Introduction to Low Impact Development

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An Introduction to Low Impact Development

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1. INTRODUCTION

1.1 DEFINITION OF LID. Low Impact Development (LID) is a stormwater management strategy concerned with maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements. LID employs a variety of natural and built features that reduce the rate of runoff, filter out its pollutants, and facilitate the infiltration of water into the ground. By reducing water pollution and increasing groundwater recharge, LID helps to improve the quality of receiving surface waters and stabilize the flow rates of nearby streams. LID incorporates a set of overall site design strategies as well as highly localized, small-scale, decentralized source control techniques known as Integrated Management Practices (IMPs). IMPs may be integrated into buildings, infrastructure, or landscape design. Rather than collecting runoff in piped or channelized networks and controlling the flow downstream in a large stormwater management facility, LID takes a decentralized approach that disperses flows and manages runoff closer to where it originates. Because LID embraces a variety of useful techniques for controlling runoff, designs can be customized according to local regulatory and resource protection requirements, as well as site constraints. New projects, redevelopment projects, and capital improvement projects can all be viewed as candidates for implementation of LID. Figure 1-1 below depicts the key elements of LID.

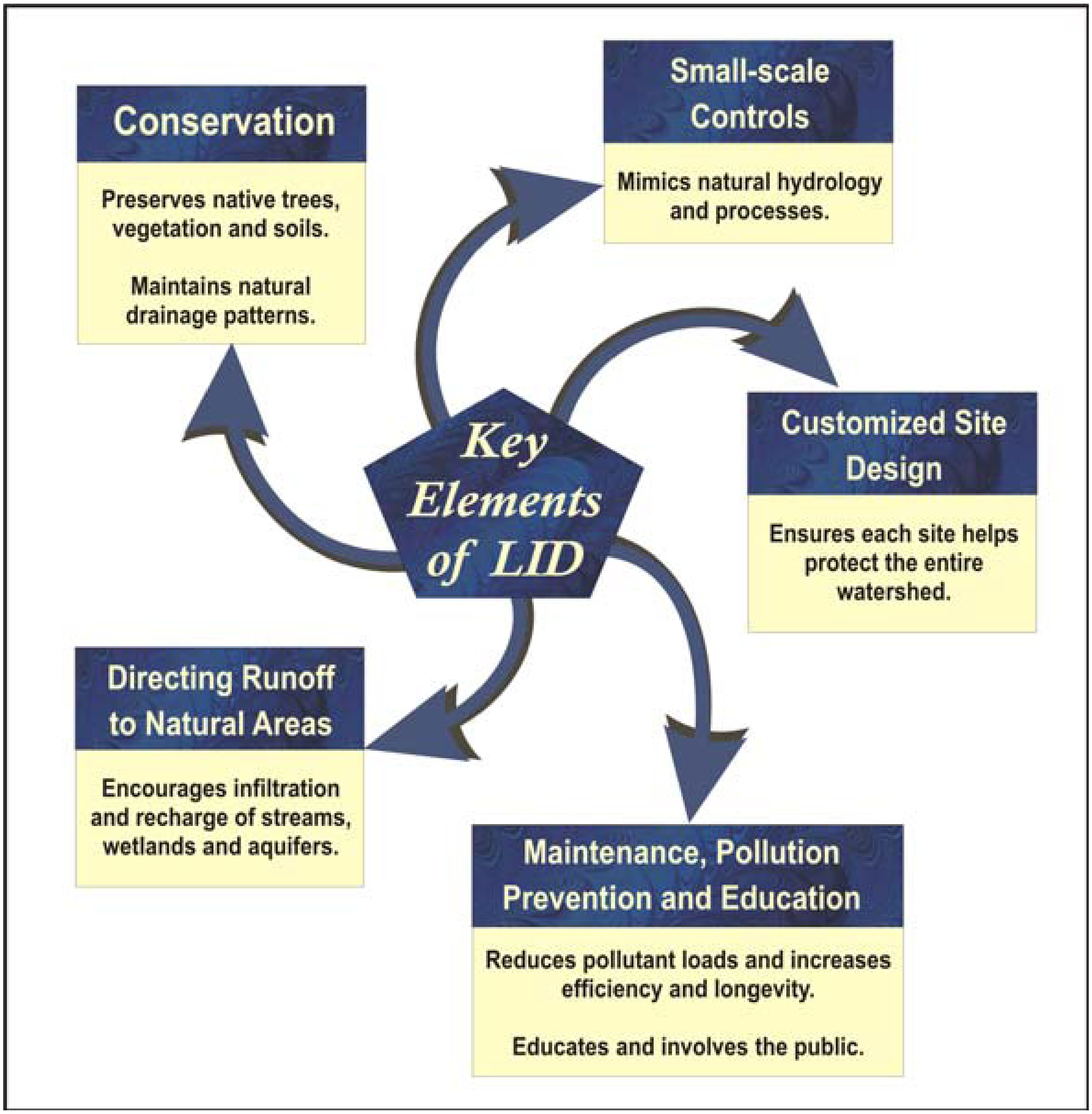


Figure 1-1
Key Elements of LID

1.2 BACKGROUND ON THE USE OF LID. The use of LID was pioneered in the 1990s by the Prince George's County, Maryland Department of Environmental Resources (PGDER). Prince George's County has a population of over 800,000, and land uses within the County are very diverse, ranging from sparsely populated natural and agricultural areas to densely populated urban centers. The LID effort in Prince George's County began with the development and use of bioretention cells. A bioretention cell is created by replacing existing soil with a highly porous soil mixture, grading the area to form a shallow depression, and replanting the area with specially selected vegetation. The vegetation must be able to tolerate temporarily saturated soil conditions as well as the pollutants contained in the local runoff. When it rains, bioretention areas collect the runoff and then filter out the pollutants as the water passes down through the soil.

The County's initial experience with bioretention led to a full-scale effort to incorporate LID into the County's resource protection program. In 1998, the County produced the first municipal LID manual. This was later expanded into a nationally distributed LID manual published in 2000. A feasibility study was prepared by the Low Impact Development Center in 2002 that provided guidance on how LID could be used to retrofit urban areas. Numerous municipalities, including Portland, Oregon, are incorporating LID techniques into their urban resource protection programs. Although LID concepts and techniques are new to many planners in the United States, many of these techniques have been successfully used in Europe and Asia for many years. The effectiveness of these projects in managing runoff, reducing construction and maintenance costs, and creating ancillary benefits such as community involvement has created significant interest in LID. The challenge is to adapt these approaches and techniques to the unique requirements of facilities on a wider scale.

1.3 THIS DISCUSSION. This discussion provides an introduction to guidelines for integrating LID planning and design into a facility's regulatory and resource protection programs. It will be useful to engineers, planners, maintenance personnel, regulatory compliance staff, and community outreach staff who want a basic understanding of the technical and administrative concepts associated with the design, construction, and maintenance of LID features. It answers the following questions:

- What is LID and what value does it have for facility owners?
- What are the basic planning, design, construction, and maintenance considerations?
- How can this approach be incorporated into facility operations?
- Where are successful examples of LID facilities and programs?
- Where can additional guidance be obtained?

1.4 LID SITE DESIGN STRATEGIES. The goal of LID site design is to reduce the hydrologic impact of development and to incorporate techniques that maintain or restore the site's hydrologic and hydraulic functions. The optimal LID site design minimizes runoff volume and preserves existing flow paths. This minimizes infrastructural requirements. By contrast, in conventional site design, runoff volume and energy may increase, which results in concentrated flows that require larger and more extensive stormwater infrastructure. Generally, site design strategies for any project will address the arrangement of buildings, roads, parking areas, and other features, and the conveyance of runoff across the site. LID site design strategies achieve all of the basic objectives of site design while also minimizing the generation of runoff. Some examples of LID site design strategies discussed include:

- Grade to encourage sheet flow and lengthen flow paths.
- Maintain natural drainage divides to keep flow paths dispersed.
- Disconnect impervious areas such as pavement and roofs from the storm drain network, allowing runoff to be conveyed over pervious areas instead.
- Preserve the naturally vegetated areas and soil types that slow runoff, filter out pollutants, and facilitate infiltration.
- Direct runoff into or across vegetated areas to help filter runoff and encourage recharge.
- Provide small-scale distributed features and devices that help meet

regulatory and resource objectives.

- Treat pollutant loads where they are generated, or prevent their generation.

1.5 LID Devices. Reevaluate the site design once all of the appropriate site design strategies are considered and proposed to determine whether the stormwater management objectives have been met. Stormwater management controls, if required, should be located as close as possible to the sources of potential impacts. The management of water quality from pavement runoff, for example, should utilize devices that are installed at the edge of the pavement. These types of controls are generally small-scale (because the site planning strategies have created small-scale drainage areas and runoff volumes) and can be designed to address very specific management issues. The objective is to consider the potential of every part of the landscape, When selecting LID devices, preference should be given to those that use natural systems, processes, and materials. The following list briefly defines the LID devices.

1.6 BASIC LIST OF INTEGRATED MANAGEMENT PRACTICES (IMP). Here is a basic list of IMPs that are available.

- *Bioretention:* Vegetated depressions that collect runoff and facilitate its infiltration into the ground.
- *Dry Wells:* Gravel- or stone-filled pits that are located to catch water from roof downspouts or paved areas.
- *Filter Strips:* Bands of dense vegetation planted immediately downstream of a runoff source designed to filter runoff before entering a receiving structure or water body.
- *Grassed Swales:* Shallow channels lined with grass and used to convey and store runoff.
- *Infiltration Trenches:* Trenches filled with porous media such as bioretention material, sand, or aggregate that collect runoff and exfiltrate it into the ground.

- *Inlet Pollution Removal Devices:* Small stormwater treatment systems that are installed below grade at the edge of paved areas and trap or filter pollutants in runoff before it enters the storm drain.
- *Permeable Pavement:* Asphalt or concrete rendered porous by the aggregate structure.
- *Permeable Pavers:* Manufactured paving stones containing spaces where water can penetrate into the porous media placed underneath.
- *Rain Barrels and Cisterns:* Containers of various sizes that store the runoff delivered through building downspouts. Rain barrels are generally smaller structures, located above ground. Cisterns are larger, are often buried underground, and may be connected to the building's plumbing or irrigation system.
- *Soil Amendments:* Minerals and organic material added to soil to increase its capacity for absorbing moisture and sustaining vegetation.
- *Tree Box Filters:* Curbside containers placed below grade, covered with a grate, filled with filter media and planted with a tree in the center.
- *Vegetated Buffers:* Natural or man-made vegetated areas adjacent to a water body, providing erosion control, filtering capability, and habitat.
- *Vegetated Roofs:* Impermeable roof membranes overlaid with a lightweight planting mix with a high infiltration rate and vegetated with plants tolerant of heat, drought, and periodic inundation.

2. STORMWATER MANAGEMENT USING THE HYDROLOGIC CYCLE APPROACH

2.1 INTRODUCTION. Development affects the natural hydrologic cycle. The hydrologic cycle consists of the following processes:

- Convection
- Precipitation
- Runoff
- Storage
- Infiltration
- Evaporation
- Transpiration, and
- Subsurface flow.

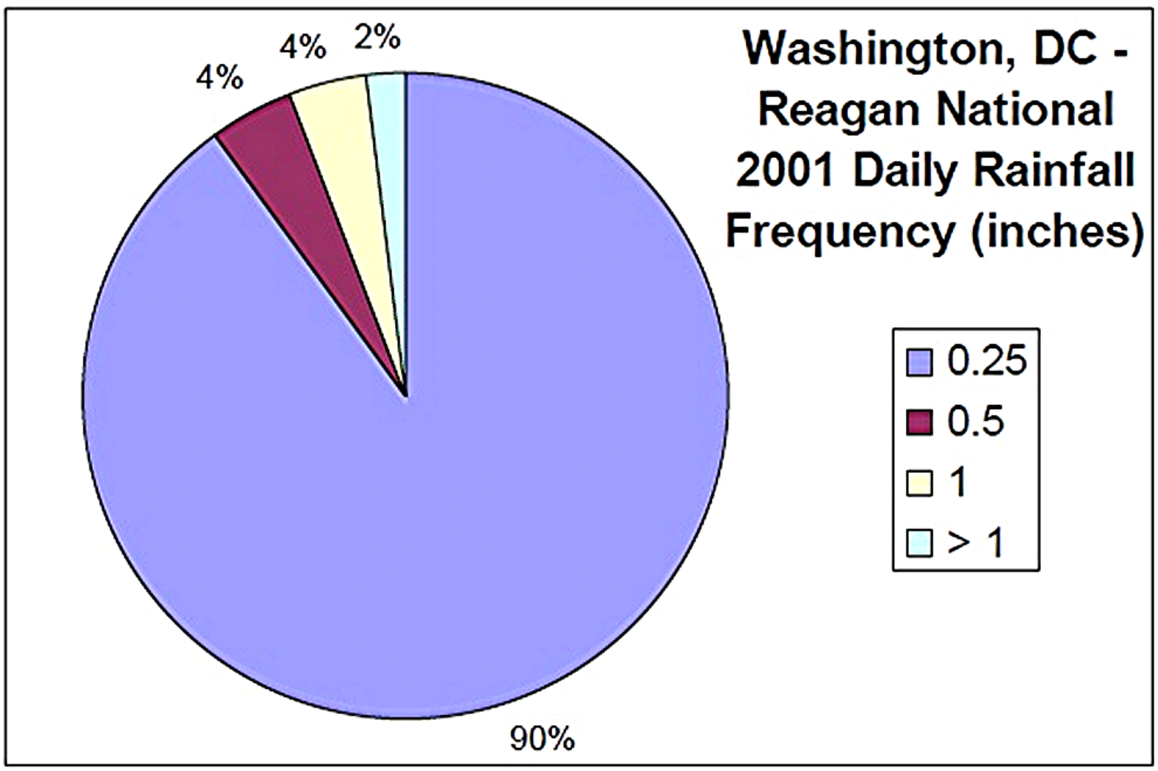
A hydrologic budget describes the amounts of water flowing into and out of an area along different paths over some discrete unit of time (daily, monthly, annually). Grading, the construction of buildings, and the laying of pavement typically affect the hydrologic budget by decreasing rates of infiltration, evaporation, transpiration and subsurface flow, reducing the availability of natural storage, and increasing runoff. In a natural condition such as a forest, it may take 25 to 50 mm (one to two inches) of rainfall to generate runoff. In the developed condition, even very small amounts of rainfall can generate runoff because of soil compaction and connected impervious areas. The result is a general increase in the volume and velocity of runoff. This, in turn, increases the amount of pollution that is carried into receiving waters and amplifies the generation of sediment and suspended solids resulting from bank erosion.

2.2 DESIGN INPUTS. Both LID and conventional stormwater management techniques attempt to control rates of runoff using accepted methods of hydrologic and hydraulic analysis. The particular site characteristics that are considered will depend on the nature of the project. Land use, soil type, slope, vegetative cover, size of drainage area and available storage are typical site characteristics that affect the generation of runoff.

The roughness, slope and geometry of stream channels are key characteristics that affect their ability to convey water. While conventional approaches to stormwater management design typically include only the hydrologic components of precipitation, runoff conveyance and storage capacity within their scopes, LID design recognizes the significance of other components of the hydrologic cycle as well. How these other components are actually taken into account will depend on the information available and purpose of the design. One LID design objective, for example, may be to maintain a natural groundwater recharge rate for a given site. Determining the appropriate number, size, and location of infiltration devices can require an extensive atmospheric data set (temperature and precipitation) to calculate evapotranspiration rates, along with measures of soil hydraulic conductivity. The following section describes how LID design can make use of precipitation, storage, infiltration, evaporation, and transpiration data. The discussion includes a brief description of each of these types of data, and compares the use of these data from LID and conventional stormwater management perspectives.

2.3 PRECIPITATION DATA. Precipitation data is often analyzed in terms of the frequency at which storm events of different magnitudes and durations occur at a given location. Stormwater management designs may take into account the total annual depths or the volume generated by a storm of a specific frequency and duration (e.g. 2-year 24-hour storm event). Hydrologic models may use precipitation data to develop a synthetic design storm that reflects the pattern and intensity of precipitation for the project location region or use actual gage data from a given storm event. The level of detail and accuracy of data used is dependent on the requirements of the hydrologic model. For example, to develop a simple water balance for on-site irrigation only a few years of annual rainfall totals may be required. Some advanced urban hydraulic models, on the other hand, may require the collection of rainfall data in 2-minute intervals over several years to determine the appropriate system design.

2.3.1 LID Precipitation Analysis. An important approach to analyzing the effectiveness of an LID design is to consider the number of storm events for which the design will provide enough storage and infiltration capacity to capture all of the precipitation on-site. This is useful because maintaining the hydrologic integrity or water balance of a site is better accomplished by managing the frequent smaller events rather than the occasional large events. For example, in the Washington, D.C. region there are approximately 80 storm events per year that collectively generate approximately 1000 mm (40 in) of precipitation. Approximately 75 of these storm events generate 13 mm (0.5 in) or less of precipitation. Figure 2-1 illustrates this concept.



Source: NOAA.

Figure 2-1

Frequency of Small Storms

This kind of analysis allows the designer to determine the overall storage and infiltration capacity required to control the desired number of storm events within any given year or period. The analysis can also be undertaken in terms of the precipitation depth associated with discrete storm events such as the 1-year 24-hour storm.

2.3.2 Conventional Precipitation Analysis. Conventional practices, as well as many state and local regulations, often require site engineers to control only specific events such as the 2-year 24-hour storm events. In the Washington, D.C. area, this would mean reducing the peak runoff to predevelopment rates for only those events in which 76 mm (3 in) of rainfall. Events that occur more or less frequently would be less effectively controlled.

2.4 STORAGE. Precipitation may be temporarily detained within site depressions or held in the soil. When the capacity of a depression is exceeded, the water is released as runoff that may be captured further downstream. Water that is not released as runoff will be infiltrated into the soil, taken up by plants, or evaporated back into the atmosphere. Natural land cover often provides depression storage in small undulations in the topography. Greater storage capacity is provided in ponds or lakes.

2.4.1 LID Storage Concepts. LID employs site planning and grading techniques to direct or maintain the flow of runoff to naturally occurring storage areas such as wetlands. Keeping the storage area volume stable helps to maintain the existing hydrologic and biological function of the storage area. An LID design may also include small-scale retention components (retention is defined as the volume of runoff that never reaches the drainage area outlet). Retention can be provided in a variety of ways that not only support the management of runoff, but also supply water for on-site use. For example, a cistern may be used to store and release water for peak flow control as well as to store water for domestic purposes. Additionally, some industrial buildings can provide roof storage and release water for use in cooling systems. Another example is a green wall within a building. The green wall is used to modify temperature and improve air quality by having stored roof water flow across the vegetation. Capturing runoff in small volumes helps to prevent erosion, because the runoff is less likely to reach damaging flow rates. The distribution of storage components also tends to result in a more robust stormwater management system, because the failure of one component will not cause the entire system to fail. Care must be taken when ponding or storing water to make sure there is adequate flow, infiltration, evaporation, or discharge, and that unwanted carriers of disease such as mosquitoes are adequately controlled.

2.4.2 Conventional Storage Concepts. Conventional stormwater strategies often include the storage of water in large centralized end-of-pipe facilities. Site designs direct and convey most runoff as quickly as possible to these facilities and then discharge through an outlet structure at a limited release rate (e.g., 2-year 24-hour predevelopment runoff rate). Conventional runoff management techniques can dramatically reduce the flow of runoff into natural storage areas such as wetlands, depriving a variety of organisms of the level of moisture they need. Conventional approaches can have other negative impacts. By removing opportunities for storage onsite, rates of ground water recharge will be reduced. In addition, the concentrated flow conveyed to large-scale facilities accumulates pollutants and increases the erosive force of the water, which must be slowed down and treated to maintain the natural energy and chemical balance of the ecosystem. An increase in temperature as the water is pooled may also be detrimental to the ecological integrity of the receiving water.

2.5 INFILTRATION. Water stored in depressions will infiltrate into the soil at different rates, depending on the soil type and the amount of moisture already in the soil. Some of the water that infiltrates into the ground may then percolate further downward into an aquifer, or travel horizontally and reappear as surface flow in a stream. A portion of the water will be held in the soil and extracted by vegetation. The capacity of the soil to absorb and infiltrate water is dependent on a variety of factors such as soil structure (e.g., pore spaces and particle size), classification (percentage of sand, silt, and clay) and biological activity (e.g., roots, worms). Water is filtered by the soil system by various mechanisms such as adsorption and chemical and biological reactions. Under natural conditions, a significant portion of the annual precipitation may infiltrate into the ground.

As land is developed, however, many natural depressions that would otherwise collect water are eliminated, the soil is compacted, and impervious area is added in the form of buildings and pavement. Consequently, levels of infiltration typically decrease when a site is developed. The additional runoff generated often results in degradation of the watercourse because of bank erosion, increased flooding, and alteration of habitat characteristics. The infiltration flow patterns and processes are extremely important to maintain the water balance in wetlands and the base flow in stream channels.

2.5.1 LID Infiltration Concepts. Maintaining natural infiltration rates is an important aspect of LID design. Accomplishing this requires an accurate understanding of the existing soils and groundcover conditions. For example, a clay soil on a predevelopment site may have very little infiltration capacity or a sandy soil, which is compacted, may have reduced capacity. The design should take care not to overload the hydraulic conductivity of existing soils. Soil maps by themselves are not sufficient to determine the capacity of the soils to absorb and filter water; additional field testing is required. Dispersing flows, maintaining natural flow patterns, and directing flows towards soils with high capacities for infiltration will help maintain ground water levels. Amending soils by adding organic materials, reducing compaction by aeration, maintaining leaf or "duff" layers in natural areas, and reducing compaction requirements for non-load bearing areas will also enhance and maintain infiltration rates and patterns. Although soils and natural areas have a high capacity to filter and treat pollutants, careful planning must take place to ensure that potential pollutants such as nitrates, oils, or other urban runoff contaminants are adequately treated before entering any potential water supply. Infiltration areas should not be located near areas that have potential for hazardous waste spills or contamination. It is important to ensure that runoff is adequately filtered before it is allowed to infiltrate, especially if local aquifers are particularly shallow. In cases where the water table is very high, it is often advisable to avoid infiltration altogether.

2.5.2 Conventional Infiltration Concepts. Conventional approaches concentrate on the infiltration capacity of a single end-of-pipe management facility such as a pond.

Infiltration potential elsewhere on the site is often discounted or only analyzed for its effect on the flow of runoff into the facility. The conventional infiltration objective is to concentrate flows in one area and then utilize the infiltration capacity of the natural soil or conduits such as gravel. Natural groundwater flow patterns and recharge are often not considered. Conventional approaches may result in the elimination of critical volumes of flows to sensitive areas such as wetlands. Additionally, in many urban areas, the high loads of fine sediments to centralized facilities and the impacts of construction compaction can severely limit the infiltration capacity of the facility.

2.6 EVAPOTRANSPIRATION. Evapotranspiration is the loss of water from the ground by evaporation and transpiration. Evaporation is the return of moisture to the atmosphere from depressions, pond areas, or other surfaces. Transpiration is the return of water to the atmosphere through plants; moisture is absorbed by the roots and released through the leaves. The rate of evapotranspiration is dependent on air temperature, humidity, wind speed, sunlight intensity, vegetation type, and soil conditions.

2.6.1 LID Evapotranspiration Concepts. LID designs use open areas and vegetation to promote evapotranspiration. Larger areas used for evaporation, such as ponds, should have a flow regime that controls mosquito breeding. LID designs should not pond water for more than 72 hours as it may provide an opportunity for mosquitoes to breed. By keeping surface areas small and shallow, water can quickly evaporate and pollutants volatilize through plant uptake or evaporation. LID designs also employ the capacity of vegetated areas to absorb, process, volatilize, and treat non-point source pollution as well as atmospheric pollution. Interception by leaves can significantly reduce the requirement for storage and infiltration. A mature canopy can intercept a significant number of small-volume, frequently occurring storms, absorbing precipitation into the plant leaves or evaporating precipitation from the leaf surface. Additionally, uptake of soil moisture by plants helps to maintain the soil’s capacity to absorb rainfall.

2.6.2 Conventional Evaporation Concepts. Conventional stormwater approaches are based on peak flow control over a short duration (usually 24 hours or less). For these single event designs, the evaporation process is often discounted or not considered.

3. LID DESIGN GOALS AND OBJECTIVES

3.1 INTRODUCTION. Agencies are faced with the responsibility of managing and protecting the natural resources of often large parcels of land reserved for many different functions. Uses can be intensive and can pose a variety of stormwater challenges. For example, an industrial facility or supermarket may generate stormwater pollutants and alter the downstream hydrology. There is no single management practice that can be universally applied to all drainage areas. Table 3-1 illustrates the removal effectiveness of various BMPs (Best Management Practices) for a variety of pollutants. The table below illustrates the complexity of stormwater management; there is no single BMP or technique that can be used to effectively address all of the potential watershed issues.

Particle Size Grading (µm)	Treatment Measures	Hydraulic Loading (m/yr)
Gross solids (>5000)	Gross Pollutant Traps	1,000,000 to 100,000
Coarse-to-Medium Particulates (125 to 5000)	Gross Pollutant Traps Sedimentation Basins Grass Swales/Filter Strips Surface Flow Wetlands	50,000 to 5,000
Fine Particulates (125 to 10)	Sedimentation Basins Grass Swales/Filter Strips Surface Flow Wetlands Infiltration Systems Sub-Surface Flow Wetlands	2,500 to 1,000
Very Fine Colloidal Particulates (10 to 0.45)	Grass Swales/Filter Strips Surface Flow Wetlands Infiltration Systems Sub-Surface Flow Wetlands	500 to 50
Dissolved Particles (<0.45)	Surface Flow Wetlands Infiltration Systems Sub-Surface Flow Wetlands	10

Table 3-1

3.2 REGULATORY AND NATURAL RESOURCE DESIGN ISSUES. Many regulatory compliance or flood control (peak rate design) schemes for construction are designed to achieve only one objective (e.g., pre-development control for the 2-year 24- hour storm event). Regulations often fail to consider overall natural resource management, hydrologic objectives, and stewardship responsibilities of facilities. Budget constraints often limit construction funding to that necessary for conveyance or flood control requirements. The limited framework may create situations where regulatory requirements are met but the design results in degradation of the natural resources. LID principles use hydrology as the integrating framework of design, and protect the overall ecology of the watershed. LID allows facilities to meet the regulatory requirement for flood control (by storing and infiltrating a sufficient volume) while sufficiently filtering targeted pollutants through natural and man-made systems.

3.3 FUNDAMENTAL SITE PLANNING CONCEPTS. The goal of LID site planning is to allow for full development and function of the intended site activity while maintaining the site's essential natural or existing hydrologic function. The LID site design process is sequential and iterative, and embraces the following five concepts:

- Hydrology is the Integrating Framework for the Design
- Distribute Controls through Micromanagement
- Stormwater is Controlled at the Source
- Utilize Non-structural Systems Where Possible
- Create Multifunctional Landscape, Buildings and Infrastructures

3.3.1 Hydrology is the Integrating Framework for the Design. LID designs have the goal of mimicking the natural site drainage processes and functions. Techniques are used to modify hydrologic processes, such as infiltration or storage, to meet the specific water quality, water quantity, and natural resource objectives. LID designs create an effective drainage process for stormwater on the site. A stormwater management system will come closest to mimicking natural flow patterns when storage and infiltration components are distributed across the site.

3.3.2 Distribute Controls Through Micromanagement. In order to emulate natural processes, it is imperative to view the site as a series of interconnected smallscale design controls. Such a structure creates opportunities for redundancy in treatment and control, the development of a "treatment train" for water quality control, and the opportunity to strategically locate LID components.

3.3.3 Stormwater is Controlled at the Source. Controlling and treating runoff as it is being generated reduces or eliminates the risks associated with transporting pollutants further downstream through pipes and channels. Management of stormwater at the source is especially valuable if remediation is required, such as in the case of an accidental spill of pollutants, because the problem can be easily isolated or the treatment system adjusted.

3.3.4 Incorporate Non-Structural Systems. LID designs recognize the potential of natural systems to intercept and filter pollutants. Phytoremediation techniques that take advantage of the biological and chemical processes of the plant soil complex have shown tremendous potential in stormwater management. These natural systems are easy to design, construct, and maintain, even though the naturally occurring filtering and treatment processes may be quite complex and multidimensional. Benefits of using these small-scale and simplified systems (such as soil amendments, landscaping, or revegetation) include the reduced need for costly large-scale construction projects (such as underground concrete vaults or proprietary filters). Figure 3-1 illustrates the range of biological and chemical processes that have been documented to occur in a bioretention cell. The bioretention cell is a landscape area constructed of specialized soil and plants that can effectively absorb and treat urban runoff.

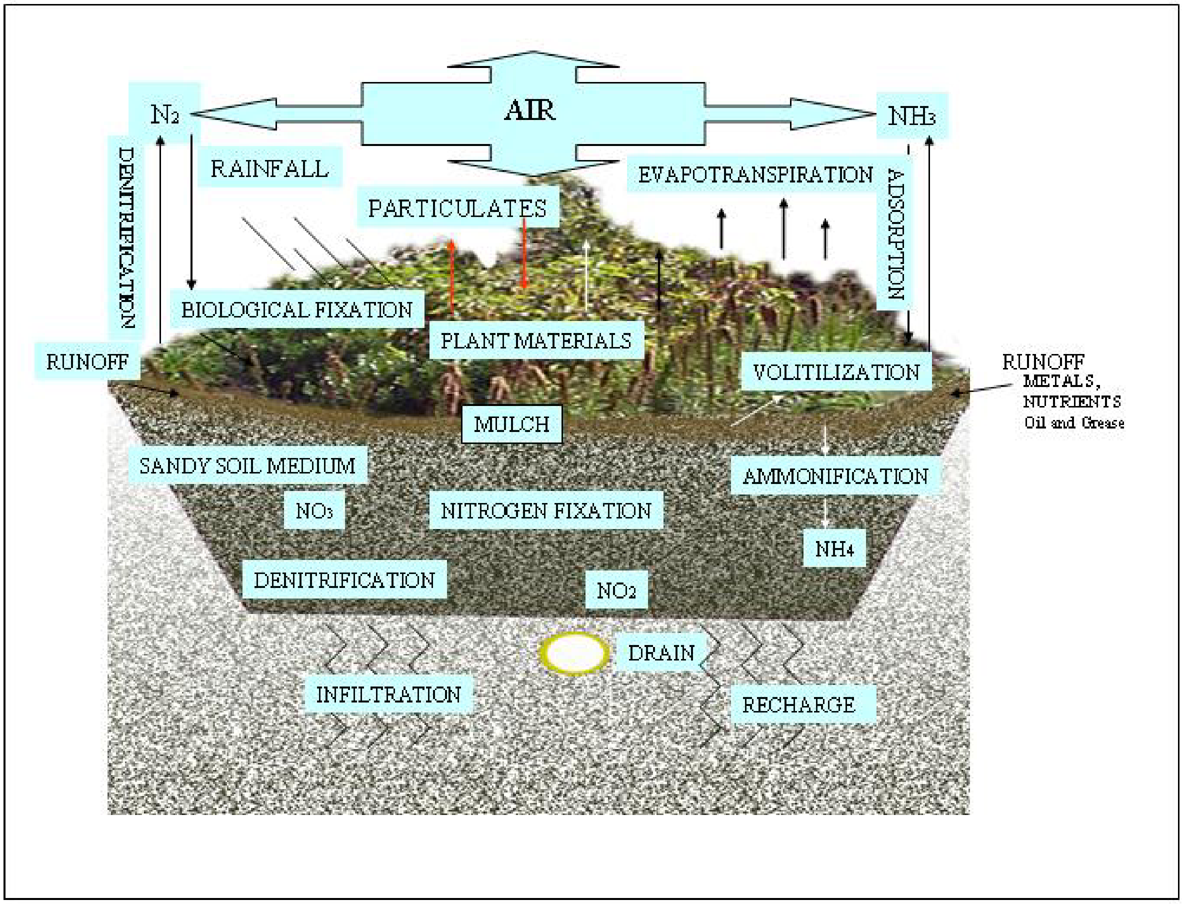


Figure 3-1

Biological and Chemical Processes that Occur in a Bioretention Cell

Source: Prince George's County, Maryland Department of Environmental Resources (PGDER), 2000.

3.3.5 Utilize Multifunctional Landscape, Buildings and Infrastructures. There are a wide variety of LID practices available. The primary criterion in selecting LID practices is that the design of the component contributes to satisfying the design and regulatory objectives. Design features are often multifunctional and satisfy multiple objectives. The development of vegetated roofs is a good example. A vegetated roof can reduce the effects of atmospheric pollution, reduce runoff volume and frequency, reduce energy costs, create an attractive environment, and have reduced replacement and maintenance, and longer life cycle costs. There are many types of vegetated roofs that can be developed including pre-made grids, or cells, or whole systems.

3.4 LID MANAGEMENT AND DESIGN STRATEGIES. LID design is an iterative process that requires a thorough understanding of the management objectives, a detailed understanding of the physical and natural resources of the site, a conceptual site design that can be refined to achieve the goal of a hydrologically functional landscape, and a long-term maintenance plan.

3.4.1 LID Site Planning Components. This section presents the aims of LID site planning and, in light of existing site development requirements, describes how LID site design can be best approached to manage runoff.

3.4.1.1 Hydrologic and Hydraulic Objectives. The purpose of LID site planning is to significantly maintain the predevelopment runoff volume and flow rate. Ideally, and where site conditions allow, this will be achieved in a way that replicates the site's predevelopment hydrologic functions. Sites that are characterized before development by porous soils, substantial vegetative ground cover, and ungraded topography naturally perform several important hydrologic functions:

- Facilitate infiltration, evapotranspiration, retention and detention of runoff
- Limit runoff flow rates because of ground surface roughness
- Help control water quality through surface and subsurface filtering of pollutants and sediments

On a developed site, these hydrologic functions can continue to be provided by the preservation of natural features or construction of a variety of man-made features. Taken together, the utilization of these features comprises a distributed source control strategy that is designed to not only meet regulatory requirements but also to provide superior natural resource protection. Maintaining areas with high soil porosity, vegetative ground cover, and shallow ponding will help meet the following objectives:

- Flood control. Facilitating the infiltration of runoff and decreasing overland flow rates reduces the risk of flooding in receiving waters. To meet design objectives and regulatory requirements completely, supplemental controls may still be required.

- Volume Control. The overall volume of runoff that leaves a site is kept as close as possible to predevelopment levels.
- Peak Control. The peak runoff rate does not increase above predevelopment levels, and the entire runoff hydrograph emulates the predevelopment hydrograph.
- Filtering and Treatment of Pollutants. Runoff is directed across vegetated areas and through porous media to provide significant reductions in the concentration of sediments and pollutants in the water.
- Groundwater Recharge. Infiltration is expedited to enhance groundwater recharge rates and help sustain base flows in nearby streams.

3.4.2 LID Design Approach. The LID approach to site design seeks to maintain or restore the hydrologic impacts of site development using a combination of runoff management strategies, site design techniques, and distributed source controls (IMPs). LID design requires that site plans address the overall natural resource and compliance issues within the watershed. The long-term success of this approach requires an understanding of the maintenance requirements and life-cycle effectiveness of the LID practices and the development of an appropriate maintenance and pollution prevention plan for the facility.

While the influence of each of the components of the design process varies from site to site, a general process has been developed to ensure that all of these components are considered. Although the preference in LID design is to reduce the hydrologic impacts on the site and to retain naturally effective hydrologic features, it is recognized that significant impacts may occur because of the nature of certain activities. When compensating features are required, LID emphasizes the use of integrated site features that control runoff as close as possible to the source, rather than transporting pollutants and attempting to mitigate for lost functions elsewhere. Table 3-2 illustrates the general flow of the design process.

1. **Conserve Natural Areas**
2. **Minimize Development Impacts**
3. **Maintain Watershed Timing**
4. **Provide Integrated Management Practices (IMP)**
5. **Manage for Pollution Prevention**

Table 3-2

LID Design Process

This approach is often an iterative process that requires several attempts to balance all of the design components in the most economical and environmentally effective way. Described below are the individual design components.

3.4.2.1 Conservation of Natural Areas. LID is a stormwater management strategy that addresses the overall regulatory and resource protection goals of a site in a watershed context. Because development typically occurs incrementally, this approach will allow for adjustments or modifications to site design strategies and techniques to reflect dynamic resource protection and regulatory issues. Communities and bases often have extensive watershed management and natural resources conservation goals; master plans identify sensitive environmental areas and preservation areas such as wetlands, mature woods, and habitats. The LID site design should address any potential impacts to these areas and encourage conservation of these areas within the site. Examples of conservation include:

- Preserving a forest corridor that connects with an existing stream valley
- Maintaining flow volume and discharge rates to offsite wetlands
- Incorporating buffers around sensitive habitat areas

3.4.2.2 Minimization of Development Impacts. Within the portion of the site selected for the placement of roads, buildings, and other development activities, minimal disturbance techniques (site fingerprinting) can be used to avoid soil compaction, retain mature trees, and limit the environmental impact of staging areas. Examples of minimal disturbance techniques include:

- Delineating and flagging the smallest site disturbance area possible
- Minimizing the size of construction impacts or offsite easements and property acquisition
- Minimizing the size of material storage areas during and after construction
- Maintaining flow patterns

3.4.2.3 Control of Watershed Timing and Runoff Patterns. Maintaining the site's natural runoff control areas and restricting building over the site's more pervious soils will help keep the infiltration capacity of the site close to predevelopment levels. Maintaining the watershed timing of a site is also important. The cumulative effects of decreasing the post-development watershed times of concentration of several sites can have a significant impact on downstream habitat. It is also desirable to maintain natural vegetation in steeply sloped areas and to retain natural drainage divides. This will encourage dispersed flow paths and, consequently, help reduce the development of channels that lead to erosion and flooding problems. Adequate drainage from buildings, walkways, and roads must be provided. Traditional designs often create a drainage system that has the effect of increasing the rate at which runoff moves into receiving waters during storm events. In turn, this produces a higher volume of runoff, a higher peak rate of flow, and an earlier runoff event than would occur under less developed conditions. The opportunity for groundwater recharge is eliminated, because infiltration into swales and grassed areas cannot effectively occur if runoff passes through quickly. The overall grading objective for LID is to provide a surface landform that will distribute flows in a shallow and slow moving pattern toward areas where the infiltration capacity is highest. Examples of LID techniques to control rates of runoff and watershed timing include:

- Use flatter rather than steeper grades, provided that adequate drainage for buildings and traffic is maintained
- Reduce the height of slopes, to prevent runoff from gaining speed as it moves downhill
- Where flow begins to accumulate, increase the length of flow paths, diverting and redirecting the flow, preferably with vegetated features
- Minimize use of curb and gutter systems and piped drainage systems in favor of grassed swales
- Minimize the amount of impervious area used for pavement
- Disconnect impervious areas by directing runoff from buildings and pavements onto lawns or other vegetated areas, keeping flow velocities at a level that will not cause erosion
- Preserve naturally vegetated areas and existing topography in places where these help slow runoff and encourage infiltration
- Use weirs and check dams in swales

3.4.2.4 Use of Integrated Management Practices (IMPs). Once all of the design strategies and techniques have been implemented, IMPs are selected to achieve the site water quality and quantity objectives. IMPs are distributed, multifunctional, small-scale controls, selected based on their ability to achieve the site design water quality and quantity objectives in a cost effective manner. IMPs are not a “one-size-fits-all” approach. For example, using amended soils to filter and store runoff may be appropriate for a rural road section with high traffic but inappropriate next to a parking area that may be subjected to compaction from overflow parking or vehicle movement.

3.4.2.5 Pollution Prevention. The goal of pollution prevention is to reduce, reuse and recycle a variety of pollutants before they become environmental problems. The final step of the LID design approach is to incorporate programs that keep pollution out of runoff in the first place and, consequently, to increase the longevity of the IMPs. Reduction of fertilizer, pesticide and herbicide use and the implementation of regular street sweeping are some common pollution prevention activities.

3.5 DESIGN GUIDANCE AND STANDARDS

3.5.1 Methods to Determine Effectiveness. Stormwater projects are typically designed with a particular objective in mind, such as flood control or water quality improvement. Such projects typically require that the designer evaluate the effectiveness of the proposed treatments at meeting the stated objectives. A number of hydrologic models have been developed to model surface runoff from a given drainage area. Because conventional models are primarily concerned with computing flow rates or flood hydrographs at a point of interest, this approach to hydrologic analysis must be modified in cases where not all of the runoff from a given site converges to a single point. Typical watershed models take into account general land cover and stream channel characteristics. To account for LID features and runoff management devices, refinement of the analysis may be desirable. A variety of tools are freely available from public agencies:

3.5.1.1 Natural Resources Conservation Service (NRCS). The NRCS, formerly called the Soil Conservation Service, has been developing runoff models for decades. The NRCS models TR-20 and TR-55 account for variations in land cover and the velocity of water movement across a watershed. Of particular interest are the determination of a drainage area's curve number (CN) and time of concentration (T_c). The value of CN reflects the degree to which land surface conditions will generate runoff, while the value of T_c indicates how quickly the runoff will converge at a particular point downstream. TR-20 and TR-55 are popular for watershed modeling but are generally not recommended for predicting runoff from small storms.

3.5.1.2 Federal Highway Administration (FHWA). The FHWA has developed a variety of software packages, primarily concerned with channel and pipe hydraulics. These programs are most useful in those areas where detailed analysis of flow behavior based on predetermined flow rates is required.

3.5.1.3 Hydrologic Engineering Center of the U.S. Army Corps of Engineers (HEC). The Hydrologic Engineering Center of the U.S. Army Corps of Engineers actively maintains a suite of tools for modeling surface water hydrology and hydraulics.

3.5.1.4 EPA. The EPA maintains the Storm Water Management Model (SWMM) that performs simulations of both water quantity and quality for urban runoff events. In late 2002, EPA extensively revised SWMM to include more detailed analysis of small-scale stormwater management devices. The SWMM algorithm is able to explicitly simulate storage and, therefore, is particularly appropriate for simulating discrete LID systems. Obtaining reasonable estimates of storage parameters needed in SWMM is of critical importance. Creative adaptations of SWMM may be necessary because the model does not directly model runoff from an impervious surface onto a pervious one.

3.5.1.5 Prince George's County, Maryland. The Prince George's County Department of Environmental Resources – Programs and Planning Division, working with Tetra Tech, Inc., has developed a BMP evaluation module to assist in assessing the effectiveness of LID technology. This module uses simplified process-based algorithms to simulate BMP control of modeled flow and water quality time series generated from runoff models such as the Hydrologic Simulation Program, FORTRAN (HSPF). These simple algorithms include weir and orifice control structures, storm swale characteristics, flow and pollutant transport, flow routing and networking, infiltration and saturation, evapotranspiration, and a general loss/decay representation for pollutants. It offers the user the flexibility to design retention style or open-channel BMPs, define flow routing through a BMP or BMP network, simulate IMPs such as reduced or discontinuous impervious surfaces through flow networking, and compare BMP controls against a defined benchmark such as a simulated pre-development condition. Because the underlying algorithms are based on physical processes, BMP effectiveness can be evaluated and estimated over a wide range of storm conditions, BMP designs, and flow routing configurations. Such a tool provides a quantitative medium for assessing and designing TMDL allocation scenarios and evaluating the effectiveness of a proposed management approach. Five basic design aspects were used to develop the methodology for the module. They are: (1) the incorporation of input runoff data, (2) design and representation of a site plan, (3) configuration of BMPs of various sizes and functions, (4) schematic representation of flow routing through a network of BMPs, and (5) evaluation of the impact of a site design with BMPs. The module interface is the platform for an interactive linkage between each of the five design features of the module.

3.5.1.6 Commercial Sources. In addition to the freely available models, there are a variety of commercial models on the market. Information about these other tools can be found on the Internet.

3.5.2 Monitoring Strategies. A variety of techniques are available to monitor the effectiveness of LID features for managing water quantity and quality.

3.5.2.1 Water Quantity Monitoring. The effectiveness of LID in controlling runoff volume and peak flow rates can be monitored either at individual features on a site or at some selected point downstream where flow paths converge and a measurement device can be installed.

3.5.2.2 Small Scale. On a small scale, both manual and automatic sampling methods can be used to calculate flow rates upstream and downstream of an LID installation, based on the depth measured using a weir or a rate of flow measured using a conveyance device.

3.5.2.3 Large Scale. On a larger scale, where LID features are used as retrofits in developed areas, the effectiveness of the retrofits can be assessed by comparing pre-LID and post-LID flow rates downstream. Using these data and some straightforward hydrologic calculations, a characteristic hydrograph can be developed to evaluate the site's response to storm events resulting from the implementation of LID treatments. Data from stream gages should indicate that runoff from smaller storms has decreased after LID implementation. As more LID features are used for stormwater retrofits on a site, the decrease in runoff will become more significant.

3.5.2.4 Water Quality Monitoring Parameters. The effectiveness of a runoff management feature can be evaluated using the flow through the feature, the quality of the receiving waters, or both. The Nationwide Urban Runoff Program (NURP) has identified the standard pollutants characterizing urban runoff in Table 3-3 below:

Pollutant	Abbreviation
Suspended Solids Concentration	**SSC**
Biochemical Oxygen Demand	**BOD**
Chemical Oxygen Demand	**COD**
Copper	**Cu**
Zinc	**Zn**
Total Phosphorous	**TP**
Soluble Phosphorous	**SP**
Total Kjeldahl Nitrogen	**TKN**
Nitrate + Nitrite	$NO_2 + NO_3$

Table 3-3

Standard Pollutants in Urban Runoff

3.5.2.5 Biological Monitoring. Pollutants in stormwater runoff have a direct effect on the biological integrity of the receiving waters. The effectiveness of water quality controls can therefore be evaluated by assessing the biological health of the receiving waters in the vicinity of the stormwater outfall. The EPA has developed Rapid Bioassessment Protocols (RBP)[13] that can be used to characterize the existence and severity of impairments to streams, and help to identify sources and causes of impairment.

3.5.2.6 Monitoring Program. There are four phases to develop a monitoring program:

1. Determine the objectives and scope of the monitoring program
2. Develop the monitoring plan in view of the objectives
3. Implement the monitoring plan
4. Evaluate and report the results

Monitoring programs are shaped by the site characteristics, the goals of the project, regulatory requirements, and available funds.

3.5.2.7 Variability. The high variability of stormwater flows and pollutant concentrations at any location makes it difficult to obtain useful monitoring results. Typically, facilities must collect a large number of samples to adequately characterize how a device is functioning under natural conditions. The monitoring approach used on any given site will depend on regulatory requirements, the pollutants of concern, the physical characteristics of the runoff management features, and the availability of funds and personnel for planning, sampling and analysis.

3.5.2.8 State and Local Program Conformance. Water quality monitoring programs should be undertaken to conform to state and local protocols. A detailed guidance manual for water quality data collection, management and interpretation is available from the Environmental Protection Agency[15] and the Department of Transportation. The guidelines, which are primarily concerned with meeting the national stormwater BMP database requirements, can be easily adapted for use in a variety of monitoring activities.

3.5.2.9 Sampling Locations. An effective monitoring effort for decentralized runoff management requires a judicious selection of sampling locations as well as sampling times and techniques. The challenge is often to complete the monitoring effort effectively under budget constraints. If the site design includes many LID features, sampling only a few may provide a reasonable basis to estimate the effectiveness of the full suite of features.

3.5.2.10 Sampling Protocols. Monitoring protocols vary depending on the expected chemical composition of the runoff, the pollutant of concern, the desirability of monitoring the effectiveness of a device at a given location, and the importance of assessing water quality at points downstream. As sampling data is collected over time, trends in the water quality become apparent. Adjustments in the monitoring plan may be appropriate to ensure that across the site samples are not taken any more or less frequently than necessary to ensure that a desirable level of water quality is maintained.

4. COMPARISON OF LID TO CONVENTIONAL PRACTICES

4.1 INTRODUCTION. Conventional stormwater management practices focus on providing an efficient site drainage system that rapidly conveys runoff away from buildings and off pavement, and then attenuates the peak runoff rate at a large stormwater management facility downstream. In contrast, LID provides runoff management as far upstream as possible – where it originates – and if necessary, also at multiple points along each flow path. LID and conventional practices can be further compared in a variety of ways:

4.2 COMPLIANCE VS. WATER RESOURCE OBJECTIVES. While conventional stormwater management is primarily concerned with attenuating the peak runoff rate from a developed site, the principal goal of LID is to ensure maximum protection of the ecological integrity of the receiving waters by maintaining the watershed's hydrologic regime.

4.3 WATER QUANTITY CONTROL. Conventional drainage practices effectively reduce peak runoff rates, but do not reduce runoff volume. Instead, conventional drainage practices increase runoff volume by not mitigating the effects of the increased impervious area. The LID features that facilitate infiltration, by comparison, help to reduce runoff volume directly. Runoff volume reductions using LID features can be significant when infiltration is increased over a sufficiently large area. Conventional drainage reduces the amount of subsurface water available to the base flow in nearby streams. LID features that enhance infiltration can have the beneficial effect of helping to maintain those base flows. Other LID features allow the strategic use of stormwater on-site, while conventional drainage designs focus on moving the water rapidly off-site. A conventional stormwater management facility has a limited ability to manage water quality because it is limited to removal by settlement of pollutants. An LID approach, by comparison, takes advantage of a variety of mechanisms that filter water either overland or via infiltration to the subsurface.

4.4 CONSTRUCTION COSTS. Construction costs for LID will vary depending on the characteristics of predevelopment site features, the density of development, the particular LID features selected, and their size and design. For example, the cost of bioretention areas will be a function of the depth of porous backfill and the degree to which underdrains are utilized. Case studies for commercial, townhouse, and detached home residential areas in Prince George's County, Maryland, have demonstrated that LID site design costs can compare favorably with conventional approaches.[17] Costs are not simple to generalize. The scale of the project, availability of materials, and skills and training of staff are all factors. IMPs involving landscaped areas are often simple to maintain because work can often be performed by landscaping crews or residents; hard structures, such as permeable paving systems with underdrains, may require more specialized maintenance.

4.5 OPERATION AND MAINTENANCE. Regular inspections of conventional stormwater management facilities are required to ensure that the storage volume has not been reduced by sediment, outlets are not clogged by debris, and structural features maintain their integrity. For a site designed using an LID approach, runoff management features will tend to be higher in number and several types of features (e.g., bioretention areas) need to be maintained by the property owner. The maintenance of these LID features is straightforward and can easily be performed as part of regular landscaping. Other LID features typically employed along public streets (such as tree filters) require more specialized maintenance to ensure that the filter media are not clogged and toxic materials such as heavy metals do not accumulate to a level at which they become a health hazard.

4.6 RETROFIT POTENTIAL. Retrofitting an already developed area with a conventional stormwater management system requires a considerable amount of space and is likely to involve extensive site disturbance. The LID micro-scale systems listed in the previous chapter require less site disturbance for each installment. LID retrofits may be much easier than conventional retrofits on sites where intensive development has already occurred. Locating sites for installing small devices is far easier than finding a large site for a stormwater management facility. LID retrofits can be customized to pollutant loads, allowing more complete control over pollutant removal.

5. DISTRIBUTED MICRO-SCALE SYSTEMS

5.1 INTRODUCTION. In addition to land surface strategies, LID practices include incorporating small landscaped features and manufactured devices into a site. The management of runoff as it is generated reduces the need for management further downstream. Small distributed systems can perform several important runoff management functions:

- Increase rates of infiltration
- Slow down runoff, reducing flow rates from the site and increasing time for infiltration
- Add retention (the amount of water stored at the surface for the duration of the storm event)
- Add detention, which causes water to be restrained temporarily before it moves further downstream
- Improve water quality by filtering pollutants through media

5.2 REPRESENTATIVE LID PRACTICES. LID uses design components (IMPs) that can be selected and customized for specific stormwater management objectives. The selective use and customization of these components will involve a variety of standards and specifications for construction and maintenance. Described below is a collection of LID practices and their design, construction and maintenance characteristics. Distributed micro-scale systems can include, but are not limited to:

- Soil amendments
- Bioretention
- Dry Wells
- Filter Strips
- Vegetated Buffers
- Grassed Swales
- Infiltration Trenches

- Inlet Pollution Removal Devices
- Rain Barrels and Cisterns
- Tree Box Filters
- Vegetated Roofs
- Permeable Pavers

Table 5-1 presents the variety of runoff management functions provided by these features.

Feature	Effect or Function				
	Slower Runoff	Infiltration	Retention	Detention	Water Quality Control
Soil Amendments		X			
Bioretention		X	X	X	X
Dry Wells		X	X		X
Filter Strips	X				X
Vegetated Buffers	X				X
Grassed Swales	X				X
Infiltration Trenches		X			X
Inlet Devices					X
Rain Barrels			X		
Cisterns			X		
Tree Box Filters					X
Vegetated Roofs	X			X	X
Permeable Pavers		X			X

Table 5-1

Functions of LID Features

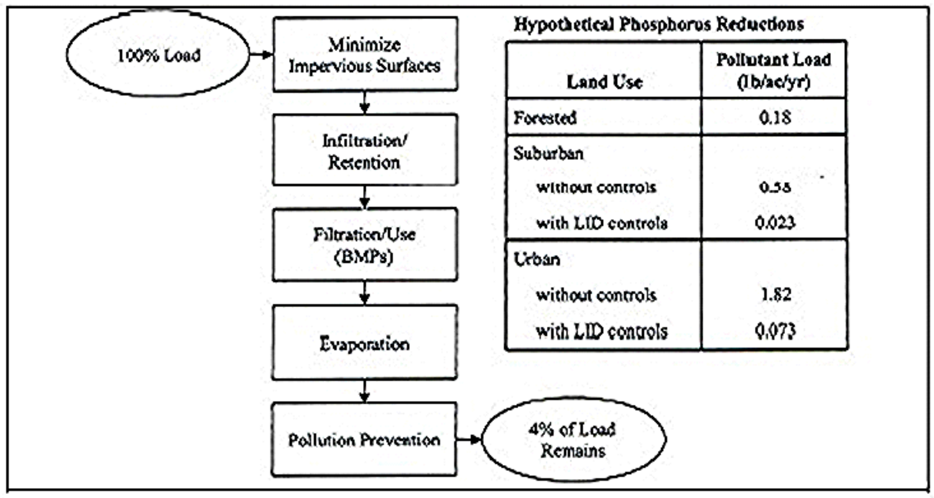
5.2.1 Nutrient Processing. Surface water runoff in urban areas can include significant quantities of chemical nutrients, particularly nitrogen and phosphorous.

When these nutrients reach local water bodies, they can contribute to eutrophication. (Eutrophication is a naturally occurring process in which nutrients accumulate in a body of water over time; the term is often used to signify acceleration of this process by human activity.) Several of the LID components described in this UFC (see Chapter 8) filter out these nutrients to various degrees of effectiveness, depending on the design. LID approaches that utilize vegetation not only filter nitrogen and phosphorous out of the water and into the soil, but also make these nutrients available to the plants to form plant tissue.

5.2.2 Treatment Train Approach to Water Quality. Following a typical flow path beginning where runoff is generated from an impervious area, runoff water quality control can be implemented in the following steps:

- *Minimization.* Design the site to treat pollutants effectively in small quantities, rather than allow larger quantities of runoff to accumulate before treatment.
- *Natural Filtration.* Use the physical, chemical and biological processes of vegetation and soils to filter pollutants.
- *Constructed Filtration.* Use the physical, chemical and biological processes of distributed micro-scale systems to filter pollutants.
- *Evaporation.* Store and evaporate water in shallow depressions so that particulates can be removed.
- *Pollution prevention.* Incorporate management practices such as restricted fertilizer use and diligent street sweeping to reduce pollutant loads. (Note that while the first four steps above pertain to site features, this final step pertains to post-construction maintenance).

Figure 5-1 shows a typical treatment train process for phosphorus removal.



Source: Adapted from PGDER.

Figure 5-1

Treatment Train Process for Phosphorus Removal

5.2.3 Energy Processing. LID features that incorporate vegetation can help to moderate high ambient air temperatures. Even on a small scale, vegetation will have a local cooling effect. Vegetation can be selected and placed to improve shading, or to provide a buffer against winds. Using vegetated roofs can result in significant energy savings in the operation of a building's air conditioning system.

5.2.4 Multifunctional Infrastructure and Buildings. Some LID features can simultaneously provide a variety of hydrologic functions. A bioretention area, for example, can filter runoff for quality control, detain it, and infiltrate the stormwater into the ground. Similarly, vegetated roofs on buildings reduce runoff, reduce pollutants in both the water and the air, and moderate the internal building temperature.

5.2.5 Ancillary Benefits. This discussion describes LID primarily in terms of hydrologic impacts. LID runoff management strategies can also contribute to an aesthetically pleasing landscape, increasing the value of the property where these strategies are employed. In a variety of completed projects, micro-scale runoff management features have provided architectural interest in various forms, such as employing berms in otherwise open spaces, rainwater channels along pedestrian streets, fountains fed by intermittent stormwater, and bioretention areas that attractively subdivide large parking lots. The visibility of these features also provides opportunities for citizens and property owners to become more aware of the importance of stormwater in our urban environment.