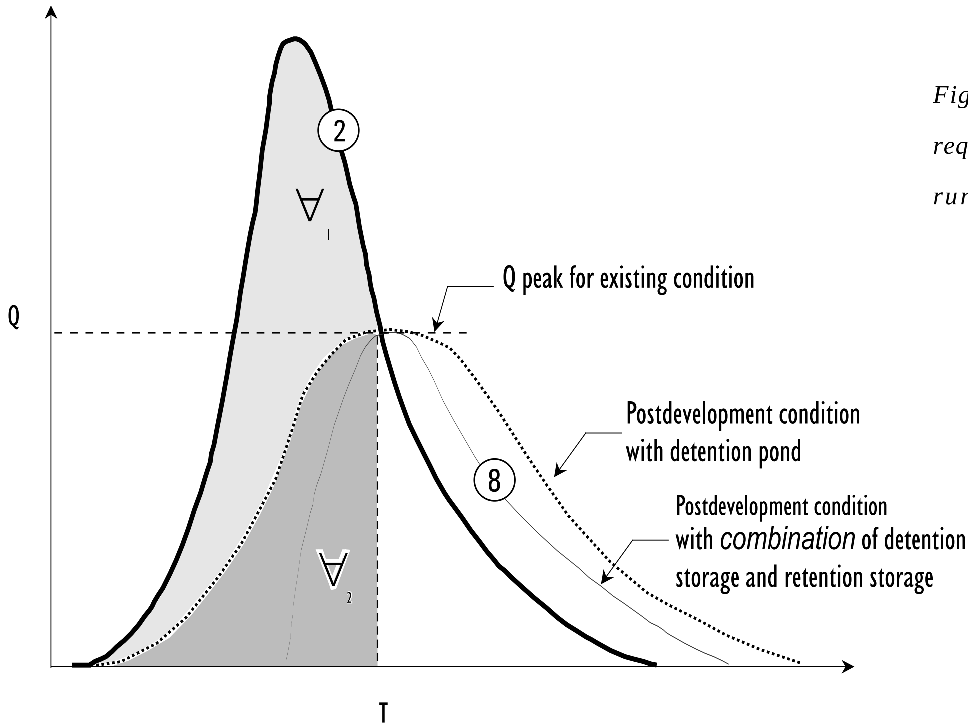


Figure A.6. Storage volume required to maintain peak runoff rate

$\forall_1$ is the storage volume required to maintain the predevelopment peak discharge ratio using 100% detention storage. The combination of $\forall_1$ and $\forall_2$ is the storage volume required to maintain the predevelopment peak discharge rate using 100% retention storage.

The following calculations apply to Design Chart Series B:

- The Tc for the postdevelopment condition is equal to the Tc for the predevelopment condition. This equality can be achieved by techniques such as maintaining sheet flow lengths, increasing surface roughness, decreasing the amount and size of storm drain pipes, and decreasing open channel slopes. Chapter 2 of this manual provides more details on these techniques.

- The depth of storage for the retention structure is 6 inches. For other depths, see Example A.2.

If the Tc is equal for the predevelopment and postdevelopment conditions, the peak runoff rate is independent of Tc for retention and detention practices. The difference in volume required to maintain the predevelopment peak runoff rate is practically the same if the Tcs for the predevelopment and postdevelopment conditions are the same. These concepts are illustrated in Figure A.7. In Figure A.7, the difference in the required IMP area between a Tc of 0.5 and a Tc of 2.0

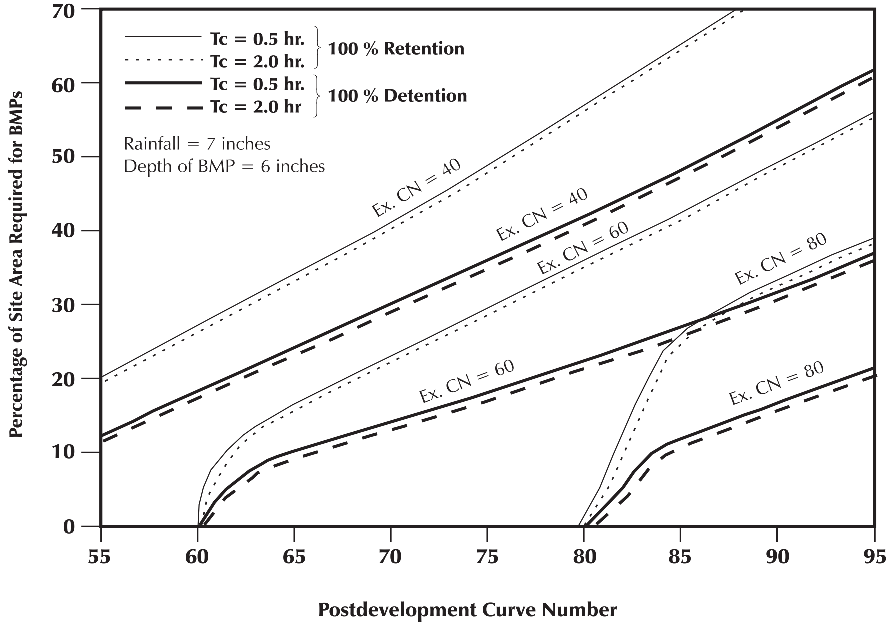


Figure A.7. Comparison of storage volumes for various Tcs.

is minimal if the predevelopment and postdevelopment Tcs are maintained.

Step 4: Determine whether additional detention storage is required to maintain the predevelopment peak runoff rate.

The storage volume required to maintain the predevelopment runoff volume using retention, as calculated in Step 1, might or might not be adequate to maintain both the predevelopment volume and peak runoff rate. As the CNs diverge, the storage requirement to maintain the volume is much greater than the storage volume required to maintain the peak runoff rate. As the CNs converge, however, the storage required to maintain the peak runoff rate is greater than that required to maintain the volume. Additional detention storage will be required if the storage volume required to maintain the runoff volume (determined in Step 1) is less than the storage volume required to maintain the predevelopment peak runoff rate using 100 percent retention (determined in Step 3).

The combination of retention and detention practices is defined as a hybrid IMP. The procedure for determining the storage volume required for the hybrid approach is described in Step 5.

Table A.2 illustrates the percentage of site area required for volume and peak control for representative curve numbers. Using a 5-inch type II 24-hour storm event and 6" design depth, with a predevelopment CN of 60, the following relationships exist:

- For a post-development CN of 65, 5.9 percent of the site area (column 4) is required for retention practices to maintain the

Table A.2. Representative Percentages of Site Required for Volume and Peak Control

Type of 24-Hour Storm Event (1)	Runoff Curve No. Existing (2)	Runoff Curve No. Proposed (3)	% of Area Needed for BMP: Volume Control Using 100% Retention Chart Series A (4)	Peak Control Using 100% Retention Chart Series B (5)	Peak Control Using 100% Detention Chart Series C (6)	Hybrid Design (Eq. 4.6) (7)	Percent of Volume Retention for Hybrid Design (Eq. 4.5) (8)
3"	50	55	1.7	1.6	0.9	1.7	100
		60	4.0	3.4	2.4	4.0	100
		65	6.9	6.2	4.5	6.9	100
		70	10.4	9.3	7.3	10.4	100
		80	19.3	18.0	15.8	19.3	100
	60	65	2.9	3.9	2.3	3.6	80
		70	6.3	6.7	4.4	6.6	96
		75	10.5	10.0	7.1	10.5	100
		90	27.5	24.9	18.7	27.5	100
	70	75	4.1	5.9	3.4	5.3	77
		80	8.9	9.7	5.8	9.5	94
		85	14.6	13.9	8.8	14.6	100
		90	21.2	18.7	12.6	21.2	100
	75	80	4.8	7.5	4.2	6.6	73
		85	10.5	11.8	7.0	11.4	91
		90	17.1	16.6	10.2	17.1	100
5"	50	55	4.8	6.9	4.0	6.3	77
		60	10.1	11.1	6.9	10.9	93
		65	16.0	15.6	10.4	16.0	100
		70	22.4	20.6	14.5	22.4	100
		80	36.7	32.8	23.9	36.7	100
	60	65	5.9	9.5	5.3	8.3	71
		70	12.3	14.6	8.4	13.9	88
		75	19.1	19.8	12.0	19.6	97
		90	42.9	37.2	25.3	42.9	100
	70	75	6.9	13.2	7.2	10.9	63
		80	14.3	18.9	10.7	17.4	82
		85	22.2	24.5	14.3	23.8	93
		90	30.7	30.5	18.2	30.7	100
	75	80	7.4	15.0	8.1	12.3	60
		85	15.3	20.6	11.6	18.9	81
		90	23.8	26.7	15.2	25.7	92
7"	50	55	7.6	12.3	6.8	10.7	71
		60	15.6	18.6	10.7	17.7	88
		65	23.9	25.0	15.1	24.7	97
		70	32.5	31.4	19.6	32.5	100
		80	50.5	44.5	30.0	50.5	100
	60	65	8.3	16.6	9.0	13.6	61
		70	16.9	23.2	13.2	21.2	80
		75	25.8	29.9	17.3	28.7	90
		90	53.7	49.7	30.7	53.7	100
	70	75	8.9	20.4	10.9	16.1	55
		80	17.9	26.8	14.7	23.8	75
		85	27.2	33.4	18.9	31.5	87
		90	36.7	42.3	23.0	39.2	94
	75	80	9.1	22.1	11.5	17.1	53
		85	18.4	28.6	15.6	25.1	73
		90	27.9	35.3	19.8	32.9	85

predevelopment volume. To maintain the predevelopment peak runoff rate (column 5), 9.5 percent of the site is required. Therefore, additional detention storage or a hybrid approach (calculated in column 7) is required.

- For a postdevelopment CN of 90, 42.9 percent of the site area (column 4) is required for retention practices to maintain the predevelopment volume. To maintain the predevelopment peak runoff rate (column 5) 37.2 percent of the site is required. Therefore, the storage required to maintain the runoff volume is also adequate to maintain the peak runoff rate. However, 42.9 percent of the site for IMPs may not be a practical and reasonable use of the site. Refer to Step 7, hybrid approach, for a more reasonable combination of retention and detention storage.

Step 5: Determine storage required to maintain predevelopment peak runoff rate using 100 percent detention. (This step is required if additional detention storage is needed.)

Chart Series C: Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention is used to determine the amount of site area to maintain the peak runoff rate only. This information is needed to determine the amount of detention storage required for hybrid design, or where site limitations prevent the use of retention storage to maintain runoff volume. This includes sites that have severely limited soils for infiltration or retention practices. The procedure to determine the site area is the same as that of Step 3. Using Chart Series C, the following assumptions apply:

- The Tc for the post-development condition is equal to the Tc for the predevelopment condition.
- The storage volume, expressed as a depth in hundredths of an inch (over the development site), is for peak flow control.

These charts are based on the relationship and calculations from Figure 6.1 (Approximate Detention Basin Routing for Rainfall Types I, IA, II and III) in TR-55 (SCS, 1986).

Step 6: Use hybrid facility design (required for additional detention storage).

When the percentage of site area for peak control exceeds that for volume control as determined in Step 3, a hybrid approach must be used. For example, a dry swale (infiltration and retention) may incorporate additional detention storage. Equation A.5 is used to determine the ratio of retention to total storage. Equation A.6 is then used to determine the additional amount of site area, above the percentage of site required for volume control, needed to maintain the predevelopment peak runoff rate.

$$x = \frac{50}{(\forall_{R100} - \forall_{D100})} \times (-\forall_{D100} + \sqrt{\forall^2_{D100} + 4 \times (\forall_{R100} - \forall_{D100}) \times \forall R}\ ) \quad \text{Eq. A.5}$$

where

$\forall R$ = Storage Volume required to maintain predevelopment runoff volume (Chart Series A)

$\forall_{R100}$ = Storage Volume required to maintain predevelopment peak runoff rate using 100% retention (Chart Series B)

$\forall_{D100}$ = Storage Volume required to maintain predevelopment peak runoff rate using 100% detention (Chart Series C)

x = Area ratio of retention storage to total storage

and the hybrid storage can be determined as:

$$H = \forall R \ x \ (100 \div x) \quad \text{Eq. A.6}$$

Equations A.5 and A.6 are based on the following assumptions:

- *x*% of the total storage volume is the retention storage required to maintain the predevelopment CN calculated from Chart Series A: Storage Volume Required to Maintain Predevelopment Volume using Retention Storage.
- There is a linear relationship between the storage volume required to maintain the peak predevelopment runoff rate using 100% retention and 100% detention (Chart Series B and C)

The procedure for calculating hybrid facilities size is shown in Example A.4.

Step 7: Determine hybrid amount of IMP site area required to maintain peak runoff rate with partial volume attenuation using hybrid design (required when retention area is limited).

Site conditions, such as high percentage of site needed for retention storage, poor soil infiltration rates, or physical constraints, can limit the amount of site area that can be used for retention practices. For sites with poor soil infiltration rates, bioretention is still an acceptable alternative, but an underdrain system must be installed. In this case, the bioretention basin is considered detention storage.

Example A.4:

Calculation of Additional Storage Above Volume Required to Maintain CN and Maintain Predevelopment Peak Runoff Rate Using Hybrid Approach

Given:

- 5-inch Storm Event with Rainfall Distribution Type II
- Existing CN = 60
- Proposed CN = 65
- Storage volume required to maintain volume (CN) using retention storage = 0.35 inch (from Chart Series A)
- Storage volume required to maintain peak runoff rate using 100% retention = 0.62 inch (from Chart Series B)
- Storage volume required to maintain peak runoff rate using 100% detention = 0.31 inch (from Chart Series C)

Step 1: Solve for *x* (ratio of retention to total storage) using Equation A.5:

$$\chi = \frac{50}{(.62 - .31)} \times \left(-.31 + \sqrt{.31^2 + 4 \times (.62 - .31) \times .35}\right)$$

$\chi = 68$

Therefore: 0.35 inch of storage needed for runoff volume control is 68% of the total volume needed to maintain both the predevelopment volume and peak runoff rates.

Step 2: Solve for the total area to maintain both the peak runoff rate and volume using Equation A.6. Therefore, the difference between 0.35 inch and 0.51 inch is the additional detention area needed to maintain peak discharge.

$$H = 0.35 \times \frac{100}{68}$$

H = 0.51 inch

Therefore , the difference between 0.35 inch and 0.51 inch is the additional detention area needed to maintain peak discharge.

When this occurs, the site area available for retention IMPs is less than that required to maintain the runoff volume, or CN. A variation of the hybrid approach is used to maintain the peak runoff rate while attenuating as much of the increased runoff volume as possible. First, the appropriate storage volume that is available for runoff volume control (∀R′) is determined by the designer by analyzing the site constraints. Equation A.7 is used to determine the ratio of retention to total storage. Equation A.8 is then used to determine the total site IMP area in which the storage volume available for retention practices (∀R′) substitutes the storage volume required to maintain the runoff volume.

$$\chi' = \frac{50}{\left(\forall_{R100} - \forall_{D100}\right)} \times \left(-\forall_{D100} + \sqrt{\forall^{2}_{D100} + 4 \times \left(\forall_{R100} - \forall_{D100}\right) \times \forall R'}\right) \quad 8 \text{ Eq. A.7}$$

Where ∀R′ = storage volume acceptable for retention IMPs. The total storage with limited retention storage is:

$$H' = \forall R' \text{ x } (100 \div x') \qquad \text{Eq. A.8}$$

where H′ is hybrid area with a limited storage volume available for retention IMPs.

Example A.5 illustrates this approach.

A.6 Determination of Design Storm Event

Conventional stormwater management runoff quantity control is generally based on not exceeding the predevelopment peak runoff rate for the 2-year and 10-year 24-hour Type II storm events. The amount of rainfall used to determine the runoff for the site is derived from Technical Paper 40 (Department of Commerce, 1963). For Prince George's County, these amounts are 3.3 and 5.3 inches, respectively. The 2-year storm event was selected to protect receiving channels from sedimentation and erosion. The 10-year event was selected for adequate flow conveyance considerations. In situations where there is potential for flooding, the 100-year event is used.

The criteria used to select the design storm for low-impact development are based on the goal of maintaining the predevelopment hydrologic conditions for the site. The determination of the design storm begins with an evaluation of the predevelopment condition. The hydrologic approach of low-impact development is to retain the same amount of rainfall within the development site as that retained by woods (or meadows, if they were the natural historical landscape), in good condition, and then to gradually release the excess runoff as woodlands would release it. By doing so, we can emulate, to the greatest extent practical, the predevelopment hydrologic regime to protect watershed and natural habitats. Therefore, the predevelopment condition of the low-impact development site is required to be *woods in good condition.*

Example A.5:

Calculation of Percentage of Site Area Required to Maintain the Peak Runoff Rate Using the Hybrid Approach of Retention and Detention

Given:

- 5-inch storm event with rainfall distribution Type II
- Existing CN = 60
- Proposed CN = 65
- Storage volume required to maintain volume (CN) = 0.35 inch (From Chart Series A)
- Storage volume required to maintain peak runoff rate using 100% retention = 0.62 inch (from Chart Series B)
- Storage volume required to maintain peak runoff rate using 100% detention = 0.31 inch (from Chart Series C)
- Only half of the required site area is suitable for retention practices, remainder must incorporate detention. ($\forall R' = 0.35 \times 0.50 = 0.18$ inch)

Step 1: Determine appropriate amount of overall IMP area suitable for retention practices. Half of area is appropriate (given above). Use Equation A.7:

$$\chi' = \frac{50}{(.62 - .31)} \times \left(-.31 + \sqrt{.31^2 + 4 \times (.62 - .31) \times .18}\right)$$

$\chi' = 41.2\%$

Therefore, 0.35 inch of site area available for runoff volume control is 41.2% of the total volume needed for maintaining the predevelopment peak runoff rate.

Step 2: Solve for the total area required to maintain the peak runoff rate using Equation A.8.

$$H' = 0.18 \times \frac{100}{41.2}$$

$H' = 0.43$ inch

Therefore, totally 0.43 inch of the site is required to maintain the predevelopment peak runoff rate but not the runoff volume. Of the 0.43 inch storage, 0.18 inch of the storage is required for retention volume.

This requirement is identical to the State of Maryland's definition of the predevelopment condition. The CN for the predevelopment condition is to be determined based on the land cover being woods in good condition and the existing HSG. The design storm is to be the greater of the rainfall at which direct runoff begins from a woods in good condition, with a modifying factor, or the 1-year 24-hour storm event. The rainfall at which direct runoff begins is determined using Equation A.9. The initial rainfall amount at which direct runoff begins from a woodland is modified by multiplying this amount by a factor of 1.5 to account for the slower runoff release rate under the wooded predevelopment condition.

$$P = 0.2 \text{ x} \left(\frac{1000}{CN_c} - 10 \right) \qquad \text{Eq. A.9}$$

where P is rainfall at which direct runoff begins.

It should be noted that this assumption will need to be adjusted for communities with different climatic conditions such as the arid southwest or the great plains.

A three-step process, illustrated in Example A.6, is used to determine the design storm event.

Step 1: Determine the predevelopment CN.

Use an existing land cover of woods in good condition overlaid over the hydrologic soils group (HSG) to determine the composite site CN.

Step 2: Determine the amount of rainfall needed to initiate direct runoff.

Use Equation A.9 to determine the amount of rainfall (P) needed to initiate direct runoff.

Step 3: Account for variation in land cover.

Multiply the amount of rainfall (P) determined in Step 2 by a factor of 1.5.

Example A.6 demonstrates this approach.

Example A.6:

Determination of Design Storm

Step 1: Determine the predevelopment CN based on woods (good condition) and HSG.

Given:

Site condition of 90% HSG soil type B and 10% HSG soil type C,

$CN_c = 0.9\ (55) + 0.1 \times (70)$

$CN_c \geq 56.5 \approx 57$ use 57

Step 2: Determine the amount of rainfall to initiate direct runoff using Equation A.9.

$$P = 0.2 \times \left(\frac{1000}{57} - 10 \right)$$

P = 1.5 inches

Step 3: Multiply the amount of rainfall by a factor of 1.5.

Design rainfall = P x 1.5

Design rainfall = 1.5 inches x 1.5

Design rainfall = 2.25 inches

Exhibit A

Storage Volume Required to Maintain the Predevelopment Runoff Volume Using Retention Storage

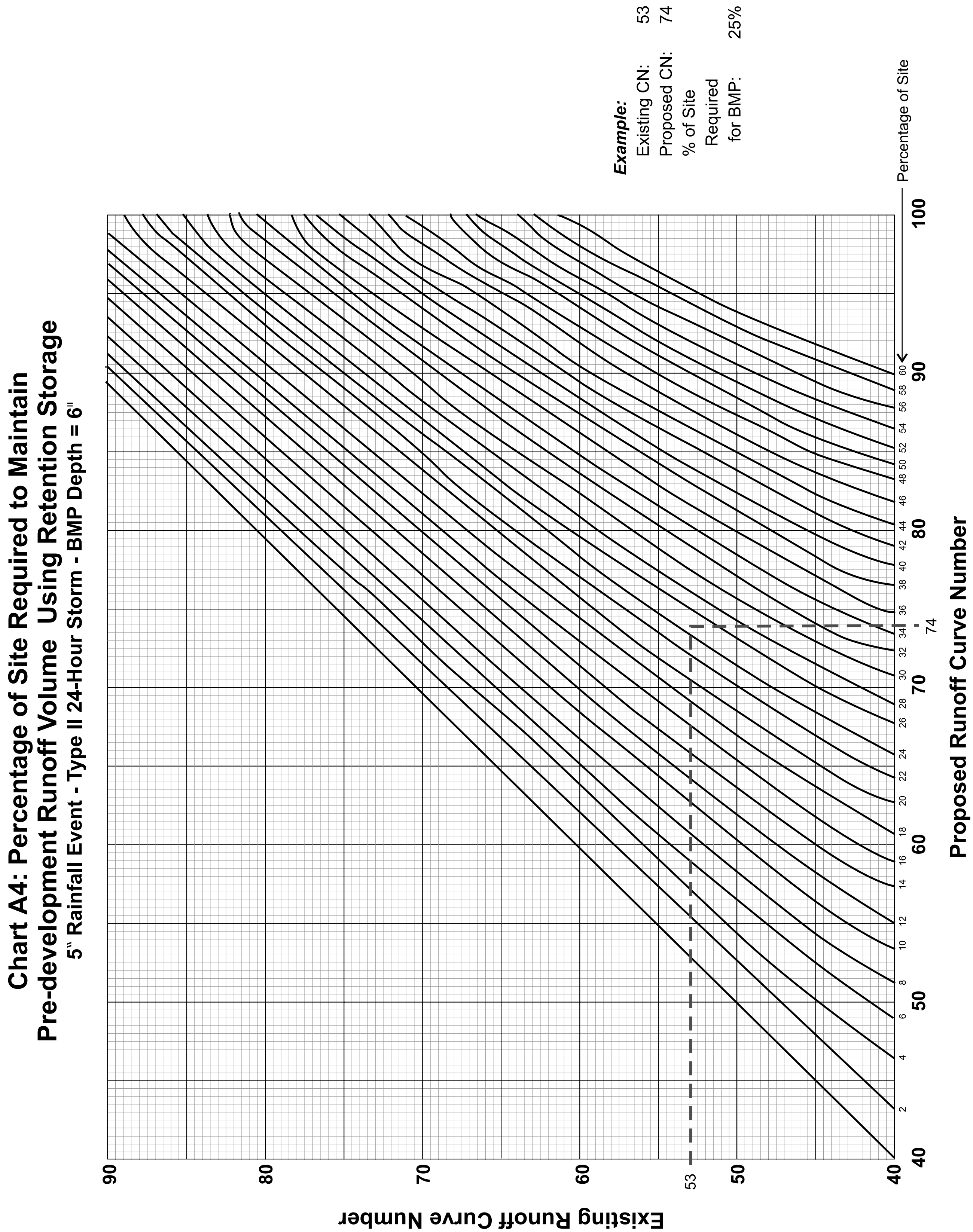


Chart A4: Percentage of Site Required to Maintain
Pre-development Runoff Volume Using Retention Storage
5" Rainfall Event - Type II 24-Hour Storm - BMP Depth = 6"
Example:
Existing CN: 53
Proposed CN: 74
% of Site Required for BMP: 25%
Percentage of Site
Proposed Runoff Curve Number
Existing Runoff Curve Number

Exhibit B

Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Retention Storage

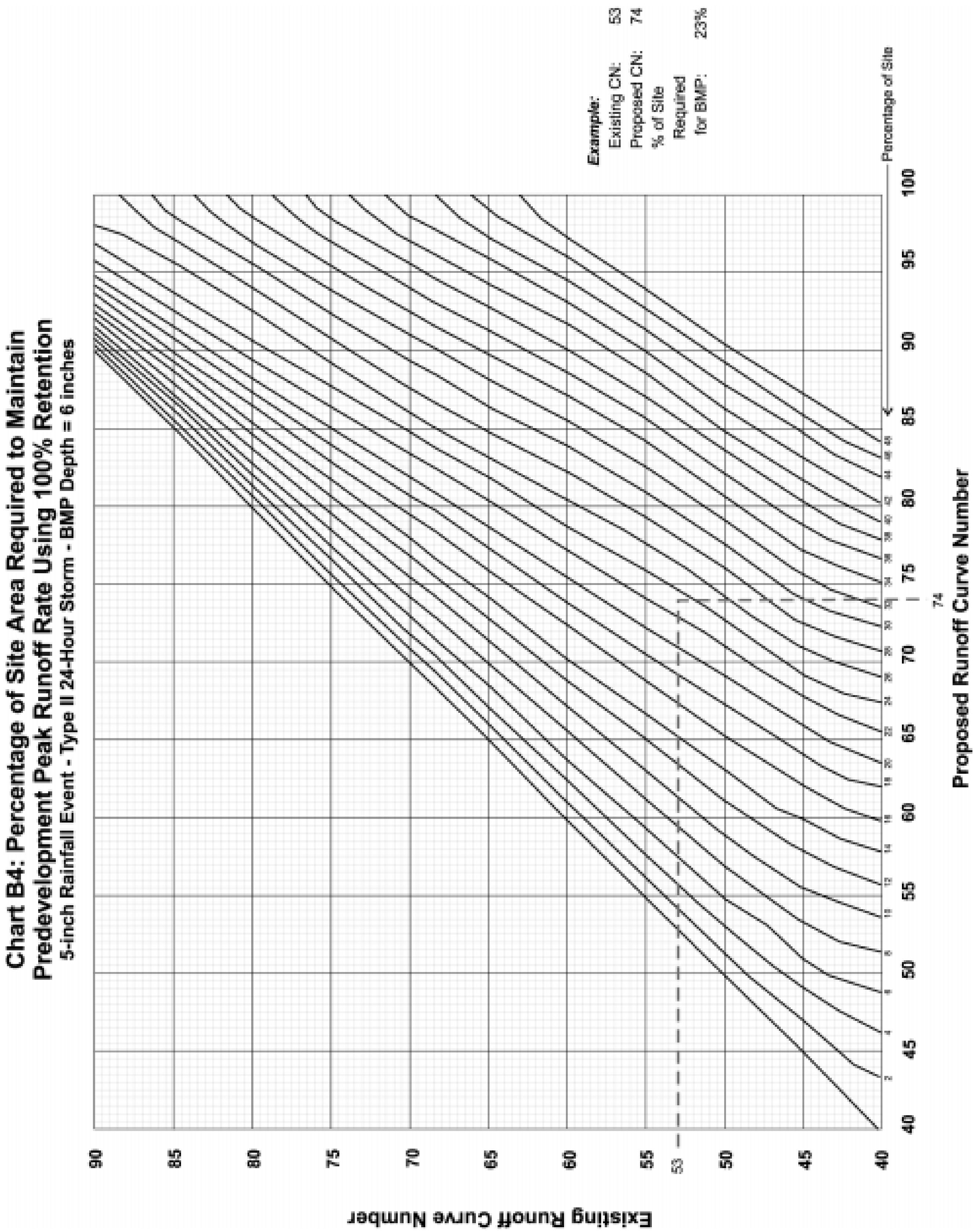


Chart B4: Percentage of Site Area Required to Maintain
Predevelopment Peak Runoff Rate Using 100% Retention
5-inch Rainfall Event - Type II 24-Hour Storm - BMP Depth = 6 inches
Example:
Existing CN: 53
Proposed CN: 74
% of Site Required for BMP: 23%
Percentage of Site
Existing Runoff Curve Number
Proposed Runoff Curve Number
40
45
50
53
55
60
65
70
74
75
80
85
90
95
100

Exhibit C

Storage Volume Required to Maintain the Predevelopment Peak Runoff Rate Using 100% Detention Storage

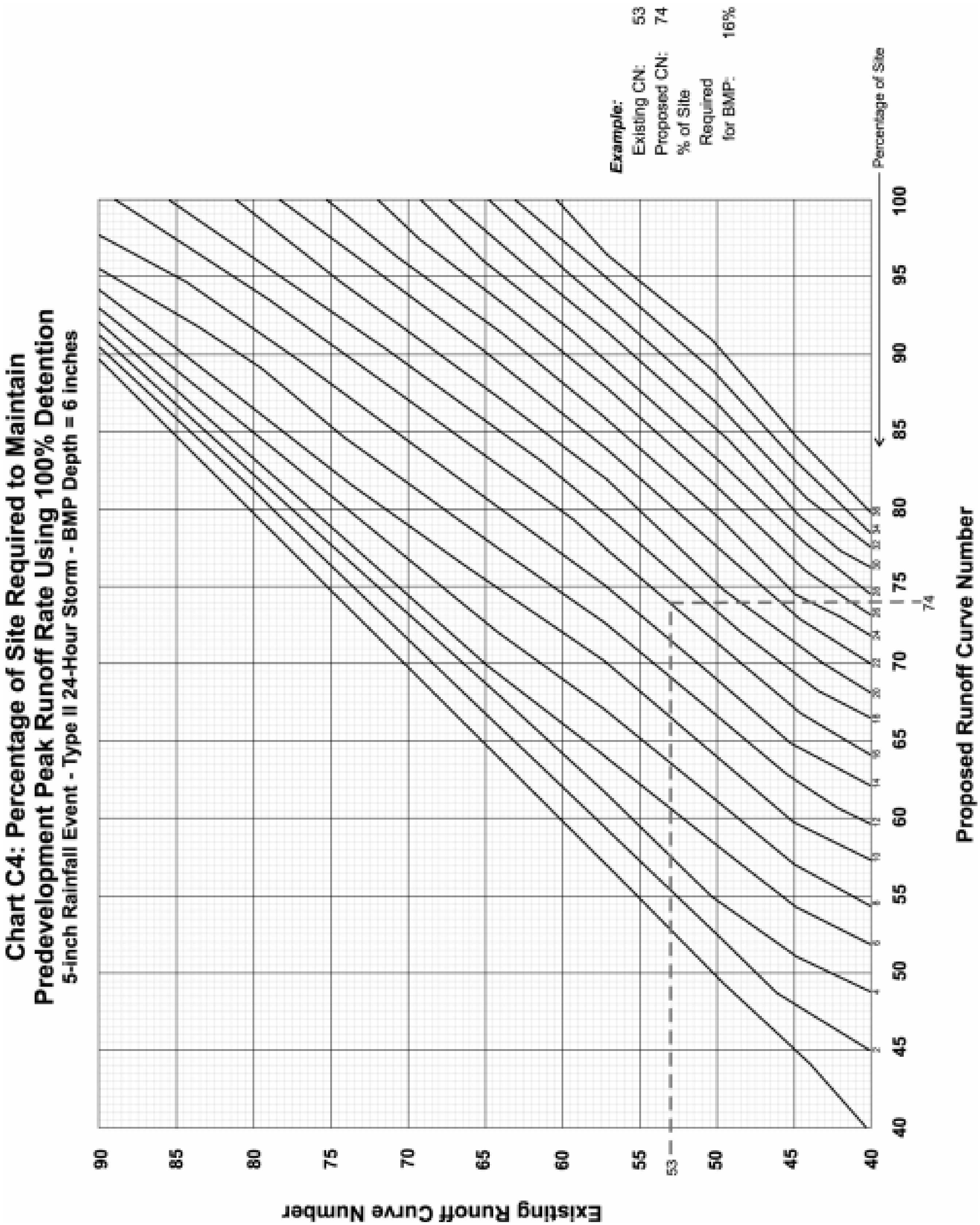


Chart C4: Percentage of Site Required to Maintain Predevelopment Peak Runoff Rate Using 100% Detention
5-inch Rainfall Event - Type II 24-Hour Storm - BMP Depth = 6 inches
Example:
Existing CN: 53
Proposed CN: 74
% of Site Required for BMP: 16%
Percentage of Site
Existing Runoff Curve Number
Proposed Runoff Curve Number
40
45
50
55
60
65
70
75
80
85
90
95
100
53
74

Appendix B - Sample Maintenance Covenant

DECLARATION OF COVENANTS
For Storm and Surface Water Facility, and
Integrated Management System Maintenance

THIS DECLARATION OF COVENANTS, made this _________________ day of ________________, 20___, by

____

hereinafter refered to as the "Covenantor(s)" to and for the benefit of (governing body—state, county, city, etc.) and its successors and assigns hereinafter referred to as the "(State, County, City, etc.)."

WITNESSETH:

WHEREAS, the (State, County, City) is authorized and required to regulate and control the disposition of storm and surface waters within the County's Stormwater Management District set forth in (cite governing laws or regulations): and

WHEREAS, Covenantor(s) is (are) the owner(s) of a certain tract or parcel of land more particularly described as:

____

____

being all or part of the land which it acquired by deed dated ________ ___________________________ from __________________________

____

grantors, and recorded among the Land Records of (governing body), in Liber ________________________ at Folio ______________________ such property being hereinafter referred to as the "the property"; and

WHEREAS, the Covenantor(s) desires to construct certain improvements on its property which will alter the extent of storm and surface water flow conditions on both the property and adjacent lands: and

WHEREAS, in order to accommodate and regulate these anticipated changes in existing storm and surface water flow conditions, the Covenantor(s) desires to build and maintain at its expense, a storm and surface water management facility and system more particularly described and shown on plans titled ______________________________

____

and further identified under approval number ____________________ ___________________; and ___________________________________.

WHEREAS, the (State, County, City, etc.) has reviewed and approved these plans subject to the execution of this agreement.

NOW THEREFORE, in consideration of the benefits received by the Covenantor(s), as a result of the (State, County, City) approval of his plans. Covenantor(s), with full authority to execute deeds, mortgages, other covenants, and all rights, title and interest in the property described above do hereby covenant with the (State, County, City) as follows:

1. Covenantor(s) shall construct and perpetually maintain, at its sole expense, the above-referenced storm and surface management facility and system in strict accordance with the plan approval granted by the (State, County, City).

2. Covenantor(s) shall, at its sole expense, make such changes or modifications to the storm drainage facility and system as may, in the (State, County, City) discretion, be determined necessary to insure that the facility and system is properly maintained and continues to operate as designed and approved.

3. The (State, County, City), its agents, employees and contractors shall have the perpetual right of ingress and egress over the property of the Covenantor(s) and the right to inspect at reasonable times and in reasonable manner, the storm and surface water facility and system in order to insure that the system is being properly maintained and is continuing to perform in an adequate manner.

4. The Covenantor(s) agrees that should it fail to correct any defects in the above-described facility and system within ten (10) days from the issuance of written notice, or shall fail to maintain the facility in accordance with the approved design standards and with the law and applicable executive regulation or, in the event of an emergency as determined by the (State, County, City) in its sole discretion, the (State, County, City) is authorized to enter the property to make all repairs, and to perform all maintenance, construction and reconstruction as (State, County, City) deems necessary. The (State, County, City) shall then assess the Covenantor(s) and/or all landowners served by the facility for the cost of the work, both direct and indirect, and applicable penalties. Said assessment shall be a lien against all properties served by the facility and may be placed on the property tax bills of said properties and collected as ordinary taxes by the (State, County, City).

5. Covenantor(s) shall indemnify, save harmless and defend the (State, County City) from and against any and all claims, demands, suits, liabilities, losses, damages and payments including attorney fees claimed or made by persons not parties to this Declaration against the (State, County, City) that are alleged or proven to result or arise from the Covenantor(s) construction, operation, or maintenance of the storm and surface water facility and system that is the subject of this Covenant.

6. The covenants contained herein shall run with the land and the Covenantor(s) further agrees that whenever the property shall be held, sold and conveyed, it shall be subject to the covenants, stipulations, agreements and provisions of this Declaration, which shall apply to, bind and be obligatory upon the Covenantor(s) hereto, its heirs, successors and assigns and shall bind all present and subsequent owners of the property served by the facility.

7. The Covenantor(s) shall promptly notify the (State, County, City) when the Covenantor(s) legally transfers any of the Covenantor(s) responsibilities for the facility. The Covenantor(s) shall supply the (State, County, City) with a copy of any document of transfer, executed by both parties.

8. The provisions of this Declaration shall be severable and if any phrase, clause, sentence or provisions is declared unconstitutional, or the applicability thereof to the Covenantor is held invalid, the remainder of this Covenant shall not be affected thereby.

9. The Declaration shall be recorded among the Land Records of (Governing Body) at the Covenantor(s) expense.

10. In the event that the (State, County, City) shall determine at its sole discretion at future time that the facility is no longer required, then the (State, County, City) shall at the request of the Covenantor(s) execute a release of this Declaration of Covenants which the Covenantor(s) shall record at its expenses

IN WITNESS WHEREOF, the Covenantor(s) have executed this Declaration of Covenants as of this_______day of___________________, 20_____.

ATTEST: FOR THE COVENANTOR(S)

_________________________ _________________________
(Signature) (Signature)

_________________________ _________________________
(Printed Name) (Printed Name and Title)

STATE OF_____________________ :

COUNTY OF __________________ :

On this________day of______________, 20___, before me, the undersigned officer, a Notary Public in and for the State and County aforesaid, personally appeared _________________________, who acknowledged himself to be__________________________, of___________________________, and he as such authorized to do so, executed the foregoing instrument for the purposes therein contained by signing his name as___________________________for said_______________________________.

WITNESS my hand and Notarial Seal

My commission expires_________________ __________________
Notary Public

Seen and approved

____
(Governing Body)

Glossary

- *Site Planning*
- *Hydrology*
- *Distributed IMP Technologies*
- *Erosion and Sediment Control*
- *Public Outreach*

Glossary

Bioretention: On-lot retention of stormwater through the use of vegetated depressions engineered to collect, store, and infiltrate runoff.

IMP: Best Management Practice; a practice or combination of practices that are the most effective and practicable (including technological, economic, and institutional considerations) means of controlling point or nonpoint source pollutants at levels compatible with environmental quality goals.

Buffer: A vegetated zone adjacent to a stream, wetland, or shoreline where development is restricted or controlled to minimize the effects of development.

Cluster Development: Buildings concentrated in specific areas to minimize infrastructure and development costs while achieving the allowable density. This approach allows the preservation of natural open space for recreation, common open space, and preservation of environmentally sensitive features.

Curbs: Concrete barriers on the edges of streets used to direct stormwater runoff to an inlet or storm drain and to protect lawns and sidewalks from vehicles.

Design storm: A rainfall event of specific size, intensity, and return frequency (e.g.,. the 1-year storm) that is used to calculate runoff volume and peak discharge rate.

Detention: The temporary storage of stormwater to control discharge rates, allow for infiltration, and improve water quality.

Dry Well: Small excavated trenches filled with stone to control and infiltrate rooftop runoff.

EPA: Environmental Protection Agency.

Erosion: The process of soil detachment and movement by the forces of water.

Filter Strips: Bands of closely-growing vegetation, usually grass, planted between pollution sources and downstream receiving waterbodies.

Greenway: A linear open space; a corridor composed of natural vegetation. Greenways can be used to create connected networks of open space that include traditional parks and natural areas.

Groundwater: Water stored underground in the pore spaces between soil particles or rock fractures.

Habitat: An area or type of area that supports plant or animal life.

Hydrology: The science dealing with the waters of the earth, their distribution on the surface and underground, and the cycle involving evaporation, precipitation, flow to the seas, etc.

IMP: Intregrated management practice. A LID practice or combination of practices that are the most effective and practicable (including technological, economic, and institutional considerations) means of controlling the predevelopment site hydrology.

Impervious Area: A hard surface area (e.g., parking lot or rooftop) that prevents or retards the entry of water into the soil, thus causing water to run off the surface in greater quantities and at an increased rate of flow.

Imperviousness Overlay Zoning: One form of the overlay zoning process. Environmental aspects of future imperviousness are estimated based on the future zoning build-out conditions. Estimated impacts are compared with watershed protection goals to determine the limit for total impervious surfaces in the watershed. Imperviousness overlay zoning areas are then used to define subdivision layout options that conform to the total imperviousness limit.

Incentive Zoning: Zoning that provides for give-and-take compromise on zoning restrictions, allowing for more flexibility to provide environmental protection. Incentive zoning allows a developer to exceed a zoning ordinance's limitations if the developer agrees to fulfill conditions specified in the ordinance. The developer may be allowed greater lot yields by a specified amount in exchange for providing open spaces within the development.

Infiltration: The downward movement of water from the land surface into the soil.

Level Spreader: An outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope to prevent erosion.

Low-Impact Development: The integration of site ecological and environmental goal and requirements into all phases of urban planning and design from the individual residential lot level to the entire watershed.

Nonpoint Source Pollution: Water pollution caused by rainfall or snowmelt moving both over and through the ground and carrying with it a variety of pollutants associated with human land uses. A nonpoint source is any source of water pollution that does not meet the legal definition of point source in section 502(14) of the Federal Clean Water Act.

NPDES: National Pollutant Discharge Elimination System; a regulatory program in the Federal Clean Water Act that prohibits the discharge of pollutants into surface waters of the United States without a permit.

Open Space: Land set aside for public or private use within a development that is not built upon.

Overlay Districts: Zoning districts in which additional regulatory standards are superimposed on existing zoning. Overlay districts provide a method of placing special restrictions in addition to those required by basic zoning ordinances.

Performance Zoning: Establishes minimum criteria to be used when assessing whether a particular project is appropriate for a certain area; ensures that the end result adheres to an acceptable level of performance or compatibility. This type of zoning provides flexibility with the well-defined goals and rules found in conventional zoning.

Permeable: Soil or other material that allows the infiltration or passage of water or other liquids.

Planned Unit Development (PUD) Zoning: Planned unit development provisions allow land to be developed in a manner that does not conform with existing requirements of any of the standard zoning districts. The PUD allows greater flexibility and innovation than conventional standards because a planned unit is regulated as one unit instead of each lot being regulated separately.

Rain Barrels: Barrels designed to collect and store rooftop runoff.

Recharge Area: A land area in which surface water infiltrates the soil and reaches the zone of saturation or groundwater table.

Riparian Area: Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding.

Runoff: Water from rain, melted snow, or irrigation that flows over the land surface.

SCS: U.S. Department of Agriculture Soil Conservation Service; renamed the Natural Resources Conservation Service (NRCS).

Site Fingerprinting: Development approach that places development away from environmentally sensitive areas (wetlands, steep slopes, etc.), future open spaces, tree save areas, future restoration areas, and temporary and permanent vegetative forest buffer zones. Ground disturbance is confined to areas where structures, roads, and rights-of-way will exist after construction is complete.

Subdivision: The process of dividing parcels of land into smaller building units, roads, open spaces, and utilities.

Swale: An open drainage channel designed to detain or infiltrate stormwater runoff.

Urbanization: Changing land use from rural characteristics to urban (city-like) characteristics.

Urban Sprawl: Development patterns, where rural land is converted to urban uses more quickly than needed to house new residents and support new businesses. As a result people become more dependent on automobiles and have to commute farther. Sprawl defines patterns of urban growth that include large acreage of low-density residential development, rigid separation between residential and commercial uses, residential and commercial development in rural areas away from urban centers, minimal support for nonmotorized transportation methods, and a lack of integrated transportation and land use planning.

USGS: United States Geological Survey, an agency within the Department of the Interior.

Watershed: The topographic boundary within which water drains into a particular river, stream, wetland, or body of water.

Watershed-based Zoning: Zoning that achieves watershed protection goals by creating a watershed development plan, using zoning as the basis (flexible density and subdivision layout specifications), that falls within the range of density and imperviousness allowable for the watershed to prevent environmental impacts. Watershed-based zoning usually employs a mixture of zoning practices.

Wet pond: A stormwater management pond designed to detain urban runoff and always contain water.

Zero-lot-line Development: A development option in which side yard restrictions are reduced and the building abuts a side lot line. Overall unit-lot densities are therefore increased. Zero-lot-line development can result in increased protection of natural resources, as well as reduction in requirements for road and sidewalk.

Zoning: Regulations or requirements that govern the use, placement, spacing, and size of land and buildings within a specific area.