Low –Impact Development Design: A New Paradigm for Stormwater Management Mimicking and Restoring the Natural Hydrologic Regime
An Alternative Stormwater Management Technology

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Abstract

Whether complying with federal or state regulations or addressing local vital watershed protection / restoration objectives, local jurisdictions are confronted with the daunting task of developing, administering and funding complex effective multi-objective stormwater management programs. Today's comprehensive stormwater program not only has to deal with runoff quantity and quality control but, may also have to address such complicated issues as ecosystem restoration, combined sewer overflow reduction, fisheries protection, potable surface / ground water source protection, and wetland, riparian buffer and stream protection. As our understanding of the technical and practical limitations of conventional stormwater management technology has increased over the past two decades, and as watershed protection objectives have changed, many jurisdictions have begun to question the efficacy and cost-effectiveness of conventional stormwater approaches in meeting today's complex environmental / water resources objectives. Older communities with existing extensive stormwater management infrastructures are also struggling with the economic reality of funding the high costs of maintenance, inspection, enforcement and public outreach necessary to support an expanding and aging infrastructure. Still more challenging are the exceptionally high costs of retrofitting existing urban development using conventional stormwater management end-of-pipe practices to restore and protect receiving waters and living resources.

With growing concerns about the limitations of conventional technology and to address the changing objectives of watershed protection, in 1990 Prince George's County's Department of Environmental Resources (PGDER) began exploring alternative stormwater management practices and strategies. The development of bioretention or "Rain Gardens" (using the green space to manage runoff within small depressed landscaped areas) lead to an understanding of how to optimize and engineer the landscape to restore hydrologic functions by uniformly integrating micro-scale management practices and impact minimization measures into the development landscape. In 1997 PGDER released the Low Impact Development (LID) Design Manual demonstrating the principles and practices of LID to create a hydrologically functional landscape.

LID stormwater management technology can maintain or restore a watershed's hydrologic regime by fundamentally changing conventional site design to create an environmentally and hydrologically functional landscape that mimics natural hydrologic functions (volume, frequency, recharge and discharge). This is accomplished in four ways. First: minimizing impacts to the extent practicable by reducing imperviousness, conserving natural resources and ecosystems, maintaining natural drainage courses, reducing the use of pipes and minimizing clearing / grading. Second: recreating detention and retention storage dispersed and evenly distributed throughout a site with the use of open swales, flatter slopes, depression storage, rain gardens (bioretention), water use (rain barrels), etc. Third: maintaining the predevelopment time of concentration by strategically routing flows to maintain travel time. Fourth: providing effective public education and socioeconomic incentives to ensure property owners use effective pollution prevention measures and maintain management measures. With LID, every site feature is multifunctional (green space, landscaping, grading, streetscapes, roads and parking lots) and helps to reduce stormwater impacts or provide / maintain beneficial hydrologic functions. The cumulative beneficial impact of using the wide array of distributed LID techniques allows the site designer to maintain or restore watershed's natural relationship between rainfall, runoff, infiltration and evaporation.

The effective use of LID site design techniques can significantly reduce the cost of providing stormwater management. Savings are achieved by eliminating the use of stormwater management ponds, reducing pipes, inlet structures, curbs and gutters, less roadway paving, less grading and clearing. Where LID techniques are applicable, and depending on the type of development and site constraints, stormwater and site development design

construction and maintenance costs can be reduced by 25 % to 30% compared to conventional approaches.

The creation of LID's wide array of micro-scale management principles and practices has lead to the development of new tools to retrofit existing urban development. Micro-scale management practices that filter, retain and detain runoff can be easily integrated into the existing green space and streetscapes as part of the routine maintenance and repair of urban infrastructure. LID retrofit techniques may lead to drastic reductions in the cost of retrofit existing urban development. Reducing urban retrofit costs will increase the ability of cities to implement effective retrofit programs to reduce the frequency and improve the quality of CSOs and improve the quality of urban runoff to protect receiving waters. LID represents a radically different approach to controlling stormwater runoff that provides effective tools to restore or maintain a watershed's hydrologic functions for new or existing development.

In 1998 EPA provided grant funding to assist PGDER in their efforts to develop a general manual describing LID's principles and practices and share this technology with other local governments throughout the nation. Efforts are currently underway with EPA to further advance LID technology by improving the sensitivity of current hydrology and hydraulic analytical models for application with small watersheds and sites and to develop new micro-scale control approaches and practices for urban retrofit. Additional efforts are also underway to demonstrate how LID micro-scale management and multifunctional infrastructure principles and practices can be used to control highway runoff within existing rights-of-way. It is hoped that the LID national manual will help to stimulate debate on the state of current stormwater, watershed protection and restoration technology and its future direction. The lessons learned about LID planning, principles, practices and research are described in detail in the reference documents 1 through 4 listed a the end of this paper. Copies of these reference documents can be obtained by calling the Prince George's County's Department of Environmental Resources at (301) 883-5832.

Background

Typically, adverse stormwater impacts are mitigated using conservation of natural resources (forests, streams, floodplains and wetlands); zoning restrictions to direct densities and increase open space; and the use of structural or non-structural control technologies (best management practices - BMP's) to treat and manage runoff quantity and quality. Many conventional stormwater mitigation approaches, such as management ponds, exhibit a number of inherent practical, environmental and economic limitations including inability to replicate predevelopment watershed hydrology, elevated water temperatures, costly maintenance burdens, and accelerated stream erosion due to the increased duration and frequency of runoff events. Furthermore, because current mitigation practices only lessen development impacts, there is concern about the cumulative impacts of the widespread use of conventional mitigation practices that may fundamentally alter a watershed's hydrologic regime and water quality, adversely affecting receiving waters and the integrity of their ecosystems. Many highly urbanized jurisdictions are beginning to question the efficacy of current technology and are finding it harder to ensure, enforce or fund stormwater programs and maintain the massive infrastructure created by conventional approaches.

Currently every site is designed with one basic overriding goal - to achieve good drainage. As we develop a site reshaping the landscape inch by inch, its hydrologic functions are altered on a micro-scale level. The cumulative impacts of micro-scale changes to the landscape drastically alter watershed hydrology. If sites can be designed to achieve good drainage, destroying natural hydrologic functions, why not design sites with the opposite objective to maintain predevelopment hydrologic functions? If inch by inch, sites are carefully and intelligently engineered to maintain hydrologic functions, would the cumulative beneficial affects result in the preservation of a watershed's hydrology? Can a site be designed in a way to remain as a functional part of a watershed's hydrological regime? To achieve a hydrologically functional development there must be a radical change in our thinking. We must not think in terms of impact mitigation as the stormwater management objective, but rather preservation of hydrologic and environmental functions. We should design sites to maintain hydrologic functions not just to mitigate impacts. Can our current stormwater management technology adequately meet our regulatory objectives and water resources / ecosystem protection needs? No one can answer that question for sure. However, it has not been shown that conventional ponds replicate predevelopment hydrology nor is there any evidence to suggest that conventional technology can ensure the ecological integrity of ecosystems. In fact, recent studies suggest that conventional approaches can not meet our water / living resources and ecological objectives.

Introduction

With growing concerns about the economics and efficacy of conventional technology, in 1990 Prince George's County Maryland's Department of Environmental Resources began exploring alternative stormwater management practices. The success that was achieved through the development and use of bioretention (filtering or infiltration runoff in small depressed landscaped areas) led to us first to an understanding that perhaps changing the form and function of the developed landscape could be important in mitigating urban stormwater impacts. Later it was realized that through intelligent site design and uniform distribution of LID micro-scale management controls that it was possible to maintain or restore hydrologic functions in a developed watershed. What is not known is how much of a watershed's hydrologic functions can be maintained or restored within a given development type (residential, commercial or industrial)?   The one limiting factor to maintaining / restoring the hydrologic regime for highly urbanized development is the lack of available micro-management tools.   Much of the current research underway is to expand the number of practices applicable in highly urbanized areas.

LID's objective is to reproduce the natural predevelopment hydrologic regime. If predevelopment hydrology and water quality can be maintained, this would provide the best level of protection possible to receiving waters and aquatic living resources. Experience over the last 20 years has demonstrated that maximizing the efficiency of conventional conservation measures and the use of conventional end-of-pipe stormwater management practices can not reasonably be used to restore watershed functions. What is needed is a new philosophical approach to site development, an approach that will allow the designer to retain a site's hydrologic functions.

The approach used in LID designs is really an old one. LID borrows its basic hydrologic principles from nature - uniform distribution of micro-management controls. In a natural setting, stormwater is controlled by a variety of mechanisms (interception by vegetation, small depression storage, channel storage, infiltration and evaporation) uniformly distributed throughout the landscape. LID mimics these mechanisms by uniformly distributing small infiltration, storage, and retention and detention measures throughout the developed landscape. What we soon began to see is that every development feature (green space, landscaping, grading, streetscapes, roads, and parking lots) can be designed to provide some type of beneficial hydrologic function.

Low - Impact Development General

LID controls stormwater at the source creating a hydrologically functional landscape that mimics natural watershed hydrology.   Low impact development (LID) achieves stormwater management controls by fundamentally changing conventional site design to create an environmentally functional landscape that mimics natural watershed hydrologic functions (volume, frequency, recharge and discharge).   LID uses four basic management planning and design principles. First: minimize impacts to the extent practicable by reducing imperviousness, conserving natural resources / ecosystems, maintaining natural drainage courses, reducing use of pipes and minimizing clearing and grading. Second: provide runoff storage measures dispersed uniformly throughout the landscape with the use of a variety of small decentralized detention, retention and runoff use practices such as bioretention, open swales and flatter grades. Third: maintain the predevelopment time of concentration by strategically routing flows to maintain travel time and control discharge. Fourth: implement effective public education and incentive programs to encourage property owners to use pollution prevention measures and maintain on-lot landscape management practices.   A developed site can be designed to become a hydrologically functional part of the watershed with comprehensive and intelligent use of LID practices and principles.

LID Basic Site Planning Strategies

The goal of LID is to design the site in a way that mimics hydrologic functions. The first step is to minimize the generation of runoff (reduce the change in the runoff curve number (CN)). In many respects, this step is very similar to traditional techniques of maximizing natural resource conservation, limiting disturbance and reducing impervious areas. The major difference with LID is you must carefully consider how best to make use of the hydrologic soil groups and site topography to help reduce and control runoff. These considerations would include how to:

1) maintain natural drainage patterns, topography and depressions,
2) preserve as much existing vegetation as possible in pervious soils; hydrologic soil groups A and B,
3) locate BMP's in pervious soils; hydrologic soil groups A and B,
4) where feasible construct impervious areas on less pervious soil groups C and D,
5) disconnect impervious surfaces,
6) direct and disburse runoff to soil groups A and B,
7) flatten slopes within cleared areas to facilitate on lot storage and infiltration and
8) re-vegetate cleared and graded areas.

Where ground water recharge is particularly important (to protect well, spring, stream and wetland flows) it is important to understand the source and mechanisms for ground water recharge. When using the LID design concepts to mimic the hydrologic regime you must determine how and where ground water on the site is recharged and where necessary protect and utilize the recharge areas in the site design.

LID Hydrologic Analysis / Response

The objective of LID site design is to minimize, detain and retain the post development runoff volumes uniformly throughout the site close to the source to simulate predevelopment hydrologic functions. Widespread use and uniform dispersion of on lot small retention and/or detention practices to control both runoff discharge volume and rate is key to better replicating predevelopment hydrology. Using LID practices also produces runoff frequencies that are much closer to existing conditions than can be achieved by typical application of conventional BMP's. Management of both runoff volume and peak runoff rate is included in the design. This is in contrast to conventional end-of-pipe treatment that completely alters the watershed hydrology regime.

The LID site analysis and design approach focuses on four major hydrologically based planning elements. These fundamental factors affect hydrologic and are introduced below.

- Curve Number (CN)- A factor that accounts for the effects of soils and land cover on amount of runoff generated. Minimizing the change in the post development CN by reducing impervious areas and preserving more trees and meadows to reduce runoff storage requirements all to maintain the predevelopment runoff volume.

- Time of Concentration (Tc) - This is related to the time runoff travels through the watershed. Maintaining the predevelopment Tc reduces peak runoff rates after development by lengthening flow paths and reducing the use of pipe conveyance systems.

- Permanent storage areas (Retention) - Retention storage is needed for volume and peak control, water quality control and to maintain the same CN as the predevelopment condition.

- Temporary storage areas (Detention) - Detention storage may be needed to maintain the peak runoff rate and/or prevent flooding.

Minimizing the Change in Curve Number CN

Reducing the change in CN will reduce both the post development peak discharge rate and volume. Calculation of the LID CN 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 engineer/ planner to

investigate the following key parameters associated with LID including:
1) land cover type,
2) percentage of and connectivity of impervious cover,
3) hydrologic soils group (HSG), and
4) hydrologic conditions (average moisture or runoff conditions).

The following are some of the LID site planning practices that can be utilized to achieve a substantial reduction in the change of the calculated CN:
1) narrower driveways and roads (minimizing impervious areas),
2) maximized tree preservation and/or afforestation,
3) site finger-printing (carefully siting lots / roadways to avoid disturbance of streams, wetlands and other resources), greater use of open drainage swales,
4) preservation of soils with high infiltration rates to reduce CN,
5) location of BMP's on high-infiltration soils and,
6) construction of impervious features on soils with low infiltration rates.

Maintaining the Predevelopment Time of Concentration Tc

The LID hydrologic evaluation requires that the post development Tc be close to the predevelopment Tc. Minimizing the change in pre and post Tc will help maintain the same frequency of runoff discharges assuming there is uniform distributed micro-scale retention and detention of LID practices. The following are some of the site planning techniques can be used to maintain the existing Tc:
1) maintain predevelopment flow path length by dispersing and redirecting flows using open swales and vegetated drainage patterns,
2) increase surface roughness (e.g., preserving woodlands, vegetated swales),
3) detaining flows (e.g., open swales, rain gardens, rain barrels etc.),
4) minimize disturbances (minimizing soil compaction and changes to existing vegetation /drainage patterns),
5) flatten grades in impacted areas,
6) disconnecting impervious areas (e.g., eliminating curb/gutter and redirecting down spouts) and,
7) connect pervious areas to vegetated areas (e.g., reforestation, afforestation).

The combined use of all these techniques results in cumulative impacts that modify runoff characteristics to effectively shift the post development peak runoff time and frequencies to that of the predevelopment condition, and lower the peak runoff rate.

Maintaining the Redevelopment Curve Number and Runoff Volume

Once the post development Tc is maintained at the predevelopment conditions and the impact of CN is minimized, any additional reductions in runoff volume must be accomplished through distributed micro-scale on-site stormwater management techniques. The goal is to select the appropriate combination of management techniques that simulate the hydrologic functions of the predevelopment condition to maintain the existing CN and corresponding runoff volume. The target design volume is equal to the initial abstraction of rainfall that would have occurred in the predevelopment condition. LID site designs maximize the use of small retention practices distributed throughout the site at the source to provide the required volume storage. The required storage volume will be reduced when the change in the pre and post CN is minimized.

Retention storage allows for a reduction in the post development volume and the peak runoff rate. The increased storage and infiltration capacity of retention LID BMP's allow the predevelopment volume (initial abstraction) to be maintained. The most appropriate retention BMP's include:
1) bioretention cells (rain gardens),
2) infiltration trenches,
3) water use storage (rain barrels and gray water uses) and,
4) roof top storage.

Other possible retention BMP's include retention ponds, cisterns and irrigation ponds but it may be difficult to distribute these types of controls throughout a development site.

As retention storage volume is increased there is a corresponding decrease in the peak runoff rate in addition to runoff volume reduction. If a sufficient amount of runoff is stored, the peak runoff rate may be reduced to a level at or below the predevelopment runoff rate. This storage may be all that is necessary to control the peak runoff rate when there is a small change in CN. However, when there is a large change in CN, it may be less practical to achieve flow control using volume control only.

Potential Requirement for Additional Detention Storage

In cases where very large changes in CN cannot be avoided, retention storage practices alone may be either insufficient to maintain the predevelopment runoff volume or peak discharge rates or require too much space to represent a viable solution. In these cases, additional detention storage will be needed to maintain the predevelopment peak runoff rates. A number of traditional detention storage techniques are available that can be integrated into the site planning and design process for a LID site. These techniques include:

1) swales with check dams, restricted drainage pipes, and inlet / entrance controls,
2) wide low gradient swales,
3) rain barrels / cisterns,
4) rooftop storage and
5) shallow parking lot / road storage.

Determination of Design Storm Event

The hydrologic approach of LID is to retain the same amount of rainfall within the development site as was retained prior to any development (e.g., woods or meadow in good condition) and then release runoff as the woods or meadow would have. By doing so, it is possible to mimic, to the greatest extent practical, the predevelopment hydrologic regime to maximize protection of receiving waters, aquatic ecosystems and ground water recharge. This approach allows the determination of a design storm volume that is tailored to the unique soils, vegetation and topographic characteristics of the watershed. This approach is particularly important in watersheds that are critical for ground water recharge to protect stream / wetland base flow and ground or surface water supplies.

LID BMP’s

Site design techniques and BMP’s can be organized into three major categories as follows; 1) runoff prevention measures designed to minimize impacts and changes in predevelopment CN and Tc, 2) retention facilities that store runoff for infiltration, exfiltration or evaporation and 3) detention facilities that temporarily store runoff and release through a measured outlet. **Table 1**, below lists some of a wide array of possible LID BMP's and their primary functions. Placing these BMP’s in series and uniformly dispersing them throughout the site provides the maximum benefits for hydrologic controls.

Table 1. Examples of LID BMP’s and Primary Functions

BMP	Runoff Prevention	Detention	Retention	Conveyance	Water Quality
Bioretention		X	X		X
Infiltration Trench			X		X
Dry Wells		X	X		

Roof Top Storage		X	X		X
Vegetative Filter Strips				X	X
Rain Barrels		X	X		
Swale and Small Culverts		X		X	X
Swales		X		X	X
Infiltration Swale		X	X	X	X
Reduce Imperviousness	X				
Strategic Clearing / Grading	X				
Engineered Landscape	X				
Eliminate Curb and Gutter	X				X
Vegetative Buffers	X				X

Water Quality

LID maximizes the use of the developed landscape to treat stormwater runoff. Not only can the landscape be used to store, infiltrate and detain runoff, the unique physical, chemical and biological pollutant removal / transformation / immobilization / detoxification capabilities of the soil, soil microbes and plants can be used to remove contamination from runoff. For example, bioretention basins or rain gardens are designed to use the upland soil /microbe /plant complex to remove pollutants from runoff. Rain gardens which look and function like any other garden except they treat runoff are designed with a layer of 2 - 3 inches of mulch, 2 –3 feet of planting soil and vegetation (trees shrubs and flowers). **Figure1** shows a parking lot landscape island rain garden (bioretention practice) that uses a high rate filter media with plants to filter and treat 90% of the annual volume of runoff from the parking lot.

Figure 1.Parking Lot Rain Garden

Studies conducted by the University of Maryland have shown rain gardens to be very effective in removing pollutants. The percent pollutant removal of various contaminants are shown below in **Table 2**. The results shown represent the average removal rates under a wide variety of flow rates and pollutant concentrations.

Table 2. Percent Pollutant Removal by Rain Gardens

Cu %	Pb %	Zn %	P %	TKN %	NH_4^+ %	NO_3^- %	TN* %
93	99	99	81	68	79	23	43

* Removal varied as a function of depth in the soil. Percent removal shown is at a depth of approximately 3 feet.

Testing Conducted by the University of Maryland, Department of Engineering

The variety of physical, chemical and biological pollutant removal mechanisms available in the complex rain garden system is staggering. A description or explanation in any detail of these mechanisms is beyond the scope of this paper. A more detailed description can be found in the 1998 "Optimization of Bioretention Design" study conducted by the University of Maryland. Mulch has been found to be very effective in removing heavy metals through organic complexing with the hydroxyl and carboxyl sites on the organic molecules. Soil bacteria can metabolize (use as a carbon energy source) oil, grease and gasoline into $C0_2$ and water in the presence of adequate nutrients and oxygen. Soil bacteria have been used for years for the remediation of contaminated soils. Plants are known to uptake, transpire, accumulate and detoxify heavy metals and many other toxic compounds. The physiologic and metabolic processes of plants are used to clean contaminated soils through phytoremediation. A goal of LID is to maximize the use of upland landscape with its soil/ microbes/ plant complex to treat runoff. Using upland systems to trap and remove pollutants allows one to more easily control the fate of contaminants and prevent them from entering the water column where they are almost impossible to contain and remove.

Public Outreach and Pollution Prevention

Pollution prevention and maintenance of on-lot LID BMP's are two key elements in a comprehensive approach. Effective pollution prevention measures can reduce the introduction of pollutants to the environment and extend the life of LID treatment BMP's. Public education is essential to successful pollution prevention and BMP maintenance. Not only will effective public education complement and enhance BMP effectiveness, it can also be used as a marketing tool to attract environmentally conscious buyers, promote citizen stewardship, awareness and participation in environmental protection programs and help to build a greater sense of community based on common environmental objectives and the unique character of LID designs.

Costs

LID case studies and pilot programs show that at least a 25% reduction in both site development and maintenance costs can be achieved by reducing grading and the use of pipes, ponds, curbs and paving. In one subdivision called Somerset which used the rain garden LID technique for water quality controls, the developer saved $4,500 per lot or a total of $900,000 by eliminating the need for curbs, ponds and drainage structures. Maintenance costs are also reduced in scale and magnitude by using the small LID practices. LID site designs require only routine landscape care and maintenance of the vegetation. This eliminates the high costs of pond maintenance associated with dam repairs and dredging.

Road Blocks to LID

In the development and acceptance of the LID site planning approach, a number of roadblocks had to be overcome. Regulating agencies, the development community and the public all had concerns about the use of new technology. The LID design manual represents the culmination of four years of work to address all of these concerns and issues. Some of the major components of the LID approach, which addressed the many concerns, include:

1) development of an hydrologic analytical methodology to demonstrates the equivalence of LID to conventional approaches,
2) development of new road standards which allow for narrow roads, open drainage and cluster techniques,
3) streamlining the review process for innovative LID designs which allow easy modification of site, subdivision, road and stormwater requirements,
4) development of a public education process which informs property owners on how to prevent pollution and maintain on lot BMP,
5) development of legal and educational mechanisms to ensure BMP's are maintained,
6) demonstrate the marketability of green development,

7) demonstrate the cost benefits of the LID approach,
8) provide training for regulators, consultants, public and political leaders and,
9) conduct research to demonstrate the effectiveness of bioretention BMP's.

Summary

LID is a viable economically sustainable alternative approach to stormwater management and the protection of natural resources. LID provides tangible incentives to a developer to save natural areas and reduce stormwater and roadway infrastructure costs. LID can achieve greater natural conservation by using conservation as a stormwater BMP to reduce the change in CN. As more natural areas are saved, less runoff is generated and stormwater management costs are reduced. This allows multiple use and benefits (environmental and economical) of the resource.

Additionally, developers have incentives to reduce infrastructure costs by reducing impervious areas, and eliminating curbs / gutters and stormwater ponds to achieve LID stormwater controls. Reduction of the infrastructure also reduces infrastructure maintenance burdens making LID designs more economically sustainable. Superior protection of aquatic and riparian ecosystems can be achieved since a LID developed watershed functions in a hydrologically similar manner as the predevelopment conditions. Recreating the predevelopment hydrological regime is a better way to protect the receiving waters than the conventional end-of-pipe mitigation approaches.

LID promotes public awareness, education and participation in environmental protection. As every property owner's landscape functions as part of the watershed, they must be educated on the benefits and the need for maintenance of the landscape and pollution prevention. LID developments can be designed in a very environmentally sensitive manner to protect streams, wetlands, forest habitat, save energy, etc. The unique character of a LID green development can create a greater sense of community pride based on environmental stewardship.

References

1. Prince George's County, Maryland. Department of Environmental Resources. *Low-Impact Development Design Manual.* (PGC, 1997)

2. Prince George's County, Maryland. Department of Environmental Resources. *Low-Impact Development Guidance Manual.* (PGC, 1997).

3. Prince George's County, Maryland. *Design Manual for use of Bioretention in stormwater Management.* (PGC, 1993)

4. Prince George's County, Maryland. *Optimization of Bioretention Design for Water Quality and Hydrologic Characteristics*. (Davis, et al 1998)