CATCHING THE RAIN

A Resource Guide for Natural Stormwater Management in the Southeast

American Rivers
Thriving By Nature

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Acknowledgements

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We gratefully acknowledge the Park Foundation for their generous support and funding of this publication.

Special thanks to Peter Gudritz, Lindsay Martin, Will Hewes and John Seebach of American Rivers; John Senn on behalf of American Rivers; Ted Brown of the Center for Watershed Protection; Jessica Opfer and Dan Keifer of the Clinton River Watershed Council; Amy Mangus of the Southeast Michigan Council of Governments; Lynne Yustick of the Macomb County Public Works Office; and Patricia Pennell of Rain Gardens of West Michigan and the West Michigan Environmental Action Council for reviewing and commenting on this report.

In addition, we would like to thank several colleagues who provided valuable information on various aspects of this report. They include:

Barbara Deutsch of the Casey Trees Endowment
Steve Apfelbaum and Dale Dean of Applied Ecological Services
Seth Hopkins of the Macomb Conservation District
Steve Nagy of the Greenville Urban Forestry Program
Bob Zimmerman of the Charles River Watershed Association
Kurt Leuthold of Barr Engineering
Greg Stoewer of LHB
Steve Anderson of the City of Proctor
Donald Tilton of Tilton & Associates, Inc.
Rich Nobel of A&L Properties

This report does not necessarily reflect the views of the above organizations and individuals.

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Introduction

Since the first *Catching the Rain* was written for the Great Lakes region in 2004, many strides have been made in both green stormwater management technology and use. Towns, cities and even the federal government are starting to apply many of the different techniques featured in this publication. While these green techniques are becoming more popular, there is still a great need to continue outreach, education and research. Hopefully this Southeastern version will help continue that trend.

If this book is your first glimpse of green stormwater management, or just stormwater in general, you're about to learn how to better utilize one of the most important resources on the planet – freshwater. Getting stuck in the rain and negotiating puddles isn't a pleasant experience. But it's important to stop and think about what a miracle it is that freshwater – an essential part of life – just falls from the sky. It's also critical that we not take this gift of nature for granted, although sadly we often do. When you're in a city, town or suburb when it rains, look around, and you will see thousands of gallons of freshwater fall to the ground, soak up dirt, gasoline and other pollutants, and then funnel straight into a drain that shunts it to the nearest stream.

Most people would agree that, despite the occasional discomforts, rain is an essential part of life, providing freshwater for our rivers, plants, lakes, and ultimately for us to drink. Whether we get water from a well, a river, or other sources, rainwater is critical for replenishing our drinking water supplies. So why do we waste so much of it?

To learn more about Low Impact Development, visit www.lid-stormwater.net/intro/background.htm and http://www.lowimpactdevelopment.org/brochures.htm

Not only are we wasting a valuable resource, we are turning it into a pollutant. Stormwater runoff from developed areas is a significant cause of water pollution in the United States. Stormwater runoff from residential, commercial, and industrial areas is responsible for 21 percent of the country's impaired lakes and 45 percent of its impaired estuaries. This is the second highest source of water pollution after agricultural runoff.

The question for citizens, developers and municipalities today is how to best manage stormwater runoff. When managed properly, water is a valuable resource. However, when stormwater is managed like a waste product it exacerbates or creates flooding, and becomes contaminated with pollutants.

This handbook is intended to provide a concise resource guide to more natural, or "soft path" solutions for stormwater problems. These methods are also sometimes referred to as "green infrastructure" or "low impact development". Natural methods offer greater environmental benefits, are more visually attractive, and can in many cases, be less expensive than traditional methods of stormwater control. Natural stormwater management, particularly low impact development methods, is becoming increasingly popular in neighborhoods and cities across the country.

These types of approaches cannot solve all stormwater problems, particularly in areas where industrial pollution or large amounts of pollutants are carried with stormwater runoff. In these cases conventional methods may be more practical. But soft path methods, when applied across a site or area, can reduce many small sources of stormwater that together add up to a significant reduction in runoff volume and pollutants.

There is a great deal of information available on soft path approaches, with sources tailored to engineers, landscape professionals, municipal staff, elected officials, and homeowners. This handbook offers an easy reference to a variety of low impact development approaches suitable for the Southeast. It is not meant to be a technical design tool, but rather a foundation for education and research on alternative stormwater management techniques, particularly for public works staff, developers, and citizens. This handbook provides basic information on use, space requirements, and cost for each method. Additionally, it lists a variety of sources that can provide further information on technical requirements, design, supporting ordinances, and other information.

Chapter One

Imperviousness and Conventional Stormwater Management: From Resource to Waste

When asked where rain or snow goes after it falls to the ground, most people will say that it soaks into the ground or flows into the gutter. Few people fully understand what happens to stormwater once it is out of sight, or how changes in the landscape can affect water quality, flooding, and drinking water. In an undeveloped watershed, rain and snow soak into the soil, where they filter down into "groundwater" or are absorbed by plants and trees for nourishment. Precipitation is absorbed, dispersed and filtered in many different ways as it makes its way, both above and below ground, to our waterways.

Water Quality Impacts

Once development occurs, precipitation that once soaked into the ground runs off of pavement and other hard surfaces, carrying contaminants that have collected on these surfaces, including oil, grease, lawn chemicals, heavy metals, hydrocarbons (combustion byproducts), bacteria, and sediment. It is well documented that the problems associated with stormwater runoff have a major impact on coast lines, rivers, lakes, and streams accross the United States, in particular the southeastern part of the country.[2] Algal blooms, high bacteria content, beach closures, and increased flooding and erosion are only some of the problems caused by stormwater runoff. Instead of being treated like a resource, rain and snowmelt are transformed into contaminated runoff and funneled into storm drains like a waste product. Yet, the connections between conventional stormwater management, water quantity and quality and the overall health of the water resouces in the Southeastern U.S. are often ignored or poorly understood.

Algal Bloom due to urban runoff (Photo: Heal the Bay)

A channelized stream in a suburban neighborhood (Photo: United States Department of Agriculture)

Hydrologic Impacts

Most watersheds in the United States are not in a completely natural state. The effects of roads, buildings, and other "impervious" surfaces have a dramatic impact on the natural cycling of water. Imperviousness (pavement, roofs, and other hard surfaces), conventional stormwater systems such as storm sewers, and alterations to natural vegetation and floodplain structure disrupt the connections between groundwater and surface water flows. The result is an overall drop in stream levels, particularly in times of drought. Impervious surfaces block water from soaking into the ground and replenishing groundwater. Instead they quickly funnel and concentrate the water into drainage ditches, streams and rivers, causing flooding and erosion. Were this runoff allowed to soak into the earth and become groundwater, stream and river levels would remain more consistent through both excessively wet and dry periods.

There are additional negative impacts of stormwater runoff that are unique to the communities of the southeast. Ground water that would normally flow into southeastern rivers and streams is slowly being diminsihed by greater water demand for irrigation and drinking water. Additionally, as impervious surfaces, like roads and buildings, increase, the amount of area available for rain to soak into the ground and recharge ground water reserves diminishes. Instead, stormwater runs off impervious surfaces into the local river in a matter of hours, and disappears downstream. This, in effect, is beginning to cause water shortages in highly urbanized areas in the southeast, like Atlanta. This kind "starvation" of ground water aquifers has begun to impact southeastern river water volumes and drinking water supplies. Unless more is done to protect the natural water recharge system by capturing and infiltrating precipitation where it falls, drinking water will become more scarce, and droughts more severe.

Impervious surfaces created through development affect the natural hydrological cycle (Photo: United States Department of Agriculture)

Water Supply Effects

Water supply is becoming a serious problem in the Southeastern U.S. Reduced groundwater infiltration requires those with private or municipal well service to continually set pumps deeper to chase an ever-falling water table.* Many communities may feel compelled to turn to rivers and inland lakes for water at the very time that these sources' flows are also dropping. Water rights issues are becoming more contentioous, as can be seen in the disputes between Georgia, Alabama and Florida occuring over flows to the Chattahoochee and Apalachicola Rivers .

The dried up bed of the Ipswich River, in Massachusetts (Photo: United States Geological Survery)

Flooding Effects

Another significant result of increased development and impervious surfaces is the increase in flooding. It is well documented that floods regularly increase in frequency and severity with the expansion of impervious surfaces.

*Deep aquifers used for drinking water are recharged through complex pathways over long periods of time. Depending on the aquifer the process can takes years, decades, or even centuries.


Roadside erosion due to flooding (Photo: Patricia Pennell)

This occurs because water is channeled off impervious surfaces into a receiving water body at a higher volume and rate than the water body is capable of handling. A 2000 study published in the Journal of Climate found that U.S. annual flood losses increased, adjusting for inflation, from $1 billion in the 1940's to $5 billion in the 1990's.[3] In 2001 alone there was $7.1 billion worth of flood damage nationally.[4]

Increased development within floodplains reduces the ability of these areas to absorb higher stream flows following rainfall or snowmelt. Developed areas reduce the amount of vegetation and pervious soil that normally soak up or detain excess water. Impervious surfaces and conventional storm drains also collect and transfer large volumes of water at unnatural rates back into rivers and streams.

Even as floodplain development accelerates, upstream urbanization is increasing the rate at which water moves off the surface of the land and into rivers and streams, placing downstream communities at ever-greater risk of flooding.

Physical Effects

The physical effects of stormwater runoff on southeastern water resources is the "flashiness" and physical damage caused by severely altered stream flows in urbanizing watersheds during wet weather. High-volume stormwater flows are a leading cause of streambed and bank erosion, habitat loss. High-volume flows also cause sedimentation, which buries aquatic habitats, reduces water clarity[5], and carries high volumes of phosphorus into rivers, streams and lakes. Additionally, erosion caused by these high-volume flows also exposes and threatens infrastructure like bridge columns, sewer and water pipes, and pier supports - not to mention the land itself.

These physical effects also have a significant impact on the recreational and aesthetic attributes of rivers and lakes. Beaches are eroded, increased erosion and decreased habitats reduce fishing areas, tree lines are incapable of growing along river banks, and a glut of sediment can change the color of the water.


Stream bank erosion due to large stormwater flows (Photo: Patricia Pennell)

Chapter Two

Municipal Stormwater Requirements

Many communities have already realized the importance of carefully managing stormwater as a valuable resource and have implemented programs to reduce the amount of stormwater that becomes runoff. In some cases, stormwater ordinances and management systems may already be in place at the local and municipal levels. Most of these efforts, however, are focused primarily on flood control. With the advent of new federal stormwater regulations, many local and municipal stormwater management systems will need to be expanded to consider pollution, public education and other aspects as well.

Under new national stormwater regulations communities that are within a designated Urbanized Area are considered regulated Municipal Separate Storm Sewer Systems (MS4's). Under regulations that went into effect March 10, 2003, these communities, along with urbanized counties and large public institutions such as universities, school districts, and hospitals, are now required to obtain general stormwater permits, develop stormwater management plans, and undertake various measures to control stormwater runoff. Construction sites larger than one acre must also obtain general permits from an approved state agency to manage soil erosion and stormwater. Phase II of the National Pollutant Discharge Elimination System (NPDES), as this regulatory program is called, is required under the Federal Clean Water Act and is overseen by the U.S. Environmental Protection Agency (EPA) and administered by state pollution control agencies.*

The Department of the Census defines an urbanized area "as a land area comprising one or more places —central place(s) — and the adjacent densely settled surrounding area —urban fringe — that together have a residential population of at least 50,000 and an overall population density of at least 1,000 people per square mile."

For more information on designated Urbanized Areas, or to find out if you live in an urbanized area, check out the EPA's Urbanized Area Web Page, located at:
http://cfpub2.epa.gov/npdes/stormwater/urbanmaps.cfm

The Phase II stormwater program is an extension of the EPA's Phase I program, which requires the permitting of medium and large municipal separate storm sewer systems (MS4s) located in incorporated places or counties with populations of 100,000 or more, construction activity that disturbs five or more acres of land, and eleven categories of industrial activity.[6]

In order to implement the Phase II program, communities and local government agencies must work together to create a plan that prevents pollutants from being washed away by stormwater. In order to reach this goal, a community must incorporate six minimum control measures into their program. These control measures include:

1. Public education and outreach

2. Public involvement and participation

* This program became effective in March 2003

3. Illicit discharge detection and elimination

4. Construction site stormwater runoff control

5. Post-construction stormwater management in new development and redevelopment

6. Pollution prevention/good housekeeping for municipal operations

The purpose of this report is to provide information in relation to the fifth control measure, which requires stormwater management practices to be installed in existing and new developments using structural and non-structural methods.

Chapters Three and Four of this report are intended to help municipalities, communities, and developers meet the goals required in the Phase II program by providing approaches and techniques that work with nature, managing stormwater wherever possible using natural soil and vegetation and other techniques that mimic the natural water cycling system.

Chapter Three

Managing Stormwater with Nature

Soft path approaches solve stormwater problems with more natural methods. These approaches slow, cool, and filter stormwater that would otherwise flow directly into rivers, lakes, and other water bodies. The goal of these approaches is to either retain or mimic the natural water system of a particular area, minimizing the amount of pollution accumulated in runoff and storing water in the ground, thus reducing flooding and water shortages. The benefit of LID and other approaches as opposed to conventional methods is that they can dramatically increase pollutant removal, decrease runoff volume, reduce runoff temperature, protect aquatic habitat, and enhance aesthetics. Examples of soft path techniques include stream buffers, rain gardens, infiltration swales, disconnected impervious surfaces, and restored and constructed wetlands. These and other techniques are described in Chapter 4.

A rain garden in North Carolina (Photo: North Carolina Aquarium)

WHAT DOES "NATURAL STORMWATER MANAGEMENT" MEAN?

In this report we use the term "natural stormwater management" to refer to approaches that do one of three things:

- *Preserve natural features, such as floodplains with a natural vegetation buffer along streams, that can slow, filter, and store storm runoff*

- *Use soil and vegetation in a constructed technique, such as rain gardens or green roofs, to mimic natural hydrologic processes like percolation through soil and plant uptake and transpiration*

- *Effectively minimize or disconnect impervious surfaces, such as rain barrels, narrower streets and permeable paving.*

Though these approaches are not as "natural" as other techniques, they still protect the natural water cycle by slowing or infiltrating precipitation rather than sending it directly into storm sewers or receiving waters.

It should be noted that there is no bright line between a "natural" and "structural" solution. Practices that use natural soil and vegetation often must be engineered and installed. And they may be connected to a structural component, such as in the case of a dry swale designed to slow and filter stormwater before it flows into a storm sewer.

Soft path methods are generally quite simple. For individual households, LID methods such as rain gardens and rain barrels are simple, low-cost methods. However, LID approaches, along with other natural stormwater control measures can be even more effective when communities use them to manage stormwater across much larger areas, such as residential subdivisions, office parks, and commercial sites. Soft path methods can be tailored for specific climate conditions, soil types, and targeted pollutants. The key to implementing an effective soft path method is to research the local area's weather patterns, soil type, and typical runoff pollutants. With these variables in mind, the suitable soft path methods can be chosen and implemented specifically to handle the stormwater runoff conditions in an area. It is important to keep in mind that the best results are often achieved when several methods are combined to create the most effective and efficient stormwater management system possible.

Value of Soft Path Approaches

Those unfamiliar with soft path approaches may think that these methods are either too expensive, not appropriate for larger communities, or not practicable. In truth, soft path approaches can work for everybody and are often less expensive than traditional methods. The many soft path methods and the flexibility of their designs allows for a wide range of applications. Individual homeowners, developers, and local governments can use low impact development techniques effectively. Communities can benefit enormously by adopting low impact development measures so that stormwater is handled through a variety of techniques, including on-site storage and infiltration through permeable soils and bioretention techniques that facilitate evapotranspiration, instead of conveying runoff into storm drains. Such measures have proved effective in a variety of places.

Street-side swales can dramatically reduce stormwater runoff from roads (Photo: Seattle Public Utilities)

For example, Seattle, Washington reduced runoff by 97 percent at a 2.3 acre site the year after converting an open ditch stormwater drain to an attractive roadside swale garden, decreasing the width of the adjacent street, planting native vegetation, and simulating native soils. Such opportunities exist where stormwater systems are either not fully developed or will be redeveloped. These methods are among the most effective non-structural solutions to stormwater impacts, infiltrating up to 97 percent of stormwater, removing excessive nutrients and contaminants, and cooling the water.[7]

WHAT'S IN A WORD?

Readers of this report may run across a number of other terms that are frequently used to refer to the same or similar objectives and practices including: green infrastructure; soft path solutions; low impact development; on-site, distributed, and decentralized approaches; and non-structural technologies. Though some experts may make distinctions among them, there is no clearly accepted set of definitions for these terms. For the purposes of this resource guide, we have used many of these terms somewhat interchangeably.

As mentioned, these type of stormwater projects not only reduce pollutants, but can be cost effective as well. Oregon's Museum of Science and Industry (OMSI) was built on a former industrial site located on the Willamette River in downtown Portland in 1990. Although there were no specific site design requirements for stormwater discharging into the river at that time, staff from Portland's Bureau of Environmental Services (BES) approached OMSI to request that the museum voluntarily redesign its landscape and parking lots to minimize stormwater runoff. BES suggested an adjustment to site grading and an alteration to landscaped medians to have vegetated swales receive stormwater runoff. Once OMSI understood the benefits, it requested that the medians be designed to retain water for longer periods. Fourteen acres of the completed parking lot now drain to vegetated swales planted with native wetland species. Net construction costs fell an impressive $78,000, and OMSI's parking lot now has capacity sufficient to infiltrate almost one-half inch of rainfall every time it rains. There are benefits for larger storms, too, as all runoff from the parking lot now filters through vegetation, which slows and cleans the stormwater before it is discharged to the river. Portland is now aggressively applying decentralized, soft-path stormwater management approaches throughout the city to control stormwater pollution, minimize combined sewer discharges of raw sewage, and protect habitat for endangered salmon. It should be noted that the precipitation levels and climate between the Northwest and Southeast regions differ, and at certain times of the year the differences can be considerable. The successful and cost effective use of these practices in the Northwest, although not directly comparable to conditions in the Southeast, may be seen as a starting point in researching the implementation of soft path stormwater management.

Basic Stormwater Management: First, Do No Harm

The best solution to a problem is to prevent the problem from occurring in the first place. Before going into more detail about solutions to current stormwater problems, it is important to talk about how to prevent problems in the first place. As mentioned above, pollution, flooding, and erosion are caused or exacerbated by impervious surfaces or alterations to watersheds and stream corridors. Of course, the simplest and most straightforward way to prevent these problems is to minimize the footprint of new development altogether. Many areas, particularly those dominated by low-density residential development, do not use space as effectively as they could. In many instances redevelopment of urban areas can significantly improve an area's economy and reduce new infrastructure costs while minimizing sprawl into suburban and rural area and the water problems associated with it.

Of course new development will continue to take place, and in these instances conservation and careful planning should be undertaken *before* development activity takes place. Communities should take care to protect critical "green infrastructure" areas such as floodplains, wetlands and groundwater recharge zones, from development. If these critical areas are lost or changed, stormwater runoff, pollution, flooding, and water supply problems will occur. Fixing these problems is much more expensive than preventing them in the first place.

The following four steps provide a basic guide for protecting vital green infrastructure and reducing the effects of stormwater runoff.

1. Reduce Floodplain Development

Riverside land that is periodically inundated by a river's floodwaters is called the floodplain. Floodplains serve important purposes. They:

- Temporarily store floodwaters;
- Improve water quality through vegetative and soil filtration;
- Provide important habitat for river wildlife;
- Create opportunities for recreation by providing areas for fishing, boating and hiking; and
- Store rain and floodwater within the soil, slowly releasing them to maintain water flows into streams during dry periods.

Flooding on the Mississippi (Photo: Federal Emergency Management Agency)

Floodplains are a natural feature of most Southeastern waterways that help reduce the heights of floods. During periods of high water, floodplains serve as natural sponges, storing and slowly releasing floodwaters. The floodplain provides additional "storage," reducing the velocity of the river and increasing the capacity of the river channel to move floodwaters downstream.

Poor land-use decisions have put many people and structures at risk by eliminating the natural flood control functions of wetlands, floodplains, and river systems. The loss of wetlands in particular has increased the height and velocity of floodwaters. Undisturbed, wetlands store and slowly release floodwaters into rivers. In many places, though, wetlands have been nearly eliminated and are still being drained at an alarming rate. Roads, buildings, and agriculture, all of which discharge large volumes of contaminated runoff, are replacing wetlands. The harm is twofold: wetlands are lost and rivers are contaminated.

Flood control structures often don't help. Despite spending more than $25 billion on federal levees and dams, national flood losses continue to rise while flood insurance costs continue to increase. In 1992 there were an average of 2.6 million flood insurance policies obtained through the National Flood Insurance Program for a total coverage of $237 billion. By 2002 this number had risen to 4.5 million policies in force in over 19,000 communities throughout the United States for a total of over $653 billion worth of coverage.[8] This rising amount of coverage, which is supported by taxpayer money, only acts as an incentive for people to rebuild in floodplains.

All too typical in urban areas, this river has been highly developed and modified. (Photo: Tim Palmer)

Some communities are charting a new course by relocating vulnerable homes, farms, and businesses, and directing new development away from flood-prone areas. They are also working with their upstream neighbors to protect and restore wetlands and floodplains throughout their river basin. Several states along the Mississippi river have taken advantage of flood "buy out" grants offered by the Federal Emergency Management Agency's (FEMA) Hazard Mitigation Grant Program and Housing and Urban Development's Community Development Block Grant program.

2. Protect Critical Open Space through Preservation and Protection

All levels of government must do more to identify and protect critical natural areas within watersheds because of the many services they provide, particularly water absorption and pollution filtration. Land preservation efforts should be targeted toward critical aquatic areas (groundwater recharge zones, wetlands, stream sides, floodplains, and small tributary streams). Local governments can protect these areas from development by aligning zoning, establishing protected areas, and changing development guidelines to use land more efficiently and preserve critical resources. States and counties should also offer tax incentives and direct sources of funding for protecting natural areas through acquisition or conservation easements.

There are many ways of building a development while incorporating open space and conservation areas. If done properly, this can raise the value of homes by providing more recreational space as well as increasing the aesthetic value and selling points of a particular development.

There are several different ways of protecting and preserving open space. Two of the most efficient are overlay zones and resource protection zoning. Overlay zones superimpose natural resource protection zoning on traditional zoning to protect riparian buffers and other critical areas while still allowing underlying uses in suitable forms. This strategy gives municipalities legal control of an area without having to own the property.[10] Municipalities can also protect riparian areas through resource protection zoning that establishes a natural resource right-of-way similar to a utility right-of-way. Setback width is then determined before construction begins. When applied to streams and rivers, resource protection zoning ordinances typically establish either a fixed buffer, which prohibits development within a certain distance of the high-water line of a perennial stream, or a floating buffer, which varies in width depending on site, soil, and runoff characteristics.[11]

An example of zoning and open space protection occuring in the Southeast can be seen in the Charlotte-Mecklenburg area of North Carolina. Charlotte-Mecklenburg has participated in the FEMA Hazard Mitigation

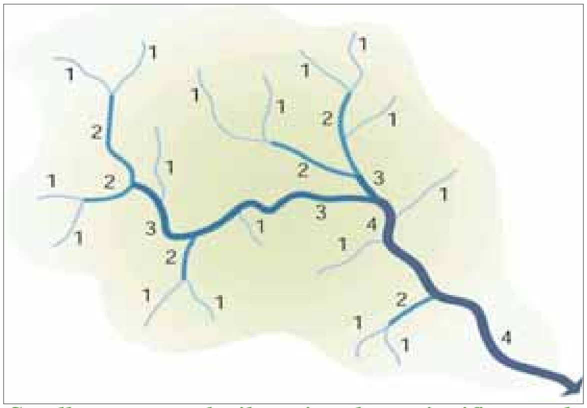
Grant Program to "buy out" and remove houses in the local flood plain and create open space in critical watershed areas. In cooperation with this program, the city has also utilized a comprehensive Watershed Information System (WISE), developed by Watershed Concepts Inc., that links together all pertinent hydrologic and hydraulic information for the region. The system is designed so that a comprehensive stormwater management plan can be established for new and extended developments in the area. Using the system has allowed Charlotte-Mecklenburg to protect and preserve the most critical open space areas to prevent flooding, while allowing development to continue in non-critical areas.

To learn more about the Charlotte-Mecklenburg stormwater program, visit their website at:
http://www.charmeck.org/Departments/StormWater/home.htm

3. Preserve Small Streams

Protecting small streams from filling, piping, and other diversions is essential to preserving the natural water cycle and preventing flooding. Small streams are essential for the proper functioning of the natural water system, the prevention of floods, and the health of larger river systems.

Small streams help store and filter potential pollutants in ways that help protect downstream water quality. Studies have shown that over 60 percent of the inorganic nitrogen entering a small stream is retained or transformed into less harmful forms.[12] These streams also help recharge groundwater and maintain water levels needed to support wildlife, biological diversity, and drinking water needs. Small streams collect rainwater and stormwater runoff, diversifying the areas in which stormwater is discharged. In urban areas where small streams have been covered over or diverted through pipes, stormwater is collected and channeled to a few discharge spots, usually in rivers. This significantly raises water temperatures and increases the risk of flooding. Most significantly, small streams reduce the costs of downstream water treatment. Development and construction can double the amount of sediments and pollutants that flow into our rivers, making downstream treatment much more costly. Small streams contribute significantly to the filtration and settlement of sediments and other contaminants, reducing water treatment costs.[13] These streams are also the most susceptible to erosion, so preservation of the stream corridor alone may not be enough. The streams should also be actively protected from changes to the local watershed.



Small streams and tributaries play a significant role in overall river health. First-order (1) headwater streams combine to create larger second-order (2) streams and so on. (Image: United States Department of Agriculture)

4. Preserve Natural Stream Buffers

Stream buffers are a soft path approach to protecting streams and rivers and are particularly popular in agricultural areas, although they can be just as useful in developed areas. It is important to note that stream buffers are a natural phenomenon. Plants and soils that soak up and reduce excessive water occur naturally along river and stream banks, but this streamside vegetation is often removed when an area is developed. By leaving these natural buffers in place, stormwater runoff is reduced and pollutant removal can be achieved without costly infrastructure. Development can still take place outside the buffer area. The amount of buffer required should generally be 5-10 percent of the stream or river's drainage area, although amounts can vary depending on the type of surrounding development. The buffer should contain three different areas. An area directly adjacent to the stream should consist of mature forest and should be protected from development. The middle portion should be approximately 50 to 100 feet of managed forest with some limited clearing allowed. The outer edge, usually about 25 feet can be a mix of light vegetation or forest.[14]

Preserving open spaces as buffers along the river can provide a cost-effective means of stormwater and flood control, reducing erosion caused by uncontrolled runoff and stabilizing riverbanks with vegetation. Buffers can prevent damages to structures from urbanized waterways as well as reduce costs to industries that need clean water. This can also lower rates for public drinking water. In addition to protecting the stream ecology, buffers can provide quality-of-life benefits such as visually appealing greenbelts, with possibilities for parks and recreation areas.[20] Generally, the most critical areas to buffer are those with steep slopes, wetlands, erodible soils, and endangered or threatened animal or plant species. Buffers should be recorded on official maps and protected through conservation easements or restrictions and signage.

Stream Buffers are important for protecting water quality and preserving small streams (Photo: Eric Eckl)

Great River Greening, a St. Paul-based non-profit organization, is working to identify buffers along three river corridors in the Minneapolis-St. Paul metro area. With the help of a staff landscape ecologist, aerial photos, and geographic information system (GIS) technology, Great River Greening has determined the areas that provide the highest-quality buffers along a stretch of the Mississippi River that encompasses seven counties. The group is creating priorities for ecological restoration, protecting and buffering natural areas, and preserving and creating wildlife habitat, especially for songbirds. Working with more than 100 landowners and the Big Rivers Partnership, a stakeholder group, Great River Greening has developed several principles adapted to different buffer situations. (More information can be found at www.greatrivergreening.org)

Chapter Four

Natural Stormwater Management Techniques

Introduction

Natural stormwater management is a fast-growing alternative to conventional stormwater management. The different methods that comprise low impact development are generally cheaper, more aesthetic, and more effective at controlling pollution and flooding.

However, because "soft path" approaches, and LID in particular, are still relatively new in many areas of the country, finding information on specific methods, their benefits, and their drawbacks can be a time consuming effort. Most of the methods contained in this handbook are considered low impact development (LID) methods, decentralized techniques that manage rainfall at the source through infiltration and detention. Infiltration basins and constructed wetlands are generally not considered low impact development because they are larger techniques which are not necessarily convenient for single home lots. Despite this, constructed wetlands and infiltration basins can be very useful natural techniques when used on a larger scale, such as neighborhoods, schools, and office complexes. In most cases, LID techniques, infiltration basins and constructed wetlands utilize natural soils and vegetation to slow and filter stormwater and to allow it to soak into the ground. This reduces flooding and pollution problems and replenishes ground water sources.

A NOTE ABOUT MAINTENANCE

Maintenance is a very important aspect of both conventional and soft path stormwater management methods. Many natural stormwater methods do not reach their full effectiveness because of lack of regular maintenance.

In general, maintenance for bioretention requires keeping vegetation at a level in which plants continue to provide maximum filtration and water uptake services but do not choke the system and prevent proper water flow and infiltration. Additionally, care should be taken to ensure that these systems not become clogged with sediment and that sediment be removed on a regular basis.

Methods with minimal vegetation or seasonal vegetation such as dry swales and rain gardens may require mowing or seasonal clearing. Rain barrels should generally be disconnected, drained, and not used during winter months. Green roofs, urban trees and dry wells should also be checked regularly and properly maintained.

This chapter provides basic information on the natural stormwater control methods that have proven most effective. Along with these fact sheets are case studies that demonstrate how some of these methods have been employed in the Southeast region. Each fact sheet also lists resources for finding more detailed information on each technique.

In addition to these listed resources, this guidebook also relies heavily on the extensive research and information presentation of some of the most prominent stormwater management guides. These include:

- The Stormwater Managers Resource Center, funded by the U.S. Environmental Protection Agency and managed by the Center for Watershed Protection (www.stormwatercenter.net);
- The Minnesota Urban Small Sites Best Management Practices Manual created for the Minnesota-St. Paul Metropolitan Council by Barr Engineering (www.metrocouncil.org/environment/Watershed/BMP/manual.htm);
- The Delaware River Keeper's Stormwater Runoff Resource Guide (www.delewareriverkeeper.org);
- The EPA's stormwater BMP webpage, as well as many of its stormwater technical papers (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm);
- The Low Impact Development Center (http://www.lowimpactdevelopment.org);
- The Prince George's County of Maryland's Low Impact Development web site (http://www.goprincegeorgescounty.com/government/agencyindex/der/esd/low-impact.asp).

When utilizing this guidebook, readers should keep in mind that each method profiled here can be used together in a system, and will often be more efficient and cost effective managing stormwater in combination. In many places it may be possible to manage most or all storm flows using a combination of soft path techniques. However, where this is not possible, individual LID practices can still be used along with traditional storm drains and sewers to positive effect.

A NOTE ABOUT SOIL TYPES

Soils in the United States are placed in one of four categories (known as hydrological groups) based on the rate at which water is absorbed or infiltrated into the soil.

- *Soils classified as "A" have a high infiltration rate and are composed of sands, gravel and loamy soil.*
- *Soils classified as "B" have a moderate infiltration rate and are composed of silts and shallow sandy soils.*
- *Soils classified as "C" have a low infiltration rate and are made up of soils mixed with clay.*
- *Soils in the "D" group have the lowest infiltration rate and consist of clay or soils with a high water table.*

The following fact sheets are designed to provide:

- Basic information on each soft path stormwater technique
- Individual and general descriptions
- Summary of advantages and disadvantages
- Basic design considerations
- Cost estimates, where available
- Typical runoff reduction data where available
- Special considerations related to soil type and cold climates.

Additionally, many of these fact sheets provide a case study example and conclude with a list of essential online resources that can be accessed for more detailed information on each technique.

Managing Mosquitoes

People may be understandably concerned about mosquitoes when considering natural stormwater management. However, studies have found that, when built correctly, most natural stormwater methods produce very few mosquitoes. Additionally, most soft path approaches can be designed to avoid retaining standing water. A series of soft path methods can be designed and built with virtually no standing water. This will eliminate most problems with mosquitoes. In fact, it has been found that soft path methods like rain gardens actually act as mosquito-traps. Mosquitos lay there eggs in the the wet areas of soft path techniques when it first rains. But these methods are designed to drain significantly quicker than mosquito larvae can hatch, effectivley killing the larvae.

Mosquitoes are persistent, and will emerge in some areas despite any stormwater management, conventional or low impact. In fact, mosquitoes thrive in the wet environment created by traditional catch basins, clogged gutters, and flowerpots. Additionally, some people may enjoy the aesthetic qualities of a wet pond or wetland and wish to keep an area that has standing water. In these cases, there are many ways to minimize mosquitoes without using chemical pesticides.

Mosquitoes can be discouraged in a variety of natural ways. The most common is to design a stormwater management area to attract dragonflies. A regular population of dragonflys has been found to substantially reduce mosquito populations. Another option, although less effective than dragonflies, is to encourage bat and bird populations by building nesting sites. Swallows, swifts and purple martins are ideal birds to attract and bats are also effective at eliminating mosquitoes. Birdhouses and bat roosts can be built or bought to attract these species. Regions of the southeast also have native mosquito eating fish that can be placed in ponds and will significantly reduce mosquito populations by eating the larvae.

There are also special biodegradable mosquito dunks and pesticides that can be bought to place in standing water that kill mosquito larvae but do not harm other organisms. Such dunks are generally made of Bacillus thuringien israelensis (Bti) or Bacillus sphaericus (Bs). Bti and Bs are bacterium that specifically target mosquito larvae and kill them within a few hours of contact. The EPA has found little to no adverse impacts on other organisms stemming from these particular control methods.

The most important part of controlling mosquitoes is to have a plan and implement it consistently. Mosquito populations are generally the largest in late summer and early fall and it is at this time when the risk of contracting a mosquito borne illness is the greatest. However, mosquito control should be started earlier to prevent this late season population growth. Effectively implementing a mosquito control plan in the late spring and continuing it throughout the summer and early fall is the best way of preventing mosquito problems. For more information, see:

- The US EPA's mosquito control website (www.epa.gov/pesticides/factsheets/skeeters.htm)
- The Louisiana Mosquito Abatement Plan - (http://www.lsuagcenter.com/en/environment/insects/Mosquitoes)
- The Gloucester County, Virginia Integrated Mosquito managemetn Plan -

  (http://www.co.gloucester.va.us/works/InformationForms/information2_files/Complete%20Final%20IMMP%204-16-07.pdf)
- The Maryland Department of the Environment Mosquito and Stormwater - (www.mde.state.md.us/assets/document/SWM_Mosquito(1).pdf)

Stormwater Management Matrix

Stormwater management techniques are often categorized by a particular attribute they possess. For example filter strips are generally placed in the category of filtration methods. However natural stormwater management methods often have similar attributes and can be difficult to categorize because they overlap numerous categories. The matrix below lists the different methods in the order they appear in this guide, and associates them with their most common uses.

Definitions

On-site *- smaller methods that collect and handle stormwater at a centralized location. They handle small drainage areas.*
Reception site *- methods that collect and deal with stormwater from various sources and service larger drainage areas*
Individual Home*s - Methods that work best for houses or small buildings.*
Neighborhoods *- Methods that work better serving collections of houses or larger buildings.*
Infiltration *- Method facilitates water into the soil and groundwater*
Filtration *- Method helps remove sediments and pollutants*
Retention *- Method that retains water for long periods of time or has a permanent supply of water*
Detention *- Method slows water down but does not permanently retain any water.*

A box left blank means that method does not fall into that category.

○ *- Method fits into this category only partially or through special design.*

● *- Method fits well in this category.*

Category / Method	On-Site	Reception site	Individual Homes	Neighborhoods	Infiltration	Filtration	Retention	Detention
Bioretention	●	●	●	●	●	●	○	●
Rain Gardens	●		●	●	●	●	○	●
Dry Swales	●		○	●		●		●
Wet Swales	●		○	●	○	●	○	●
Filter Strips	●		●	●		●		●
Urban Stream Buffers	●			●	○	●		●
Urban Trees	●		●	●	●			●
Infiltration Basins		●		●	●	●		●
Constructed Wetlands		●		●		●	●	
Green Roofs	●		●					●
Rain Barrels	●		●				●	
Dry Wells	●		●		●		●	
Porous Pavement	●		●	○				●
Green Parking	●		○	●		●		●

Bioretention

General Information

Summary

Bioretention does not refer to a specific stormwater mitigation method, but is a general concept that can be employed in a wide variety of situations. Bioretention systems generally consist of a shallow depression filled with sand and soils conducive to infiltration and plant growth. Native vegetation is planted in the depression with the goal of absorbing common runoff pollutants. This vegetation usually includes a variety of plants, trees, shrubs, and flowers. Bioretention can be designed in concert with parkland and other open areas.

A biortention area in an apartment complex in Portland, Oregon (Photo: Betsy Otto)

Advantages

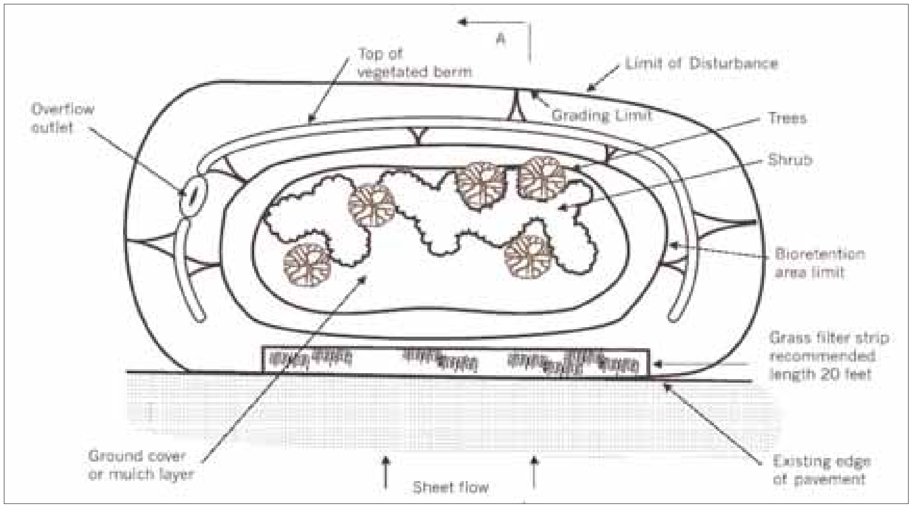
- Bioretention is flexible for many uses and designs and is ideal for parking lot islands, medians, and other impervious surface drainage areas.
- It is aesthetically pleasing, particularly since the selection of native plants and trees is generally very wide, allowing for a variety of landscaping opportunities.
- It is good at reducing runoff volume and for filtering out sediments, trace metals, nutrients, and bacteria.
- Like most other low impact development methods, bioretention can help reduce costs at down stream water treatment facilities.

Disadvantages

- Bioretention can consume space, as it generally requires about 5 percent of the drainage area serviced.
- The landscaping can be costly depending on the cost of vegetation and the amount of grading necessary. The cost generally becomes prohibitive for larger drainage areas, so the technique is most useful for smaller, targeted sites.

Conventional Alternatives

Alternatives to bioretention include no retention, traditional landscaping (e.g. grass, trees, and shrubs in parking lot islands that are not designed to detain or infiltrate water), or traditional turf-grass in the swales and filter strips described previously. Bioretention techniques can be used in areas that would normally be planted with traditional landscaping and serviced by a conventional stormwater system. Bioretention areas can also replace non-vegetated rock-lined erosion buffers and rock-covered parking islands. Bioretention areas can be used to break up large parking lots that are traditionally covered entirely with impervious surfaces



A plan view of a bioretention area (Diagram: Prince George's County LID Design Strategies)

Design Information

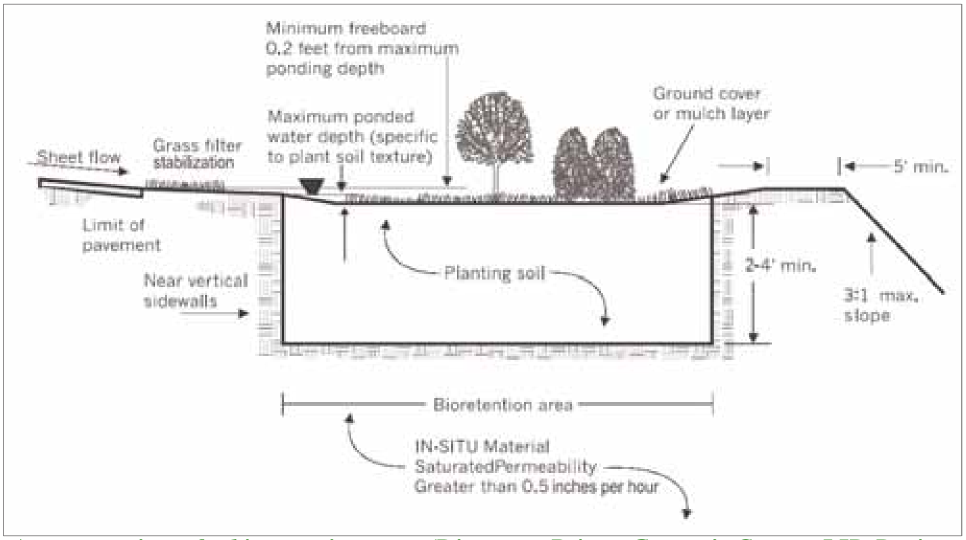
Bioretention areas can be clogged by sediment, so larger bioretention systems should be designed with some sort of pretreatment, such as filter strips. Separating contaminated (e.g. runoff from impervious surfaces and fertilized areas) and non-contaminated runoff (e.g. those from natural non-fertilized areas) can also be a cost effective way of reducing sediments and other pollutants. The contaminated runoff can be treated before being released into the bioretention area. Optimal bioretention areas should also have a ponding area to collect water, an organic mulch layer and planting soil bed to foster vegetation, and an under drain to collect water during periods of excessive precipitation.

Uses in combination with other techniques

Bioretention can be used in filter strips, infiltration basins, rain gardens, and swales.

Cost

In Maryland, construction costs of bioretention areas were found to be approximately $1.25 per square foot. This includes excavation of 2 to 3 feet and planting of minimum vegetation. Soil replacement is not included in this estimate. Cost estimates are higher when using bioretention to retrofit existing development areas, as additional work is usually needed for demolishing existing asphalt or structures and adding soil.[15] Costs also rise with an increase in the smount and size of the vegetation installed.



A cross section of a bioretention area (Diagram: Prince George's County LID Design Strategies)

Additional maintenance costs are usually minimal. Maintenance costs for a grassed parking median ($200/year) were identical to those for one with bioretention landscaping.

Runoff Reduction

A study by the University of Maryland published by the Maryland Department of Environmental Resources found that bioretention could remove approximately 97 percent of the copper, 95 percent of the zinc and lead, 65 percent of total phosphorus, and 52 percent of nitrogen.

Specialized Information

Soil Types

Bioretention can be built in all soil types, though design consideration and modifications will usually have to be made for clay soils and karst. Clay soils do not allow for much infiltration, so often times soil amending or complete replacement is necessary. In regions where karst is prevalent, the project area should be examined to determine if karst is present and what type of karst it is. Some karst types can have bioretention built on it while some types can not.

Additional Sources

EPA informational guide
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_24.cfm

EPA Technology Fact sheet
http://www.epa.gov/owm/mtb/biortn.pdf

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STFiltBioretention.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT6%20-%20filtering%20BMPS.pdf

The Prince Georges County, Maryland Bioretention Manual (a very good design source).
www.goprincegeorgescounty.com/Government/AgencyIndex/DER/PPD/LID/bioretention.asp?h=20&s=&n=50&n1=160

Bioretention research at the University of Maryland
http://www.ence.umd.edu/~apdavis/Bioongoing.htm

Center for Water and Watershed Studies
http://depts.washington.edu/cwws/

Applied Ecological Services
www.appliedeco.com

Rain Gardens

General Information

Summary

Rain gardens are also known as recharge gardens. They are small detention and infiltration areas that use native vegetation to achieve an appealing, aesthetic look. They are simple, inexpensive, and easy to install. Rain gardens are an extremely popular form of stormwater mitigation, as they are easy retrofits for existing developments and are well suited for small sites like individual homes, or larger sites such as common areas and schools. They are a small form of bioretention.

A shrub rain garden in Maplewood, Minnesota (Photo: Maplewood Public Works)

Advantages

- Rain gardens only require the work necessary for any ordinary landscaping project.
- They can be designed to work in most soil types.
- Rain gardens also provide an aesthetic value, runoff volume control, and attract wildlife such as birds and butterflies.

Disadvantages

- If built incorrectly, rain gardens can accumulate standing water or increase erosion. These problems can be avoided by following published design guides.

Conventional Alternatives

Rain gardens take the place of conventional landscaping. Conventional landscaping, such as turf grass, will produce some runoff and may require fertilizers or regular maintenance such as mowing, mulching, etc. Rain gardens do not need fertilizer or pesticides and require only periodic weeding.

Design Information

A rain garden should be kept at least 10 feet downslope from a house, so that any overflow flows away from the structure. A rain garden should be a 2 to 6 inch deep dish shaped depression if standing water is not desired and approximately 18 inches if standing water is desired. A typically sized rain garden is approximately 70 square feet and in a shape or design that follows the drainage system of the landscape. All utilities should be marked before installing a rain garden to avoid digging up or over water mains and electrical lines. Rain gardens should not be built over or near septic drain fields. They do not need to be (and should not be) fertilized or exposed to pesticides. Additionally, avoid building gardens in right of way areas (e.g. phone lines, adjacent public roads) unless specific permission is received from the utility that owns the right of way.

Uses in combination with other techniques

Rain gardens are small stormwater mitigation areas, and can be used in connection with other individual soft path techniques. Rain barrels work well in conjunction with rain gardens.

Cost

Rain gardens can be very inexpensive or even free if you use plants that you already own. Designs can be found for free online, and the gardens can be dug and planted by homeowners with costs limited to time and the price of the desired vegetation. Costs can rise depending on the size of the project desired. Garden builders and designers can be hired, although costs vary by region, design, and contractor. Soil replacement, new vegetation and gravel drain outlets increase the price. Large rain gardens, with new plants, soil and gravel drain beds can cost as much as $4000.[16]

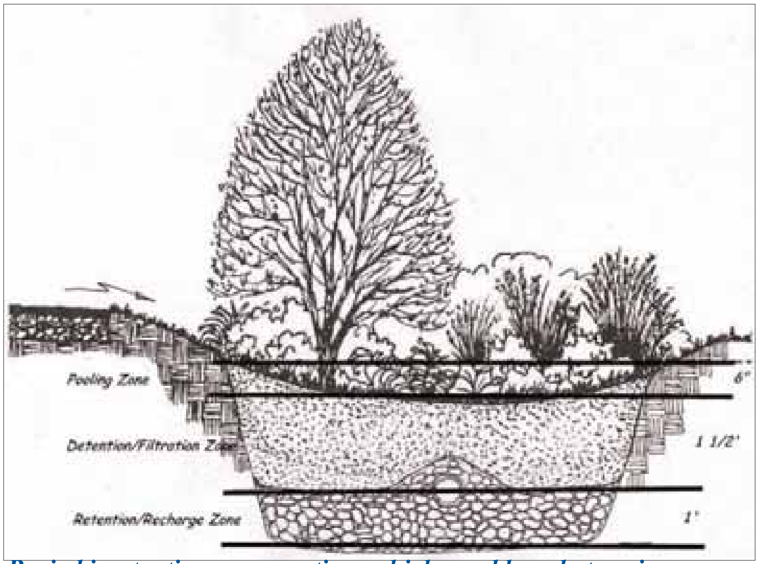
Runoff Reduction

The amount of stormwater and pollutants that rain gardens can absorb depends on the size of the gardens and the plants used. Rain gardens have been found to be successful in reducing bacteria and 80-90% of heavy metals and other common pollutants. They reduce only small amounts of nitrogen, phosphorus, and salt. Designed properly they can substantially reduce stormwater runoff volume.

Specialized Information

Soil Types

Rain gardens can be built on both sandy and clay soils. The proper vegetation should be chosen for the soil type, although in many instances soil replacement or amendment is recommended, particularly in clay soils. Over time, native vegetation adapted to clay soils, such as prairie grass, will become established enough to uptake water and change the soil.



Basic bioretention cross section, which would apply to rain gardens (Prince George's County, MD Bioretention Manual)

Case Study - City of Alexander, AL

The City of Alexander is located on Lake Martin in Central Alabama. Historically, the city's economy has been based on the industrial manufacturing of the Russell Corporation. However, the city has recently been attempting to take advantage of the many recreation opportunities that are offered by Lake Martin. Rain gardens are being explored as a means to control and filter stormwater runoff for cleaner water.

In an effort to reduce pollutants like oil, pet waste and excess pesticides from washing into Lake Martin through stormwater runoff, The City of Alexander, Middle Tallapoosa Clean Water Partnership, Auburn University Landscape Architecture Department and Alabama Cooperative Extension System partnered together to install raingardens. As the initial stage of the project, this partnership helped install demonstration rain gardens at three local schools.

Early observations have shown the effectiveness of these rain gardens in decreasing downstream flooding and improving water quality. In addition, through presentations at town hall meetings and around the region, these sites have allowed for further education of others in the community about the effects of stormwater pollution and the benefits of rain gardens.

For more information, see: Alabama State Water Program http://www.aces.edu/waterquality/mg.htm.

A typical rain garden below the soil (Painting by Ruth Zachary, permission to use by Rain Gardens of Western Michigan)

Additional Sources

Rain Gardens of West Michigan - General rain garden information site with design suggestions
www.raingardens.org

The Prince Georges County, Maryland Bioretention Manual (a very good design source).
www.goprincegeorgescounty.com/Government/AgencyIndex/DER/PPD/LID/bioretention.asp?h=20&s=&n=50&n1=160

City of Maplewood Rain Garden Website
http://www.ci.maplewood.mn.us/index.asp?Type=B_BASIC&SEC={F2C03470-D6B5-4572-98F0-F79819643C2A}

City of Maplewood Report on homeowner reactions to rain gardens.
http://www.ci.maplewood.mn.us/vertical/Sites/{EBA07AA7-C8D5-43B1-A708-6F4C7A8CC374}/uploads/{E0CE291E-3C1B-4776-B33A-7C5A4C5F5860}.PDF

Bioretention research at the University of Maryland
http://www.ence.umd.edu/~apdavis/Bioongoing.htm

The Southeastern Oakland County Water Authority - Rain Gardens on the Rouge River
http://www.socwa.org/nature/PDF/Rain%20Gardens.pdf

University of Wisconsin Extension
http://clean-water.uwex.edu/pubs/raingarden/

Wisconsin Department of Natural Resources
http://www.dnr.state.wi.us/org/water/wm/nps/rg/

A typical rain garden (Photo:Maplewood Public Works)

Dry Swales

General Information

Summary

Dry swales, also known as grassed channels or vegetated swales, are shallow vegetated depressions that are strategically placed to receive stormwater flow from surrounding areas and convey it away from a site, while detaining the water and allowing it to infiltrate into the soil to a limited degree. When designed properly, swales slow stormwater flows, reducing peak discharges while providing an aesthetic addition to a developed landscape. They can be used in neighborhoods and are especially useful when used in parking lots or along roadways.

A vegetated dry swale (Photo: Applied Ecological Services)

Advantages

- Dry swales act as channels, diverting water flow away from buildings and roadways.
- When vegetated properly, swales actually slow water flow and allow the soil to absorb some of the water. This keeps water from inundating local streams and increasing small floods.
- Swales provide some filtration, decreasing small amount of pollutants carried by stormwater, such as sediment, oils, grease, and nitrogen.
- Dry swales do not retain a standing body of water and thus can be mowed and treated as a normal aspect of the landscape.

Disadvantages

- Dry swales are only effective if designed properly and maintained regularly. Because they are vegetated they require occasional maintenance and upkeep depending on the area in which they are built. Maintenance includes mowing, removing invasive species, or sediment removal.
- They must be designed to receive the proper amount of water and to slow and absorb water flow. Too much water or water moving too fast through the swale can cause erosion.
- Off street parking, snow removal, and improper maintenance can damage the swale.
- Swales are not recommended for areas with industrial sites or those areas with a high risk of flooding as they merely slow, but do not significantly reduce total water volumes.

Conventional Alternatives

Swales are meant to replace conventional systems like pipes and curb gutters which channel water swiftly away from an area. They are generally cheaper and easier to build than these conventional systems.

Design Information

The amount of land used varies on the design. Bottom widths need to be at least 2 to 8 feet in order to ensure maximum pollution treatment, and slopes should be 2:1 or flatter. Dry swales should also have an under-drain to catch excess and standing water. The primary differences between wet and dry swales are the under-drain, shape, and soils. Dry swales have an under-drain, a deeper layer of pervious soil, and an elongated shape to help facilitate the removal of standing water. Wet swales are designed more for detention and infiltration.

Uses in combination with other techniques

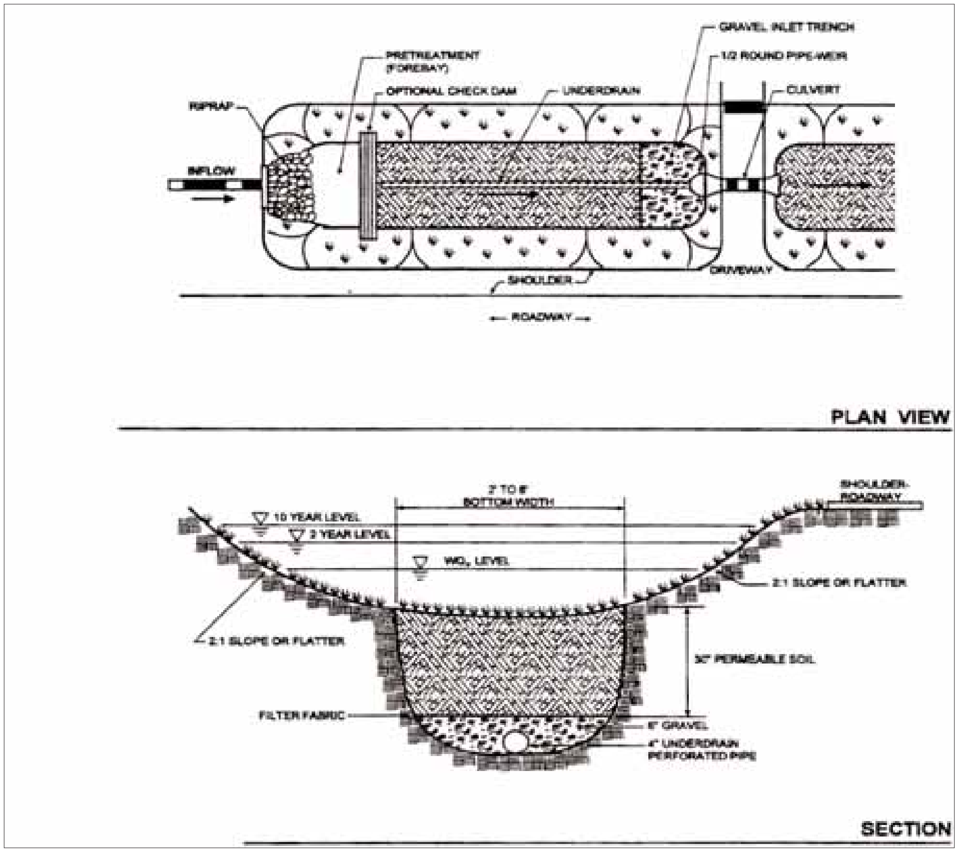
Vegetated swales are best used when servicing a small number of homes or along a roadside. One swale can only service a small area, but when used in a series dry swales can collect and channel stormwater for school grounds and neighborhoods. They work particularly well when combined with green parking methods such as curb cuts that allow water to flow into the swale. Additionally they work very well when combined with infiltration trenches and filter strips, which add additional pollution removal.

Cost

Swale design and cost vary depending on landscape and grading but are generally cheaper than curb and gutters. Estimates have swales costing approximately $5 per linear foot.[17] When clearing, grading, and leveling are added, estimates rise to $8.50 to $50.00 per linear foot, depending on the amount of additional work required.[18]

Runoff Reduction

Runoff reduction estimates vary depending on soil type, vegetation, depth, width, and design. A swale with a 2 to 8 foot bottom depth and depth of 18 inches can safely convey 2-year storm design velocities of less than 4 feet/second . Overall runoff reduction is also increased when dry swales are used in combination with other infiltration methods such as infiltration basins.



Dry swale design (Diagram: Prince George's County, MD- Low Impact Design Strategies)

Specialized Information

Cold Climates

Swales are useful in cold climates since they can be used to store and treat snowmelt in addition to normal stormwater treatment. When swales are used along roadways, salt-resistant vegetation should be used to help mitigate the effects of snow treatment runoff.

Soil Types

Dry swales are most effective when built on moderately permeable soils. They can work in most soils except those with the lowest rates of infiltration, Class D soils (see the note on soil types in Chapter 4 for further explanation of soil classifications).

Additional Sources

EPA informational guide and pollutant removal matrix
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_24.cfm

EPA technology fact sheet on swales
http://www.epa.gov/owm/mtb/vegswale.pdf

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STDetDrySwale.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT7%20-%20OPEN%20CHANNELS.pdf

California Stormwater BMP Handbook
http://www.cabmphandbooks.com/Documents/Development/TC-30.pdf

Applied Ecological Services
www.appliedeco.com

Wet Swales

General Information

Summary

Wet swales are similar to dry swales in that they are a shallow depression designed to channel water away while filtering and detaining it. The key difference is that wet swales act more like small wetlands and therefore have water-saturated soils, unlike dry swales, which are built to facilitate water movement and not to retain it. This means that wet swales can have standing water periodically if not all the time.

Prairie to collect swale runoff at Wild Meadows (Photo: Applied Ecological Services)

Advantages

- Wet swales are beneficial in similar ways to dry swales. In addition to their channeling properties and cost effectiveness in comparison to conventional methods, wet swales generally have greater detention and retention capability than dry swales. While dry swales primarily detain water, wet swales actually retain it, decreasing peak storm water flows.

- Because wet swales are similar to small wetlands they attract birds and are perfect for indigenous plant species.

- Like dry swales they are cheaper than conventional stormwater control methods.

Disadvantages

- Wet swales, like dry swales are only effective when they are designed properly.
- They may be impractical in areas where space is limited and erosion can begin to occur over a series of large storm events, making replanting necessary.
- Wet swales can accumulate standing water at times and mosquitoes may propagate, although there are simple solutions for insect control. See the note on mosquito control in Chapter 4 for further information.

Conventional Alternatives

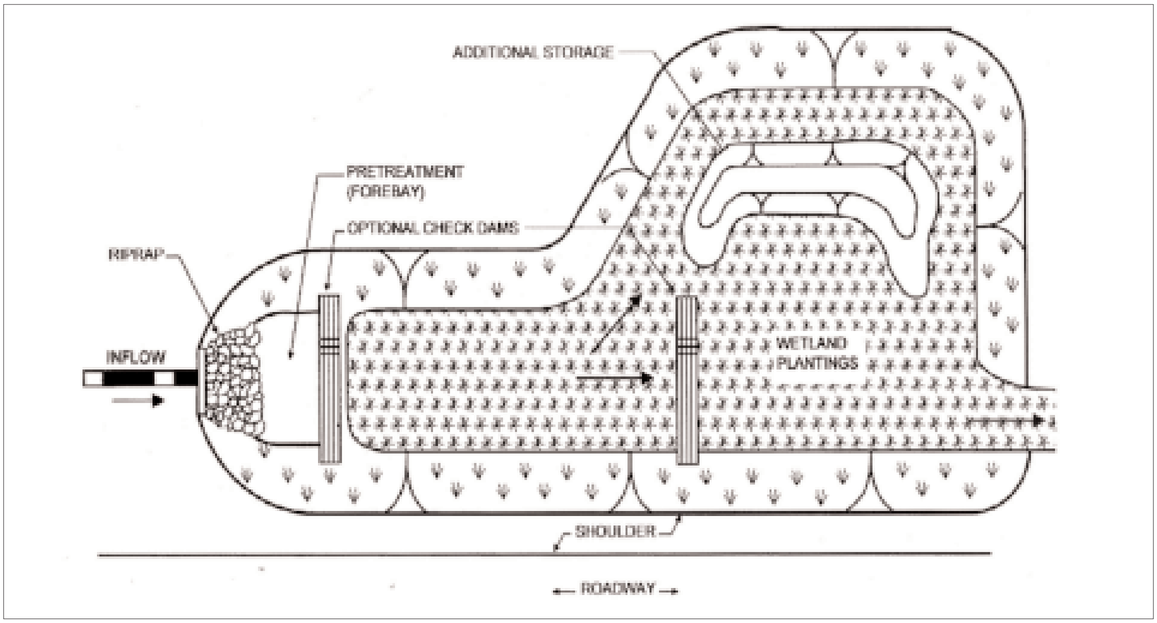
Swales are meant to replace conventional systems like pipes and curb gutters which channel water swiftly away from the area. They are generally cheaper and easier to build than these conventional systems. They can also take the place of conventional detention basins when designed appropriately.

Design Information

The amount of land used varies on the design. Bottom widths need to be at least 2 to 8 feet, and the side slopes should be gentle. Check dams should be spaced at about 50 to 100 feet for longer swales with a slope greater than 1 to 2 percent. In general wet swales tend to be more useful along roads that are not broken by driveways. The primary difference between wet and dry swales is the under-drain, shape and soils. Dry swales have an under-drain, a deeper layer of pervious soil and an elongated shape to help facilitate the movement of water and prevent standing water. Wet swales do not have an under drain. They are shaped in a less "channelized" manner to facilitate water detention and optimally retain the natural soil conditions to allow slow but steady water infiltration.

Uses in combination with other techniques

Wet swales are best used like dry swales, by servicing a small number of homes or along roadsides. One swale can only service a small area, but when used in a series dry swales can collect and channel stormwater for school grounds and neighborhoods. Additionally they work particularly well when combined with green parking methods, such as curb cuts, that allow water to flow into the swale.



Wet Swale Design (Diagram: Stormwater Managers Resource Center)

Cost

Swale design and cost vary depending on landscape and grading but are generally cheaper than curb and gutters. Estimates have swales costing approximately $5 per linear foot. When clearing, grading, and leveling are added, estimates rise to $8.50 to $50.00 per linear foot, depending on the amount of additional work required. Wet swales are generally more expensive than dry swales due to planting costs. These costs vary depending on the amount and type of plantings desired, as well as the time of year the plants are purchased.[19]

Runoff Reduction

Runoff reduction estimates, like dry swales, vary depending on soil type, vegetation, depth, width and design. A swale with a 2 to 8 foot bottom depth and depth of 18 inches can safely convey 2-year storm design velocities of less than 4 feet/second. Overall runoff reduction is also increased when wet swales are used in combination with other infiltration methods such as infiltration basins.

Specialized Information

Soil Types

Wet swales are most effective when built on undisturbed soils without a drain system. They can work in most soils except those with the lowest rates of infiltration, Class D soils (see the note on soil types in Chapter 4 for further explanation of soil classifications).

Additional Sources

EPA informational guide and pollutant removal matrix
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_24.cfm

EPA Technology Fact sheet
http://www.epa.gov/owm/mtb/vegswale.pdf

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STConstWLWetSwale.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT7%20-%20OPEN%20CHANNELS.pdf

VEGETATED FILTER STRIPS

General Information

Summary

Vegetated filter strips are areas of grass or other dense vegetation that are placed strategically between an area that creates runoff in sheet flows, such as driveways, roads, and other impervious surfaces and a stormwater reception site, such as a stream, swale or river. Filter strips slow stormwater runoff, filtering it as it flows to a reception site. Strips do not even need to be directly next to a particular reception site, but only down slope from a runoff source.

A vegetated filter strip seperates this stream from the fields on either side (Photo: USDA NRCS)

Advantages

- Vegetated filter strips are simple and cheap to install.
- They have the potential to remove up to 80 to 90 percent of solid pollutants and sediments, while blending in naturally with most landscapes.
- Designed with the right vegetation, filter strips can significantly increase the time it takes for stormwater to reach a stream or other water body.
- Planted with trees or tall grasses, filter strips can be used to block out roads and other eyesores.
- They require very little maintenance.

Disadvantages

- Vegetated filter strips work best on shallow slopes, although heavier and deep-rooted vegetation can be used to some effect on steeper slopes. On steeper slopes, water tends to accumulate and form rivulets, decreasing the strips' ability to slow and filter the water. For filter strips to be effective, they should be at least 15 feet wide and built on a gentle slope for maximum effect. Narrower strips with soil specially mixed for filtration and more vegetation can been used in areas that are more densely populated and where space is limited. Filter strips slow water but offer minimal pollutant removal. They are most effective at reducing sediment.

Conventional Alternatives

Vegetated filter strips provide a similar function as baffles might - slowing water flow. Baffles are concrete or rock structures built to impede but not stop the flow of water. The water follows a circuitous route that dissipates its energy. In contrast, filter strips use friction and natural vegetation to reduce the rate of water flow. Filter strips also perform infiltration and some pollution reduction services as well.

Design Information

Vegetated filter strips work best when built on a 2 to 6 percent slope, but can work on slopes of up to 15 percent. Gentler slopes encourage water to flow in a particular direction at a rate that prevents it from forming rivulets. On steeper slopes, vegetation or plastic can be used to prevent concentration of flows into rivulets while stone trenches at the base of the strip can act as level spreaders. Filter strips should mimic the contour of the runoff area that they abut and should be a minimum of 20 feet wide and approximately 50 to 75 feet long. A minimum width of 150 feet should be used if the filter strip is directly adjacent a water body. Dense grass and other deep-rooted vegetation are acceptable, although trees generally provide the best detention and filtration (See section on urban stream buffers).

Uses in combination with other techniques

Vegetated filter strips can be used on their own or in combination with other methods. Curb cuts or other stormwater conveyances can all be used to deliver water to a filter strip. A filter strip can also be used to slow water and remove sediment and pollutants before the water reaches a swale or infiltration basin.

Cost

Filter strips vary in cost with the design. Basic grass filter strips cost $0.30 to $0.50 per square foot and may overlap with general landscaping, further reducing costs. More elaborate filter strips involving sand, peat, or gravel underlay may be moderately more expensive.[20]

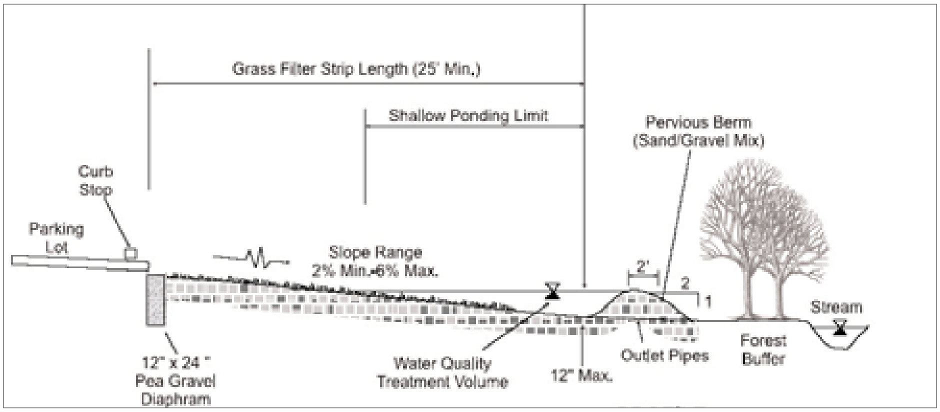
Runoff Reduction

When directed through vegetated filter strips, annual runoff volumes can be decreased by 40 percent. Agricultural studies have also shown that a 15-foot wide grass buffer can remove 50 percent of nitrogen, phosphorus, and sediment levels, while a 100-foot buffer can remove 70 percent of those pollutants. Within urban settings studies show that filter strips reduce sediment by 40 percent and nutrients by 35 percent.

Specialized Information

Soil Types

Soil conditions should be non-compacted and good enough to allow for vegetation to take root and stabilize while grasses or trees mature. Re-grading may be necessary in some areas to achieve the best slope. Caution should be used if adding topsoil, as bare topsoil can erode easily during rainfall. Clay soils should be avoided, as some infiltration is required for filter strips to function well. In some cases, soil replacement or amendment can be an option to improve infiltration and filtration abilities.



Filter strip diagram (Diagram:Prince George's County LID Design Strategies)

Additional Sources

EPA informational guide and pollutant removal matrix
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_11.cfm

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STFiltFilterStrips.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets)

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT6%20-%20filtering%20BMPS.pdf

URBAN STREAM BUFFERS

General Information

Summary

Stream buffers (also known as riparian buffers, conservation buffers, or riparian filter strips) are a bioretention method used to separate streams and rivers from developed areas. The vegetation in the buffers, generally trees and grasses, lock soil into place to reduce erosion caused by runoff and can also filter out sediment and other pollutants. Buffers function best when kept in a natural condition, but areas along rivers and streams can also be restored or replanted for effective buffers.

An urban stream buffer (Photo: University of Wisconsin Extension)

Advantages

- Buffers can slow runoff and enhance infiltration.
- Because buffers slow stormwater runoff, they also reduce flooding.
- Buffers trap sediment, fertilizers, pesticides, pathogens, and heavy metals.
- They provide snow storage, and can cut down on blowing soil in areas with strong winds.
- They protect wildlife from harsh weather and provide connecting corridors that enable wildlife to move safely from one habitat area to another.
- Buffers also provide aesthetic border areas that can raise property values.
- Conservation buffers help stabilize stream banks and provide shading, which helps main tain cooler water temperatures.

Disadvantages

- Installing buffers can be expensive.
- Buffers can be less effective in pollutant removal and volume reduction on steep surfaces.
- Proper buffer widths may be difficult to maintain in areas where land values are high.

Conventional Alternatives

Stream buffers may replace detention ponds, traditional storm drains, and stream banks where native vegetation has been replaced with turf-grass.

Design Information

The amount of buffer required should generally be 5 to10 percent of the stream's or river's drainage area, although amounts can vary depending on what the developed land is used for. The buffer should contain three different areas. An area directly adjacent to the stream should consist of mature forest or other native vegetation and protected from development. The middle portion should be approximately 50 to 100 feet of managed forest with some clearing allowed. The outer edge, usually about 25 feet, can be a mix of light vegetation or forest. Native vegetation, grasses and shrubs are recommended for the outer edge as they promote infiltration and detention. Turf-grass can be used but is not recommended as its detention and infiltration abilities are limited.

Uses in combination with other techniques

Riparian buffers can be used with grass filter strips to help filter, slow and infiltrate water directed at it from lawns, agriculture, and even parking areas that may use green parking methods.

Cost

Stream buffers are a type of bioretention, that costs approximately $1.25 per square foot. Additional maintenance costs are usually minimal, consisting of invasive species removal, undergrowth removal, or sediment removal. When existing natural vegetation is protected, there is no cost at all. Other costs can be involved, such as the time taken to create or edit the proper zomning ordinances.[21]

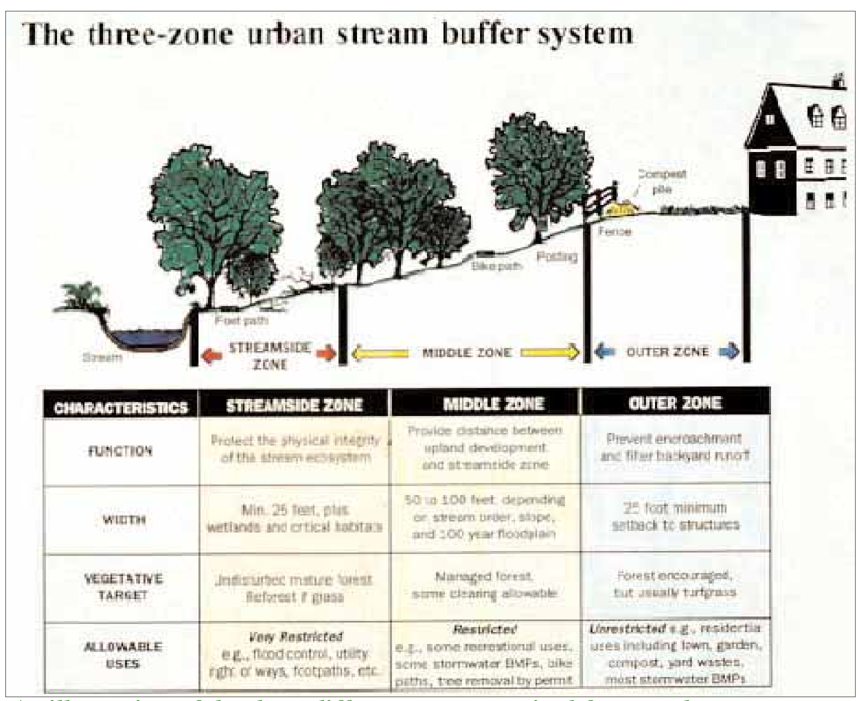
Runoff Reduction

Stream buffers are effective at pollution filtration, removing as much as 50 percent or more of nutrients and pesticides and 75 percent of sediments.

Specialized Information

Soil Types

In general, any type of filtration site works better on more porous and non-clay soils. Native vegetation should be effective if the topography has not been altered substantially. In areas where development has changed the topography or soil type, grading may be required or vegetation suited to more compacted soils could be used to help improve soil conditions. In cases where the soil is incapable of supporting or propagating vegetation, proper soil may have to be imported.



CHARACTERISTICS	STREAMSIDE ZONE	MIDDLE ZONE	OUTER ZONE
FUNCTION	Protect the physical integrity of the stream ecosystem	Provide distance between upland development and streamside zone	Prevent encroachment and filter backyard runoff
WIDTH	Min. 25 feet, plus wetlands and critical habitats	50 to 100 feet depending on stream order, slope, and 100 year floodplain	25 foot minimum setback to structures
VEGETATIVE TARGET	Undisturbed mature forest Reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	*Very Restricted* e.g., flood control, utility right of ways, footpaths, etc.	*Restricted* e.g., some recreational uses, some stormwater BMPs, bike paths, tree removal by permit	*Unrestricted* e.g., residential uses including lawn, garden, compost, yard wastes, most stormwater BMPs

An illustration of the three different zones required for an urban stream buffer (Diagram: Stormwater Managers Resource Center)

Additional Sources

Center for Watershed Protection: Aquatic Buffers
http://www.cwp.org/aquatic_buffers.htm

Macomb County Buffer Initiative (information can be found underneath Annual Report Articles)
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STConstWLSwWetland.pdf

National Resources Conservation Service Buffer Information
http://www.nrcs.usda.gov/feature/buffers/

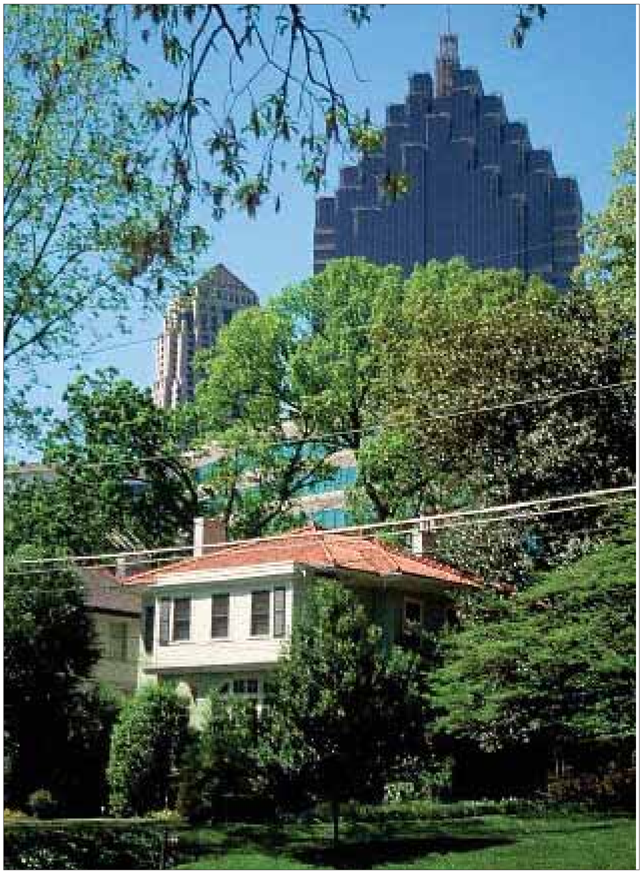
EPA Information Guide
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_6.cfm

URBAN TREES

General Information

Summary

Urban tree planting is one of the simplest and most cost effective ways of reducing stormwater problems in urbanized areas. Planting trees that are indigenous to an area can beautify the area, reduce air pollution and stormwater runoff, and provide a number of other environmental services. A mature tree with a 30-foot crown can intercept 4600 gallons of water per year. Trees intercept stormwater in a variety of ways. First, rain is caught in branches and leaves and evaporates. Trees promote infiltration through macropores, which are large interconnected pores in the ground created by roots. Trees also absorb water from the soil, creating more room for absorption. Maintenance is low, requiring leaf removal and basic tree care throughout the year. Additionally, tree planting is a great community event that develops community pride.



Urban tree cover in Georgia (Photo:Georgia Urban Forest Council)

Advantages

- According to the USDA, a city's urban forest can reduce peak storm runoff by 10 to 20 percent, depending on the intensity and amount of precipitation.
- Trees provide an aesthetic value to neighborhoods, city streets, and other public areas.
- Trees provide more than just stormwater management. They can reduce air pollution, provide shade, lower energy costs, prevent soil erosion, and reduce noise levels along with many other beneficial services.
- Trees are particularly beneficial in riparian areas. They provide shade and leaf litter, which promotes a healthy river habitat for fish, amphibians, reptiles and invertebrates.

Disadvantages

- Trees provide less stormwater control in the winter, when they lose their leaves during dormancy.
- Younger trees do not provide as great a stormwater benefit as older trees, so new tree planting programs may take years to see significant stormwater management benefits.

Conventional Alternatives
Conventional alternatives to trees include turf-grass islands, street curbs, gutters, and storm drains.

Design Information

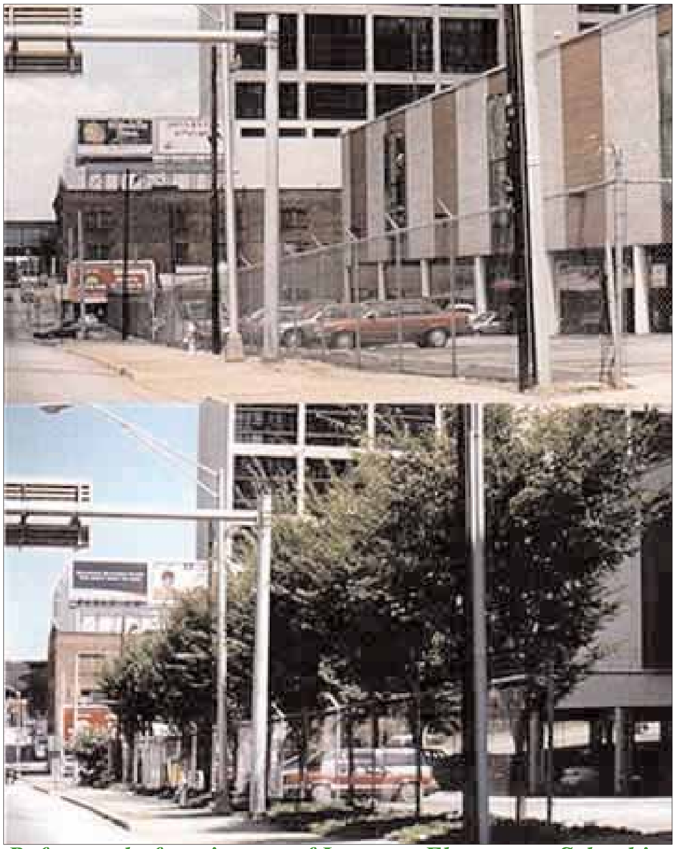
Absorption by trees is dependent on many factors; the condition of the trees, soil conditions, type of trees, time of year, and seasonal variations. The factors are critical to consider when selecting tree types and locations. Where possible, indigenous trees should be used, so as to avoid using non-native species. Additionally, the right tree needs to be put in the right place to maximize stormwater interception potential. A mix of tree types is highly recommended.

The size of the spot for the tree should also be taken into consideration, as tree growth is limited by the amount of root space available. In a natural environment, root systems can extend horizontally many times the tree's height and can be very deep. However, there is a linear relationship between tree size and root space. In areas of limited space and depth, tree height will be minimal and tree width will be limited to the amount of horizontal root space available. Additionally, soil compaction should be avoided around the trees as this will decrease infiltration and can harm the tree.

Tree maintenance should be regular to ensure healthy trees and minimize risk of damage to people and property.

Uses in combination with other techniques

Tree plantings are often placed alone within heavy urban areas. However, they can also be used in combination with infiltration basins, buffers, and other bioretention methods to increase infiltration, evapotranspiration, and provide shade, habitat, and an appealing appearance.



Before and after pictures of Lowman Elementary School in California (Photos: Images Courtesy Trees Atlanta / TreeLink)

Cost
Tree planting costs vary with the area in which the tree will be planted. Soil restoration may be necessary in more developed areas. Different tree species and sizes will cause differences in cost.

Runoff Reduction
A mature urban forest can reduce peak storm runoff by 10 to 20 percent.

Specialized Information

S*oil Types*
Different trees thrive in different soil types, although more porous soils and soils that are not compacted provide the best environment. Soil additives or soil replacement may be necessary depending on the condition and composition of the soil and the needs of specific tree species.

Additional Sources

American Forests
http://www.americanforests.org/

Casey Tree Endowment
http://www.caseytrees.org

Tree People - Los Angles Urban Forest and Tree Group
http://www.treepeople.org/

The National Arbor Day Foundation
http://www.arborday.org/

City of Chicago Urban Tree Page
http://www.cityofchicago.org/Environment/CityTrees/

The Center For Watershed Protection. *Using Trees to Protect and Restore Urban Watersheds*. Ellicott City, MD. January 6, 2004

USDA Forest Service Urban Tree Page
http://www.fs.fed.us/ne/syracuse/

INFILTRATION BASINS

General Information

Summary

Infiltration basins are vegetated depressions designed to capture and hold a volume of stormwater runoff and allow it to infiltrate into the ground over several days. They are generally very simple and are used as an "end of pipe" method to catch water from small creeks, channels, swales, and other stormwater conveyance methods. This method allows water to infiltrate the soil and recharge groundwater rather than discharging directly into sewers and rivers. Infiltration basins are subtle stormwater control methods that can appear as ordinary landscape features such as wet meadows, marshy areas, or even tree-lined fields.

An infiltration basin using bioretention in Largo, Maryland (Photo: Dr. Allen Davis, University of Maryland)

Advantages

- Infiltration basins are a very useful method for reducing stormwater volme during rainstorms. Infiltration basins decrease stormwater volume and reduce downstream and local flooding in a manner that also provides groundwater recharge and base flow for local aquifers and streams.

- They are one of the more effective tools for reducing sediment, trace metals, nutrients, bacteria, and organic material from stormwater runoff.

- They work well for small sites of 2 acres or less and can be an attractive feature when landcaped.

- Infiltration basins are not designed to hold a permanent pool of water, so mosquito problems are generally minimal.

- They can be designed with vegetation and habitat areas in order to provide benefits similar to wetlands.

Disadvantages

- Infiltration basins need to be placed, designed and maintained well or they may not function prop erly. The basin must be placed in a location that receives water appropriately. Deep-rooted plants are necessary to allow water to infiltrate the ground, and the right assortment of plants needs to be planted to absorb the areas particular mix of pollutants.

- Regular cleanup and maintenance needs to be completed to ensure that the basin does not become clogged with sediment. If a basin does become clogged, standing water can result, causing problems with mosquitoes and odors. These conditions can be avoided with proper planning and maintenance.

- Detention basins are not recommended for areas where runoff is highly contaminated, such as near industrial facilities. Pollutants may not be completely removed and could infiltrate into ground water supplies.

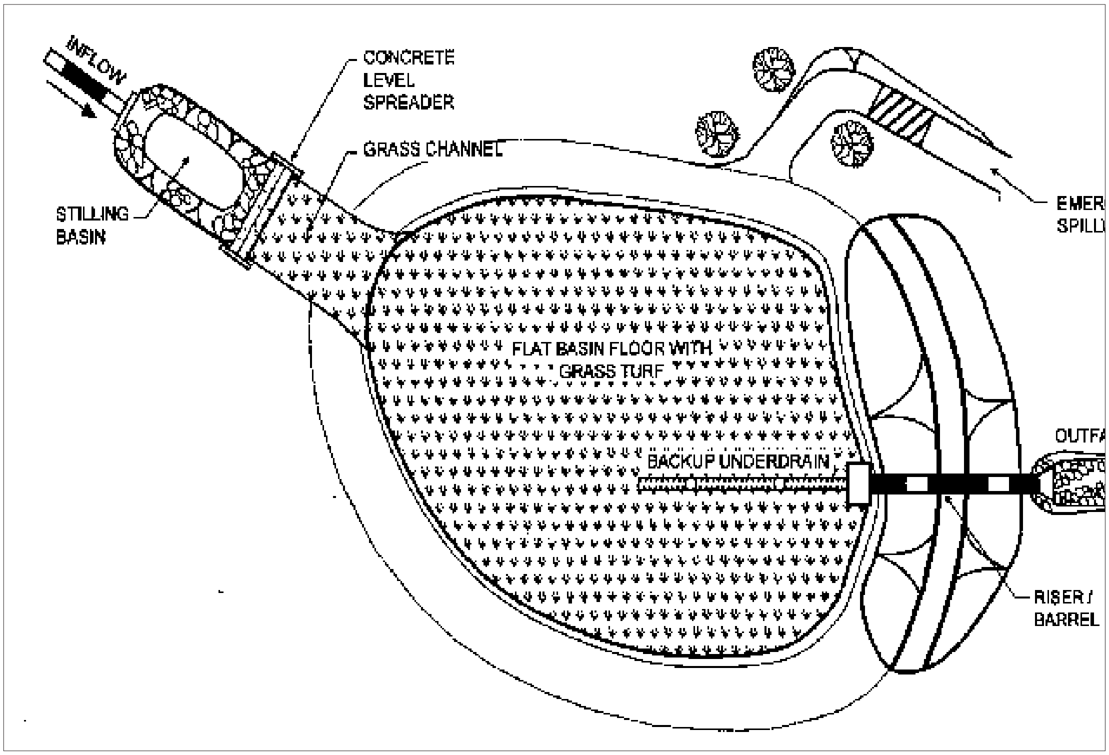
- Detention basins are not recommended for areas with high sediment loads in runoff, as excess clogging will occur.

Conventional Alternatives

Infiltration basins are meant to replace detention ponds, which are designed only to hold and slowly discharge stormwater, rather than allowing it to be filtered and infiltrate into the soil. Strategically placed infiltration basins can also relieve pressure on wastewater facilities that receive stormwater.

Design Information

The amount of land used varies with design. However, basins should be located at least 150 feet away from drinking water wells to limit contamination, and be situated 10 feet down gradient and/or 100 feet up gradient from building foundations to avoid seepage problems. Basins are generally recommended for drainage areas of 2 acres or less and are generally not effective for larger drainage areas. Additionally basins require a backup underdrain to minimize pooling during excessive rainfall.



Infiltration Basin Design (Diagram: Stormwater Managers Resource Center)

Uses in combination with other techniques

An infiltration basin is an "end of pipe" method that works well when receiving water from wet and dry swales, channels, curb cuts, and other water conveyance methods. It should be noted that water infiltration is meant to be slow in these basins and channeling too much water to a basin not designed for that water amount could potentially cause flooding or erosion damage to the basin. Additionally, drywells can be placed near or in infiltration basins to encourage subsurface infiltration. Detention ponds can also be used to capture water before it is discharged into an infiltration basin. This allows most sediment to settle out before entering the infiltration basin, so maintenance only needs to be done on the detention pond rather than the vegetated infiltration basin (See case study below).

Cost

Infiltration basins are generally low cost, at approximately $2 per cubic foot for a one-quarter acre basin. This does not include maintenance costs, which will increase the price. Maintenance costs include typical landscaping care and sediment removal. Costs will depend on the amount of sediment entering the infiltration basin and how often it needs to be removed.[22]

Runoff Reduction

Runoff reduction estimates vary depending on soil type and vegetation. Soils can have a wide range of infiltration rates.

Specialized Information

Soil Types

Infiltration basins work best with soils that have higher infiltration rates, such as Hydrologic Soil types A or B (see the note on soil types in Chapter 4 for further explanation of soil classifications). In general, water should be able to infiltrate at 0.5 to 3 inches per hour. Infiltration basins can be designed to work well in the C soils, which have lower infiltration rates, but should be designed for lower water volume rates or longer infiltration times. In all cases, proper standards and guidelines should be followed with respect to local soil conditions. See the box on soils in Chapter 4 for more information.

Additional Sources

EPA informational guide and pollutant removal matrix
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_13.cfm

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilBasins.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT5%20-%20INFILTRATION.pdf

Applied Ecological Services
www.appliedeco.com

Constructed Wetlands

General Information

Summary

Constructed wetlands are wetlands created to mimic the stormwater benefits of natural wetland systems. They consist of various trenches, small islands, and pools designed to capture, infiltrate and filter stormwater. Except in times of drought, they are designed to contain water at all times. This can include either standing water above ground or water saturated just below the soil surface. They are different from natural wetlands in that they are designed specifically for the task of stormwater capture and filtration. They do not contain the breadth of vegetation nor the full ecological services provided by natural or restored wetlands.

Constructed wetland vegetation (Photo: Applied Ecological Service, Inc.)

Advantages

- Constructed wetlands are low maintenance and can significantly improve downstream water quality by removing sediments, oil, grease, and some forms of nitrogen and phosphorus.
- They are very good at reducing peak flows and preventing flooding, and can service a large drainage area.
- They also add an attractive feature to the landscape. Depending on vegetation and other design features they can also attract wildlife, such as birds.
- Studies by the EPA that have found that wetlands can increase the sales value of homes by 10 percent and the perceived value to homeowners by 15 to 25 percent.
- They are most helpful for developers or municipalities as they are expensive for individuals to build.

Disadvantages

- Like many natural systems, wetland plants hibernate to a degree during the winter and release stored nutrients in the fall, thus pollutant discharges from wetlands may be higher in winter.
- Vegetation may be unable to grow or survive if flow conditions become too erratic or too high.
- Pollutant removal may be lower than expected until the vegetation matures.

- Constructed wetlands are among the most costly stormwater management practices to build.

- Wetlands consume about 3 percent to 5 percent of the land that drains to them, which is relatively high compared with other stormwater management practices.

Conventional Alternatives

Constructed wetlands take the place of conventional stormwater detention ponds. Unlike detention ponds, wetlands are more aesthetically pleasing and offer other environmental benefits. They are also more efficient at encouraging infiltration, trapping sediment and excess nutrients, and reducing flooding.

Design Information

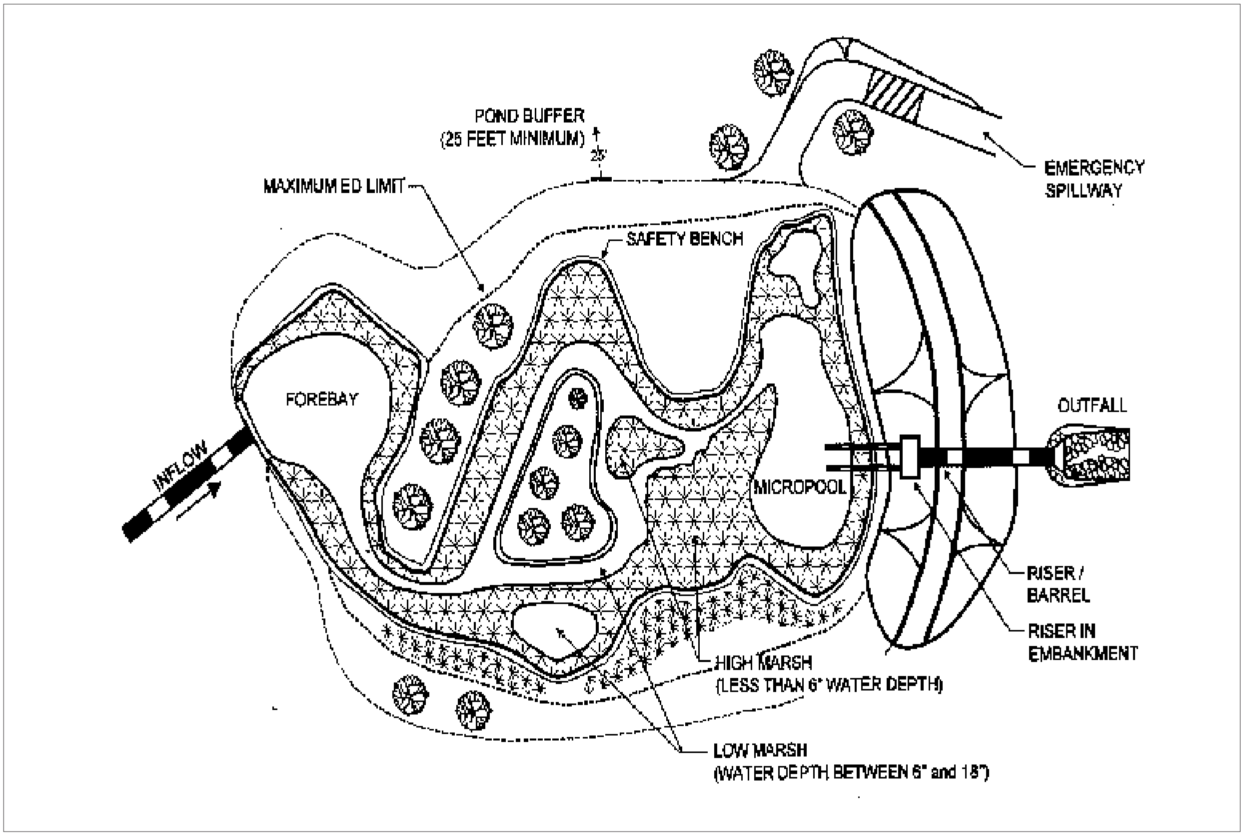
The amount of design information for constructed wetlands is quite substantial given the variety of options. There are four basic design types:

Shallow marsh systems

These systems are made up of shallow marshes with some deep marshes with sinuous water "pathways" that help slow the water down and increase retention time. It is the shallowest type of constructed wet land.

Pond/Wetland systems

Pond wetlands include a pond to help sediment drop out and settle to the bottom before the water enters a system of shallow and deep marshes.



Extended wetland diagram (Diagram: Stormwater Managers Resource Center)

- ***Extended detention wetlands***

Extended detention wetlands provide a greater degree of downstream channel protection through a series of deep and tiered marshes. These systems also provide more vertical water storage, so water levels can rise as much as three feet during a rainstorm but will return to normal within 24 hours.

- ***Pocket wetlands***

These are small wetland areas that can be utilized by sites of between 1 to 10 acres. They must be deeper to accommodate water intake and generally extend down to the water table. These wetlands are almost exclusively fed by stormwater and may have trouble supporting wetland vegetation during dry periods.

Uses in combination with other techniques

Wetlands can be built with filter strips along the edges to help attenuate water flow and reduce sediment loads. Depending on how close the wetland is to buildings or parking lots, flow attenuation methods such as filter strips or buffer strips are recommended. With filter strips in place, green parking methods such as curb cuts can be used to channel water toward the wetland.

Cost

There is little hard data on constructed wetland costs, although a general assumption is that wetlands are 25 percent more expensive than a stormwater detention pond of equal volume. Using estimates developed by Brown and Schueler[23] approximate wetland costs are estimated to be:

- $ 57,100 for a 1 acre-foot facility
- $ 289,000 for a 10 acre-foot facility
- $ 1,470,000 for a 100 acre-foot facility

Runoff Reduction

The runoff reduction of wetlands depends on the size of the drainage area, but they can generally absorb up to 90 percent of stormwater runoff during an average rainstorm.

Specialized Information

Soil Types

When used in areas with underlying limestone, an impervious liner should be placed underneath to prevent the formation of sinkholes.

Case Study - Griffin, GA

Located about 50 miles south of Atlanta, Griffin, GA, began to experience growth in the late 80's and 90's. With the city's aging stormwater infrastructure unable to keep up with the expansion of its population, an area known as the North Griffin Basin experienced routine flooding following rainfalls. This flooding primarily affected a large subdivision in the area.

In 1997, the City of Griffin implemented a formal stormwater management program and a Storm Water Utility to raise funds to begin to address the flooding problems and to improve the quality of stormwater runoff. One of the initial projects undertook by the management program and the Storm Water Utility was the North Griffin Regional Detention Pond (NGRDP), which included a drainage channel, a regional detention pond and two constructed wetland areas. This project brought together national, state and local government agencies in partnership with private sector water resource consultants.

The NGRDP was initially designed as a runoff quantity control system, allowing stormwater to be diverted around the subdivision and back into the creek around the subdivision. However, shortly after design of the project began, it was found that a water-quality-enhancement component could be added. After consulting with various water-quality consultants, the city incorporated numerous plant species around the pond as natural treatment systems. Among others, these included cattail, wool grass and shallow hedge.

The pond and constructed wetlands of the project ultimately use natural filtration processes, rather than mechanical means, to improve the quality of the stormwater runoff. Testing of the NGRDP has shown a significant improvement in water quality. In 2000, The American Consulting Engineers Council awarded the City of Griffin and Integrated Science & Engineering, Inc with the Engineering Excellence Award for this project.

Additional Sources

EPA informational guide
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_27.cfm

EPA Technology Fact sheet
http://www.epa.gov/owm/mtb/wetlands.pdf

Metropolitan Council of Minnesota Design Guide
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STConstWLSwWetland.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Stormwater Center Cold Climate Information
http://www.stormwatercenter.net/Cold%20Climates/CHAPT4%20-%20WETLANDS.pdf
and
http://www.stormwatercenter.net/Cold%20Climates/CHAPT3%20-%20PONDS.pdf

Joint Service Pollution Prevention Opportunity Handbook
http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/10-5.html

Applied Ecological Services
www.appliedeco.com

GREEN ROOFS

General Information

Summary

The green roof atop Atlanta's City Hall (Photo: City of Atlanta)

Green Roofs, also known as vegetated rooftops or eco-roofs, are essentially rooftop areas that have been installed with living vegetation. There are a variety of different types of green roofs, ranging from small gardens and planters to roofs that are completely covered by sod and plants. They have been used in Europe for decades and are growing in popularity in the U.S. and Canada. Lighter, thinner green roofs are known as extensive roofs, while the heavier more layered roofs are known as intensive. Green roofs can only be used on flat roofs or on roofs with gentle slopes (although some innovative techniques in Europe have grown turf on 45 degree angles). While weight is generally not an issue, as most green roof vegetation is actually lighter than a standard gravel and tar roof, consideration must still be given to soil selection and building structure to assure structural stability. The soil collects and holds rainwater and filters out contaminants, while plants soak up the water and provide evapotranspiration.

Advantages

- Roofs represent a large percentage of impervious surfaces; placing vegetation on them can substantially reduce stormwater runoff.
- Green roofs can manage much or all of the runoff that would otherwise be generated by a building's roof area.
- Green roofs cover normal roofing materials, shielding them from wear and prolonging their life.
- Rooftop vegetation adds to the insulation of a building, reducing cooling and heating requirements.
- The collective effect of several buildings with green roofs can reduce the "heat island" effect of urban areas, improve air quality, and reduce dust and other airborne particles.

Disadvantages

- Installing green roofs as a retrofit on an existing building can be costly in both design and construction if the additional weight requires extra roof support. Additional costs are incurred when building for a slanted roof, as erosion controls are necessary.

- Leaks in roofing material could pose substantial problems and costs to repair, although some companies offer electronic leak detectors.

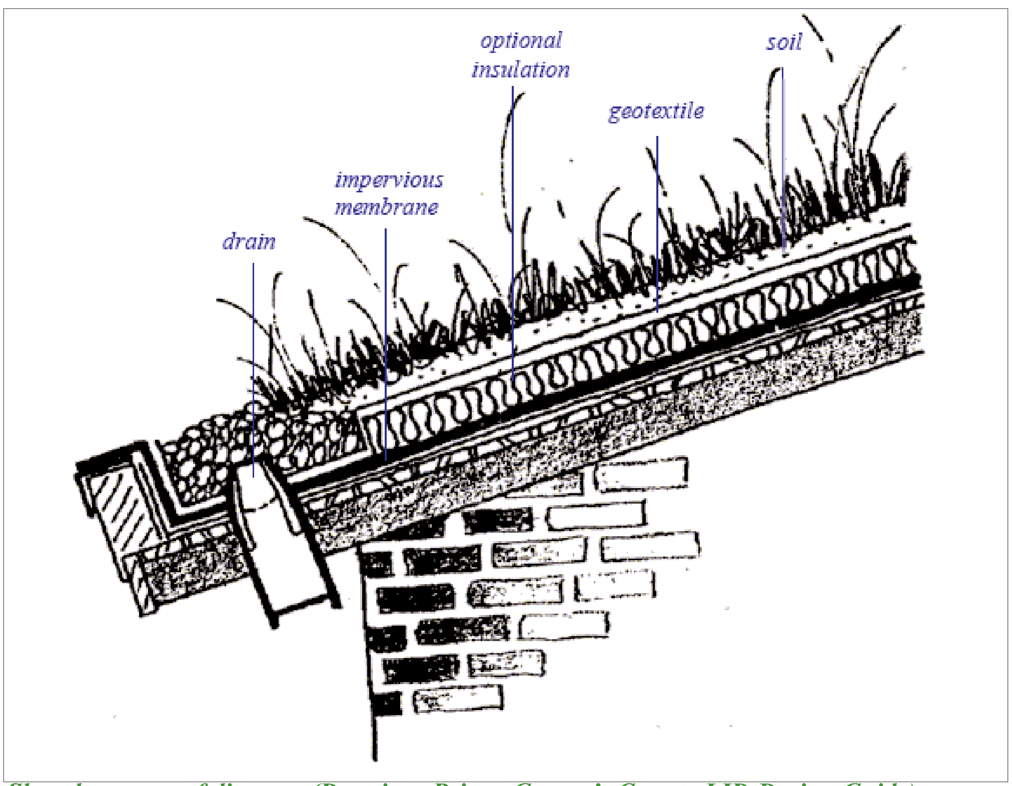
- Maintenance for rooftop vegetation can be labor intensive, depending on access to the roof and the extent of the vegetation.

Conventional Alternatives
Green roofs replace rooftop gutters and drains that feed into sewers.

Design Information

Three major design factors must be considered when installing a green roof: weight, drainage, and slope. Considerations must be taken into account for saturation. Green roofs will be heavier during and after a rainfall than when they are dry. Additional load-bearing capability may be necessary for green roofs that weigh more that 17 pounds per square foot. Green roofs are most easily built on flat surfaces. They can be built on slopes, but 25 degrees is generally the maximum allowable incline. Various membranes and water proofing materials are available, but a drain system is required to drain water that soaks through any soil. Other design factors that should be considered include plant type and access for maintenance.

Uses in combination with other techniques
Green roofs can be combined with rain barrels, dry wells, and bioretention to collect excess runoff.

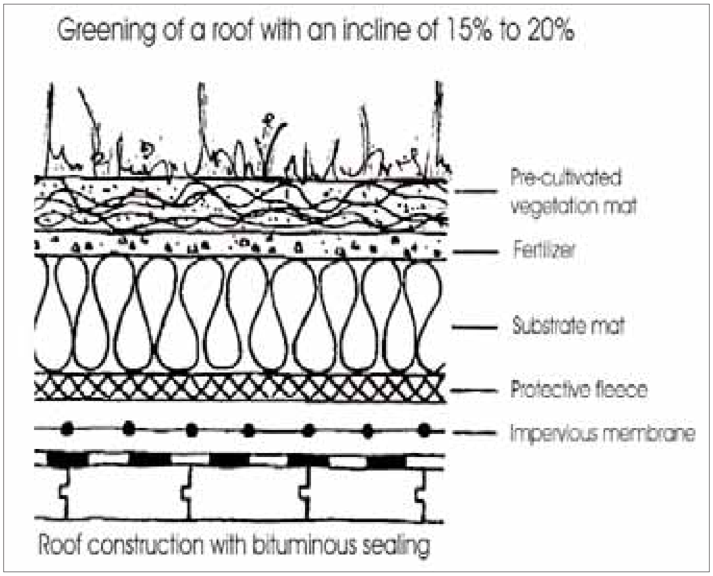


Sloped green roof diagram (Drawing: Prince George's County LID Design Guide)

Cost
Green roof costs can vary depending on the size and weight of the roof, access, the amount of retrofitting or new construction, and the region. For example, the green roof built by Ford Automotive at its Dearborn, Michigan plant cost approximately $8 per square foot. Because the project was so large (450,000 square feet) economies of scale lowered the cost. For more common projects, prices range from $14 to $25 per square foot for smaller roofs and $25 to $40 for more intensive heavier roofs.[24]

Runoff Reduction

As mentioned in the rain barrel section, rooftops can produce a great deal of water. One inch of rain over a 1000 ft^2. roof can create 600 gallons of water. A roof with vegetation that uses the water, retains it in soil, and promotes evapotranspiration that can significantly reduce or eliminate this runoff.



Green roof cross section (Drawing: Prince George's County LID Design Guide)

Specialized Information

Soil Type

Green roofs must use lightweight "engineered" soils that are manufactured so as to be devoid of weeds, pollutants and other potential problems. This relieves added stress on the building and helps maintain a healthy growing environment.

Case Study - Atlanta City Hall

Hoping to set an example of sustainability for its citizens and the region, in 2003 Atlanta City Hall invested in a 3,000 square-foot green roof on the building's fifth floor. The project was sponsored by City of Atlanta's Department of Watershed Management with strong support from Mayor Shirley Franklin. The green roof was the first of its kind in the South, although similar municipal projects have been carried out in other cities in other regions, including Chicago and Seattle.

The design and implementation of this green roof is expected to improve energy efficiency, storm water retention and lifespan of the roof. In terms of stormwater management, the roof is expected to absorb and filter water, improving water quality and reducing the amount of total runoff. The Department of Watershed Management funded $42,000 of the project with a grant from the Georgia Environmental Facilities Authority to make up the additional $18,000 needed.

Most of the plants used for the roof design were drought-resistant sedums with some cacti and herbs included. Located on the fifth floor adjacent to the cafeteria, the roof was designed with 2000 square-feet of vegetated area and 1000 square-feet of pavers. Having previously been a patio for City Hall staff, the City wanted to maintain the patio area as well as making it accessible to visitors of the building.

Following the construction of the green roof, the City of Atlanta adopted a Sustainable Development standard for all municipal financed construction projects. The aim is to promote green roof design as a tool available for sustainable design and clean water throughout the City of Atlanta.

Additional Sources

Green Roof Resource Center
http://www.greenroofs.com/

Green Roofs for Healthy Cities
http://www.greenroofs.ca/grhcc/index.html

Green Roof Resource Center Research Links
http://www.greenroofs.com/research_links.htm#Private

Green Roofs for Healthy Cities Contractor and Designer FAQ
http://www.greenroofs.ca/grhcc/gr_suppliers.pdf

Green Roof Program and Michigan State University
http://www.hrt.msu.edu/faculty/Rowe/Green_roof.htm

Roofscapes, Inc.
http://www.roofscapes.com/index.html

RAIN BARRELS

General Information

Summary

Rain barrels are designed to collect roof runoff. Essentially any water-tight barrel can be set next to a building with a gutter downspout funneled into it to collect and store water that can later be used to water lawns and gardens. Manufactured barrels with lids and spigots are available through catalogues and hardware stores and are safe for households with children.

A typical rain barrel (Photo: EPA)

Advantages

- Rain barrels are an inexpensive means of controlling rooftop runoff and can be easily employed by individual homeowners throughout a neighborhood.
- Many downspouts are connected directly to storm drains; connecting rooftop downspouts to rain barrels can reduce storm runoff discharges into sewers.
- They are a good means of collecting and recycling rainwater for use on gardens and lawns, thus lowering water bills.
- They are relatively unobtrusive and can be an aesthetically acceptable addition to gardens adjacent to houses.

Disadvantages

- Runoff mitigation for neighborhoods is minimal unless used by multiple homeowners.
- Insect growth can be a problem if the barrel is not set up or managed properly.

Conventional Alternatives

Normal downspouts and gutters connected to gutters and sewers.

Design Information

Average rain barrels are generally between 35 to 40 inches tall and 23 to 30 inches wide although smaller and larger ones can be found. On average they take up about 3 ft^2 (.27 m^2) in area. Most commercially made rain barrels come with mosquito-proof lids and covers. A thin layer of cooking oil can also be added to the surface of the water to further discourage insects.

Uses in combination with other techniques

Rain barrels can be used in combination with rain gardens, rain gutter retrofits, small swales and pervious paving to reduce the runoff from a home or small cluster of houses. They can also be connected to dry wells, so that overflow is captured and infiltrated into the ground.

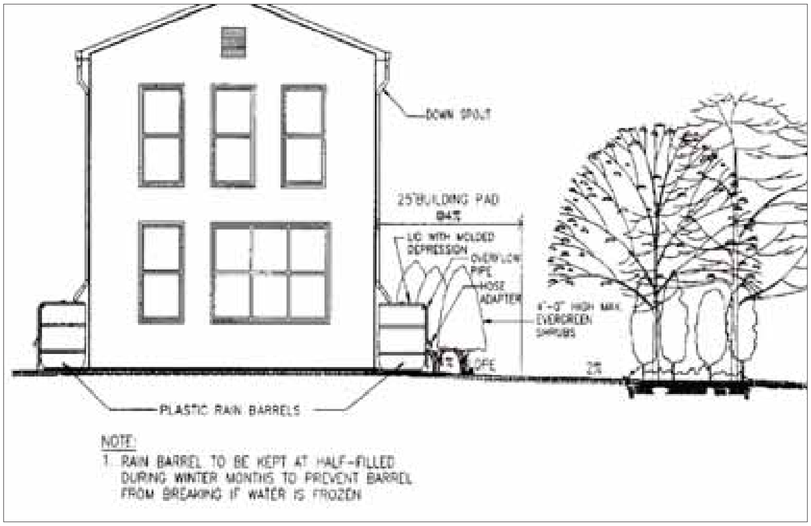


Diagram of rain barrel placement around a house (Drawing: Prince George's County LID Design Guide)

Cost

Rain barrels cost from $40 to $260 depending on the size and manufacturer. A 75-gallon barrel with lid and spout can cost between $100 to $150. Designs are also available for individuals wishing to construct their own rain barrel at less cost.

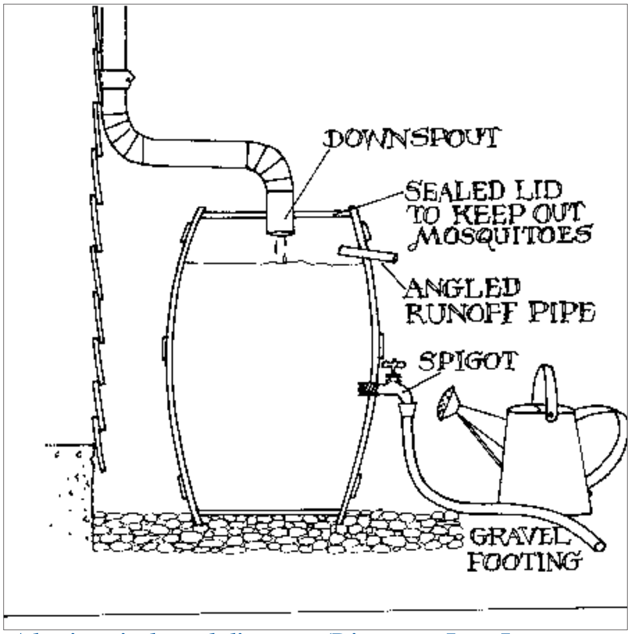
Runoff Reduction

The amount of runoff that rain barrels can prevent varies depending on the number of rain barrels a home installs, the size of the barrels, the amount of rainfall the area receives per year, and the roof surface area of the house.

In general, every inch of rain that falls on an impervious surface of 1000 square feet creates approximately 600 gallons of runoff. Roof surface area is equal to the total square area of the house plus the extension of the eaves. A calculation for a 30 ft x 40 ft house with one-foot eaves on two sides would look like this:

(1+1+30) x 40 = 1280 ft2

If 1 inch of rain over 1000 ft^2 creates 600 gallons, then 1280 ft^2 creates 768 gallons. Rain barrel capacity ranges from 20 to 80 gallons. Having one or two rain barrels in place and using the water in them can reduce stormwater runoff, but will not manage all runoff, particularly during larger rainfalls. However, rain barrels work very well to detain runoff from small storms and when used in combination with other stormwater mitigation methods, they can help slow water flow from the house and provide free water for gardens and lawns.



A basic rain barrel diagram (Diagram: Low Impact Development Center)

Specialized Information

Soil Types

Soil type has no effect on Rain Barrel use.

Additional Sources

On-line rain barrel guide
http://rainbarrelguide.com/

University of Michigan and Friends of The Rouge River Rain Barrel Project

http://www.snre.umich.edu/riverflows/Restoration_project/Rain_Barrel.html

City of Ottawa - Build your own rain barrel
http://www.city.ottawa.on.ca/city_services/water/27_1_4_3_en.shtml

Garden Gate - Build your own rain barrel
http://www.gardengatemagazine.com/tips/40tip11.html

Seattle rain barrel initiative
http://www.cityofseattle.net/util/rain barrel/default.htm

Santa Fe rain barrel initiative
http://sfweb.ci.santa-fe.nm.us/waterwise/rain barrel/rbrebateprogram.asp

Dry Wells

General Information

Summary

Dry wells are subsurface basins used to capture and infiltrate runoff. They are either manufactured or merely a trench filled with gravel or other porous material. The basic concept is for dry wells to be placed near areas that accumulate standing water, or to receive rooftop runoff from gutters. After being stored, the runoff infiltrates into the soil where pollutants are filtered out. Contaminants can also be filtered out to a degree when porous materials are used. But this is usually not an option with manufactured wells, which are used primarily for detention reasons. Dry wells work well as long as the water they infiltrate is funneled into the soil rather than stored and discharged into a sewer system. Otherwise, the method becomes little different than traditional stormwater treatments and no true infiltration into the soil will occur.

Manufactured dry well system after installation. The dirt areas indicate where the well was buried. The green objects are storage tanks with a pump. Drywells also work well receiving rain barrel overflow (Photo: Charles River Watershed Association)

Advantages

- Dry wells are advantageous for areas with limited space, as they are built underground and meant to be dug deep, rather than wide.
- They are useful for improving the permeability of clayey soils although they will not completely alleviate this problem.
- Their subsurface nature also means that they are resistant to freezing temperatures.

Disadvantages

- The pollutant filtering capacity of drywells is not well documented, thus they should be used more for volume control than water quality control.
- They can be more expensive than bioretention due to construction costs.

Conventional Alternatives

Drywells act much like wet vaults or subsurface drains that store or move water. The difference is that drywells rely on infiltration into the surrounding soils whereas wet vaults store and transfer water, and drains merely transfer water. The benefit of a drywell is its ability to reduce stormwater volume and cleanse it while replenishing groundwater stores through infiltration.

Design Information

Drywells should be built at least 10 feet away from any building foundation. The top should be approximately 12 inches below surface and can be anywhere between 3 and 12 feet deep. The well bottom must be at least 2 feet above any bedrock or high water table. An observation well and an overflow structure should also be built to monitor water levels in the well and provide an escape should the well overflow.

Uses in combination with other techniques

Dry wells can be used with infiltration basins and trenches to facilitate infiltration and to reduce standing water. They can also be effectively combined with rain barrels.

Cost

Dry well costs vary depending on the method employed and the region. However, gravel dry wells can be as cheap as $4 to $5 per cubic foot. Manufactured dry wells can cost between $7 and $14 per cubic foot, but this does not include shipping or installation costs. Shipping and installation costs vary by region but can cost approximately $2 per cubic foot.[25]

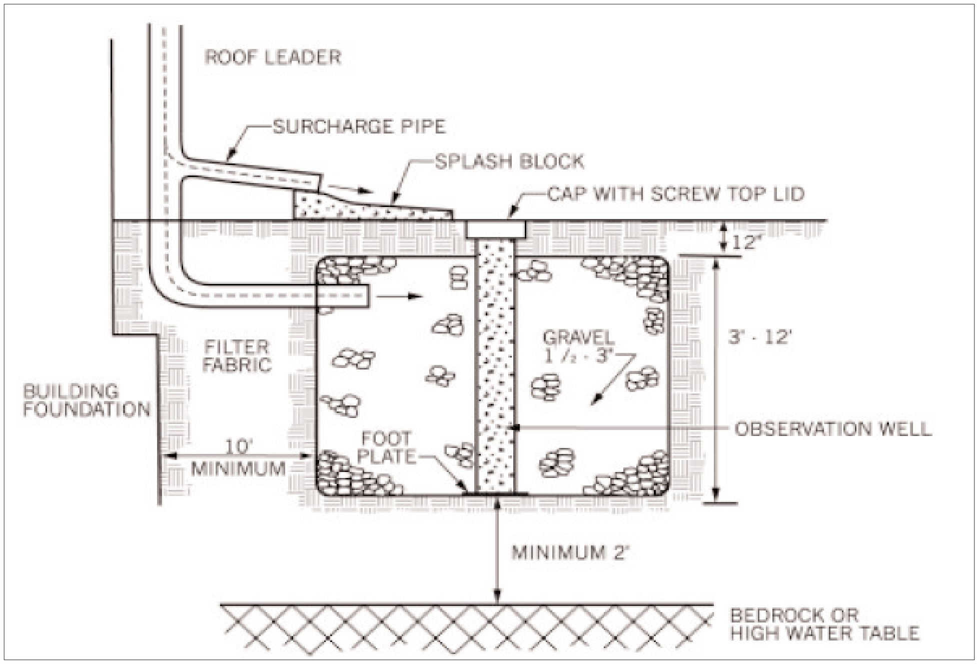
Runoff Reduction

Dry wells differ in the amount of water storage they can provide. The larger the system, the more water it can store. However, different types of wells have different amounts of storage capacity. Gravel wells generally provide 30 percent water storage space out of their overall volume, while manufactured wells can have as much as 90 percent water storage.

Specialized Information

Soil Types

Dry wells should be built in soil with permeability of .27 to .5 inches of water infiltration per hour, to ensure the well empties within 3 days.



Gravel Fill Dry Well (Diagram: Prince Georges Co. LID Design Strategies)

Additional Sources

Charles River Watershed Association - Smart Storm System
www.rainstay.com

Invisible Structures
www.invisiblestructures.com

Prince Georges County Low Impact Development Design
http://www.epa.gov/owow/nps/lid/lidnatl.pdf

The black grids are part of a manufactured dry well. Once installed in the ground, stormwater will be funneled to storage in the grid system (Photo: Charles River Watershed Association)

Porous Pavements

General Information

Summary

Porous pavements can take many different forms, but the term refers to pavement surfaces that allow water to pass through them. Areas can even be designed with porous pavers built over a reservoir designed to further detain stormwater and slowly release it to the surrounding soil. Additionally the porous pavement and the reservoir can also filter out certain pollutants. The four main types of porous pavers are porous asphalt, pervious concrete, grid pavers and grass pavers. Porous asphalt and pervious concrete look much like normal asphalt and concrete but are manufactured to have gaps through which water can flow into the gravel basin beneath. Grass pavers are interlocking blocks shaped in a symmetrical way to fit together and leave spaces for grass to grow through. Grid pavers are similar to block pavers but use plastic material rather than blocks. This makes them more flexible and they can be used on uneven surfaces.

The top photo is of grass pavers. If grass is undesired, gravel or stones can also be used. The lower photo is of pervious pavement (Top Photo: Todd Litman, VTPI; Botom Photo: John Cummins, PermaPave)

Advantages

- Porous pavements are an excellent way to reduce runoff from impervious surfaces, such as driveways and streets, in residential areas.
- They are just as stable as conventional methods and provide the same functionality as regular paving.
- It has been found that snow melts faster on porous pavements because of the improved drainage.
- Porous pavements are useful in overflow parking areas that are only used infrequently and would otherwise contribute unnecessarily to stormwater runoff if paved with impervious materials.

Disadvantages

- Porous paving is more expensive than traditional pavers like asphalt.
- Porous paving cannot withstand heavy, high-speed traffic and should be used in lower volume traffic areas and on driveways.

- Maintenance is required more often than conventional pavement. When not maintained, porous concrete and asphalt can become clogged with small pieces of sediment, rendering the surface impervious. With proper maintenance, such as regular sweeping and cleaning, porous pavements can retain their permeability longer.

Conventional Alternatives

Concrete and asphalt pavement are the accepted conventional alternatives.

Design Information

There are three basic site requirements for effective use of porous pavements:

- Soils need to have a permeability between 0.5 and 3.0 inches of water flow per hour.
- The porous pavement should be placed at least 2 to 5 feet above the seasonally high groundwater table, and at least 100 feet away from drinking water wells.
- Porous pavement should be located only on low traffic or overflow parking areas that are not expected to be sanded during wintertime conditions.

Additional design considerations for porous pavement consist of five different segments: pretreatment, treatment, conveyance, maintenance reduction, and landscaping. More detail on these design criteria is provided in the Additional Sources listed below.

Uses in combination with other techniques

Porous pavements work well when placed near other infiltration mechanisms.

Block Paver and Permeable pavement being tested at the University of Washington (Photo: Center for Water and Watershed Studies)

Cost

Porous pavement is more expensive than traditional pavement, costing $2 to $3 per square foot as opposed to $.50 to $1 per square foot for traditional asphalt. Interlocking pavers can cost between $5 and $10 per square foot.

Runoff Reduction

The total amount of runoff that can be prevented depends on the amount of porous pavement used and its infiltration ability. In general, porous pavement is normally designed to handle small storms with precipitation around .5 to 1.5 inches.

Specialized Information

Soil Types

Porous pavements should be used on soils with an infiltration rate between 0.5 and 3.0 inches per hour.

Case Study - Mickey's Pastry Shop, Goldsboro, NC

When North Carolina State University Professor Bill Hunt was looking for permeable pavement test sites, he came across Mickey's Pastry Shop. Owner Jerry Ray was planning on moving the facility from its location next to the County Courthouse to a nearby location and thought the new building could benefit from a new approach to stormwater management.

Built in 2001, the new site called for a roughly 32,000 square-foot lot, including a 4000 square-foot test area of permeable interlocking concrete pavement (PICP). Professor Hunt agreed to make up the cost difference between the standard, all-asphalt parking lot and the new design with the permeable pavement border. The difference came out to about $2 per square foot. Installation of the stone bed, a filler combination of sand and stone, as well as the PICP took approximately three days.

The permeable pavement is designed to retain and filter stormwater as it slowly infiltrates into the ground water system. After numerous heavy rains, Jerry Ray commented that the new pavement kept stormwater from running into nearby Stoney Creek. Instead, the water simply percolated into the ground. In addition, sampling runoff from the site showed that in 2003 and 2004, zinc and phosphorous levels were lower than in asphalt areas.

Additional Sources

EPA informational guide
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_21.cfm

EPA technology fact sheet
http://www.epa.gov/owm/mtb/porouspa.pdf

Stormwater Managers Resource Center
www.stormwatercenter.net (information can be found underneath fact sheets).

Grid Pavers on NEMO
http://nemo.uconn.edu/reducing_runoff/grid_pavers.htm

Center for Water and Watershed Studies
http://depts.washington.edu/cwws/

Low Impact Development Center - Permeable Paver Costs
http://www.lid-stormwater.net/permeable_pavers/permpaver_costs.htm

EPA Porous Paving Fact Sheet
http://www.epa.gov/owm/mtb/porouspa.pdf

Green Roads & Parking

General Information

Summary

Green roads and parking consist of many techniques that reduce paved surfaces and increase infiltration. They include simple methods that can be implemented in parking lots or even along neighborhood roadways. One example is curb cuts, which are basically structured gaps in a curb that allow stormwater to flow into a grassed filter strip or other detention facility. Other examples include:

A curb cut into a small bioretention area (Photo: Applied Ecological Service, Inc.)

- Narrower neighborhood streets and sidewalks;
- Cul-de-sac islands with vegetation designed for bioretention;
- Narrower driveway design;
- Parking area islands with vegetation designed for bioretention; and
- Driveway sharing.

Advantages

- Green parking and road design can significantly reduce costs as there is less pavement to engineer and install and the benefit to infiltration can be significant. Two lane roads in neighborhoods are often built much wider than minimum requirements.
- Keeping road and parking stall dimensions to minimum requirements can significantly reduce the amount of impervious surface as well as slow traffic and create a more pedestrian friendly atmosphere.

Disadvantages

- Certain road width reductions or additions, like cul-de-sac islands, may require changes to existing ordinances.
- Built improperly, cul-de-sac islands can block effective turning radii. They are expensive as retro fits.

- Improperly designed curb cuts can cause erosion and loss of vegetation.
- Developers are often under intense pressure to provide more parking than is necessary or wider road widths to avoid potential consumer or municipal complaints.

Conventional Alternatives

Conventional methods are the standard curbs, road sizes and cul-de-sacs seen in most typical developments.

Design Information

The amount of land used varies on the design. However, infiltration areas should be located at least 150 feet away from drinking water wells to limit contamination, and should be situated 10 feet down gradient and 100 feet up gradient from building foundations to avoid seepage problems.

Uses in combination with other techniques

Green roads and parking can significantly reduce runoff when used in combination with swales, filter strips and other bioretention methods.

Cost

Most green parking and road techniques reduce the total amount of pavement, which generally costs between $.5 and $1.5 per square foot. Thus cost savings can be measured in the amount of pavement not used. In contrast, bioretention areas, such as that used in cul-de-sac islands are generally $1.25 per square foot.

Runoff Reduction

Runoff reduction depends on the amount of impervious surface that is reduced and what replaces it. If a square foot of road is 100 percent impervious, then 1 inch of rain creates two-thirds of a gallon of water. For every square foot of pavement eliminated, two-thirds of a gallon of runoff can be reduced for every inch of rain.

Narrower streets reduce impervious surfaces and improve safety by slowing traffic in neighborhood areas (Photo: US DOT)

Specialized Information

Soil Types

Soil types vary for green parking and green roads. For uses that involve infiltration, such as curb cuts and cul-de-sac islands, soils recommended for infiltration methods should be used, such as using type A or B soils (see the note on soil types in Chapter 4 for further explanation of soil classifications). For projects like reducing road widths and impervious surfaces, the soil types used should comply with local and national building guidelines.

Additional Sources

Metropolitan Council of Minnesota Design Guide

Street Design
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPImpStreet.pdf

Cul-De-Sac Design
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPImpCuldeSac.pdf

Parking Lot Design
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPImpParking.pdf

EPA Informational Guide
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/post_12.cfm

Center for Watershed Protection - Better Site Design
http://www.cwp.org/better_site_design.htm

Parking median bioretention with curb cut (Photo: Portland Bureau of Environmental Service)

END NOTES

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[3]Pielke Jr., Roger A and Mary W. Downton. *Precipitation and Damaging Floods: Trends in the United States, 1932-97*. Journal of Climate: Vol. 13, No. 20, pp. 3625-3637.
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[6]EPA NPDES website http://cfpub.epa.gov/npdes/stormwater/swphases.cfm accessed February 24, 2004
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[13]Center for Watershed Protection, http://www.cwp.org/aquatic_buffers.htm, accessed March 12, 2004
[14]Otto, Betsy, Kathleen McCormick and Michael Leccese. *Ecological Riverfront Design: Restoring Rivers, Connecting Communities.* American Planning Association. PAS Report Number 518-519. March 2004.
[15]EPA. Stormwater Technology Fact Sheet: Bioretention, Sept. 1999 http://www.epa.gov/owm/mtb/biortn.pdf accessed March 13, 2004.
[16]Phone interview with Patricia Pennel, Rain Gardens of Western Michigan on June 3, 2004.
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[18]EPA. Stormwater Technology Fact Sheet: Vegetated Swale Sept. 1999 www.epa.gov/owm/mtb/vegswale.pdf accessed March 30, 2004.
[19]ibid
[20]Stormwater Managers Resource Guide, www.stormwatercenter.net, accessed April 5, 2004
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[24]Greenroofs.com, www.greenroofs.com, accessed April 15, 2004
[25]Phone interview with and Invisible Structures, Inc. sales associate. Based upon a $15.80 per 25 gallon Rainstore3 unit. April 10, 2004.

Other Resources For Stormwater Management

Stormwater Manuals

Summary of Maryland Stormwater Manual
http://www.mde.state.md.us/assets/document/sedimentStormwater/SWM_Program_fs.pdf

Complete Maryland Manual
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Michigan Stormwater Manual (Includes model ordinances, relevant regulations and BMP's)
http://www.deq.state.mi.us/documents/deq-swq-nps-WholeGuidebook.pdf

New York Manual
http://www.dec.state.ny.us/website/dow/swmanual/swmanual.html

Vancouver, BC stormwater manual
http://wlapwww.gov.bc.ca/epd/epdpa/mpp/stormwater/stormwater.html

Prince Georges County, MD
http://www.epa.gov/owow/nps/lid/lidnatl.pdf

Vermont Stormwater Manual
http://www.anr.state.vt.us/dec/waterq/stormwaterPublications.htm

Infrastructure

S.E.A. Street initiative in Seattle
http://www.cityofseattle.net/util/SEAstreets/default.htm

Article on Nonstructural Preventative Stormwater Management
http://www.epa.gov/ORD/WebPubs/nctuw/Horner.pdf

Green Infrastructure Resource Page
http://www.resourceventure.org/stormmgmt_body.htm

Puget Sound Natural Approaches to Stormwater Management
http://www.psat.wa.gov/Publications/LID_studies/LID_approaches.htm

Green Infrastructure Home Page
http://www.greeninfrastructure.net/?article=2052&back=true

Miscellaneous

Site Planning for Urban Stream Protection
http://www.cwp.org/SPSP/TOC.htm

Low Impact Development Center Design Guide
http://www.lid-stormwater.net/intro/homedesign.htm

Rocky Mountain Institute
http://www.rmi.org/sitepages/pid277.php

Main NEMO web page on reducing runoff
http://nemo.uconn.edu/reducing_runoff/index.htm

Ohio NEMO Program
http://nemo.osu.edu/

INDIANA POWER Program (similar to Ohio NEMO)
http://planningwithpower.org/

Great Lakes Regional Water Quality Program Urban Stormwater Page
http://www.uwex.edu/ces/regionalwaterquality/FocusAreas/watershed/urban.htm

Low Impact Design Paper from the National Planning Conference
http://www.asu.edu/caed/proceedings98/Coffmn/coffmn.html

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US EPA. *Economic Benefits of Runoff Controls*. Office of Wetlands, Oceans, and Watersheds. Washington, DC Publ. 8410S-95-0022; 1995.

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