Low Impact Development for Sustainable Development and Stormwater Management

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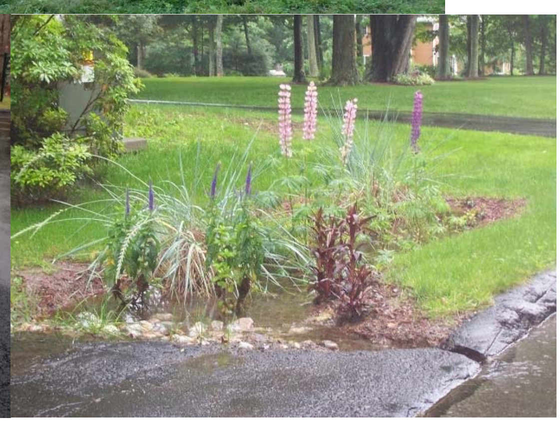

Introduction

The Clean Water Act (CWA) was adopted by the United States in 1972 to address point source discharges of pollutants into the many rivers and lakes in the United States. Over the 41 years, the CWA has had the desired result of restoring the water quality in these water bodies which were often so polluted that they were unsuitable for use by the public.

However, another problem soon became very apparent. While the discharge of pollutants from point sources was virtually eliminated to surface water systems due to the CWA, it was observed that many waterbodies were still being impacted by various types of pollutants. Based upon monitoring data, it was determined that the source of these other pollutants was diffuse and was not due to a point discharge. Ultimately, these discharges became known as non-point source discharges and were the result of rainfall washing accumulated pollutants off the many different types of impervious surfaces, such as building roofs, road networks, driveways, parking lots and even landscaped areas. The non-point source discharges were proving to be very difficult to identify, quantify and correct.

These pollutants were being discharged to streams, rivers, and lakes and over time, these water bodies were experiencing undesirable aquatic vegetation as a result of increased nutrient discharges, particularly phosphorous and to a lesser degree nitrogen. Populations of different aquatic species were being adversely impacted by the presence of metals and hydrocarbons in the water, which can be toxic even at very low concentrations. Additionally coarse and fine sediments was being deposited on the bottom of cold water streams preventing benthic organisms from reproducing and thus adversely affecting the entire aquatic food chain.

In addition to the water quality impacts, the approach to dealing with stormwater from developed sites caused a significant unintended consequence on small receiving streams. Starting in the late 1970's, the concept of peak rate reduction of post-development stormwater became the rule in many areas of the United States. It was simple enough in theory; reduce the peak rate of runoff for post-development conditions to the peak rate of runoff for pre-development conditions for a certain size rainfall event by using a detention basin to hold back and meter out the accumulated runoff over a longer period of time. "This is easy to do and will protect the environment", was the prevailing thought of regulators and developers of this approach.

What no one considered at the time was the fact that the small streams were now seeing increased durations of flow at the bank full flow condition. This was the result of the large detained volume of runoff being discharged over an extended time period, well past the end of the actual rainfall event. The impact of the increased volume of runoff was erosion of the stream channel banks with the resultant discharge of sediment farther down the stream channel or into a larger water body. The discharge of sediment created turbid water, which reduced the ability of sunlight to penetrate the water column resulting in other adverse aquatic impacts to plants and fish.

In the early 1990's, Prince Georges County in the State of Maryland started looking at solutions to the non-point source issue as the pollutant discharges into Chesapeake Bay were adversely affecting the blue crab population and the economic health of the many communities which depended upon the resources of Chesapeake Bay.

Larry Coffman, the Associate Director of Prince George's County, Maryland's Department of Environmental Resources, started looking for solutions to non-point source discharges. He began observing how natural environment systems such as woods and meadows handled rainfall. He and his technical staff of engineers also studied the rainfall events themselves and found that most of the annual rainfall events only generated a small of amount of rain within a 24 hour period. He realized that rainfall which occurred in these natural systems was attenuated in many ways by these systems. Leaves on trees intercepted rainfall preventing it was ever reaching the ground, the dense litter layer on the ground dissipated the velocity of the falling raindrop, preventing erosion of the soil surface and lastly, any runoff which made to the ground surface simply infiltrated into the soil or was taken up by vegetation on the ground surface. The rainfall which infiltrated into the soil was filtered through physical, chemical and biological processes within the soil. What a great system; reduce or eliminate runoff, filter runoff by infiltration through the soil and maintain the integrity of ecosystems. Could these natural processes be recreated to treat non-point source runoff? The answer was a resounding *yes*. When these observations were coupled with research by Dr. Robert Pitt of the University of Alabama for the National Urban Runoff Program on how pollutant loads were occurring on impervious surfaces, the framework for Low Impact Development (LID) was created.

What is Low Impact Development (LID)?

LID is an ecologically friendly approach to site development and stormwater management that aims to mitigate development impacts on the land, water and air. The LID approach emphasizes the integration of site design and planning techniques that conserve the natural systems and hydrologic function on a site. LID also embraces the philosophy that rainfall is a resource to be reused and recycled in the environment and not something to be gotten rid of.

LID works to manage rainfall at the source using uniformly distributed decentralized micro-scale controls. The primary goal of LID is to mimic a site's pre-development hydrology by using design techniques that infiltrate, filter, store, evaporate, and detail runoff close to its source, thus creating a site which demonstrates "Hydrologic Transparency". Hydrologic Transparency is defined as "The use of LID design strategies and stormwater treatment systems for a development scenario that yields hydrologic conditions matching or in extremely close proximity to the hydrologic conditions of the natural site prior to development".

In the past twenty-five years, the concept of LID and the various types of treatment systems have been the subject of research at Villanova University (http://www3.villanova.edu/VUSP/) under the direction of Dr. Robert Traver, North Carolina State University (http://www.bae.ncsu.edu/stormwater/) under the direction of Dr. Bill Hunt, University of Maryland (http://www.waterresources.umd.edu/) under the direction of Dr. Allen Davis, and the University of New Hampshire Stormwater Center (http://www.unh.edu/unhsc/) under the leadership of Dr. Tom Ballestero and the former director Dr. Robert Roseen to name a few of the predominant research facilities. The research conducted by these institutions have not only proved that the concept of LID works, but have refined the design standards and processes for the treatment systems to ensure long term functionality.

In addition to addressing stormwater quality and volume for small, frequent rainfall events, LID also includes strategies to minimize impacts of development on the natural land form. There are five tools in the LID tool box to address development patterns:

- Encourage Conservation Measures,
- Reduce Impervious Areas,
- Slow Runoff by using landscape features,
- Use multiple measures to reduce and clean post-development stormwater runoff, and
- Pollution Prevention

Each of these tools will be described in greater detail in the following section.

(1) Encourage Conservation Measures:

a. Implement Open Space or Cluster Development Regulations for residential development to preserve large portions of the site,

b. Implement “Site Fingerprinting” which defines a percentage of the parcel which may be cleared of vegetation. This reduces land clearing and minimizing disturbance of the native soils,

c. Minimize compaction of native soils during the construction process. If native soils are significantly disturbed, then amend the soils to restore the native infiltrative capacities.

(2) Reduce Impervious Areas:

a. Reduce the extent of directly connected impervious area on a site,

b. Reduce road widths for residential development without compromising access for emergency vehicles,

c. Consider using permeable pavement systems (Porous asphalt pavement, porous concrete, interlocking concrete permeable paver systems) for low traffic areas on a site,

d. Amend zoning standards to reduce the number of spaces required for various commercial land uses. Most parking requirements are based on a maximum requirement, which is only needed for a few times during a year,

e. While reducing the overall parking requirements for permanent spaces, utilize permeable pavement systems for overflow parking areas which will be used for limited time periods, such as the Thanksgiving to Christmas shopping season.

(3) Slow Runoff by using Natural Features:

a. Direct runoff from impervious areas such as building roofs onto vegetated areas, particularly undisturbed natural areas,

b. Maintain natural overland flow patterns for runoff to the maximum extent possible. This will slow runoff down and allow infiltration to occur,

c. Minimize the extent of structural drainage systems, such as curbing along roads, catch basins and underground piping,

d. Utilize non-structural conveyance systems such as grassed swales and/or stone lined swales along road systems,

(4) Use multiple measures to reduce and clean post-development stormwater runoff:

a. Install stormwater management systems at the point where runoff is actually generated from impervious areas (source control),

b. Utilize rain barrels to collect runoff from residential roofs for reuse as irrigation water for landscape beds,

c. Utilize Bioretention cells to filter and infiltrate overflow from residential rain barrels,

d. Install multiple stormwater treatment systems in series to better reduce pollutant loads found in non-point source runoff,

(5) Pollution Prevention:

a. Test the nutrients levels annually on a residential lawn and then only use a fertilizer which contains the deficient nutrient,

b. Prevent the over fertilization of residential lawns by applying more material than specified by the manufacturer of the product,

c. Minimize the application of sand and chloride compounds on impervious surfaces during winter operations,

d. Consider weekly sweeping of large open impervious parking areas to remove pollutants from the impervious surface.

In addition to the above concepts, land use regulations for residential development can be modified to result in more environmentally sensitive development patterns. Cluster development concepts which allow the reduction of minimum lot sizes while not increasing the density of the development allows for more of the site to be preserved in its natural condition. Front yard building setbacks can be reduced, which allow the homes to be placed closer to the street. This permits a shorter driveway, thus reducing impervious area. Another concept is the use of rear access alleys which place the primary vehicle access to the residences at the rear of the homes, allowing for more connected green space in the front of the residences, which in turn increases the feeling of community for the homeowners. In many cases, the rear alleys can be constructed with permeable areas to also function as a stormwater management system. This approach has been implemented in the Seattle area with great success.

Cluster development concepts when coupled with the application of Environmental Site Design (ESD) strategies yields development concepts which preserve large extents of undisturbed land while locating the development on the land most suitable for development. In the ESD approach, the existing natural resources on a site are identified and preserved to the Maximum Extent Practical. The primary natural resources include inland wetlands, watercourses, vernal pools, marshes, steep slopes and well drained soils. Secondary natural resources include upland buffer areas from wetlands & watercourses, unusual vegetative communities, and ridge lines.

Figures 1 and 2 below show the identification of sensitive environmental resources (wetlands, steep slopes, well drained soils, and vegetative communities) on a site in Connecticut. Figure 3 shows the final development plan which preserves over 60% of the site as dedicated open space. Another 16% of the woods will remain on the individual lots through the implementation of site fingerprinting, which limits clearing on each lot by specifying a percentage of the area that can be cleared. The limit of site fingerprinting is flexible, so that it can move in the field, but the percentage of clearing remains fixed. By the preservation of these resources, other environmental benefits are realized, such as the sequestering of carbon in the vegetation and undisturbed soils. Green vegetation, both woody and herbaceous will also absorb carbon dioxide and give off oxygen as a result of photosynthesis.

From a hydrologic standpoint, the preservation of 50% or greater of a site in its natural condition helps reduce and can prevent changes to the hydrologic cycle. When the preservation is coupled with using LID systems to infiltrate runoff from impervious areas at the source, peak rate attenuation requirements will be significantly reduced.

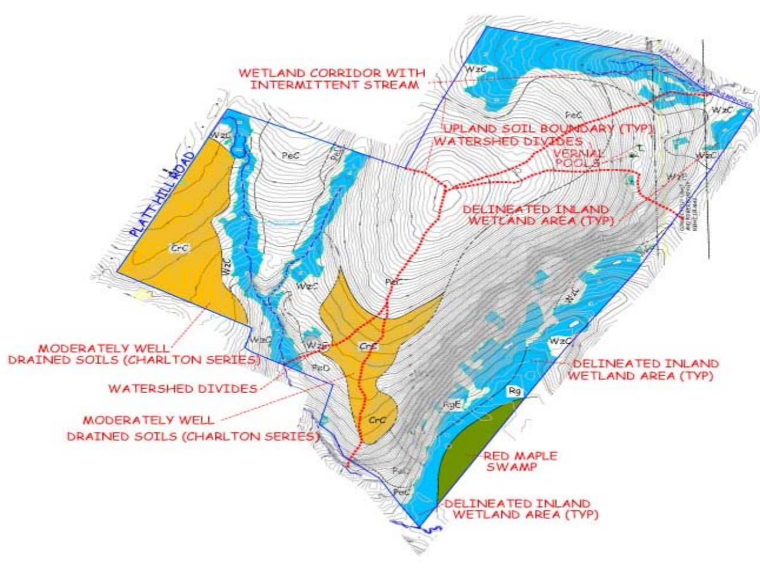

Figure 1 - Identification of Wetlands & Soil Types

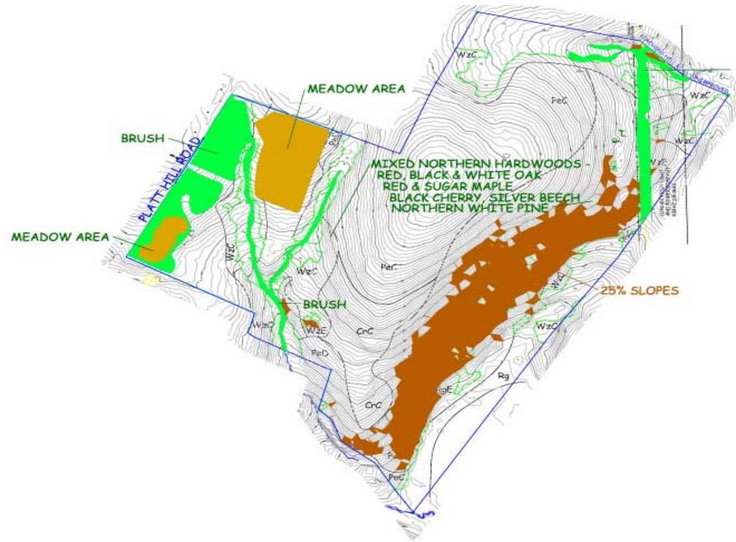

Figure 2 - Identification of Steep Slopes & Vegetation Communities

Figure 3 - Final Site Plan

LID Hydrologic Parameters

LID is a performance based upon to stormwater management which is in direct contrast to the prescriptive approach used to design stormwater management systems over the past 35 years. From a stormwater management perspective, the focus of LID is on what is termed the "90% storm event". This is the amount of rainfall which occurs over 24 hours and storms this size and smaller that constitute approximately 90% of the total annual rainfall for an area.

While the size of the 90% storm event varies geographically, it is generally 2.5 cm (1.0”) of rainfall in 24 hours in the United States. In Arid regions, the 90% rainfall event may only be 0.3” or less.

Another issue with current stormwater management is that it does not address runoff volumes which are responsible for many adverse impacts to small stream morphology. The implementation of LID is to mimic the natural infiltration rates for the 90% storm event for the different soil types. Sandy soils will infiltrate most, if not all of the 90% event, while a clay soil will infiltrate very little. By locating LID treatment systems throughout a project site, pre-development infiltration rates can be maintained so that the developed site will act like the natural site from a hydrologic standpoint for the 90% storm event. By mimicking the natural environment, surface runoff volumes are reduced, which minimizes the risk and extent of flooding from these small rainfall events.

In addition to matching pre-development infiltration rates, LID systems will reduce pollutants loads by filtering the runoff through vegetative and soil systems. Sediments are easily trapped on the ground surface in swales, filter strips and Bioretention systems. Native vegetation planted in these system will uptake both water and nutrients in the stormwater, thus further reducing pollutant loads as well as reducing runoff volumes. Water taken up by the plants is transpired back to the atmosphere during photosynthesis.

Types of LID Treatment Systems

The most commonly used LID treatment system is the Bioretention system. A Bioretention system is a depressed landscaped area with a specified soil media which is planted with native grasses, perennials or shrubs. Runoff from the first 1” of rainfall is directed to the Bioretention system and the runoff will temporarily pool in the depression and then infiltrate into the native soils. Pollutants found in the runoff are reduced by the physical, chemical and biological processes of the soil and plants in the Bioretention system. Metals and hydrocarbons from in stormwater have an affinity to attach themselves to sediment particles, so if sediment being trapped in a Bioretention system, so were these pollutants. Nutrients, both in soluble and particulate forms are taken up by the vegetation for growth purposes.

Figure 4 - Bioretention System (Trinkaus Engineering, LLC)

A variation of the Bioretention system is the Bioswale (aka Linear Bioretention or Dry Swale). A Bioswale can be used along roadways to convey and filter runoff just like a Bioretention cell. A key design aspect of all types of LID infiltration systems is obtaining a comprehensive soil evaluation in the area of the proposed system. The types of soil must be identified as well as potential limiting factors such as the depth of groundwater or bedrock. In addition, infiltration testing is required of the soil layers at or below the bottom of the Bioretention facility to ensure that a minimum infiltration rate of 1.25 cm/hr (0.5"/hr) is obtained.

LID infiltration systems can be installed in soils with infiltration rates slower than 1.25 cm/hr.; however the design must be modified to address the slower infiltration rate by increasing storage volume or adding an underdrain to the system.

Figure 5 - Bioswale (Trinkaus Engineering, LLC)

There are many types of permeable pavement systems that can be used to reduce impervious areas, reduce runoff volumes and provide water quality improvement. If the soil conditions are not adequate to fully infiltrate the runoff from the 90% storm, then a filter course, consisting of a well graded sand and gravel must be included in the base material of the pavement section to provide the water quality benefit. Figures 7 and 8 show different types of permeable pavement systems which can be utilized for low traffic applications.

In addition to Bioretention, Bioswales, and permeable pavement systems, other LID includes Wet Swales, Vegetated Filter Strips, Vegetated Level Spreaders, Tree Filters, Infiltration Basins and Trenches, Surface Sand Filters, and subsurface gravel flow wetlands. All LID systems can be modified for use in highly urbanized areas to primarily address water quality issues as infiltration is often not feasible or desirable in highly urbanized areas.

Figure 6 – Porous Concrete (at left), Paver Stones with Gravel Infill (at right)
(Photo by S. Trinkaus of Cincinnati, Ohio LID Demonstration Project)

Figure 7 – Paver Bricks with Coarse Sand Infill (at left) and Ornamental Pavers with Stone Infill (at right)
(Photo by S. Trinkaus of Cincinnati, Ohio LID Demonstration Project)

Figure 8 - Permeable Pavement & Standard Pavement during rainfall

LID Applications in the United States

In the United States, there are certain areas where LID has generally been embraced by the regulatory community, designers and most importantly the public. However, we are still experiencing resistance to the implementation of LID in other areas due to a lack of knowledge and education about the adverse impacts of stormwater on our environment. Public education and outreach to all of the stakeholders in the development process is extremely important to overcoming resistance to LID and to facilitate the widespread acceptance and implementation of LID approaches on a local, regional, or national basis.

While the concept of LID is fairly simple, there have been many issues with proper functioning of the systems over both the short and long term. These issues can be attributed to several major factors, an inappropriate design, missing or unclear construction specifications and details, lack of oversight during the construction process and contractors that are not familiar with the installation of LID systems. When LID systems are constructed in public locations which do not function properly, it increases the public resistance to LID which is very difficult to overcome.

Public education about LID systems can help shape positive opinions of LID. One of the best approaches is the creation of a LID demonstration project. The city of Cincinnati, Ohio sewer authority in conjunction with other groups created a standalone LID demonstration project on a site of a former gas station. The site showcases many types of permeable pavements, green roofs, rainwater harvesting and a bioswale. Simple, but engaging signage throughout the site explains issues with stormwater and how these LID systems can address them. This type of project allows the public to see how these systems work and understand the importance of addressing stormwater in an environmentally friendly manner.

LID is easy to apply for new developments as there is inherent flexibility when working with vacant land. LID strategies can consist of the following: Environmental site design, Site fingerprinting, impervious area disconnection, Vegetative filter strips, Bioretention systems or rain barrels for roof runoff and Green roofs. There are many LID tools available to create sustainable projects.

Addressing stormwater volume and water quality issues in the urban environment are more challenging, but can be addressed by the creative application of LID. While there are typically many potential barriers to LID in the urban environment, such as space constraints, utility conflicts and urbanized (disturbed & compacted) soils, these barriers can be overcome to implement LID. Infiltration systems such as Bioretention and Permeable Pavers can be designed with underground storage systems to account for slow infiltration rates.

The City of Portland, Oregon (http://www.portlandoregon.gov/bes/34598) has pioneered the implementation of LID in the urban environment by the creation of "curb bump outs" which locate Bioretention systems along the gutter line of a street. LID planters are Bioretention systems installed in a portion of a sidewalk to not only treat stormwater, but create more "green space" in the urban area. Water quality improvement is the primary goal for the implementation of LID in an urban area as the disturbed soils are generally not suitable for infiltration. Permeable pavement systems can be utilized for on-street parking lanes to reduce the impervious area.

A common misconception about LID is that the treatment systems are expensive to construct and maintain. This has been proven to be false. LID treatment systems have been shown to be less expensive to construct and maintain when compared to Conventional stormwater management systems, such as catch basins and pipe and standard detention systems. While the installation of Permeable Pavement is more expensive than standard pavement, a cost saving is still realized because no Conventional drainage systems are needed when Permeable Pavement is used. On average, the use of LID treatment systems will result in an infrastructure cost saving of 10 – 30% over Conventional designs. In urban areas, the cost saving may not be as high due to the more site constraints, but the improvement of water quality is well worth the cost.

The cost and installation for LID systems, particularly permeable asphalt and porous concrete are high at the current time, but these higher costs a simply a reflection of it being a new system and both manufacturers and installers are conservative in their pricing. Economies of scale also come into play, the larger the area, the lower per unit price will be. As contractors become more comfortable with the installation of LID systems, the costs associated with the installation will be reduced, thus end users will see further reductions in the cost of stormwater infrastructure.

The maintenance of Bioretention systems is not only simple, but is needed less frequently than in Conventional practices. Basically, Bioretention systems are depressed landscape areas, so weeding and the removal of leaves in the fall constitute the typical maintenance requirements. Depending upon the location of the system, accumulated sediment will need to be removed from the soil surface and can readily be done by hand once or twice a year. Maintenance of permeable pavement systems generally consists of cleaning on a quarterly basis using a regenerative vacuum truck at an annual cost of $ 1,200.

The Future of LID

More and more cities and towns are becoming subject to Municipal Separate Storm Sewer Systems (MS4s) requirements to address stormwater management as administered by the Federal EPA. The primary focus of the MS4 program is addressing water quality issues associated with stormwater runoff. This is particularly true in communities where there is a CSO system, which is subject to frequent discharges of untreated stormwater mixed with sanitary sewer water to receiving waterways.

Stormwater management in MS4 communities consist of structural collection and conveyance systems which often discharge directly into natural stream systems. LID stormwater management strategies, such as Bioretention, and Bioswales can be installed along roadways to intercept the runoff from the first inch of rainfall and provide filtering of the runoff to reduce pollutant loads. Infiltration from these systems may also be possible depending upon underlying soils, which will provide the added benefit of reducing runoff volumes. Where infiltration in not feasible, the treated runoff can be released back into the conventional drainage system. Permeable pavement systems can be used in urban areas for on-street parking aisles to also provide treatment of runoff, similar to a Bioretention system. The permeable pavement systems for parking areas can be sized to treat runoff from the adjacent impervious areas also, thus further improving the quality of the runoff. As the use of LID will become more common place and will lead to more sustainable development and positive environmental outcomes.

LID concepts have worldwide appeal and are being implemented in different parts of the world. South Korea is embracing LID and Pusan National University is currently constructing a state of the art research facility for LID concepts to further the academic and practical knowledge of how LID work in different environmental conditions. In England, these concepts are known as “Sustainable Urban Drainage System” (SUDS). In Australia, it is commonly called “Water Sensitive Urban Design” (WSUD), while in China it is called Sponge City/LID.

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