Design Principles and Case Study Analysis for Low Impact Development Practices

- Green roofs, Rainwater Harvesting, Vegetated Swales

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Abstract

Design Principles and Case Study Analysis for Low Impact Development Practices - Green Roofs, Rainwater Harvesting and vegetated Swales
- Shalini ramesh

This thesis on Low Impact Development (LID) Practices provides design guidelines and principles for three important LID practices: green roofs, rainwater harvesting and bioswales. The most important component of the thesis is the qualitative analysis of various case studies based on the LID objectives drawn from the literature review for each LID practice.

Through the course of my research, I found that there was no one single source which provided information on the design guidelines accompanied by case examples which could help the designer with built examples where the LID practices have been executed. Therefore, developing this thesis document which provided all this information started as my masters thesis project. The document is designed to be used by people with a variety of expertise like landscape architects, landscape contractors, engineers and clients.

The manual is organized into five chapters. The manual details the process of stormwater management and then gradually leads to the evolution of Low Impact Development Practices and detailing out three important LID practices: green roofs, rainwater harvesting, vegetated swales and briefly about infiltration systems. The LID principles outlined in this manual were developed over the last few years to address runoff issues associated with the new residential, commercial and industrial suburban developments. Information to develop this manual has been drawn from numerous sources like the Low Impact Design Strategies developed by the Prince George's County, Maryland, US EPA, Low Impact Development urban design tools and numerous other research papers.

It is my hope that the manual will provide adequate information to its users by not only providing design guidelines but also provide built examples through the case studies.

Adopt the pace of nature: her secret is patience

- Ralph Waldo Emerson

Acknowledgement

I would like to express my gratitude for my advisor Dr. Patrick Miller, for his continued encouragement, excellent guidance and faith in me not only during my thesis but through the journey of my Master's Program at Virginia Tech. I would also like to thank Dr. John Randolph and Dr. Tamim Younos for their time, support and advice which helped me shape my master's research.

I would like to thank my family for all their support emotionally and financially during my stay at Virginia Tech.

How to use this document

This thesis document consists of five chapters (see table below). Section 1 gives an introduction to stormwater management, evolution of Low Impact Development (LID) practices and site design using LID practices. Sections 2,3,4, and 5 gives design specifications on four LID practices and technologies that can be included into the site development process to attain pre-development hydrologic conditions. Keeping in mind the project objectives, site designers should explore the application of either an individual practice or a combination of practices. For instance, planning for a residential community and protecting of water resources on the project site may involve both stormwater and waste management technologies. Therefore, developers and site designers can first learn the objectives of LID (Section 1) and identify practices and technologies and review case examples (Section 2-6) for better understanding of the application of the practice. This helps in maximizing the project economic and environmental goals.

Chapter 1: Stormwater management	- Evolution and types of stormwater management practices - Low impact development site planning - Rating systems and LID
Chapter 2: Green roofs	2.1: Design and technical specifications 2.2: Case study details and analysis
Chapter 3: Rainwater harvesting systems	3.1: Design and functioning of a rainwater harvesting system 3.2: Case study details and analysis
Chapter 4: Vegetated swales	4.1: Design and grading of a vegetated swales 4.2:Case study details and analysis
Chapter 5: Infiltration systems	- Design objectives and guidelines for: * Infiltration trenches * Permeable pavements

Table 1: Overview of the document

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Chapter 1: Stormwater Management

The Hydrologic Cycle:

The natural hydrologic cycle is simply the constant exchange of water between the atmosphere and the ground in the form of precipitation and evapotranspiration. When precipitation comes down in the form of rain or snowfall, it finds its way downhill if not infiltrated. Foliage intercepts and disperses the energy of raindrops, protecting the ground surface by lessening the rainfall's erosive force. Healthy, vegetated soils slow precipitation down, allowing water to soak in or infiltrate. Un-intercepted precipitation is called stormwater runoff.

The movement of stormwater depends on:
1. Path of movement
2. Slope of site
3. Surface type on which precipitation falls
4. Duration and intensity of storm

In the process of urbanization, areas of forest, agricultural and grassland soils that once permitted water hitting their surface to infiltrate, are covered with roofs, concrete or asphalt, it becomes lawn, an often nearly impervious surface where underlying soils are compacted by heavy equipment during the construction process. Engineers have designed and built complex infrastructures to collect stormwater and transport it to streams and rivers, where it is discharged. This, however, raises several important issues relating to stormwater. They are: cumulative effect of creating even more impervious surface and removal of stormwater quickly from the sites, the resulting water quality and its effect on one stream and river.

The effects of urbanization on increasing stormwater runoff require addressing management on several scales simultaneously - project scale, watershed scale and global scale.

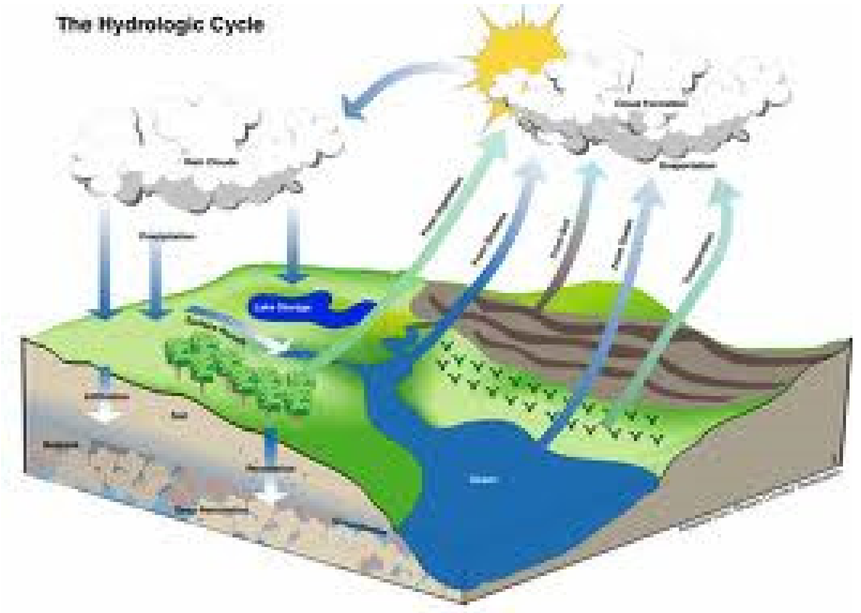

Figure 1.1: The hydrologic cycle
(Source: www.h2owell.com, 2011)

The vicious cycle:

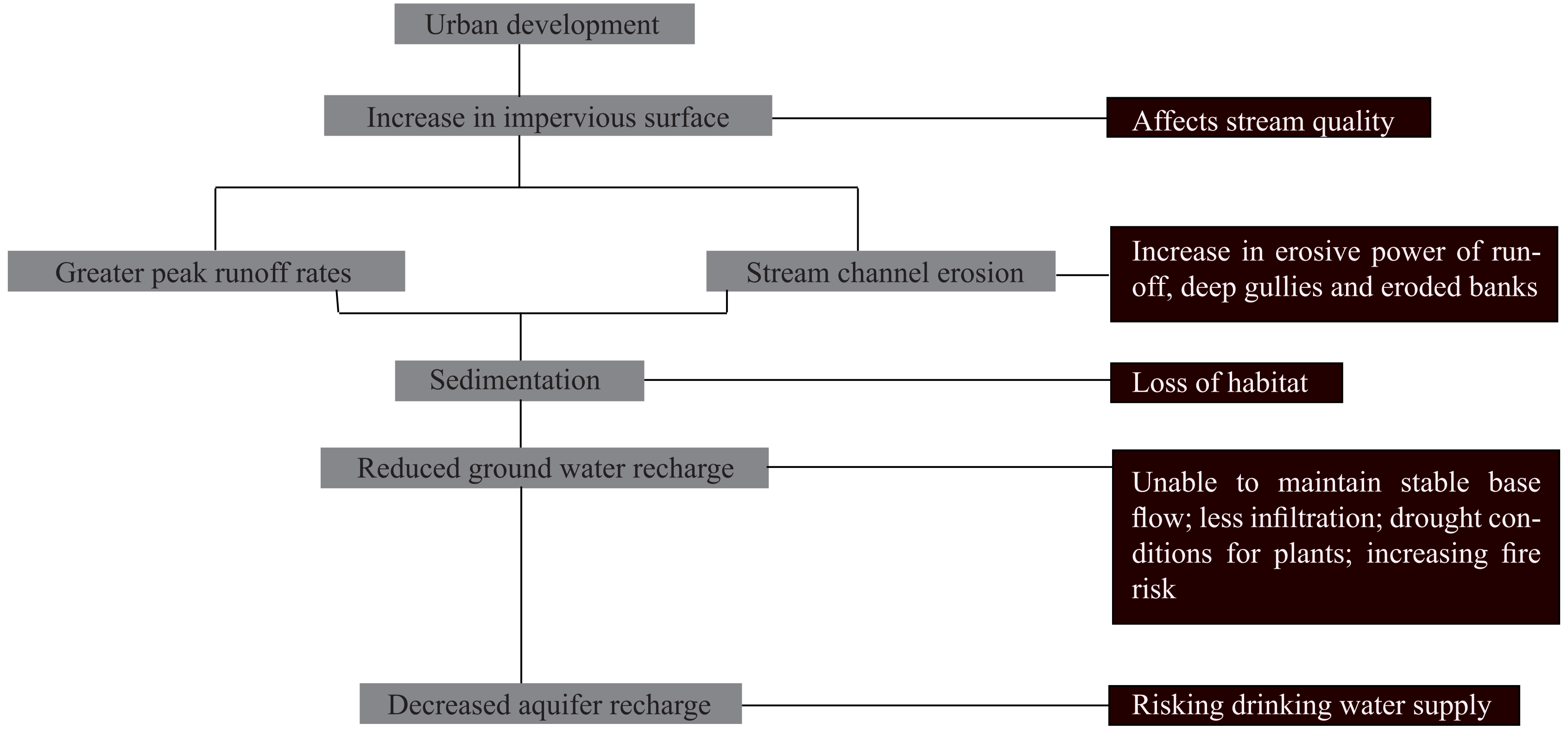

Figure 1.2: Flow chart representing runoff effects
(Source: Author)

In areas where the water reside in the soils, soils become saturated closer to the surface, decreasing the soils bearing capacity and resulting in earth slides. In addition, petrochemicals, salt and sand also lead to polluted runoff.

Evolution of stormwater management

During the 1960's, the City of Milwaukee, Wisconsin, had a large influx of immigrants which increased its population to nearly 750,000. Due to this increase and also due to its ease of access to Lake Michigan, Milwaukee's Menomenee Valley Region emerged as a home to many industries like manufacturing, stockyards, rendering plants, shipping and other heavy industries.

By the late 1990's, the available jobs in the region dropped to less than 7000, which gave rise to high rates of unemployment. This resulted in negatively impacted economy for the valley's neighborhoods. One such industry which lost business and closed down was the Milwaukee Road shops and facilities. This left a dozen of vacant and dilapidated buildings and acres of contaminated land. The redevelopment authority of Milwaukee acquired this property in 2003 and implemented redevelopment strategies like demolish, remediate and construct new infrastructure on the site. The main highlights of the redevelopment project were the centralized stormwater management facility - *"The Stormwater park"* that services 70 of its 100 acres.

A master plan for a new industrial and recreational development was proposed for the Menomonee Valley Industrial Center and Community Park (MVIC)

Figure 1.3: Hydrologically functional landscape
(Source: www.werf.org/livablecommunities, 2011)

Types of stormwater management

Centralized Stormwater Management

Centralized municipal stormwater basins are built to control the peak flow from the development site and water quality improvement is carried out through the settlement of pollutants in the detention basins *(DOD 2004)*. The centralized approach efficiently transports runoff through directly connected curbs, gutters, roadways and pipes and then collects the runoff at a centralized facility. Multiple stages of outflow structures are used at the detention facility to control the outflow at the pre-development level *(VDCR 1999)*. Though centralized systems are successful in reducing peak flow rate to the pre-development conditions, it is ineffective in reducing flooding beyond some point downstream due to the aggregated increase in volume.

The centralized approach was feasible on a lot by lot basis which was the development design prior to 1945. Every feature of a conventionally developed site is carefully planned to quickly remove runoff to a centrally located management device, usually at the end of a pipe system. Roadways, roofs, gutters, downspouts, driveways, curbs, pipes, drainage swales, parking and grading are all typically designed to dispose of the runoff in a rapid fashion *(Prince George County 1999)* . The cumulative effects of such approaches have been a major cause of increased flooding, often accompanied by diminishing groundwater supplies, as a direct result of urbanization, or have necessitated development downstream engineering works to prevent flood damage.

Distributed Stormwater Management

Rapid urbanization, aging infrastructure, increased climatic variations and need for enhanced sustainability of urban water resources pose significant challenges to conventional stormwater management. Advanced stormwater measures are required to mitigate the risk of flooding and pollution. They are also required to protect the aquatic ecosystem and enhance the beneficial uses of urban waters. It is true that no single measure can address all urban water issues. A multi barrier approach which includes innovations on the property level, neighborhood level and watershed level proves to be the most effective in addressing the urban water issue. A newer approach is to focus on the green water components of the hydrologic cycle, which aims at intercepting, infiltrating, detaining and evapotranspiring as much of the rainfall possible, rather than conveying surface runoff into pipes and streams *(Ellis 2008)*.

Some of the stormwater management practices on the property level consist of harvesting roof runoff and re-using water, managing rainwater by infiltration in swales and into soils in bioretention areas, minimizing impervious surfaces and using pervious pavements.

Low impact development site planning concepts

In order to achieve a successful and workable plan using Low Impact Development technology, there are few site planning concepts which guides the initial site design. These fundamental concepts include:

1. Using hydrology as the integrating framework
2. Thinking micro management
3. Controlling stormwater at the source
4. Using simplistic, non structural methods
5. Creating a multifunctional landscape

Using Hydrology as the integrating framework:

With the application of low impact development techniques, site drainage is intended to mimic the natural drainage functions. In this, care is taken not to drain the site rapidly and efficiently as was done with conventional stormwater methods. The LID method relies on various planning tools and control practices to preserve the natural hydrologic functions of the site. When analyzing the site hydrology, questions which need to be addressed are: What are the essential pre-development hydrologic functions of the site and how can these essential functions be maintained while allowing full use of the site?

LID allows for a hydrologically functioning landscape, distributed micro management practices and minimizes impacts. Implementation of LID strategies helps maintain infiltration capacity, storage and longer time of concentration of the site. LID helps in protecting sensitive areas like buffers, floodplains, wetlands, steep slopes, high permeability soils and woodland conservation from development. Some of the LID practices used to restore sites to pre development hydrologic conditions are bio retention areas, increased flow paths, infiltration devices, drainage swales, retention areas and cisterns.

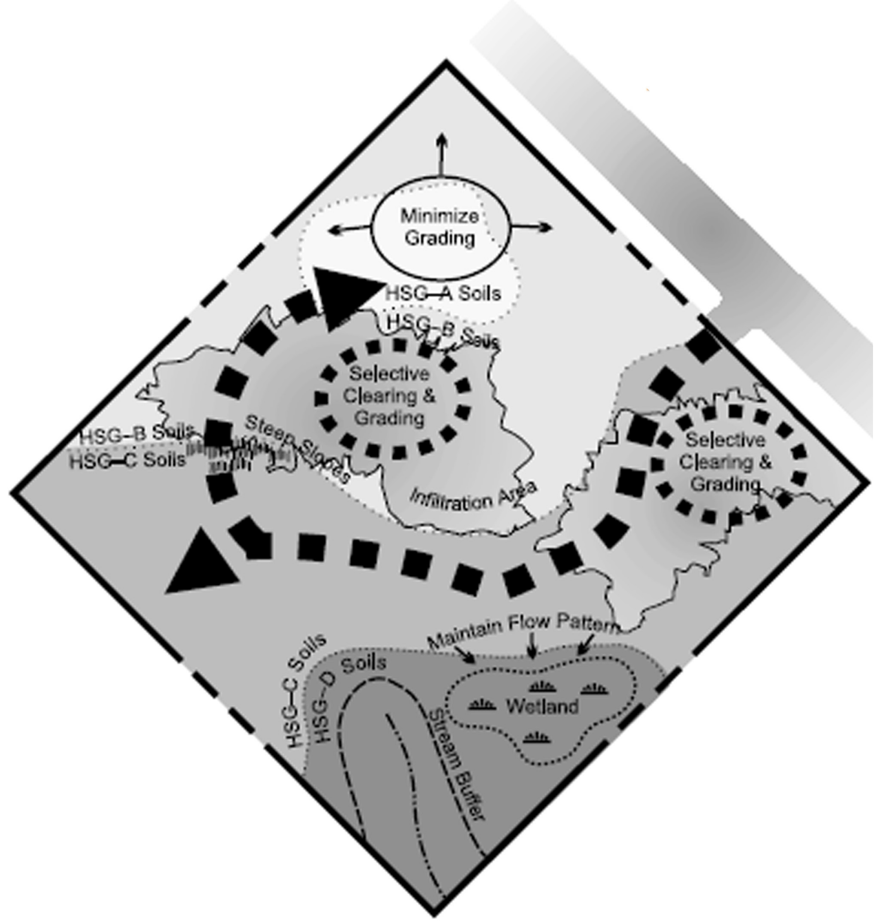

Figure 1.4: Hydrologically functional landscape

(Source: Prince George's County, 1999)

Low impact development site planning concepts

Think micro management:

LID concepts work efficiently when the site is addressed as smaller pockets of land instead of a large piece of land. Micro management techniques implemented on small sub catchments, or on residential lots as well as common areas, allow for a distributed control of stormwater throughout the entire site. The micro management techniques used in LID site design is referred to as Integrated management Practices (IMP's). Other advantages of micro management include:

- Provide greater range of control practices that can be used and adapted to site conditions
- Allow use of control practices that can provide volume control and maintain pre-development groundwater recharge functions
- Allow on-lot control practices to be integrated into the landscape, impervious surfaces, and natural features of the site.
- Reduce site development and long-term maintenance costs through cost-effective designs and citizen participation and acceptance

(PGCM, pg 2-3, 2-4)

Controlling stormwater at the source:

One of the easiest ways of restoring the pre-development hydrologic conditions is by treating stormwater at the source of generation. When using conventional stormwater practices or end of pipe stormwater management, restoring hydrologic functions like interception, storage and infiltration is next to impossible. Therefore, using micro management techniques is one of the main goals of Low Impact Development practices.

Utilization of simplistic, non-structural methods:

Use of simple methods like rainwater harvesting, retaining vegetation have proven to be more effective in preserving the natural hydrologic functions of the site more than structural engineered systems. The planting bed (soil medium) itself provides infiltration of runoff, removal of pollutants through various processes like filtration and adsorption, groundwater recharge and evapo transpiration through plant material.

(Source: Prince George's County, 1999)

Low impact development site planning process

Site planning is a process which involves the organization of land use zoning, access, circulation, privacy, security, shelter, land drainage and other factors. The incorporation of Low Impact Development techniques. The incorporation of Low Impact Development technologies into this site planning process introduces a various new considerations to better mimic the site's pre-development and create a hydrologically functional landscape. The steps involved in this process are:

Step 1: Identify applicable zoning, land use, subdivision and other local regulations

- Zoning ordinances pre-designate the use and physical character of a developed geographic area to meet urban design goals. The zoning requirements are intended to regulate the density and geometry of development, specifying roadway widths, parking and drainage requirements and define natural resource protection areas.

Zoning Requirement	**Purpose**
Land use restriction	Separate residential, commercial and industrial uses and/or specify the percentage mix of these uses
Equal-sized or similarly shaped lots	Provide consistency among residential use or districts
Minimum lot sizes	Provide consistency among residential use or districts
Frontage requirements	Provide additional distinction among residential zones; access
Fied setbacks for front, back and side yards	Provide additional distinction among residential and side yards provide consistency among residential zones; control coverage by buildings
Road width	Ensure vehicular and pedestrian safety and avoid rights of way facility burdens
Road turnarounds	Prevent undue fire safety hazards; provide adequate fire safety vehicular access
Sidewalks and pedestrian walkways	Ensure vehicular and pedestrian safety and avoid access public safety burdens
Residential and commercial developments	Ensure vehicular and pedestrian safety and avoid access public safety burdens
Common or shared facilities	Prevent environmental or safety hazards from unmaintained facilities such as shared septic systems or driveways
Curbs/ gutters and storm drains	Prevent undue burden of development on off-site water, streets and buildings
Stormwater quality and quantity structures	Prevent undue burden of development on off-site water, streets and buildings
Grading to promote positive drainage	Prevent soil problems due to drainage

Table 2: Common zoning components
(Source: Prince George's County, 1999)

The LID site planning process recognizes that all LID approaches need to meet the local zoning requirements.

Low impact development site planning process

- By using LID practices a number of flexible zoning options can be used to meet the environmental objectives of a site without disturbing urban growth. These zoning options have additional environmental benefits over and above the conventional zoning. Alternative zoning options such as overlay district, performance zoning, incentive zoning, impervious overlay zoning and watershed based zoning allow for innovative design, site layout and design techniques.

Step 2: Define development envelope and protected areas

After the zoning code and regulations have been analyzed for the site, the next step is to analyze and prepare a development envelope. The development envelope demarcates the protected areas, setbacks, topographic features and existing sub drainage areas and other important site features unique to the site. Some of the site features that it is important to protect riparian buffers, floodplains, stream buffers, wetlands, important existing trees, woodlands, steep slopes, highly permeable areas and erosive soils.

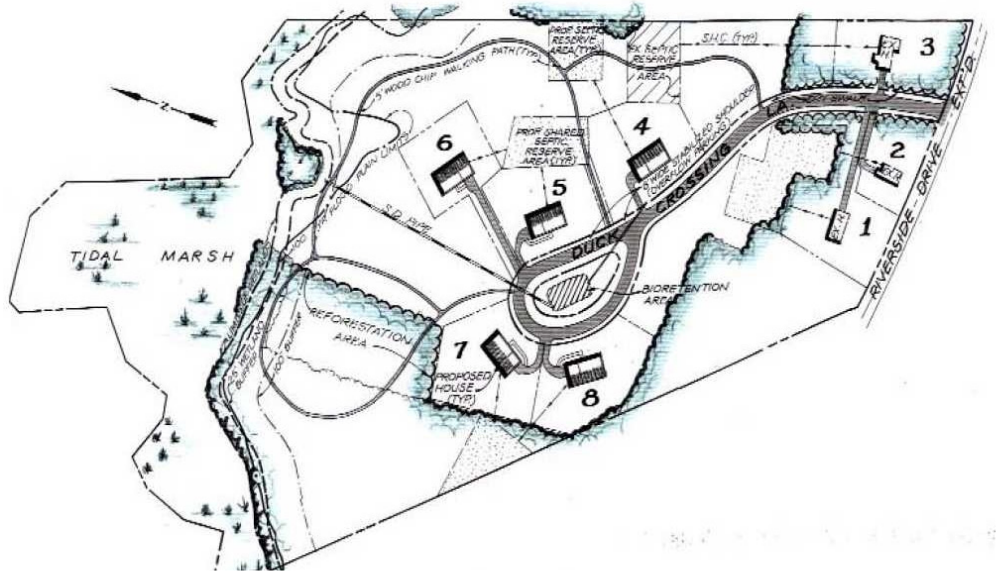

Figure 1.5: Development envelope with protected areas
(Source: www.eot.state.ma.us/smartgrowth, 2011)

Step 3: Reduce limits of clearing and grading

Clearing and grading of a site is limited to the area of the site where development occurs. The development area includes impervious areas, like roads, sidewalks, rooftops and pervious areas like graded lawns and open drainage systems. To minimize the hydrologic impacts on existing land cover, the area of development should be located in areas that are less sensitive to disturbance or have lower value in terms of hydrologic functions. It is best if the development is places outside the sensitive areas and the protected site areas.

Low impact development site planning process

Step 4: Use drainage/hydrology as a design element:

In order to design a hydrologically functional landscape, understanding of the site's hydrologic features is extremely important. With urbanization, there is an increase in the impervious area which directly increases the impacts on the receiving headwater streams. In order to reduce these impacts on the streams, LID site planning employs drainage strategies by carefully evaluating and analyzing the site's pre development conditions and mimicking the same.

Spatial organization of the site layout is also important *(Prince George's County, 1999)*. In the traditional stormwater method, pipe conveyance system was used which hid the water beneath the earth surface and addressed site topography as a separate entity. On a site which uses LID strategies, the landform and the site hydrology is treated together this creates a more aesthetically pleasing relationship to the natural features of the site.

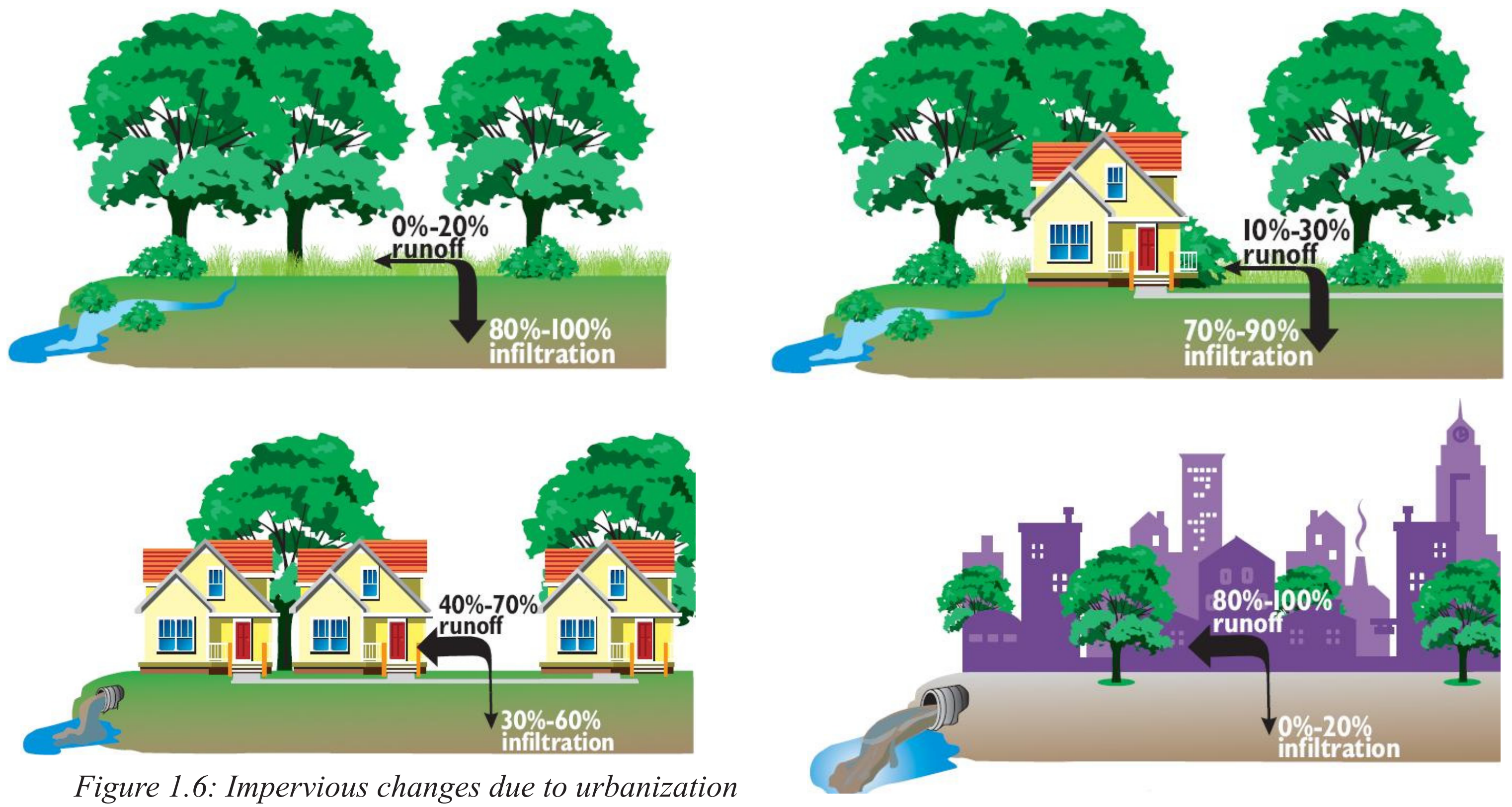

Figure 1.6: Impervious changes due to urbanization
(Source: Public domain)

Low impact development site planning process

Step 5: Reduce/minimize total impervious areas

Increase in urbanization, leads to vast areas of traffic network which is the greatest source of impervious surfaces. Due to the increase in impervious cover, the hydrologic features like runoff rate, recharge volumes, peak concentration is greatly altered. The most important aspect of using LID features on a site is to manage the impervious cover. Methods like pervious pavements, medians with bioretention, green streets and be used to restore the site's hydrology to pre development conditions. Some of the methods used to achieve reduction on impervious cover are:
1. Alternative roadway layout: The patterns in which roads are designed play an important role in the area of impervious cover which influences the hydrology of the site.

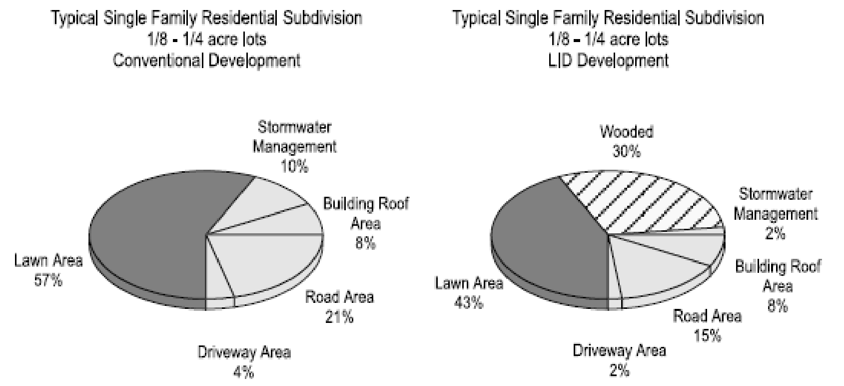

Figure 1.7: Typical impervious ratios for conventional and LID residential development design

(Source: Used under fair use, 2011)

Selection of an alternative road layout can result in a total site reduction in impervious surface of 26 percent.

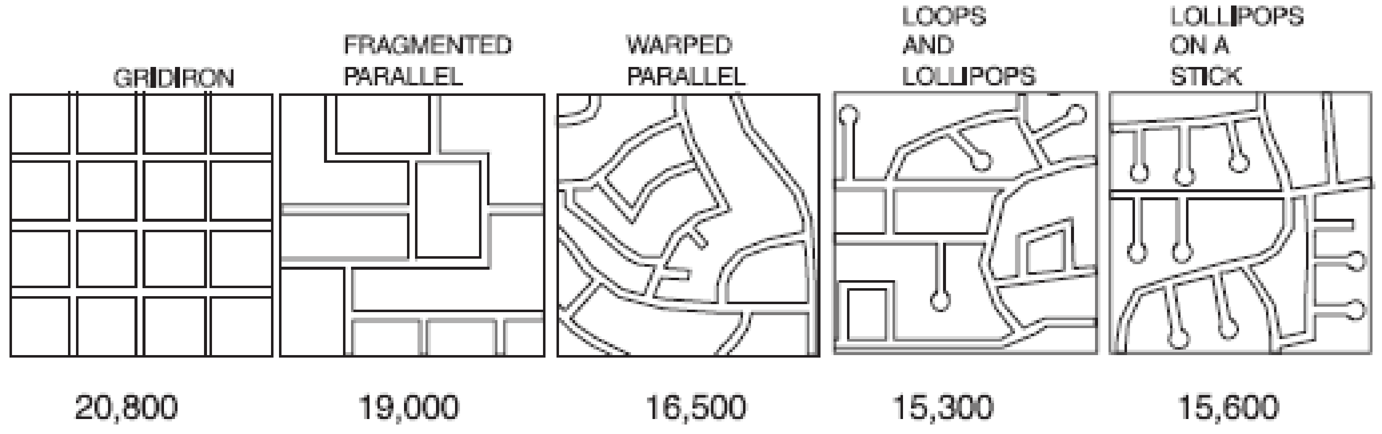

Figure 1.8: Impervious surfaces associated with various road layouts (Length of pavement),
(Source: Used under fair use, 2011)

Low impact development site planning process

2. Narrow road sections: By reducing the width of the roads where possible (i.e. by taking into account the traffic conditions on the road), the impervious asphalt cover can be reduced to a considerable extent.

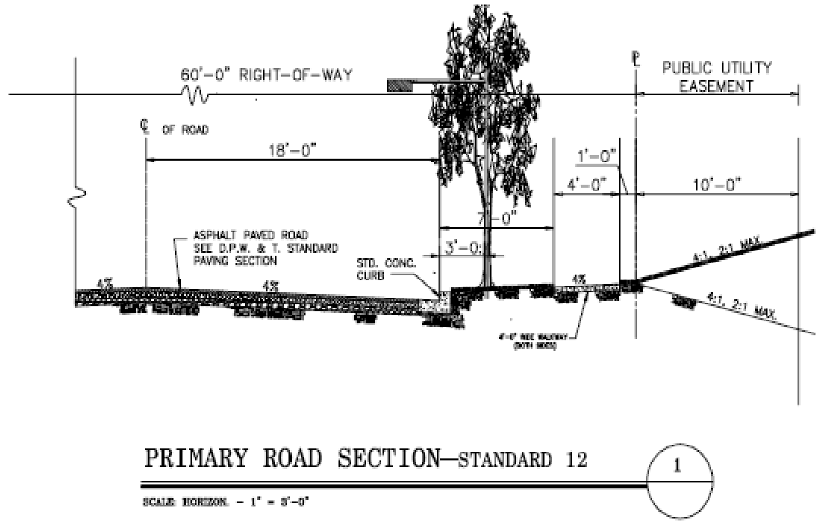

Figure 1.9: Typical Road Sections
(Source: Used under fair use, 2011)

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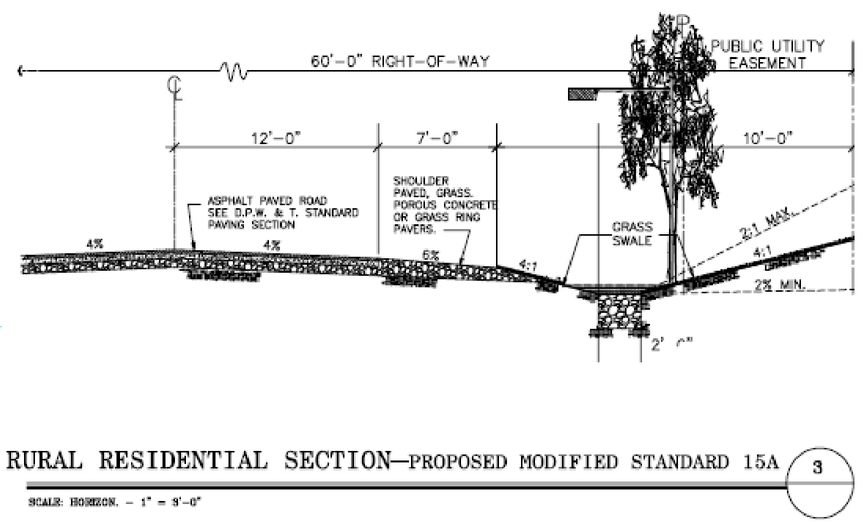

Figure 1.10: Typical Road Sections
(Source: Used under fair use, 2011

By using the rural residential section in place of the primary residential section, the width of the paving can be reduced from
36 to 24 feet, which accounts to 33 percent reduction in paved width. The rural section also eliminates the use of concrete curb and gutter which reduces construction costs substantially and facilitates the use of vegetated roadside swales.
3. Reduced applications of sidewalks: The total impervious cover can also be reduced by limiting sidewalks to one side of the road where it is possible and eliminate sidewalks on certain roads.
4. Reduced on-street parking: Reducing on-street parking requirements to one side, or even elimination of on-street parking altogether, has the potential to reduce road surfaces and therefore overall site imperviousness to 25-30 percent *(Sykes, 1989)*. For example, *Sykes (1989)* noted that allowing parking on both sides of the street provides space for 4.5 to 6.5 cars per residence.
5. Rooftops: Rooftops contribute to the greatest extent to the percentage of impervious cover on a site. Keeping this is mind, vertical construction is more environment friendly and minimizes the impact on the site hydrology compared to horizontal construction which increases the square footage of rooftops.
6. Driveways: Using shared driveways, reducing driveway widths to 9 feet, minimizing building setbacks to reduce driveway length, and using porous asphalt/concrete which reduces runoff and increases travel times helps in maintaining site hydrology.

Low impact development site planning process

Step 6: Develop integrated preliminary site plan

After analyses of the development envelope and the site imperviousness, a preliminary hydrologic site plan is prepared which compares the pre-development and the post development hydrologic conditions and determines if the necessary design objectives have been met. These procedures are aimed at disconnecting the unavoidable areas like parking lots, as well as, using techniques to modify the drainage flow paths so that the post development time of concentration of stormwater runoff can be maintained as close as possible to the pre development conditions *(Prince George's County, 1999)*

Figure 1.11: Integrated preliminary site plan.
(Source: clearwatercommons.com/siteplans.php, 2011)

Low impact development site planning process

Step 7: Minimize directly connected impervious areas

After the preliminary plan has been developed, additional environmental benefits can be achieved by disconnecting unavoidable impervious areas by disconnecting roof drains and directing flows to vegetated areas, breaking up flow directions from large paved surfaces, encouraging sheet flow and directing impervious surfaces to drains into natural systems, vegetated buffers, natural resource areas and soils which have good filtration capacity.

Step 8: Modify/increase drainage flow paths

Time of concentration on a site, along with other hydrologic features, affects the peak discharge rate for a storm event. Travel distance, slope of the surface, surface roughness, channel shape, pattern and material components affect the time of concentration. Some of the LID concepts that can be incorporated into the plan to control the time of concentration are:

- Maximize overland sheet flow
- Increase length of flow paths
- Lengthen and flatten site and lot slopes
- Maximize use of open swale system
- Increase and augment site and lot vegetation

Step 9: Compare pre and post-development hydrology

The hydrologic analysis will quantify both the level of control that has been provided by the site planning process and the additional level of control required through the use of the integrated management practices (Prince George's County, Maryland).

Step 10: Complete LID site plan

Upon completion of comparing the pre and post development hydrologic conditions of the site, additional stormwater control requirements of the LID site are identified and implemented by using various low impact practices. A trial and error iterative process is then used until all the stormwater management requirements are met.

(Source: Prince George's County, 1999)

Challenges and regulations pushing the implementation of LID practices

Although LID practices benefits in various ways the developer, the municipality and the environment, it poses challenges in order to implement the practice. Two of the most frequent challenges facing developers who contemplate the use of LID are restrictive local ordinances and local officials and citizens opposition to the approach. However, careful project planning, close collaboration with the local municipality and education programs can reduce these challenges.

Local ordinances guide the design and construction of new development. Sometimes, these ordinances are from years ago such that the regulations no longer reflect today's development practices, especially those of LID. In many cases, developers wishing to use LID may have to obtain some type of variance or waiver from their local planning agency until local codes are updated to reflect current practice. One way to address this issue is to have municipalities revise their zoning ordinances in order to allow LID in residential land development projects. One thing that would help facilitate the ordinance revision process is the development of a nationwide database containing information on ordinances supporting the use of LID. This database would provide the entire development industry, including local planning officials, with a centralized resource that would provide examples of ordinances that encourage the LID approach.

Incentives to implement LID practices:

Public officials that want developers to use LID technologies can tie incentives, such as expedited permitting process times, to developments incorporating those technologies. Until development ordinances are amended to allow innovative practices and technologies by-right, other incentives, such as density bonuses and reduced impact, application, or development fees can also be negotiated between developers and municipal officials to help offset additional costs. To help homeowners, and sometimes even municipal officials, understand the benefits of LID techniques, developers are encouraged to prepare brief educational presentations or publications on LID for both the general public and municipal officials. Studies have shown that once residents understand the benefits to local water quality, they are more likely to support and accept alternative technologies. Often, homeowners view practices such as bioretention cells as extra builder landscaping. (*PATH, 2003)*

LID implementation examples:

Many municipalities in the U.S. are encouraging the implementation of LID practices for on-site control of stormwater such as: The City of Olympia, Washington, has been very proactive in requiring certain sustainable storm water management practices to reduce the impact of impervious areas (e.g., narrower streets and permeable parking bays) and have adopted new codes and development guidelines. The City of Portland, Oregon, has revised zoning codes for parking lots to reduce the minimum size of parking bays and increase the required interior landscaping. Santa Monica, California, has modified its municipal code to encourage the use of sustainable practices including a number of site, landscape and water conservation technologies.

LID implementation examples

Portland, Oregon—Amendments to Zoning Code

Objective:

To promote integration of storm water management facilities into parking lot layouts, to decrease the size of parking stalls and aisles, and to increase parking lot landscaping.

Key Elements:

Promotes management of parking lot runoff within parking lot landscaping.
Reduces parking space dimensions to 16 feet x 18½ feet for 90-degree parking.
Reduces aisle width to 20 feet.

Comments:

An effort was made to permit and promote the management of parking lot runoff within interior landscaping, but to avoid creating excessive complications for retrofits of existing parking lots. The zoning code does not explicitly require that storm water runoff be managed within parking lot landscaping. *(Source: Anne Guillette, 2010)*

LID implementation examples

King County, Washington-LID / Built Green™ Demonstration Projects

Objective:

To create three safe, healthy, and diverse communities that are sustainable and affordable, and to study the efficiency of the development review process as it affects project affordability.

The three pilot projects will:

- Demonstrate environment friendly storm water management techniques (low impact development) that use landscaping and small-scale hydrologic devices to capture, filter, and infiltrate storm water runoff.
- Demonstrate ecologically sound approaches to manage the built environment using the Built Green construction principles.
- Feature recycled materials, energy efficiency, and natural habitat protection.

The three projects are:

1. Hope VI Park Lake Homes in White Center: An urban infill mixed-use redevelopment site of 900 units; new single family and multi-family housing units developed by King County Housing Authority
2. Shamrock in Renton: An urban single family residential project of 100 single family housing units developed by Camwest, a private developer
3. Sunflower Development on Vashon Island: A housing project of 14 single family homes

Key Elements:

The modifications and waivers to standard development regulations that may be modified for the low impact development and Built Green demonstration projects may include:

Zoning, density and dimensions
Design requirements
King County road standards, parking and circulation
Landscaping and water use, drainage review requirements
Environmentally sensitive areas
Signs

(Source: Anne Guillette, 2010)

Selection of LID practices

Site design which employs low impact development practices emulates the pre-development temporary storage (detention) and infiltration (retention) functions of the site.

Run-off volume control: The pre-development run-off volume is maintained by minimizing site disturbance from pre-development conditions and then providing retention LID practices. Retention practices like swales, green roofs are structures that retain the run-off for the design storm event.

Peak run-off rate control: Low-impact development is designed to maintain the predevelopment peak runoff discharge rate for the selected design storm events. This is done by maintaining the predevelopment Tc and then using retention and/or detention IMPs (e.g., rain gardens, open drainage systems, etc.) that are distributed throughout the site. The goal is to use retention practices to control runoff volume and, if these retention practices are not sufficient to control the peak runoff rate, to use additional detention practices to control the peak runoff rate. Detention is temporary storage that releases excess runoff at a controlled rate. The use of retention and detention to control the peak runoff rate is defined as the hybrid approach.
(Source: Prince George's County, 1999)

The low-impact analysis and design approach focuses on the following hydrologic analysis and design components:

1. Runoff Curve Number (CN): Minimizing change in post development hydrology by reducing impervious areas and preserving more trees and meadows to reduce the storage requirements to maintain the pre development runoff volume.

2. Time of Concentration (Tc): Maintaining the predevelopment Tc in order to minimize the increase of the peak runoff rate after development by lengthening flow paths and reducing the length of the runoff conveyance systems.

3. Retention: Providing retention storage for volume and peak control, as well as water quality control, to maintain the same storage volume as the predevelopment condition.

4. Detention. Providing additional detention storage, if required, to maintain the same peak runoff rate and/or prevent flooding.
(Source: Prince George's County, 1999)

LID practices used in today's site design include: green roofs, vegetated swales, rainwater harvesting systems, infiltration trenches, filter strips, vegetated buffers, tree box planters, wetlands and porous pavements. For the study of this thesis, I have selected green roofs, rainwater harvesting systems and vegetated swales since each of the practice has a design objective to achieve all of the above discussed hydrologic and design components as compared to other LID practices. Another reason for the selection of these LID practices is due to the extensive research conducted, which have generated stronger results for the implementation of the LID practice. These three practices are also known to functioning exceptional well when used in conjunction with each other, which is noted in few of the case examples that have been discussed in the later chapters.

Selection of case examples

The case studies for the three LID practices have been selected based on the following criteria:

1. Availability of information: All case examples have been selected were adequate information is available for analysis. Qualitative analysis requires information on parameters like infiltration rates, size of the project, vegetation type, water quality and water quantity. Therefore, projects have been selected keeping in mind the analysis criteria and the available information for each of the criteria's.

2. Varied land use: Selecting projects from different land uses like residential, commercial and institutional, provides information like cost of the project for the given land use as compared to the same LID practice implemented in a different land use, performance of the LID practice in a particular land use as compared to other land uses, and understanding the modifications in a LID practice for better performance to suite the given land use. It helps the user better understand the efficiency of the LID practice according to their requirements.

3. Unique features and award winning designs: Award winning projects are monitored and tested for there performance rates unlike other projects with LID practices. Providing case examples which have been monitored and tested for performance, genuinely proves that the LID practice meets the goals and objectives intended to achieve by the practice. This not only helps in increasing the awareness among the public but also helps the user implement their designs based on the guidelines and principles set by the case examples. This helps in the implementation of well functioning LID practices which in turn improves the environment.

LID, LEED and Alternative Rating Systems

LEED - New Construction:
The U.S. Green Building Council's LEED rating system has been described as the dominant green rating system in the US (U.S. Department of Energy 2006). The LEED - New Construction and Major Renovations (LEED - NC) rating system was developed to guide the design and construction of "green" commercial and institutional projects, including office buildings, high-rise residential buildings, government buildings, recreational facilities, manufacturing plants and laboratories *(USGBC 2009a).*

The LEED - Neighborhood Development:
This rating system has more limited application, guiding the development of dense, compact neighborhoods, portions or neighborhoods, or multiple neighborhoods, with particular emphasis on neighborhood connectivity and facilitating alternative modes of transportation *(USGBC 2009b)*. This rating system helps achieve water quality benefits by incorporating dense, compact neighborhood development.

GreenPoint Rated-Single Family:
A program of Build It Green, a California non-profit organization, the GreenPoint Rated System specifically addresses development in California. It offers rating systems for green development of single family and multi family residences, as well as a rating system for existing homes *(Build It Green 2009b)*.

The Sustainable Sites Initiative:

The American Society of Landscape Architects, Ladybird Johnson Wildflower Center, and U.S. Botanic Society are leading this initiative to develop a green development rating system specific to land development and long-term management *(Sustainable Sites Initiative 2009a)*. The USGBC is participating in the initiative and anticipates incorporating the Sustainable Sites Initiative Guidelines and Performance Benchmarks into future iterations of LEED *(Sustainable Sites Initiative 2009b).*

LID, LEED and Alternative Rating Systems

Each of the four green building rating systems includes a list or "menu" of a wide range of environmentally sustainable features that could potentially be included in a development project. A specific number of points or credits is assigned to each sustainable feature included in the rating system. Project developers then choose which sustainable features to include in their project, which will be certified as a green project if it receives a sufficient number of points. In order to receive credit for any of the sustainable features, the project must demonstrate that it has met the criteria specified in the applicable rating systems (Integrating Low Impact Development Techniques with Green Building Design, Page 800).

LID Techniques	**LEED - NC 2009**	**LEED - ND 2009**	**GreenPoint Rated - Single Family (4.0)**	**Sustainable Sites Initiative 2009**
Conserve/Restore Sensitve areas	SS - Credit 1	SLL - Credit 7 SLL - Credit 8	---	3.3 3.4 4.8
Reduce surface parking footprint	SS - Credit 4.4	NPD - Credit 5	A.4	---
Reduce disturbance/ Preserve Vegetated areas	SS - Credit 5.2	GIB - Credit 7	A.1	4.6
Restore native plant communities	---	---	---	4.9
Plant shade trees	---	NPD - Credit 14	C.5	---
Stormwater Control: Quantity	SS - Credit 6.1	GIB - Credit 8	P.A.	3.5
Stormwater Control: Quality	SS - Credit 6.2	---	---	3.6
Design stormwater features as landscape amenity	---	---	---	3.7

Table 3: LID techniques in various rating systems

SS - Sustainable sites	NPD - Neighborhood pattern and design
SLL - Smart location and linkage	GIB - Green infrastructure and buildings

LID, LEED and Alternative Rating Systems

LID Techniques	LEED - NC 2009	LEED - ND 2009	GreenPoint Rated - Single Family (4.0)	Sustainable Sites Initiative 2009
Green roof/open gri paving (heat island effect)	SS - Credit 7.1 SS - Credit 7.2	GIB - Credit 9	---	4.11
Percent reduction in portable water for irrigation	WE - Credit 1	GIB - Credit 4	C.11	3.2
Specify native/ adapted plants	---	---	C.3.c	4.7
Avoid invasive species	---	---	C.3.a	Pre-requisite
High efficiency irrigation	---	---	C.6	---
Minimize turf	----	---	C.4	---
Rainwater harvesting/use	WE - Credit 2	---	C.8	---
Submetering for irrigation and/or hydrozoning	---	---	C.1 C.10	---
Mulch and/or compost	---	---	C.2 C.7	---

Table 3: LID techniques in various rating systems

Sources: USGBC 2009a, USGBC 2009b, Build It Green 2009a, Sustainable Sites Initiative 2009.

SS - Sustainable sites
WE - Water efficiency
GIB - Green infrastructure and buildings

LID and rating systems

LID Technique / Rating system	LEED - NC (2009)		LEED - ND (2009)		GreenPoint Rated: Single Family (4.0)		Sustainable Sites Initiative (2009)	
	Credit No.	Points	Credit No.	Points	Credit No.	Points	Credit No.	Points
Conserve/Restore Sensitive areas	SS -1	1	SLL - 7 SLL - 8	1 1	---	0	3.3 3.4 4.8	8 5 6
Reduce surface parking footprint	SS - 4.4	2	NPD - 5	1	A.4	1	---	0
Reduce disturbance/ Preserve Vegetated areas	SS - 5.2	1	GIB - 7	1	A.1	3	4.6	8
Restore native plant communities	---	0	---	0	---	0	4.9	5
Plant shade trees	---	0	NPD - 14	2	C.5	3	---	0
Stormwater Control: Quantity	SS - 6.1	1	GIB - 8	4	P.A.	3	3.5	10
Stormwater Control: Quality	SS - 6.2	1	---	0	---	0	3.6	9
Design stormwater features as landscape amenity	---	0	---	0	---	0	3.7	3
Green roof/open gri paving (heat island effect)	SS - 7.1 SS - 7.2	1 1	GIB - 9	1	---	0	4.11	5
Percent reduction in portable water for irrigation	WE - 1	4	GIB - 4	1	C.11	2	3.2	5
Specify native/ adapted plants	---	0	---	0	C.3.c	3	4.7	4

Table 4: LID techniques in various rating systems with possible points that can be achieved

SS - Sustainable sites NPD - Neighborhood pattern and design
SLL - Smart location and linkage GIB - Green infrastructure and buildings

LID and rating systems

LID Technique / Rating system	LEED - NC (2009)		LEED - ND (2009)		GreenPoint Rated: Single family (4.0)		Sustainable Sites Initiative (2009)	
	Credit No.	Points	Credit No.	Points	Credit No.	Points	Credit No.	Points
Avoid invasive species	---	0	---	0	C.3.a	1	Pre-requisite	0
High efficiency irrigation	---	0	---	0	C.6	5	---	0
Minimize turf	---	0	---	0	C.4	6	---	0
Rainwater harvesting/use	WE - 2	2	---	0	C.8	2	---	0
Submetering for irrigation and/or hydrozoning	---	0	---	0	C.1 C.10	2 1	---	0
Mulch and/or compost	---	0	---	0	C.2 C.7	2 3	---	0
Maximum Points for LID		**14**		**12**		**37**		**73**
Points Needed for Certification		**40**		**40**		**50**		**100**
Percentage of Points needed for Certification theoretically achievable with LID Techniques		**35%**		**30%**		**74%**		**73%**

Table 4: LID techniques in various rating systems with possible points that can be achieved

Sources: USGBC 2009a, USGBC 2009b, Build It Green 2009a, Sustainable Sites Initiative 2009.

Conclusion

The review of the four rating systems identified a wide range of opportunities to obtain green building credits for including LID techniques in development projects in each of the rating systems, which can create additional incentives for project designers and builders to incorporate LID in their projects. The review of the rating systems also identified some missing information in the availability of green building credits for LID techniques, specifically in the categories of sustainable landscaping and preservation of environmentally sensitive areas.

1. Sustainable landscaping practices:

The LEED - NC, LEED - ND and the sustainable sites initiative offer fewer points for landscaping practices than are offered by the GreenPoint Rated system. From the above table analysis, it is noted that LID techniques can contribute only a maximum of 20 points needed for GreenPoint rated certification.

2. Protecting environmentally sensitive areas:

From the comparison table 3 listed above, it is noted that Sustainable sites initiative offers more credits than the other three rating systems for preserving environmentally sensitive areas. Projects that emphasize the protection of environmentally sensitive areas may benefit from using the sustainable sites initiative, either currently as pilot projects or in the future public version of this rating system.

Chapter 2.1: LID Practice 1 - Green roof systems

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Introduction

Chapter three on green roof systems details the history and evolution of green systems. Green roof systems is an important method towards achieving sustainable design not because it addresses stormwater issues, but also adding to benefits like keeping temperatures down and pollution reduction in urban areas. The chapter is organized into 3 sections:

1. History/Evolution of green roofs
2. Green roof components
3. Green roof construction

Introduction

A green roof, also known as a vegetative roof, is one passive technique that can be used to address environmental issues in an urban setting. As urbanization in every city increases, the number of buildings increases as well, with which there is an increase in the number of the roof tops. The increase in number of roof tops leads to an increase in the area of impervious surfaces like roads, parking lots and pavements. As a result, cities increasingly struggle to cope with the urban heat island affect, increased storm water runoff, altered weather patterns, air pollution, loss of tree canopy and green space, noise and loss of wildlife habitat. Increase in impervious surfaces also affects the quality of air and water in these urban areas. As cities grow, we need to be more thoughtful about the way we use our limited assets.

One of the many strategies for replenishing our depleting resources, by integrating landscape and architecture, is the green roof systems. The chapter details the construction of a green roof system with various case examples and analysis of the case examples leading to design recommendations.

Figure 2.1: Impervious Urban Rooftop
(Source:www.celsias.com,2011)

Figure 2.2: Imaginary urban Green Rooftop
(Source: www.celsias.com, 2011)

History of green roofs

Roof planting has many historic precedents, from the hanging gardens of Babylon to Scandinavian sod roofs. Sod roofs were constructed around 500 B.C. These roofs were built over arched stone beams, and waterproofed with layers of reeds and thick tar. Sod was used as a planting material for insulation during winter and a cooling material during the summer seasons.

Introduction

Figure 2.3: Scandinavian Sod roofs
(Source: inhabitat.com, 2011)

In the last five years, the term green roof has taken ecological and social significance beyond its simplistic description. Today green roofs are based on German designs from the 1970's, which have made technological advances from the ancient sod roofs. Green roofs today significantly reduce the runoff peak of most rainfall events, help in pollutant removal through filtration in rainwater through the growing medium. Green roofs also have an impact on the heat island effect of urban areas through increasing evapotranspiration of water. These roofs have become an epithet for the reduction of pollution and urban heat islands, for large scale mitigation of storm water runoff and for maximum utilization of urban land.

The term "green roof" today is often used as an umbrella term for a number of sustainable systems built over a structural decking and serves as a roof to that portion of a structure. Green roofs also known as eco-roofs are multi beneficial structural components that help to mitigate the effects of urbanization on water quality by filtering, retaining and detaining rainfall. They are constructed of a light weight soil media underlain by a drainage layer and a high quality impermeable membrane that protects the building structure. The plants selected for the roof are a mix of species that can thrive in harsh weather conditions, dry or high temperatures without irrigation and rainfall.

Regardless of the location and the extent of the green roof system over a structure, the benefits of a single system is enormous. Thus, when planning and design process occurs beyond the project's property line, the positive impact on our natural, social and cultural environment is significant.

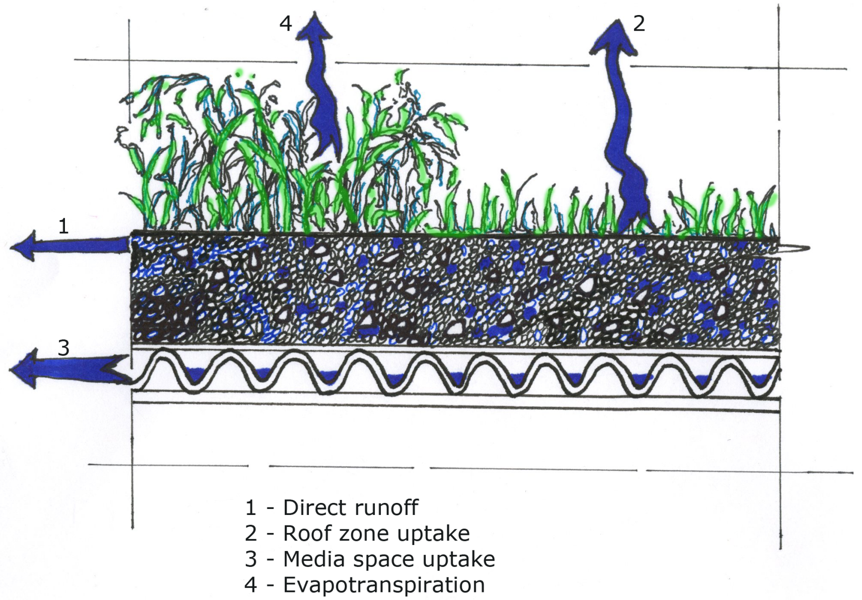

Figure 2.4: Green Roof Top Processes For Stormwater Management
(Source: Author)

Benefits of green roof systems

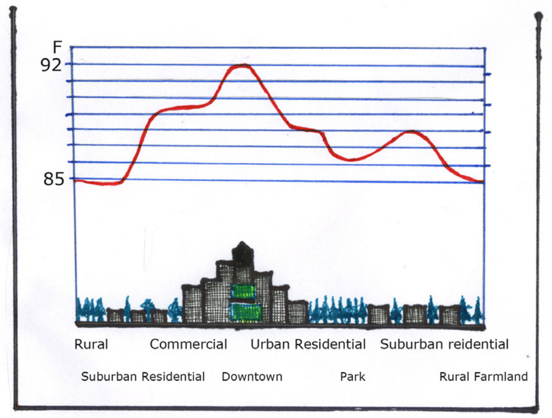

Figure 2.5: Sketch of a Urban heat island profile
(Source: Author)

Green roof systems over an impervious building rooftop has numerous benefits at the project scale, as well as, at an urban scale.

Reduce heat island effect:

The transpiration of the vegetation provides an evaporative cooling effect that can lower the air temperature locally to below ambient temperatures, helping to reduce urban heat island effect. This is also achieved by absorbing sunrays and not reflecting them back into the atmosphere.

Reduce carbon dioxide impact and air pollution:

Vegetation on the green roofs convert carbon dioxide and sunlight into oxygen and glucose through photosynthesis. This cyclical process supplies animals and humans with oxygen and food reducing the carbon dioxide concentration in the atmosphere. Green roofs also act as bio-filters which help in absorbing the pollutants in the atmosphere.

Reduce energy consumption:

The growing medium and vegetation cover help isolate the roof surface, preventing solar heat gain and loss that in turn lowers the energy consumption. The roof isolates the building making it cooler in the summer and warmer inside the building during winters.

Lengthen roof life:

Green roofs lengthen roof life by 2-3x times by protecting it from intense UV degradation and continued expansion and contraction due to fluctuating temperatures.

Working process of green roof systems

Green roofs provide stormwater benefits by:

1. Utilizing the biological, physical and chemical processes found in the soil and the plants to prevent air borne pollutants from entering the storm drain system.
2. Reducing the runoff volume and peak discharge rate by holding back and slowing down the water that would otherwise flow quickly into the storm drain system. Some of the water is also absorbed, evaporated and transpired by the plants.
3. By reducing peak flow runoff volume, green roofs help reduce potential flooding and destruction of natural stream channels.

On an average, a 2.5 inch deep extensive roof, with sedum and grass layer constructed on a flat surface retains about 67% of the rainwater. A 2.5 inch deep roof with a porosity of 30-35% retains about 0.5 gallons of rainwater per square foot, or 40% of the rain amount. The retained water is either used by the vegetation during seasons of less precipitation or excess water is transported through pipes into a rainwater harvesting system depending upon the nature of the project.

Flat green roofs provide maximum water storage capacity when its soil medium is dry. Dry soil medium is most likely to occur in summer. The roof slope is a variable that influences the green roof systems water retention capacity, and storage volumes. Flat roof or low sloped have greater retention capacity but must include a drainage layer to allow excess water to drain towards the roof drain. Increased roof slopes forces water out of the soil medium void spaces by gravity and hence reduces the retention capacity.

Runoff studies have found that water storage capacity is near 100% at any time of the year if a storm is preceded by atleast 5 dry days. On the other hand, retention capacity is lower if the soil medium is moist or wet.

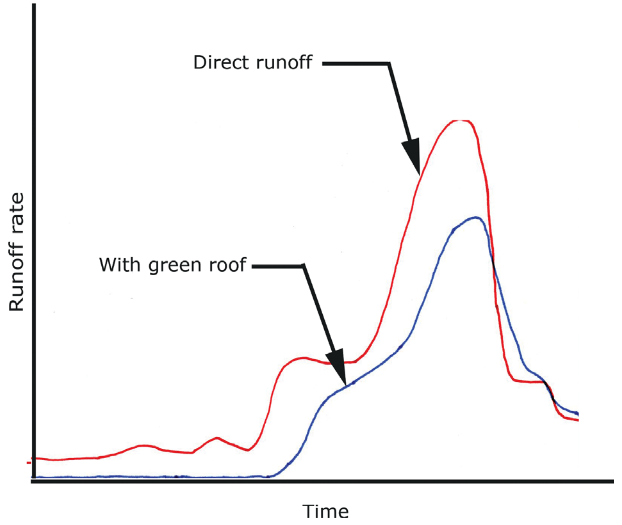

Figure 2.6: Stormwater runoff for a 3.35-inch, 24-hour rainfall event.
(Source: Author)

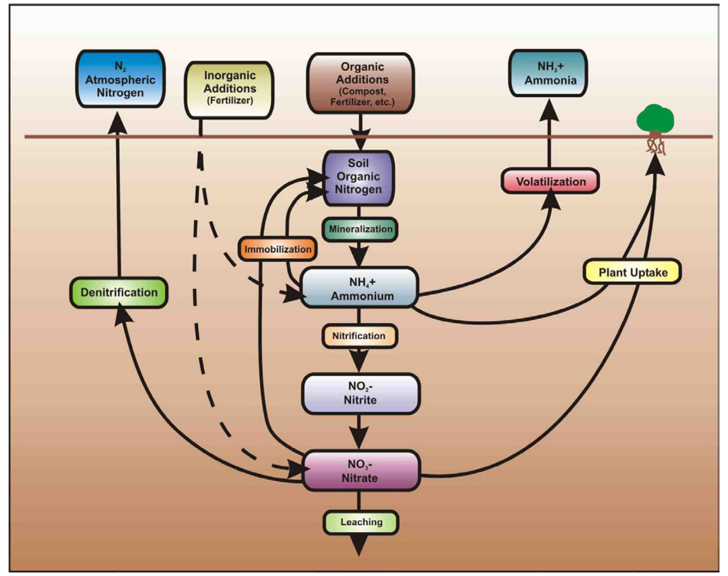

Figure 2.7: Nitrogen cycle in the soil
(Source: www.lowimpactdevelopment.org, 2011)

Types of green roof systems

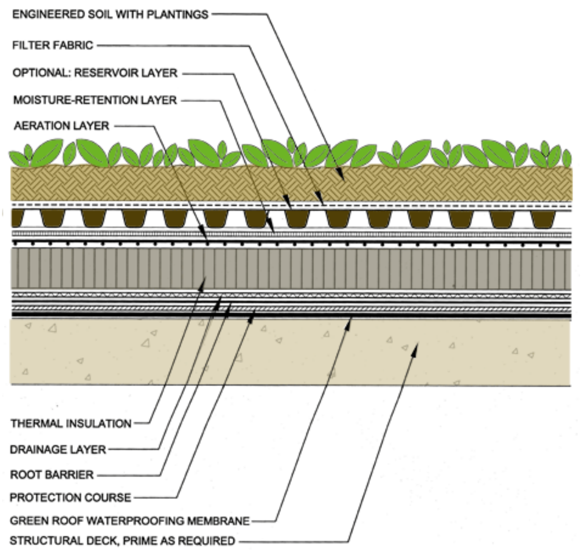

Figure 2.8: Section of an extensive green roof system
(Source: ecobrooklyn.com)

Figure 2.9: Section of an intensive green roof system
(Source: www.lowimpactdevelopment.org)

Green roofs can be classified into two types:

1. **Extensive Green roofs**: These roofs are generally very shallow in depth of soil or growing media which is usually 3-6 inch although they can be even 1 inch in depth. Extensive roofs are primarily used for their environmental benefits such as storm water management and insulating properties. They do not require irrigation except during the initial growth period and require little or no maintenance. They are usually not intended to be accessed directly for use as a garden or open space, by paved walkways and seating areas.
The lack of consistent supplemental watering, shallow soil depth and exposure to intense and desiccating sunlight and wind require vegetation capable of surviving these harsh, dry conditions. Generally, plants used for this are known as succulents. Sedums are most often used for these conditions. Maintenance required for extensive roofs is initial hand watering during installations and establishments. Occasional weeding, fertilizing and spot repair is required.

2. **Intensive roofs**: These roofs systems have greater depth of soil or growing medium which allows for greater diversity in size and type of vegetation. The growing medium is typically 6-8 inches and can go upto 15 feet or more. Ideally, these green roofs have relatively flat roof surfaces (1-1.5%) or mild roof slope percentage of 3%. Pathways, terraces, water fountains, ponds and other architectural features result in beautiful and dramatic spaces that can often be accessed by people.
Since intensive roofs have greater depth compared to extensive roofs, they are capable of storing water for longer periods. For this reason, intensive roofs have additional layers such as protection boards and water retention mats that are usually included in the design to prevent the roof from any leakage. Due to the increased number of layers intensive roofs are expensive and require higher maintenance.

Construction of green roof systems

The top and bottom layers of a green roof are the vegetation and the roof deck.

Vegetation:
For *extensive roofs*, vegetation is generally sedums. Sedums are well adapted to the thin layers of the growing medium and extreme conditions of drought, heat, cold, wind and exposure. Sedums are sometimes supplemented by other plants, often with a similar look but from different plant families. A variety of plant materials is a practical way to ensure diversity on the green roof because some species may not survive and other species can take over and become well established. In addition, diversity gives some protection against infestations and diseases, in which some species will be resistant.
For *intensive roofs*, since the thickness of the growing medium increases, the variety of plant material also increases. Wide range of plant materials from sedums and perennial grasses to shrubs and small trees both evergreen and deciduous is suitable for intensive roofs.

Growing medium/substrate:
The most preferable growing medium is a well drained sandy loam soil. The growing medium contains a well drained, light weight soil mix. Soils with high percentage of organic content may have disadvantage for green roofs, whether extensive or intensive, since organic components decompose and the surface level of the soil recedes. This also leads to clogging of the filter fabric and the drainage layer and also results in excessive nutrient loss by the plants. Typical substrate includes expanded shale, pumice, lava, terra cota, calcined clay, expanded slate or brick.
The growing medium that is finally used for green roofs should be carefully specified to comply with requirements like pH, weight, percentage of organic materials, drainage rate, maximum density, coarseness/fineness of the substrate, ability to retain water, slope of the roof, if sterile/weed free.

Construction of green roof systems

Filter Fabric:
Though minimal in thickness, the filter fabric is critical since it prevents fine particles of the growing medium from clogging the drainage layer, which could prevent water from flowing or draining freely throughout the system. Water build up can stress the structure of the roof and damage the plants.

Drainage and water retention layers:
The drainage layer may be synthetic or composed of highly permeable granular mineral, manufactured or contained in a sheet. The drainage layer collects any excess water not absorbed by the plants and growing medium and directs it into a network of drainage channels built into the system. Sometimes the drainage and the retention systems are combined into one unit.
The retention layer can augment the natural water holding properties of the green roof. Most green roofs retain 35-45% moisture by volume. The retention layer, with its numerous small reservoirs or pockets also may increase aeration and air flow into the green roof. Drainage layers may retain moisture long enough for most of it to be utilized by the plants and the remainder released into storm drainage systems over time.

Depending on the design, roofs may connect to an :
- Internal drain areas and storm drainage systems
- External drains that are gutters or scuppers that release water to the outside of the building or pipes affixed to the building.

Root protection layer:
Some kind of protection layer or root barrier is required to prevent the roots from penetrating into the waterproofing layer and causing leaks. Most commonly used materials are thermoplastic membranes, copper foil and root retardant chemicals. Copper is sometimes restricted because it may chemically react with other elements or may leach into the water system. Sometimes root barriers are integrated into other systems such as the waterproofing layer.

Insulation:
The insulation layer is required to further limit heat gain and loss into the building structure. Depending on the green roof design the insulation layer may be installed above or below the waterproofing layer. Common materials used for insulation are polystyrene and polyisocya nucate.

Construction of green roof systems

A typical Garden roof assembly consists of:

1. *Carefully selected plants*- extensive plants for low maintenance landscaping including the drought resistant, self-regenerating varieties available from Hydrotech. There are a wide range of plants for intensive landscaping that can be supplied by garden centers and nurseries. GardMac erosion control blankets are also available no aid in plant establishment.
2. *Engineered lightweight growing medium*- must have a well-balanced structure and low weight. The pH values, nutrients, degree of porosity and vapor permeability must be suitable. The type and thickness of the growing media ultimately determine the plant choice as well as the structural load imposed on the roof structure. The growing media is specifically blended to meet the requirements of each project.
3. *System Filter*- to prevent fine particles from being washed out of the substrate soil and therefore maintaining the efficiency of the drainage layer.
4. *Drainage/retention/aeration element*- The retention layer retains water in the profiled troughs, even on sloping roofs. Excess water drains away through channels between the troughs. Strategically located holes provide the necessary aeration and ensure that moisture below diffuses up into the growing media.
5. *Moisture Mat*- Made of non-rotting fiber to retain moisture and nutrients as well as provide physical protection to the roof barrier and water proofing membrane. (An air layer is required when placed directly over insulations – not shown)
6. *Insulation* - situated above the roof membrane, an extruded polytyrene insulation, which exhibits excellent moisture resistance, is dimensionally stable and has a high R-value. Dow Chemical's Styrofoam brand insulation is typically utilized.
7. *Root barrier*- prevents roots from affecting the roof membrane. The type, thickness and method of installation depend on the nature of the landscape planned and the shape and slope of roof.
8. *Roofing membrane*- Assembly with protection layer.
9. *Structural roof deck*- must be designed to support the weight of the green roof as well as any other dead or live loads. Acceptable deck types include case in-place concrete, precast concrete, metal deck with cover beard and plywood.

Figure 2.10: Components of a Green roof assembly
(Source: www.productspec.net, 2011)

Construction of green roof systems

Waterproofing:
Waterproofing is an essential layer to prevent water leakage. Some of the materials used for the waterproofing membrane are thermo plastics - PVC, EPDM rubber, liquid applied polyurethane.

Roof Decks:
Common roof deck types are reinforced concrete, pre-cast concrete planks, steel concrete composites. Retrofit projects may involve plywood or tongue and groove wood decks.
For extensive green roofs, the roof deck is built so that its minimum load bearing capacity is greater than which the green roof is planned for. Semi-intensive roofs rely on load bearing walls and structural columns where the deepest layers are installed. In intensive roofs, cost efficient ways are sort to vary structural detailing of the concrete deck where the most additional load capacity is required.

Special factors for green roof design

1. Load/weight requirements:
The load on a green roof can be of three forms-
- *Dead load:* actual weight of materials used to construct the roof
- *Live load:* weight added to the dead load as a result of use of space such as people moving on and off the roof.
- *Other loads:* impact of winds, snow or seismic action.

Therefore, the design of a green roof must allow for a safety factor. The total weight of all built components as a result of all loads must be less than the maximum load permitted by codes. In most constructions, the majority of the weight is supported at the parapet walls and at points directly over the intersections of structural beams.

2. Leak detection:
One of the important steps in the construction of a green roof is to perform the leak detection test. Methods used to perform the leak detection test are:
- *Flood test:* Upon completion of the waterproofing layer, verifying water tightness can be accomplished by flooding the roof to a certain depth. With thermoplastic non-adhered singly ply assemblies, cuts are made at low points following the flooding to determine if moisture has entered below the membrane during the flood test. This test can be very time consuming and does not give the exact locations of the leaks.
- *Electric field vector mapping (EFVM):* This method involves the installation of waterproofing over a conductive deck, such as steel or re-inforced concrete. Points of water entry through the membrane appear as electrical grounds on the surface and can be mapped manually using a voltmeter and quickly isolated.

Conclusion

As an evergrowing percentage of the world’s population live in cities, the displacement of open land by impervious surfaces of streets, driveways and buildings will intensify rainfall runoff. Increase in runoff not only increases the risk of flooding but also pose a threat to water resources through pollutants transported from impervious surfaces. A review of the literature examines the role of green roofs in urban drainage considering both management of water quantity and quality. We know that green roofs provide adequate benefits by reducing stormwater runoff, pollutant removal, reduces urban heat island effects. Therefore green roofs can be used for runoff management with the objective of enhancing aesthetical values followed by increased property prices. With the combination of energy saving on heating/cooling the green roofs will turn into a profitable investment.

Based on the conclusions drawn from the literature review, six case studies, two each from three main land use types are analyzed. These case studies are analyzed based on the LID objectives for green roofs which are listed below:
1. Reduction of peak flow by retention and detention
2. Reduce urban heat island effect
3. Reduction of pollutant
4. Provide rainwater harvesting

Some of the factors which assist in analyzing the LID objectives are:
1. Green roof type: Determining the type of green roof is the first step towards designing a green roof system. The type of green roof system helps us determine the stormwater management and aesthetic benefits that can be achieved. Roof type also helps in determining the type of vegetation for the green roof.

2. Vegetation type: Understanding the type of vegetation to be selected depending on the green roof type is an important factor in determining the retention capacity and the pollutant removal capacity of the system.

3. Retention/detention capacity: Retention capacity of the green roof system directly relates to the reduction of peak flow rate of runoff. Higher the retention capacity of the green roof, higher is the reduction in peak flow rate of the runoff. Increase in detention capacity also gives room to rainwater harvesting apart from the common benefits of a green roof system.

Chapter 2.2: Green roof system case studies

Case study 1: The Solaire Building, New York

" In its most modest and minimal form, green roofs offer an antidote to the impervious paved world in which we live and which we have few chances to modify as part of an already built up city",Diana Balmori, Principal of Balmori Associates

Figure 2.11: View of the green roof on Solaire, New York
(Source: www.streetsblog.org)2011

Project background:

The Solaire multi family housing at 20 River Terrace is a 27 - storey, 293 unit, glass and brick residential tower in Battery Park City, a planned residential and commercial neighborhood built on landfill bordering the west side of New York City's financial district and directly adjacent to the site of the World Trade Center.

It is the first building designed in accordance with new environmental guidelines instituted in 2000 by the Battery Park City Authority (BPCA). 20 river terrace was designed to consume 35% less energy, reduce peak demand for electricity by 65% and require 50% potable water than a conventional, residential high rise building. An on-site black water treatment and reuse system supplies the cooling tower and the buildings toilets with water.

Design Team

Client:
Albanese Development Corporation for Hugh L.Carey, Battery Park City Authority
Owner:
River Terrace Associates, LLC
Architects:
Cesar Peli and Associates
Landscape Architect:
Balmori Associates Inc

Project Highlights

Location:
New York
Year of Project completion:
2003
Building type:
Multi unit residential
Construction type:
New construction
Project scope:
27 - storey building
Project area:
357000 ft^2

Case study 1: The Solaire Building, New York

Green roof design:

In Solaire, the stormwater management measures are intended to accomplish the following:
1. Decrease the stormwater volume and velocities associated with development induced in hydrology.
2. Remove suspended soils and associated pollutants entrained in the stormwater volumes
3. Retain hydrological conditions that closely resemble those of the pre-disturbance condition.

There are two types of green roofs on top of the Solaire Building:
- An intensive, accessible green roof garden of approximately 5000 sq. ft. on the 19th floor
- An extensive, inaccessible green roof of approximately 4800 sq. ft. on the 28th floor.

Both green roofs were built with the layered garden roof assembly. The installation consisted of:

Irrigation system:
A drip irrigation system that saves water by minimizing evaporation was installed on both roofs.
The sedums used on the extensive green roof do not need any irrigation after the initial growing period except for long periods of drought.

Figure 2.12:View of seating area on the green roof
(Source: www.greenroofs.com, 2011)

Figure 2.13: View of walkway on the green roof
(Source: www.greenroofs.com, 2011)

Case study 1: The Solaire Building, New York

Green roof Analysis:

The green roofs on top solaire constitutes about 75% of the open roof area, which constitutes to 57% of the site area. The average annual rainfall of New York city being 39.28 in/yr, allows a conventional roof to generate a runoff of approximately 36,554 gallons/yr.

Retention/Detention features:

Beneath the vegetation and soil design includes a water retention layer that reduces the velocity of water flow which helps in retaining 75% of the rain water.
The stormwater retention system is designed to retain 10,000 gallons of stormwater in a tank located in the basement of the building. The system will capture approximately 170000 gallons per year to be used for irrigation of the roof top garden. The system was designed to precisely accommodate the irrigation load for the site, allowing for reduction of the capacity of the retention tank by 60% and utilizing 100% of the captured stormwater on site.

Vegetation:

The intensive green roof has been planted with a mixture of ground covers, grasses, perennials, shrubs and bamboo trees and the extensive green roof with a mixture of sedum mix. The planting material include drought tolerant self sustaining shrubs, perennials and bamboo resistant to wind damage and adaptable to shallow soil depths between 6” and 18”. The roof system beneath the plants was designed to retain nearly 70% of the rainwater for eventual use by plants.

Case study 1: The Solaire Building, New York

1. Land Use Type: Residential

2. Green roof area: Intensive System: 5000 square feet
Extensive system: 4800 square feet

3. Average annual rainfall*:* 39.28 in/yr

4. Green roof type: Intensive and extensive systems

5. Roof depth: 30 inches - 60 inches

6. Vegetation type: Native plants were used for the green roof plant palette for water efficiency, extreme heat tolerance and unique geographical constraints. Mature live oaks and other native shade trees were installed to reduce urban heat island effect.

7. Retention capacity: High
Beneath the vegetation and the soil, the green roof includes a water retention layer that reduces the velocity of the runoff and helps retain 75% of the rainwater.

8. Detention capacity: High
The stormwater retention system is designed to retain 10,000 gallons of stormwater in a tak located in the basement of the building.

9. Did the green roof system successfully meet LID objectives: Yes

10. Unique features:
The system contains both intensive and extensive green roofs. The intensive green roof system on the 19th floor is accessible, which acts as an aesthetic feature to the system. The important feature of this system is that not only does the green roof help prevent stormwater runoff but also encourages rainwater harvesting by capturing about 170000 gallons of water per year.

Case study 2: The Liptan garage, Portland

Figure 2.14: View of the green roof on Liptan Garage, Portland
(Source: www.landscapeandurbanism.blogspot.com, 2011)

Project Background:

Tom Liptan, an environmental specialist with the city of Portland converted his single car garage roof to a green roof as an stormwater experiment. The experiment was to prove that green roofs can sponge up some of the city's perpetual rain, thereby reducing flooding storm sewer overflows and related problems.

Design Team

Client:
The Liptan Family
Owner:
The Liptan Family
Architects:
Tom Liptan
Landscape Architect:
Tom Liptan

Project Highlights

Location:
Portland
Year of Project completion:
1996
Building type:
Single family residential
Construction type:
Retrofitted
Project scope:
1 storey
Project area:
180 square foot

Case study 2: The Liptan Garage, Portland

Green Roof Design:

Since the green roof is a retrofit project and the garage's wood frame was very light, Liptan had to brace it to support additional weight. The waterproofing layer was inexpensive plastic sheeting, over which was two inches of soil mixed with compost.

Vegetation:

Vegetation consisted of variety of sedums and also volunteer grasses and other species including native wildflowers. The extensive green roof thrived without any additional irrigation or fertilization.

Water Retention:

From a storm of 0.4 inches of rain, approximately 40 - gallons of rainwater on the 180 square foot roof, only 3 - gallons of runoff reached the ground. During heavy rainfall events, the green roof is less effective in retaining stormwater runoff. Depending on the intensity of rainfall, the green roof is estimated to retain between 15-90% of the rainwater.

Figure 2.15: View of vegetation on the green roof
(Source: www.greenroofs.com, 2011)

Case study 2: The Liptan garage, Portland

***1. Land Use Type**:* Residential

***2. Green roof area**:* 180 square feet

3. Average annual rainfall: 37.07 in/yr

4. Green roof type: Extensive

5. Roof depth:

6. Vegetation type: Native sedums, wildflowers and volunteer grasses

7. Retention capacity: High
From a rainfall event which generated about 40 gallons of rainwater on the 180 square foot green roof, approximately about 37 gallons of the rainwater was retained by the green roof. During heavy storm events, the green roof retained lesser water. Therefore, depending on the rainfall intensity, the green roof retained between 15% - 90% of the precipitation

8. Detention capacity: Medium
The detention capacity of the green roof system depends on the rainfall intensity. With higher rainfall intensities, when the retention layer is completely saturated, the runoff flows from the roof into a rainwater harvesting system continuously for a few days.

9. Did the green roof system successfully meet LID objectives: Yes

10. Unique features:
Unique feature about the green roof system is that the system does not require any additional irrigation or fertilization. The vegetation thrived with the water from the precipitation and the water stored in the retention layer. The green roof is a retrofit project which was built to experiment the retention and the detention features of the system.

Case stusy 3: The Austin City Hall,Texas

Regarding the Austin City Hall and Public Plaza greenroof, the City of Austin, Texas website says, "Joint venture partners, Eleanor McKinney and Carolyn Kelley, created a landscaping style that is uniquely Austin by integrating the plants and materials of its natural environment into the dynamic downtown area."

Figure 2.16: Green roof plan of Austin City Hall, Texas *(Source: www.eot.state.ma.us/smartgrowth, 2011)*

Project Background:

The new city hall of Austin features a plaza on top of the underground parking garage. The City Hall consists of two types of green roofs within one plaza. The public plaza has a green roof over the parking garage, while the upper garden terraces are over occupied spaces.

Design Team

Client:
City of Austin
Owner:
City of Austin
Architects:
Antoine Predock Architects
Landscape Architect:
McKinney Kelley

Project Highlights

Location:
Austin, Texas
Year of Project completion:
2007
Building type:
Municipal/Government
Construction type:
New construction
Project scope:
Double storey
Project area:
12,000 square foot

Case study 3: The Austin City Hall, Texas

Design concept

The design process for the Austin City Hall and public plaza began on the banks of the Bull creek in northwestern Travis County. The diverse eco-system of Travis County - the dry, rocky Edwards Plateau to the west and the deep clay post oak savannah to the east, was continued by Landscape Architect McKinney Kelley.

Some of the unique design features include use of groundwater to irrigate the green roofs, use of HVAC condensate for the waterfall. Mature live oaks and other native shade trees were installed to reduce urban heat island. The project received the first LEED gold certification in the city of Austin.

Green Roof Design:

The green roof covers close to 12,000 sq foot at an approximate cost of $30 per square foot and used growing medium ranging from 30-60 inches in depth. The vegetation which consisted of native plants responded to the ecosystem of Travis county.

Figure 2.17: View of Green roof
(Source: www.greenroofs.com, 2011)

Figure 2.18: View of green roof
(Source: www.greenroofs.com, 2011)

Case stusy 3: The Austin City Hall,Texas

Vegetation:

Native plants were used for the green roof plant palette for water efficiency, extreme heat tolerance and unique geographical constraints.

The plaza level consists of large native shade trees, limestone boulders, plans of lawn, bed areas and raised planters. The depth of the soil in the plaza level is approximately 5ft deep to accommodate the root balls of the large trees.

The upper terrace consist of raised planters with native trees and shrubs. The depth of the soil is approximately 3ft deep for the root balls of the smaller trees as well as to provide sufficient soil moisture during the long hot summers.

The western side of the plaza and the upper roof terraces consisted of mountain laurel, agaves, yuccas, sotols, prickly pear, and feather grass with low ground cover of wooley stemodia and silver pony foot.

The eastern side was dominated by yaupon holly, red bud, gulf muhly, and colorful prairie perennials such as blue bonnets, black eyed susan and prairie cone flower, bald cypress with horsetail fun, button bush and inland sea palmettos and columbine revealed moist shady overhangs.

Figure 2.19: North side planters: Lower lying creek canyons with moist, shady overhangs featuring dwarf palmettos, ferns and yellow columbine.

Figure 2.20: East side: Deep clay Post Oak Savannah and prairie, featuring live oaks, cedar elms, redbud, gulf muhly, and colorful prairie perennials such as bluebonnets, black-eyed Susan and coneflower.

Figure 2.21: West side and upper level terraces: Dry, rocky Edwards Plateau hillsides featuring mountain laurel, agaves, yuccas, feather grass, wooly stemodia and silver pony foot.

(Source: www.ci.austin.tx.us, 2011)

Figure 2.22: South side near the water feature: Sunny creek or river terrace featuring bald cypress, horsetail fern, buttonbush, and inland sea oats.

Case study 3: The Austin City Hall,Texas

1. Land Use Type*:* Commercial

2. Green roof area*:* 12,000 square feet

3. Average annual rainfall: 34.70 in/yr

4. Green roof type: Intensive and extensive systems

5. Roof depth: 30 inches - 60 inches

6. Vegetation type: Native plants were used for the green roof plant palette for water efficiency, extreme heat tolerance and unique geographical constraints. Mature live oaks and other native shade trees were installed to reduce urban heat island effect.

7. Retention capacity: High
Since the vegetation consists of live oaks and native vegetation, the green roof system is considered to have a good retention capacity.

8. Detention capacity: High
The garden included a continuous 5 foot deep trench to nourish several live oak trees.

9. Did the green roof system successfully meet LID objectives: Yes

10. Unique features:
The design features the use of ground water to irrigate the green roof. The unique feature of this system is the use of HVAC condensate for the waterfall and the solar panels for the amphitheater canopy. Mature oak trees and native shade trees were installed to reduce urban heat island effect.

Case study 4: 601 Congress Street, Massachusetts

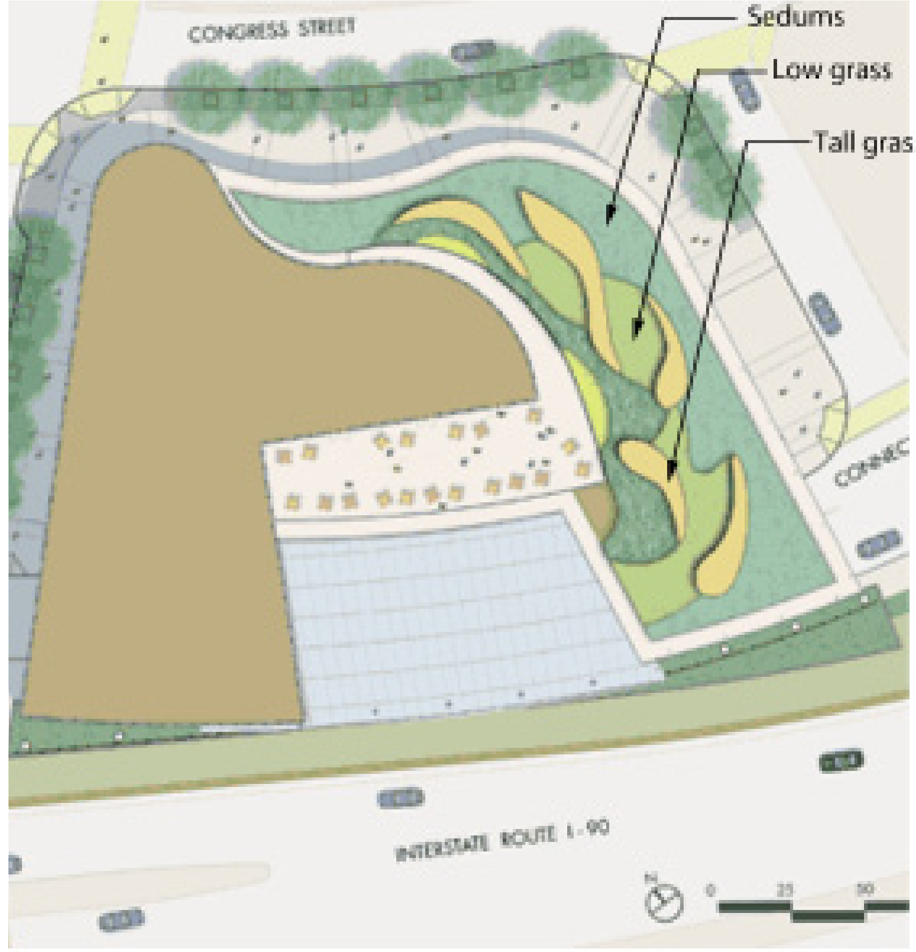

Figure 2.23: Green roof plan of Manulife Financial Headquarters, Massachusetts
(Source: www.sasaki.com, 2011)

Project Background:
The 14 storey Manulife Building houses the U.S. operations of Canada's largest life insurance company. Completed in 2004, the 470,000 sq foot building has added a contemporary profile to south Boston's emerging sea port district.

Design Team

Client:
Manulife Financial U.S. Head Quarters
Owner:
Manulife Financial
Architects:
Skidmore, Owings & Merrill, LLP
Landscape Architect:
Sasaki Associates, Boston

Project Highlights

Location:
Boston, MA
Year of Project completion:
2004
Building type:
Municipal/Government
Construction type:
New construction
Project area:
12,000 square foot

Case study 4: 601 Congress Street, Massachusetts

Design concept

The main design objective was to achieve LEED certification. Taking this opportunity, Sasaki Associates created a terrace garden which served as an amenity to the occupants as well as contributed as a component to the LEED certification. The terrace is provided with seating space with views of the surrounding urban landscape and harbor. A glass railing separates the paved terrace from the planted area without obscuring the visual impacts of plants forms, colors and textures, including seasonal changes in appearance.

Green Roof Design:

The building is stepped at the 12th floor, leaving an open roof area with direct access from adjacent offices and visibility from the floor above. The 11,000 square foot green roof provided on top of the 12th floor helps reduce heating and cooling costs, provides acoustic insulation, greatly extends the roof life expectancy, reduces urban heat island effect and provides an effective filtering and retention system for stormwater.

Soil depth on the 12th floor terrace was limited to 6" at the perimeter to about 12" where low points occur in sloped roof drainage system due to loading limitations. The light weight soil mix was composed of 55% rotary kiln expanded lightweight aggregate, graded sand and treated compost derived from cranberry waste.
Due to safety reasons, the access to the planted area was restricted only to maintenance personnel.

Figure 2.24: View of the stepped green roof
(Source: www.flickr.com/photos, 2011)

Figure 2.25: View of the vegetation on the green roof
(Source: www.greenroofs.org, 2011)

Case study 4: 601 Congress Street, Massachusetts

Waterproofing/Drainage:

The drainage system manufactured by American Hydrotech was installed over a layer of closed cell extruded polystyrene insulation. The drainage system consists of lightweight panels of 100% recycled polyethylene, molded to form water retention cups and drainage channels and are engineered to promote irrigation through capillary action and evaporation into the soil/vegetation layer.

Vegetation:

The low parapet increases the roof exposure to the elements and made for very harsh environmental conditions. The presence of drying winds necessitated the selection of drought tolerant plant materials that could cover and shade the ground plane to prevent extensive water loss through evaporation.

The planting scheme is composed primarily of natural grass masses that vary in height from 1-2 feet. These masses are punctuated by drifts of taller, ornamental Miscanthus grass. In protected areas near the buildings interior walls beds of low growing sedums provide a variety of colors and floral texture.

Using drought tolerant ornamental grasses and perennials of varying heights planted in the roof garden’s 6”-14” deep soil media, Sasaki has created a landscape pattern of colors and textures designed to give the appearance of wind blown drifts set directly against a cloud scattered sky.

Figure 2.26: View of the natural grass vegetation on the green roof

(Source:www.hydrotechusa.com, 2011)

Figure 2.27: View of the natural grass vegetation on the green roof

(Source: www.hydrotechusa.com, 2011)

Case study 4: 601 Congress Street, Massachusetts

1. Land Use Type*:* Commercial

2. Green roof area*:* 11,000 square feet

3. Average annual rainfall: 43.13 in/yr

4. Green roof type: Intensive

5. Roof depth: 6 inches - 12 inches

6. Vegetation type: Vegetation was selected based on the very harsh environmental conditions. The presence of drying winds necessitated the selection off drought tolerant plant material that could cover and shade the ground plane to prevent extensive water loss through evaporation. The planting scheme composed primarily of natural grass masses and sedums in protected areas near the building interior walls.

7. Retention capacity: High
The system consisted of water retention cups made from 100% recycled polyethylene. Since irrigation was provided through capillary action and evaporation into the soil/vegetation, the retention capacity of the green roof system is considered to be high.

8. Detention capacity: High
The excess water from the precipitation is stored in the water retention cups.

9. Did the green roof system successfully meet LID objectives: Yes

12. Unique features:
The unique feature of the green roof system is its aesthetic appeal created by Sasaki Associates. Sasaki has created a landscape pattern of colors and textures designed to give the appearence of wind blown drifts set directly against a cloud scattered sky.

Case study 5: California Acedemy of Sciences,California

“Every scientist is a pioneer. Every scientist loves projects that push the envelope of knowledge. This is another example.”—Frank Almeda, Senior Botanist; California Academy of Sciences

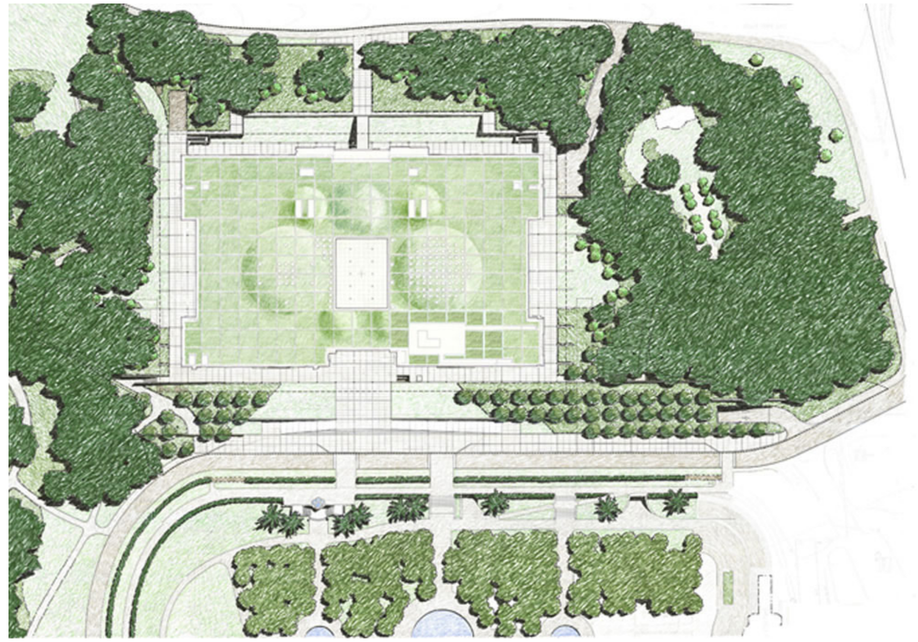

Figure 2.28: Green roof atop California Academy of Sciences building
(Source: www.swagroup.com, 2011)

Project Background

In the heart of one of the country’s largest urban parks, the California Academy of Sciences,built a new LEED Platinum Green Museum in San Francisco’s Golden Gate Park. One of the visions of Architect Renzo Piano was to incorporate the continuing topography of San Francisco through the Academy’s rooftop. Mimicking the hills of Twin Peaks, the roof has four undulating, steeply sloped domed structures. The 2.5 acre undulating green roof sits 35 feet above in the air. These undulating domes, however posed design challenges for installation of plant materials. To solve the installation problem and technical challenges, Rana Creek worked with the design team to develop a built up green roof system with stacked benefits. The key to this process was the BioTray, a bio degradable, reinforced, modular propagation tray made from rapidly renewable coconut coir fibres.

Design Team

Client:
California Academy of Sciences
Owner:
California Academy of Sciences
Architects:
Renzo Piano Building Workshop
Landscape Architect:
SWA Group

Project Highlights

Location:
San Francisco, CA
Year of Project completion:
2007
Building type:
Institutional
Construction type:
New construction
Project area:
197000 square feet

Case study 5: California Academy of Sciences, California

The undulating domed green roof reflects the exhibits below: the Steinhart Aquarium entrance and two 90 foot diameter spheres, one a planetarium seating 300 and the other a three level living rain forest exhibit. Throughout the integrated design is an emphasis on water and energy efficiency, natural light, natural ventilation, indoor environmental quality, sustainable site management. Recycled building materials are incorporated where possible and native plant materials are used not only on the green roof but also in the surrounding landscape.

Figure 2.29: Infographic view of the green roof system
(Source:www.fastcompany.com, 2011)

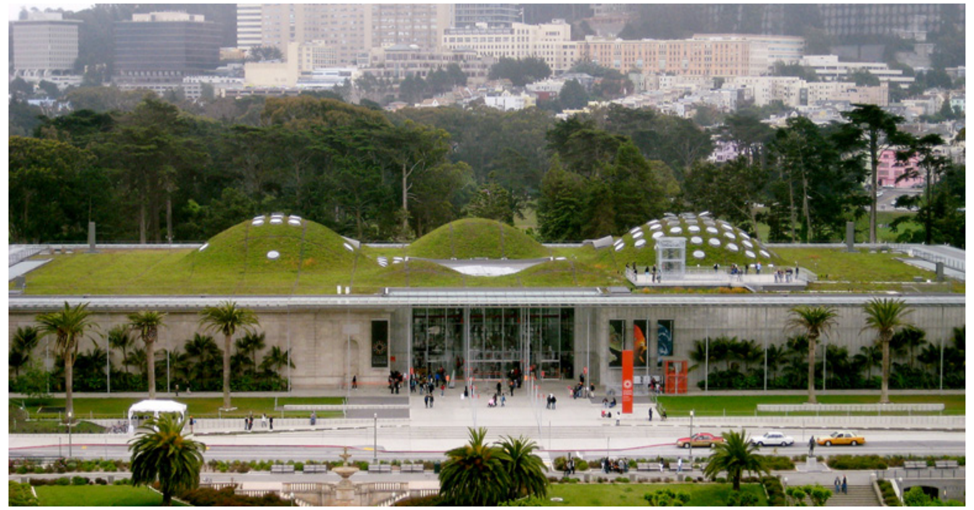

Figure 2.30: Green roof combining ecological space + social space
(Source: www.eot.state.ma.us/smartgrowth, 2011)

Case study 5: California Acedemy of Sciences, California

Green Roof Design:

The green roof measures approximately 130,000 square feet with a depth of 6-7 inches costing approximately $17 per square foot. The architectural form of the green roof is constructed with steel and concrete. There is almost a 40 foot elevation change between the lowest and highest points. The top layer is vegetation and the slopes on the dome which are at an angle of 40% requires soil retention system made with interlocking gabion grid. In between the gabions, the built up section of the green roof contains the growing medium, vegetation mat and drainage mat with water retention and insulation. A Biotray composed of biodegradable, reinforced, modular propagation made from rapidly renewable coconut coir is used as growing medium. Coconut coir is long fiber extracted from the husk of the nut. The plant materials have been grown in a nursery in coconut fiber trays, approximately 2 feet square which is directly placed on the green roof for ease of installation and will decompose allowing roots to expand and create a strong vegetative layer that bonds to the roof.

Vegetation:

The green roof is planted with a variety of wild flowers and other native species. The native plant palette include: Fragaria chiloensis, Prunella vulgaris, Armeria maritime, Sedum spathulitholium, Layia platyglossa, Lupinus bicolor, Eschscholzia erecta, Lasthenia califronica.

Figure 2.31: Natural lighting in the green roof system
(Source: www.archdaily.com, 2011)

Figure 2.32:Native California plant species on the green roof
(Source: www.calacademy.org, 2011)

Case study 5: California Academy of Sciences,California

Waterproofing:

The waterproofing layer contains monolithic hot rubberized asphalt application with a root barrier cap sheet providing additional protection. The reservoir type board allows retention of water within egg crate like structures and drainage of excess water through pinholes into the building storm drainage system. The drainboard retains a quarter cup of water per square feet and can drain as much as 350 gallons of water per square feet per hour. Therefore, the green roof has the capacity to handle large sudden rain events.

Green Roof Analysis:

- Through the green roof components that use, store and absorb water, it is estimated that the stormwater runoff from the building will be reduced by half or about 2 million gallons annually, preventing 70% of the rainwater that falls on the roof from becoming runoff. Runoff from the roof and on site is directed into underground recharge chambers adjacent to the building.
- An 18,000 gallon recharge chamber releases collected water back into the aquifer on the site, and also supplies irrigation water for use during the driest summer months and other periods.

Figure 2.33: Natural lighting system in the green roof system
(Source: www.archdaily.com, 2011)

Case study 5: California Academy of Sciences,California

***1. Land Use Type**:* Institutional

***2. Green roof area**:* 1,30,000 square feet

3. Average annual rainfall: 17.28 in/yr

4. Green roof type: Extensive

5. Roof depth: 6-7 inches

6. Vegetation type: The green roof is planted with a variety of wild flowers and other native species.

7. Retention capacity: High
The reservoir type board allows retention of water within egg crate like structures. The drainboard retains a quarter cup of water per square feet.

8. Detention capacity: High
The excess water is transported though pinholes into the building storm drainage system. It drains as much as 350 gallons of square feet per hour. Therefore, the green roof has the capacity to handle large sudden rain events.

9. Did the green roof system successfully meet LID objectives: Yes

12. Unique features:
The important feature of this project is the combination of the green roof system and a rainwater harvesting system. Through the green roof components that use, store and absorb water, it is estimated that the stormwater runoff from the building will be reduced by atleast half or about 2 million gallons annually, preventing 70% of the rainwater that falls on the roof from becoming runoff. Runoff from the roof and on site is directed into underground recharge chambers adjacent to the building.

Case study 6: Oaklyn branch library,Indiana

“A unique earth-sheltered building with a “green-roof” that merges into its encompassing site. The design process and design solution are an innovative response to a dramatic though difficult site.”
- Storrow Kinsella Associates

Figure 2.34: Green roof plan of the public library, Indiana
(Source: www.storrowkinsella.com, 2011)

Project Background:
William M. Brown, the lead Architect, capitalized on the steeply sloping profile of the lot to create an earth sheltered structure blending the roof with the landscape on the uphill side. The publicly accessible green roof was designed to create a native ‘mesic meadow prairie’ - a native plant community that would cloak the entire site, blending into the landscape. The prairie plant community echoes the landscape of the remainder of the project providing a high habitat value and contributing to the restoration of the prairie landscapes in this region.

Design Team

Client:
Evansville Vanderburgh Public Library
Owner:
Evansville Vanderburgh Public Library
Architects:
Veazey Parrott Durkin & Shoulders, Indiana
Landscape Architect:
Storrow Kinsella Associates, Inc., Indianapolis

Project Highlights

Location:
Evansville, Indiana
Year of Project completion:
2002
Building type:
Institutional
Construction type:
New Construction
Project area:
17,250 square feet

Case study 6: Oaklyn branch library, Indiana

Figure 2.35: View of the library building
(Source: actionmanual.cityparksphila.org, 2011)

The seven-acre site is located along Oak Hill Road on the edge of the built-up area of Evansville, Indiana. The site had been cleared by the previous owner.

The earth-sheltered structure has three “buried” sides with a Mesic Prairie meadow roof. The meadow embraces the majority of the site creating a seamless edge between it and the hidden footprint of the building. Drainage from the overall site and the 103 car parking lot passes through a cypress-edged sedge meadow filtration depression before flowing into an existing stormwater retention pond, and Pigeon Creek beyond.

Case study 6: Oaklyn branch library, Indiana

Green Roof Design:

- The 17,250 green roof system is a 2-layer roof system, that combines a base layer of granular drainage material with an upper layer of growing media. The total depth of this intensive system is 12 inches.

- To minimize long-term service and maintenance costs, the roof deck is designed without roof drains. To provide roof drainage, the roof deck pitches uniformly at 3% towards one edge of the building, where the runoff is reduced, slowed by percolation through the system. The runoff discharges from the down gradient side of the roof, where it is collected in meandering swales. During large rainfall events, the roof incorporates an internal drainage network of perforated rectangular conduits that intercept water during heavy rainfall and discharges it to the storm sewer.

To emulate a mesic meadow prairie ecosystem, characterized by a deep soil profile and perched water-table, Roofscapes, Inc. selected an irrigated two-layer Roofmeadow® Type IV: Meadow 1 green roof system. Designed to last the life of the building, the six inch base layer of granular drainage media and eight inch upper layer of growth media are under-girded by hot-air welded waterproofing membranes. The waterproofing membranes are Sarnafil G-476 reinforced 80 mil PVC waterproofing, supplemented by an upper PVC protective membrane

Figure 2.36: Installing drainage course using pneumatic media handling methods
(Source: www.concreteconstruction.net, 2011)

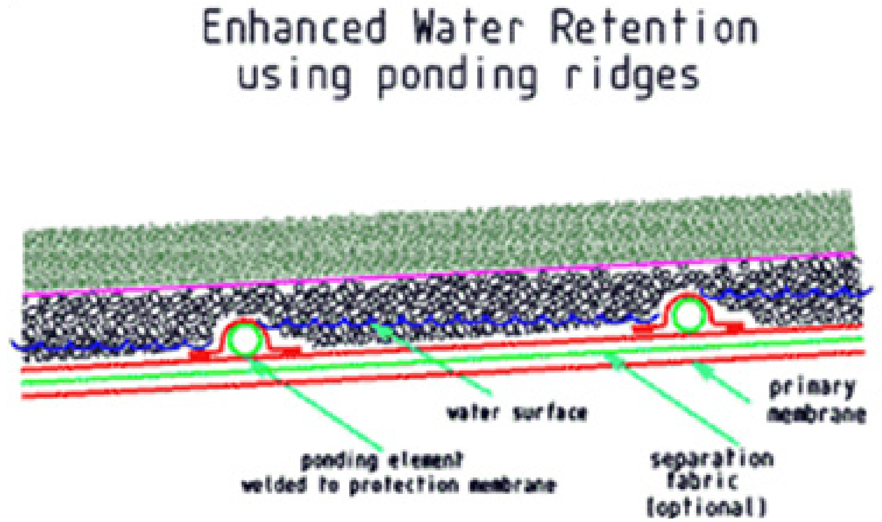

Figure 2.37: Schematic design for riffling ridges
(Source: www.concreteconstruction.net, 2011)

Case study 6: Oaklyn branch library, Indiana

Irrigation System:

A Base level trickle irrigation system is implemented, which furnishes water at the bottom of the green roof profile and only at the rate demanded by the plants. As a result, evaporative loss of irrigation water is negligible and monitoring of soil moisture conditions is not required.

Vegetation:

The prairie meadow is edged with a meandering turf line that sweeps down to the lower level. Informal groupings of red oak and flowering viburnum are arranged around the building side slopes in order to create a transition to the lower level. Masonry parapet walls and a paved perimeter path made from compatible materials harmonize with the natural plant palette. The plant palette contains:
Andropogon scoparious, Bouteloua curitpendula; Centaurea cyanus, Campanula rotundifolia, Carex annectans, Carex bicknellii, Coreopsis tinctoria, Elymus Canadensis, Liatris spicata, Phlox drummondii, Phlox pilosa, Sphaeralcea coccine, and Sporobolus heterolepis.

Figure 2.38: Irrigation controller
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Figure 2.39: Installing innovative ponding ridges and trickle irrigation system
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Figure 2.41: Mature roof
(Source: www.concreteconstruction.net, 2011)

Case study 6: Evansville Public Library,Indiana

***1. Land Use Type**:* Institutional

***2. Green roof area**:* 17250 square feet

*3. **Average annual rainfall**:* 42 inches per year

4. Green roof type: Intensive system.

5. Roof depth: 12 inches

6. Vegetation type:

Vegetation mainly consists of a prairie meadow, with a meandering turf line that sweeps down to the lower level. Informal groupings of red oak and flowering viburnum are arranged around the building side slopes in order to create a transition to the lower level.

7. Retention capacity: High

A Base level trickle irrigation system is implemented, which furnishes water at the bottom of the green roof profile and only at the rate demanded by the plants

8. Detention capacity: High

The runoff discharges from the down gradient side of the roof, where it is collected in meandering swales. During large rainfall events, the roof incorporates an internal drainage network of perforated rectangular conduits that intercept water during heavy rainfall and discharges it to the storm sewer.

9. Did the green roof system successfully meet LID objectives: Yes

10. Unique features:

The important feature of this project is the combination of green roof and swales to address excess precipitation. Also, to minimize long-term service and maintenance costs, the roof deck is designed without roof drains. To reduce the potential for long-term service and maintenance costs, the roof deck was designed without roof drains. To promote drainage, the roof deck pitches uniformly at three percent toward one edge of the building. Normal runoff, reduced and slowed by percolation through the system, discharges from the down gradient side of the roof, where it is collected in a meandering grass swale. During large rainfall events, an internal drainage network composed of perforated rectangular conduits intercepts percolated water, directs and discharges it to a perforated storm sewer embedded in the swale

Conclusion

Green spaces are at a premium. Roofs, on the other hand account for 15 % - 25% of land surface in cities. There is a significant body of research on the environmental benefits of green roofs, but there are not many green roofs outside of academic setting that are both monitored and accessible. And since green roofs are still relatively new in the United States, there is a great demand for successful local examples. Building owners and developers want to know that these projects are feasible and marketable. Public officials and regulatory authorities want to know that they will deliver the promised benefits. All these can be achieved from the six case studies described and analyzed previously. From the six different case studies from three important land use types, it is observed that green roofs if constructed properly, helps achieve pre-development hydrologic conditions. The system if designed properly helps reduce peak runoff rate to a great extent. Green roofs in addition to providing stormwater benefits also provide an aesthetic appeal to the building functions. In addition, green roofs also provide rainwater harvesting benefits if designed with storage facilities. This eventually reduces the use of portable water were non - portable water can be used.

The case study examples analyzed provide useful insights for the design and installation of green roofs. The green roofs projects studied varied in size, function, roof type, land use and construction technique. However, the composite of all the projects creates a bigger picture from which conclusions can be drawn. The lessons learned from the case studies are discussed below:

Design recommendations:

1. Compatibility of green roof components: Successful implementation of green roofs require that the building structure can support the green roof, plant selected should be suitable to the climate type, the soil mix specified is compatible with the plants selected and the irrigation system provided is adequate to water the plants. The case studies indicate that common challenges that required measures for green roofs included inappropriate plant selection and inappropriate irrigation method adopted.

2. Irrigation system: Most of the green roof case studies have provided an irrigation system for use only during the establishment period. It is important to take into consideration the average rainfall and other climatic factors into consideration when making the plant selection for the green roof system. It is important to specify plants that are drought tolerant if the project intends no irrigation of the green roof after the establishment period. The Solaire building has achieved a good irrigation system by means of drip irrigation technique that saves water by minimizing evaporation as compared to the Austin City Hall, where due to the long hot summer months the vegetation requires constant irrigation. Therefore, in such cases it is important to specify drought tolerant plants to meet the green roof LID objectives successfully.

3. Accessibility for maintenance: Green roofs should be provided with easy access for maintenance purposes. Green roofs which are not designed for accessibility by building occupants often encounter maintenance issues. Weeds which are a persistant problem during the establishment period should be taken care off which require maintenance access.

Conclusion

4. Feasibility study: A structural feasibility study should be done to ensure that the green roof strategy can be implemented especially on existing building roofs that may have structural load limitations. The roof structure must be capable of accommodating the industry recommended minimum of 2” soil depth.

5. Coordination of design team members: Successfully design and implementation of green roofs require coordination of several design team members such as the architect, roofing contractor, landscape designer and horticulturists. All these roles play an equally important part in the design implementation and successful construction of the green roof system.

6. Maintenance: This is one of the most important elements for a successful green roof system. Information about the irrigation system and the design intent should be conveyed to the maintenance staff through an Operations and Maintenance Manual. It is important to update maintenance procedures after the establishment period because often green roof projects encounter than the maintenance efforts required for tasks such as removing weeds and watering plants during the establishment period are different than what was anticipated.

Chapter 3.1: LID Practice 2 - Rainwater harvesting systems

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Introduction

Rain, a form of precipitation is the first form of water in the hydrologic cycle, the continuous circulation of water in the earth atmosphere system. Currently most part of the world depend on secondary sources of water which are rivers, streams, lakes and groundwater against the primary source which is rain. Rainwater catchment directly responds to the value of this primary source of water making optimal use of rainwater where it falls.

The aim of rainwater harvesting is to concentrate runoff and collect it in a basin or cistern to be stored for future use. Rainwater captured from roof catchments is the easiest and most common methods used to harvest rainwater. Other means of rainwater harvesting may be from any hard surfaces such as stone or concrete patios, and asphalt parking lots.

The chapter is organized under three titles; Rainwater harvesting systems which details the history behind using these systems, components of a rainwater harvesting systems which details the various components involved in the design of the system, planning process which details the planning criteria's for the system and types of storage systems which details the various types of storage tanks available to use in the system.

Figure 3.1: Residential rainwater harvesting system
(Source: www.rwh.in, 2011)

Rainwater harvesting systems

Rainwater harvesting for water supply had been perfected in ancient times in various cultures and is not a new concept for water resource management. Two thousand years ago, the Romanian builder Vitruvius created rainwater collection plants. The atrium collected rainwater flowing from the roofs into an overground and underground water basin that looks like bottle with small opening which was easily locked to protect water from external pollution.
These systems are used for small and large scale projects, retrofit an existing site or to be an integral part of a new project. They can be designed as a passive, low cost system or active, more complex and costly system. The decision for the type of system to be adopted depends on:
1. Intended use of the system (portable/non portable use)
2. Intensity of use of a system

Intended use of the system
The intended water demands must be evaluated through a water budget. The demand for water during a rainy season may be low but water may be on a high demand during the dry period. Therefore the water required during dry periods will determine the quantity of rainwater collected during rainy periods and also determine the storage capacity of the rainwater harvesting systems. Systems may be classified like:
- Small systems: 1000-5000 gallons
- Medium systems: 5001 – 10,000 gallons
- Large systems: 10,001 – 25,000 gallons
- Very large systems: upto 100,000 or 200,000 gallons.

Figure 3.2: Chand Bhori Step well, Abhaneri, India
(Source: www.apanbear.spaces.live.com/blog, 2011)

Figure 3.3: Step well near Bikaner, India
Step wells in India used as Rainwater Harvesting Systems
(Source: www.indiamike.com/photopost, 2011)

Rainwater harvesting systems

Intensity of use of the system:

1. *Occasional:* a small storage capacity system that collects rainwater for one or two days of use. This system is best for climates with a uniform rainfall pattern and very few dry days between rainfall events.
2. *Intermittent:* a small to medium storage capacity system where the user's needs are met for the portion of the year. This system is best for climates with a single rainy season where it can meet most of the user's needs during that part of the year.
3. *Partial:* medium-large storage capacity systems. This system is best in areas where a dependable, uniform rainfall occurs in a single or two short wet seasons.
4. *Full:* large storage capacity system that provides all of the water needed by the user for the whole year. Best option for areas with no alternate water source.

All factors classifying a rainwater harvesting system can be determined and evaluated with the creation of a water budget.

Water budget (water balance analysis):

Amount of rainwater that can be collected in the project catchment area and to determine if that amount will meet the user's water demands.
It also provides a demand supply analysis on a monthly basis which helps in determining the size of the storage area. It also helps in determining how much, supplemental water is needed to augment the intended use of collected water.

Figure 3.4: Underground Rainwater Harvesting System
(Source: www.oak-barrel.com/house_rainwater_supply, 2011)

Components of rainwater harvesting systems

The six basic components of a rainwater harvesting system are:
1. Catchment area
2. Conveyance systems
3. Roof washing devices
4. Storage devices
5. Distribution devices
6. Storage devices

1. **Catchment area:** They are defined as the surface upon which the rain falls. It may be a roof or an impervious pavement which might include landscape areas. Catchment surfaces for non potable use can't be achieved with any type of roofing material. For potable use, desirable roofing materials are metal, clay and concrete. Water collected from roof surfaces that contain zinc coatings, copper, asbestos sheets or asphaltic compounds, lead flashings or painted with lead based paints cannot be used for potable use. An accepted roof coating for potable use of water is Raincoat 2000.
Other catchment areas include patio surfaces, driveways, parking lots or channeled gullies. The water from these surfaces cannot be used for potable use due to high degree of contamination, stormwater collected from ground level catchment areas unless a purification system is accompanied by the distribution system.
Rainwater being acidic always carries minerals when it flows into the storage systems. Due to this, in places where rainwater is intended for potable use, the first step should be to test the water collected for the water content and the minerals which need to be removed and if the catchment system needs any alteration.
The amount of rainwater collected varies extensively by the size and texture of the catchment area. Most times, 90 percent of the rainwater can be collected from rooftop rainwater harvesting. Good water quality comes from smoother, more impervious catchment or roofing materials. Captured rainwater quality also depends on pattern and frequency of rainfall. Greater rainwater volumes and frequencies will transport fewer pollutants to the first flush device.

Figure 3.5: Rooftop catchment area
(Source: www.lastormwater.info/blog, 2011)

Components of rainwater harvesting systems

2. **Conveyance:** These are channels or pipes that transport the water from the catchment area to storage. Commonly used rainwater conveyance systems comprise of gutters with downspouts and rain chains.

There are two types of conveyance systems, wet and dry systems.

- A wet system involves downspouts that lead to a storage system where standing water is maintained; downspouts run down the wall and underground and then up into the tank.

- A dry system drains the downspout into the storage system, thus eliminating any standing water in the conveyance system after a rain event. Dry systems reduce the potential of mosquito habitat.

Gutters should always be kept clean and free from debris to increase the life of the gutter material, since clean gutters dry out faster after a rain event and they last upto three times longer than wet gutters which equates to a significant cost savings. In order to keep gutters clean and free from leaf debris, they should have continuous leave screens made out of one quarter inch wire mesh screen in a metal frame or a similar product covering the entire length of the gutter.

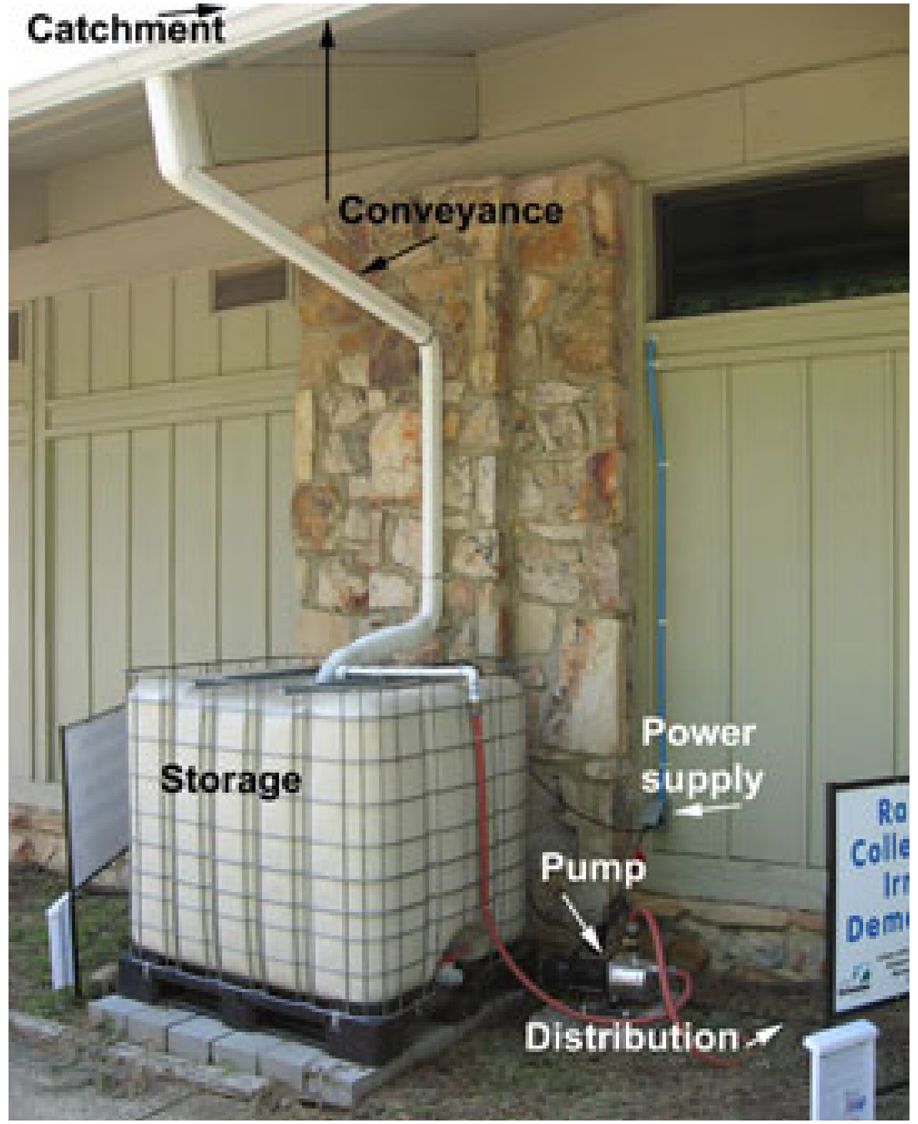

Figure 3.6: Rainwater conveyance pipes

(Source: www.rainharvesting.com, 2011)

Components of rainwater harvesting systems

3. **Roof washing:** Defined as the initial process to reduce debris and soluble pollutants that may enter the rainwater harvesting system.
Roof washing devices include gutter leaf guards, rainheads, screens, and/or first flush devices. First flush devices are mainly used when water is to be used for human consumption.
Rainfall that falls first on a large area roof surface carries the highest concentration of debris and soluble pollutants.

Reasons for reducing debris and silt that may enter a rainwater storage system:

- Reduce frequency of tank cleaning
- Reduce bacterial inflow which is often attached to solids
- Reduction in nutrient level which helps in reducing or eliminating mosquito larvae growth
- Reduce organic loading, creating less chance of anaerobic conditions and odor in the tank.

First flush devices are located prior to a cistern or storage tank inlet.
First flush devices are particularly necessary when a rainfall follows a long dry period of no rain, since dry spells, debris and other pollutants build up on the catchment surface. During such periods large volumes of water may be required to clean the contaminants, sometimes surpassing the storage capacity of the first flush devices.
Roof washing systems perform well only when its use is combined with other filtering devices on gutters, downspouts and first flush devices, especially when potable water is required from the rain water harvesting systems.

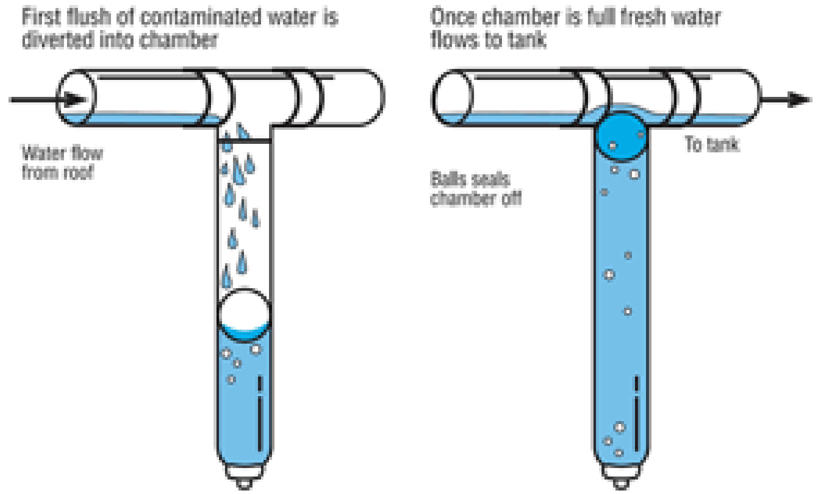

Figure 3.7: A first flush diverter removes the initial flush of water from the catchment surface so it does not end up in the storage tank. The size of the diverter tube should be proportionate to the catchment surface. *(Source: www.rainharvesting.com, 2011)*

Figure 3.8:The leaf beater and first flush diverter (left) as a unit and installed into a home catchment system (center). The leaf beater removes leaves and large objects from the water flow before the water enters the first flush diverter (right).

(Source: www.rainharvesting.com, 2011)

Components of rainwater harvesting systems

4. **Storage:** Storage cisterns can be classified into 3 categories:
-Surface, at grade or above ground cisterns
-Below grade or underground cisterns
-Integral cisterns or tanks built into a devilling or commercial building.

Cisterns need to be waterproof at the base, sides and cover. Cisterns are typically covered and made of stone, steel, concrete, ferro cement, plastic or fiberglass. A storage system should be durable, attractive, water tight, clean and smooth inside, sealed with a non toxic joint sealant, easy to operate and able to withstand the forces of standing water. The tank should be sealed well to prevent evaporation and mosquito breeding and to keep insects, birds, lizards, frogs rodents from entering the tank. Cisterns and tanks should not allow sunlight to enter the tank which will cause algae to grow inside the tank. Storage cisterns sometimes contain settling compartments that help in any roof or pavement runoff contaminants to settle rather than remain suspended.
Types of storage systems depend on technical and economic considerations:

- Options available locally
- Space available
- Storage quantity desired
- Cost of the vessel
- Cost of excavation and soil composition
- Aesthetics

Best cisterns will have two intakes, one floating intake for potable water and one stationary intake lower in the tank to allow the mixing water to be used for non potable uses. The best overflow would be one that would allow water to exit from the anaerobic zone in the tank.

Figure 3.9.1: Types of storage tanks

Figure 3.9.2: Types of storage tanks

Figure 3.9.3: Types of storage tanks
(Source: www.rainharvesting.com, 2011)

Components of rainwater harvesting systems

5. **Distribution**: stored rainwater may be conveyed or distributed by gravity or by pumping. Submersible or at grade pumps may be used in any rainwater storage system. The storage system overflow may act as distribution system that delivers excess water to an adjacent landscape. All overflows exposed or out letting above ground should have some means of stopping rodents and insects from entering the storage system.
For landscape irrigation, stored rainwater may go through additional filters before it is directed into an irrigation pump and distribution lines to avoid clogging of the irrigation system. For portable water, the water must go through a purification process prior to distribution.

6. **Purification**: If harvested rainwater is to be used for portable use, the rainwater needs to be pumped to the purification system before distribution. Portable water treatment systems include filters, disinfection and buffering for pH control. Filtering and disinfecting are two components that will enhance a portable system.
Rainwater quality is generally acceptable for portable use except when contaminated by organics such as leaves. Chemicals may be used to sterile and purify the stored water. Purification of rainwater is enhanced largely by first flush devices. Hence they should be emptied after each storm; gutters should be clean and free of debris and overflow lines should be free of obstacles that may block the pipe.
Filters, pumps and cisterns should be inspected periodically to check for loss of efficiency and to flush any debris that may have collected at the bottom.

Figure 3.10: Distribution Pump
(Source: www.rainharvesting.com, 2011)

Figure 3.11: A screened basket in the manhole will prevent a lot of organic matter and mosquitoes from entering the tank.
(Source: www.rainharvesting.com, 2011)

Planning process

Factors considered during design and implementation stage of catchment areas are rainfall, buildings, catchment area type, soil and formation, ground water, quality of pure rainwater and quality of rooftop rainwater.

Rainfall: The quantity and quality of fallen rainfall are the key factors on the quality of runoff over both roofs and roads. The total quantity of rainfall in each storm, rainfall intensity, return period and duration are used mainly in the design of the storage volume needed for the collected rainwater. The quality of rainfall is important in places with high rate of air pollution.

Buildings: The building sizes, location, ages and layout i.e crowded, scattered or remote are key factors for estimating the runoff water that comes from the roof. The quality of rooftop water is affected by the roof type: concrete, bitumen sheets or clay tiles. For instance, concrete roof runoff has lead concentration as compared to clay tiled roofs. The roof type also affects the value of pH which is the key factor in chemical precipitation of pollutants of runoff. Concrete roof runoff has high pH values which is a good media for heavy metal compounds precipitation. The use of the roof and the periodic cleaning greatly affects the quality of rooftop runoff.

Open catchment areas: Quality and quantity of the rain water runoff depends on the land uses, soil cover and topography. In agriculture land uses, the runoff is affected by eutrophication. Also the water is expected to be highly polluted if it passes industrial zones or areas with badly maintained waste water network.

Soil type: Soil type plays an important role when collected runoff is diverted to infiltration basins to replenish the groundwater system. The infiltration capacity and the vulnerability of the soil to clogging play an important role. The soil type also plays an important role in the purification of the collected stormwater in the removal of organic matters and bacteriological pollution in addition to sorption of heavy metals. Soils such as sand and gravel have low pollutant removal rate whereas have high infiltration rate and soils like clay and silt have low infiltration rate but are effective in pollutant removal.

Groundwater system: Recharge of groundwater using rainwater harvesting systems depends on quantities of recharged water, quality and hydraulic parameters of the receiving ground water system. The groundwater table should be at sufficient depth from the floor of the infiltration system to give the chance of water purification in the unsaturated zone.

Planning Process

Quality of pure rain water
During precipitation there are inorganic acid compounds resulting from solution of air carbon dioxide and nitrogen oxides in addition to other organic compounds. This decreases the pH value of the fallen rainwater to different extents depending on the place and the air pollution from industrial gas emissions.

Quality of rooftop rainwater
Pathogen levels of rooftop rainwater are much lower compared to stormwater. The quality mainly depends on the roof type. Roof water takes contents of sulfates, nitrate and heavy metals like lead, cadmium and zinc is addition to organic components. The degree of pollution depends on the land use type, roof type and its location, if it is residential, industrial or commercial. The quality also depends on the age of the roof. The accumulating quantity of dust during dry periods also determines the quantity of the runoff.

Most common roof types are:

1. **Concrete roofs**: These roofs contain an alkaline material calcium carbonate in addition to the dust particles accumulated on the roof. The location of the roof and the age of the concrete roof play an important role. This changes the quality of the rainwater runoff and increases the pH value which in turn has a positive effect on removing the heavy metals from the runoff.
2. **Tile roof**: These roofs include clay tiles and horizontal tiles. The influences of quality of rainfall runoff from tiled roofs are very minimal.
3. **Bitumen roofs**: Theses roofs contain oil products. Due to their unpleasant smell and yellowish coloring, it is suspected to lead to cancer when in long contact with the skin. The bitumen strips contain quartz, gravel and sand which is important in adsorption of heavy metals in the existence of high pH values.
4. **Asbestos roofs**: This material contains toxic dust which is harmful for the environment and the human body. Therefore, water collected from asbestos roofs is not suitable for portable uses.
5. **Metal roofs**: These roofs can increase the metal content in the roofs which makes the roof water unsuitable for portable uses.

Types of storage tanks

Above and below ground storage tanks

Above ground storage systems can be made up of concrete, metal/steel, poly, fiberglass tanks and bladders. Underground systems can be incorporated as part of a new construction which helps in space saving solutions. Ideal for urban areas where the small house blocks prohibits the use of above ground tanks, many concrete tanks are trafficable and can be located under the driveway of the house, with only the access covers visible

Figure 3.12: Cast in-situ, below ground storage tank

(Source: www.rainharvesting.com.au/concrete_tanks.asp, 2011)

Figure 3.13: Above ground, wooden rain barrel

(Source: www.starkenvironmental.com/images, 2011)

Types of storage tanks

Metal tanks

Metal/steel tanks have been popular for years and have continued to grow with the development of new contours, shapes and sizes. Metal tanks are also available using a modular construction system which ensures strength, water quality and makes delivery onsite more manageable. These modular tanks can be built to store significant water volumes and are extremely popular in rural and commercial applications.

Figure 3.14: Above ground, metal storage tank

(Source: www.rainharvesting.com.au, 2011)

Poly or Plastic Tanks

These are the most popular and fastest growing type of tanks used. They are made from polyethylene which is treated, impact modified and food grade which implies that it is suitable for portable use. These tanks are popular due to its lightweight material which makes it easy for site preparation and installation. They are most commonly used for household use and they come in various shapes, sizes and colors.

Figure 3.15: Above ground, Poly ethylene storage tank

(Source: www.rainharvesting.com.au, 2011)

Types of storage tanks

Concrete tanks:

These tanks can be either cast in situ or can be pre cast tanks. An ideal in-ground solution. Feature load bearing tank lids, so they can be installed under garages or driveways.
Site Preparation : Compacted cracker dust or compacted sand, stabilized around the edge.

Bladders:

These are sealed, flexible, enormously high puncture resistant which are designed to be located in the sub floor space and can be used in areas as low as 750mm in height and without inducing any structural load to the dwelling.
By placing the bladders under a house or deck, they can collect ALL of the rain that falls on the roof by diverting the ALL downpipes to a common in-flow pipe which goes into the side of the bladder. This means that more rainwater can be collected much faster than in a traditional water tank. Once the bladder or bladders are full, any excess water diverts to the existing storm water system so that there is no fear of over-filling.

If space permits, multiple bladder tanks can be installed either end-to-end or side-by side for maximum storage, as demonstrated in the diagram below. Bladders are typically designed to fill to a maximum height of 600mm.

Figure 3.16: Bladders, used as sub-floor or underground storage
(Source: www.rainharvesting.com.au, 2011)

Conclusion

From the literature review, it can be concluded that, in-situ rainwater harvesting practices has a positive effect on the landscape function and help preserve water as natural resource. Rainwater harvesting shows significant promise, both as a sustainable stormwater management strategy as well as a water conservation and source substituted approach. It is seen that from harvesting all the rainwater from the roofs before it reaches the ground and becomes stormwater, water used for non-portable uses can be taken care of using this harvested water. This helps in the reduction of the use of portable water to almost nearly 70% in any given site. Rainwater harvesting also helps in the overall reduction of cost and energy usage for the project.

Based on the conclusions drawn from the literature review, five case studies from different land uses have been analyzed. These case studies are analyzed based on the rainwater harvesting objectives listed below:

1. Quantity of rainwater harvested: The quantity of rainwater that can be harvested is calculated using the average rainfall date for the region and the catchment area. Quantity of rainfall helps determine the sizing of the cisterns and the rain barrels required. This calculation also gives an idea of the amount of portable water that can be saved using the harvested rainwater for uses like landscape irrigation, toilet flushing and other non-portable uses.

2. Quality of harvested rainwater: In the case studies, the quality of harvested rainwater is accessed based on the infiltration criteria and the quality of the catchment surfaces. If the harvested rainwater meets one of the criteria : groundwater infiltration or catchment surface is a green roof, the quality of the harvested rainwater is considered to be good. If the harvested water is not infiltrated and the catchment surfaces are concrete or metal roofs, the quality of the rainwater is considered to be medium due to the presence of pollutants on the roof surface. The quality of rainwater also helps in determining the amount and type of purification required if the harvested rainwater is planned to be used for landscape irrigation, toilet flushing or clothes washing.

3. Rainwater re-use: If the harvested rainwater is put to good use like landscape irrigation, flushing of toilets and other non-portable water uses along with groundwater infiltration, the rainwater harvesting system is considered to be efficient in stormwater management helping reduce runoff and flooding.

Chapter 3.2: Rainwater harvesting system case studies

Case study 1: 10th @ Hoyt Apartments, Portland, Oregon

Figure 3.17: View of the courtyard at 10th @ Hoyt Apartment

(Source: www.artfulrainwaterdesign.net/photos, 2011)

Project background:

One great example of rainwater harvesting is the 10th @ Hoyt courtyard located in downtown Portland, Oregon. This apartment courtyard harvests rainwater to blend aesthetics and functions and turns rainwater into art. Located in the heart of Portland sits the Pearl District, best known for its arts, restaurants and shopping. In March 2003, the 10th @ Hoyt apartments were completed adding to the residential boom of the Pearl District, this 8,500 square foot courtyard is surrounded on all sides by six storey buildings with apartments on the top five floors and retail space on the ground floor.

Design Team

Client:
Tramell Crow Residential
Landscape Architect:
Koch Landscape Architecture, Portland, OR
Architect:
Ankron Moisan Associated Architects, Portland, OR
Managed by:
Riverside Residential

Project Highlights

Year of Project completion:
2003
Building type:
Multi unit residential
Construction type:
New construction
Project area:
8500 square feet

Case study 1: 10th @ Hoyt Apartments, Portland, Oregon

The courtyard features a green roof that captures, conveys and creatively displays on site stormwater runoff. With Portland having an average annual rainfall of over 36 inches per year, it is no surprise that the City of Portland requires all new and re-development projects with over 500 square feet of impervious surface to manage the runoff.

Rainwater Harvesting System Design:

The main goal for Koch Landscape Architecture was to combine landscape history, design, art, sculpture, stormwater collection, detention and re-circulation into this courtyard to create an experience to the resident and the visitor. This was done using a series of copper gutters that collect the stormwater, display it through artistic fountains, detain it and then re-circulate it though two sculptural fountains. The stormwater management for this site is addressed through treatment and detention. This was accomplished by using an underground cistern that holds the majority of the rainwater runoff from the roofs of the surrounding buildings. This cistern treats the stormwater by allowing for some particles to be settled out during detention and relieves the city's municipal system for a short period after a rain storm.

When one first enters the courtyard, you enter through a portal on the west side of the site which is meant to be an extension of the street suggested by the paving pattern. This portal leads your eye directly into one of the three copper downspouts that convey rooftop rainwater from all the buildings. These downspouts then channel nearly all rooftop rainwater into pre-cast runnel systems, two of these runnels empty water onto locally constructed Cor-ten steel plates penetrated with multi colored glass buttons and eventually into shallow detention basins filled with river rock. These two downspouts account for about half of the rainwater from the roofs on the site. The other downspout accounts for the other half of rooftop rainwater and transfers this water through a pre-cast runnel system and then eventually sends the rainwater into a concrete cistern constructed from Calite concrete (A faster settling concrete that requires no waterproofing). This cistern retains water and then re-circulates it through a series of two separate Cor-ten weir boxes (using pumps), which are also penetrated by glass buttons and lit from within. Several hours after the water is circulated through, it is released to the city of Portland municipal system but not before it is treated according to the city code.
This cistern has the capacity to hold all of the roof rainwater for a 1/8" storm event and detain it for approximately 30 hours after the storm.

Case study 1: 10th @ Hoyt Apartments, Portland, Oregon

Aesthetic features of the system:

The great thing about detaining the stormwater on-site is having the advantage of artfully using the water that is detained. Steve Koch design did just that by beautifully displaying the detained water through a series of fountains.

Drawbacks:

The entire landscape is built on a concrete slab over a parking garage which limits the opportunities for on site infiltration into the soil as well as re-charging the aquifer, but this constraint was taken full advantage of and utilized for a significant amount of on-site detention. The riverside management company in charge or maintenance of the courtyard does not fully understand how the system works, and what needs to be done in order to properly maintain the system. One major problem includes the drain getting plugged on the cistern, so that the water does not drain into the cities system. If the cistern outlet is being blocked so that the water cannot be drained, then the water just keeps recalculating through the fountains longer than 30 hours after the rain storm, which was not the intent of the design.

Figure 3.18.1: View of Cor-ten steel plates with multi colored glass buttons

Figure 3.18.2: View of Cor-ten steel plates with multi colored glass buttons

Figure 3.19: View of copper downspout

(Source: www.artfulrainwaterdesign.net/photos, 2011)

Case study 1: 10th @ Hoyt Apartments, Portland, Oregon

1. Roof top type: Green roof

2. Average annual rainfall: 36 inches per year

3. Catchment area: 8500 square feet

4. Quantity of rainwater that can be harvested:

Total catchment area = 8500 square feet
Divide by 1000 = 8.5
Multiplying by 550 to determine gallons collected per one inch of rain = 4675 gallons per one inch of rain
Multiple this by average annual rainfall of Oregon = 4675 x 36 = 1,68,300 gallons per year
The amount of water that can be collected = 1,68, 300 gallons per year

5. Quality of harvested rainwater: Since the harvested rainwater is collected from the green roof system, the water is considered to be good.

6. Usuage of harvested rainwater: Rainwater is used as part of an aesthetic feature in the courtyard. and is eventually released to the City of Portland municiplan system after treating it in accordance with the city code.

7. Comments: The system has a disadvantage of not being able to infiltrate the harvested rainwater since the entire landscape is built over a concrete slab. If the water is collected in infiltration trenches or cisterns stored underground, infiltration then becomes a possible option. Also, since the harvested rainwater is relatively free from pollutants, it could be used for landscape irrigation which the system does not seem to be doing.

Case study 2: The Florida House Learning Center, Tampa, Florida

Figure 3.20: View of the entrance of the Florida Learning Center
(Source: www.harvesth2o.com, 2011)

Design Team

Architects:
Osborn Sharp Associates
Landscape Architect:
David Young

Project Highlights

Location:
Sarasota, Florida
Year of Project completion:
1994
Building type:
Single family residential
Construction type:
New construction
Project area:
3900 square feet

Project background:

The Florida House Learning Center is a demonstration home and yard featuring an environmentally friendly building, rainwater harvesting, and sustainable landscaping materials and methods. The landscape was designed to be a "Model Florida Yard", demonstrating the use of native and drought tolerant plants, xeriscaping, rainwater catchment, pervious walkways and other ways to reduce detrimental run-off into Florida's estuaries and bays. The house which opened on earth day in 1994, has been visited by millions of visitors and clearly demonstrates environmentally appropriate design strategies and technology for living in southwest Florida.

Case study 2: The Florida House Learning Center, Tampa, Florida

Florida, which boasts an abundance of rain every year, rainwater harvesting focuses more on protecting precious resources than on catching limited resources. The Florida House is located in Sarasota, Florida, an area that typically gets over 50 inches of rain a year. Much of this rain normally becomes runoff on the streets, catching pollutants such as fertilizers and pesticides on the way to the lakes, streams and waterways.
The "Model Florida Yard" at the Florida House demonstrates the use of rainwater harvesting, xeriscaping, edible landscaping, micro-irrigation, composting, and recycled mulch, as well as the reduced use of fertilizers, pesticides, water, energy and reduction of detrimental run-off into our waterways.

"The rainwater collection system was included in the project because it's important to show a better way of managing water locally" states Betty Alpaugh, Project coordinator at the Florida House. The average water per capita use in Florida has been reduced by almost 40% from 140 gallons to 88 gallons per day, in the years since the Florida House opened.

Rainwater harvesting system:

The key components of the rainwater harvesting system contains:

- Metal roofing and gutter system
- Two 2,500 gallon tanks
- Two 1.6 gallon faucets
- Two low-flow shower heads
- One 1.6 gallon dish washer
- One 1.6 gallon toilet using cistern water
- One high efficiency clothes washer using cistern water

The system includes both a traditional rainwater catchment system, as well as a greywater system to fully demonstrate ways to maximize water usage.

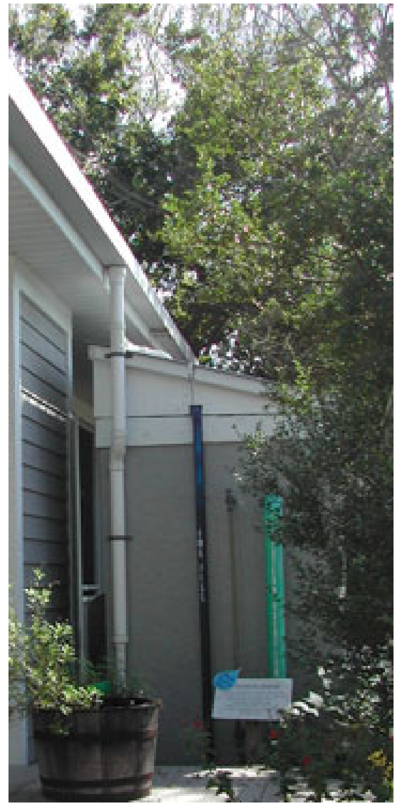

Figure 3.21: View of the rainwater catchment system at Florida House
(Source: www.harvesth2o.com, 2011)

Case study 2: The Florida House Learning Center, Tampa, Florida

The rainwater catchment system uses fairly standard equipment (tanks, gutters, pumps and valves), but has some unique aspects to it - like using rainwater in the washing machine. Florida House features a dramatic storm water pond and ground water recharge area. The pond contains a liner at the very bottom to hold around 18 inches of water year-round, but the sides are sandy. All cistern overflow is directed into this pond to recharge the groundwater.

Some of the other conservation features highlighted at the Florida House include:

- Kitchen faucet with sensor to automatically turn on and off the water
- Dual flush toilet using .8 gallons (3 liter) for liquid flushes and 1.6 gallons (6 liter) for solid flushes
- Clothes washing machine using cistern water
- Passive solar 40 gallon (152 liter) hot water heater
- Closed-loop hot water recirculating system to bring hot water at the touch of a button.

No single innovation will succeed in saving our natural resources, but by cultivating an awareness of the multitude of ways we can be environmentally friendly, the Florida House is contributing significantly to a future based on sustainable development.

Figure 3.22: View of the pond where excess runoff is directed
(Source: www.harvesth2o.com, 2011)

Case study 2: The Florida House Learning Center, Tampa, Florida

***1. Roof top type**:* Metal roof

***2. Average annual rainfall**:* 50 inches per year

3. Catchment area: 3900 square feet

4. Quantity of rainwater that can be harvested:
Total catchment area = 3900 square feet
Divide by 1000 = 3.9
Multiplying by 550 to determine gallons collected per one inch of rain = 2145 gallons per one inch of rain
Multiple this by average annual rainfall of Oregon = 2145 x 50 = 1,07,250 gallons per year
The amount of water that can be collected = 1,07, 250 gallons per year

5. Quality of harvested rainwater: Since the landscape contains practices like xeriscaping, composting and reduction in the usage of fertilizers, pesticides, the runoff from the learning center is considered to be fit for ground water recharge.

6. Usage of harvested rainwater: The harvested rainwater is re-used for landscape irrigation, flushing of toilets and most innovative use of the harvested water is its use in clothes washer.

7. Comments: The rainwater collected in this project is put to excellent use from the analysis. This is the only project among the five case study analysis where harvested rainwater is used in the clothes washer. In addition to this, it is also used for landscape irrigation, faucets and ground water recharge as well. This project has enabled the reduction of water usage in Florida by 40% from 140 gallons to 88 gallons, since the learning center opened.

Case study 3: Northgate Civic Center, Seattle, Washington

Figure 3.23: View of Northgate Civic Center
(Source: www.seattle.gov, 2011)

Project Background

Northgate Library, Community Center and Park anchors the redevelopment of Northgate, a suburban-style commercial area in Seattle. It combines three programs and funding sources into one integrated development, and converts a fully paved site into a multi-use pedestrian friendly campus with close connections to transit and adjacencies to green space.
The community center was designed to take advantage of natural systems, featuring natural ventilation and natural light. An underground detention vault retains stormwater from the site along with cleaned stormwater from adjacent 5th Avenue, releasing it gradually into the watershed.

Design Team

Owner:
Seattle Parks and Recreation
Architects:
Miller Hull
Landscape Architect:
Site Workshop

Project Highlights

Location:
Seattle, Washington
Year of Project completion:
2006
Building type:
Commercial
Construction type:
New construction
Project area:
10,000 square feet

The system for water harvesting, treatment, and detention is a major feature of the project. A large stormwater vault collects runoff from roofs and paved surfaces on the site, releasing it for natural filtration and diverting it from the storm sewer system. It supplies all irrigation needs and helps to restore natural hydrology by gradually releasing the water into the downstream channel of Thornton Creek.

Rainwater Harvesting System:

An 11,780-cubic-foot underground concrete detention vault with a 267,000 gallon capacity, located under the lawn on the project, collects water from the roofs and paved surfaces of the site. It is adequate for a 100-year, 23-hour storm event. From October through April, water is pumped steadily out and released into the storm system at rates set by new city standards, which match those of the same land without any impervious surfaces.
From May to September, the releasing pump is reset for use only on site, and the water is collected and drawn down for irrigation. Through water harvesting, the system yields approximately 300,000 gallons per year diverted from site runoff. Combined with a reduction of impervious surfaces on the site, these measures reduce the rate of stormwater runoff leaving the site by over 30 percent after redevelopment.

In addition to accommodating on-site stormwater, the system is designed to accommodate one acre of natural tributary area offsite, and also to provide storage for runoff from neighboring 5th Avenue Northeast. Although not required by regulations, street and parking runoff is pre-treated, routed through a manhole chamber to remove 70 percent of total suspended solids. The storage vault water is also used for irrigating the landscape, entirely eliminating the need for potable water for irrigation. With the exception of irrigated turf, all plants chosen for the site are native to the area, making them well-suited for the efficient drip irrigation system. A combination of waterless urinals and low-flow fixtures reduces potable water consumption inside the buildings by an estimated 84,453 gallons per year, or 41 percent over baseline fixtures according to the national water efficiency standard (EPA 1992). Together, the rainwater harvesting system and water conserving fixtures will generate $2,500 in annual cost savings. The combination of rainwater harvesting and reuse and efficient low-flow fixtures results in a total reduction in potable water consumption of 77 percent for the project.

Case study 3: Northgate Civic Center, Seattle, Washington

1. Roof top type*:* Concrete Roof

2. Average annual rainfall*:* 52 inches per year

3. Catchment area: 10,000 square feet

4. Quantity of rainwater that can be harvested:

Total catchment area = 10,000 square feet
Divide by 1000 = 10
Multiplying by 550 to determine gallons collected per one inch of rain = 5500 gallons per one inch of rain
Multiple this by average annual rainfall of Oregon = 5500 x 52 = 2,86,000 gallons per year
The amount of water that can be collected = 2,86,000 gallons per year

5. Quality of harvested rainwater: The quality of the harvested rainwater is considered to be good for infiltration. Before storage in tanks, the runoff is pre-treated by routing it through Votechnics 3000 manhole chamber to remove 70% of the total suspended solids.

6. Usage of harvested rainwater: The harvested rainwater is used for landscape irrigation, toilet faucets, eliminating entirely the need for use of portable water.

7. Comments: The system for rainwater harvesting, treatment and detention is a major feature of the project. The system is well designed in a way to supply all irrigation needs which can use non-portable water like landscape irrigation and flushing of toilets. This helps to restore the natural hydrology by gradually by gradually releasing the water into the downstream channel of Thortons Creek. Due to the rainwater harvesting and water conserving fixtures, the project yields a saving od $2500 annually and reduction of use of portable water by 77 percent.

Case study 4: Stephen Epler Hall, Portland, Oregon

Figure 3.24: View of Stephen Epler Building
(Source: www.pdx.edu/sites, 2011)

Design Team

Architects:
Mithun Interface
Landscape Architect:
Atlas Landscape Architecture

Project Highlights

Location:
Portland, Oregon
Year of Project completion:
2003
Building type:
Institutional
Construction type:
New construction
Project area:
11,150 square feet

Project Background:

Portland State University has grown from a two-year college, founded in Vanport in 1946, to Oregons's largest and only urban, public university with nearly 23,000 students. This new student housing facility is named in honor of Dr. Stephen E. Epler, the original head and champion of Portland State University. The building is 62,500 square feet and houses 130 student units, classrooms, and academic office space. In developing a new student housing facility for the university, the design team, headed by Mithun Architects of Seattle, also incorporated innovative, environmentally sound concepts in order to create a healthy living space for students choosing to live on-campus. The building has been LEED certified by the US Green building Council.

Case study 4: Stephen Epler Hall, Portland, Oregon

The design techniques employed in the design and construction of the hall was innovative with environmentally conscious design methods. The design team composed of Mithun Architects and the engineering team selected by the Architect.
One of the goals of Epler was to make stormwater management interesting and engaging for the public. Therefore, the system was designed to be visible and interactive. Interface was integral in the design of the rainwater harvesting system that is built into the landscape.

Rainwater Harvesting system:

The system was designed to divert 26% of storm water from Epler hall and the neighboring King Albert Hall. Rain from the building's roofs is diverted to collection areas via "splash boxes" in the public plaza, creating a water feature for the building. The water flows to underground retention tanks and is treated using ultraviolet light before resurfacing for use as flush water in the first floor rest rooms and in landscape irrigation. The campus is expected to harvest 230,000 gallons per year from this system.

Figure 3.25: View of the rainwater collection system
(Source: greenfutures.washington.edu, 2011)

Figure 3.26: View of the rainwater collection splash box
(Source: greenfutures.washington.edu, 2011)

Case study 4: Stephen Epler Hall, Portland, Oregon

1. Roof top type*:* Concrete roof top

2. Average annual rainfall*:* 36 inches per year

3. Catchment area: 11,150 square feet

4. Quantity of rainwater that can be harvested:
Total catchment area = 11,150 square feet
Divide by 1000 =11.15
Multiplying by 550 to determine gallons collected per one inch of rain = 6132.5 gallons per one inch of rain
Multiple this by average annual rainfall of Oregon = 6132.5 x 36 = 2,20,770 gallons per year
The amount of water that can be collected = 2,20,770 gallons per year

5. Quality of harvested rainwater: The harvested rainwater is considered to be moderate since the rainwater is not infiltrated into the ground.

6. Usuage of harvested rainwater: The rainwater is re-used for use as flush water in the first floor rest rooms and in landscape irrigation. The harvested rainwater flows to an underground retention tank where it is treated using ultra violet light (UV) before use in toilets.

7. Comments: Connecting the design of the rainwater harvesting system that is built into the landscape with the users of the space is an integral part of the design. The design achieves aesthetic features using the harvested rainwater.

Case study 5: Carkeek Environmental Learning Center, Seattle, Washington

Figure 3.27: View of the Environmental Learning Center
(Source: www.seattle.gov, 2011)

Project background:

The Environmental Learning Center (ELC) at Carkeek Park, in the Broadview neighborhood of Northwest Seattle, is small, multi-purpose building designed to demonstrate sustainable systems, while providing a setting for environmental education programs. With its open plan and high clerestory windows, the building envelope is designed to integrate daylighting and ventilation and to bring in views.

Carkeek Park is a hilly, naturalized woodland site which spans the ravines and delta of the Pipers Creek watershed in northwest Seattle. Due to the urbanization of the surrounding areas of the creek, the creek has deteriorated over time. With the combined efforts of the community groups and public agencies efforts have been made to restore the creek.

Design Team

Client:
City of Seattle, Washington
Owner:
City of Seattle; Seattle Parks and recreation
Architects:
Miller Hayashi Architects
Landscape Architect:
Herrera Environmental Consultants, Inc

Project Highlights

Location:
Seattle, Washington
Year of Project completion:
May 2003
Building type:
Institutional
Construction type:
New construction
Project area:
13,068 square feet

With public interest in urban streams and inspired countless hours of volunteer effort, and the City of Seattle, Seattle Public Utilities and King County Metro worked together to revise urban infrastructure like storm drains, streetscapes and waste systems, to protect these watersheds from rapid urbanization. One of the primary goals of the ELC is to translate long term goals for the Pipers Creek watershed into a model for residential-scale development.
Stormwater strategies adopted in the design of the learning center consists of rainwater harvesting systems, infiltration trenches and detention vaults. Rainwater from the roof is collected in cisterns and rain barrels. The water that is stored in the cisterns is used for flushing toilets, and the water from the rain barrels is used for landscape irrigation. A metal roof with Energy Star Finish was selected for water collection. Most of the stormwater from paved surfaces is directed and collected in infiltration trenches and is naturally filtered as it seeps into the ground. Stormwater from the parking lot is collected in a detention vault where it is treated for total suspended solids and total phosphorous to reduce pollutants before being discharges into the receiving water body, Puget Sound.
Vegetation selected was native to the watershed and plants were adapted to create habitat and prevent biodiversity. Selection of healthy soils amended with compost absorb and hold moisture for the vegetation. Irrigation for the plants were mainly through the rainwater harvested from the rooftop and stored in rain barrels when required. The park aims at reducing pollutant load by using natural fertilizers and pest control methods since native landscaping does not require fertilizers. There are no impervious surfaces in the landscape. Over 30 permeable walkway surfaces are shaded in the summertime.

Figure 3.28: View of the Puget sound water body discharge area

Figure 3.29: View of the native vegetation and solar panels as part of the sustainable features of the design

(Source: www.seattle.gov, 2011)

Case study 5: Carkeek Environmental Learning Center, Seattle, Washington

Rainwater Harvesting System:

The total impervious area of the site is 38.71 percent, even with twice the roof area of the pervious structure. Therefore, there is a net reduction of 8 percent compared to the previous site conditions. The excess roof runoff during high winter conditions is directed into infiltration trenches, providing stormwater treatment up to the two-year storm event.
Rainwater from the metal roof is harvested in a 3,850 gallon catchment cistern that serves as a pressurized stormwater re-use system. The water stored in the cistern is used for toilet flushing and hose bibs for irrigation. In addition to the rainwater cistern, a smaller rain barrel system is used for hand irrigation demonstration. The cistern and a system of pre-filters and ultra-violet (UV) purification provides water supply for the pressurized toilet flushing system.

The use of harvested rainwater and the landscaping design helps reduce portable water use by 50 percent from the City of Seattle baseline standards, saving about 10,518 gallons per year. Documentation shows that the highest anticipated use of water occur in the driest summer months. Water savings improve substantially as the building receives more wintertime use. The savings in the overall portable water use is estimated to be approximately 33 percent over City of Seattle baseline standards, which totals to about 15,638 gallons of water.

Figure 3.30: View of the Rainwater harvesting system
(Source: www.seattle.gov, 2011)

Figure 3.31: View of the rainwater storage cistern
(Source: www.seattle.gov, 2011)

Case study 5: Carkeek Environmental Learning Center, Seattle, Washington

1. Roof top type*:* Metal roof

2. Average annual rainfall*:* 52 inches per year

3. Catchment area: 13,068 square feet

4. Quantity of rainwater that can be harvested:

Total catchment area = 13,068 square feet
Divide by 1000 = 13.068
Multiplying by 550 to determine gallons collected per one inch of rain = 7187.4 gallons per one inch of rain
Multiple this by average annual rainfall of Oregon = 7187.4 x 52 = 373744 gallons per year
The amount of water that can be collected = 373744 gallons per year

5. Quality of harvested rainwater: The quality of rainwater is considered to be good since the excess runoff from the roof is directed into infiltration trenches. Also, the harvested rainwater in the cistern and the rain barrel is purified through a system of pre-filter and ultra-violet (UV) purification devices.

6. Usage of harvested rainwater: The rainwater harvested in cisterns is used for toilet flushing and hose bibs for irrigation. The excess runoff during large storm events is infiltrated into the ground.

7. Comments: The use of native vegetation in the landscape design and use of rainwater harvesting system, helps reduce portable water by 50 percent from the City of Seattle baseline standards saving about 10,518 gallons per year.

Conclusion

The effectiveness of a rainwater harvesting system lies in its ability to meet the site specific requirements and the end use preferences. Based on the five case study analysis, it can be concluded that rainwater harvesting provides numerous benefits in addition to conserving our nature's water. The case studies show that rainwater harvesting is gaining back importance from the ancient times when it was used. Ancient practices only involved catchment of rainwater and using it for non-portable uses. But with today's technology and design ideas, we see how harvested rainwater can be used as a design feature in the landscape as well as for irrigation, toilet flushings and even in washing machines. It is seen how rainwater harvesting has become an integral part of landscape design rather than mere storage tanks to the building corner.

Design recommendations:

1. Combination with other LID practices: From the 10th @ Hoyt case study, it is noted that rainwater harvesting systems when combined with other LID practices like green roofs helps improve the quality of the harvested rainwater. Before collection, the rainwater is purified by the process of retention, absorption and detention by the green roof system.

2. Aesthetics features: From the 10th @ Hoyt case study, it is observed that the collected rainwater is used as an aesthetic feature. The collected rainwater is circulated through copper downspouts before it is finally collected in cisterns. Therefore, through this case study it is observed that instead of merely collecting rainwater from the roof into rain barrels or cisterns, it can very well be used as an aesthetic feature while utilizing the water for landscape irrigation.

3. Beyond conventional uses: Typically, most rainwater harvesting systems utilize the harvested rainwater for landscape irrigation and flushing of toilets as seen in four of the five case studies. But the Florida house and learning center moves a step forward in this process by utilizing the harvested rainwater for use in the clothes washer as well as ground water recharge. Therefore, when designing rainwater harvesting systems, depending on the budget for installation of purification systems and the amount of pollution in the urban environment, we need to think out of the box to put the harvested rainwater to more than conventional uses. By installing purifications systems and treating the harvested rainwater, the water can be used in kitchens, clothes washer and increase ground water recharge to a great extent. This in turn helps in the reduction of the overall portable water consumption of an household, reduction in usage of ground water and reduction in electricity. If every household took care of water in this manner, this would lead to overall reduction all over the city and the country. This will help maintain the pre development hydrologic conditions and also help preserve our natural resources.

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Figure 4.18: Meadowlake farms bioswale approximately a year after completion
http://niswander-env.com/mfarms.html
Figure 4.19: Aerial view of OMSI parking lot
Google maps
Figure 4.20: Southern lot vegetation
http://www.portlandonline.com/bes/index.cfm?a=78489&c=45388
Figure 4.21: Northern lot vegetation
http://www.portlandonline.com/bes/index.cfm?a=78489&c=45388
Figure 4.22: Aerial view of Florida aquarium parking lot
Google maps
Figure 4.23: Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and shown in more detail in the next diagram. Numbered black boxes indicate sampling locations in the strand and the pond.
http://www.swfwmd.state.fl.us/documents/reports/files/9ICUD02.pdf
Figure 4.24: Site plan of the parking lot swales delineated by the dotted lines
http://www.swfwmd.state.fl.us/documents/reports/files/9ICUD02.pdf
Figure 4.25: The Florida Aquarium Parking lot vegetated swale
http://www.sustainablesites.org/cases/show.php?id=16

Introduction

Vegetated swale is a term given to any vegetated ditch or depression that conveys stormwater and helps in the removal of pollutants. Vegetated swales are commonly referred to as bioswales, biofilters, since the grasses and vegetation filter the stormwater runoff as it flows through and/or over the vegetated surface (U.S.EPA, 1996). Vegetated swales provide treatment, storage and infiltration of stormwater by conveying the runoff in vegetated systems which helps in reducing overall runoff generated by the project drainage area.

There are some design variations of the vegetated swales, including grassed channels, dry swales and wet swales. These designs may also include an underlying rock reservoir, with or without a perforated underdrain. The specific design features and treatment methods differ in each variation, but all are considered improvements on traditional drainage ditches. Fully vegetated, trapezoidal cross-section swales help in remediation of pollutants in the stormwater runoff. When swales are used along steep slopes, check dams are used to further enhance attenuation and infiltration opportunities.

Figure 4.1: Vegetated swale at Brea Sports Park, California

(Source: www.riversides.org, 2011)

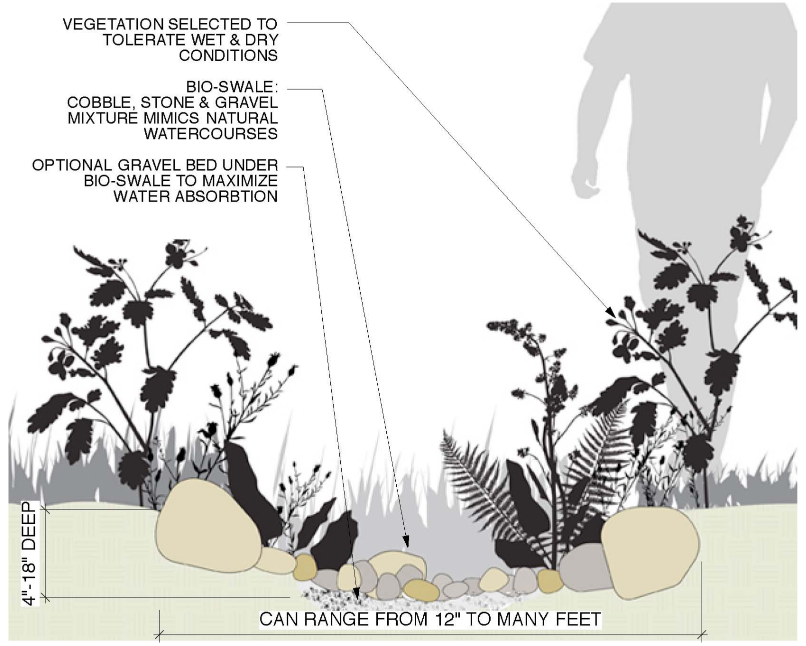


Figure 4.2: Typical section of a vegetated swale

(Source: www.deercreekliving.com, 2011)

Each type of swale incorporates modified geometry and other design features to allow it to treat and convey stormwater runoff. A typical swale bottom is flat in cross section, 600 to 2400 mm wide, with a 1-2% longitudinal slope. In a vegetated swale, side slopes are usually no more than 3:1, horizontal to vertical.

Variations of a vegetated swale

There are 3 types of swales:

1. **Grass Swale**: A grass swale is a broad and shallow earthen channel vegetated with grass, erosion resistant and flood tolerant plants. Grass swales are often used in residential developments due to low cost of construction.

2. **Dry Swale**: A dry swale consists of an open channel that has been modified to enhance its water quality treatment capability by adding a filtering medium consisting of a soil bed with an under drain system *(CRC, 1996)*. A dry swale is generally sized to accept the entire water quantity during a storm event and is designed to drain down between storm events within one day.

3. **Wet Swale**: A wet swale also consists of a broad open channel capable of temporarily storing the water quantity but does not have an underlying filtering bed *(CRC, 1996)*. Wet swales are generally constructed within existing soils and may not intercept the water table. A wet swale functions similarly to a wetland in terms of water quality treatment which relies primarily on settling of suspended soils, adsorption and uptake of pollutants by vegetated root systems.

Figure 4.3: Grass Swale

(Source: www.nemo.uconn.edu, 2011)

Figure 4.4: Dry Swale

(Source: www.tvaed.com/sustainable, 2011)

Figure 4.5: Wet swale

(Source: www.golfcoursetravelblog.blogspot.com, 2011)

Benefits of vegetated swale

Swales reduce peak flows:

Vegetated swales reduce peak flows by slowing runoff, by incorporating micro stage elements such as ponding behind check dams and by infiltrating water into the ground. Water in swales must flow over the relatively rough ground surface and through dense vegetation. Each of these acts to slow waters velocity, reducing the rate at which runoff is conveyed downstream.

Vegetated swales can also be designed to infiltrate water into the ground, recharging the ground water and restoring or maintaining the base flow of water into streams. Swales can incorporate check dams or other micro stage features to increase the amount of stormwater runoff that is captured.

Swales reduce pollutants:

All urban land uses contribute pollutants to urban stormwater runoff. Pesticides, herbicides and fertilizers come from residential lawns, commercial landscaping, recreational facilities like golf courses. Heavy metals come from cars and roofs and industrial sites. Oil and grease drip regularly from cars onto streets and are occasionally dumped into storm drains by residents. Pathogens and bacteria in runoff can come from pet waste or sanitary sewer overflows.

Vegetated swales can remove and immobilize or break down large portions of pollutants found in stormwater runoff. They can also remove a moderate percentage of metals and nutrients in runoff. Vegetated swales are very important in performing microbiological actions like converting substances into insoluble harmless substances, changing the REDOX action (i.e. where phosphorous helps in the reduction of ferric iron(Fe^{3+}) to ferrous iron (Fe^{2+}) which allows the iron bound phosphorous to become soluble. As the phosphorous become soluble reactive, it is available for biological uptake) increasing the capacity of the wetland soil to remove pollutants and largely responsible for recycling of nutrients.

Retrofit Projects:

Grassed swales are commonly used to replace existing drainage ditches in retrofit projects. Ditches are traditionally designed only to convey stormwater away from roads. By incorporating bioswales, it is possible to trap sediment, slow runoff, infiltrate and recharge groundwater.

Pollutants commonly found in urban runoff

Pollutants	Sources	Impacts
Sediment	1, 2, 3,4	Transports attached nutrients; increases turbidity and reduces light penetration; decreases submerged aquatic vegetation; impairs respiration of fish and aquatic invertebrates; impairs commercial, recreational fishing resources; silts up BMP's; degrades the benthic community
Nutrients	1, 2, 3, 4, 5, 6	Eutrophication; lowers dissolved oxygen levels' fish kills and benthic habitat destruction; surface algal scum; unpleasant odor
Bacteria and Viruses	2,4 5, 6	Contaminates drinking water; closes beaches and shellfish beds
Oxygen-demanding substances	2, 3, 4, 5, 6	Eutrophication; fish kills; changes to aquatic food chain; loss of biodiversity; surface algal scum; and unpleasant odor
Oil and Grease	1, 2, 3, 4, 5, 6	Aquatic organism mortality; collect in bottom sediments and affect benthic communities; limit fishing for bottom-feeders
Heavy metals	1, 2, 3, 4, 5, 6	Toxic to aquatic life; potential groundwater contaminants; danger of bioaccumulation
Toxins: Priority Pollutants	Material dependant	Similar effects as above with other toxins such as chemicals, including pesticides, phenols and polycyclic aromatic hydrocarbons
Floatables	2, 3, 4, 6	Contains concentrations of heavy metals, pesticides and bacteria
Temperature	N/A	Alters the conditions necessary for organisms to survive; decrease biodiversity and ecosystem stability
Salt	1	Typically from winter road salting; harms or kills plants and trees

Table 5: The sources and impacts of pollutants commonly found in urban runoff
Key: 1- Automobile/ atmospheric deposition; 2 - Urban housekeeping/ landscaping practices; 3- Industrial activities; 4 - Construction activities; 5 - Nonstormwater (sewer) connections; 6 - Accidental spills and illegal dumping

Limitations of vegetated swales

1. Vegetated swales are more effective when used in conjunction with other stormwater management practices such as wet ponds, infiltration strips and wetlands.

2. Vegetated swales are ineffective at reducing bacteria levels and pollutant removal in stormwater runoff if designed improperly.

3. Grassed swales and wet swales are incapable of treating highly polluted runoff. Highly contaminated runoff can be generated by some land uses where pollutant concentrations exceed those found in typical runoff. Runoff generated from land uses like commercial nurseries, recycling, industries, fueling stations, marinas, public works yard are highly contaminated. With the exception of dry swales, this runoff cannot be directed towards grassed swales since they infiltrate stormwater and can intersect the water table which is a threat to the water table.

4. Thick vegetation cover is required for proper bioswale function. Water table fluctuation, long-term inundation, erosive flow, excessive shade, poor soils and improper installation can affect vegetation growth.

Design and grading of vegetated swales

The design of a vegetated swale requires minimum of inputs. The primary design variable is the discharge that the swale must pass. This can be computed using a peak discharge model such as the rational method or the NRCS graphical method. The discharge will depend on the design return period, the area and the land cover of the contributing area and the appropriate rainfall characterization necessary for the peak discharge model. The characteristic of the site where the swale is located is also important. This includes the longitudinal slope of the swale site, the extent to which the site can be graded to control run off, the side slope and the roughness of the vegetation to be used to line the swale. The flow mechanism is more concentrated and should be deeper in a swale. The swale may receive flow only at the inlet and convey it to an outlet or it will also receive flow from the side slopes. This side slope flow is usually sheet flow. Grassy swales must both convey and treat the storm water runoff they convey. To meet both these criterion swales must be sized not to erode during peak flows, but also to convey smaller flows slowly enough to treat them.

An effective swale design consists of three components:

1. Conceptual, engineering and planting design: This initial stage of the swale design should occur during the planning process of a project. The goals of this stage are to develop a swale design such that the finished swale will:

- Remain stable under normal operations and carry the peak design flow without eroding or overflowing.
- Provide water quality treatment for a smaller water quality design storm
- Aesthetically fit into and operate at a given site.

In this stage of design, the swale is placed into the overall site plan. What portions of the site will drain into each swale and how the swale fits into the site’s drainage plan is determined. Given the site constraints, the design should maximize the swale’s length in order to improve water management.

2. Water quality volume: The most polluted runoff is usually generated by small storms, or by the first portion of a storm cycle. The oils, metals and other pollutants accumulated over a dry period are washed off rooftops, roadways and other surfaces in the first light rain or in the first minutes of a large storm. Thus treating this first flush of runoff by using oil/grit separators, vegetated swales or water quality ponds is the key to controlling non-point source pollution. For this reason, swale design must consider both the peak volumes for flood control as well as quality volume for pollution control.
The depth of the water quality storm varies according to local rainfall, climate and regulations. Municipalities recommend that swales infiltrate the first one half inches of runoff. The swale inlet can be designed to allow peak flows to bypass the swale and be conveyed by a conventional conveyance system. This also prevents the larger, higher velocity flows of large storms from washing out the sediments or eroding the vegetation in the swale.

3. Peak flow design storm: Swales are a part of a larger storm drain system that drians water from developed areas. Therefore, they must also be sized to convey a peak flow design storm without eroding. The design storm is often the ten year, twenty four hour storm. Given a large enough storm, swales will overflow. Overflows can be controlled by directing runoff to adjacent roads or parking areas, into adjacent landscapes or by using dual drainage system. For example, in Folsom California, a dual drainage system combines grassy swales with conventional curb-and-gutter system on a arterial street *(LATIS, 2008)*

Design and grading of vegetated swales

Design Principles:

1. ***Longitudinal slope*** of a vegetated swale is a critical design element which affects to a large extent the performance of the swale. Appropriate slopes range from 1%-6%.
Optimal: $0.01<s<0.02$
Marginal: $s<0.01$
Steep: $0.02<s<0.06$
Excessive: $s<0.06$
2. ***Swale cross section*** can be classified into 4 types: rectangular, triangular, trapezoidal and parabolic each having different hydraulic properties. Trapezoidal sections are the most commonly used because they are easy to construct, offer good hydraulic performance, facilitate maintenance and are aesthetically pleasing. Triangular cross-sections can also be used if the side slopes are very gentle (approximately 10:1 or shallower). Rectangular cross sections are generally not used for grass swales because they are difficult to construct and maintain, and because the vertical side slopes present a relatively high public liability.
3. ***Side slopes*** are an important design parameter as they help to limit erosion, facilitate maintenance, and reduce public liability risks. Therefore, shallower side slopes are desirable though they increase the amount of area required for the swale.
4. ***Bottom width*** which is wide and flat maximizes the available treatment area and pollutant removal while also providing east of maintenance. If the swale will be mowed, the bottom should be atleast two feet wide. The swale bottom should be less than eight feet wide, unless it will be hand finished. This will avoid rilling and gullying.
5. ***Depth of the swale*** should be at least 6 inches deeper than the maximum design flow depth. This additional depth is known as "freeboard", and provides a safety factor to prevent the swale from overflowing onto adjacent areas if the channel becomes obstructed or if runoff volumes exceed the design size.
6. ***Residence time*** is the time it takes water to flow from its inlet into the swale to the swale's outlet. For vegetated swales, the residence time should be a minimum of 5 minutes, since the greater the residence time, the greater a swales ability to remove pollutants from the runoff. This can be done by maximizing the swale's length since this will increase the contact time of the runoff with the swale.

Planting and maintenance of vegetated swales

Planting:

The vegetation planted along a swale maintains channel stability and improves the swale's ability to filter pollutants from storm water. In order to achieve this vegetation should meet the following criteria's:
1. Provide a dense cover and a fibrous root or rhizome structure that holds the soil in place and resists erosion.
2. Stand upright, at least during water quality level flows to provide maximum residence time and pollutant removal
3. Tolerate a swale's soil conditions
4. Tolerate periodic inundation

Grasses meet most of the functional criteria for swale vegetation, such as dense cover, fibrous root or rhizome structure and upright growth form. The types of grasses which can be used are annual grasses, perennial grasses, sod-forming or bunch-grasses. Woody plant materials such as shrubs and trees are appropriate for planting on the side slopes of swales, since they withstand flooding and stabilize soils. They provide shade and cover, enhancing the habitat value of the swale.

Maintenance:

Typical maintenance practices for swales include attention to both plant material and the swale's structure. General plant maintenance includes regular mowing, irrigation, and pruning. Regular mowing stimulates plant growth, encouraging dense coverage. Removal of grass clippings following this practice removes pollutants that have been absorbed by the grass blades. Maintenance includes periodic inspection of surface drainage systems to ensure clear flow lines, repair the surfaces that have been damaged by erosion, plants and replenishment of mulch cover. Inspection and repair to swales should be scheduled before the first seasonal rains and during and after each major storm.

Plants used for vegetated swales

Abundant and standing moisture during all seasons


Calamagrostis stricta

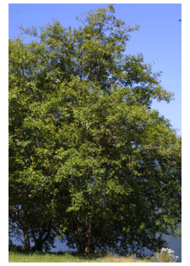

Carex kelloggii


Glyceria grandis


Scirpus microcarpus


Salix scouleri


Sambucus racemosa

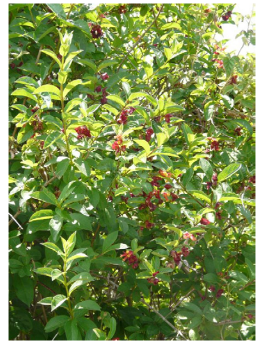

Alnus rubra

Standing water in winter, dry in summer


Cornus sericea


Amelanchier alnifolia


Crataegeous douglasii


Lonicera involucrata

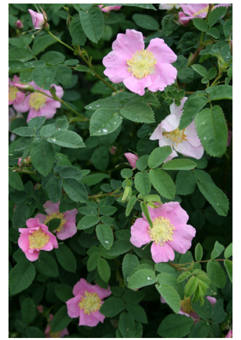
Abundant moisture in winter, dry in summer


Prunus emarginata


Acer glabrum


Amelanchier alnifolia


Mahonia nervosa


Polystichum munitum


Fragaria chiloensis

Conclusion

In conclusion, vegetated swales provide water treatment, infiltration and storage of stormwater by conveying the runoff in vegetated systems. It has been noted that swales help reduce overall runoff generated by the project drainage area and swales help in pollutant reduction from stormwater runoff. Based on the above conclusions drawn from the literature review, the following five case studies are analyzed based on the following hydrologic and design parameters:

1. Land use type: This is helpful in determining the type of pollutants entering the swale which directly concern the water quality of the stormwater runoff. Land use type also helps in sizing of the bioswales according to the size of the development and the watershed areas contributing to the runoff.

2. Average rainfall of the region: Computing the average rainfall of the watershed area helps determine the water quantity treated by the bioswale. Determining the water quantity also helps in sizing of the bioswale.

3. Soil characteristics: In order to determine the infiltration capacity of the swale and possibilities of soil erosion, studying the soil characteristics underlying the swale is very important. For example, soils having high clay content does not infiltrate as much compared sandy loam soils. In highly commercialized urban areas and industrial regions, stormwater is highly polluted with automobile deposition, industrial activities, construction activities, accidental spills and illegal dumping. This leads to highly contaminated stormwater which should not be allowed to infiltrate through the swale and reach the ground water table. In such cases, understanding soils which prevent infiltration in very important. Study of soil characteristics is also important in determining the type of vegetation that best grows on the given soil. This aids in the growth of healthy vegetation without additional care.

4. Possible pollutant types: Understanding the types of pollutants which may enter the bioswale is an important factor when deciding if the swale needs to have a high infiltration capacity. Pollutants passing through the swale also influences the growth of the vegetation to a large extent.

5. Type of vegetation: Vegetation plays a very important role in the functioning of a bioswale. Thick vegetation can prevent soil erosion, provide adequate pollutant removal, increase infiltration and provide shade.

Therefore, the following 5 case studies are analyzed based on:
1. Infiltration rate
2. Peak flow reduction
3. Storage
4. Pollutant removal
5. Native vegetation
6. Aesthetics
7. Provide wildlife habitat
8. Comments/views

Chapter 4.2: Vegetated swales case studies

Case study 1: Glencoe Elementary School Parking Lot, Portland, Oregon

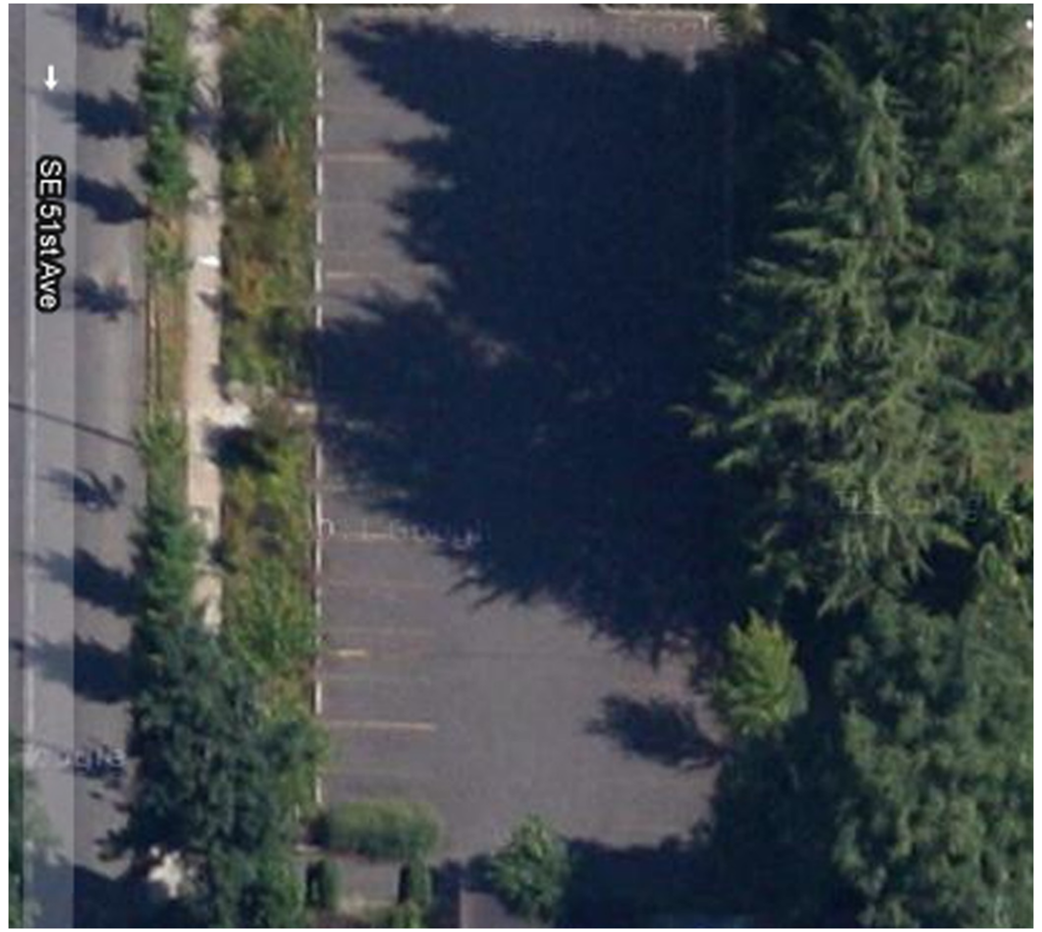


Figure 4.6: Aerial View of Glencoe Parking Lot
(Source:Google maps, 2011)

Project background:

The stormwater management goal was to maximize the capacity of the swale system given the existing conditions. Located on 825 SE 51st Street, the school contains a parking lot swale and a rain garden. An impervious surface area of 4,400 square feet was converted to landscape areas.

Design Team

Client:
Glencoe Elementary School
Owner:
The Bureau of Environmental Services (BES)
Landscape Architect:
BES, Portland Parks, and Recreation Bureau

Project Highlights

Location:
Portland
Year of Project completion:
2002
Building type:
Institutional
Construction type:
Retrofitted
Project area:
4,400 square feet

Case study 1: Glencoe Elementary School Parking Lot, Portland, Oregon

Bioswale Design:

The swale was constrained to a footprint of approximately 1,000 square feet even though the new parking configuration provided significantly more landscape area with which to work. Constraining factors included the existing topography, the space and geometry of the new sidewalk and two parking entrances. Two speed bumps intercept sheet flow from the parking lot and direct it to the swale. Raised parking strips also help direct flows into the swale. Along with the drainage berms, the topography of the lot results in more than half the runoff entering the middle and lower half of the swale.

Most of the runoff enters the swale at three entry points: top, middle and bottom. The swale addresses a catchment area of 9,700 square feet of asphalt, with a building footprint of approximately 1,000 square feet. The swale is approximately 150 feet long and 6 feet wide. The average depth is 18 inches; the check dams pond runoff a maximum of 6 inches deep in the compartments. The side have slopes of between 2:1 and 3:1. The swale's longitudinal slope is 4-7%.

There are four planting zones:

- The bottom of the swale was planted with native rushes and sedges, and over-seeded with a native wetland grass mix.
- The swale side-slopes were planted with a mix of shrubs, perennials, groundcovers and grasses. The mix is half native and half ornamental; the plants were selected for low maintenance requirements in dry and exposed conditions.
- The planting outside the swale - approximately 3,000 square feet on the east and north sides - consist of low maintenance shrubs and groundcovers.
- The grassy median between the sidewalk and street receives runoff from the adjacent sidewalk. Four Douglas firs were planted in the median to demonstrate the benefits of evergreen street trees.

Figure 4.7: View of Glencoe Parking Lot before retrofit
(Source: Portland Bureau of Environmental Services, 2004)

Figure 4.8: View of Glencoe Parking Lot after retrofit
(Source: Portland Bureau of Environmental Services, 2004)

Case study 1: Glencoe Elementary School Parking Lot, Portland, Oregon

Landscape Performance Benefits:

1. The impervious area of the parking lot was reduced by almost 30% and just three parking spaces were lost out of the original 38 parking spots.

2. The swale helps reduce local surcharging of the combined sewer, helps reduce combined sewer overflows (CSO's) and improve runoff water quality.

3. Log check dams help retain stormwater passing through the swale. In larger storm events when the system reaches capacity, excess flow drains through a standpipe in the bottom compartment of the swale.

Figure 4.9: View of Glencoe Parking vegetation
(Source:www.portlandonline.com, 2011)

Cost of the project:

According to the budget developed by the BES, the estimated project cost was $93,858.

Non-construction activities: The total estimated cost for management, design and permitting was $26,219, comprising approximately 28% of the total budget.

- Management - $14,700 (16%)
- Design - $10,419(11%)
- Permitting - $1,000 (1%)

Construction activities: Excavation, grading, construction and landscaping costs totaled $67,639, comprising 72% of the total budget.

- Demolition, excavation and grading - $26,040 (28%)
- Construction - $25,608 (27%)
- Landscaping - $15,991 (16%)

Case study 1: Glencoe Elementary School Parking Lot, Portland, Oregon

1. Land Use Type*:* Institutional parking lot retrofit

2. Catchment area*:* 9,700 square feet

*3. **Average annual rainfall:*** 37.07 inches/year

4. Soil type: Urban land - latourell complex - 3 to 15 percent, were major portion of the parking lot has 8 to 15 percent slopes. Also, part of the lot contains soils having a moderate infiltration rate and the other part contains soils having slow infiltration rate.

5. Infiltration rate: ☐ High ■ Medium ☐ Low

Reducing the asphalt area in the parking area by 30% increases the area for infiltration. Although, since high rates of pollutants can be discharged from the parking lot, infiltration is highly discouraged. The parking lot is composed of group B and group D soils which have moderate and slow infiltration rates.

6. Peak flow reduction: ■ Yes ☐ No

All the runoff from the parking lots is directed into the swales. The runoff is intercepted by two speed bumps from the parking lot which reduces the peak flow rate considerably. Also, since the runoff is directed to enter the swale at three different points, increases the travel time of the runoff.

7. Storage capacity: ☐ High ☐ Medium ■ Low

Since the parking lot swales do not provide good infiltration rates, the storage capacity is considerably low.

8. Pollution removal: ■ High ☐ Medium ☐ Low

Since the area draining into the swale is a parking lot, the runoff is highly contaminated with pollutants from automobile and atmospheric deposition, urban housekeeping practices, non-stormsewer connections and accidental spills. Due to presence of high pollutants, treatment of runoff is average.

9. Native vegetation: ■ Yes ☐ No

Use of native rushes and sedges with native wetland grass mix.

10. Provides wildlife habitat: ☐ Yes ■ No

11. Aesthetics: ■ Yes ☐ No

In comparison to a plain asphalted parking lot without any landscaping area, the introduction of swales adds to the aesthetic look of the parking lot.

12. Comments:

Vegetation can be provided in the form of evergreen shading trees which would not only help reduce pollutants but also help cool the surroundings in the parking lot. Also, with the design of the swale in the parking lot, there was no loss of parking spaces.

Case study 2: Mt.Tabor Middle School, Portland, Oregon

Figure 4.10: Aerial View of Mt. Tabor parking lot
(Source: Google maps, 2011)

Project background:

Mt. Tabor located on 5800 SE Ash Street, Portland, Oregon incorporates Integrated Stormwater Management techniques like rain gardens, parking lot swale, downspout planters, drywells and curb extensions. This school retrofit protects nearby residents from basement sewer back ups, provides an outdoor classroom for students and helps cool the building and surrounding impervious surfaces. A variety of landscaped stormwater management technologies intercept stormwater runoff from about two acres of impervious surfaces. The facilities keep stormwater out of the sewer system and help reduce combined sewer overflows (CSOs) and basement backups.

Design Team

Client:
Mt.Tabor Middle School
Owner:
Portland Public Schools
Landscape Architect:
Nevue/ Ngan

Project Highlights

Location:
Portland
Year of Project completion:
2007
Building type:
Institutional
Construction type:
Retrofitted
Project area:
1.400 square feet

Case study 2: Mt.Tabor Middle School, Portland, Oregon

Bioswale Design:

The parking lot swale was retrofitted with two landscapes features: a 1,400 square feet swale that runs east-west down the center of the parking lot and a 200 square foot planter in the northwest corner. The 200 square foot planter along with the bioswale manage runoff from 15,000 square foot of asphalt. The swale has multiple check dams with adjustable weirs to retain runoff and promote infiltration. Runoff enters along the north side of the swale through curb cuts; the south edge has a flush curb that allows runoff to enter along the entire length of the facility. In large storm events, the swale and planter overflow safely to the stormwater curb extension and an underground sump under the street.

The bottom of the swale is planted with rushes and sedges, the drier upslope areas are planted with compact Oregon grape dwarf heavenly bamboo, hebe and euonymus. Trees used are tupelo and aspen. The parking stales along the south side of the swale are set six feet from the swale so pedestrians can easily access the three swale crossings. A post and chain fence along the perimeter deters pedestrian access to the swale.

Figure 4.11: The parking lot swale after placement of 10" of imported soil, foot compaction and final grading
(Source: Portland Bureau of Environmental Services, 2004)

Figure 4.12: Parking lot swale after construction highlighting the curb cuts for runoff entry
(Source: Portland Bureau of Environmental Services, 2004)

Case study 2: Mt.Tabor Middle School, Portland, Oregon

Landscape Performance Benefits:

1. The facility captures runoff from about two acres of roof, parking lot, play area and street.
2. Most of the captured water is infiltrated, helping reduce combined sewer overflows (CSO's)
3. The swale has multiple check dams with adjustable weirs to retain runoff and promote infiltration.

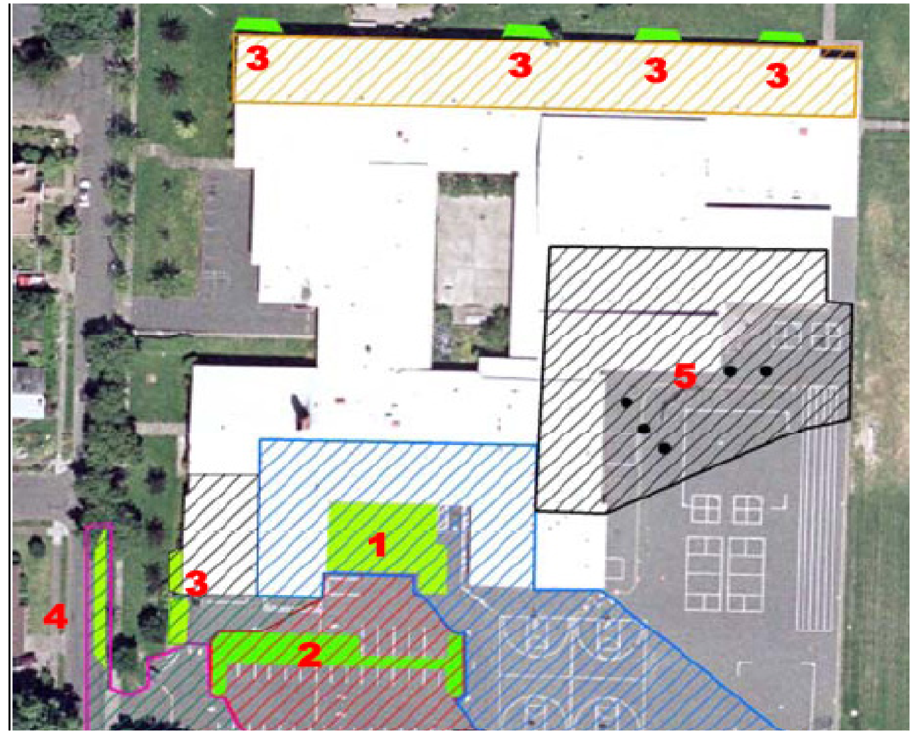


Figure 4.13: 1- Facilities with Catchment Areas; 2- Parking lot swale
(Source: Portland Bureau of Environmental Services, 2004)

Figure 4.14: Prior to construction, looking north across the parking lot toward the site of the rain garden. The parking swale was constructed between rows of parking stalls in the foreground.
(Source: Portland Bureau of Environmental Services, 2004)

Cost of the project:

The total budget for the parking lot swale and the planters was $326,000 from the overall budget of $822,000. The total cost for pre-design and design activities was $257,000, or 47% of the construction costs.

Case study 2: Mt.Tabor Middle School, Portland, Oregon

***1. Land Use Type**:* Institutional parking lot

***2. Catchement area**:* 15,000 square feet

*3. **Average annual rainfall:*** 37.07 inches/year

4. Soil type: Urban land - latourell complex, 0 to 3 percent slopes. Group D soils which have high clay content and slow infiltration rate.

5. Infiltration rate: ☐ High ■ Medium ☐ Low
The swale is designed with multiple check dams which promotes infiltration. Although infiltration is achieved through check dams, the soil itself has a slow infiltration rate due to the presence of clays that have a high shrink well potential. These soils have a very slow rate of water transmission.

6. Peak flow reduction: ■Yes ☐ No

The check dams detain and reduce runoff. During large storm events, the swale and the planter overflow safely to the stormwater curb extension

7. Storage capacity: ■ High ☐ Medium ☐ Low

Since the swale is designed for large storm events as well, adequate storage capacity has been provided where the water drains into an underground sump into the street

8. Pollution removal: ■ High ☐ Medium ☐ Low
Since the swale captures water and promotes infiltration, combined sewer overflows (CSOs) is reduced to a considerable extent.

9. Native vegetation: ■ Yes ☐ No

10. Provides wildlife habitat: ☐ Yes ■No

11. Aesthetics: ■ Yes ☐ No

12. Comments: Swale combines with another LID practice; rainwater harvesting system to provide water storage.

Case study 3: Meadowlake Farms, Bloomfield, Michigan

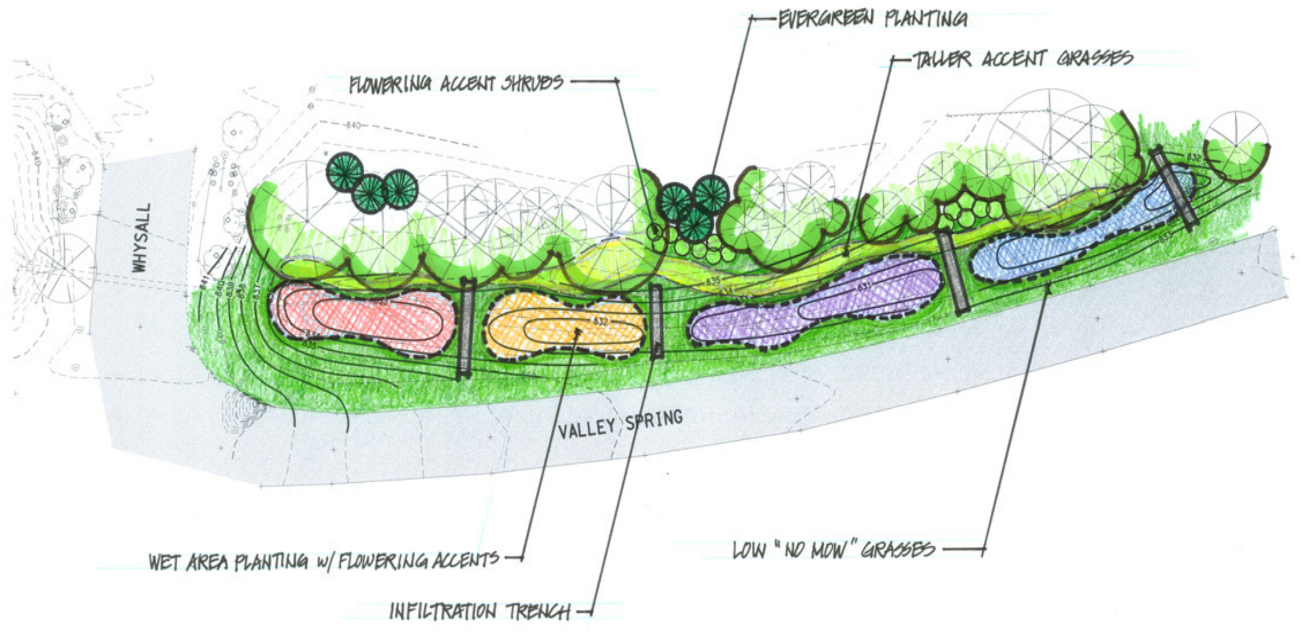


Figure 4.15: Plan of bioswale
(Source: www.hrc-engr.com, 2011)

Project Background:

Meadowlake is a 50 acre in a residential area in Bloomfield Township, Oakland County, Michigan. The purpose of the Meadowlake Farms Bioswale Project was to improve the quality of stormwater that discharges into Meadowlake, a 50-acre residential lake in Bloomfield Township that is a tributary to the Franklin branch of the main 1-2 subwatershed of the Rouge River. The project was designed to address and treat the daily pollutants entering the swale and improve the water quality of the discharge from the swale and ultimately the aesthetics of the lake and downsteeam reaches of the rouge river.

The secondary purpose of this project was to increase the public awareness of the impacts of stormwater and actions that individual residents can take to improve the overall water quality of Meadowlake.

Design Team

Client:
Bloomfield Township
Owner:
Bloomfield Township
Landscape Architect:
Hubbell, Roth and Clark (HRC) Architects and Niswander Environmental

Project Highlights

Location:
Michigan
Year of Project completion:
2005
Building type:
Residential
Construction type:
Retrofitted
Project area:
30-acres

Case study 3: Meadowlake Farms, Bloomfield, Michigan

Design of the bioswale:

In order to address the polluted stormwater runoff, a vegetated swale was installed by converting the roadside ditch into a vegetated swale. This was done by land balancing and establishing the swale with plants native to Michigan. The main design of the vegetated swale includes four distinct planting zones each consisting of a monoculture of plants with similar flowering color. This also adds to the appearance of the vegetated swale in addition to providing water quality benefits. The swale has been widened from 6 feet to 12 feet which will aid in reducing flow velocities and encourage uptake and infiltration of the stormwater.

Figure 4.16: Existing drainage ditch at Meadowlake farms prior to construction
(Source: Niswander Environmental, 2005)

Figure 4.17: Mulch blankets used over top soil used to reduce soil erosion and stabilize new plant material
(Source: Niswander Environmental, 2005)

Cost of the project:

The total estimated cost of the project was $60,000 and the project was finally completed with a cost of $63,000.

Case study 3: Meadowlake Farms, Bloomfield, Michigan

Design challenge:

Historically, the stormwater discharged from the sewer has been a source of significant amounts of sediment, nutrients and other pollutants. The discharges have been the subject of frequent concern and complaints from the residents of the lake.

Landscape Performance Benefits:

1. The vegetated swale provides for infiltration through the infiltration trenches filled with 1inch x 3 inch crushed aggregates. The infiltration trench provides area where stormwater will be detained and allowed to seep into the soil. The space constraints of the site prevent the use of inline detention for water storage.

2. The vegetated swale is designed to reduce the amount of sediment and nutrients reaching Meadow Lake and the downstream reaches of the Rouge River by naturally treating stormwater before it enters the lake. The vegetated swale collects stores and infiltrates stormwater runoff into the ground and removes pollutants through plant absorption and soil filtration.

3. The vegetated swale constructed by excavating the existing drainage ditch to create a 12 foot wide swale with a level channel bed, increases the surface area and helps slow the stormwater velocity.

4. The vegetated swale enhances wildlife habitat and provides visual amenity.

5. A low maintenance lawn mix is planted along the adjacent road to reduce maintenance costs and an area of tall prairie grass shrubs planted along the north side of the swale to screen out the maple and add additional color to the landscape.

Figure 4.18: Meadowlake farms bioswale approximately a year after completion
(Source: Niswander Environmental, 2005)

Case study 3: Meadowlake Farms, Bloomfield, Michigan

1. Land Use Type: Residential parking lot

2. Catchement area: 50 acres

3. Average rainfall: 32.23 inches/year

4. Soil type: Urban land - Spinks complex, 0 to 15 percent slopes.

5. Infiltration rate: ■ High ☐ Medium ☐ Low
The swale provides for infiltration through the infiltration trenches filled with 1 inch x 3 inch crushed aggregates. The infiltration trench provides area where stormwater will be detained and allowed to seep into the soil.
6. Peak flow reduction: ■ Yes ☐ No
The swale has been widened from 6 feet to 12 feet which helps reduce flow velocities

7. Storage capacity: ■ High ☐ Medium ☐ Low
Storage is provided where stormwater is detained in infiltration trenches. The space constraints of the site prevent the use of inline detention for water storage.
8. Pollution removal: ■ High ☐ Medium ☐ Low
The bioswale is designed to reduce the amount of sediment and nutrients reaching the Meadow lake and the downstream reaches of Rouge river by naturally treating stormwater before it enters the lake. The bioswale collects and stores and infiltrates stormwwater runoff into the ground and removes pollutants through plant absorption and soil filtration.
9. Native vegetation: ■ Yes ☐ No
The planting material was selected with a substantial number of native and wetland plants such as red twig, dogwood, creeping buttercup.

10. Provides wildlife habitat: ■ Yes ☐ No

11. Aesthetics: ■ Yes ☐ No

12. Comments:
The bioswale is provided with Mulch blankets over the top soil which reduces soil erosion and stabilizes new plant material. A notiable feature of the swale is that, it is a ditch converted into a vegetated swale.

Case study 4: Oregon Museum of Science and Industry (OMSI) Parking Lot, Portland, Oregon

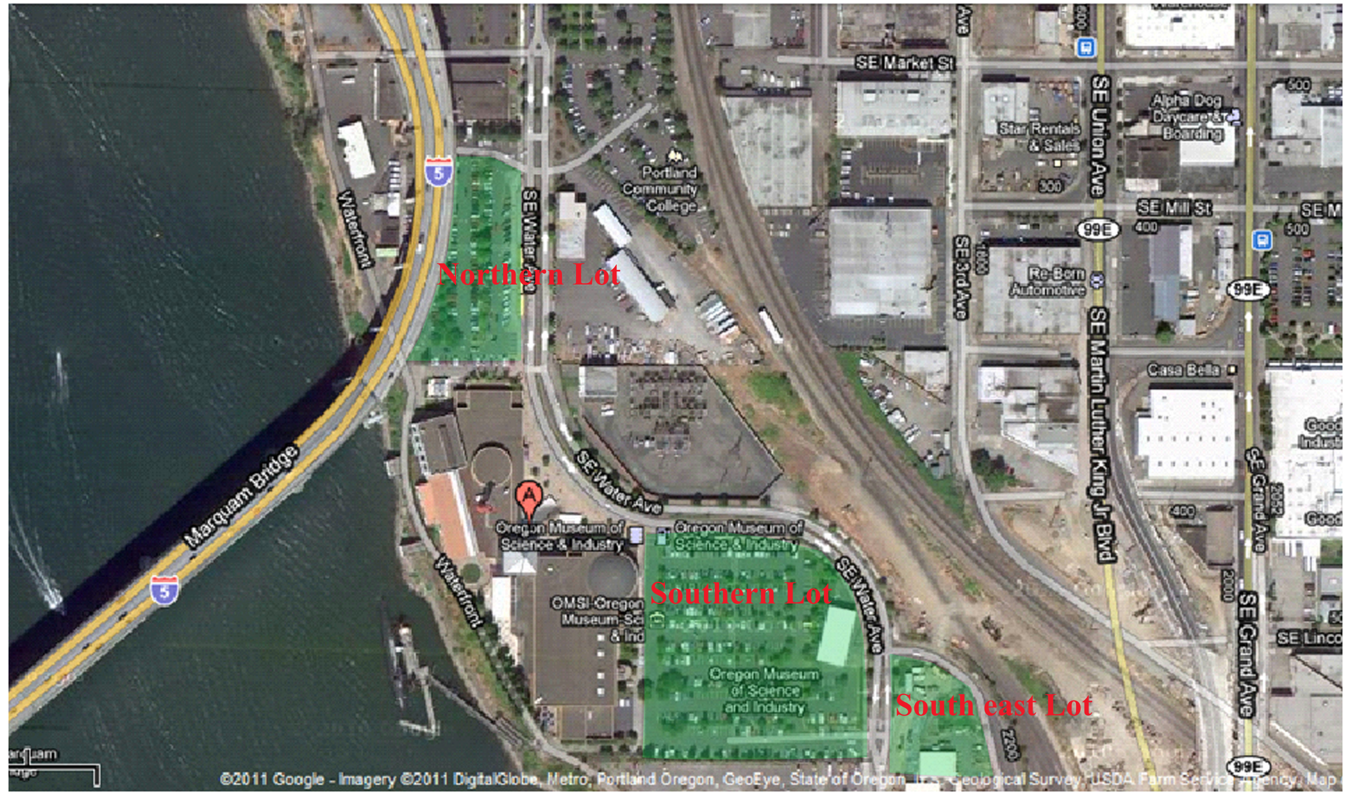


Figure 4.19: Aerial View of Oregon Museum of Science and Industry (OMSI) Parking Lot 2003
(Source: Google maps)

Project background:

OMSI is a non-profit educational and entertainment facility serving over 1.1 million visitors annually. The museum and the exhibition space occupy over 100,000 square feet adjacent to the Williamette River. The site was formerly a brownfield site used for light industry. Two parking lots total over 174,000 square feet.
Located in downtown Portland, OMSI places seven bioswales in its 10-acre, 800 car parking lot to prevent pollutants from entering Williamette River.

Design Team

Client:
OMSI
Owner:
The Bureau of Environmental Services (BES)
Landscape Architect:
Robert Murase, Murase Associates

Project Highlights

Location:
Portland
Year of Project completion:
1990 - 1992, modified in 1996
Building type:
Commercial Parking Lot
Construction type:
Demonstration redesign
Project area:
174,000 square feet

Case study 4: Oregon Museum of Science and Industry (OMSI) parking lot, Portland, Oregon

Design of the Bioswale:

The bioswales at the parking lot demonstrate Portland's first large scale on-site stormwater treatment and infiltration practices. Before the installation of the swales, over 522,000 cubic feet of untreated stormwater runoff discharged directly to the Willamette River annually.
In 1996, the parking lots and several bioswales were modified to accommodate alterations to the adjacent stormwater avenue which bisected the lot, creating two separate parking areas. Investigation of the swales infiltration capacity indicated that the soil infiltrated at a rate of 8 inches per hour. The swales are 6 feet wide and vary in length from 100 to 250 feet for a total length of 2,330 feet. There is one 12 inch wide curb every 30 feet on center to allow runoff to enter the swales from the parking lot surface.
The planting material was selected with a substantial number of native and wetland plants such as red twig, dogwood, creeping buttercup, and douglas spirea. However, the swales drained so well during the rainy season and remained dry during the summer period that the wetland plants requiring constant wet soils did not survive.

Figure 4.20: Southern lot vegetation
(Source: Portland Bureau of Environmental Services, 2004)

Figure 4.21: Northern lot vegetation

Case study 4: Oregon Museum of Science and Industry (OMSI) parking lot, Portland, Oregon

Landscape Performance Benefits:

1. Infiltration tests: Pre-development soil testing indicated poorly draining soils and clay. In actuality, the soils underlying the bioswales included very permeable fill material. The soil survey maps indicate the soils have a 0-3 percent slope. The soils drained at a rate of 8 inches per hour. Wooden check dams were installed every 50 feet to slow the flows and encourage infiltration.

2. The bioswales were wide enough to accommodate peak storm water runoff volume.

3. Some curb cuts require modifications because they do not allow enough water from the parking lots to enter the swales. This is mainly due to the buildup of sediments, which block runoff from entering the swale. The performance of the swales could be improved by increasing the number of curb cuts from one every 30 feet on center to one every 10 feet on center.

4. A water quantity audit shows that the swale system removes 50% of the average annual total suspended solids (TSS) which pollute the rainwater.

Cost of the project:

The unit cost for the bioswales was not tracked separately from the costs for the larger site redevelopment project. The project realized a cost savings of $78,000 over conventional stormwater management techniques *(Portland Bureau of Environmental Services, 2005)*

Case study 4: Oregon Museum of Science and Industry (OMSI) parking lot, Portland, Oregon

1. Land Use Type*:* Commercial parking lot

2. Catchement area*:* 1,74,000 square feet

3. Average rainfall: 37.07 inches/year

4. Soil type: Urban land. The soil survey maps indicate the soils have a 0-3 percent slope. Soils survey maps indicate group D soils underlying the bioswale which means soils have slow infiltration rates.
5. Infiltration rate: ■ High ☐ Medium ☐ Low
The soils underlying the bioswales included very permeable fill material. The soils drained at a rate of 8 inches per hour. Wooden check dams were installed every 50 feet to slow the flows and encourage infiltration.
6. Peak flow reduction: ■ Yes ☐ No
Since the soils have good infiltration rates and check dams slow down the flow of the runoff, there is adequate peak flow reduction.

7. Storage capacity: ☐ High ■ Medium ☐ Low

Since the soils encourages infiltration at a slow rate, storage of water was achieved to some extent.

8. Pollution removal: ■ High ☐ Medium ☐ Low
A water quantity audit shows that the swale system removes 50% of the average annual total suspended solids (TSS) which pollute the rainwater.

9. Native vegetation: ■ Yes ☐ No
The planting material was selected with a substantial number of native and wetland plants such as red twig, dogwood, creeping buttercup.

10. Provides wildlife habitat: ■ Yes ☐ No

11. Aesthetics: ■ Yes ☐ No

12. Comments:
The planting material selected were native and wetland plants.

Case study 5: Florida Aquarium Parking Lot and Queuing Garden, Tampa, Florida

Figure 4.22: Aerial View of Florida Aquarium Parking Lot
(Source: Google maps, 2011)

Design Team

Client:
Florida Aquarium
Owner:
The Bureau of Environmental Services (BES)
Landscape Architect:
Southwest Florida Water Management District

Project Highlights

Location:
Tampa
Year of Project completion:
1995
Building type:
Commercial Parking Lot
Construction type:
Urban redevelopment
Project area:
11.5 acres

Project background:

In 1993, Florida Aquarium in mid town Tampa partnered with the Southwest Florida Water Management District to build a 11.25 acre stormwater research and demonstration area to evaluate the effectiveness of alternative low impact parking lot design to reduce runoff and improve the quality of water flowing into Tampa Bay. The fundamental goal of the project was to extend the environmental education objectives of the aquarium to the parking lot and the aquarium's shaded queuing garden near the entrance.
The swale was configured to maximize the use of green space vegetated with native plants to convey, infiltrate and filter stormwater runoff.

Case study 5: Florida Aquarium Parking Lot and Queuing Garden, Tampa, Florida

Florida Aquarium is an urban redevelopment site, built on a former Coca-cola bottling factory. Situated in downtown Tampa, on the waterfront next to the entertainment venues, restaurants and shops and draws many visitors. The study area is 11.25 acre parking lot that currently serves approximately 700,000 visitors annually.

Bioswale Design:

The research was designed to determine pollutant load reductions measured from three elements in the treatment train. Different treatment types in the parking lot included: different treatment types in the parking lot, a planted strand with native wetland trees and a small pond used for final treatment. The stormwater runoff was directed from the aquarium roof and parking lot into a chain of bioswales, into smaller basins that flow into larger ones. The extremely shallow swales in high water table conditions improved infiltration.

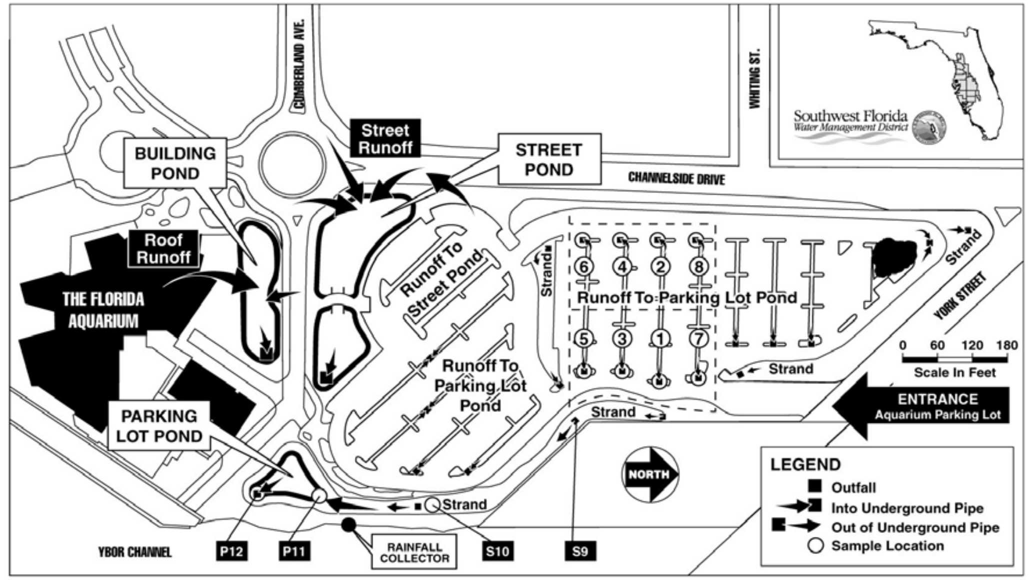


Figure 4.23: Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and shown in more detail in the next diagram. Numbered black boxes indicate sampling locations in the strand and the pond.
(Source:Rushton, B, 2002)

The site consisted of urban soils of poor quality. The soils lacks organic compounds and had a high pH due to which use of native species were employed.

The site had to maximize efficiency of parking and user function at the same time that sustainable practices were employed. Reconfiguring green space into swales required a waiver of the city landscape code. Changing regulations by making parking spaces 0.62m shorter provided land for swales without reducing number of parking spaces. The change did not compromise parking because the design simply called for the front end of vehicle to overhang grass rather than impermeable paving *(Sustinable sites, 2009)*.

Case study 5: Florida Aquarium Parking Lot and Queuing Garden, Tampa, Florida

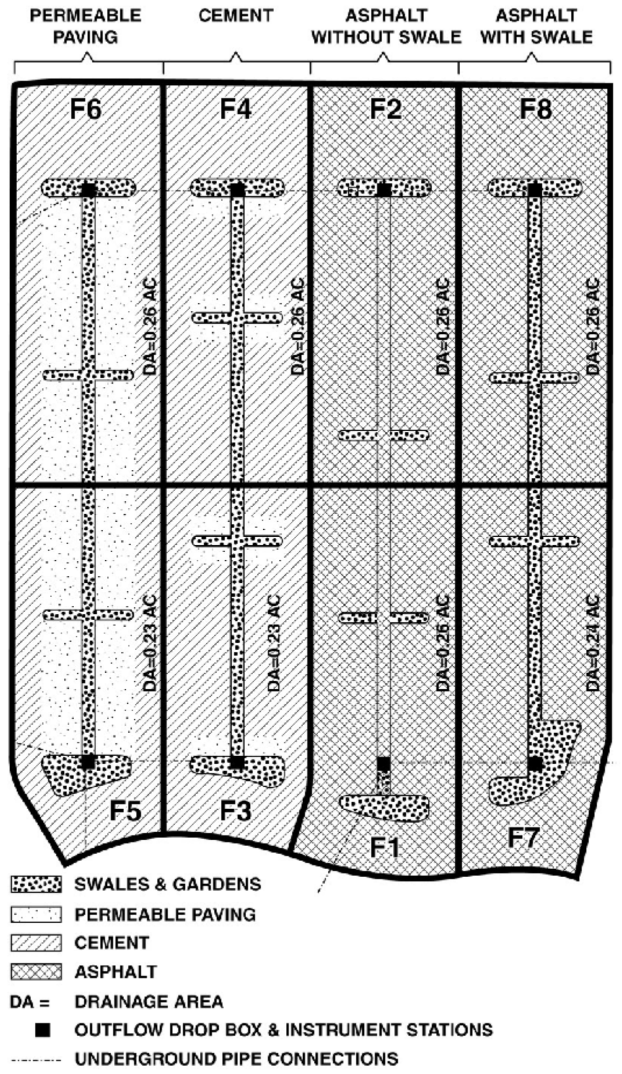


Figure 4.24: Site plan of the parking lot swales delineated by the dotted lines
(Source:Rushton, B, 2002)

The experimental design in the parking lot allowed for the testing of three paving surfaces as well as basins with and without swales, creating four treatment types with two replicates of each type. The eight basins were instrumented to measure discharge volumes and take flow-weighted water quality samples during storm events. The four treatment types included:
1. Asphalt paving with no swale (typical of most parking lots),
2. Asphalt paving with a swale,
3. Concrete (cement) paving with a swale, and
4. Porous (permeable) paving with a swale.

The swales are planted with native vegetation. The basins without swales still had depressions similar to the rest of the parking lot, but the depressions were covered over with asphalt. All basins had some landscaped garden areas providing opportunities for runoff to infiltrate *(Rushton, 2002)*

Cost of the project:

Sustainable Base cost: site work with stormwater system = $1,091,000
A direct comparison of infrastructure cost savings of a natural drainage system versus the original pipe/curb/retaining wall intensive plan showed a 19 percent reduction from the original design's budget. Money saved by using less concrete pipe, along with the elimination of curbing and a retaining wall, was re-invested in additional trees and swale plantings and experimental pavement test areas.

Sustainable Base cost + Enhancements: The sustainable plan with enhanced paving and landscaping = $1,634,000 (This included $275,000 in additional natural system improvements including landscaping, low volume irrigation and shoreline enhancements to Ybor Channel. It also included an additional $268,000 for pervious and concrete paving in the parking area). These features were planned as part of the project, and alternative grant funding was specifically sought *(The Case for Sustainable Landscapes, 2009).*

Case study 5: Florida Aquarium Parking Lot and Queuing Garden, Tampa, Florida

Landscape Performance Benefits

1. The queuing garden near the entrance of the aquarium treated stormwater runoff, but it did not drain into the parking lot system; rather it was pretreatment for runoff that flowed directly into the parking lot pond.

2. Green space was increased by 10% by reducing the dimensions of individual parking spaces by 2 ft. This created more efficient layouts that allowed the incorporation of bioswales without reducing the number of parking spaces. It also did not compromise parking, since the design had the front end of the vehicles hanging over grass rather than impervious paving.

3. The bioswales treated water that came from three different surfaces asphalt paving, concrete paving and porous paving. After careful monitoring of the sustainable practices, calculations showed that almost all the runoff was retained on the site.

4. Basins paved with porous pavement had the best percent removal of pollutant loads, with removal rates for metals greater than 75% in the basin with small garden area and 90% with large gardens.

Figure 4.25: The Florida Aquarium Parking lot vegetated swale
(Source: Initiative, T. S. S2008)

5. Soil conditions have improved with the growth of roots and trapping of detritus in landscape areas *(The Case for Sustainable Landscapes, 2009).*

6. Water was discharged only once from the site even with high precipitation rate. Such infrequent discharges are unusual and the total reduction in loading exceeded the benefit of filtration and sedimentation values *(The Case for Sustainable Landscapes, 2009).*

Case study 5: Florida Aquarium Parking Lot and Queuing Garden, Tampa, Florida

1. Land Use Type*:* Commercial parking lot

2. Catchement area*:* 11.25 acres

3. Average annual rainfall: 43.9 inches/year

4. Soil type: Urban land

5. Infiltration rate: ■ High ☐ Medium ☐ Low
Infiltration capacity was noticed to be high with basins containing porous pavements and vegetated swales.

6. Peak flow reduction: ■ Yes ☐ No
Compared to parking lots without swales, parking lots with swales discharged lesser volume of runoff. In contrast, the basins with larger garden areas had much lower runoff volumes demonstrating the value of recessed areas for infiltration to occur the same manner as it did before development. Pavements and swales reduced runoff by 50%.

7. Storage capacity: ☐ High ■ Medium ☐ Low

8. Pollution removal: ■ High ☐ Medium ☐ Low
The basin with vegetated swale and porous pavements produced significant reductions for most constituents . The removal rates were observed to be greater than 90%. Higher phosphorous loads were discharged from the basins with vegetated swales due to the phosphorous in the vegetation and in the soils.

9. Native vegetation: ■ Yes ☐ No

10. Provides wildlife habitat: ☐ Yes ■ No

11. Aesthetics: ■ Yes ☐ No

12. Comments: Originally a brownfield development which housed the coca- cola company, the site has transformed itself into a landscape friendly development. The swales did a good job with the pollutant removal from the parking lots to about 90% which encouraged infiltration.

Conclusion

Successful application of vegetated swales involves the coordination of many disciplines and activities. It requires careful follow through from concept to design to construction and maintenance. From the case studies above, it is noted that swales help in reducing peak flow rate only if properly designed and maintained well. Swales help a great extent in reducing the pollutants from urban runoff. Vegetated swales is one of the LID practices which promoted infiltration and ground water recharge depending on the water quality of the runoff and the pollutant removal capacity of the swale.

From the OMSI case study, it is also observed that swales when combined with other stormwater practices like wetlands, function at a higher efficiency. The Meadowlake Township case study highlights that swales help to a great extent in preventing soil erosion and help in soil stabilization. This is achieved by incorporating design techniques like addition of a mulch blanket layer beneath the vegetation.

Vegetated swales when combined with other LID practices like rainwater harvesting systems, as in the Mt.Tabor case study, not only helps reduce peak flow rates but also helps to a great extent in infiltration and collection of rainwater. Rainwater from the roofs is harvested and the excess water and the stormwater from the parking lots are directed into vegetated swales.

Therefore, swales when designed and maintained becomes a landscape feature in addition to providing stormwater benefits. From the case studies, it is noted that vegetated swales when used in combination with other LID practices offer more landscape and stormwater benefits.

Chapter 5: Infiltration systems

Low impact development practices for infiltration

An infiltration trench is a long, narrow, excavated trench backfilled with a stone aggregate, and lined with a filter fabric. Runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. Infiltration trenches perform well for removal of fine sediment and associated pollutants (ACOLA, 2010). Infiltration trenches may be used in conjunction with another Best Management Practice (BMP) such as buffer strips, vegetated swales or detention basins to provide both water quality and peak flow control.

Figure 5.1: Buckman Heights courtyard infiltration basin (430 NE 16th Ave)

(Source:www.sustainableportland.org, 2011)

Infiltration trenches are often used in place of other Best management practices where limited land is available. Runoff that contains high levels of sediments or hydrocarbons (oil and grease) that may clog the trench are often pre treated with other BMPs. Examples of some pretreatment BMPs include grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips (SEWRPC, 1991, Harrington, 1989)

Infiltration trenches

Advantages of infiltration trenches:

1. Infiltration trenches provide 100% reduction in the load discharge to surface waters
2. A significant portion of the average annual rainfall runoff is infiltrated rather than flushed directly to creeks
3. If the water quality volume is adequately sized, infiltration trenches can be useful for providing control of channel forming (erosion) and high frequency flood events
4. As an underground BMP, trenches are unobtrusive and have little impact on site aesthetics.

Disadvantages of infiltration trenches:

1. The functioning of infiltration trenches fail if soil and subsurface conditions are not favorable
2. Not suitable for industrial sites or locations where spills may occur
3. Infiltration trenches can handle a maximum area of 5 acres and not more
4. Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with hydologic soil types C and D
5. If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated prior to infiltration to protect groundwater quality
6. Not suitable on fill sites and steep slopes
7. There is a possibility of groundwater contamination in very coarse soils
8. Once the trench is clogged, it is difficult to restore the functioning of the trench.

Source: (CASQA, 2010)

Rainfall Storage Infiltration

Figure 5.2: Processes in an infiltration trench

(Source: ricecreekwatershed.govoffice2.com, 2011)

Design and sizing of Infiltration trenches:

1. The infiltration trench shall be sized to store the full 48 - hour water quality volume
2. In-situ/ undisturbed soils shall have a low silt and clay content and have percolation rates greater than 0.5 inches per hour. Acceptable soil texture classes include sand, loamy sand, sandy loam and loam. These soils are within the A or B hydrologic soil group. Soils in the C or D hydrologic groups should be avoided. It is advised to perform in-situ testing to confirm percolation rate of the trench site.
3. There shall be at least 10 feet below the trench to the water table to prevent potential ground water problems. A set back of 100 feet from building foundation is recommended unless shorter distance is approved by geotechnical engineer and local standards.
4. The drainage areas must be fully developed and stabilized with vegetation before constructing an infiltration trench. Runoff from unstabilized areas should be diverted away from the trench into a construction period sedimentation control BMP until vegetation is established.
5. Infiltration trenches work best when the upgradient area slope is less than 5 percent. The down gradient slope should be no greater than 20 percent to minimize slope failure and seepage

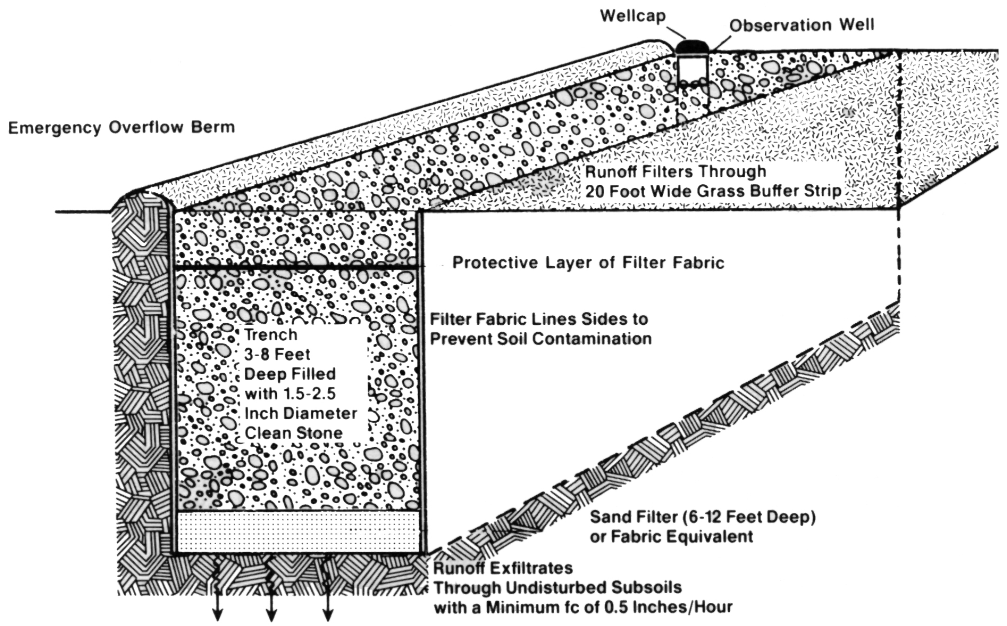


Figure 5.3: Typical section of an infiltration trench
(Source: Schueler, 1987)

6. A trench surface may consist of stone or vegetation with inlets to evenly distribute the runoff entering the trench. Runoff can be captured by depressing the trench surface or by placing a berm at the down gradient side of the trench.
7. Generally trench rock that is 1.5 to 2.5 inches in diameter or pea gravel to improve sediment filtering and maximize the pollutant removal in the top 1 foot of the trench is used
8. A vegetated buffer strip atleast 5 feet wide, swale or detention basin shall be constructed adjacent to the infiltration trench to capture large sediment particles in the runoff.
9. If runoff is piped or channeled to the trench, a level spreader shall be installed to create sheet flow
10. A site-specific trench depth can be calculated based on the soil infiltration rate, aggregate void space, and the trench storage time. The stone aggregate used in the trench is normally 1.5 to 2.5 inches in diameter, which provides a void space of 35-40 percent. A minimum drainage time of 6 hours shall be provided to ensure satisfactory pollutant removal in the trench.

(Source: ACOLA, 2010)

Maintenance and operation

Infiltration trenches should be inspected on a regular basis for the proper functioning of the trench. Maintenance is mainly necessary to check for clogging, which may lead to the failure of the trench. Infiltration trenches along with any pre treatment BMP's used should be inspected thoroughly especially after large storm events for any accumulated debris. Trenches with the filter fabric layer should be inspected for sediment deposits by removing a small portion of the top soil.

Costs

Construction of an infiltration trench include clearing, excavation, placement of the filter fabric and stone, installation of the monitoring well, and establishment of a vegetated buffer strip. Additional costs include planning, geotechnical evaluation, engineering and permitting. The Southeastern Wisconsin Regional Planning Commission *(SEWRPC, 1991)* has developed cost curves and tables for infiltration trenches based on the 1989 dollars. The 1993 construction cost for a relatively large infiltration trench (1.8 meters deep and 1.2 meters wide with a 68 cubic meter volume ranged from $8,000 to $ 19,000. A smaller infiltration trench (0.9 meters deep and 1.2 meters wide with a 34 cubic meter volume) is estimated to cost from $3,000 to $8,500. Annual maintenance costs would average $700 for the large trench and $325 for smaller trenches. Typically, annual maintenance costs are approximately 5 to 10 percent of the capital cost *(Schueler, 1987)*.

Infiltration trenches

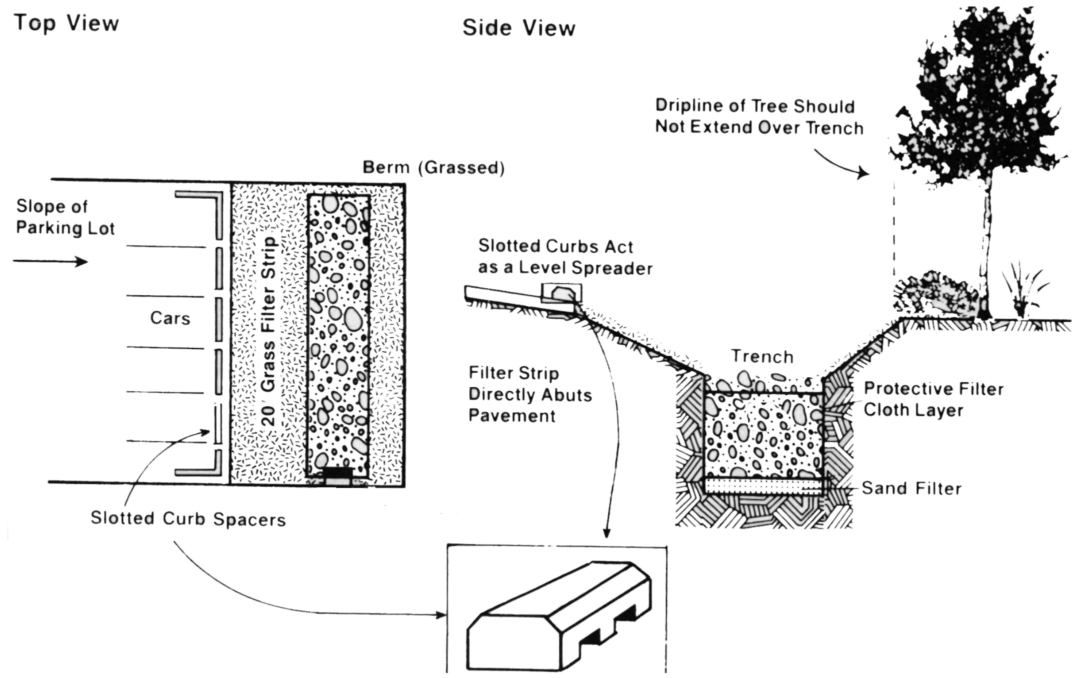


Figure 5.4: Parking lot perimeter trench design
(Source: Schueler, 1987)

Performance of infiltration trenches

Based on the table below, infiltration trenches can remove upto 90 percent of sediments, metals, coliform bacteria and organic matter and up to 60 percent of phosphorous and nitrogen in the runoff *(Schueler, 1992)*

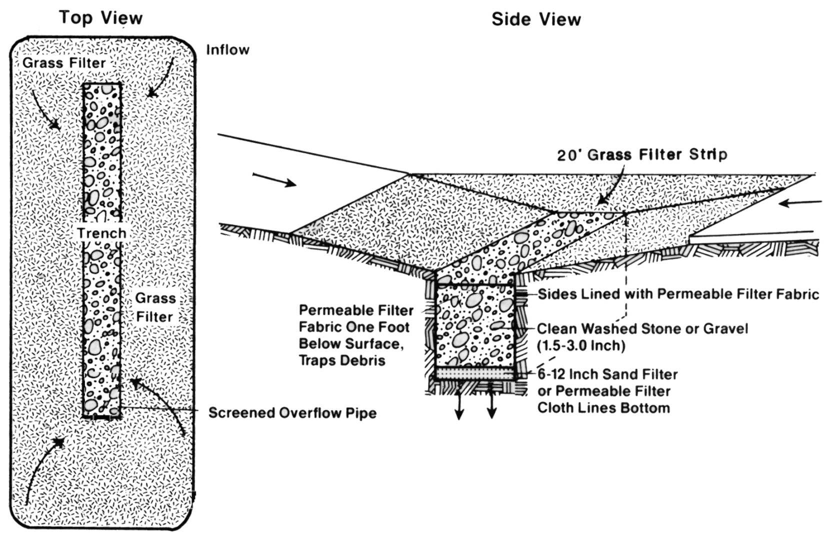


Figure 5.5: Median strip trench design
(Source: Schueler, 1987)

Case sudy: Buckman Terrace, Michigan

The infiltration trench measures 15 feet long by 8 feet wide and approximately 13 feet deep and occurs approximately 3 feet off the bottom (on side slopes) of the adjacent basin. Thee lower portion of the basin was designed as a sedimentation basin to allow sediment to settle prior to runoff reaching the infiltration trench. The basin is planted with deep rooted native vegetation, and has not maintained a permanent pool of water since construction in 1999.

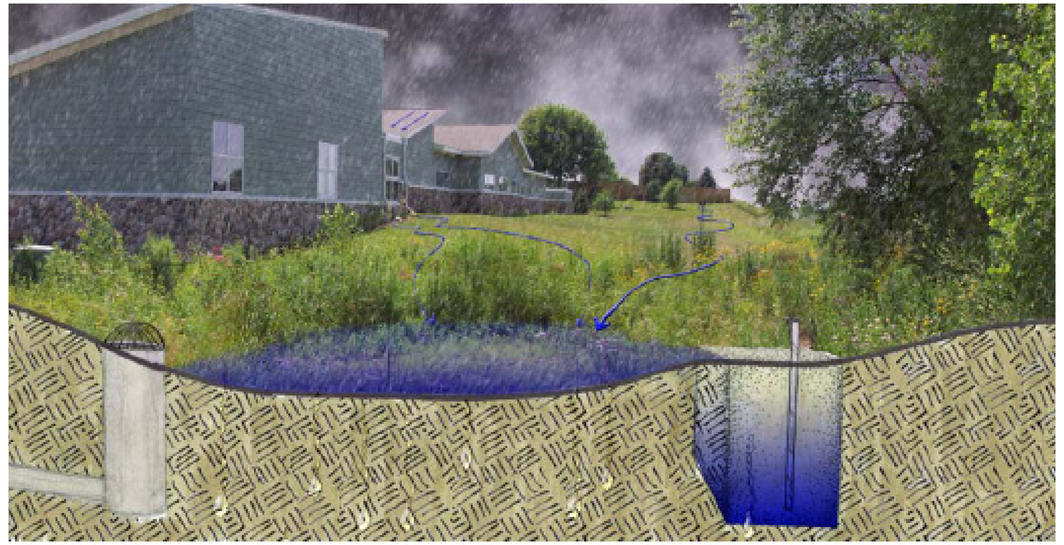


Figure 5.6: Cross section of the MSA infiltration trench
(Source: stormwaterbook.safl.umn.edu, 2011)

The MSA trench drains only 0.4 ha from a portion of the school roof, a swale detaining a high traffic road and a small amount of open space.

Infiltration Trench (Number of years monitored)	**Infiltration rate (mm/hour) Average rate**
MSA trench (Rainfall - 5; snowmelt - 4)	23.6

Table 6: Infiltration rate for MSA trench

Research has shown that the rate of infiltration is increasing with each year. The reason for this improvement has been speculated to be good vegetative growth in the entire basin. This has improved conditions through energy dissipation and solids filtration prior to infiltration, massive root growth downward by the native plants and the insect boring that are visible at the site.

It is also observed that the infiltration rate of snowmelt runoff, although very effective, is not as high as it is for rainfall events.

Permeable pavements

Most of the paving in developed areas is due to asphalted roads and pavements, and parking lots, which play a major in transporting increased stormwater runoff and contaminant loads to the receiving watersheds. By using permeable pavements, infiltration of rainwater can be increased along with reducing runoff leaving the site. This eventually helps in decreasing downstream flooding, the frequency of combined sewerflow (CSO) events, and the thermal pollution of sensitive waters. Use of permeable materials can also eliminate problems with standing water, groundwater recharge, control of stream beds and river banks, provide for pollutant removal, and provide for a more aesthetically pleasing site. Use of permeable pavements can also eliminate the requirement for underground sewer pipes and conventional stormwater systems. Infiltration and controlling drainage by incorporating permeable pavements is an important component of LID site design in order to achieve pre-development site hydrologic conditions.

Paking lots *Roadways* *Sidewalks* *Patios* *Airports/Boat ramps*

Figure 5.7: Applications of permeable pavements
(Source: www.eot.state.ma.us/smartgrowth, 2011)

Any surface that is paved with an impervious surface can be converted to a permeable pavement system. Permeable pavements are particularly useful in high density areas where there is limited space for other stormwater management practices. Permeable pavements can also be used for parking lots, basketball courts, playgrounds, plazas, sidewalks and trails.

Permeable pavements provide alternatives to standard asphalt and concrete , which are completely impervious surfaces. Various types of permeable pavements available today are pervious concrete, pervious concrete, pervious asphalt, permeable interlocking pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavements.

Permeable pavements

Components of a permeable pavement system:

A typical section of a permeable pavement system contains:
1. Inflow/Surfacing
2. Storage
3. Infiltration/Outflow

Inflow/Surfacing: There are different types of structural surface materials that allow water to flow through void spaces within the material. All of these surfaces serve as a source of conveyance and filtration for the storage bed below. Some of the surfacing systems used are:

1. Porous concrete: Porous concrete was developed in the U.S. by the Florida Concrete Association in the 1970s. According to the ACI Committee Report 522R-06, the term “pervious concrete” typically describes a zero-slump, open graded material consisting of portland cement, coarse aggregate, little or no fine aggregate, admixtures and water. Porous concrete is produced by substancially reducing the number if fines in the mix in order to establish voids for drainage.

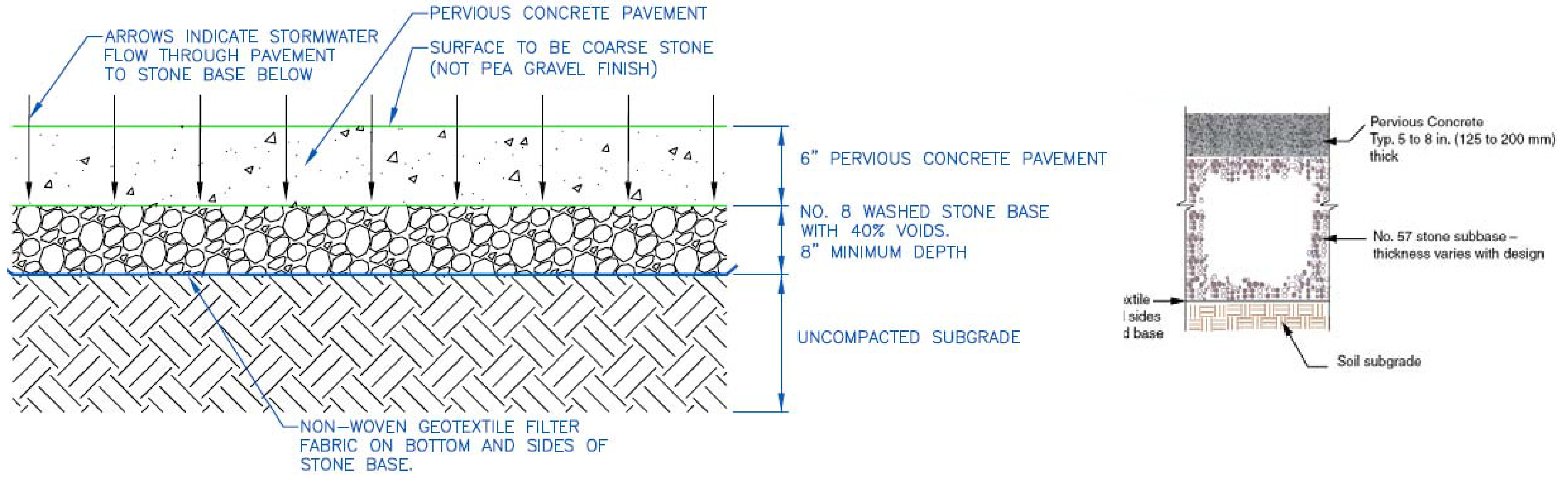


Figure 5.8: Typical section of porous concrete paving

(Source: www.indy.gov, 2011)

Permeable pavements

Porous asphalt: Porous asphalt pavement was first developed in 1970s and consists of standard bituminous asphalt in which fines have been screened and reduced, allowing water to pass through very small voids. Porous asphalt is very similar in appearance to conventional, impervious asphalt.

Permeable pavers: Permeable pavers are interlocking units (often concrete) with openings that can be filled with a pervious material such as gravel. This type of pavement is aesthetically pleasing and generally well suited to plazas, patios, small parking areas, and sidewalks.

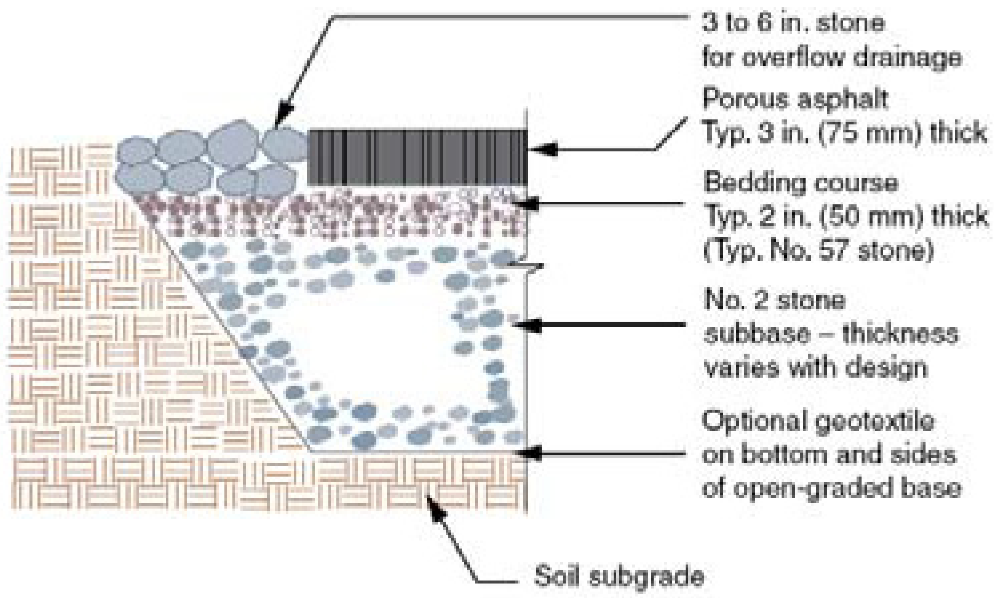


Figure 5.9: Typical section of porous asphalt paving
(Source: www.indy.gov, 2011)

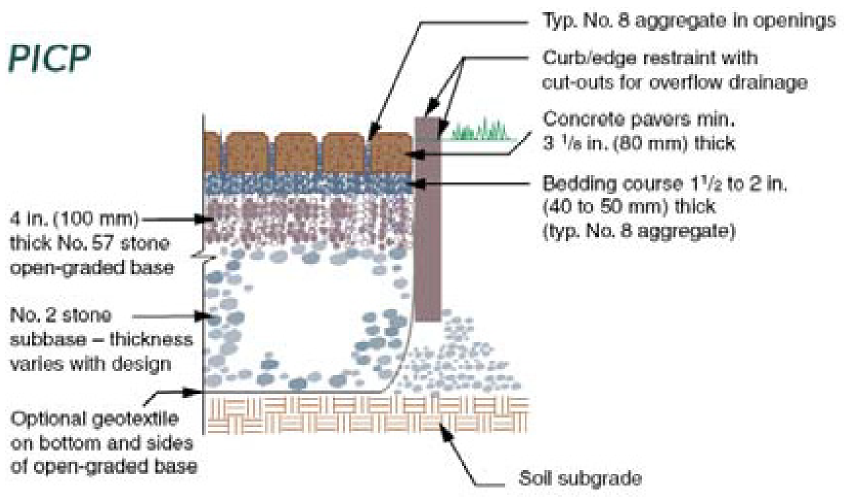


Figure 5.10: Typical section of permeable interlocking pavers (PICP) paving
(Source: www.indy.gov, 2011)

Reinforced turf: Reinforced turf consists of interlocking structural units with openings that can be filled with soil for the growth of turf grass and are suitable for traffic loads and parking. They are often used in overflow or event parking as well as emergency access for fire trucks. Reinforced turf grids are made of concrete or plastic and are underlain by a stone and/or a sand drainage system for stormwater management. While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units may provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. The grids protect the root structure and minimize the impact on the grass by traffic loads *(COI, 1995)*

Permeable pavements

Storage: In addition to distributing mechanical loads, coarse aggregate laid beneath porous surfaces is designed to store stormwater prior to infiltration into soils or discharging to a stormwater BMP. The aggregate is wrapped in a non-woven geotextile to prevent migration of soil into the storage bed and resultant clogging. In porous asphalt and porous paver applications, the storage bed also has a choker course of smaller aggregate to separate the storage bed from the surface course. The storage bed can be designed to manage runoff from areas other than the porous surface above it, or can be designed with additional storage and control structures that meet the parameters required within the Stormwater Design and Specification Manual.

Infiltration/outflow: Positive overflow must be provided for porous pavement systems. Positive overflow conveys runoff from larger storms out of the system, prevents flooding and prevents water from standing within the porous structural surface which minimizes freeze-thaw impacts. One solution for a positive overflow is a stone buffer along the edges of a porous pavement lot. The stone, typically river rock or a stone with aesthetic value, is connected to the stone sub-base below the pavement to allow a path for excess water to flow out of the system. The stone should allow positive overflow to occur at an elevation below the structural surface. A perforated pipe system can also convey water from the storage bed to an outflow structure. *(Source: GISS, 2009)*

Figure 5.11: Comparison of standard asphalt with porous asphalt
(Source:www.indy.gov/eGov/City/DPW/SustainIndy/WaterLand, 2011)

Permeable pavements

Design considerations:

1. The suitability of pervious pavements for a particular site will depend on the loading criteria required of the pavement. Where the system is to be used for infiltration purposes, the vulnerability of local groundwater sources to pollution from the site should be low, and the seasonal high water table should be atleast 4 feet below the surface. Ideally, the pervious surface should be horizontal in order to intercept local rainfall at the source. On sloping sites, pervious surfaces may be terraced to accommodate differences in levels *(CSBHND, 2010)*.

2. A washed aggregate base must be used, and washed 57-size stone is generally acceptable. Fine particles from standard “crusher run” will clog the pores at the bottom of the pavement and will not be allowed.

3. The seasonally high water table must be at least 2 ft from the base of the permeable pavement or gravel storage layer. Water tables approaching the permeable pavement system will not allow water to infiltrate.

4. Permeable pavement should not be placed where upland land disturbance is occurring or will potentially occur. Land disturbance upland of the lot could result in frequent pavement clogging.

5. The completed permeable pavement must be installed at a grade less than 0.5%. Steeper slopes will reduce the storage capacity of the permeable pavement.

6. During preparation of the subgrade, special care must be made to avoid compaction of soils. Compaction of the soils can reduce the infiltration capacity of the soil.

7. Permeable pavement should not be designed to receive concentrated flow from roofs or other surfaces. Incidental run-on from stabilized areas is permissible, but the permeable pavement should primarily be designed to infiltrate the rain that falls on the pavement surface itself. No credit will be given for volume or peak reduction for run-on from impervious surfaces.

8. The construction sequence will be inspected to insure that the surface installation is planned to be completed after adjacent areas are stabilized with vegetation. Run-on to the permeable pavement from exposed areas can cause the system to perform ineffectively.

Case study: Galbraith pervious concrete, Oregon

Project background:

An old Medford home was transformed into the office of Galbraith & Associates, Inc. a landscape architecture firm in Oregon. In addition to major building renovations, a parking lot needed to be installed to meet the needs of the firm. To comply with city code regarding drainage and handicap access, a conventional concrete parking lot would have required significant lengths of storm sewer connections and tricky grading solutions. It also would have severely damaged a mature oak tree . To eliminate the cost of storm sewer connections and to save the root structure of the oak, pervious pavement was chosen as an alternative.

The parking lot is approximately 1085 ft² that connects to the street. A large oak stands within the parking area. The soil is Coleman loam which is a very deep and moderately well drained soil. The permeability of this soil class is slow but is sufficient for permeable pavement considering the water storage capacity of the gravel base. The average rainfall in Medford is 18.9 inches annually.

Site preparation included the compaction of an 8 inch layer of 1-inch diameter rock on top of the existing natural soil surface. Once this base was in place, a 4 inch layer of StoneyCrete pervious pavement was poured. The concrete is a mixture of 1/8 inch diameter rock with bonding material that consists of 80% Portland cement and 20% fly ash. Fly ash is a by product of coal burning that can be used to improve strength and durability of cement mixtures. This combination of rock and bonding material creates 20% airspace in the concrete, which allows it to accommodate drainage for a 10 year storm event.

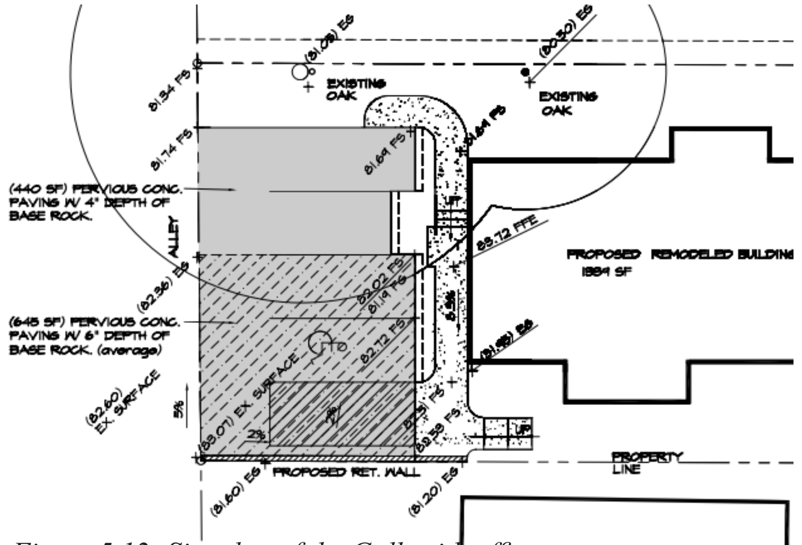


Figure 5.12: Site plan of the Galbraith office
(Source: Stromwater solutions, 2009)

Cost of the project:

The pervious concrete is estimated to cost $6.50 per square foot, totaling $6500 for the entire parking lot. Traditional asphalt for this area is estimated at $4.50 per square foot and traditional concrete is estimated to cost the same. However, by eliminating the need for a storm sewer connection, the Galbraith firm saved $6000 in connection costs.
(Source: Stormwater solutions, 2009)

Conclusion

The study for this thesis started off as a literature review for three commonly used LID practices: Green roofs, rainwater harvesting systems and vegetated swales. From the literature review, design and technical objectives were deduced which led to the study and analysis of the case examples for each of the three practices. The case examples gives the audience an in depth knowledge of the LID practice and there functioning in the real world.

The thesis also helps in understanding LID practices and how to get the community and the local ordinances to apply them into there design.

Five things you can do to promote LID in your local ordinance are:
1. Revise the local ordinances in order to encourage the use of LID practices
2. Revise street and parking standards to comply with the main goal of LID
3. Encourage properly designed parking lots and streets with practices like porous pavements, green median strips, buffer strips, rain gardens, vegetated swales, and tree box planters as an alternative to curbs, cul-de-sacs and gutters.
4. Incorporate LID site design principles in the local ordinances
5. Incorporate incentives for sites achieving LID goals.

Five things you can do to promote LID in your community are:
1. Spread and increase the awareness of the practice of LID through educational programs, fact sheets and demonstration projects
2. Reach out to your developer about LID so that they can incorporate certain practices into the site design
3. Get projects on the ground which could be as small as a rain garden or a rainwater harvesting system which could inform the neighbors the advantages of the practice
4. Reach out to local community authorities to incorporate LID practices into their local guidelines
5. Provide educational training in terms of seminars and presentation in schools and colleges to educate the youth about the advantages of LID practices

Hence, this thesis can very well be used as an educational tool to increase the awareness and usability of low impact development practices. Furthermore, this thesis can be developed into a more comprehensive design manual which could include other practices like infiltration trenches, dry wells, bio retentions cells, tree box planters and wetlands. The expanded version can provide various other case examples for each of the LID practice.

This thesis can therefore be used as a guideline for understanding the three LID practices by the users which will help them better understand other technical manuals listed in the appendix.

Appendix

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Appendix B- List of Figures

Appendix B - List of figures

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Appendix C - Relavant codes and regulations

Relevant codes and standards which help in the better design of a site using low impact development practices are:

1. Chesapeake Bay Agreement 2000
2. Clean Water act
    - Section 303: Total Maximum Daily Loads
    - Section 311: Spill Prevention, Control and Countermeasure Requirements
    - Section 319: State Non-Point Source Management Program
    - Section 401: Certification and Wetlands
    - Section 402: National Pollutant Discharge Elimination System (NPDES) Program
    - Section 404: Regulation of Dredged or Fill Material
3. Safe Drinking Water Act Wellhead Protection Program
4. Coastal Zone Management Act
5. Energy Policy Act of 1992
6. Estuaries and Clean Water Act of 2000
7. National Environmental Policy Act of 1969
8. Sikes Act

Appendix D - Additional resources

Fact Sheets

This fact sheet is one of a series of four prepared by EPA Region 1. The others are listed below and are available on the EPA Region 1 website. **http://www.epa.gov/region1/npdes/stormwater**

- Managing Stormwater with Low-Impact Development Practices: Addressing Barriers to LID
- Funding Stormwater Programs
- Restoring Impaired Waters: Total Maximum Daily Loads (TMDLs) and Municipal Stormwater Programs

Green Infrastructure Approaches to Managing Wet Weather with Clean Water State Revolving Funds
http://www.epa.gov/OW-OWM.html/cwfinance/cwsrf/green_if.pdf

Incorporating Green Infrastructure Concepts into Total Maximum Daily Loads (TMDLs)
http://www.epa.gov/owow/tmdl/stormwater/pdf/tmdl_lid_final.pdf

Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas: Case Studies and Design Principles
http://www.epa.gov/brownfields/publications/swdp0408.pdf;
http://www.epa.gov/brownfields/publications/swcs0408.pdf
Set of four page publications produced by the EPA Brownfields program in cooperation with the Low Impact Development Center. Discusses opportunities, constraints and measures for implementing green infrastructure for stormwater management on Brownfield sites.

Manuals and Reports

Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices
http://www.epa.gov/owow/nps/lid/costs07
Information on the costs and benefits of using Low Impact Development (LID) strategies and practices to help protect and restore water quality.

EPA Green Infrastructure Municipal Handbook documents Four Handbooks: Funding; Retrofit Policies; Green Streets; Rainwater Harvesting Policies
http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm

Low-Impact Development Hydrologic Analysis
http://www.epa.gov/owow/nps/lid_hydr.pdf
Prepared by the Prince George’s County Maryland Department of Environmental Resources Programs and Planning Division, with assistance from EPA.

Stormwater Best Management Practices - National Menu Stormwater Best Management Practices
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm
LID design strategies and fact sheets for meeting Phase II Stormwater requirements for Post-Construction Stormwater Management in new development and redevelopment. reference document for officials with environmental responsibilities designed to assist with finding the means of financing environmental protection initiatives. Contains over 300 financial tools that can be used to pay for environmental systems.

Appendix D - Additional resources

Urban Stormwater Best Management Practices Performance Tool
http://cfpub.epa.gov/npdes/stormwater/urbanbmp/bmpeffectiveness.cfm
Provides easy access to approximately 220 studies assessing the performance of over 275 BMPs.

Using Smart Growth Techniques as Stormwater Best Management Practices (EPA), 2005
http://www.epa.gov/smartgrowth/pdf/sg_stormwater_BMP.pdf
Guidance to help communities (i.e. NPDES Phase II communities) develop comprehensive stormwater and planning documents, outreach programs and compliance tracking. Offers innovative measures for improving stormwater management through redevelopment, infill, urban parks and green building techniques.

Green Parking Lot Resource Guide
http://www.epa.gov/watertrain/smartgrowth/resources/resident.htm

Guidebook of Financial Tools: Paying for Sustainable Environmental Systems
http://www.epa.gov/efinpage/publications/GFT2008.pdf
A reference document for officials with environmental responsibilities designed to assist with finding the means of financing environmental protection initiatives. Contains over 300 financial tools that can be used to pay for environmental systems.

Stormwater TMDL Implementation Support Manual
http://www.epa.gov/ne/eco/tmdl/assets/pdfs/Stormwater-TMDLImplementation-Support-Manual.pdf

LID Guidance Manual for Maine Communities: Approaches for implementation of Low Impact Development practices at the local level, State Planning Office, 2007.
http://www.maine.gov/spo/landuse/docs/publications.htm
The purpose of this manual is to guide municipalities that review development of subdivisions and small commercial projects, and issue building permits, to help municipalities implement LID practices

Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows
http://www.nrdc.org/water/pollution/rooftops/rooftops.pdf
Provides policy guidance for decision-makers and includes nine case studies of cities that employed green techniques successfully. on small, locally permitted development projects.

Websites

EPA New England's Stormwater website
http://www.epa.gov/region1/topics/water/stormwater.html

EPA Headquarter's TMDL and Stormwater website
http://www.epa.gov/owow/tmdl/stormwater
This web page contains resources for developing stormwater source TMDL's and implementing them in NPDES permits, particularly the "TMDL's to Stormwater Permits Draft Handbook."

EPA Green Infrastructure
http://cfpub1.epa.gov/npdes/home.cfm?program_id=298

Appendix D- Additional resources

EPA National LID
http://www.epa.gov/owow/nps/lid
A compilation of a number of resources, with links to Web sites, a literature review, fact sheets, and technical guidance.

EPA Nonpoint Source Outreach Toolbox
http://www.epa.gov/nps/toolbox
Web-based resources to assist communities with watershed education and outreach activities. Includes a searchable catalog of print, radio, and TV ads and outreach materials and resources on LID techniques.

Low Impact Development Center
http://www.lowimpactdevelopment.org
A nonprofit organization whose goal is to promote water resource and environmental protection through proper site design techniques that replicate preexisting hydrologic site conditions. The Web site contains a variety of technical resources and case studies exemplifying LID techniques.

National LID Clearinghouse
http://www.lid-stormwater.net/clearinghouse
Tools and techniques for meeting regulatory and receiving water protection program goals for urban retrofits, re-development projects, and new development sites.

Center for Watershed Protection
http://www.cwp.org
A nonprofit organization that provides technical tools for protecting water resources to local governments, activists, and watershed organizations. The center has developed a number of excellent publications pertaining to site design and watershed protection.

Green Values Stormwater Toolbox
http://greenvalues.cnt.org
This site by the Center for Neighborhood Technology contains an overview and definition of green infrastructure practices and hosts the Green Values Stormwater Calculator that allows users to select green interventions and enter site characteristics, returning hydrologic and financial outcomes for each scenario. It also includes a pocket guide called Water: From Trouble to Treasure, A Pocket Guide to Green Solutions.

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) Smart Growth/Smart Energy Tool kit. Low Impact Development concepts, model bylaw, case studies, presentation, brochure, and links.
http://www.mass.gov/envir/smart_growth_toolkit/pages/modlid.html

University of New Hampshire Stormwater Center
http://www.unh.edu/erg/cstev/index.htm
The Center serves as technical resource for stormwater practitioners by studying a range of issues for specific stormwater management strategies including design, water quality and quantity, cost, maintenance, and operations. The field research facility serves as a site for testing stormwater treatment processes, and for providing technology demonstrations and workshops.

Rhode Island Stormwater Low Impact Development (LID) Inventory
http://www.uri.edu/ce/wq/RESOURCES/STORMWATER/LID_tour.htm
Shows LID sites from the inventory by clicking on the interactive map or selecting sites based on LID treatment practice. In the future, you will be able to find companies that design and install these LID practices

Appendix D- Additional resources

The Massachusetts LID Toolkit, Metropolitan Area Planning Council
http://www.mapc.org/lid.html
Includes fact sheets on Low Impact Site Design, roadways and parking areas, permeable paving, bioretention, vegetated swales, filter strips, infiltration trenches and dry wells, cisterns and rain barrels, and green roofs.

New England Environmental Finance Center
http://efc.muskie.usm.maine.edu/pages/tools.htm
A U.S. EPA and Muskie School project to research, publish, and extend creative approaches to environmental protection and management. Provides a Directory of Watershed Resources, which is a searchable database of funding sources.

Innovative Stormwater Technologies Clearinghouse
http://www.mastep.net/
The Massachusetts Stormwater Technology Evaluation Project (MASTEP) has created this web site to host a source of verified technical information on stormwater Best Management Practices (BMPs) to provide information on innovative technologies to BMP users.

New Hampshire-UNH Stormwater center
http://www.erg.unh.edu/stormwater/index.asp

Natural Resources Outreach Coalition (NROC)
http://extension.unh.edu/CommDev/NROC/CANROC.cfm

Rhode Island NEMO program
http://www.uri.edu/ce/wq/NEMO/index.htm

Innovative Stormwater Treatment Technologies Best Management Practices Manual-May, 2002, New Hampshire Department of Environmental Services (DES)
http://des.nh.gov/organization/divisions/water/wmb/was/manual.htm
Provides innovative stormwater treatment technology information for developed areas within New Hampshire, with detailed product information including function, installation, operation and maintenance, and relative cost, this manual also offers decision making criteria to help in determining the most efficient Best Management Practice (BMP) system for specific site conditions

Maine NEMO Program
http://mainenemo.org/

Operates under the auspices of the Partnership for Environment Technology Education (PETE)

Vermont NEMO Program
http://nemonet.uconn.edu/programs/about_members/vt/vermont.htm

Connecticut NEMO (Non-Point Education for Municipal Officials)
University of Connecticut Cooperative Extension
http://nemo.uconn.edu/
Includes: Center for Land Use Education and Research-Clear
http://clear.uconn.edu/ and LID inventory
http://nemonet.uconn.edu/hub/initiatives.htm

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