13

Low Impact Development for Stormwater Quantity and Quality

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Low impact development, also known as LID, is an innovative stormwater management approach modeled after nature. This chapter provides information and case studies on the use of standards to model and design sustainable stormwater LID measures. Modeling requirements and various models that can be used to analyze and design LID measures are described. The benefits of LID measures for effective stormwater management are demonstrated using examples. The chapter also provides information on the latest sustainable design standards for urban stormwater management and construction of green stormwater infrastructure. A Washington, D.C., case study is presented to illustrate the implementation of these design standards. Modeling results that quantify the LID benefits in terms of stormwater quantity and quality are presented. The chapter includes an example of using USEPA's (2009) Storm Water Management Model (SWMM) to quantify the stormwater quantity and quality benefits of a rain garden bioretention system.

13.1 Introduction

A sustainable stormwater management approach keeps more water in the environment, minimizes hydrological disruption of watersheds, and utilizes reuse and reclamation components. Using the concept of decentralized systems, it incorporates small-scale technologies for local treatment and closed-loop systems that reuse water for nonpotable uses, such as toilet flushing, irrigation, and

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cooling. Sustainable stormwater systems also feature green infrastructure that can reduce stormwater pollution caused by stormwater runoff and sewer overflows, including combined sewer overflow (CSO) and sanitary sewer overflow (SSO) discharges. This green approach can be combined with smart growth by clustering development and incorporating onsite treatment to achieve watershed restoration (WEF, 2008).

Low impact development is an innovative stormwater management approach modeled after nature. It aims to maintain a site's predevelopment hydrologic cycle through distributed decentralized practices. Conventional stormwater management involves piping a site's runoff as quickly as possible without any treatment. The LID measures, on the other hand, mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source; and remove contaminants that can pollute lakes, rivers and streams as stormwater moves through the site. LID also includes measures to conserve the natural and physical resources at a site. Therefore, LID techniques manage rainfall and provide stormwater management at the source where runoff originates (Shamsi, 2009).

A bioretention cell or rain garden is a notable LID practice used to manage stormwater quantity and quality. As shown in Figure 13.1, it is designed as a garden in a low spot that catches and slows storm water from downspouts, driveways, parking lots, and roads and allows it to infiltrate into the soil with the help of deep-rooted plants that like water. Figure 13.2 shows a rain garden designed by Michael Baker Jr. Inc. in the city of Charleston, West Virginia.

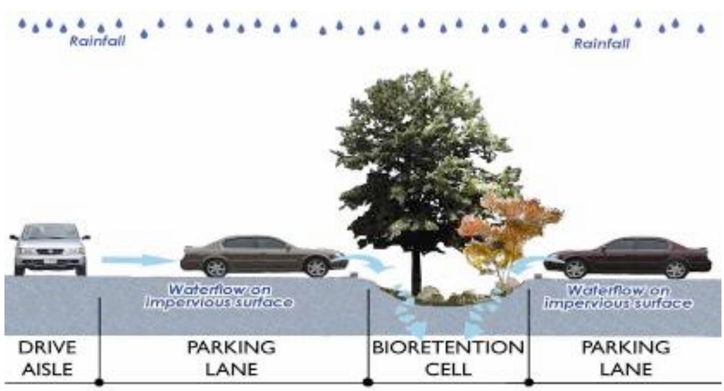


Figure 13.1 Conceptual diagram of a bioretention cell.

Figure 13.2 A rain garden in Charleston, West Virginia (Photo courtsey of Michael Baker, Jr. Inc.).

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings. It provides building owners and operators with the tools they need to have an immediate and measurable impact on their buildings' performance. The LEED Neighborhood Development Rating System integrates the principles of smart growth, urbanism and green buildings into the first national system for neighborhood design. LEED certification provides independent, third-party verification that a development's location and design meet accepted high levels of environmentally responsible, sustainable development.

Michael Baker Jr. Inc. is assisting many U.S. cities in the development of design guidelines and standards (Baker, 2008). Examples of these efforts include:

- Anacostia Waterfront Initiative Transportation Architecture Design Standards;
- Anacostia Waterfront Corporation Environmental Sustainability Standards; and
- Northern Virginia Regional Commission Low Impact Development BMP Handbook.

A case study is presented below that demonstrates the application of some of these standards in designing sustainable stormwater management facilities.

13.2 Case Study

Transforming a 60 acre (24.40 ha) section of a city with a long and storied past is both delicate and valuable work. When that particular 60 acre (24.40 ha) section of a city happens to be the Hill East waterfront, along the southern boundary of Washington, D.C., and includes an important, yet fragile, water resource such as the Anacostia River, the transformation work becomes an integral thread in the fabric of the community and the life-blood for future economic development for this long-neglected region of our nation's capital. See Figure 13.3 for the existing site conditions.

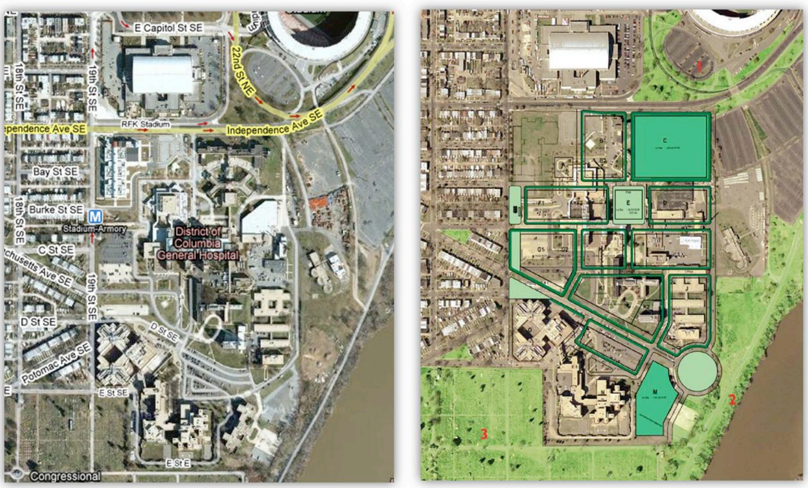


Figure 13.3 Green Hill East waterfront redevelopment before (left) and after (right) the green design.

Environmental changes resulting from residential and commercial development and agricultural uses in the Washington, D.C., area over time, have resulted in the Anacostia River being classified as one of the most polluted rivers in the nation. As part of its efforts to implement sustainable and environmentally responsible development practices, the District of Columbia envisioned the Anacostia Waterfront Initiative (AWI). The Hill East waterfront redevelopment, a LEED neighborhood development pilot project, is a visionary effort connecting the Hill East neighborhood to the Anacostia River. This project required a higher level of stormwater management because of its proximity to the river and restoration goals for the river.

The existing District standards primarily addressed building construction. The District wanted to enhance the building requirements but also wanted to address stormwater management. Therefore, before this project began, Baker (2008) developed the AWI design manual which lays the foundation for all infrastructure development projects within the AWI right-of-way. The guidelines allowed for the integration of green infrastructure, including stormwater management, and sustainable design. The manual developed feasible design and performance standards for green buildings, energy conservation, reduction of potable water consumption, lessening heat island effects, and targeting more natural stormwater hydrology. The design standards support the District's Municipal Separate Storm Sewer System (MS4) Agreement and CSO Long Term Control Plan. One of the most notable aspects of this manual was how innovative stormwater management solutions could be integrated into the urban public realm design. This is referred to as *Integrated Management Plan* or IMP. For example, the project included construction of bioretention cells, a popular LID technique, designed to work with the District's standard drainage system, also referred to as retrofit design. Each cell collects the 1 in. (25.4 mm)/24 h storm and can retain 600 ft^3 (16.95 m^3)water. Forty-five (45) bioretention cells were constructed on Massachusetts Avenue providing a total water storage capacity of 27 000 ft^3 (762.71 m^3).

Because the AWI project site was located in a very urban environment, every available space was maximized to manage stormwater. That is why some of the stormwater techniques were built in or very close to the roads, into parking lots, and even rooftops—basically tying some of these stormwater requirements and techniques into an urban landscape.

13.3 LID Modeling

There are only a few models specifically designed for LIDs. The flow duration design model (FDDM) from Pacific Water Resources (2008) is an LID specific model. It looks and feels like a spreadsheet and is based on the hydrologic simulation program—FORTRAN (HSPF) continuous hydrologic model. FDDM includes conventional extended detention and six different LID practices:

1. Porous pavement;

2. Rain garden;
3. Green roof;
4. Planter boxes (treats them differently from rain gardens);
5. Smart cistern; and
6. Blue roof.

A blue roof is a green roof without the dirt and vegetation. All of the rainfall is stored on the rooftop. The advantage of a blue roof over the green roof is that the blue roof needs no additional stormwater detention storage (no stormwater vault is needed). An orifice on the roof controls the release of rooftop runoff to pre-development conditions which helps meet nature's flow duration standard. Standing water on the rooftop evaporates at the potential rate.

When LID specific models are not available, one can use an existing hydrologic and hydraulic (H&H) and water quality model, such as USEPA's SWMM or a third party SWMM derivative like PCSWMM.NET (CHI, 2009). SWMM features that are especially suitable for LID modeling are:

- SWMM computes storm water runoff quantity and quality from different land cover types;
- SWMM routes flows and pollutants through conveyance, detention, and treatment systems;
- SWMM performs both single event (e.g., 10 y/24 h) or continuous simulation for several months or years ;
- SWMM computes pollutant buildup over different land uses;
- SWMM computes pollutant washoff during runoff events; and
- SWMM computes reduction in washoff from best management practices (BMPs).

The current SWMM version called SWMM5 (Build 5.0.015, 2009 04 10) does not have LID specific modeling options but it can be used to create approximate LID models using the approach presented below. EPA plans to release a new version of SWMM5 in late 2009 that will have LID specific modeling features and will include a BMP editor. Please see the chapter on this topic in this monograph (Rossman, 2009).

13.3.1 LID Water Quantity Modeling

The water quantity (runoff reduction) of an LID technique can be modeled using the percentage imperviousness (percentage of land area which is impervious) input parameter in SWMM5 subcatchment editor. For example, percentage imperviousness of the subcatchment where a rain garden will be constructed can be reduced by the area of rain garden. The modeled subcatchment runoff hydrograph and runoff statistics can be used to quantify the reduction in runoff peak flow and volume, respectively.

13.3.2 LID Water Quality Modeling

The water quality impact (pollutant reduction) of an LID technique can be modeled using SWMM5 land use editor. Shown in Figure 13.4, land use editor's Washoff tab can be used to enter a BMP efficiency defined as the pollutant removal efficiency (percentage) associated with any BMP that might have been implemented. The washoff load computed at each time step is simply reduced by this amount. For example, a 90% BMP efficiency can be entered to model removal of total suspended solids (TSS) by a rain garden in a subcatchment. The modeled subcatchment TSS pollutograph and TSS statistics can be used to quantify the reduction in TSS peak concentration and load, respectively.

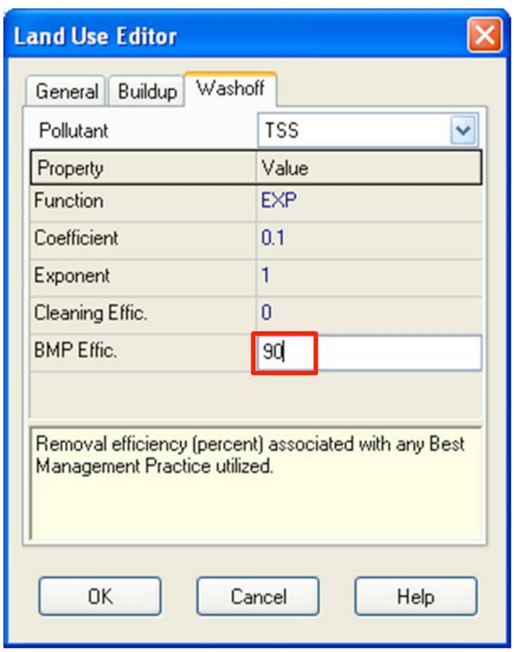


Figure 13.4 SWMM5 land use editor.

13.3.3 LID Modeling Example

SWMM5 Example 1 (included with the software as a sample model) was used to demonstrate the LID quality and quantity modeling approach presented above. It models runoff quantity and quality in a small hypothetical drainage area, shown in Figure 13.5. It consists of eight subcatchments connected to a system of 1 ft to 2 ft (305 mm to 610 mm) diameter storm drains. There are two pollutants (TSS and lead) and two land uses (residential and undeveloped). Rainfall data for both a short term 36 h period and a long term 2 y period are provided.

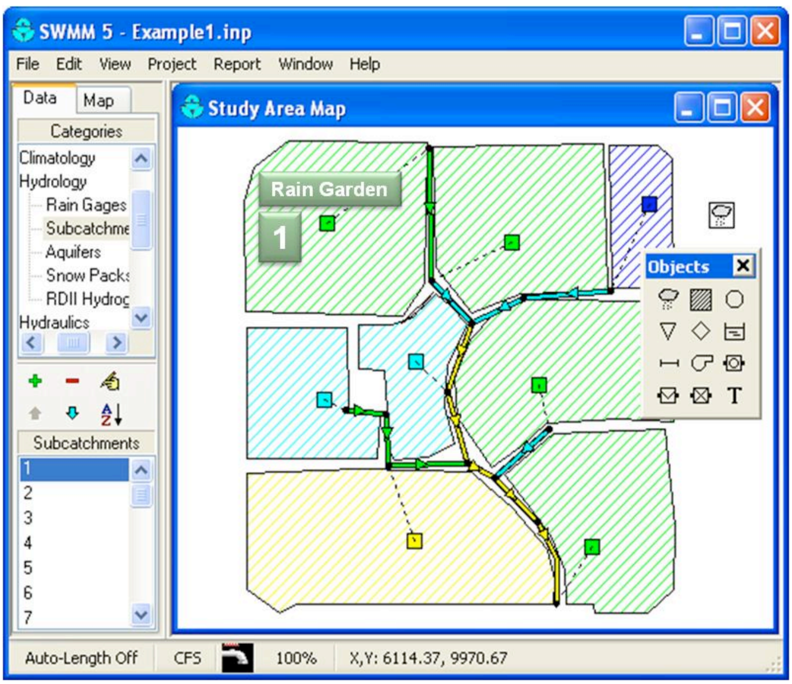


Figure 13.5 LID modeling example.

Figure 13.6 shows the existing (pre LID) subcatchment 1 (area = 10 acres and imperviousness = 50%) hydrograph and TSS pollutograph as well as flow and TSS statistics. The modeled rainfall event had 2.65 in. rainfall in 30 h. Peak rainfall intensity was 0.8 in./h. Modeling results are summarized in Table 13.1.

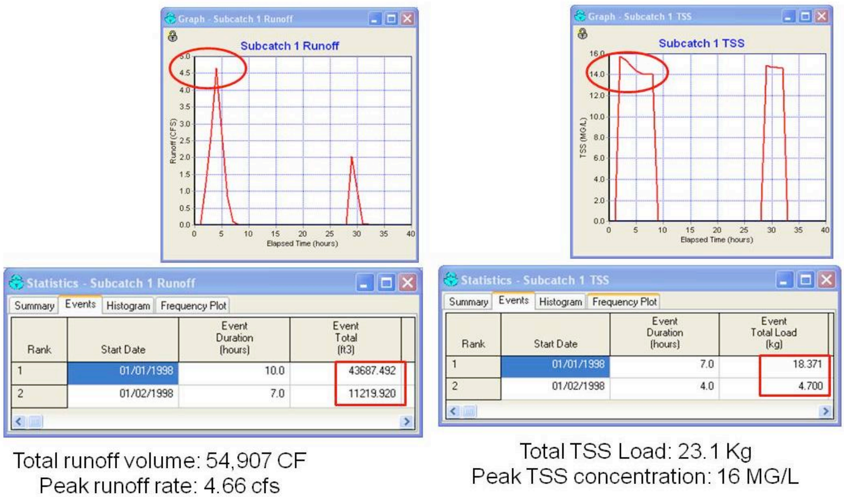


Figure 13.6 Pre-LID runoff and TSS modeling results.

Table 13.1 Results of example LID model.

Output Parameter	Value
Total runoff volume	55 000 ft^3
Peak runoff rate	4.7 ft^3/s
Total suspended solids load	23 kg
Suspended solids concentration	16 mg/L

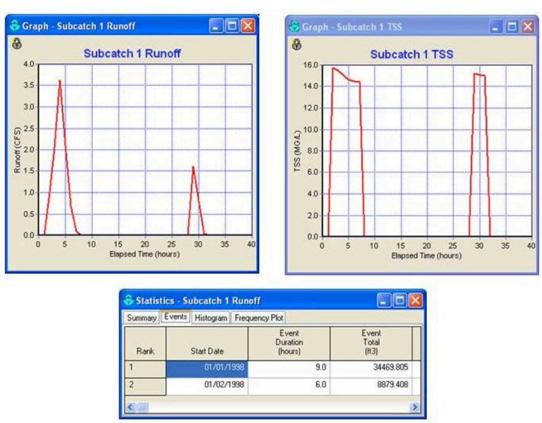
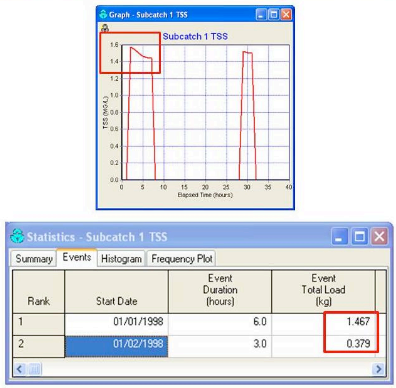


Figure 13.7. Post-LID modeling results with planting new trees.

Figure 13.8 shows a rain garden LID scenario for subcatchment 1 TSS pollutograph and statistics. This figure depicts post-development modeling results if a 90% suspended solids removal efficiency rain garden was added in subcatchment 1 in addition to planting new trees. The modeling results show substantial water quality improvement. Suspended solid peak concentration was reduced by 90% and suspended solid total load was reduced by 92%.



Rank	Start Date	Event Duration (hours)	Event Total Load (kg)
1	01/01/1998	6.0	1.467
2	01/02/1998	3.0	0.379

Figure 13.8 Post-LID modeling results with planting new trees and a rain garden.

13.4 Summary and Conclusions

The new LID techniques are more suitable to support sustainable development than conventional stormwater management. LID design guidelines are available. Most existing hydrologic and hydraulic models can be used to model the stormwater quantity and quality benefits of LID but, at the present time, they lack the LID specific features to model comprehensive design scenarios.

Stormwater is the single largest source affecting the quality and biohabitats of many rivers in the country. It seems reasonable to start with sensible stormwater management there as we redevelop neighborhoods—creating buildings and streets that effectively handle the stormwater impacts due to the loss of impervious surface areas. Forty years ago, recycling and energy conservation were radical ideas. Now they are an integral part of the way we live. Less than a decade ago LEED set the standard. We can push the envelope of sustainability and create a community that goes “Beyond LEED,” one that revolves around healthy lifestyle choices for its members and becomes the model for communities of the future. Radical? Maybe. Achievable? Definitely.

Acknowledgments

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