GREEN INFRASTRUCTURE DESIGN

USING LOW IMPACT DEVELOPMENT

METRO WATER SERVICES STORM WATER

US Army Corps of Engineers

DECEMBER 2009

Contents








Appendices

Overview

Nature is composed of interacting systems that work together to maintain balance. Many ecological components including trees, meadows, wetlands, and buffer zones contribute to maintaining water quality and sustainable, high-quality stream flow.

Human impact interferes with the natural cycles of the environment. Many of the costs of development actually go to correcting the negative effects of that interference, particularly in the area of water control, water quality, and stream ecology. A more balanced approach starts with encouraging the conservation of the valuable resource of rainwater. Specific measures such as covering less of the natural terrain with pavement, using rainwater for irrigation, and preserving existing elements of the terrain all offer the opportunity to keep the natural ecosystems in balance.

Beyond that, a new approach called Low Impact Development (LID) has sustainable solutions to water management that mimic the way nature handles rainfall. Low-cost techniques infiltrate, filter, store, evaporate and detain run-off close to its source. LID provides a system to implement LEED (Leadership in Energy and Environmental Design) Green Building standards for environmentally sustainable construction, with specifications for landscaping, stormwater run-off, and heat island management. Developments earn points for their level of sustainability, which count toward sustainability certification by the U.S. Green Building Council.

By treating stormwater as a resource, LID can enhance the environment, protect health, and improve livability—while saving developers and local governments money.

Environmentally sound, economically sustainable

Sustainable systems are economical as well. It saves money to keep water at its source, and it's cheaper to keep it clean than to treat it after it's polluted.

WHO BENEFITS?

As a **regulator**, you can use LID to address a wide range of wet weather flow issues, including combined sewer overflows, National Pollutant Discharge Elimination System, MS4 permit compliance, Total Maximum Daily Load permits, Nonpoint Source Program goals, and other water quality standards.

Local **permitting agencies** can use LID as a model in revising development and stormwater regulations in favor of more cost-effective, ecologically sound development practices.

Developers can achieve greater project success and cost savings through the intelligent use of LID.

Designers can apply these techniques for innovative, educational, and more aesthetically pleasing sites.

LID is simple and effective. Instead of complicated infrastructure for storage, transport, and treatment, LID provides integrated solutions at the site.

LID is economical. These techniques cost governments less than conventional systems because of reduced infrastructure requirements. LID typically costs developers from 15% to 80% less than traditional construction methods—and frees up more land to sell.

LID is flexible. These techniques can be applied equally well to new development, urban retrofits, and redevelopment/revitalization projects in highly urbanized constrained areas, open regions, or environmentally sensitive sites.

Stormwater programs require addressing complex and challenging goals affecting human health and the ecosystem. Many of these goals are not being met by conventional stormwater management techniques, and communities are struggling with the economic reality of funding aging and ever-expanding stormwater infrastructure. LID provides a key to unlocking sustainable options.

About the Green Infrastructure Design Manual

This manual presents an overview of the principles of LID and how it mimics the way nature handles water. It examines why protecting water quality is so important, the costs of conventional practices, and the benefits of sustainability.

Intended for use by designers, developers, agencies, and individuals, it offers a brief look at frequently used LID techniques with descriptions, estimated cost factors, and typical maintenance requirements. The appendices offer specific information, advice, and costs for each component.

The Green Infrastructure Design Manual concludes with an overview of the Mill Creek Watershed Feasibility Study.

MILL CREEK WATERSHED FEASIBILITY STUDY analyzes six sites along Mill Creek and proposes sustainable solutions including LID, stream assessment, bioretention techniques, and riparian and meadow restoration and creation.

The goal is to apply as many LID techniques as feasible to each site, demonstrating how these methods can be utilized on existing development and undeveloped lands.

Green Infrastructure Design Team
Metro Water Services, Stormwater Division
Tom Palko, Michael Hunt and Michelle Barbero

U.S. Army Corps of Engineers
Sue Ferguson, Project Manager

Armour&Armour Environmental Marketing
Editorial content and design

Ashworth Environmental Design, LLC
Carol Ashworth, Landscape Architect

Cumberland River Compact
Mekayle Houghton, Project Blue Streams Director

KCI Technologies
Gary Myrncza, Project Manager

Lipscomb University Institute of Sustainable Practices
Dodd Galbreath, Executive Director

Metro Parks & Recreation
Bob Parrish, Superintendant, Warner Parks

Tennessee Stream Mitigation Program
Joey Woodard, Program Director

Tennessee Wildlife Resources Agency
Kim Elkton, Environmental Services

The Big Picture

The hydrologic cycle is a constant circle: Water from the surface evaporates into the atmosphere, where it precipitates and falls back to earth. Over and over again.

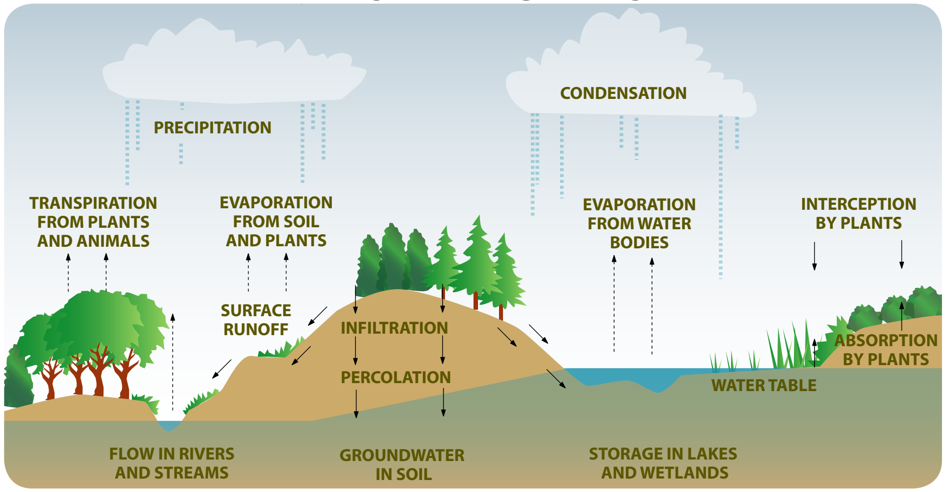
This precipitation replaces water in rivers, streams, and oceans and infiltrates the surface to replenish underground aquifers. Plants take up water through their roots and release it as vapor through transpiration. Throughout the process, the total volume of water on Earth remains fairly constant. Put another way, we already have all the water on Earth we will ever have; no new water is being created.

The water cycle is essential for keeping natural ecosystems in balance. The interaction of water with living organisms, the atmosphere, and the geology of the Earth provides essential services taking place all the time, all over the planet: climate regulation, pollution control, waste management, and other key processes directly affecting human life. The interdependent ecosystems also influence food, habitat, health, and cultural development. On the most basic level, the vast recycling of water makes life on Earth possible.

That's why the human impact on the natural hydrologic cycle is so serious. Diverting the natural flow of huge amounts of water through dams and reservoirs contributes to imbalances, as does pulling water from underground aquifers for agricultural, industrial, and residential use. Human practices like clear-cutting trees to make land available for development or farming often disrupt natural flows by creating run-off of water that would naturally be stored in the leaves and stems of trees and plants. Stormwater has been identified as a major source of water pollution in the U.S. because run-off picks up contaminants on its way to the nearest body of water.

We already have all the water on Earth we will ever have; no new water is being created.

The Hydrologic Cycle



Ashworth Environmental Design

Much stormwater run-off is a result of human interference in the natural water cycle, particularly the use of non-sustainable development practices. The acts of replacing vegetation with pavement and compacting soil deliberately or incidentally—frequent practices when natural areas are developed—affect the way water moves and often result in flooding, erosion, and water pollution.

The conventional methods of treating stormwater rely on collecting water as it runs off roads, sidewalks, and roofs, and transporting it via pipes, channels, curbs, and gutters to a treatment facility or directly into a body of water. A significant problem with this approach is that the run-off collects pollutants as it flows: petrochemicals, sediment, heavy metals, pet waste, and more. Polluted run-off can harm plants, fish, wildlife, and human beings. Another problem comes from the flow itself: Large amounts of fast-running water lead to erosion and flash flooding before reaching a treatment facility. It also denies water a chance to infiltrate to the water table and sustain our streams in Middle Tennessee.

Treat stormwater as a resource

The solution to the problems created from stormwater run-off starts with a simple shift in perspective: We need to stop treating stormwater as waste and start viewing it as a resource. Rather than getting rid of it as fast as possible, we must find ways to harvest stormwater to use for irrigation, replenishing groundwater and flushing waste.

This creates widespread benefits, including keeping streams flowing during droughts. Replenishing the water table directly affects small streams because they typically are fed by groundwater. Harvesting stormwater provides economic benefits as well, because keeping water clean in the first place is almost always less expensive than trying to clean it up. Keeping water close to its source is vastly less expensive than sending it elsewhere. Harvested water lowers the cost of potable supplies.

The most efficient ways to handle stormwater rely on patterning systems on the hydrologic cycle and the natural water management practices already in place.

KEY POINT

Keeping water clean is almost always less expensive than trying to clean it up after it is polluted.

"The first rule of sustainability is to align with natural forces, or at least not try to defy them."

—Paul Hawken

Costs and Benefits

How cities and towns choose to handle stormwater determines whether their residents face escalating costs and a diminishing natural resource, or whether they focus instead on protecting a resource and seeing decreasing costs. All too often, a shortsighted approach to developing systems and processes for dealing with stormwater overlooks many of the true costs associated with wastewater management, while undervaluing the inherent benefits of a valuable commodity.

A municipality may find itself caught in an escalating downward spiral that takes it increasingly farther away from the goal of protecting water quality. Traditional stormwater sewers may collect rainwater run-off and dump it untreated into a body of water. In areas with combined sewer and stormwater systems, heavy rains can potentially cause overflows that dump untreated sewage into rivers and streams. The result: impaired water quality, stream bank erosion, and loss of aquatic and wildlife habitat and recreation.

The Environmental Protection Agency estimates that literally billions of dollars will be required to control combined sewer overflows in the coming years, unless sustainable stormwater management practices are put into place.

Meanwhile, evidence mounts that sustainability is more than just the right thing to do; it makes economic sense as well. Keeping

CASE STUDY

A 2006 study of stormwater run-off in Puget Sound estimates that damage to public health, wildlife, and the terrain in the next ten years could reach more than a billion dollars. These costs come from several areas:

- Flood-related property damage and financial loss
- Capital costs to construct new stormwater-handling infrastructure
- Cleaning up water polluted by stormwater run-off
- Restoring and protecting wildlife habitat

water clean costs less than cleaning it up after it is polluted, and protecting clean water helps to keep groundwater replenished so that adequate supplies are available to meet demands.

Green savings

Potential savings from incorporating sustainable "green" elements into municipal infrastructure include:

Reducing the volume of stormwater run-off. One key to reducing the amount of run-off is implementing systems that copy the water-management practices of nature. A first step is using vegetation and pervious paving in place of asphalt and concrete to enhance water retention and absorption. When more stormwater seeps into the soil, less of it runs off into sewers and ultimately into bodies of water—and that adds up to millions of dollars in annual savings, money that would have been spent on building and maintaining storm sewers.

Replenishing aquifers. The underground water table relies on rainfall to replenish water levels. Using vegetation, pervious pavement, and natural infiltration techniques allows more unpolluted water to recharge aquifers. This is essential to preserving quality of life, as groundwater supplies an estimated 40% of the water needed to maintain normal flow rates of rivers and streams. In periods of low rainfall, it is sometimes the *only* water in the creek. More pure water moving into the aquifers means more fresh drinking water to meet human demands, and lower pumping costs to maintain water pressure.

Reducing pollution. Stormwater picks up much of its pollution as it flows, so putting collection and absorption infrastructure close to the point where precipitation falls helps to prevent pollutants from being collected and moved into bodies of water. When stormwater seeps through roots, rocks, and soil, natural systems are able to break down many common pollutants found in stormwater.

GREEN = SAVING MONEY

Reducing the volume of stormwater run-off

Replenishing aquifers

Reducing pollution

Cutting capital expenditures

Protecting habitats and recreation opportunities

Supporting resource industries

Cutting capital expenditures. Lowering the volume of run-off reduces the incidence of flooding, which protects property values. Fewer and less severe floods cuts the costs of cleanups, riverbank reconstruction, and replacing bridges and culverts.

Protecting habitats and recreation opportunities. Controlling stormwater run-off limits the damage to aquatic and wildlife habitats caused by flashflooding and erosion, and it keeps waterways pure for swimming, fishing, and boating.

Supporting resource industries. Commercially harvested fish and timber are just two markets that benefit from controlling stormwater run-off. Polluted waters obviously harm the fishing industry, while the timber industry is susceptible to flooding and erosion.

Developers also are gradually becoming advocates for implementing sustainable building practices, as they realize cost reductions first-hand. Typical savings come from reduced costs in site preparation, stormwater drains, paving, and landscaping. Studies indicate savings from 15% to 80% over traditional construction methods that require curbs, gutters, and culverts. In many cases, more lots are available for development as smaller systems replace large retention ponds or other structures. Smart developers find other ways to maximize their return on investment, for example by landscaping water treatment zones as visually attractive “water features” that increase selling prices.

Having sustainable stormwater structures in residential neighborhoods creates an additional educational benefit. Studies show that homeowners whose property includes green infrastructure become more aware of and are better advocates for water quality issues.

Green infrastructure delivers indirect benefits as well. For example, roof gardens, tree box filters, and other landscaping components not only reduce the amount of stormwater to be handled by city services, but also provide savings in reduced energy

Sustainable building practices save from **15% to 80%** over traditional construction methods

CASE STUDY

A concrete example of how sustainable practices affect the bottom line is seen in New York City. More than 15 years ago city officials launched a long-term plan to protect its drinking water supply. A planned investment of about $1.5 billion helped the city save from $4 billion to $6 billion, money that would have been required to build a water treatment plant that it no longer needed. The EPA estimates that city saves about $35 million annually in stormwater management by diverting run-off from sewers.

costs by keeping areas cooler in the summer, providing windbreaks in winter—and roof gardens actually insulate buildings from heat loss and gain.

Improved public health can be indirectly attributed to using green infrastructure. An obvious benefit is in minimizing sewer overflows, which potentially compromise sanitary water supplies. Likewise, using natural filtration to trap bacteria and pollutants enhances public welfare by trapping harmful substances. Plus, studies show that green infrastructure in urban settings improves mental health and in some cases physical health.

The impact of having sustainable stormwater systems may eventually reach global proportions, as the need for freshwater resources around the world continues to grow. Chronic water shortages may become commonplace, as U.S. residents already see in the Northwest, where so much water is diverted from the Colorado River that it sometimes no longer reaches the ocean. Here in the Southeast, residents in Georgia, Alabama, and Florida rely on water from Lake Lanier, a reservoir created by damming the Chattachoochee River. The worst period of drought in a hundred years has caused lake levels to drop critically, leaving little doubt that regional residents can no longer take for granted always having as much water as they want.


National Weather Service

Georgia's Lake Lanier in 2008

These are direct benefits of protecting the public water supply. Other factors are harder to evaluate monetarily. For example, how does one place a dollar value on sitting beside a bubbling stream and communing with nature? How does one assign a cost to losing an endangered species due to polluted waters? These costs and benefits are real, even though we lack tangible measures to report them.

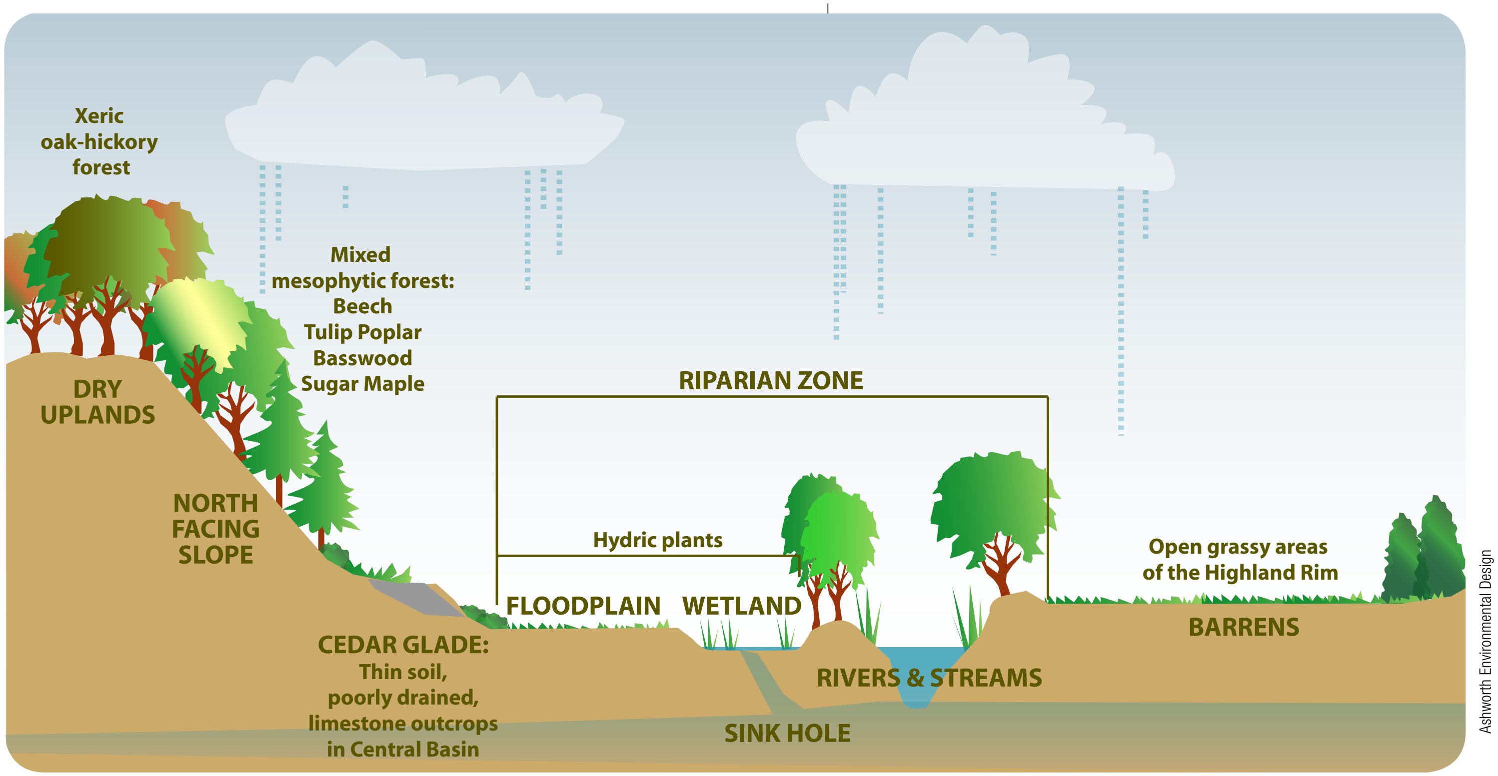
Design Guidelines

The key to optimum handling of stormwater run-off comes from looking at the balance of nature. The solutions that have the most sustainable impact on water quality likewise benefit surrounding landscapes.

It all comes back to treating stormwater as a resource, beginning with putting systems in place to capture every drop of rainwater close to where it falls. This opens options to use the captured water in place of water from the pipes. Why take from Water Services what you can get for free from the sky?

The first principle in creating sustainable designs is to preserve, restore, and enhance soil structure and critical native topography: forest slopes, wetlands, sink holes, floodplains, water channels, and stream banks. Preserving and planting native vegetation plays a key role, as native plants typically have deeper roots to capture contaminants and prevent erosion.

Middle Tennessee's Physiographic Landscape



New roadways and developments should be situated to avoid sensitive natural areas and bodies of water such as springs, seeps, streams, and wetlands. Constructing roadways no wider than necessary and designing sites with the least possible impervious surface area minimizes their negative impact, and development can be clustered to maximize undisturbed natural open space.

Keeping the water close to where it falls requires using natural drainage in vegetated swales and filter strips in place of storm sewers, which offers the added benefit of cleaning up pollutants as the water seeps. Eliminating the need for paved sewer connections is ideal.

Stormwater detention basins and ponds can temporarily hold large amounts of rainwater to prevent downstream flooding. When properly designed, pollutants and contaminants can be filtered out of the stormwater.

Riparian buffer zones provide a transition between developed areas and waterways. Buffers should be situated a minimum of fifty feet from water's edge; one hundred feet or more maximizes the zone's protection.

When properly designed and constructed, riparian zones offer significant benefits in preserving water quality and maintaining healthy stream banks. Besides catching and filtering sediment and debris from run-off and trapping pollutants before they flow into water supplies, riparian zones also help to regulate stream flow by slowing the rate and volume of run-off. The roots of vegetation stabilize stream banks and prevent erosion.

KEY POINTS

Preserve, restore, and enhance soil and topography

Preserve and plant native vegetation

Avoid sensitive areas and waters

Minimize roadway width

Use the least possible impervious surface area

Cluster development to maximize open space

Keep water close to where it falls

Design detention basins to filter pollutants

Use buffer zones between developments and waterways

Low Impact Development

Low Impact Development (LID) has been adopted successfully in the past few years by cities and towns across the country as a stormwater management strategy. The principles and practices of LID deliver measurable benefits including reducing run-off, filtering pollutants, and preserving water purity and flow in our streams.

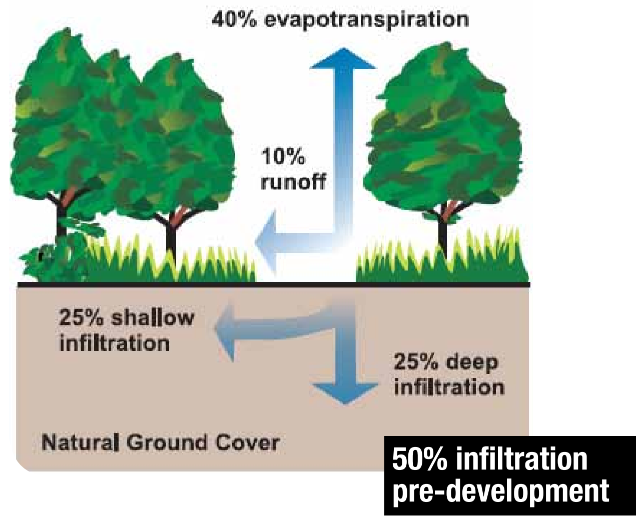
The principles of LID can be applied to nearly any setting: urban areas, residential subdivisions, commercial developments, open areas, and environmentally sensitive sites. Any landscape feature can be modified to handle stormwater more sustainably, and LID techniques can be customized to conform with existing design standards.

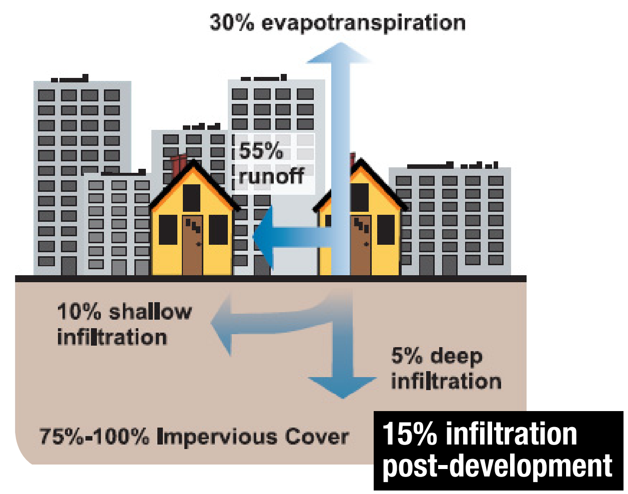
LID also lowers costs of construction and ownership. Typically, less infrastructure is required and water can be captured to use for irrigation. The beauty of LID is that it protects the environment while reducing costs.

LID elements mimic the way nature handles water, from the time it falls as rain or snow, when it flows across the ground, and as it seeps underground. As the figure at right shows, dense urban development has a significant negative impact on the water that infiltrates underground. Whereas approximately half of all rainwater seeps into open land (25% shallow and 25% deep infiltration) only about 15% of rainwater makes it into the ground underneath urban areas, and only 5% infiltrates deeply.

The best site designs first take into account how water drains naturally from the site then specify systems that use the natural flow of water to their advantage. This can be critical to protecting aquatic resources and water quality in developed areas.

As information about LID designs continues to spread, developers are pleasantly surprised to find that LID practices typically offer cost savings over traditional





Evapotranspiration: The transport of water into the atmosphere from surfaces (evaporation) and from vegetation (transpiration).

development practices. Concerns about maintenance and aesthetics are easily answered when officials, developers, and residents see for themselves the sustainability of LID practices.

Cost savings come at several points. Because the total volume of run-off is reduced through infiltration and evapotranspiration, less extensive infrastructure is required to handle it, and less strain is placed on existing components. Some preliminary evidence indicates that LID can help control sewer overflow volumes at lower cost than conventional controls.

Controlling stormwater at the site offers economic advantages, not the least of which for developers is increasing the number of lots that can be sold as a result of eliminating stormwater ponds. Builders also save money by replacing curbs, gutters, and stormwater pipes with bioswales, pervious pavement, and other LID elements.

A 2005 study of ten subdivisions by the Conservation Research Institute found that LID practices combined with natural drainage patterns saved on average 36% when compared to a subdivision developed with conventional stormwater controls. A 2006 study in Rhode Island compared conventional subdivisions to conservation subdivisions that combined LID methods with site plans that optimized existing drainage patterns, looking at the cost of developing the lots and their market value. The researchers found LID lots cost less to develop (on average $7,400 less) and sell for 12% to 16% more per acre—and stay on the market about half the time of conventional lots.

LID practices save an average of 36% over conventional subdivision costs

Buying a lot in an LID subdivision also brings a greater return on investment to owners. A study in Massachusetts showed that homes in LID developments appreciated 26% more in eight years than equivalent homes in non-LID areas.

CASE STUDY

A green residential development in Maryland utilizing rain gardens and grass swales saved the developer around $900,000. In addition, eliminating onsite stormwater ponds provided six additional lots to be sold. On a smaller scale, another subdivision developer also realized significant savings:

- Eliminating two stormwater ponds saved $200,000.
- Eliminating curbs and gutters saved $60,000.
- Making streets narrower (which reduced the amount of impervious surface) cut paving costs by 17%.
- Clearing the land cost $160,000 less than traditional development methods.
- Two additional lots were available for sale and development.
- Open land totalling 2½ acres was retained, which improved the appeal of the subdivision to home buyers.

It is important that everyone involved in development—regulators, developers, engineers, architects and landscape architects—cooperate to ensure that the process flows efficiently. Keeping all the players informed and allowing them to buy in to the concept can help minimize delays and misdirections. In particular, regulators have a responsibility to update codes and guidelines to accommodate LID so that builders and developers do not have to file variances to utilize non-traditional LID practices.

The best LID designs incorporate a variety of sustainable elements to manage stormwater. Many can be tailored to the needs of an individual site. For example, a developer can eliminate the need for a treatment pond by putting a bioretention area in each yard, directing downspouts so they don't dump water onto driveways, removing curbs, and using grass swales. A series of elements each with a small impact combine to eliminate the need for a large facility such as a detention wet pond.

Categories of Green Infrastructure Design

Conservation designs. Incorporating natural methods of handling stormwater reduces the need for constructing large control devices like retention ponds, stormwater drains, and pipes, which decreases the total costs of a project. Preserving open space in designs reduces the amount of run-off by providing areas where water can infiltrate or evaporate. It helps in protecting wetlands and filter buffers, and minimizes damage to soil from compaction and grading. Designers can further reduce the total run-off by making roads and sidewalks narrower and parking lots smaller.

Infiltration practices. Giving water an opportunity to infiltrate, by either natural landscape features or by constructed devices, reduces the amount of stormwater run-off and directly contributes to purfying and recharging ground water. This offers cost savings by cutting the amount of infrastructure required to control, move, and treat run-off.

Conservation Design

- Cluster development
- Open space preservation
- Reduced pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)
- Site fingerprinting during construction to document its unique characteristics

Infiltration Practices

- Porous pavement
- Disconnected downspouts
- Rain gardens and other vegetated treatment systems

Run-off Storage Practices

- Parking lot, street, and sidewalk storage
- Rain barrels and cisterns
- Depressional storage in landscape islands and in tree, shrub, or turf depressions
- Green roofs

Run-off storage practices. Capturing rainwater and storing it for reuse provides savings on two fronts: less infrastructure required to handle run-off, and free water available for irrigation of landscaping. The reduced run-off also protects nearby streams from erosion. In large commercial settings, water storage vaults can be constructed under impervious parking areas.

Run-off conveyance practices. Heavy rainfall requires having a way to convey stormwater that does not infiltrate and cannot be stored, and route it through and off the site. Ideally, natural conveyance systems slow down the speed of run-off and keep it from creating flash flooding and eroding streambeds. LID conveyances with rough permeable or vegetated surfaces cost less than curb-and-gutter and storm sewer systems to install and maintain. They have the added benefits of promoting infiltration and evaporation. Whereas conventional structures move water offsite quickly, LID conveyances take longer for the water to reach streams and delay peak flows.

Filtration practices. Filtering run-off through plants and soil captures specific pollutants depending on the content of the media the water passes through. Filtration practices offer the same benefits of infiltration practices: reduced volume of stormwater running offsite, recharged and purified ground water, and protection to streams from erosion and thermal pollution. While removing the built-up of pollutants can be a concern, generally the pollutants are trapped in the upper layers of soil where removing and replacing topsoil is relatively easy.

Low-impact landscaping. Careful planning, selection and placement of plants can create an aesthetically pleasing design that reduces the amount of energy, water, and chemicals required to keep the landscape healthy. The key is selecting species well-suited to the particular area being landscaped. Choosing native varieties with deep root growth and resistance to pests improves the long-term viability of the site with minimal upkeep and maintenance.

Run-off Conveyance Practices

- Eliminating curbs and gutters
- Creating grassed swales and grass-lined channels
- Roughening surfaces
- Creating long flow paths over landscaped areas
- Installing smaller culverts, pipes, and inlets
- Creating terraces and check dam

Filtration Practices

- Bioretention/rain gardens
- Vegetated swales
- Vegetated filter strips/buffers

Low Impact Landscaping

- Planting native, drought-tolerant plants
- Converting turf areas to shrubs and trees
- Reforestation
- Encouraging longer grass length
- Planting wildflower meadows rather than turf along medians aand in open space
- Amending soil to improve infiltration

Components of Successful Designs

Successful LID plans frequently include the following techniques.

Start by planting **native trees and vegetation** instead of conventional landscape plants. Native vegetation typically has deeper and more extensive root systems, which helps in several ways: More rainfall is absorbed, sometimes cutting run-off volume by 65%. More pollutants like heavy metals, phosphorous, and nitrogen are filtered. Erosion is prevented more effectively. Plus, the reduced need for maintenance of native landscaping saves money, and it provides suitable habitat for birds, butterflies, and beneficial insects.

Rain gardens, also called bioretention areas or bioinfiltration cells, are shallow depressions used to improve the absorption and infiltration of stormwater run-off. They can be designed to filter out specific pollutants and are especially effective as parking lot islands. Carefully selecting the vegetation for a rain garden is important because most plants do well in either dry, average, or wet conditions but cannot tolerate all three conditions. A rain garden should be located at least ten feet away from buildings so that water does not drain into the foundations and sewer lines.

Rain barrels and cisterns are old ideas gaining new popularity. The point is to collect stormwater that traditionally runs through downspouts and into sewers. Besides the benefit of keeping the run-off out of storm sewers, the stored water can be used for irrigation.

Permeable paving affects one of the largest contributors to polluted run-off: stormwater flowing across roads and parking lots. Replacing solid coverage of asphalt or concrete with pervious asphalt, pervious concrete, plastic grid systems or blocks with sand or soil in between allows rain water to soak into the ground.


Native plants


Rain garden


Rain barrel


Permeable paving

Green roofs—live plants growing on the top of buildings—help manage stormwater and improve water quality of the run-off by retaining and filtering water. Less stormwater runs off the roof, and the water that does run off is cooler, cleaner, and slower-flowing.

Filter strips of vegetation adjacent to paved surfaces help by slowing the flow of stormwater and reducing the volume of run-off. Although filter strips may be planted with turf grass, native plants are preferred for the reasons cited above. A filter strip is most effective when the paved area beside it is no more than four to five times the area of the strip, and when situated on a gentle slope.

Bioswales, channels planted with native vegetation, move and temporarily store run-off as an alternative to storm sewers and concrete ditches. They slow down the flow of stormwater, absorb some of it as it passes, and filter out pollutants. Depending on the soil type, a bioswale can reduce the volume of run-off by 15% or more, as compared to curbs, gutters, and sewers. A depressed median recessed within a paved area can be used as an alternative to raised parking lot islands.

Naturalized **detention basins** are designed to look like a natural lake or wetland, with perimeters landscaped with native plants. They help prevent flooding and reduce run-off rates, just like conventional detention ponds. The naturalized basins are also effective at improving water quality by removing sediments through settling (60% to 90%) and dissolved pollutants (40% to 80%). Stable shorelines using native plants that are not susceptible to erosion help keep the detained water clear.

Infiltration basins, also known as recharge basins, differ from detention basins in that a detention basin is designed to discharge water to a downstream body of water whereas an infiltration basin holds water and lets it gradually seep underground. Besides the obvious benefit of minimizing stormwater run-off, an infiltration pond prevents erosion caused by fast-running water and flooding, improves the quality of the water as it infiltrates, and recharges the supply of groundwater.


Green roof


Filter strip


Bioswale


Detention basin


Infiltration basin

Maintenance and Cost Factors

Low Impact Development offers sustainable solutions to managing stormwater run-off that provide immediate return on investment as well as long-term benefits. Often, using LID over comparable traditional design practices offers cost savings that more than offset any initial expenses. In addition, LID components generally require less monitoring and maintenance than conventional stormwater infrastructure.

A discussion of initial investment costs and projected maintenance activity follows for frequently used LID components.

Best Management Practice	Typical Initial Cost	Reduction in Water Volume/Pollutants
Green Roof:Extensive Intensive	$8-12/sq.ft. $15-25/sq.ft.	Cadmium, copper & lead: 95% reduction; zinc: 16% reduction Captures and stores run-off from small to moderate storms.
Rain Barrel	$20-150 each	Captures and stores run-off from small to moderate storms.
Permeable Paving	2 to 3 times conventional costs	Reduces quantity of surface run-off from small to moderate storms.
Natural Landscaping	Similar to conventional costs, from $2,000-4,000/acre	Suspended solids/heavy metals (such as cadmium, lead): 80%; Nutrients (such as phosphorus & nitrogen): 70% Reduces residential run-off by 65%
Filter strip	Similar to conventional costs	Suspended solids & heavy metals (such as cadmium & lead): 70-90% Nutrients (such as phosphorus, nitrogen) and organics: 25-65%
Rain Garden	$3-4/sq. ft.	Removes run-off and pollutants from small storms.
Bioinfiltration	$10-40/sq.ft.	Best option for reducing surface run-off and removing pollutants.
Drainage Swale	Less than conventional costs	Suspended solids: 30-70% removal; nutrients: 10-30% removal. Best at removing run-off in small storms.
Detention Basin	Similar to conventional costs	Reduces stormwater run-off rates and pollutants. Suspended sediments & pollutants: 60-90%. Nutrients & organic matter: 40-80% removal.

Natural Landscaping

The cost of landscaping with native plants to assist in handling stormwater is virtually the same as landscaping with non-natives. Either way, the landscaper has a great deal of flexibility in setting a budget based on the size and variety of plants selected. The cost of installation is about the same for traditional turf grass versus native grasses: an average of $2,000 to $4,000 per acre, according to one estimate. However, the cost of traditional landscaping rises significantly if sod and irrigation systems are installed—which may not be necessary with native plantings.

Maintenance costs on a natural landscape are a fraction of upkeep on conventional landscaping, once it is established. In the first couple of years native landscaping may need occasional watering during prolonged drought and perhaps some spraying or weeding to eliminate invasives.

Native grasses require less-frequent mowing and irrigation than conventional turf grass, and it seldom if ever needs fertilization or pesticides (which in itself contributes to water purity). Typically a site can be maintained with mowing once a year, or if the site's jurisdiction permits, an annual controlled burn—one of the best ways to maintain natural landscaping. NOTE: Burning is not permitted in Nashville.

Native trees used in landscaping will be better suited to growing conditions than exotic species. They will be better able to tolerate extremes in temperature and precipitation, and their extensive canopy and root systems aid in preventing erosion and capturing pollutants.

Long-term, natural landscaping will cost at least half and perhaps as little as one-fifth of the expenses associated with maintaining conventional landscaping.

APPLICATION: River or wetland edges, detention basin and drainage features, parks, green roofs, residential areas and gardens, commercial, industrial and institutional developments.

MAINTENANCE: Much less irrigation, mowing, fertilizer, pesticides than conventional. Some initial watering and spot spraying for weeds, annual mowing.

COST: Similar to conventional turf, roughly $2,000 to $4,000 per acre.

POLLUTION REDUCTION: Suspended solids and heavy metals such as cadmium and lead: 80%, nutrients such as phosphorus and nitrogen: 70%.

WATER REDUCTION: Reduces residential run-off by 65%.

Rain Gardens

The type of underlying soil affects the costs of establishing a successful rain garden. Sandy soils that drain quickly will not need extra conditioning, while claylike or heavily compacted soil may require additional underground drainage. Underlying bedrock as is found in Davidson County may require an underdrain system.

Typical costs range from $10 per square foot to $40 per square foot, depending on the type of plants selected as well as the need for drains. Installation averages about $4 per square foot.

The accumulation of sediment mandates the need for maintenance of the biofiltration system to remove clogs that prevent water from flowing through. The incidence of clogging can be reduced by pre-treatment, simply routing the water through grass as a preliminary filter before flowing into the biofiltration cell. Removing sediment regularly will prevent loss of functionality.

Rain garden filtration is based on the simple principle of nature that water is cleaned by passing through a filtration medium such as sand or soil. Therefore, it represents a stable option for water treatment, unlike treatment methods relying on activated sludge, in which aerobic organisms suspended in liquid in concentrations in excess of those found anywhere in nature require active aeration to remain alive. The very simplicity of rain garden biofiltration results in lower maintenance and monitoring costs than more complicated systems.

Keeping a rain garden healthy requires about the same level of attention as tending any garden: periodic weeding and occasionally replacing plants that die. Selecting hardy native plants well-suited to the prevailing conditions will minimize the care and attention the garden needs.

APPLICATION: Parking lot islands, residential developments with swale drainage, commercial developments with filter strips, and campus developments with swale drainage and filter strips.

MAINTENANCE: Periodic inspection, vegetation management, sediment removal.

COST: $3 to $40 per square foot

SAVINGS: Reduced size and cost of downstream conveyance and storage.

WATER/POLLUTION REDUCTION: Removes run-off and pollutants from small storms.

BENEFITS: Allows some additional infiltration to water table and maintains flows in streams.

Rain Barrels and Cisterns

Rain barrels and cisterns are basically the same—containers that collect rain water as it runs off a roof. "Rain barrel" typically refers to a relatively small container used in a residential setting, while "cistern" describes a more elaborate collection system suited to collecting larger amounts of water, usually in a commercial setting.

The level of complexity makes a cistern system cost more than a simple rain barrel. A typical 55-gallon rain barrel consisting of a closed plastic container with a hole in the top to receive water from a downspout and a faucet at the bottom to release water as needed costs around $50 to $100. An industrious homeowner can construct one from simple parts for less than that. Four 55-gallon rain barrels positioned at each corner of a house can handle the run-off from a 1,200-square-foot roof.

Commercial-grade cisterns may be on a roof or completely or partially underground, which requires a pump to get the water back to ground level. They provide greater capacity, as well as having water pressure to simplify irrigation. A single cistern can collect water from multiple downspouts or even multiple roofs.

Cisterns are more expensive because of the excavation required and the need for a pumping device, typically in the range of $3,000 to $5,000 for an 800-gallon system. Other cost considerations include first-flush diversion, filtration, disinfection and maintenance of systems. Because of the large capacity, the cost of a single cistern can spread across several properties: only one excavation, one container, and one pump.

Rainwater harvesting can reduce utility bills, depending on how much water is typically used. Once the collection system is set up, the water is essentially free, and the supplies can be ample. A 1,000-square-foot roof discharges around 600 gallons of rainwater during a one-inch rainfall. Putting about an inch of water on a four-by-twelve-foot flower bed (48 square feet) requires about 30 gallons of water, so one good rain supplies several waterings.

APPLICATION: most residential, commercial and institutional properties where vegetation is limited, provided that collected water can overflow to open green space areas.

MAINTENANCE: Occasional cleaning. Barrel must be sealed during the warm months and drained prior to winter.

COST: $20 to $150. Homeowners can reduce costs by making their own.

WATER REDUCTION: Captures and stores run-off from small to moderate storms.

Permeable Paving

Roads and parking lots play a major role in transporting stormwater run-off and contaminants. "Permeable" describes paving that allows water to flow around paving tiles and seep into the ground below. These alternate materials let more water infiltrate close to where it falls and reduce the amount of run-off leaving the site. This helps decrease downstream flooding, combined sewer overflows, and pollution of the receiving water. The spaces between pavers may be filled with grass, gravel, or sand. As in rain gardens, the type of underlying soil affects how efficiently the water seeps and how much soil preparation is required before installing the paving.

Permeable paving can become clogged from debris filling in the spaces between pavers. This mandates regular monitoring and periodic cleaning. Filler material may need to be added to the spaces between pavers from time to time. Pavers with grass between the tiles requires occasional mowing.

The material costs of permeable paving can be at least 50% more than conventional concrete or asphalt paving. This is partially offset by its longevity, as permeable paving typically lasts about 20% longer than impervious materials. Installation costs are equivalent to standard paving. After factoring the indirect savings from decreased need for installation, maintenance, and repair on underground pipes, reservoirs, storm sewer extensions, and conventional stormwater systems, the cost savings are substantial. In some regions, builders receive credits from local municipalities for contributing to stormwater management with pervious paving, which offsets some of the increased cost of materials.

APPLICATION: Overflow and special event parking, driveways, utility and access roads, emergency access lanes, fire lanes and alleys.

MAINTENANCE: Vegetated paving blocks may require occasional mowing. Snow plowing may require special care.

COST: Although material costs are greater than conventional concrete or asphalt, longevity and reduced infrastructure needs create substantial savings.

SAVINGS: Less frequent replacement. Reduced stormwater engineering and infrastructure.

Green Roofs

Depending on the load-bearing capacity of the building, green roofs can be constructed as an extensive system (two to four inches of soil) or intensive system (six to twelve inches of soil). As expected, the extensive system using short plants with shallow roots costs less to install and maintain than the intensive system with deep-rooted plants and trees.

Apart from the usual maintenance required by any garden, the only special attention a green roof needs is regular inspection of the roof membrane and drainage paths.

Designing and installing a green roof averages from $5 to $20 per square foot for an extensive systems and $15 to $25 per square foot for an intensive system, depending on the type of roof and the plants selected. An intensive system may also require irrigation. The initial cost of setting up a green roof is offset by reducing the need for replacing the roof periodically, as well as lower energy costs provided by the insulation of the soil and plants.

An intensive green roof can be installed with modular interlocking units that have been prepared ahead of time with layers of the drainage material, filter cloth, soil, and plants in place, or with each component brought in separately. Modular installation is not recommended for extensive green roofs. Maintenance is more complicated for a modular system, since an entire unit would have to be moved to access the underlayer for repair.

As with any roofing job, the cost of the waterproofing material is the single largest cost factor. The cost of waterproof membrane for a green roof may be higher because commonly used waterproofing materials require a root barrier between the waterproofing materials and the vegetated cover. The extra cost is offset because the roof membrane is protected from ultraviolet rays by the green roof, doubling or tripling its expected life.

APPLICATION: New building designs, rehab opportunities for residential, commercial, industrial and institutional properties.

MAINTENANCE: Minimal. Inspection, some watering, weeding. Typical garden care

COST: $8 to $25 per square foot

SAVINGS: Reduced roof maintenance and replacement, utility costs.

WATER REDUCTION: Captures and stores run-off from small to moderate storms, slows the velocity of run-off volume to sewer systems by 60% to 90%.

POLLUTION REDUCTION: Cadmium, copper and lead: 95% reduction, zinc: 16% reduction.

Naturalized Detention Basins

The costs associated with a naturalized detention pond generally are less than a conventional detention basin because natural methods need less excavation and such materials as gravel, stone, or concrete. Native plants used along the shoreline are comparable in cost and require less maintenance than turf grass, and the inherent qualities of native vegetation are more effective at protecting from erosion.

Unlike a conventional pond that needs regular mowing around the perimeter, a naturalized version needs mowing (or controlled burning) once a year. Naturalized basins may need dredging to remove sediment, but probably no more frequently than a conventional pond.

Converting to naturalized detention can be cost-effective as a retrofit to improve the quality of water being released from an existing conventional detention pond.

APPLICATION: All development types except very small sites.

MAINTENANCE: Annual (or less frequent) mowing once the vegetation is established, occasional sediment removal and trash control.

COST: Comparable or less than conventional.

SAVINGS: Reduced needs for conventional turf maintenance.

WATER REDUCTION: Reduces stormwater run-off rates and pollutants.

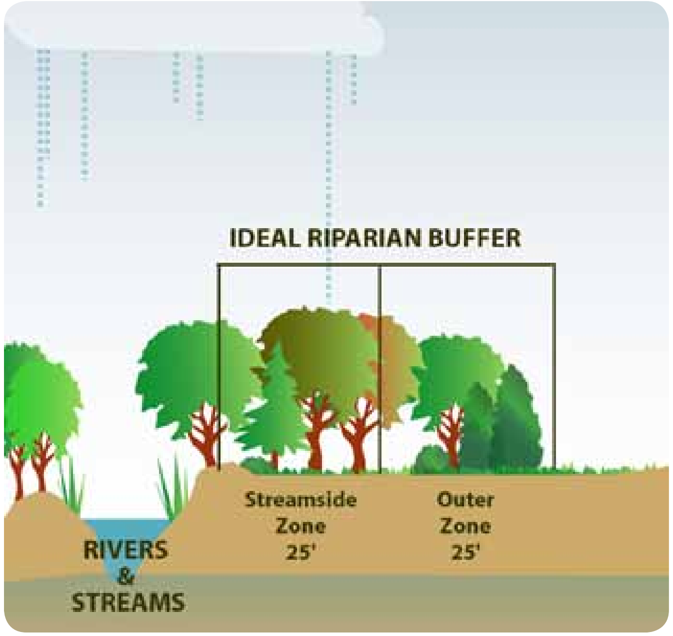
POLLUTION REDUCTION: Suspended sediments and pollutants: 60% to 90%, nutrients and organic matter: 40% to 80%.

Filter Strips and Buffers

Filter strips and buffers are uniformly graded, vegetated areas of land that remove pollutants from run-off through filtration and infiltration. They're recommended between developed areas and sensitive aquatic environments, as well as for land uses that generate high pollutant levels like roadways and parking lots.

Filter strips and buffers differ primarily in where they are applied. Filter strips are positioned between impervious paved spaces, while buffers protect waterways from developed areas. Buffers reduce maintenance, stabilize streambanks, intercept and purify water, and provide shade. The cost factors for each are similar.

An initial cost comes in removing existing vegetation or turf grass and replanting with native species, ideally a combination of live plants and seeds to promote immediate establishment. Plantings, including materials and labor, probably will average $2,000 to $3,000 per acre.



Ashworth Environmental Design

Maintenance costs for filter strips and buffers are usually lower than for conventional landscaping, since less mowing is required and fertilizing is not needed. The spaces will need monitoring to remove invasive exotics and replant any natives that die.

A lower-cost option is simply to direct stormwater to an existing vegetated area instead of to sewers.

APPLICATION: Residential and commercial developments with expanses of green spaces next to impervious surfaces such as parking lots. Also vegetated buffers next to streams or wetlands.

MAINTENANCE: Mowing, trimming, removal of invasive species, additional planting, periodic cleaning.

COST: No additional cost to direct run-off to an open vegetated area rather than a storm sewer. A level spreader may be necessary to evenly spread run-off water.

SAVINGS: Reduced need for infrastructure devices.

POLLUTION REDUCTION: Suspended solids and heavy metals such as cadmium and lead: 70% to 90%, nutrients such as phosphorus and nitrogen and organics: 25% to 65%.

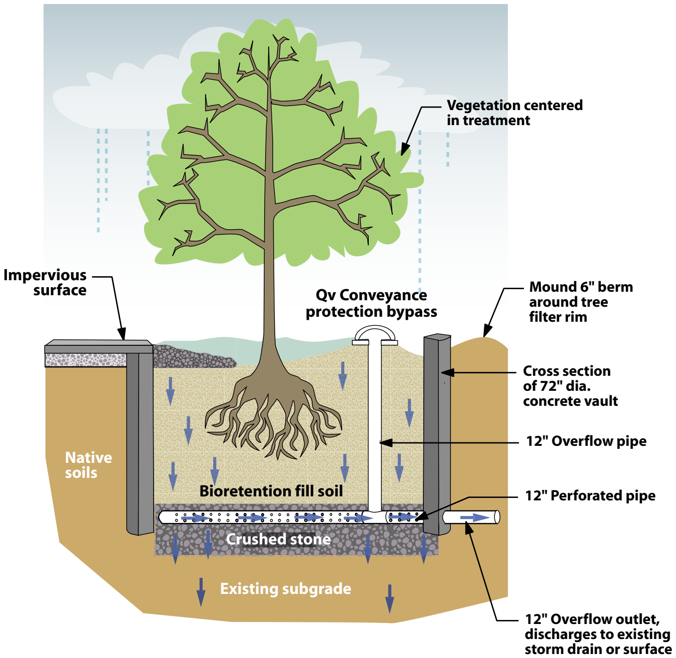
Bioswales

Vegetated drainage channels may be used either as an alternative to storm sewers and concrete ditches, or in densely developed areas in conjunction with conventional drainage infrastructure. A bioswale costs no more to excavate, and generally speaking the costs of planting vegetation are considerably less than paving.

A bioswale may require periodic maintenance to clear out trash or debris, as a storm sewer or concrete ditch does, and perhaps an annual mowing. Bioswales, however, never have to be repaired or replaced as their conventional counterparts do.

Tree Box Filters

Tree box filters on street trees or in parking lots play a role in controlling run-off, particularly when several are used in the same area. They serve as miniature bioretention cells, filtering the run-off that is directed to the tree box through soil and vegetation before directing the water to a catch basin. Each tree box is essentially a "rain garden" of one tree.



The system consists of a container filled with a soil mixture, a mulch layer, and an underdrain system. The tree box is landscaped with shrubs, ornamental grasses, and flowers along with a tree. The can be adapted to fit into any landscape as a way to reduce urban heat islands, offer habitat to wildlife, and add beauty to the setting.

APPLICATION: All development sites including office campus, commercial, industrial, multi-family residential, parking lots, residential parkways and highway drainage.

MAINTENANCE: Periodic cleaning.

COST: Less than conventional considerations

SAVINGS: $4,000 to $5,500 per acre of developed area plus no replacement costs.

POLLUTION REMOVAL: Suspended solids: 30% to 70% removal, nutrients: 10% to 30% removal.

WATER REMOVAL: Best at removing run-off from small storms.







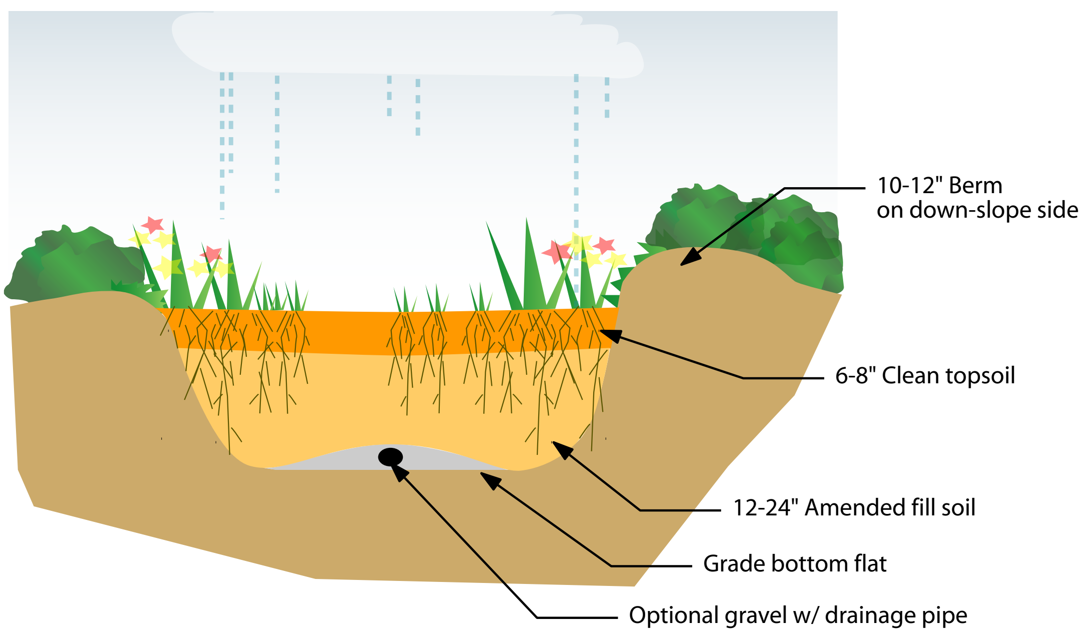

APPENDICES

Rain Gardens

Research conducted by North Carolina State University evaluated the performance of six rain gardens in four North Carolina cities, analyzing how efficiently they removed various pollutants. The study found the following results:

- Bioretention cells can be very effective when designed to remove specific pollutants.
- Rain gardens can contribute to the recharging of groundwater supplies.
- Large amounts of nitrogen can be removed by bioretention, typically reducing the amount of nitrogen entering storm sewers by 40% or more.
- The levels of phosphorus removed depends on the amount of phosphorus already in the soil, the P-Index. Lower P-Index soils produce the best results.
- The rain garden removes fewer contaminants when the run-off is less polluted.

Rain Garden



Applicability

- Bioinfiltration is suitable for developments that have sufficient room for the water to be absorbed. Suggested applications include: parking lot islands, residential developments utilizing swale drainage for pre-treatment, commercial developments utilizing filter strips adjacent to parking lots for pre-treatment, and campus developments utilizing swale drainage and filter strips for pre-treatment.

What Rain Gardens Can Clean

Total Suspended Solids. A bioretention cell's depression storage, which temporarily stores run-off, removes suspended particles through sedimentation. Some fine particles are filtered through the top layers. No specific soil-mix is required, because most particles are removed before water infiltrates the cell.

Metals. A University of Maryland study found that more than 95% of metal removed through bioretention was trapped in the top eight inches of fill soil, and that 18 inches of fill soil in the bioretention cells is sufficient. The soil mix should allow infiltration of at least two inches per hour.

Bacteria and Pathogens. Scientists and engineers generally agree than most of the bacteria and pathogens affected by bioretention are killed at the surface, where the soil is exposed to sunlight and dries out. Soil depth is not a factor, but sparsely vegetated cells work best because of maximum exposure of the soil to sunlight.

Total Nitrogen. A study at Penn State University showed that nitrogen is removed more effectively when water stays in the bioretention cell longer, preferably infiltrating no faster than one inch per hour. Fill soil depth may be limited in the Middle Tennessee area because of underlying bedrock. A minimum depth of 12 to 24 inches is desirable; if possible, 48 inches is optimal.

Total Phosphorus. Fill soil must have a low P-Index in the range of 15 to 30; higher levels will not adequately remove phosphorus, and lower levels will not support plant life. The soil mix should allow infiltration of at least one inch per hour so that the cell's top layer does not become saturated, with a minimum depth of 24 inches.

Temperature. Bioretention cells can reduce water temperatures by five to ten degrees Fahrenheit. Deep soil, perhaps two to four feet, along with ample shade enhances temperature reduction. An internal water storage zone at the bottom of the fill soil may reduce temperatures further.

Maintenance Considerations

- Bioinfiltration maintenance includes periodic inspection to ensure the system is operating properly, along with management of the vegetation.
- If a practice fails due to clogging, rehabilitative maintenance will restore it to proper operation. Incorporating pretreatment helps to reduce the maintenance burden of bioinfiltration and reduces the likelihood that the soil bed will clog over time.
- Rain garden maintenance is similar to that for a typical garden—including weeding and reestablishing plants as necessary. Periodically removing sediment may be required to ensure the proper functioning of these systems. It is best for runoff to be pretreated via swales and/or filter strips before entering the rain garden to avoid sediment accumulation.
- Plants should be selected to reduce maintenance needs and to tolerate snow storage and winter salt and sand, where appropriate.

Preventing Problems

Most problems with bioretention systems come from filters becoming clogged with sediment, often during construction. Designers can prevent problems by taking a few simple precautions.

Placement

- Avoid disturbed areas.
- Stay away from sites where future development may occur uphill.

Timing

- You can dig the hole at any time, but you should wait about placing underdrains, gravel layer, and fill soil until construction is complete. Otherwise, sediment from construction activity may contaminate the components.
- Do final paving after fill soils are in place.
- Plant vegetation and spread mulch after parking areas and landscaping are complete.

Material

- From the bottom, place six to eight inches of gravel (washed #57 stone) and underdrain pile.
- A permeable filter fabric may be used between the gravel layer and the fill soil above it, provided the site will remain stable during construction and future development is unlikely.
- In situations where permeable filter fabric is not recommended, create a filter layer between the gravel and fill soil. Use about two inches of choking stone (washed #8 or #89) and two to four inches of washed sand.
- Use the following formulas from the Federal Highway Administration to

Cost Considerations

- Bioinfiltration costs can range between $10 to $40 per square foot, based on the need for plants, control structures, curbing, storm drains and underdrains. Bioinfiltration should reduce the size and cost of necessary downstream conveyance and storage devices.
- The costs of rain gardens will vary depending on how much work is completed by the owner and the types of plants desired. Rain garden installations average $3 to $4 per square foot depending on soil condition and density and types of plants used. If planned and designed properly, a rain garden is likely to retain its effectiveness for over 20 years.

determine whether a choking material will keep the overlying soil in place. DX is the particle size at which X percentage of particles are finer. If both equations are met, the choking material will keep overlying soil in place.

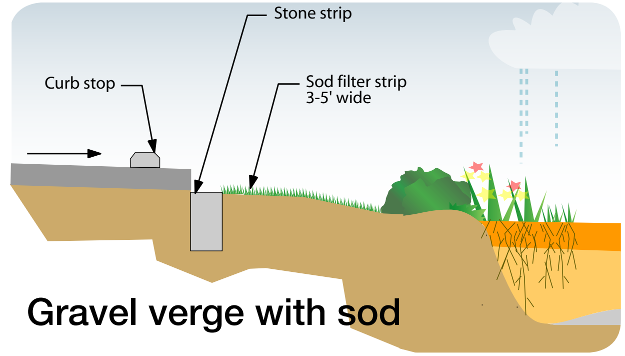
D_{15} open-graded base divided by D_{50} choke stone < 5 *and*

D_{50} open-graded base divided by D_{50} choke stone > 2

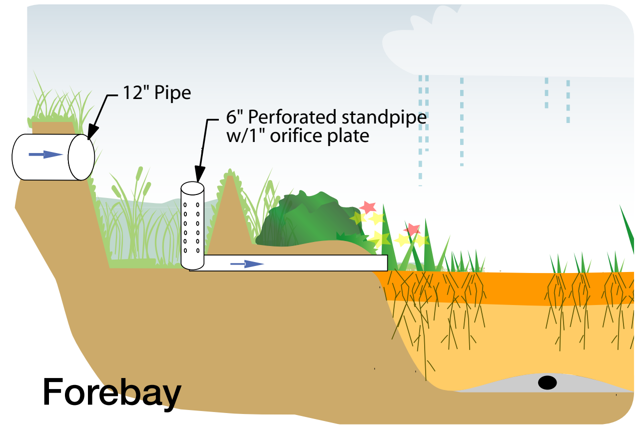
- A basic recipe for fill soil calls for 85% to 88% washed medium sand, 8% to 12% fine soil particles like clay and silt, and 3% to 5% organic matter such as newspaper mulch or peat moss.
- Vary percentages of sand and fine particles in the fill mix to target specific pollutants. For example, using a higher percentage of fine particles reduces the infiltration rate.
- The amount of organic matter does not change for different pollutants. Use 3 to 5 percent regardless.

Pre-treatment to prevent clogging

- **Gravel verge with sod.** You can disperse the flow entering the bioretention cell by placing a level strip of gravel about eight inches wide and a strip of sod (at least three feet wide, up to five fee wide) downhill from the gravel, positioned between the edge of pavement and vegetation. The sod stabilizes the perimeter and prevents internal erosion.
- **Grassy swale.** A broad channel covered by grass slows the flow and provides intermediate filtering before water enters the bioretention cell. Most sediment is trapped in the first 10 to 15 feet of a swale, though the optimum dimensions will depend on size and composition of the drainage site.
- **Forebay.** Forebays can be used in areas where standing water is not a hazard and verges or swales cannot be used. A forebay 18 to 30 inches deep will stop run-off and allow sediment to settle. Forebays can be lined to prevent the water from entering underdrains and bypassing the bioretention filtration.



Gravel verge with sod



Forebay


Grassy swale

Bioretention Maintenance Tasks

Task	Frequency	Maintenance Notes
Pruning	1 to 2 times per year	Nutrients in run-off often cause bioretention vegetation to flourish
Mowing	2 to 12 times per year	Frequency depends on location and desired appearance
Mulching	1 to 2 times per year	
Mulch removal	1 times every 2 to 3 years	Mulch accumulation reduces available water storage volume. Removal of mulch increases surface infiltration rate of fill soil.
Watering	1 times every 2 to 3 days for first 1 to 2 months, then sporadically	Watering after the initial year may be required during droughts.
Fertilization	1 time initially	Need one time for “first year” vegetation
Remove and replace dead plants	1 time per year	10% of the plants may die within the first year. Survival rates increase with time.
Miscellaneous upkeep	12 times per year	Tasks include trash collection, spot weeding, and removing mulch from overflow device.

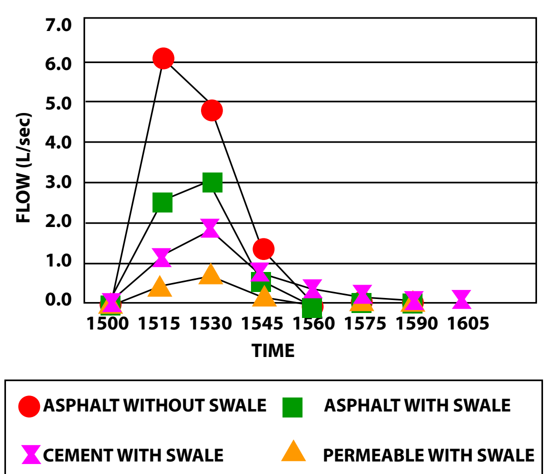
Permeable Pavers

Permeable pavers with permeable interlocking concrete pavers demonstrate up to a 90% reduction in runoff volume in field studies.

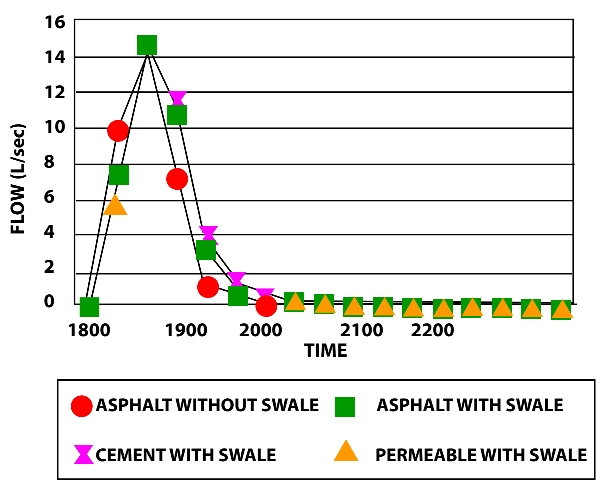
The use of swales reduced runoff volume, but paving type also played a major role in runoff reduction, with permeable pavers being the most effective. Note that the use of swales and permeable pavers has the most influence on runoff during small storms.

For high intensity rainfalls or when soil conditions are saturated, runoff is not reduced as substantially. Note the different scales on the graphs below. The graph on the left measures a rain event that produced just over 0.5 inch of rain in about 75 minutes. The graph on the right shows an event producing almost 2.5 inches in under two hours and occurring less than 24 hours after four days with rain.

COMPARISON OF PAVING TYPES
JULY 31, 1998 RAIN=1.73 CM



COMPARISON OF PAVING TYPES
AUGUST 9, 1998 RAIN=6.27 CM



CASE STUDY

Kinston, North Carolina, installed 8,500 square feet of turfstone and grass paver parking

Cost for two-inch asphalt: **$6,500**

Cost for permeable pavers: **$6,200**

Average costs for installation per square foot*

Asphalt	**50¢ to $1**
Porous concrete	**$2 to $6.50**
Grass / gravel pavers	**$1.50 to $6.75**
Interlocking concrete paving blocks	**$5 to $10**

Total cost comparison

Impervious (Drains, reinforced concrete pipes, catch basins, outfalls and stormwater connects)	**$9.50 to $11.50**
Permeable system	**$4.50 to $6.50**

*Prices compiled 2009 by University of Minnesota from Low Impact Development Center, ToolBase.org, and Seattle Rite of Way Manual

Types Of Permeable Pavement Materials

Porous Asphalt


Porous asphalt

- Easy to use because it uses the same mixes and application equipment as conventional asphalt
- Appropriate for pedestrian and low-volume, low-speed traffic areas such as parking lots and driveways
- Ideal for dense urban areas
- Lower load-bearing capacity than traditional asphalt
- Not appropriate for areas with high pollutant levels in stormwater, because water is not pretreated before infiltration

Porous Concrete



Porous concrete

- Easy to use because it uses the same mixes and application equipment as conventional concrete paving
- Contains larger pea gravel and less water-to-cement for a pebbled open surface
- Contains little or no sand, which leaves spaces for water to pass through
- Appropriate for pedestrian and low-volume, low-speed traffic areas such as parking lots and driveways
- Ideal for dense urban areas
- Lower load-bearing capacity than traditional asphalt

CASE STUDY

Nashville, Tennessee, installed 2 acres of permeable asphalt and 3060 SF of permeable pavers

Cost for permeable asphalt (included some impermeable)	**$200,000/AC**
Cost for permeable pavers	**$19/SF**

Spring Hill, Tennessee, nstalled 7 acres of impermeable asphalt and conventional storm system

Cost for impermeable asphalt	**$98,500/AC**
Cost for storm system	**$113,000/A**

2009, SSOE, Inc.

Types Of Permeable Pavement Materials

Plastic Grid Systems

Plastic grid

- High-strength grids often made from recycled materials
- Can be filled with sand and soil to grow grass, or with gravel
- Appropriate for pedestrian and low-volume, low-speed traffic areas such as parking lots and driveways
- Prevents erosion by acting as a miniature holding pond
- Flexible material to accommodate uneven surfaces
- Not appropriate for receiving large volume of runoff from impervious areas because grids can clog from sediment

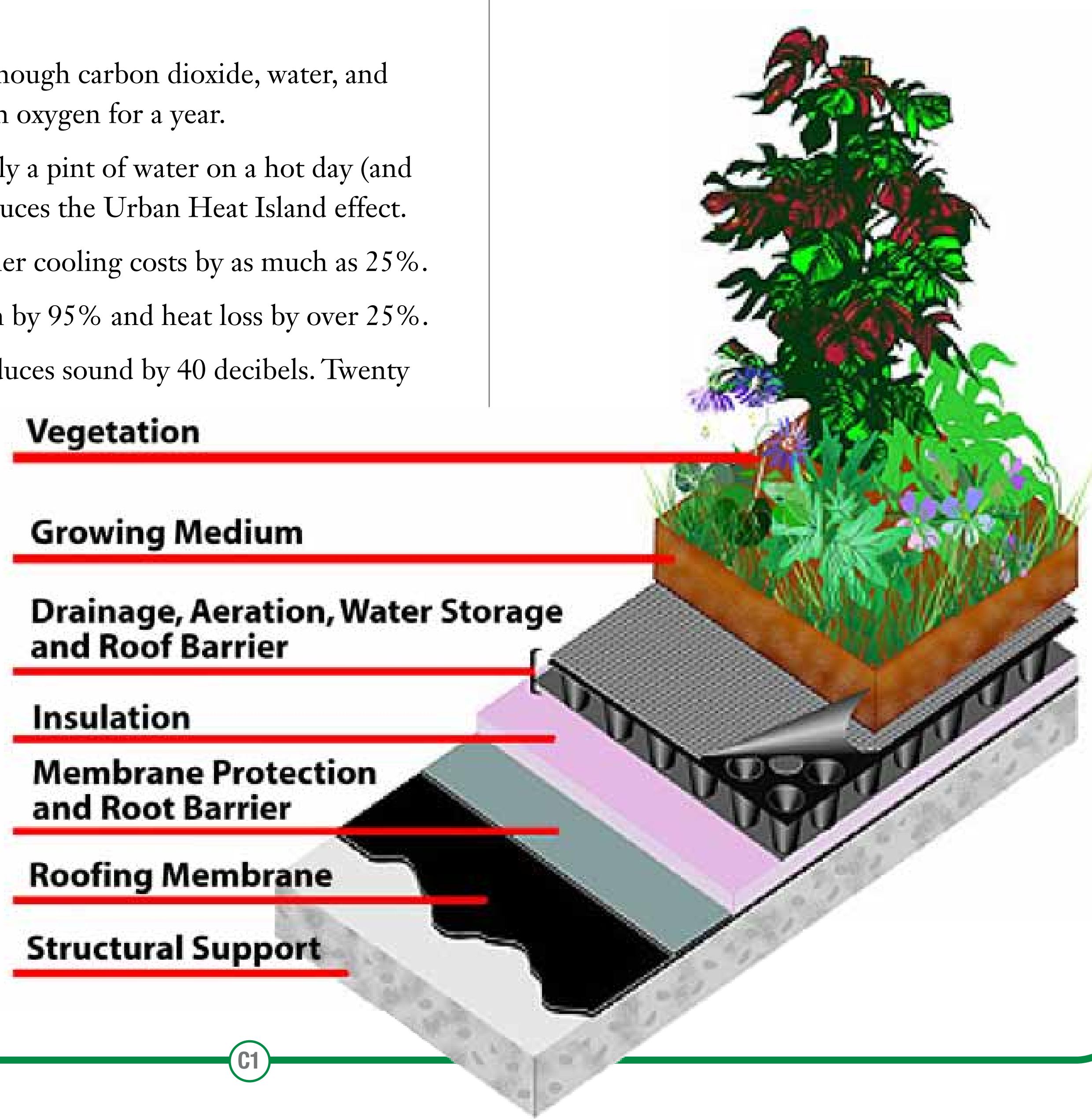
Block Pavers

Block pavers

- Frequently constructed from concrete
- Open space left between interlocking pavers to allow water to infiltrate
- Spaces around pavers filled with gravel, sand, or soil
- Appropriate for pedestrian and low-volume, low-speed traffic areas (parking lots, driveways)
- Not appropriate for areas with heavy road-salting or sanding in winter because grids can clog

Green Roof

- A green roof filters the air moving across it. One square meter (about 10.76 square feet) of rooftop grass can remove more than four pounds of airborne particles per year from the air.
- Sixteen square feet of uncut grass converts enough carbon dioxide, water, and sunlight into oxygen to supply one adult with oxygen for a year.
- A square meter of foliage can evaporate nearly a pint of water on a hot day (and more than 2,600 gallons in a year) which reduces the Urban Heat Island effect.
- Soil less than four inches deep can cut summer cooling costs by as much as 25%.
- Soil at least six inches deep reduces heat gain by 95% and heat loss by over 25%.
- A green roof with five inches of substrate reduces sound by 40 decibels. Twenty inches of substrate increases sound reduction up to 50 decibels.
- On a 77-degree summer day, a gravel roof can reach temperatures of 140 degrees or more. Covering the roof in grass cuts the temperature back to 77 degrees.
- Eight inches of substrate covered by eight to sixteen inches of thick grass insulates as well as six inches of fiberglass.
- A roof with grass two to eight inches thick can absorb two to six inches of rainfall.



Green Roof Pollutants

One of the most consistent runoff water quality influences of a green roof is the ability of a green roof to neutralize acid precipitation. Because acid rain is filtered through the media which is generally buffered to a pH over 7, runoff pH is increased relative to runoff from a non-green roof.

The capacity of a green roof to neutralize acid precipitation is influenced by the parent material of the media. Accelerated aging tests suggest that most of the commercially available media have the potential to neutralize the equivalent of 10 to 20 years of acid rain.

Green roofs also are effective at reducing pollutants in stormwater run-off through naturally occurring physical, chemical, and biological processes. Preliminary studies indicate that many heavy metals and nutrients are trapped by the soil substrates in green roof gardens, preventing them from being released into streams and rivers. For example, one study found that about 95% of lead, copper, and cadmium can be affixed by green roof substrates.

Cost Comparison

21,000 square foot roof

Green roof installation:	$464,000
Traditional roof installation:	$335,000
Savings realized from green roof:	$200,000
Green roof savings from reduced heating and cooling costs:	$133,000+

Other sources of savings: Stormwater management, public health improvement from absorption of nitrogen oxides

Rain Barrels / Cisterns

- Because of the low pressure of the discharge, rain barrels are most effectively used with a drip irrigation system.
- Rain barrels should be childproof and secured against disturbance by people or animals. Any openings should be sealed with mosquito netting.
- If present, a cistern's continuous discharge outlet should be placed so that the tank does not empty completely, ensuring water availability at all times, while also providing at least some storage capacity for every storm.
- A diverter at the cistern inlet can redirect the "first flush" of runoff, which is more likely to contain particulates, leaves, and air-deposited contaminants from the roof.
- Minimize the amount of leaves and debris in the storage tank by placing a screen at the top of the downspout.
- Screen rain barrels and exposed cisterns with shrubs or other landscaped features.
- Direct overflow from rain barrels and cisterns to a dry well, infiltration trench, rain garden, bioretention area, or grassed swale sized to infiltrate the overflow volume. Use pond routing to account for retention of early runoff in the storage tank. Massachusetts Stormwater Policy does not require treatment of most roof runoff prior to infiltration.

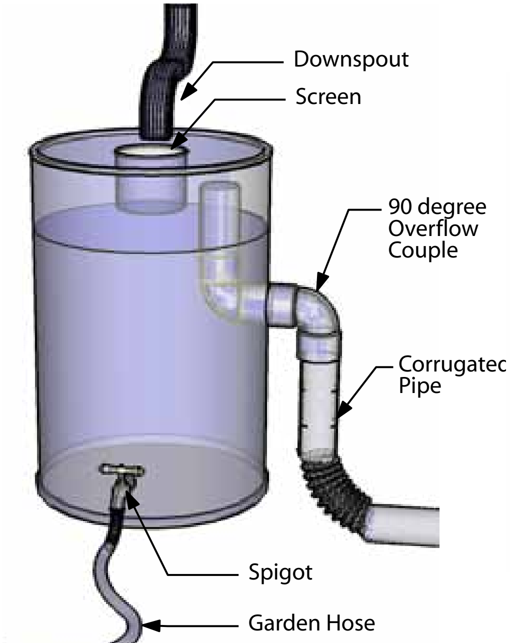
Cost guide for pre-manufactured cisterns

Small System

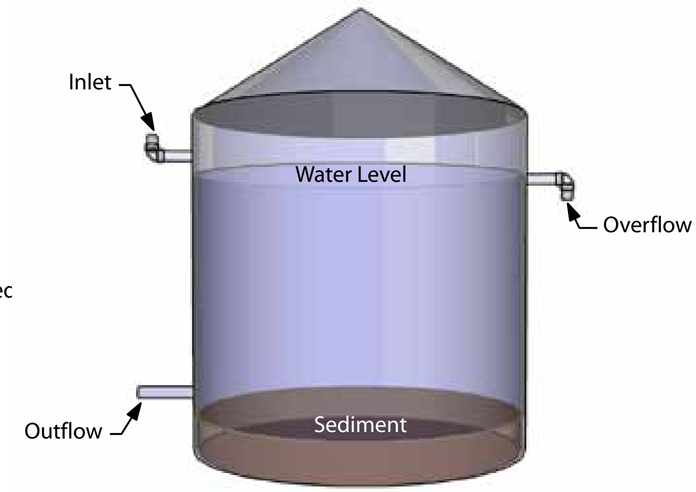
Galvanized steel	$225 for 200 gallons
Polyethylene	$160 for 165 gallons
Fiberglass	$660 for 350 gallons
Fiberglass/ Steel Composite	$300 for 300 gallons

Large System

Galvanized steel	$950 for 2,000 gallons
Polyethylene	$1,100 for 1,800 gallons
Fiberglass	$10,000 for 10,000 gallons
Fiberglass/ Steel Composite	$10,000 for 5,000 gallons



Rain barrel



Cistern

Filter / Buffer Strip

- Minimum treatment area 25 feet (minimal effectiveness) to 150 feet (highly effective)
- Width of filter strip to match width of impervious area
- Width of filter strip along body of water to match width of property
- Maximum of 75 feet impervious surface draining into filter strip
- Maximum of 150 feet pervious surface draining into filter strip
- Recommended slope 2% to 6%
- Top and toe of slope as flat as possible to encourage sheet flow and prevent erosion
- Top of slope two to five inches below adjacent pavement
- Water table and bedrock horizons two to four feet below filter strip surface
- Strip 580 feet wide by 75 feet long handles one acre of impervious surface

Pollutant Reduction in a Vegetated Buffer Strip

Mean EMC Constituent	Influent (mg/L)	Effluent (mg/L)	Removal %	Significance P
TSS	119	31	74	<0.000
NO3-N	0.67	0.58	13	0.367
TKN-N	2.50	2.10	16	0.542
Total Na	3.17	2.68	15	-
Dissolved P	0.15	0.46	-206	0.047
Total P	0.42	0.62	-52	0.035
Total Cu	0.058	0.009	84	<0.000
Total Pb	0.046	0.006	88	<0.000
Total Zn	0.245	0.055	78	<0.000
Dissolved Cu	0.029	0.007	77	0.004
Dissolved Pb	0.004	0.002	66	0.006
Dissolved Zn	0.099	0.035	65	<0.000

Effectiveness at removing targeted substances

Sediments	High
Metals	High
Oil and grease	High
Trash	Medium
Organics	Medium
Nutrients	Low
Bacteria	Low

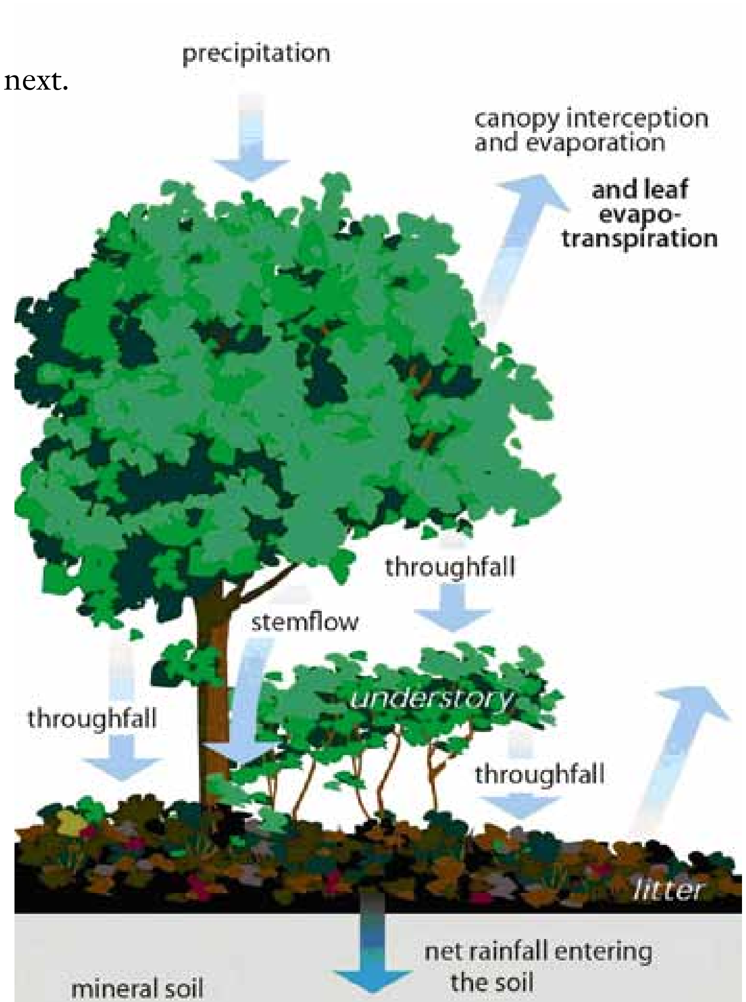
Native Plants

Native trees

Native trees play an important role in restoring landscapes to their natural diversity. This is most effectively accomplished by imitating the layering that occurs in nature:

- Canopy trees on top.
- Understory trees and shrubs next.
- Leaf litter as groundcover.

In urban landscapes, this can be accomplished by arranging trees and shrubs in zones (much like landscaped beds) with the edges defined by mowing. The leaf litter naturally accumulates and should be allowed to remain as a spongy groundcover to intercept rainwater.



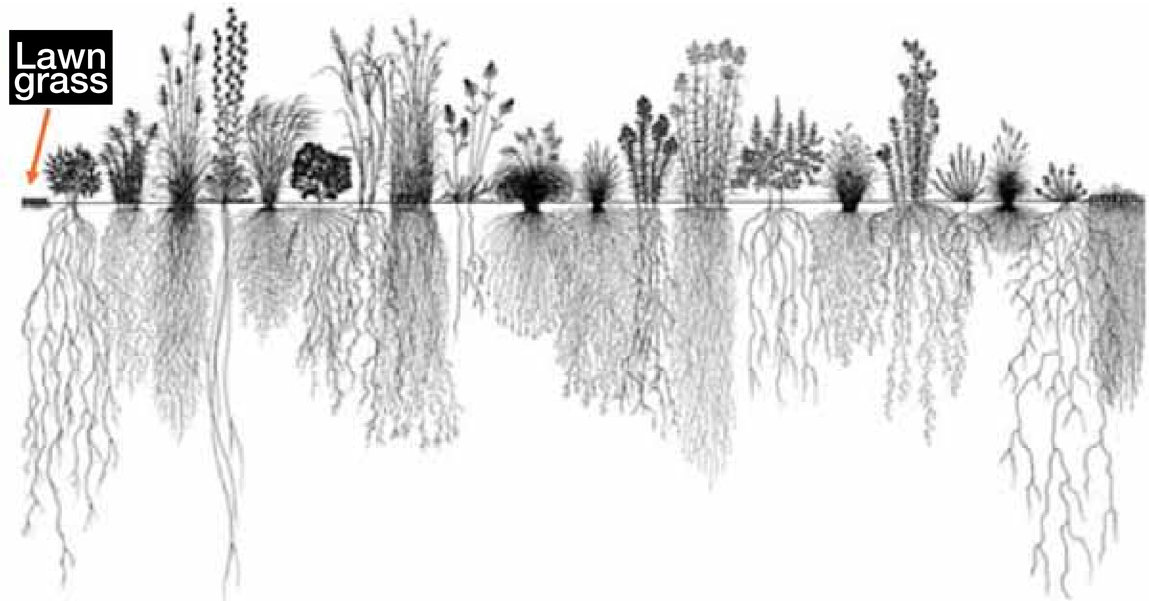
10,000 trees intercept 10 million gallons per year

Middle Tennessee trees recycle 30 to 54 inches per year

A 30-inch dbh sweetgum intercepts more than one-half inch of rain

Native plants

Along with the species selected, the mix and placement of native herbaceous plants affects stormwater management. Specifically, converting areas covered by lawn grasses to spongy cover better replicates the water is handled in nature. This can be achieved by using native understory trees and shrubs under all drip lines, where the accumulation of leaf litter creates a spongy groundcover to intercept rainwater. Limiting the areas devoted to conventional lawn reduces the water consumption required for irrigation and the cost of mowing.



Deep roots create deep water channels

Limited mowing areas

Native Trees for Middle Tennessee

Latin Name	Common Name	Spread	Height	Notes	Flower Color
Acer rubrum	Red maple	25-45'	40-50'		
Acer saccharum	Sugar maple	30-40'	50-75'		
Asimina triloba	Paw paw	15-20'	15-30'	Small tree	
Betula nigra	River birch	40-60'	40-70'		
Carpinus caroliniana	Ironwood	20-30'	20-30'	Small tree	White
Cercus canadensis	Redbud	25-35'	20-30'	Small tree	Purple
Chionanthus virginicus	Fringetree	12-20'	12-20'	Small tree	White
Cladratis lutea	Yellowwood	40-45'	30-45'		
Cornus florida	Flowering dogwood	15-20'	15-30'	Small tree	White
Fraxinus pennsylvanica	Green ash	25-30'	50-60'		
Ilex opaca	American holly	18-35'	30-60'	Evergreen	
Liquidambar styracifula	Sweetgum	50-75'	60-100'		
Magnolia virginiana	Sweetbay magnolia	10-20'	10-60'	Evergreen	White
Oxydendrum arboreum	Sourwood	10-15'	20-30'	Small tree	White
Platanus occidentalis	Sycamore	60-80'	70-100'		
Quercus bicolor	Swamp white oak	50-60'	50-60'		
Quercus shumardii	Shumard oak	40-60'	40-60'		
Rhamnus caroliniana	Carolina buckthorn	12-20'	15-30'	Small tree	
Salix nigra	Black willow	30-40'	40-50'		

Native Shrubs for Middle Tennessee

Latin Name	Common Name	Spread	Height	Notes	Color
Buddleia davidii	Butterfly bush		5’		Blue
Callicarpa americana	American beautyberry		4-6”	Purple fruit	
Cephalanthus occidentalis	Button bush		6-10’		White
Corylus americana	American hazelnut		6-12’		Yellow
Hamamelis virginiana	Witch-hazel		10-15’		Yellow
Hibiscus moscheutos	Swamp mallow		3-8’		White
Hydrangea quercifolia	Oakleaf hydrangea		3-6’		White
Hypericum frondosum	Goldern St. John’s Wort		3’		Yellow
Hypericum prolificum	Shrubby St. John’s Wort		3’		Yellow
Ilex decidua	Possumhaw viburnum		15-30’	Red berries	
Ilex glabra	Inkberry		6-12’	Evergreen	
Itea virginica	Virginia sweetspire		6-8’		White
Viburnum rufidulum	Blackhaw viburnum		18’		White

Anne Norman

Native Grasses and Sedges for Middle Tennessee

Chasmanthium latifolium	Upland Sea Oats			3’
Equisetum hyemale	Horsetail	Invasive		4’
Juncus effusus	Common Rush			4’
Scirpus cyperinus	Woolgrass			6’
Spartina bakeri	Cordgrass			5’

Native Herbaceous Plants for Middle Tennessee

Wet Zone: Full Sun

Latin name	Common name	Note	Color	Height
Asclepias incarnata	Marsh milkweed		Pink	3-4'
Aster novae-angliae	New England aster		Blue	2-5'
Cephalanthus occidentalis	Buttonbush		White	15'
Eupatorium perfoliatum	Boneset		White	3-5'
Eupatorium purpureum	Sweet Joe-Pye weed		Purple	3-6'
Liatris spicata	Dense blazingstar		purple	1.5'
Monarda didyma	Bee balm		red	3'
Penstemon digitalis	Smooth white beardtongue		White	2-3'
Solidago rugosa	Rough-leaved goldenrod		Yellow	1-6'
Veronacastrum virginicum	Culver's root		White	3-6'
Veronia noveboracensis	Tall ironweed		Purple	3-4'

Mesic Zone: Full Sun

Aquilegia canadensis	Wild columbine		Pink	1-2.5'
Asclepias purpurescens	Purple milkweed		Purple	3'
Asclepias verdis	Green milkweed		Green	2'
Asclepias verticillata	Whorled milkweed		White	2.5'
Aster laevis	Smooth aster		Blue	2-4'
Echinacea purpurea	Purple coneflower		Purple	3-4'
Liatris microcephalla	Small-headed blazingstar		Purple	3'
Monarda fistulosa	Wild bergamot		Purple	1-3'
Oenethera fruticosa	Sundrops		Yellow	
Penstemon smallii	Beardtongue		Purple	1-2'
Pycnanthemum tenuifolium	Slender mountain mint		White	1.5-2.5'
Ratibida pinata	Gray-headed coneflower		Yellow	5-Feb

Native Herbaceous Plants for Middle Tennessee

Dry Zone: Full Sun

Latin name	Common name	Note	Color	Height
Asclepias syriaca	Common milkweed		Orange	2-5’
Asclepias tuberosa	Butterfly milkweed		Orange	2
Aster sericeus	Silky aster		Purple	1-2’
Chamaecrista fasciculata	Partridge pea		Yellow	1-2’
Conoclinium coelestinum	Mist flower		Blue	1-2’
Coreopsis lanceolata	Lance-leaf coreopsis		Yellow	6-8’
Echinacea pallida	Pale purple coneflower		Purple	2-3’
Liatris aspera	Rough blazingstar		Purple	2-5’
Liatris squarrulosa	Southern blazingstar		Purple	2-6’
Penstemon hirsutus	Hairy beardtongue		White	1-3’
Rudbeckia hirta	Black-eyed Susan		Yellow	3
Salvia lyrata	Lyre-leaf sage		Purple	1-2’
Solidago nemoralis	Gray goldenrod		Yellow	2’

Native Herbaceous Plants for Middle Tennessee

Shady Zone

Latin name	Common name	Note	Color	Height
Arisaema triphyllum	Jack-in-the-pulpit			1-3’
Arisaema dricontium	Green dragon	Red berries		1-1.5’
Asarum canadense	Wild ginger		Red-brown	.5-1’
Aster cordifolius	Blue wood aster		Blue	1-3’
Aster divaricatus	White wood aster		White	1-3’
Geranium maculatum	Wild geranium		Pink	1-3’
Iris cristata	Dwarf crested iris		Blue-violet	4-16”
Lobelia cardinalis	Cardinal flower	Riparian	Red	1-6’
Lobelia siphilitica	Great blue lobelia	Riparian	Blue	2-3’
Mertensia virginica	Virginia bluebells		Blue	1-2’
Osmunda cinnamomea	Cinnamon fern	Riparian		6’
Phlox divaricata	Blue phlox		Blue	.5-2’
Podophyllum peltatum	May apple		White	1-1.5’
Polemonium repens	Jacob’s Ladder		Blue	1-1.5’
Polystichum acrostichoides	Christmas fern	Evergreen		1-2’
Saururus cernuus	Lizard’s tail	Riparian	White	4’
Solidago caesia	Woodland goldenrod		Yellow	1-3’
Stylophorum diphyllum	Wood poppy		Yellow	12-14”

Native Herbaceous Plants for Middle Tennessee

Edge Zone: Full Sun, Part Shade

Latin name	Common name	Note	Color	Height
Asclepias syriaca	Common milkweed		Orange	2-5'
Asclepias tuberosa	Butterfly milkweed		Orange	2
Aster sericeus	Silky aster		Purple	1-2'
Chamaecrista fasciculata	Partridge pea		Yellow	1-2'
Conoclinium coelestinum	Mist flower		Blue	1-2'
Coreopsis lanceolata	Lance-leaf coreopsis		Yellow	6-8'
Echinacea pallida	Pale purple coneflower		Purple	2-3'
Liatris aspera	Rough blazingstar		Purple	2-5'
Liatris squarrulosa	Southern blazingstar		Purple	2-6'
Penstemon hirsutus	Hairy beardtongue		White	1-3'
Rudbeckia hirta	Black-eyed Susan		Yellow	3
Salvia lyrata	Lyre-leaf sage		Purple	1-2'
Solidago nemoralis	Gray goldenrod		Yellow	2'

Cost Comparisons

One analysis of the costs of conventional controls vs. LID shows that LID controls can be competitive with or cheaper than conventional controls.

Gallons of Stormwater Managed per $1,000 invested

Stormwater Control	Gallons
Conventional Storage Tanks	2,400
Green Street	14,800
Street Trees	13,170
Green Roof	810
Rain Barrel	9,000

A study of 12 projects found from 15% to 80% savings of LID over conventional costs. (Negative numbers denote increased lid costs over conventional.)

Cost Comparisons Between Conventional and LID Approaches

Project	Conventional Cost	LID Cost	Difference	% Difference
Project 1	$868,803	$651,548	$217,255	25%
Project 2	$2,360,385	$1,598,989	$761,396	32%
Project 3	$27,600	$5,600	$22,000	80%
Project 4	$52,800	$12,800	$40,000	76%
Project 5	$4,620,600	$3,942,100	$678,500	15%
Project 6	$324,400	$260,700	$63,700	20%
Project 7	$765,700	$1,502,900	–$737,200	-96%
Project 8	$1,654,021	$1,149,552	$504,469	30%
Project 9	$12,510	$9,099	$3,411	27%
Project 10	$1,004,848	$599,536	$405,312	40%
Project 11	$2,456,843	$1,671,461	$785,382	32%
Project 12	$3,162,160	$2,700,650	$461,510	15%

CASE STUDY

Traditional vs. Sustainable Gardens

The city of Santa Monica, California, installed a traditional garden and a sustainable garden in adjacent residential front yards in 2004. Each garden was approximately 1,900 square feet. The sustainable garden used climate-appropriate California native cultivars, low-volume drip irrigation with a weather-sensitive controller, and a system for capturing stormwater runoff for groundwater recharge. The traditional garden used exotic plants from northern Europe and the eastern United States with a standard, user-controlled sprinkler irrigation system and no provision for runoff mitigation.

CONSTRUCTION COSTS

Traditional garden $12,400 Native garden $16,700

MONITORING FROM 2004-2008

Water use (gallons)

Traditional garden	283,981 gallons
Native garden	64,396 gallons

Difference: 219,585 fewer gallons for native garden

Green waste (pounds)

Traditional garden	647.5 pounds
Native garden	219.0 pounds

Difference: 428.5 fewer pounds from native garden

Maintenance labor (U.S. dollars)

Traditional garden	$223.22
Native garden $	70.44

Difference: $152.78 less required by native garden

LID Savings in Commercial Developments

Cost savings attributed to installing LID stormwater controls in commercial developments

	SAVINGS
Parking Lot Retrofit, Largo, Maryland One-half acre of impervious surface. Stormwater directed to central bioretention island.	$10,500-$15,000
Old Farm Shopping Center, Frederick, MD 9.3-acre site redesigned to reduce impervious surfaces, added bioretention islands, filter strips, and infiltration trenches.	$36,230 or $3,986 per acre
270 Corporate Office Park, Germantown, Maryland 12.8-acre site redesigned to eliminate pipe and pond stormwater system, reduce impervious surface, added bioretention islands, swales, and grid pavers.	$27,900 or $2,180 per acre
OMSI Parking Lot, Portland, Oregon 6-acre parking lot incorporated bioswales into the design, and reduced piping and catch basin infrastructure.	$78,000 or $13,000 per acre
Light Industrial Parking Lot, Portland, Oregon 2-acre site incorporated bioswales into the design, and reduced piping and catch basin infrastructure.	$11,247 or $5,623 per acre
Point West Shopping Center in Lexana, Kansas Reduced curb and gutter, reduced storm sewer and inlets, reduced grading, and reduced land cost used porous pavers, added bioretention cells, and native plantings.	$168,898

LID Savings in Commercial Developments	SAVINGS
Office Warehouse, Lexana, Kansas Reduced impervious surfaces, reduced storm sewer and catch basins, reduced land cost, added bioswales and native plantings.	$317,483
Retail Shopping Center 9-acre shopping development reduced parking lot area, added porous pavers, clustered retail spaces, added infiltration trench, bioretention and a sand filter, reduced curb and gutter and stormwater system, and eliminated infiltration basin.	$36,182 or $4,020 per acre
Commercial Office Park 13-acre development reduced impervious surfaces, reduced stormwater ponds and added bioretention and swales.	$160,468 or $12,344 per acre
Tellabs Corporate Campus, Naperville, Illinois 55-acre site developed into office space minimized site grading and preserved natural topography, eliminated storm sewer pipe and added bioswales.	$564,473 or $10,263 per acre
Vancouver Island Technology Park Redevelopment, Saanich, British Columbia Constructed wetlands, grassy swales and open channels, rather than piping to control stormwater. Also used amended soils, native plantings, shallow stormwater ponds within forested areas, and permeable surfaces on parking lots.	$530,000

LID Savings in Residential Developments

Cost savings attributed to installing LID stormwater controls in residential developments.

	SAVINGS
Meadow on the Hylebos Residential Subdivision, Pierce County, Washington 9-acre development reduced street width, added swale drainage system, rain gardens, and a sloped bio-terrace to slowly release stormwater to a creek. Stormwater pond reduced by two-thirds, compared to conventional plan.	LID cost 9% less than conventional
Somerset Community Residential Subdivision, Prince George 80-acre development included rain gardens on each lot and a swale drainage system. Eliminated a stormwater pond and gained six extra lots.	$916,382 or $4,604 per lot
Pembroke Woods Residential Subdivision, Frederick County, Maryland 43-acre, 70-lot development reduced street width, eliminated sidewalks, curb and gutter, and 2 stormwater ponds, and added swale drainage system, natural buffers, and filter strips.	$420,000 or $6,000 per lot
Madera Community Residential Subdivision, Gainesville, Florida 44-acre, 80-lot development used natural drainage depressions in forested areas for infiltration instead of new stormwater ponds.	$40,000 or $500 per lot
Prairie Crossing Residential Subdivision, Grayslake, Illinois 667-acre, 362-lot development clustered houses reducing infrastructure needs, and eliminated the need for a conventional stormwater system by building a natural drainage system using swales, constructed wetlands, and a central lake.	$1,375,000 to $2,700,000 or $3,798 to $7,458 per lot

LID Savings in Residential Developments

Project	SAVINGS
Residential street retrofit, Seattle, Washington 1-block retrofit narrowed street width, installed swales and rain gardens.	$40,000
Gap Creek Residential Subdivision, Sherwood, Arkansas 130-acre, 72-lot development reduced street width, and preserved natural topography and drainage networks.	$200,021 or $4,819 per lot
Poplar Street Apartments, Aberdeen, North Carolina 270-unit apartment complex eliminated curb and gutter stormwater system, replacing it with bioretention areas and swales.	$175,000
Kensington Estates Residential Subdivision, Pierce County, Washington 24-acre, 103-lot hypothetical development reduced street width, used porous pavement, vegetated depressions on each lot, reduced stormwater pond size.	$86,800 or $843 per lot
Garden Valley Residential Subdivision, Pierce County, Washington 10-acre, 34-lot hypothetical development reduced street width, used porous paving techniques, added swales between lots, and a central infiltration depression.	$60,000 or $1,765 per lot
Circle C Ranch Residential Subdivision, Austin, Texas Development employed filter strips and bioretention strips to slow and filter runoff before it reached a natural stream.	$185,000 or $1,250 per lot

Helpful Links and Sources

Best Management Practices

Pennsylvania Best Management Practices	http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/Section06-StructuralBMPs-part1.pdf
EPA Best Management Practices	http://cfpub.epa.gov/npdes/home.cfm?program_id=298
Stormwater Management Plan	http://www.mpcnaturalresources.org/PDF/StormWater-PDF2009/0109%20Stormwater%20Mangement%20Plan%20020109.ppt

Cost

LID Cost Comparison Calculator	http://greenvalues.cnt.org/calculator
Costs factors	http://www.epa.gov/owow/nps/lid/costs07/

Components

Bioretention	http://www.lowimpactdevelopment.org/epa03/biospec.htm
	http://www.lowimpactdevelopment.org/epa03/biospec_print.htm
	http://www.lid-stormwater.net/bio_costs.htm
	http://www.co.monroe.in.us/stormwaterquality/bioretention.html
	http://www.bae.ncsu.edu/stormwater/PublicationFiles/Bioretention2006.pdf
	http://www.raingardens.org
Cisterns, Rain Barrels	http://www.rpi.edu/~kilduff/Stormwater/cisterns1.pdf
	http://www.getrichslowly.org/blog/2007/05/19/do-rain-barrels-save-money/
	http://www.greenertennessee.org
Filter strips	http://www.duluthstreams.org/stormwater/toolkit/filterstrips.html
Green roof	http://www.greenroofs.org/index.php?option=com_content&task=view&id=26&Itemid=40
	http://www.epa.gov/heatisland/mitigation/greenroofs.htm
	http://web.me.com/rdberghage/Centerforgreenroof/pH.html
	http://www.lid-stormwater.net/greenroofs_benefits.htm
Natural landscaping	http://www.epa.gov/greenacres/toolkit/chap5.html
	http://www.co.monroe.in.us/stormwaterquality/natural_landscaping.htm
Permeable paving	http://www.lowimpactdevelopment.org/qapp/permpaver_costs.htm
	http://www.uri.edu/ce/wq/NEMO/Publications/PDFs/PP.WhatsItDoingOnMySt.pdf
	http://www.arboretum.umn.edu/porouspaving.aspx

Human Impact

Human impact	http://www.princeton.edu/~chm333/2002/spring/Biochemical/hydro_cycle/human_impact.html
	http://www.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

Other Cities

Portland Green Streets project	http://www.portlandonline.com/BES/index.cfm?c=44407
Portland design examples	http://www.artfulrainwaterdesign.net/projects/
Portland examples, Parks and Recreation	http://www.artfulrainwaterdesign.net/projects/show/38/
	http://www.artfulrainwaterdesign.net/projects/show/24/
	http://www.artfulrainwaterdesign.net/projects/show/45/
Portland examples, Greenways	http://www.artfulrainwaterdesign.net/projects/show/33/
	http://www.artfulrainwaterdesign.net/projects/show/27/
Seattle natural drainage	http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Natural_Drainage_Overview/index.asp
	http://www2.seattle.gov/util/tours/Broadview/slide1.htm
	http://www2.cityofseattle.net/util/tours/seastreet/slide1.htm
Monroe, Indiana, stormwater quality	http://www.co.monroe.in.us/stormwaterquality/

Reviews

Nashville summary of resource links	http://www.nashville.gov/stormwater/LIDResources.htm
Summary of literature	http://www.econw.com/reports/ECONorthwest_Low-Impact-Development-Economics-Literature-Review.pdf

Technical Guidelines

Technical guidelines	http://your.kingcounty.gov/solidwaste/greenbuilding/documents/Low_Impact_Development-manual.pdf
	http://www.cpd.wsu.edu/SSI_Guidelines_Draft_2008.pdf

Local Projects

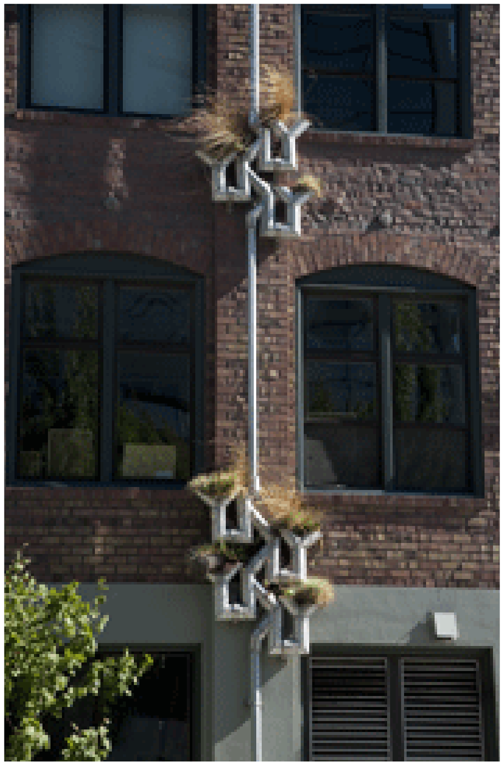
LID parking lots	Richard H. Fulton Complex 2nd Avenue and Lindsley, Nashville, Tennessee
Green roof	Westview Condominiums 179 8th Avenue South, Nashville, Tennessee
Natural drainage parking lots	Vanderbilt Health 100 Oaks 719 Thompson Lane, Nashville, Tennessee
Bioretention basin	O'Charley's Inc. 3038 Sidco Drive, Nashville, Tennessee
Rain gardens	Ellington Agricultural Campus Crieve Hall neighborhood, Nashville, Tennessee
Low Impact Development	The Gulch Redevelopment 401-501 12th Avenue South, Nashville, Tennessee
Meadow restoration	Henry Horton State Park I-65, exit 46, near Columbia, Tennessee

Richard H. Fulton Complex

A group of artists created an innovative project in Seattle, Washington, to change perceptions about run-off using art.

The Growing Vine Street Project redirected the “urban watershed” to keep run-off as an above-ground asset rather than a liability flushed out of sight.

Their design nurtured the streetscape with run-off from roofs and permeable surfaces through an interconnected system of green roofs, cisterns, detention planters, and street watercourses.



10th@Hoyt, Portland, Oregon

Mt. Pleasant, South Carolina

110 Cascades, Seattle, Washington