

Managing Stormwater Using Low Impact Development (LID) Techniques

Carmen T. Agouridis and John T. McMaine, Biosystems and Agricultural Engineering Department

In the year 1800, 3 percent of the world's population lived in urban areas. Today that number is closer to 50 percent, and it is expected to increase to 70 percent by 2050. This increase in urbanization means that more of our watersheds are covered with impervious surfaces such as buildings, roads, sidewalks, and parking lots. As more land is covered by impervious surfaces, less rainfall infiltrates into the ground and instead becomes

runoff (Figure 1). Too much runoff is problematic. Flooding increases, streambanks erode, and water quality is reduced (Figures 2-4). An increase of impervious area of as little 10 percent has been shown to negatively impact streams. The purpose of this publication is to explain low impact development strategies and how they can be used to improve stormwater management by reducing impacts on streams.

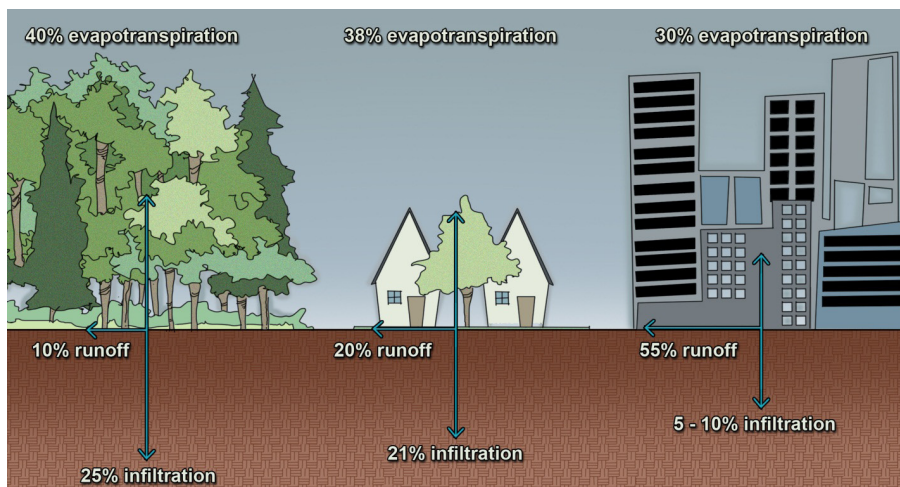


Figure 1. When a watershed urbanizes, infiltration and evapotranspiration decrease while runoff increases.

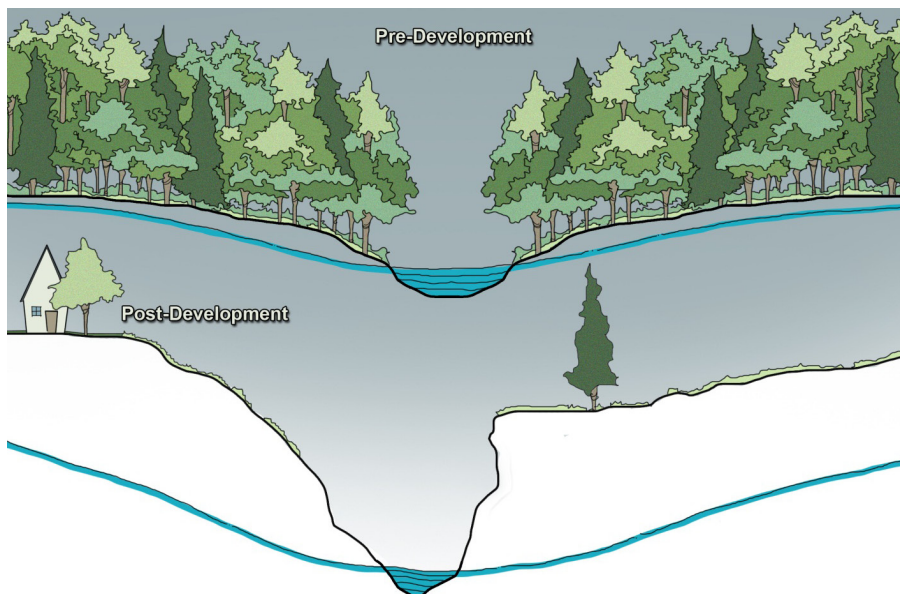
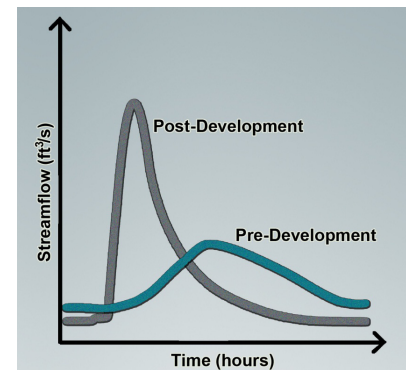


Figure 2. Stream-bank erosion and channel incision are common in urbanizing landscapes.

Hydrograph

A hydrograph is a chart that shows the change in discharge or flow over time. When rain falls on a watershed, some of the rain infiltrates into the ground and some undergoes evapotranspiration. The remainder becomes runoff.



Urbanization directly affects the amount and the rate at which runoff reaches a stream. Prior to development, most of the rainfall soaked into the ground. Relatively little runoff reached the streams, and what did required a longer travel time or time of concentration. Smaller runoff volumes and longer times of concentration meant that the water level in the streams rose slowly and did not get that deep. The hydrograph now has a long peak and is elongated.

Following development, more runoff is produced as impervious areas allow little rainfall to soak into the ground. Downspouts, curbs, gutters and pipes quickly transport stormwater to streams. The combination of more runoff and faster delivery of this runoff to streams results in what is called a peaked hydrograph. Water level in the streams rises quickly and becomes deep.



Figure 3. Many urban streams have high levels of pathogens, which pose a hazard to human health.



Figure 4. Excess nutrients and high temperatures promote bacterial growth and algal blooms.

Conventional Stormwater Management

The goal of conventional (gray) stormwater management techniques is to rapidly route runoff from impervious areas to receiving water bodies. Curbs and gutters are used to direct runoff from roof tops, parking lots, streets and the like into a series of underground pipes called the storm sewer. The storm sewer carries the collected and untreated runoff mostly to streams but sometimes is sent to reservoirs and lakes. To handle to this runoff, some streams were enlarged and concreted.

Conventional stormwater management techniques also give little consideration to improving runoff water quality. Generally,

no barriers exist between the pollutant source, such as fertilizers from lawns or heavy metals and hydrocarbons from parking lots, and the receiving water body. In some cities, the storm sewer was combined with the sanitary sewer. The sanitary sewer is the pipe network that carries water from devices such as toilets, showers and washing machines to the municipal water treatment plant. The problem with this design is that during storm events, more water is sent to the municipal water treatment plant than it is capable of treating. When the capacity of the municipal water treatment plant is exceeded in such an instance, water—both stormwater and sewer water—is sent into the streams untreated. Such an event is called a combined sewer overflow (CSO).



Figure 5. Conventional stormwater management is designed to collect and rapidly convey runoff to streams, some of which have been lined with concrete because they eroded so badly.

Stormwater detention basins

Stormwater detention basins may be used to collect and hold runoff in order to release it at a more controlled rate. These basins are designed to reduce the post-development peak flow so that it matches the pre-development peak flow. However, post-development runoff volumes are not reduced, just the peaks. The large runoff volumes are released from the basins over a long period of time meaning streams experience these larger flows for a much longer time than normal. Because of this, streambank soils are weakened and streambank erosion is common.



A stormwater detention basin near a shopping center in Lexington, KY.

LID Philosophy

Low impact development (LID) or green infrastructure is a management approach that seeks to reduce runoff and associated pollutants by managing them at the sites where they are generated. LID is focused on controlling stormwater at the individual lot level unlike conventional stormwater management which uses a large control structures at the outlets of watersheds. This means that with LID numerous small control structures are spread throughout the watershed. Instead of trying to control runoff from large, rare storm events, LID focuses on controlling runoff from the small storms, which comprise the majority of the average annual rainfall.

To control runoff, LID primarily seeks to increase infiltration and evapotranspiration rates within the watershed so that the post-development hydrology matches the pre-development hydrology as closely as possible. LID accomplishes this primarily by:

- Minimizing or reducing the total amount of impervious area in a watershed
- Protecting hydrologically sensitive areas
- Minimizing directly connected impervious areas
- Planting more vegetation

When it comes to stormwater, the basic tenants of LID are to spread treatment throughout the watershed, slow down the movement of runoff, and allow stormwater to soak into the ground. In addition to managing hydrology, LID also seeks to improve runoff water quality by utilizing the ability of soils and vegetation to remove pollutants.

LID Techniques

Low impact development techniques are divided into two types: resource preservation and structural controls. Resource preservation seeks to protect the hydrologic and water quality characteristics of an undeveloped site to the maximum extent possible. Such activities include protecting riparian buffers (see later section) and soils with the ability to infiltrate rainfall quickly, using fewer fertilizers on lawns and fields, and picking up trash and pet waste.

Structural controls are designed to decrease runoff volume by increasing infiltration and evapotranspiration. In LID, stormwater is routed to these controls where it is held so that infiltration can occur. By allowing stormwater to infiltrate, both

Curve number

The U.S. Department of Agriculture Natural Resource Conservation Service (formerly the Soil Conservation Service) developed the curve number (CN) method to model the amount of rainfall that becomes runoff for a watershed. In this method, the CN accounts for the effects the watershed's land use and soils have on generating runoff. For example, land that is pastureland generates less runoff than land used for parking lots. Likewise, some soils have high rates of infiltration while others only allow water to infiltrate slowly.

CNs can range from 30 to 100. Lower CNs mean less rainfall becomes runoff while higher values mean more runoff is generated. A CN of 100 indicates that all rainfall becomes runoff.

To promote infiltration, LID seeks to reduce the CN by decreasing the amount of impervious area in the watershed and protecting hydrologically sensitive areas. These hydrologically sensitive areas include streams, riparian buffers, floodplains, wetlands, steep slopes, and highly permeable soils. Protecting highly permeable soils or those soils that allow a lot of water to infiltrate quickly is an important method for reducing runoff. Unfortunately, protection of such soils is rarely done.

Time of concentration

The term "time of concentration" is defined as the time it takes for a drop of water to travel from the most hydrologically remote location in a watershed to the outlet. In other words, how long does it take for a drop of water that falls at the most distant point in the watershed to travel to the outlet?

What is important about time of concentration is that it is used to determine peak discharge. Runoff that travels quickly to the outlet means the peak discharge will happen quickly. When a watershed undergoes development, the time of concentration is reduced largely because of conventional stormwater management methods. Not only is more runoff produced because the watershed CN is increased, but curbs, gutters and pipes quickly route the stormwater to the watershed outlet.

A fundamental goal of LID is to increase the time of concentration by disconnecting impervious areas. For example, instead of rainfall from a parking lot being directed to curb inlets to enter the storm sewer system where it is quickly routed to a stream, LID would encourage infiltrating the rainfall onsite. This means that none or very little rainfall enters the storm sewer system.

runoff volumes and peaks are reduced and stormwater quality is improved. When using structural controls, it is best to start in the headwaters of a watershed as controls located in these areas are more effective at protecting streams than controls located at the watershed outlet.

When designing a LID-based stormwater management plan, a number of structural controls that use the LID philosophy are available. These controls vary in size and complexity from small ones suitable for a residential lot to large ones typically used by developers, commercial businesses, and governments. This publication will examine a few of the more commonly used ones.

Rain Gardens

Rain gardens are shallow depressions that use a conditioned planting bed (media mix) and landscaping to filter stormwater. Rain gardens are typically designed to capture runoff from a 1-inch storm event and infiltrate the rainwater within 24 to 48 hours. Rain gardens can be planted with trees, shrubs, grasses, and/or flowers (Figure 6). When choosing vegetation for a rain garden, it is important to use native vegetation. Native vegetation is acclimated to the local climate and does not require excessive maintenance to survive. Because rain gardens undergo periods of drought and inundation, it is also important to choose plants that can withstand these conditions.



Figure 6. Rain gardens may contain trees and shrubs, such as this one at the Coca-Cola Bottling Facility in Lexington, Ky.

Rainwater Harvesting

Rainwater harvesting is one of the simplest and oldest LID techniques. With rainwater harvesting, rainwater from roof tops and other impervious areas is collected and stored in rain barrels or even cisterns for future use (Figure 7). In some cases, excess rainwater is redirected from the rain barrel to a rain garden. Collected rainwater is often used to wash automobiles, irrigate or flush toilets. Harvested rainwater is not potable so it is not safe to drink.

Riparian Buffers

Riparian buffers are vegetated areas adjacent to streams. Typically comprised of three vegetation zones, riparian buffers provide many benefits to stream systems (Figure 8). The roots of riparian vegetation help hold streambank soils in place, protecting the banks from high flows, and thereby reducing erosion. Riparian vegetation provides the stream with shade which helps control temperature and algal growth while improving dissolved oxygen levels. Leaves and twigs from riparian vegeta-



Figure 7. Rain barrels are ideal for collecting rain water from roof tops for future use.

tion provide aquatic organisms with a source of food while birds and animals consume fruits and nuts produced by the plants. Riparian buffers also improve stream water quality by filtering sediment, nutrients and other pollutants from overland flow.

The effectiveness of a riparian buffer is strongly linked to its width, and the required buffer width is strongly linked to topography, land use, hydrology, and the constituents of concern. If the buffer is too narrow, it will not meet the site objectives. For sediment removal, a buffer width of 25 feet may be sufficient but a width of 100 feet may be needed for nitrate removal. Socioeconomic factors will also play a role in determining the appropriate buffer width, particularly in urban areas.

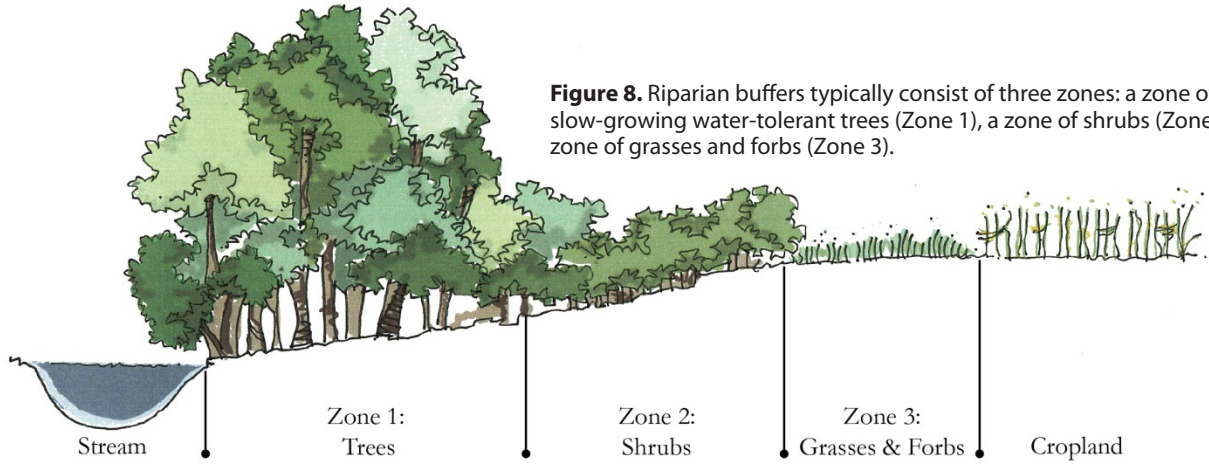


Figure 8. Riparian buffers typically consist of three zones: a zone of fast- and slow-growing water-tolerant trees (Zone 1), a zone of shrubs (Zone 2), and a zone of grasses and forbs (Zone 3).

Green Roofs

A green roof, also called a landscaped roof or rooftop garden, consists of a soil media and plants. These systems can be rather simple consisting largely of hardy groundcover plants such as sedums or more complex with a park-like setting (Figure 9). The simpler green roof design is called an extensive system while the more complex one is an intensive system.

Rainwater that falls on green roofs undergoes evapotranspiration, which reduces runoff volumes and peak flows. Evaporation combined with shading from the plants helps cool the roofs. Studies have shown that temperatures on green roofs are much cooler than the surrounding air temperature.

When designing a green roof, it is important to determine what type of additional structural support may be needed to support the extra weight. Extensive systems are lighter than intensive ones, and as such, require less additional structural support. Like rain gardens, native plants should be used. Vegetation on green roofs is exposed to the wind, sun, ice and other harsh conditions with little or no relief. Care must be taken to choose hardy plants.

Permeable Pavement

Permeable pavement is an asphalt or concrete paving surface specially mixed with fewer fine particles which creates more void spaces. In addition to continuous type surfaces, interlocking concrete or brick pavers are also used. Permeable pavement consists of a paving course, filter course, stone reservoir, and filter fabric layer (Figure 10). Water easily flows through permeable pavement and infiltrates the underlying soils. The common types of permeable pavement are pervious concrete, porous asphalt, interlocking concrete pavers, concrete grid pavers, and plastic reinforced grids filled with either grass or gravel.

Permeable pavement is most commonly used in parking lots, driveways, walking paths, residential streets, and other such locations where the traffic volumes are light. This LID technique is effective at reducing peak flows and total runoff volumes and has shown some promise at removing pollutants such as heavy metals and nutrients from runoff. Due to concerns over clogging, permeable pavement is not recommended for use in areas with high sediment loads.

Bioswales

Bioswales are shallow, wide, low-sloped channels, which are lined with vegetation or rock (Figure 11). Used in lieu of pipes, bioswales transport runoff to the storm sewer system or to receiving waterbodies. As such, bioswales are ideal for use alongside roadways or within parking medians. Bioswales are designed to promote infiltration by slowing down runoff. They also improve water quality via filtration and settling. The depth of flow should be less than the height of the vegetation or rock.



Figure 9. Green roofs, such as this one, help reduce runoff volume and reduce the building's energy usage.



Figure 10. Permeable pavement, such as these interlocking clay brick pavers, is ideal for light traffic areas such as parking lots.



Figure 11. Parking medians, such as this one at the Sanitation District 1 parking lot in Northern Kentucky, are ideal locations for bioswales. Photo courtesy of Jim Hansen of EcoGro.



Figure 12. Stormwater wetlands provide habitat for wildlife in addition to improving stormwater quality.

Stormwater Wetlands

Stormwater wetlands or constructed wetlands consist of shallow pools and rooted vegetation (Figure 12). In addition to the shallow pools, stormwater wetlands generally have two deep pools: one located at both the inlet and one at the outlet of the wetland. The deep pool at the inlet acts like a forebay allowing particulates to settle out of suspension. At the outlet, the deep pool helps prevent clogs by keeping vegetation from growing near the outlet.

Stormwater wetlands are effective at pollutant removal. Similar to natural wetlands, settling, filtration and biological uptake are the three primary methods for removing pollutants in stormwater wetlands. Stormwater wetlands also provide habitat though the level of biodiversity may be less than natural wetlands. While stormwater wetlands are similar to natural wetlands, it is important to note that natural wetlands should not be used for stormwater treatment. Routing stormwater into a natural wetland can alter its hydrology thus affecting the vegetation.

LID Concerns

One of the biggest concerns with LID techniques is the cost. Will it cost more to design, implement and maintain LID controls as opposed to using conventional stormwater methods? The answer is that it depends. Costs are site specific. Factors such as existing soil conditions, topography, land availability,

vegetation, stormwater control size and complexity, and desired maintenance level will drive costs. With regards to maintenance costs, vegetation management is usually the most costly item, so selecting low-maintenance vegetation is important. It is also important to prevent large sediment loads, such as those associated with construction activities, and litter from impacting LID controls. Sediment is the number one enemy of LID controls; it causes clogging and shortens the control's useful life. A forebay, which is a small, cleanable pool located at the inlet of the LID control, is often used to prevent incoming sediment and debris from clogging LID controls.

Summary

Stormwater management is an important issue for developing communities. While conventional stormwater management techniques are effective at routing stormwater from impervious areas to receiving water bodies, they are not effective at reducing runoff volume or improving runoff water quality. LID techniques, on the other hand, promote infiltration and evapotranspiration in an effort to reduce runoff volumes and improve runoff water quality. And unlike conventional stormwater management, which often uses a large control structure at the outlet of a development such as a shopping center or neighborhood, LID promotes the use of many small control structures spread throughout the watershed.

Resources

Stormwater Pollution Prevention

- Lexington-Fayette County Division of Water Quality: <http://www.lexingtonky.gov/index.aspx?page=665>
- Sanitation District No. 1 (Northern Kentucky): <http://sd1.org/>
- Louisville Metropolitan Sewer District: <http://www.msdlouky.org/>
- U.S. Environmental Protection Agency: <http://www.epa.gov/>

Resource Protection and Structural Controls (University of Kentucky Cooperative Extension Publications)

- Reducing Stormwater Pollution (AEN-106)
- Building a Rain Barrel (HEV-201)
- Riparian Buffer Planting (ID-185)
- Permeable Pavement (AEN-108)

References

- Claytor, R.A. and T.R. Schueler. 1996. Design of stormwater filtering systems. Center for Watershed Protection. Available at: http://mckenziewaterquality.org/documents/stormwater_filtration_system_design.pdf.
- Collins, K.A. W. F. Hunt, and J.M. Hathaway. 2011. Evaluation of various types of permeable pavements with respect to water quality improvement and flood control. Proceedings of the 8th International Conference on Concrete Block Paving, San Francisco, CA, pp. 129-39. Available at: <http://www.icpi.org/sites/default/files/techpapers/1301.pdf>.

- FISRWG. 10/1998. Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN3/PT.653.
- Hunt, W.F. 1999. Urban stormwater structural best management practices (BMPs). North Carolina State, North Carolina A&T State University Cooperative Extension. Available at: <http://www.bae.ncsu.edu/stormwater/PublicationFiles/UrbanBMPs1999.pdf>.
- Lexington-Fayette Urban County Government. 2009. Stormwater manual. Lexington, KY. Available at: <http://www.lexingtonky.gov/index.aspx?page=780>.
- U.S. Environmental Protection Agency (EPA). 2008. Reducing Urban Heat Islands: Compendium of Strategies, Chapter 3 Green Roofs. Available at: <http://www.epa.gov/hiri/resources/pdf/GreenRoofsCompendium.pdf>.
- U.S. Environmental Protection Agency (EPA). 2000. National Menu of Stormwater Best Management Practices. Available at: <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/>.
- Water Environment Federation (WEF), American Society of Civil Engineers (ASCE), and the Environmental and Water Resources Institute (EWRI). 2012. Design of urban stormwater controls: WEF Manual of Practice No. 23, ASCE/EWRI Manuals and Reports on Engineering Practice No. 87. McGraw Hill, Alexandria, VA.

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