Missouri Guide to GREEN INFRASTRUCTURE

Integrating Water Quality into Municipal Stormwater Management

MISSOURI DEPARTMENT OF NATURAL RESOURCES

PUB2446, May 2012

Cover Photo: Lewis and Clark State Office Building. Platinum LEED Certified. www.dnr.mo.gov/greenbldg/
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FORWARD

By: Matt Belcher, CGP

Confluences, as used in this guide, are a coming together of waters. Just north of St. Louis is one of North America's most important confluences: Where the Missouri River joins the Mississippi.

This spot, where two of the world's most powerful rivers come together, not only is a significant center of natural resources but for more than a thousand years, has been a crossroads for economic activity. The people that settled this area in mass numbers beginning about 600 AD considered this the center of the world, where resources were traded and for the time economically, literally was the hub of the yet to be discovered America and the rest of the North American continent. This is also where the well known "Corps of Discovery" launched their four year trek on one of the most scientifically significant efforts the world has known. Captains Lewis and Clark realized the abundance of natural resources at this confluence and the benefit to their corps and set camp here to ride out the winter and spring of 1804 instead of just downstream in St. Louis.

This guide is also meant to create a confluence. It was put together by the many stakeholders that it will benefit, and impact. It is created to be a guiding document for municipalities to educate them about stormwater issues and some practical ways to manage them. It is also a guide that can be used by industry to illustrate means to achieve better stormwater management and provide options to mitigate potential problems in a cost effective manner. In the same manner that the information for this guide was collected and assembled, the same outreach and interaction process needs to be used in its implementation to maintain the natural resources that stormwater can impact while sharing pragmatic experience to maintain the economic viability of the local municipality, county or state.

Having worked both in the field of code enforcement and in industry, experience has proven that the communications between all stakeholders is key and better, more cost effective projects are the result.

One important part of that process is recognizing the fact the advancements in technologies often outpace the ability of codes to accommodate them. Therefore it is imperative that codes, laws and other mandates, while important to maintain minimum standards and level the playing field in the industry, need to remain flexible enough to accommodate innovative practices and advancements in technology. Municipalities can take advantage of the wealth of knowledge and experience from those in the industry to improve local conditions and the knowledge of their own municipal personnel while providing guidance to those working to improve local infrastructure and development.

Matt Belcher is an experienced and nationally recognized consultant on the subject of High Performance building and development. He has been actively involved in the St. Louis area construction industry for nearly three decades, including six years as a top building codes official. In 2008, Mr. Belcher was invited to testify to the U.S. House Energy and Air Quality Subcommittee on Climate Benefits of Improved Building Energy Efficiency.

PREFACE

Disclaimer and Purpose

This guide is not a technical design manual; instead, it describes the processes and tools a community can use to develop sustainable site designs and development plans, land use plans, stormwater management programs, land use ordinances and technical design manuals to help meet social, environmental and financial goals. This guide is designed to be flexible so it may be used for a wide range of runoff conditions, soils, quality of receiving waters, development practices and community values. It is also designed to address concerns with both small and large communities.

The contents of this guide should not be interpreted as representing federal, state or local regulation.

The contents also do not necessarily represent regulations, policies or recommendations of other referenced agencies or organizations. Refer to state, federal and local regulations and permits for applicable stormwater management requirements and criteria. Permission has been granted for all copyrighted photos and sketches as applicable.

Green infrastructure should be the base of any program, but it is important to note that green infrastructure alone and without adequate application will not satisfy community goals for resource protection. However, a very effective integrative stormwater management program for all types of development will minimize the amount of pollutant discharges to your waterways and significantly reduce the rate of degradation. Green infrastructure can also help to reduce loads and discharges in retrofit situations, although prevention versus retrofitting is less costly.

This is not a complete list of urban-applicable practices. For more complete information, visit the Department's stormwater clearinghouse at www.dnr.mo.gov/env/wpp/stormwater or contact your nearest Missouri Department of Natural Resources' Regional Office at www.dnr.mo.gov/regions/regions.htm.

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EXECUTIVE SUMMARY

The purpose of this document is to provide guidance to municipalities and their development community. In particular, this guide will assist communities, developers and contractors in complying with state and federal stormwater regulations while building vibrant communities. Guidance is offered on tools, processes and other resources that best meet the community's specific social, environmental and economic needs. It also aids compliance with the Municipal Separate Storm Sewer System (MS4) permit requirements for permanent runoff management – requirements that have changed significantly over the past several years as a way to meet the country's renewed water quality goals.

This guide addresses economic costs and benefits to developers and municipalities, as well as environmental benefits. Much state-of-the-practice management has been reviewed, excellent ideas have been incorporated and numerous technical manuals have been referenced. Missouri and other midwest management examples are included to demonstrate regional effectiveness of state-of-the-practice projects. While this guide focuses on permanent stormwater management through better planning and up front site design, it is also intended to be a companion guide to the *2011 Protecting Water Quality Field Guide: a field guide to erosion, sediment and stormwater best management practices for development sites in Missouri and Kansas.* That guide is available online at www.dnr.mo.gov/env/wpp/wpcp-guide.htm.

This guide is designed to be useful across Missouri where there is a wide range of runoff conditions, soils, quality of receiving water, development practices and community values. This guide addresses small and large communities, built-out and high growth communities, in different geological areas of Missouri and their opportunities to capitalize on the green infrastructure opportunities to infiltrate, evapotranspire or reuse stormwater runoff at the site.

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1 Introduction to Green Infrastructure

Development and urbanization change the landscape from forests, to farms, to towns and cities. This development increases impervious surface by adding pavement and rooftops, while decreasing vegetated cover. Land disturbance from development also mobilizes sediment and releases nutrients to lakes, streams and wetlands - fundamentally changing aquatic habitats and their potential uses.

This change in the landscape decreases groundwater recharge and increases the pollutant load, frequency and volume of surface stormwater runoff.

A major focus of this guide is to define green infrastructure as a sustainable approach to stormwater management by employing strategies to maintain or restore natural hydrology. Such strategies include infiltration, evapotranspiration, capture and reuse of stormwater.

This guide is not intended to be a design manual. The purpose of this guide is to present green infrastructure as a strategic approach to land development that addresses ecological, economical and social needs, also known as the triple bottom line. It is intended to aid municipalities and their development communities in a general understanding of how to incorporate green infrastructure into the community.

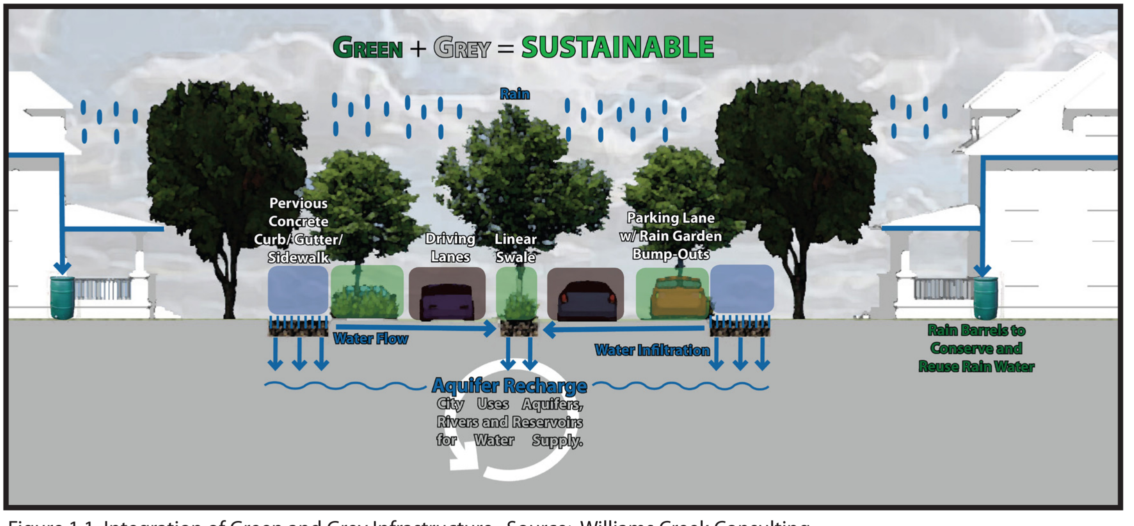


Figure 1.1 Integration of Green and Grey Infrastructure. Source: Williams Creek Consulting

"Most homebuyers today favor housing developments that include green space, biking and pedestrian paths, and natural areas. " (McMahon, 2000).

This guide may also motivate a community to develop an integrative green infrastructure plan as a "greenprint" for conservation in the same way gray infrastructure plans are prepared for roads, sewers and utilities. A plan that integrates green and gray infrastructure can create a framework for future growth while preserving significant natural resources for future generations. It can also complement goals to reduce combined sewer overflows.

Green infrastructure plans and sustainable site development plans can help reduce opposition to new development by assuring civic groups and environmental organizations that growth will occur only within a framework of expanded conservation and open space lands. Communities and their partners can make green infrastructure an integral part of local, regional and state plans and policies (Benedict and McMahon, 2002).

Figure 1.2 shows some examples of on-site green infrastructure practices.

There are issues that need to be considered when locating and siting any stormwater management feature, and green infrastructure is no exception. Not all practices are appropriate or effective in a given situation. For example, porous pavement should not be used in highly contaminated areas unless engineered to avoid risks to groundwater. In another example, rain barrels can significantly contribute to volume reduction only if they are used in conjunction with other practices such as rain gardens that more effectively disconnect rooftop runoff from primary conveyance. (Rain barrels that are directly connected to the conveyance system are not very effective in addressing runoff volume reduction due to their limited storage capacity.)

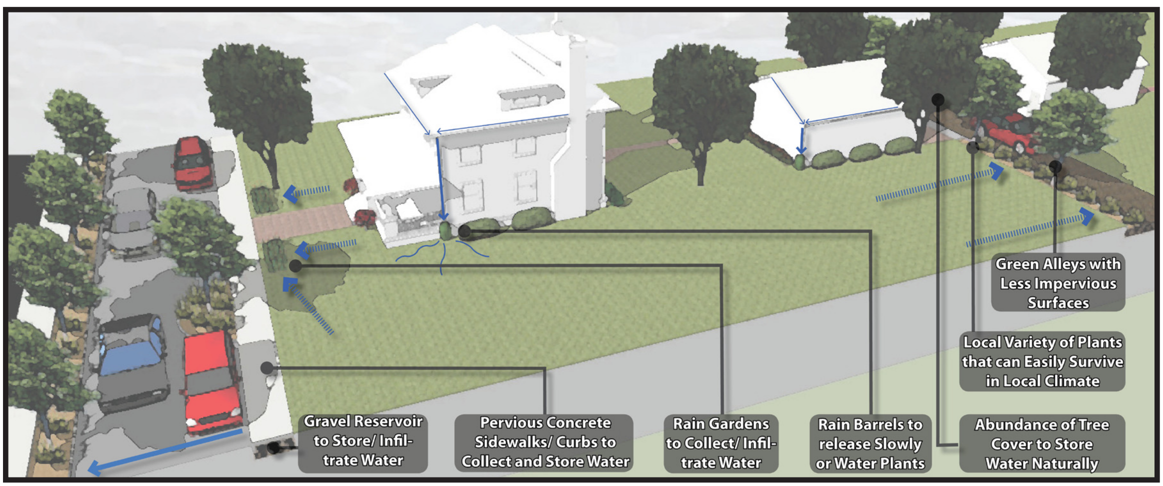


Figure 1.2 Examples of on-site green infrastructure practices. Source: Williams Creek Consulting.

Consideration also needs to be given to maintenance costs, retrofitting costs, groundwater contamination potential, poor performance of improperly designed systems, etc. Many of these precautions are discussed later in the document, and they are discussed in more detail in the numerous design manuals of reference.

Meeting the goal of today's water quality goals in stormwater runoff requires a change in runoff management strategies. This guide contains references to many of the resources available describing the methods that can be used to help maintain or restore pre-construction runoff conditions.

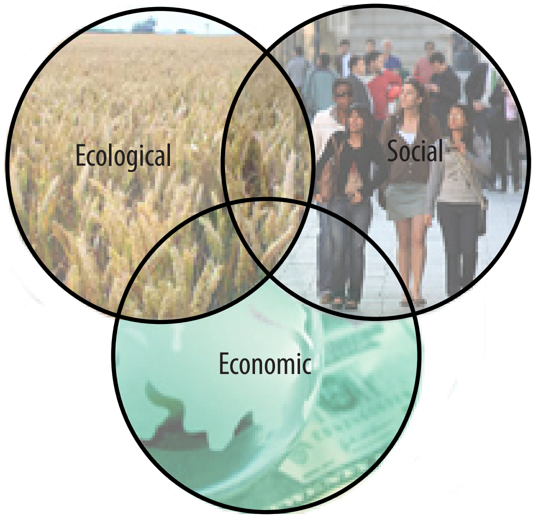


Figure 1.3 Triple Bottom Line. Source: Williams Creek Consulting

1.1 Concepts, Terminology and Trends

Historical Trends

Early on, communities focused stormwater management on flood control. Many communities are now required to implement stormwater management programs to address stormwater runoff pollution. Stormwater regulations require pollution prevention to the maximum extent practicable in new and redevelopment projects. On new development projects, state-of-the-practice stormwater management is now designed to mimic pre-construction runoff conditions as a way to better control pollutant runoff. The approach is to maximize infiltration, evapotranspiration, (a combination of water evaporation and plant transpiration) and reuse.

Because stormwater management has historically focused on flood control, many structural control measures familiar to the stormwater management community were not designed to meet water quality goals. Some of the best and most familiar stormwater control measures for flood control (pipe and pond systems, for example) provide limited water quality benefit relative to retention-based structural stormwater control measures and non-structural stormwater control measures that decrease the potential volume of runoff. Wet ponds do not necessarily retain clay particles, but they do retain some fine-grained particles and can offer robust performance when properly designed and used in conjunction with upland infiltration practices. Such combinations can result in some of the most robust and best performing systems available.

Historical trends in stormwater management have not been successful enough in meeting the goals of the Clean Water Act. The conventional approach to stormwater management has been to move stormwater off-site quickly through curb, gutter and basin systems, or more recently, within the past 20-30 years, to build large dry detention facilities to manage large but infrequent storm events. But, these conventional methods do not control the increase in runoff volume due to development.

Given abundant development and the resulting increases in volume and velocity of stormwater runoff, the consequences have been degraded streams, increased flash flooding and costly repairs at an accelerated rate. The more current concepts presented in this guide are based on more than 40 years of collective effort performed to help meet the goals of the Clean Water Act and other environmental goals, as well as social and economic interests. While green infrastructure alone is not likely to meet all the water quality goals, it should be the base of any program that works effectively to minimize pollutant loading to local and interconnected waterways. Certainly other factors such as those described throughout this guide need to be addressed, but green infrastructure offers a huge improvement over conventional stormwater management practices that have relied primarily on grey infrastructure alone. The integration of green and grey infrastructure requires a different approach in designing grey infrastructure; slowing runoff down in places, rather than moving it off site as fast as possible.

Terminology

The terms sustainability, green infrastructure, low impact development, conservation development, sustainable development and others are often used interchangeably in the stormwater industry. For the purpose of this publication, many terms are self-evident or are described as they appear in context. However, a brief explanation in the origin and evolution of these terms may be helpful.

Sustainability

Sustainable practices define effectiveness in terms of financial, social and environmental benefits or a "triple bottom line." This approach bases project decisions on an analysis of the cost and benefits where there is a balance between the effects on the environment, a project's financial commitments and the community where the project is located.

In addition to improved water quality, triple bottom line benefits may include neighborhood revitalization, expanded recreational opportunities, business attraction and retention, unique and aesthetically pleasing landscapes, lower cost development and increased property values.

Green Infrastructure

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems designed to mimic nature by soaking up and storing water.

The green infrastructure approach to urban stormwater management is the employment of sustainable site designs that apply smaller scale systems - dispersed more widely, located closer to the sources of runoff (buildings, parking lots, etc.), and integrated with other infrastructure systems and green networks. However, the concept of green infrastructure for stormwater management originates from a broader applicability. As defined by Mark Benedict and Ed McMahon, green infrastructure is an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife (Benedict & McMahon, 2006).

EPA defines green infrastructure as "systems and practices that use or mimic natural processes to infiltrate, evapotranspire (the return of water to the atmosphere either through evaporation or by plants), or reuse of runoff on the site where it is generated."

Large blocks of contiguous natural vegetative cover provide organic matter and nutrients to aquatic ecosystems (e.g., headwaters). Riparian vegetative zones also provide nutrients and organic material to streams. Vegetative cover maintains natural hydrology and functions as a buffer, filtering pollutants. Vegetative hubs and corridors connect terrestrial animals to sources of water and food, maintaining the food web. The extent, composition, and pattern of green infrastructure are critical components in a landscape condition assessment.

As we build needed infrastructure, like roads, sewers and water lines, every community should strive to maintain or enhance the natural resources it may displace as part of this process. Prior to disturbance, the incorporation and enhancement of these systems provide a form of natural green infrastructure that help to minimize the cost by providing natural ways to manage the rate, volume and quality of stormwater runoff. Man-made green infrastructure restores or enhances these natural systems into the built urban environment to provide similar functions and values.

Low Impact Development

About the same time green infrastructure was introduced around 1994 to reflect upon the larger green network systems in Florida, Larry Coffman was developing an on-site approach to low impact development in Prince George's County, Maryland. With limited capacity for county planning and zoning, low impact development was applied as "rain garden" requirements for back yards. However, green infrastructure has grown to encompass small scale applications and low impact development has grown to include the broader community planning level. The terms are often used interchangeably, however low impact development, conservation development and similar practices fit well under the

Impacts from Changes in the Landscape with Development and Impervious Cover		
Changes in the Landscape	**Results**	**Impacts**
Increased impervious cover, hard surfaces.	Increased stormwater runoff; increased pollutants in runoff	Degraded water quality. Eroded streambanks/degraded streams.
Removal of riparian corridor.	Increased pollutants in streams.	Eroded streambanks/degraded streams. Impaired water quality, loss of habitat.
Building in floodplain	Loss of natural flood conveyance capacity. Increased runoff	Higher flooding potential. Increased stormwater quantity downstream, potential damage to downstream communities or property.
Exposed land surface	Increased runoff. Increased soil erosion.	Degraded water quality from sediment. Eroded streambanks/degraded streams from higher runoff quantity and sediment load.

Table 1.1 Degraded water quality from sediment. Source: Williams Creek Consulting.

umbrella of green infrastructure. These concepts all serve to support minimizing the increase in run off volume and velocity by emphasizing the use of non-structural stormwater control measures and on-site controls.

Distinguishing Between Construction and Post-Construction

For the purpose of this guide, best management practices are methods directed primarily at construction phase erosion control and runoff management. Stormwater control measures, post-construction best management practices, are methods directed primarily at permanent post-construction phase runoff management. Best management practices and stormwater control measures are required for new and redevelopment, however retrofitting existing development is briefly discussed in Chapter 5.

Missouri state stormwater regulations require both construction best management practices and post-construction stormwater control measures in projects that disturb an acre or more. Construction best management practices are those designed and installed specifically to minimize the impacts of sediment carried in runoff from active construction sites. Examples include inlet protection, sediment fences and temporary seeding.

Post-construction stormwater control measures are permanent and designed to capture and treat runoff on a long-term basis following completion of construction. A conventional example of this is a detention basin. However, today's examples may include rain gardens, bioretention cells and vegetated swales designed into the conceptual plan.

Figure 1.4 Porous asphalt alley, St. Louis, MO. Source: Metropolitan St. Louis Sewer District

Even though construction best management practices and post-construction stormwater control measures have distinct purposes, this does not preclude the use of a single practice for both purposes. For instance, a sediment basin used to capture sediment-laden runoff during construction can be converted to a detention pond to capture, partially treat and gradually release runoff. Careful planning, design, operation and maintenance and inspection are needed to ensure the basin is effective both during construction and in the long-term.

1.2 A Vision for Urban Sustainability

The green infrastructure approach to urban sustainability calls for replacing the choice of large-scale curb, gutter or basin systems with smaller scale urban systems, distributed more widely, located closer to the sources of runoff, integrated with elements of buildings, and integrated with other infrastructure systems. The placement of these systems will connect well with the broader green infrastructure of our highly valued natural resources and trails within.

Every new residential, commercial and industrial development can be seen as an opportunity to integrate sustainable stormwater management with green building, self-reliant energy management and waste control, service orientation (rather than building orientation) and multi-purpose, mixed-use development for community benefit.

These opportunities require creativity, attention to regulatory goals and incorporation of new funding and management mechanisms. However, the benefits of transition will ultimately add value to the environmental, social and economic interests of the community.

Figure 1.5 Rain garden in roundabout designed to capture/infiltrate stormwater, Milwaukee, WI. Source: Bob Newport, EPA Region 5

1.3 Principles of Green Infrastructure and Its Tools

Applied principles of green infrastructure stormwater management can improve water quality and reduce the volume and velocity of stormwater runoff, by reducing the overall generation of runoff through increased green space and on-site low-impact stormwater practices. According to the Low Impact Development Center, "If the full suite of low impact development controls and site design practices are creatively used, low impact development is capable of automatically controlling the 10 and 100-year storms through its primary strategy of restoring the built area's natural rainfall-runoff relationship."

Unlike conventional stage-discharge management of large storms in centralized basins, non-structural stormwater control measures can control up to 90 percent of all storms through minimizing or eliminating runoff to the collection system through a strategy of green infrastructure and low impact development techniques. Certainly this is true for individual controls, lots and even highly controlled larger areas. Monitoring efforts are just now beginning to measure benefits of green infrastructure on large scale projects of 100 acres or more, so data is still forthcoming.

These principles and corresponding practices can be applied to new development, redevelopment and retrofit scenarios.

A. Streams, undisturbed green spaces, wetlands and riparian areas are all efficient low-cost natural stormwater management features. They are the existing stormwater management system and should be preserved and utilized where practical. Replacing the free services provided by these natural systems with man-made systems requires significant capital

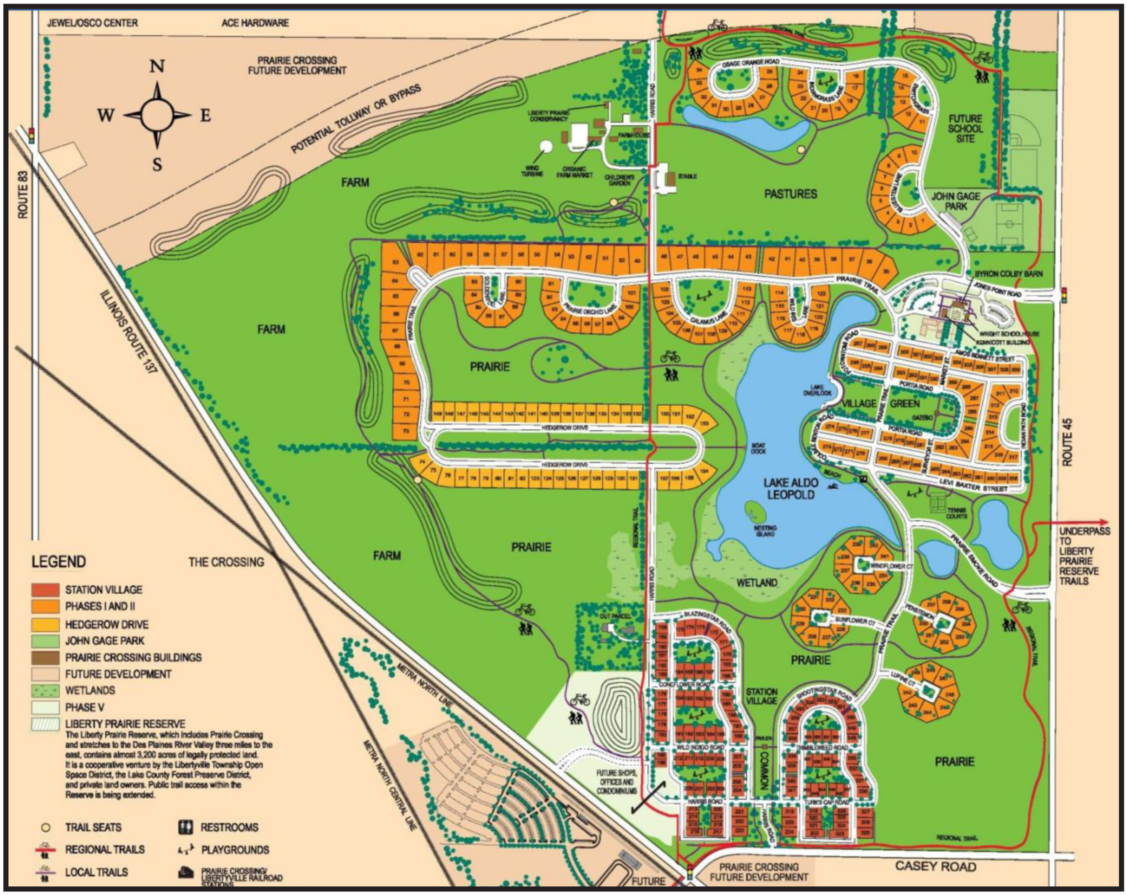


Figure 1.6 Prairie Crossing Development Site Plan. Source: Victoria Ranney, Co-Developer

Figure 1.7 Fields Neighborhood rain garden
Source: Peter Scherrer, ManShire Villages Development

investment and time, creates the need for ongoing operation and maintenance of these systems, and reduces the value of natural resources.

B. Capture rain where it falls. Prior to development, the rainfall-runoff process may be slow because precipitation falls on multiple vegetation layers and native soils whose horizons and structures have not been disturbed. Intact soil structures can allow a large portion of the precipitation to infiltrate, even in heavy clay soils. Runoff also tends to follow relatively long pathways across vegetated areas prior to entering streams.

Conventional stormwater practices tend to convey runoff away from where it falls and deliver it to centralized management areas such as ponds. The conventional pipe and pond style of runoff management concentrates runoff, increasing flow rates and reducing runoff travel times. It often consumes large areas of land otherwise available for buildings or parking, requires great amounts of earthwork to provide adequate slope for drainage and employs long runs of buried stormwater pipes.

Managing rain in close proximity to where it hits the ground can reduce the need for pipes, ponds, and earthwork, and can provide a more efficient means for infiltration and treatment of runoff. This system can be described as distributed storage.

In practice, the distributed storage areas may include rain gardens, bioretention, pervious pavement and pavers, rain barrels, and vegetated swales or linear dry detention systems. These systems can also help create a more aesthetically pleasing environment, provide improved pedestrian connectivity, maintain natural areas, reduce heat islands and even improve air quality.

C. Minimize impervious surfaces and direct connection. Impervious surfaces, such as roadways, parking lots and rooftops, eliminate infiltration and increase the rate and volume of runoff. Conventional curb and gutter systems compound the effects through direct connection throughout the conveyance system. Although many MS4 communities use rate control techniques such as detention basins, these are not necessarily effective at volume reduction.

Figure 1.8 Olivette, MO rain garden. Source: David A. Wilson, East-West Gateway Council of Governments.

By minimizing impervious surfaces and breaking direct connections of runoff, stormwater volume and flow rates can be decreased, thereby reducing likelihood of flash flooding, stream channel erosion and impaired water quality. There are many techniques to minimizing impervious surfaces, and they can include angled or directional parking, use of pervious pavements, maximum width streets, home clustering or conservation design. These, and other techniques, are outlined in Chapters 2 and 5 of this guide.

D. Optimize green space. Integrating stormwater management into green space helps minimize the need for separate, dedicated stormwater management areas. Green space can include parks, plazas, sidewalks and the urban forest. Dry detention basins can be designed to flood only during large storms, thus preserving their primary use. Shopping plazas can incorporate depressed planters to receive runoff, rather than using elevated or at-grade landscape areas. And existing, large diameter trees can be preserved to take advantage of their high rates of evapotranspiration and rainfall interception.

1.4 Benefits of Green Infrastructure: Environmental, Social and Economic

The following description touches on the general benefits of green infrastructure in stormwater management. These benefits are discussed in more detail and quantified in a report titled, *The Value of Green Infrastructure – A Guide to Recognizing Its Economic, Environmental and Social Benefits.* www.cnt.org. (Center for Neighborhood Technologies and American Rivers. 2010)

Figure 1.9 Pervious alley in St. Louis City.
Source: Metropolitan St. Louis Sewer District

1.4.1 Environmental Benefits

Missouri has an abundance of natural resources enjoyed by millions each year. As one of the most diverse geological states in the nation, Missouri touts beautiful streams, rivers, wetlands, caves, lakes, rock formations, fishery resources, conservation areas, state parks and historic sites. Katy Trail State Park is just one of many state parks enjoyed by millions of tourists and residents alike that demonstrate an appreciation of our natural resources. As the population grows and development expands, these resources and those in our neighborhoods are at risk of rapid degradation without responsible approaches to stormwater management in development. Green infrastructure in development not only helps to protect existing resources, it provides for greater enjoyment of those environmental resources within a community and it connects that community to the broader green infrastructure system enjoyed across the state.

Applying green infrastructure, low impact development and other sustainable design concepts, provides more than reductions to stormwater runoff rate and volume. These additional benefits add to the quality of life, carbon sequestration, traffic calming and economic development.

"Green infrastructure and its corresponding tools of low impact development are beneficial to a community's environmental, social and economic interests." (The Sheltair Group, 2001).

Annual Volume Reductions
Conventional or "grey" pipe and pond systems are designed to efficiently collect, store and release runoff. Green infrastructure focuses on decreasing the rate and volume of runoff to the collection system which better mimics pre-construction runoff conditions.

Improved Capacity to Piped Collection Systems
Green infrastructure can reduce the rate of runoff to existing collection systems, resulting in increased capacity for downstream inlets. It may also reduce peak rates used in sizing collection systems.

Integrating green infrastructure with grey may be the most effective approach in reducing peak flows and delaying discharges to combined sewers. Sending stormwater to treatment plants during periods of lower flows when overflows are not a threat, may be the best approach in an ultra-urban area where many green infrastructure controls are challenging to locate. Integrating the best features of both grey and green infrastructure provide an overall increased benefit compared to using one set of tools.

It is important to note that rehabilitation of existing systems is likely needed whether green infrastructure is incorporated or not; it is certainly not acceptable to retain leaking combined sewers because green infrastructure is being used. During one Missouri demonstration, Dr. Robert Pitt, PE noted that the flows in the combined sewers increased significantly after relining/repairing the sewers. They were leaking out more than infiltration in was occurring. The green infrastructure systems are very critical in this area to help offset the increased flows. Again, combinations of controls may be the most effective overall strategy.

Enhanced Groundwater Recharge
Green infrastructure can help to infiltrate runoff, which can improve the rate at which groundwater aquifers are recharged or replenished. Shallow groundwater provides about 40 percent of the water needed to maintain normal base flow rates in our rivers and streams. Enhanced groundwater recharge also boosts the supply of drinking water for private and public uses.

Improved Air Quality
Green infrastructure facilitates the incorporation of trees and vegetation in urban landscapes, which can contribute to improved air quality. Trees and vegetation absorb certain pollutants from the air

Figure 1.10 A mature tree can squester 250 pounds of carbon dioxide per year and can remove several thousand gallons of water from the ground annually. Source: Williams Creek Consulting

through leaf uptake and contact removal. If widely planted throughout a community, trees and plants can even cool the air and slow the temperature-dependent reaction that forms ground-level ozone pollution.

Increased Carbon Sequestration

The plants and soils that are part of the green infrastructure approach serve as sources of carbon sequestration, where carbon dioxide is captured and removed from the atmosphere via photosynthesis and other natural processes.

Additional Wildlife Habitat and Recreational Space

Greenways, parks, urban forests, wetlands and vegetated swales are all forms of green infrastructure that provide increased access to recreational space and wildlife habitat.

Improved Human Health

An increasing number of studies suggest that vegetation and green space - two key components of green infrastructure - can have a positive impact on human health. Recent research has linked the presence of trees, plants and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performances, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders.

Urban Heat Island and Energy Demand Reduction

Urban heat islands form as cities replace natural land cover with pavement, buildings, and other surfaces that retain heat. Tall buildings and narrow streets trap and concentrate waste heat from vehicles, factories, and air conditioners. Green infrastructure provides increased amounts of urban green space and vegetation, helping to mitigate the effects of urban heat islands and reduce air conditioning related energy demands.

Figure 1.11 Native parking lot bioswale. Anita B. Gorman Conservation Discovery Center - Kansas City, Missouri. Source: Copyright © Missouri Conservation Commission. All rights reserved - used with permission.

1.4.2 Social Benefits

Aesthetics and Sense of Community

The nature of green infrastructure provides for a more 'human-scale' environment versus the automobile centric environment, providing more walkability, "bikability" and functional and aesthetic gardens and landscapes. The vegetation and watercourses for the stormwater systems can be designed with landscape architectural prowess to present landmarks and community statements.

According to Dr. Robert Pitt, PE, "we have found these benefits (improved curb-side aesthetics for example) to be profound in retrofitted green infrastructure areas, especially in areas of prior poor infrastructure. Any expected increased costs associated with green infrastructure can likely be offset by these direct and indirect benefits."

Multi-Use Amenities

Communities can benefit from recreational amenities skillfully designed into utility services as multi-purpose capitol projects.

A Greater Choice of Lifestyles

Sustainable communities provide a greater choice for buyers who are increasingly aware of development impacts to the environment, to the tax base and to neighborhood amenities.

Flexibility

On-site infrastructure can allow communities more flexibility to effectively use their land base and can thereby minimize the challenges of locating gray infrastructure within right-of-ways and in a manner that requires long-term costly maintenance and repair.

Conflict Avoidance and Resolution

Integrating green infrastructure into development recommendations will more likely be amenable to community acceptance of development projects, thereby minimizing delays commonly associated with public protest.

1.4.3 Economic Benefits

Lower Costs and Delayed Capital Outlays

Depending on the type of development, green infrastructure can result in lower capital cost and lower operation and maintenance costs. While some costs may increase for project planning and site design, greater cost reductions come with reduced raised curbs, asphalt, storm sewer pipes and basin construction. Effective and efficient stormwater management reduces penalties for regulatory noncompliance. Cost savings are also associated with operation and maintenance of green buildings utilizing green infrastructure near and within the buildings (for example, lower energy bills associated with cooler buildings). Given the added federal and state regulatory emphasis on water quality protection, green infrastructure is more economical than adding treatment processes to conventional methods. (See case studies throughout this guide.)

User-pay

Integration of green infrastructure into the development project, on-site and within buildings, results in lower public expenditure due to demand side management. This user-pay principle encourages more efficiency and conservation within the marketplace, but also results in fewer stream bank restoration projects, basin dredging, and other repairs associated with stormwater damage from poorly designed systems.

Improved Investments by Stakeholders

Monthly management fees can be reduced for homeowners and their associations, as well as commercial and industrial owners. Such reductions increase marketability of development.

Figure 1.12 Prairie Crossing Home with native plant and rain garden. Source: Victoria Ranney, Co-Developer

Local Green Job Creation and Procurement

More efficiency means more dollars in the hands of local residents. Choosing green infrastructure requires green design services that can be procured locally, along with landscaping services and less money is spent on constructing and operating systems in remote locations.

Increased Land Values

A number of case studies suggest green infrastructure can increase surrounding property values. In Philadelphia, a green retrofit program that converted unsightly abandoned lots into clean and green landscapes resulted in economic impacts that exceeded expectations. Vacant land improvements led to an increase in surrounding housing values by as much as 30 percent. This translated to a $4 million gain in property values through tree planting and a $12 million gain through lot improvements.

Utility Savings

Installing rain water harvesting systems such as storage tanks or cisterns for watering residential landscaping, or for capture and reuse in industrial or commercial applications can lower a facility's water costs by 25 percent or more.

1.5 Rethinking Stormwater

Water Quality and Small Storm Management

Small storm events have typically been overlooked in conventional stormwater management. The focus has been on large storms that reduce flood risk. However, technical research and other studies have clearly demonstrated the significance of small storm events to water quality and stable in-stream channels. Many municipalities are now expected to minimize pollution through better management of small storms, because the federal and state National Pollutant Discharge Elimination System regulations now regulate stormwater runoff quality.

The concentration of pollutants in urban stormwater runoff is generally highest in the initial stages of the storm. "The initial runoff, or 'first flush', mobilizes pollutants that have built up on pervious and impervious surfaces. Thus, pollutants are more concentrated in this 'first flush' with concentrations gradually diminishing as rainfall continues" (Mid-America Regional Council and APWA, 2009).

"Significant first flushes occur in small areas having large amounts of impervious cover (commercial areas, for example); it is much less obvious in larger areas having substantial pervious areas or complex drainage systems where the flows from the separate source areas (that have first flushes) combine over a longer period of time, erasing this effect. Therefore, source controls, such as most green infrastructure components, can be effective in this regard, while outfall controls less so." (Dr. Robert Pitt, PE)

In addition to runoff pollutants in the first flush, smaller, more frequent storms have been found to contribute to increased volume and energy in the streams causing incising, down cutting, erosion and channel destabilization, which ultimately increases sediment pollutant levels in streams due to the channel erosion. In the past, design criteria for a two year storm for channel protection was commonly used, however, now the recommended channel protection criteria is for the one year storm event.

According to Dr. Robert Pitt, PE from the University of Alabama, "Rains between 0.5 and 1.5 in. (12 and 38 mm) are responsible for about 75 percent of the runoff pollutant discharges and are key rains when addressing mass pollutant discharges" (Pitt, 1999). Small storm management can address factors such as rainfall intensity, site conditions, pollutant mobility, and flood potential.

Agricultural lands are not typically regulated under NPDES requirements, although cropland can erode an estimated 2.7 tons per acre per year nationally (USDA - NRCS, 2010.) Comparatively, Wisconsin Department of Natural Resources estimates that up to 30 tons per acre per year of sediment can be discharged from active construction sites (University of Wisconsin et al, 1997), while post-construction developed areas discharge up to 0.5 tons per acre (Burton et al, 2002).

Many technical reference manuals are now focusing on design of stormwater quality practices for storm events that produce up to 90 percent of the annual runoff volume, i.e. 0.5-1.5 inch rain events. These frequent rainfall events are relatively small when compared to large storm events used for designing flood control facilities. However, managing these small storm events with a decentralized approach on site can reduce the volume and rate of runoff, thereby minimizing pollutants carried off site and providing protection against flooding.

Stormwater as a Resource, not a Hazard

In conjunction with changes in federal, state and local regulations, many communities are now rethinking how to better manage stormwater runoff as a resource, rather than a hazard. Green infrastructure principles including low impact development, can be applied to capture, infiltrate, evapotranspirate or reuse stormwater to better mimic the natural runoff conditions.

A wide variety of individual stormwater controls usually must be combined to form a comprehensive wet weather management strategy (Pitt et al, 2008). According to the Low Impact Development Center, "If the full suite of low impact development controls and site design practices is creatively used, low impact development is capable of automatically controlling the 10 and 100-year storms through its primary strategy of restoring the built area's natural rainfall-runoff relationship."

National organizations such as the Association of State Floodplain Managers (Association of State Floodplain Managers, 2008) support “no adverse impact” for managing floodplains. This means that new developments and significant redevelopment should not increase flood depths or velocities.

Environmental protection and economic development are often viewed as conflicting objectives, especially when formulating public policy. This common viewpoint is being challenged in communities that have successful stormwater management programs to protect natural resources and streams alongside vibrant new developments. One such development is the Winterset subdivision in Lee’s Summit, Mo.

According to Winterset developer Dave Gale with Gale Communities, “Planning with the land to minimize costs of cut and fill for both developer and builder, saving native trees and designing stormwater detention into the usable green-space plan have been keys to our consistent home site absorption and momentum during our 20 year history, and the reason for our receiving several national awards.”

The most successful programs integrate environmental and economic interests. They also establish clear goals, guidelines, and criteria from the very initial stages of conceptual development through long-term operations and maintenance of best stormwater control measures so that all understand the requirements.

Volume as a Pollutant

Historically, stormwater runoff across the nation has been viewed as a potential flood hazard or source of property damage. To help prevent flooding, policy makers required that runoff be moved quickly away from structures and roadways and then detained to control the rate of release to receiving streams. While this helped reduce the short term flood hazards posed by runoff, flood management policies did not address the long term natural resource degradation which resulted from increased runoff volumes, rates and pollutants associated with development. In an extreme example of rate control with no concern for total volume, some post-construction stormwater basins have been lined to prevent infiltration.

Reducing runoff volume and rate can:

- Protect downstream channels.
- Reduce impacts from flash flooding during short, but high intensity storms.
- Improve base flow in small streams.
- Help conserve overbank storage areas in floodplains along larger streams.

To address volume as a pollutant and help minimize continued stream degradation, land development techniques and stormwater management systems need to reasonably mimic pre-construction runoff conditions in new development projects. This includes conserving natural grades and vegetation to the extent practicable, minimizing new impervious surface area, providing infiltration post-construction stormwater control measures to control and infiltrate small, frequent storm events, and minimizing or eliminating land disturbance within the floodplain or meander belt of receiving streams.

In areas of karst topography, wellhead protection, or other special groundwater concern, infiltration may not be desirable. In these areas, techniques such as reducing impervious area, maintaining existing vegetation, and installing restorative vegetation to increase evapotranspiration can be used to help achieve similar goals.

Where groundwater is a resource, care should be taken to minimize groundwater contamination. An example contaminant source is snow melt water infiltration and contamination from treatment media and salt. Except for salt, many potential groundwater contaminants can be reduced by pre-treatment (filtering through surface soils or media.) Such steps should also help to minimize stormwater contamination via dry wells or through porous pavement.

Using Infiltration and On-Site Practices to Control Volume and Pollutants

Figure 1.2 shows St. Louis, MO rain and runoff distributions between 1984 and 1992. According to Dr. Robert Pitt, "for Missouri, it is likely this figure is reasonably accurate for most of the state. The actual values for any community are dependent on location (rain patterns, etc.) with the same general shape shifting left or right."

Given these rainfall distributions, infiltration (with on-site beneficial use, if possible) should be used to remove as much of the water quality volume runoff as possible. Additional water quality runoff volume not captured through infiltration, evapotranspiration or re-use, should be treated. Channel forming events occur at that upper limit (typically the one-inch storm event is used), so energy reducing controls in these larger events will likely need to be added. It may be less practical to treat runoff events larger than the water quality volume event.

Finally, drainage design must be used to handle the rare events to prevent loss of life and property damage. Extreme events occur, and secondary drainage systems are then needed to safely move or temporarily store the water. Therefore, it is obvious that many stormwater controls are needed for a comprehensive stormwater management program. Green infrastructure and other infiltration devices need to be applied first, and their use will reduce the "sizes" of the other components. Critical source area controls (and pollution prevention), construction erosion control, inappropriate discharge reductions are also all needed.

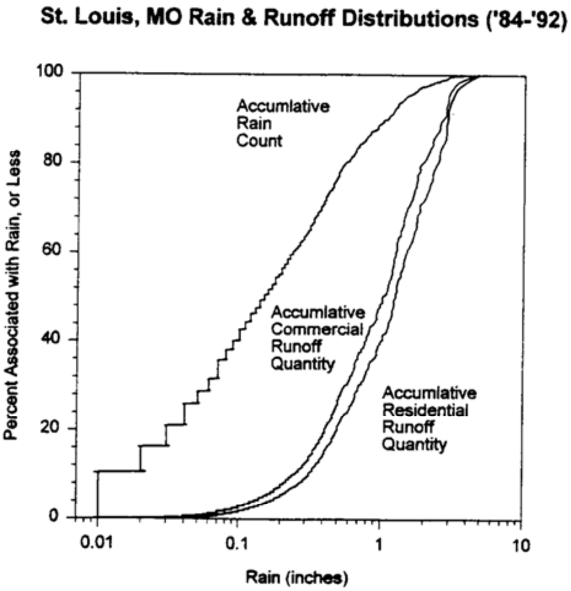
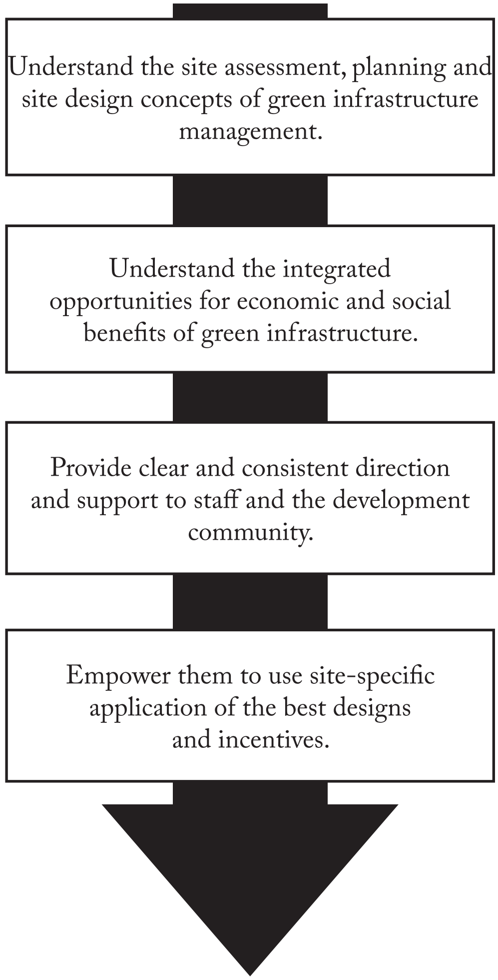


Figure 1.13 St. Louis, MO Rainfall and Runoff Distributions (1984-1992). Source: Dr. Robert Pitt, PE

1.6 Leadership is Key

Strong leadership is critical to a stormwater management program that simultaneously improves quality of life, protects natural resources, and improves economic development. Without a local champion, many of these efforts fail due to lack of oversight and a return to business as usual. For leaders to be successful in planning and implementing a program, they need to team up with local champions to:



Understand the primary strategies and concepts of green infrastructure stormwater management. This document provides the vocabulary needed by leadership to better understand and describe the value of stormwater management and green infrastructure to the community of stakeholders including government personnel, developers and the general public.

Understand the ancillary economic and social benefits of green infrastructure. Communities educated on the value of their streams, lakes and wetlands may be more likely to place a higher priority on stormwater management. Further education on the financial and social benefits provided by green infrastructure can help provide the support needed for implementation of funding programs necessary to implement stormwater improvements including the creation of stormwater utilities and their associated fees.

Provide clear direction and guidance to staff and the development community. Planning efforts for improvements present an opportunity for local leaders to collaborate on setting goals, removing roadblocks, and establishing or revising relevant policies and ordinances. This collaboration can create land use policies and regulations that give staff the tools they need to work across internal and intragovernmental departments, and to better create public and private partnerships with the development community.

It is important to ensure equity through consistent application of criteria and the prevention of exemption abuse.

Empower to the development community to use the best planning and design tools available

Leadership is important in creating an atmosphere of cooperation between the government and land developers. Green infrastructure techniques may be in conflict with existing policies or ordinances governing land use, transportation or subdivision control. To resolve these potential conflicts, community leaders must clearly delegate decision making authority to relevant directors of planning, public works, street departments and economic development agencies who coordinate approval of development projects.

1.7 Use and Organization of this Guide

Effective stormwater management involves the full spectrum of local government elected officials, management, staff-level plan reviewers, developers, contractors and citizens. This guide was written to speak to each of these audiences. All must work in partnership to create and implement a stormwater program that results in multiple community benefits such as neighborhood revitalization, expanded recreational opportunities, attractive businesses, inviting landscapes, increased property values as well as improved water quality.

Elected Officials

Elected officials can use this guide as a tool for engaging the community in policy discussions and enabling department leaders and their staff to implement a quality stormwater program.

Information is also provided on:

- Typical regulatory requirements and recommendations for a post-construction runoff control program.
- The role of elected officials in developing goals, policies and local regulations that support a post-construction runoff control program.
- Why stormwater management is incorporated at the initial stages of the development process and that inter-departmental coordination is needed.

Planning Management, Economic Development Staff and Citizens

Leaders responsible for planning management and economic development staff will find Chapter 2 beneficial. They incorporate stormwater management into long range plans, the land development process and recommendations for water quality protection up front in site planning and design. Chapter 5 includes specific information about site design and on-site practices to be addressed in plan review and approval. Citizens will also be able to see in Chapters 2 and 5 where they have opportunities to influence the process and ensure their community values and goals are incorporated.

Public Works Directors

Public works directors have often been responsible for the implementation of the entire stormwater program. The guide describes each step of development and implementation of your post-construction runoff program. Current trends, key questions to consider, and references to examples and models are included to help with implementation. However, today's water quality requirements demand a close working relationship with planning departments as well.

Developers

Members of the development community can use this guide to help influence local policy toward more flexible yet functional stormwater practices. By understanding how the recommended practices meet state and federal requirements, they will also be able to influence a more streamlined approval process to remove local roadblocks and to provide more economical approaches to water quality requirements. Chapter 2 and Chapter 5 will be of most interest to developers. Chapter 2 provides information and suggestions on planning for stormwater management throughout the development submittal process. It identifies tools to use to protect natural resources and control stormwater runoff from pre-submittal stages through final submittals. Examples of opportunities for cost-savings will also be provided. Chapter 5 is focused on the details of site design and choosing best stormwater control measures. In addition, Chapter 3 and Chapter 4 discuss how to be involved in developing a community's stormwater management goals and stormwater program.

Designers, Engineers and Planners

Designers, engineers and planners may primarily be interested in Chapters 2 and 5, which discuss sustainable site design, and provide information on the impacts of precipitation patterns, soils and local geology. Also provided is an overview of on-site practices, existing design manuals and selected references from within the state and across the country; and, some detail on how the land development submittal process can be modified to allow or encourage green infrastructure. As communities implement these ideas, it will be useful to understand the background and drivers for making changes. A successful program requires keen leadership commitment to these changes until they become common practice. Designers and engineers may also be interested in Chapter 3, which describes the process for setting goals in a community, and Chapter 4, which summarizes the steps for developing the local ordinance or regulation to provide for stormwater quality management.

Plan Reviewers and Planning Commissioners

Staff members who typically review plans will primarily be interested in Chapter 5, which provides an overview of the latest site assessment and design approach for stormwater quality management. This group will also be interested in Chapter 2 which describes the updates needed to properly incorporate stormwater quality management into the land development review and approval process.

Chapters 3 and 4 may also be of interest to plan reviewers. The chapters describe steps and considerations for developing or updating a program and the regulatory mechanisms required to meet stormwater quality management goals.

2 Sustainable Site Design, Development Plan and Land Use Planning

Sustainable site design is one of the most economical and critical tools for incorporating green infrastructure into development projects. Green infrastructure serves to protect water quality in streams, lakes and wetlands and thereby can meet community needs and regulatory requirements. Specifically, sustainable site design incorporates stream buffers, bioswales, rain gardens, reduced hard surfaces and similar low impact development practices into a network of green spaces can help improve or reasonably mimic preconstruction runoff conditions. Efforts to reasonably mimic pre-construction runoff in new development can help to prevent flash floods, store and treat stormwater runoff as nature would and provide for community values such as recreation and aesthetic green space.

Green infrastructure can be incorporated into new, redevelopment or retrofit projects. Unfortunately, many communities have found that their own development codes and standards can actually work against this goal. For example, local codes and standards often create needless impervious cover in the form of wide streets, expansive parking lots and large-lot subdivisions and they often require excessive clearing and grading. At the same time, local codes often give developers little or no incentive to conserve natural areas that are important for watershed protection.

This chapter addresses the integration of green infrastructure using a nested approach at different scales, including:

- Project or site level.
- Municipal/watershed scales.
- Regional scale.

EPA's Water Quality Scorecard is a useful tool for communities to use in considering all the elements discussed in Chapter 2. The scorecard offers policy options for protecting and improving water quality across different scales of land use and across multiple municipal departments. (United States Environmental Protection Agency, October 2009). Refer to Chapter 4 for addition discussion on policies and ordinances.

In particular, green infrastructure is identified as a critical component of sustainable site design criteria, an important consideration of the plan review and approval process, and a corresponding tool

"A comprehensive approach to stormwater management involves developing stormwater management practices that can be applied at the regional, district/neighborhood, and site scales. It also involves looking at where and how development occurs within the community. This is best done by examining common land development regulations and policies that dictate the location, quantity or density, and design of development" (Center for Watershed Protection, 2008).

in comprehensive municipal planning. Therefore, planning departments have a critical role to play in municipal stormwater management, alongside public works departments.

This chapter also includes a discussion and consideration of Missouri's physiographic regions.

2.1 Sustainable Development Planning and Site Design

Integrating green infrastructure into the site design requires integrating its principles into site master planning. This will optimize land use, pedestrian and vehicular circulation and access, natural resource preservation and protection, parking, utilities, runoff management, recreation and landscaping.

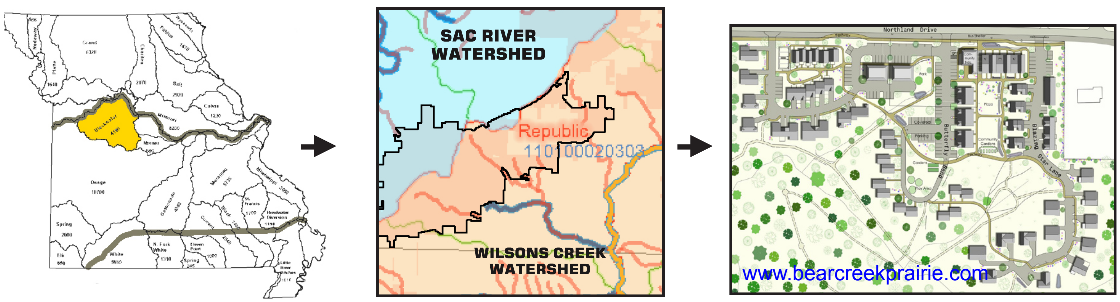
Principles and goals tied to these items will affect the design development of every relevant discipline and, they can be utilized whether the site is urban, suburban, commercial or industrial and whether the site is new, redevelopment or retrofit focused.

On-site low impact development practices can then be selected, sited, calculated for performance and implemented to aid the integration of green infrastructure into the community and its connecting green networks.

The incorporation of green infrastructure needs to be considered at all scales of planning, analysis and design in order to most economically achieve water quality protection or improvement (Figure 2.1 and Table 2.1). Municipalities often sit atop multiple watersheds or portions thereof. Hence, it is important municipalities utilize watershed planning as they incorporate the protection, incorporation or improvement of green infrastructure into comprehensive planning and carry it through to checklists for site plan review.

Watershed planning goes hand in hand with green infrastructure planning as outlined in the article *Green Infrastructure Plan Evaluation Frameworks* (McDonald –King, et al, 2005). In the article, these authors lay out a green infrastructure planning framework that municipalities and their stakeholders can easily use for goal setting, analysis, synthesis and implementation – complete with checklists, applicable at any scale and useful to any planning entity according to the authors.

Municipalities can make great progress toward water quality goals, requirements and recommendations by developing their own green infrastructure plan, related criteria and review checklists for new growth, redevelopment and even stormwater retrofit projects.



Regional Scale | Municipal/ Watershed Scale | Neighborhood/Site Plan Scale

Figure 2.1 Green infrastructure planning scales. Source: Missouri Department of Natural Resources

Sustainable Planning Scales			
Planning Scale	**Stakeholders**	**Planning and Policy Goals**	**Planning and Design Tools**
Regional	Regional planning commissions. Rural networks. Levee districts. Transportation departments. Multiple municipalities. Environmental organizations. Recreational organizations.	Transit systems. Large scale parks, contiguous trails and vegetated corridors. Federal and state regulation compliance. Comprehensive planning. Watershed planning. Green infrastructure planning. Solid waste management systems. Renewable energy systems.	Land use planners. Economic developers. Professional stormwater modelers. Landscape and land use modeling. System for Urban Stormwater Treatment and Analysis INtegration, or SUSTAIN Model. Sanitary Sewer Overflow Analysis and Planning Toolbox.
Watershed/Municipal	Municipalities. Economic developers. Environmental organizations. Patrons. Citizens. Homeowner associations. Recreationists. Developers. Builders and consultants.	Jurisdictional planning. Infill and redevelopment. Policy development. Flood control. Plan review criteria. Federal and state regulation compliance.	Stormwater regulations. Zoning. Stream buffer ordinances. Water quality criteria for new development, redevelopment and retrofit projects. Modeling programs. Plan review checklists.
Neighborhood, Residential, Commercial, or Individual Sites	Municipalities. Patrons. Citizen and homeowner organizations. Developers. Designers. Engineers. Consultants.	Sustainable site designs. Pocket parks. Contiguous buffers. Walkable/bikable trails and connections to larger trail systems. Urban fishing, swimming, other recreation. General overall sense of community. Desirable home and work facilities and structures.	Project site reconnaissance. Analysis and design. SUSTAIN model. Stormwater Management Model. Sanitary Sewer Overflow Analysis and Planning Toolbox, www.epa.gov/nrmrl/wswrd/mmd.html. Best management practice selection and design. International BMP database www.bmp.database.org.

Table 2.1 Sustainable Planning Scales. Source: Adapted from Shockey Consulting Services

Figure 2.2 Green infrastructure infill, redevelopment and retrofit features. Graphic by Williams Creek Consulting

Many tools as shown in Figure 2.2, exist to aid the planners, modelers, designers and reviewers. Examples of design tools include the System of Urban Stormwater Treatment and Analysis, or SUSTAIN model and the international best management practice performance database. For example, the SUSTAIN model can aid the designer in locating and selecting an appropriate best management practice, such as a bioswale or rain garden, and the best management practice database can provide information on what type of water quality or volume function will be provided in a particularly sized or designed best management practice.

The following low impact development principles listed by the Natural Resource Defense Council go hand in hand with the green infrastructure goals in this chapter.

- Integrate stormwater management early in site planning activities.
- Use natural hydrologic functions as the integrating framework.
- Focus on prevention rather than mitigation.
- Emphasize simple, non-structural, low-tech and low cost methods.
- Manage as close to the source as possible.
- Distribute small-scale practices throughout the landscape.
- Rely on natural features and processes.
- Create a multifunctional landscape.

www.nrdc.org/water/pollution/storm/chap12.asp

During concept development, stormwater management planning has often consisted of setting aside placeholders for basins or other centralized management features, and often these features have been designed at the end of the design process. Even where distributed storage and conveyance systems such as rain gardens and swales are included in planning, these features are responses to problems created by the proposed change in land use.

The non-structural stormwater control measures, such as stream setback requirements and similar regulatory tools, can be used to promote runoff source control through minimizing land alterations and taking advantage of existing natural features to help manage runoff. Principles such as those promoted by green infrastructure can be given more weight during concept development and preliminary design. Integrating green infrastructure into plans is much easier to accomplish when considered at the beginning of the site design process, rather than at the end. Implementing this concept can be simplified into three questions (Brown, et al 2007), to the maximum extent practicable:

1. Does this minimize land disturbance?
2. Does this preserve vegetation?
3. Does this minimize impervious cover?

These questions are not meant to prevent land development, but rather help it occur with minimal cost – both financially and environmentally. Where program goals can be achieved while minimizing earthwork, clearing and construction of stormwater management infrastructure, it also helps minimize environmental impacts while reducing the cost of construction. It can also reduce operation and maintenance costs.

2.1.1 Sustainability in Site Master Planning

Master site planning must consider green infrastructure design goals at the beginning of the process where the greatest opportunity exists to:

- Preserve natural systems.
- Engineer management systems to enhance natural systems and reasonably mimic natural, pre-construction functions through practices that:
    - Enhance evapotranspiration.
    - Enhance infiltration.
    - Minimize increases in surface runoff rates and volume.

Planning principles (design goals) differ from design techniques. Planning principles set project goals such as minimizing impervious surface, creating green space connectivity and similar non-structural stormwater controls. In contrast, design techniques include specific details such as where pervious pavements are needed, where road widths can be minimized to meet those goals or prescribe specific structural stormwater control measures needed to manage runoff from defined areas.

It is useful to employ plan review checklists, such as that provided by Southeast Michigan Council of Governments in their *Low Impact Development Manual for Michigan.* (Southeast Michigan Council of Governments, 2008) See Figure 2.3.

This is also an opportunity to employ incentives for green infrastructure and low impact developments, such as reduced setbacks, reduced fees, credits and streamlined reviews.

Plan Review Checklist

- Is this project consistent with comprehensive, watershed or green infrastructure plans.
- What are the major or minor watersheds?
- What is the state stream use/standards disignation/classification?
- Are any streams classified or 303(d) impaired streams?
- Is additional development anticipated for the area that could lead to further opportunities?
- Have the important natural site features been inventoried or mapped?
- Is the development concept consistent with other plans in the community?
- Is development consistent with local existing regulations?
- Will there be concentrated or clustered uses and lots?
- Are the lots or development configured to fit natural topography?
- Does the development connect open space or sensitive areas with larger community greenways plans?
- Does the development consider re-forestation or re-vegetation opportunities?

Figure 2.3 Plan review checklist.
Source: Southeast Michigan Council of Governments, 2008

Planning for the following green infrastructure design principles will provide the conceptual basis on which the design will be created. Sustainability in master planning typically goes beyond minimum regulatory requirements and can address not only physical site issues, but also programmatic, building, operational and geographic issues.

Preserve, Enhance and Protect Natural Resource Areas

Natural resources should be identified during the due diligence of a proposed project. Streams, undisturbed green spaces, wetlands and riparian areas are all efficient low-cost natural stormwater management features. They are the existing stormwater management system and should be preserved, enhanced and utilized where practical. Replacing the free services provided by these natural systems with man-made systems requires significant capital investment and time, creates the need for ongoing operation and maintenance of these systems and reduces the community's quality of natural resources.

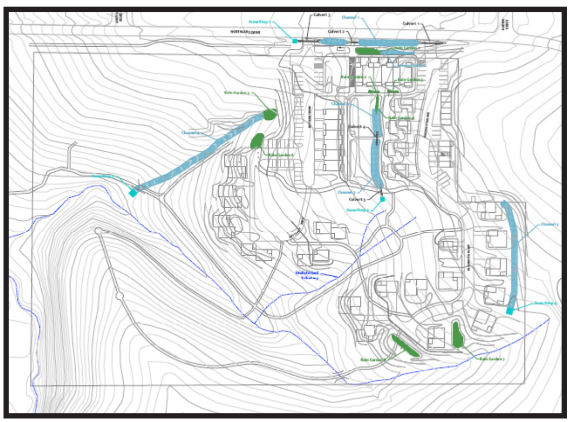


Figure 2.4 Proposed Bear Creek Prairie Project, Columbia, MO.
Source: Andy Guti

Existing site conditions can be evaluated to identify areas most suitable for development, preservation or integration into site programming needs. Unsuitable development areas can be steep slopes or mature forests. Areas that may be unsuitable for development but may be integrated into stormwater management include wetlands or intermittent streams. Once identified, the planning and design process can focus on how to meet programming goals within available suitable areas while integrating or enhancing unsuitable development areas.

Minimize Impervious Surface and Direct Runoff Connections

Building structures, parking areas, parcels and transportation networks can be oriented within areas designated suitable for development in order to minimize their impact on runoff while meeting site objectives. During the planning and design phases:

- Parcels can be placed to minimize infrastructure connection distances.
- Green spaces can be connected in a stormwater treatment series.
- Structures can be converted to multiple-stories to decrease their roof area without sacrificing square footage.
- Road widths can be minimized and still provide emergency vehicle access.
- Parking areas can be laid out to minimize drive aisle widths and better integrate stormwater features into buffers and parking islands.

The result of these efforts should minimize costs associated with construction and maintenance of structural stormwater control measures and also reduce costs associated with earthwork, clearing, pavement and stormwater collection systems.

Figure 2.5 Boulevard Brewery, Kansas City, MO.
Source: Boulevard Brewing Company

Programming to the Triple Bottom Line

Defining the project goals drives the spatial requirements, character and budget. Program goals include land use type, the type(s) of internal and external access and connectivity. The program can determine the interaction of the site's residents and visitors with the proposed development and help set the overall design principles for a sustainable development. Consistency can be checked with comprehensive, watershed and green infrastructure plans.

Program decisions include "big picture" items such as whether the proposed project will be a commercial, residential or mixed use development; or whether a residential development may be traditional, conservation, estate or other sub-type. Example sustainability principles relevant to site programming include the following:

1. Environmental
Is the proposed land use appropriate or does it pose unusual risks to the environmental setting? If not, what alternatives may there be?

- For example, a proposed project may be located in a zoned industrial park but adjacent to a protected stream. Project goals could include exceeding protection standards prescribed in local ordinances.
- Although the site is zoned industrial, the project owner may choose to use a non-structural stormwater control measure such as:
  - Excluding heavy industrial tenants.
  - Creating a larger stream setback than required by ordinance.
  - Locating loading docks and other material handling areas as far from the stream as possible.

2. Social
Is the project near a wetland or other valuable natural resource area? If so, how can program goals enable the area to be integrated into green space and pedestrian connectivity improved?

- For example, the project may set goals to enhance pedestrian access to these areas while minimizing disturbance during connection. The corresponding design technique could be at grade trail construction using pervious materials.
- Non-structural stormwater control measures could include placing the area in a permanent conservation easement to ensure its long-term availability as a public amenity and natural stormwater management area.
- Trading project locations in exchange for protection of critical area.

Figure 2.6 Prairie Crossing Homes.
Source: www.planningwithpower.org

3. Financial
Is the project near a wetland or other valuable natural resource area? If so, how can program goals promote this feature in marketing the proposed project?

- Wetlands, streams and other natural resource areas cost money to fill, move and mitigate. Many of these areas can serve as part of a stormwater management area if adequate pretreatment is provided.

Minimizing Building Footprints
The relative type, size and location of buildings needed to support program goals. Considering building needs at this point in the project helps avoid large changes during design development. Example sustainability principles relevant to building facilities may include:

1. Environmental
Is the proposed building footprint restricted to one-story or can two-story units be used? If not, what alternatives may there be?

- A proposed project may be zoned residential at a density of two units per acre. Program goals could include requiring two story homes on a greater percentage of lots than typically required or desired by a developer. The smaller footprint of homes would reduce roof area and associated runoff volumes, allow the use of smaller lot sizes to minimize land disturbance during construction and free up more land area for green space.
- Other non-structural stormwater control measures include requiring downspout disconnection in site architectural standards.

2. Social

Is the proposed building footprint restricted to one-story or can two-story units be used? If not, what alternatives may there be?

- Again, program goals requiring two story homes on a greater percentage of lots than typically required could allow smaller lot sizes to free up area for green space and increase opportunities for parks and trails.

3. Financial

Is the proposed building footprint restricted to one-story or can two-story units be used? If not, what alternatives may there be?

- Minimizing building footprints can improve opportunities for clustering of homes near existing utility connections. Clustering can shorten utility runs and associated installation costs.
- Clustering and minimizing building footprints also decreases road lengths, which decreases impervious surface, which decreases runoff volumes, which decreases the cost and size of stormwater management systems needed to manage the runoff.

Operational Issues

Project implementation, operations, finances and functional issues. Planning for long term viability during master planning helps ensure the project can be successfully marketed through completion and properly maintained once constructed. Perimeter sand filters for example do not provide volume reduction, but they may be used to provide pre-treatment prior to stormwater discharging to a rain garden or similar green infrastructure practice. This practice will require routine maintenance. In another example, a hydrodynamic separator can result in very poor water quality when not maintained properly.

Example sustainability principles relevant to operational issues may include:

1. Environmental

Does the site contain stormwater control measures with special maintenance needs?

- Easements and maintenance responsibilities need to be clarified during planning. Assuming who the long term maintenance entity may be without confirmation can result in changes to the types of stormwater control measures applied during design. For example, if the owner assumes that pervious concrete in the right of way is going to be maintained by the municipality, confirmation is needed to ensure that the city has the proper equipment and is willing to perform the service.

Figure 2.7 Perimeter sand filter. Source: Center for Watershed Protection

Geographic Issues

Unique or special natural resources need to be highlighted, not hidden. (See Section 2.5 in Chapter 2 for consideration of Physiographic Regions.) Example sustainability principles relevant to building facilities may include:

1. Environmental

Is the proposed project near significant rock outcrops, lakes or shallow groundwater?

- Program goals can include a full suite of non-structural low impact development principles to help ensure and maintain long term integrity of existing scenic waterbodies. Specifically, minimizing land disturbance and rock excavation during construction can be a highly effective tool, as phosphorus or fine grained sediments released during construction can permanently damage waterbodies.
- Groundwater resources should also be considered when selecting practices. See Table 2.2: Existing Natural Resources Considerations and Table 5.4: Groundwater Contamination Potential for Stormwater Pollutants Post-Treatment.

2. Social

Does the site contain conservation areas that will serve as amenities?

- Easements guaranteeing the preservation and maintenance of these areas need to be committed to during planning and design.

3. Financial

Who will maintain common areas that serve dual purpose park and stormwater management needs?

Identifying whether the owner or tenants will maintain common areas may drive the type of amenities offered within them. For example, trail materials and other features with longer service life may be selected where the anticipated maintenance entity is not likely to have the resources or technical expertise to properly maintain them.

Figure 2.8 English Landing Park, Parkville, MO.
Source: Shockey Consulting

2. Social

Is the proposed project near significant rock outcrops or lakes?

- Program goals can include setbacks from significant geographic features to help maintain viewsheds. Public access to lakes can be promoted through placing stormwater management or conservation easements between areas of development on the shoreline.

3. Financial

Is the proposed project near significant rock outcrops or lakes?

- Minimizing land disturbance, particularly rock excavation, can lower costs during construction. Maintaining viewsheds and public access to natural resource amenities through proper planning can help market and maintain property values.

Construction Issues

The construction process for sustainable sites that include green infrastructure and other innovative elements is in many ways unchanged. Construction documents are issued, bid and awarded to a qualified contractor; then, the owner or their designated representative oversees the construction process, inspecting the process at predetermined milestones. However, potential elements that may be atypical to the construction process include types of materials, construction sequence and maintenance.

Construction Material Installation - A primary green infrastructure strategy includes the use of pervious pavements – concrete, asphalt or pavers. Material installation may require special training and contractors should submit training certifications related to the material being installed.

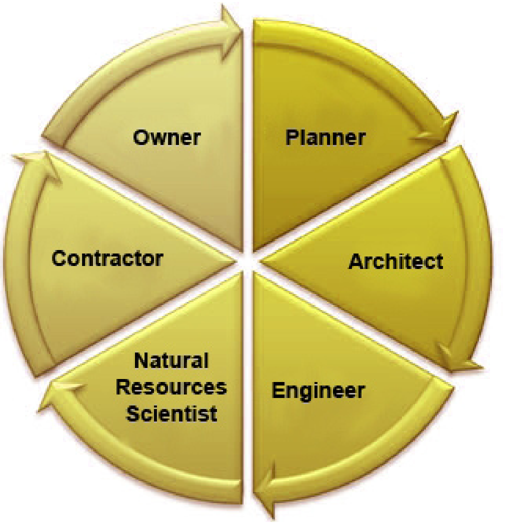
Native Landscape Installation - Use of native vegetation can create landscapes that are unfamiliar to many urban and suburban areas. Design and installation of these landscapes is a specialty field. While mature native landscapes are typically hardy and require less maintenance than most non-native landscapes, they may take longer to establish and require more maintenance during the first one to three years following installation. Designers may need to consult with local native plant nurseries to help developing materials lists and maintenance specifications.

Construction Sequencing - Infiltration and other stormwater control measures can be damaged or otherwise degraded due to poorly planned or implemented construction sequencing. Two factors important to green infrastructure elements include:

- Soil compaction. Infiltration areas need to be protected to avoid compaction or over excavation after site work in order to help ensure adequate soil permeability. Field testing can be required during construction to decide whether or not over excavation is required.
- Sedimentation. Construction phase best management practices are used to control suspended solids in runoff. These areas can be revised as post construction stormwater control measures assuming they are inspected and rehabilitated after construction is completed
- Contractor Oversight. Additional oversight is needed in green infrastructure projects where contractors are inexperienced or otherwise unfamiliar with green infrastructure installation and function. Because many non-structural and structural methods are uncommon to traditional construction practices, contractors may misinterpret plans based on a perceived need to “fix” things that may not be broken.

Expensive mistakes can be made when contractors don't understand the change in design approach. For example, a parking lot may be designed to sheet flow across infiltration practices, but the contractor "corrects" the design by grading a slope that directs runoff to a curb - a curb the contractor believed was accidentally left out of the design.

Special inspections may also be required to ensure subgrades in infiltration areas are not over-compacted, lime stabilized or otherwise damaged during construction.



Building Your Team

Similar to planning at the regional or municipal level, integrating sustainability concepts into a site design generates opportunities and constraints that require input from a multi-disciplined team. Each team member should understand how their specialty fits into the overall needs of the project and prepare to find solutions where perceived conflicts of interests or goals occur. Pending the size of the project and resources available, some team roles will be combined and be the responsibility of one team member.

In practice, assembling complete teams can cost more and require more time for planning and design than conventional projects. However, case studies in this and other documents support the cost benefit of added investment of time and money up front. Where resources may not support the creation of a complete multi-disciplined team, the owner may be able to rely on direct coordination with stormwater coordinators, economic development directors, local or state environmental agency personnel and other relevant agency personnel.

Owner

The owner can be an individual or a private or public entity that provides resources that make the project design and implementation possible. The owner identifies the objectives or purpose of the project and provides consistent and clear direction on expectations, budget and schedule. The owner also makes decisions where multiple feasible options exist

Planner

Helps the team organize the vision and goals for the project and develops concept plans to portray the vision. Planners may need to revise programmed passive recreation areas to accommodate infrastructure needs. Examples may include integrating green space into a network of parks that can also serve to collect, convey and treat stormwater runoff; review community needs relevant to locally available goods and services to help estimate the need and frequency of street uses and alternative transportation options; and relocation of proposed development areas to accommodate natural resource areas or their buffers.

Architect

Building and landscape architects help the team integrate function and form - placing one ahead of the other only when necessary to support the goals or requirements of the project. Building architects may need to minimize building footprints, incorporate on-lot stormwater control measures or reduce on-lot impervious surface percentages through shared drives or revised sidewalk details to include pervious pavement and subsurface infiltration. Architects may also need to evaluate green roof options to help control runoff, conserve building energy or provide urban rooftop open space.

Landscape architects will likely need to consider several atypical factors. Irrigation may not be available, native plant materials may be required and landscapes may be prone to frequent inundation.

- Temporary irrigation may be required in non-stormwater management areas in order to establish plant materials. However, the deeper root systems associated with many native plant species used in sustainable design should prevent or minimize the need for long term irrigation systems.
- Native plant selection will require a balance between diversity (which is good for ecology) and appearance (which is required for long term acceptance in most communities). Native plant nurseries can assist landscape architects in selecting materials, specifically regarding the seasonality and height of different species, to help create a year-round aesthetically pleasing environment.

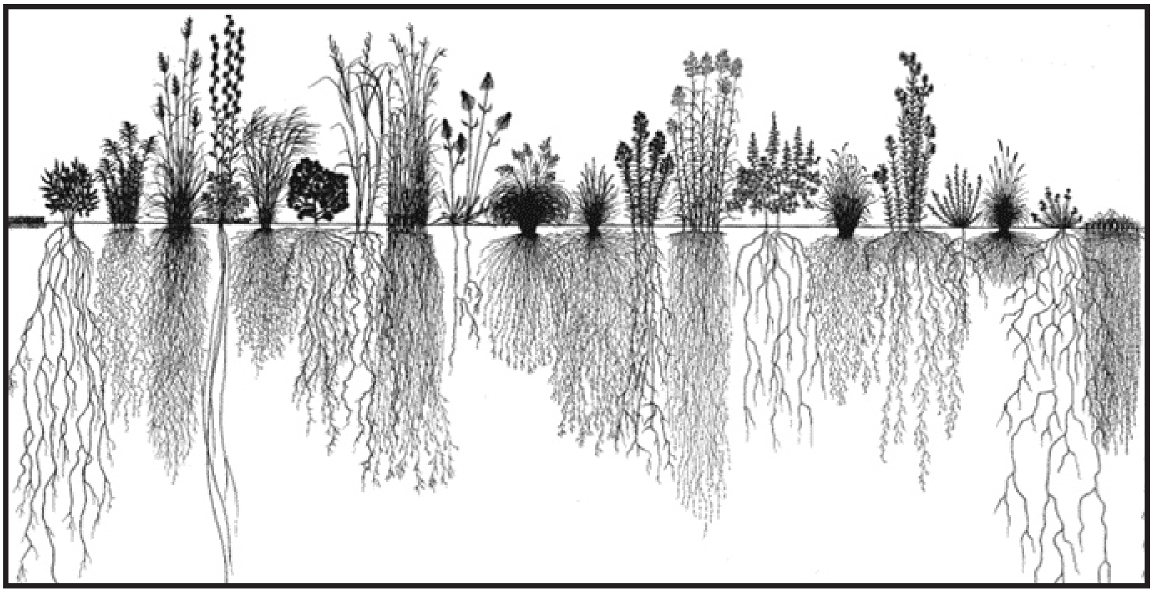


Figure 2.9 Comparative root systems. Source: *Native Plant Guide for Streams and Stormwater Facilities in Northeastern Illinois* Prepared by USDA-NRCS Chicago Metro Urban and Community Assistance Office in Cooperation with EPA Region 5, U.S. Fish and Wildlife Service, Chicago Field Office and U.S. Army Corps of Engineers, Chicago District, December 1997 (Revised May 2004).

- Plants that can undergo extremes in wet conditions need to be chosen for many green infrastructure systems. Periodic inundation for several days can kill many plants, making trial and error expensive. Testing plants for specific sites, can help determine survivability.
- Native plant nurseries are becoming more common. Some municipal or nonprofits establish native plant nurseries for this purpose, creating green collar jobs.
- Most native grasses and forbs spend one to three years developing the deep root systems that make them hardy and more drought tolerant than their non-native counterparts. Note the short turf grass roots in Figure 2.9. While these root systems play a major role in sustaining long-term infiltration capacity of soils, the time period for root development may create aesthetic and maintenance issues in the short term.

  To help minimize the potential for aggressive weed development and maximize the potential for a quicker developing native landscape, designers should specify weed-free topsoil, live plant material in lieu of seed and require adequate thickness of leaf compost or other appropriate mulch.
- The stormwater engineer should be able to provide the architect with guidance on the maximum allowable amount of impervious surface per lot and should be able to assist the landscape architect with information such as frequency, duration and depth of flooding that can be expected in landscaped stormwater management areas.

Engineer

Engineers are needed with special skills and training in the area of green infrastructure to compliment their skills in drainage designs. While Missouri does not require certification for stormwater quality, some states do. Advanced contractor training is very important, also.

Engineers provide design, modeling and infrastructure coordination to support concepts and designs developed by the project team. They are responsible for evaluating site plan concepts to quantify the size, type and location of structural stormwater control measures, and they develop the grading plans necessary to minimize disturbance during construction.

Engineers also design the transportation and parking network to the necessary level of service while minimizing impervious surface, including developing the typical road cross sections to help minimize the widths. Streets, greenways and in some cases public transit facilities, should be designed to minimize their cost and ecological footprint while still providing safe, reliable access for motorized vehicles, bikes and pedestrians.

In context of sustainable site design, transportation networks should consider integrating stormwater management through retention in the right of way where feasible, use of permeable pavements, narrow streets, and stabilized vegetated shoulders where possible as substitutes for grey infrastructure. They may also need to consider regional greenway plans, public transportation initiatives or other external connectivity issues. See Green Highways Partnership at www.greenhighways.org and Green Streets at www.lowimpactdevelopment.org/greenstreets/.

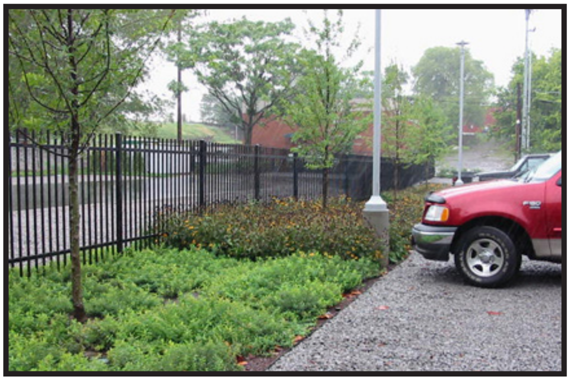


Figure 2.10 Bioretention. Source: *Green Infrastructure Digest*

Design development provides the opportunity to collect and analyze anticipated intensity of use and other relevant data to assess which alleys, collectors or arterial roads can best be modified or minimized beyond local standards in support of project sustainability goals. Transportation studies should be shared with other project team members to ensure compatibility with future land use

Natural Resource Scientist

Wetland, stream, soil, wildlife or other natural resource scientists may be a critical part of the team where sensitive ecological issues are affected by site development. Natural resource specialists may need to help develop alternative solutions to better integrate wetlands, streams or other natural resource features or begin preparing mitigation plans and permit applications. They may also serve as an advisor on native landscape vegetation issues related to hardiness, behavior or maintenance requirements.

Natural resource professionals should review site plans to recommend integrating natural resources where possible. Planners, engineers and other team members will need to provide site use and functions to help integrate the natural resource (without degradation) or will need to provide the basis and need for unavoidable impacts. Example solutions include providing water quality treatment prior to discharging to wetlands, thus maintaining water flow to the wetland and taking advantage of its natural stormwater management function. This technique is allowable in most areas providing that the natural hydrologic conditions of the wetland are not altered in any way that would decrease its functions and values.

Contractor

Experienced contractors, trained in green infrastructure, can verify assumptions made during the design development process. Contractors can help designers verify pricing, because many green infrastructure elements may cost more or less than their conventional counterparts. They may also lend insight to construction sequencing. How to construct integrated infrastructure in the field can influence design decisions on paper. For example, substitutions can be made for some stormwater control measures that may not be readily constructible due to soil types, high groundwater table or other concerns. Training and experience can be very important, because many devices can fail due to overfilling or compacting the soil media. Contractors may think they are improving or correcting the specification.

Land Use Issues

Structural and non-structural stormwater control measures can be restricted or otherwise affected by proposed land use. Urban sites have a natural scarcity of land areas available for large dedicated stormwater management areas. Suburban areas have land, but can lack pedestrian connectivity and usable green space due to disconnection by large stormwater management features. Greenfield commercial/industrial sites with large percentages of impervious area can generate unusually high increases in post-development runoff rates and volumes relative to suburban or urban improvements. Due to these different challenges, different tools may be needed to address stormwater management for different land uses.

Urban Tools

1. Minimize impervious surface and direct connections.

- Substitute pervious pavements when repairing or replacing curb, gutter and sidewalk sections.
- Eliminate unnecessary or rarely used parking areas and replace with vegetation.
- Allow minimal on-site parking where adequate on-street parking is available nearby.
- Allow and encourage green roof technologies to increase open space for building tenants while decreasing runoff.
- Disconnect downspouts from collection systems or connect to storage systems.
- Use pervious pavements with infiltration capacity in parking areas and driveways.

2. Maximize infiltration and reuse.

- Apply distributed storage in the right of way using bioretention in place of elevated landscapes.
- Connect treatment practices in a stormwater treatment train when possible.
- Create distributed pocket parks in vacant or abandoned properties to manage overflows from water quality stormwater control measures.
- Use rain barrels, storage tanks or cisterns where possible to harvest rainwater for reuse.
- Reduce volume.

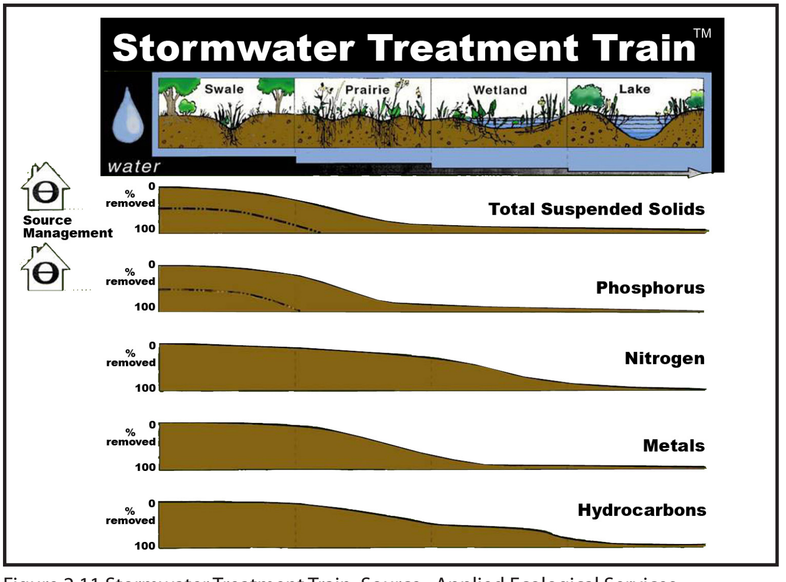


Figure 2.11 Stormwater Treatment Train. Source: Applied Ecological Services. See www.appliedeco.com for more STT information and project examples.

The Stormwater Treatment Train,™ or STT, graphic was created by Applied Ecological Services Inc. in the early 1980's. It was developed after working on a study of the Des Plaines river and to study how discharge in the river has changed since mid-1800's. This STT graphic shows the elements developed for the Prairie Crossing project, Grayslake, IL. The dashed line in the graphic is expected reductions in nutrients, road de-icing salts, fertilizers and other contaminant constituents from source control. This aids changing landowner behavior to reduce home lawn fertilizer, herbicide, and pesticide uses. This graphic is stylized modeling output from the USGS HSPF model. Any questions about this graphic or the studies behind it can be directed to Steven I. Apfelbaum (steve@appliedeco.com) at Applied Ecological Services, Inc.

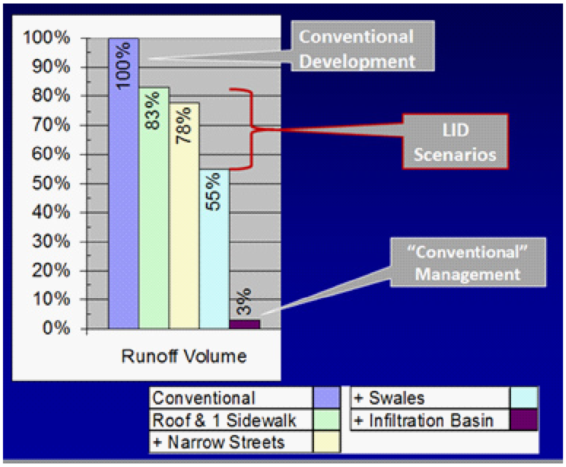


Figure 2.12 Runoff Reductions by Site Components. Source: Dr. Robert Pitt, Personal Communication, February, 2012.

Water volume should also be represented. Figure 2.12 is from an actual large-scale monitoring project by Wisconsin DNR/USGS in Cross Plains, one of the more comprehensive reports on the performance of conservation design. It shows the benefits of the treatment trains, and the need for multiple components using green infrastructure and sedimentation and large scale infiltration. The results were as predicted before construction using WinSLAMM which was used to help design the project.

3. Maximize native plantings, favoring hardy species. Plantings can increase the aesthetic value of communities, and also manage stormwater. In an urban setting, vegetation must fight for space with competing land uses.

Some issues to consider are:

- Select hardy vegetation resistant to urban stresses such as road salt, limited groundwater recharge and air pollution.
- Favor shade trees over ornamentals where possible to help reduce heat island effects and increase carbon sequestering. Trees also provide the greatest water uptake.
- Consider root patterns that may affect adjacent pavements.
- Provide adequate structural or other planting soil to support the mature tree size.
- Select deep rooted herbaceous species and favor perennials over annuals to decrease watering needs and seasonal replanting.

4. Make green infrastructure features part of public outreach programs.

- Sustainable features can increase a community's value and can be the start of economic revitalization.
- Provide educational signage to define these methods and how they work.
- Manage stormwater within otherwise necessary site features – the limited land area available makes this principle more important in urban areas than other land uses. Capture, treat, infiltrate and otherwise manage runoff in the right of way, beneath parking, on the roof and in the landscape.
- Combine Funds – Urban redevelopments often have multiple potential stakeholders interested in assisting with green infrastructure. Community development corporations, municipal governments and parks departments all may be interested in partnering to help bring a green infrastructure project to their area.
- Enhance community spirit and sense of place. Green infrastructure can be used as identifying features for a community. The design and location of these features can define neighborhood boundaries without expensive signage.

Suburban Development Tools

1. Minimize impervious surface and direct connections as part of development.

- Minimize roadway lengths and widths using planning techniques.
- Allow shared driveways.
- Cluster homes.
- Minimize building footprints using multi-story product types.
- Use pervious pavements in low traffic areas.

2. Maximize infiltration and reuse.

- Apply distributed storage in the right of way using bioretention in place of elevated landscapes, and use flat curbs, curb cutouts and pervious walkways in place of impervious concrete.
- Infiltrate runoff in common areas or "stormwater parks."
- Use rain barrels, storage tanks or cisterns where possible to harvest rainwater for reuse.

3. Maximize native plantings, favoring hardy species. Plantings can increase the aesthetic value of communities, but can serve the dual purpose of also managing stormwater. Some issues to consider are:

- Select hardy vegetation resistant to right-of-way stresses such as road salt.
- Favor shade trees over ornamentals where possible to help reduce heat island effects, and increase carbon sequestering and water uptake.
- Consider root patterns to help decrease risks to adjacent pavements.
- Provide adequate planting soil to support the mature tree size.

Figure 2.13 Rain garden in roundabout designed to capture/ infiltrate stormwater, Milwaukee, WI. Source: Bob Newport, EPA Region 5

Figure 2.14: Residential rain barrel. Source: *ABCs of BMPs*

Figure 2.15 Green roof- Orthwein Animal Nutrition Center, St. Louis Zoo. Source: SWT Design. Source: Shockey Consulting

- Select deep rooted herbaceous species and favor perennials over annuals to decrease watering needs and seasonal replanting.

4. Make green infrastructure features part of public outreach programs.

- Sustainable features can increase a community's value and can be the start of economic revitalization.
- Provide educational signage to define these methods and how they work.

5. Use linear vegetated stormwater features to treat, store and convey stormwater runoff and to produce increased pedestrian connectivity.

6. Detention areas can also be used as parks and open recreation. These areas can be designed to only be inundated during large, infrequent rain events when most people are not outside for recreational purposes due to unpleasant weather.

Commercial/ Industrial Development Tools

1. Minimize impervious surface and direct connections.

- Use angled, one-way directional parking to minimize impervious surface.
- Use extensive green roof technologies to decrease runoff from large roof areas.
- Minimize parking counts.
- Use turf pavers or other permeable material for seasonal overflow parking areas.
- Incorporate green parking lot, features. See www.greenparkingcouncil.org, for example.

2. Integrate stormwater management into otherwise necessary site features.

- Substitute bioretention for parking islands.
- Manage runoff in the perimeter buffer.
- Integrate infiltration trenches into pervious curb and gutter at the parking lot perimeter.
- Use long, linear islands parallel to parking aisles in lieu of isolated parking islands at aisle ends.
- Design parking lots to include stormwater management features.

3. Use linear vegetated stormwater features to treat, store and convey stormwater runoff and to minimize the need for earthwork on large sites with little or no slope.

4. Limit turf areas. They require frequent mowing, excessive watering and increase the need for chemical application.

5. Implement low impact development techniques as part of planning.

- Minimize clearing.
- Minimize earthwork.
- Minimize impacts to wetlands and watercourses.

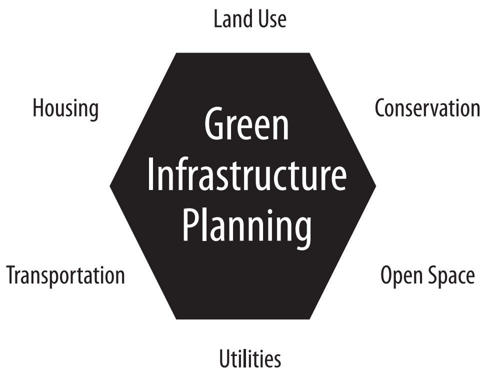
Figure 2.16 Parking Lot Bioswale- Anita B. Gorman Conservation Discovery Center, Kansas City, MO. Source: Shockey Consulting

2.2 Planning and Permitting at the Municipal Scale

Municipal scale planning areas may or may not be regulated MS4s. They often do not control the entire watershed or other natural resource areas in which they are located, but do have regulatory authority to enforce land use management programs and ordinances. In addition to considering regulatory compliance requirements, municipal stormwater planning should integrate the goals, priorities and desired land uses of geographically relevant regional, watershed or other municipal comprehensive plans.

"Increasingly, communities are looking for ways to maximize the opportunities and benefits associated with growth while minimizing and managing the environmental impacts of development. Balancing these priorities is playing out in planning commission meetings, boardrooms, mayor's offices and public meetings throughout the United States" (Brown et al 2007).

Example Goal: *City of Cape Girardeau, Missouri*



Comprehensive Planning

"Policy 3.3.5: Create minimum standards and encourage the use of Green Infrastructure through programs, policies, regulations and incentives."

Figure 5.17 Theis Park rain garden- Kansas City, MO.
Source: Shockey Consulting

Green Infrastructure and Municipal Planning

Typical municipal planning elements may include:

Land Use - Designates the general location and intensity of housing, business, industry, open space, education, public buildings and grounds, waste disposal facilities and other land uses.

Conservation - Addresses the conservation, development and use of natural resources including water, forests, soils, rivers and mineral deposits.

Open Space - Details plans and measures for preserving open-space for natural resources, the managed production of resources, outdoor recreation, public health and safety and the identification of agricultural land.

Utilities - Details plans for the location of utilities such as wastewater, water supply, stormwater, electricity and telecommunications.

Transportation - Identifies the general location and extent of existing and proposed major roads, transportation routes, terminals and public utilities and facilities. It must be correlated with the land use element.

Housing - Provides a comprehensive assessment of current and projected housing needs for all segments of the community and region. It sets forth local housing policies and programs to implement those policies.

Land Use and Green Infrastructure

A comprehensive plan includes descriptions or definitions of specific land use designations that can have positive impacts on water quality. Some examples include:

- Restricting development within floodplains.
- Providing buffers around environmentally sensitive areas, such as streams, wetlands and the like.
- Consistency with watershed or regional scale planning, where available.
- Allow for mixed use developments to promote connectivity, conservation development to increase open space and high density development to help prevent sprawl – but require all types of development to meet environmental quality goals.

The following steps (Brown et al, 2007) are helpful when integrating stormwater management into land use decisions:

- Minimize the need for impervious cover and set long term goals for reductions in impervious cover. Introduce maximums where minimums may currently exist – placing limits on parking spaces, road widths and side yard setbacks can all help minimize impervious cover.
- Remove requirements for direct runoff connection to collection systems where possible. Restrict direct connection of building downspouts and limit the number of inlets per curb length.
- Develop relationships between planners, engineers, managers and other stakeholders through public outreach programs.
- Use watersheds as the broader organizing tool where practicable.

Existing Natural Resource Considerations		
Natural Resource	**Questions**	**Mapping Actions**
Wetlands	Are wetlands on-site? Are permits needed (e.g., 404/401 permits) from the Army COE or Missouri Department of Natural Resources?	Show all wetlands on map. Obtain COE/DNR permits or documentation before plan approval.
Streams and Floodplains	Are major waterways on the site? Are permits needed from the Army COE or Missouri Department of Natural Resources? Is the site located within the 100- or 500-year flood plain? Is the municipal or county stream buffer (setback) shown? Is the site in a flooding or erosion prone area?	Show major waterways. Obtain COE/DNR permits or documentation before plan approval. Obtain local floodplain Development permit if applicable Show 100- and 500-year flood plains on map. Show stream buffer, areas prone to flooding and stream bank erosion areas.
Karst	Are sinkholes, springs or seeps located on the site? What is the depth to bedrock?	Local buffer requirements may apply and should be shown. Show sinkholes, springs, seeps and other karst features. Show areas with shallow depth to bedrock.
Existing Topography	What is the existing topography? Are there areas with slopes steeper than 20 percent? What are the site's soil types? What is the existing stormwater drainage area and flow path?	Show existing topography, identify areas with slopes greater than 20 percent. Show site soil type. Show areas with erodible soils. Show gullies, swales, ditches, etc.
Ponds	Are there existing ponds on or adjacent to the property? Does the pond provide recreational benefits? Does the pond provide flood detention benefits? What is the condition of existing ponds (i.e., depth of sediment in pond, bank erosion, invasive plants)?	Show all ponds on map, including any existing detention basins.
Vegetated Cover	Is the site forested? Are grassy/prairie areas on the site?	Show forest and prairie areas. Show large trees (>12" diameter).
Existing Property Use	What is the site's current use? What buildings, structures and other impervious surfaces are present? Are there utilities through the site?	Show existing impervious areas and utilities.
Surrounding Property Use	What is the surrounding property use?	Show property boundary and surrounding property uses.

Natural Resource	Questions	Mapping Actions
Groundwater	What are the opportunities for infiltration, and how might it help to maintain base flow? What is the potential for groundwater contamination?	Define how green infrastructure features will provide water quality and help to maintain base flow. Define the effectiveness of green infrastructure features in preventing concentrated contaminants from travelling through the soils and vadose zone to the groundwater.

Table 2.2 Existing natural resource consideration. Source: Adapted from MSD et al., 2009

Site Development Goals, Questions and Methods

Goal	Questions	Methods (To the Maximum Extent Practicable)
Minimize the Generation of Stormwater Runoff	Can land disturbance be minimized? Can additional green space be preserved? Can proposed development be located in already developed areas?	Limit clearing, grading, and earth disturbance. Use clustered development with open space designs. Use narrower, shorter streets, right-of-way and sidewalks. Allow smaller radii for cul-de-sacs. Reduce parking space requirements. Preserve and protect forested areas, especially areas with large trees. Show tree preservation areas on plans. Allow for shared driveways and parking areas. Provide incentives for site redevelopment.
	Can stormwater safely flow overland to buffer areas (i.e., avoid piping)?	Grade to allow stormwater to sheet flow into buffer or conservation easement areas. Limit use of conventional curb and gutter streets, using hybrid curb systems or flat curbs where appropriate. Use grass channels for street drainage and stormwater conveyance. Allow roof downspouts to flow overland into vegetated cover.
	Can stormwater be captured and infiltrated into the ground?	Rainwater infiltration systems. Examples include rain gardens, dry wells and other landscape infiltration methods. Emphasize managing stormwater at the point of generation.
Minimize Erosion of Site Soils	Can land disturbance be restricted to less sensitive areas? Is the development located outside the 100-year flood plain?	Land disturbance SWPPP requirements apply. Avoid grading areas with steep slopes and erodible soils. Limit disturbance areas within the 100-year floodplain.

Minimize Stream Bank Erosion	Is the development located outside the stream bank setback buffer? Does the development warrant engineering channel protection controls (because of development size or stream bank erosion problems)?	Development should not encroach municipality's stream bank buffer. **Show stream buffer on preliminary plan.** MSD rules and regulations require channel protection detention for the 1-year 24-hour rainfall event. **Show detention basin on preliminary plan.** Locate outside limits of 100-year floodplain. If feasible, stabilize the stream bank using other engineered methods.
Minimize Impact Environmentally Sensitive Areas	Does the development plan avoid sensitive areas?	**Untreated stormwater should not discharge into sinkholes, wetlands, fishing ponds, and other sensitive areas.** Provide a buffer around sensitive areas. Preserve the existing stormwater flow path.
Adequately Treat Stormwater Before Discharge	Does the site development plan utilize stormwater credits? Does the development plan show structural BMPs? What is the acreage of drainage to the BMP? Will the BMP be above or below ground?	Show locations of any (non-structural) "credit" areas and show locations of any structural stormwater BMPs on preliminary plan. Locate structural BMPs outside the 100-year flood plain. Provide a BMP drainage area map. Only certain wet ponds and wetlands may be used for drainage areas larger than 10 acres. Encourage stormwater credits, managing stormwater at the point of generation, and aboveground stormwater BMPs. "Regional BMPs" and underground BMPs should be avoided when possible. As a rule of thumb, the development should provide 35% minimum green space for a structural BMP(s).
(Bold items reflect {MSD} project requirements)		

Table 2.3 Site deveolpment goals, questions and methods. Source: Metropolitan et al., 2009

Open Space and Green Infrastructure

When municipalities make decisions regarding park and open space planning, they typically face three decisions associated with incorporating parks or open space policies into a plan:

- Where are new parks needed?
- What should be done with existing park land?
- How do we better connect people and parks?

Stormwater management should play a role in all of these decisions. When preserving new park land and open space, municipalities should identify natural areas that already function as natural green infrastructure stormwater management systems.

A typical example of a natural green infrastructure stormwater system would be stream corridors and associated floodplains, wetlands and woodlots. All can provide valuable water quality and flood management services as well as wildlife habitat and passive and active recreational opportunities for citizens.

For existing active use park lands, designed green infrastructure stormwater management will require careful planning and installation, such as playgrounds and athletic fields, so as not to create public hazards and liability for the municipality. Rain gardens, infiltration trenches and swales may all work well in public access areas, but steep-sided detention ponds for example could potentially be hazardous.

A popular integration tool is the use of hybrid curb-sides, using conventional curb and gutters along with swales. The curbs drain to the adjacent swales and provide an edge to protect the pavement, gives snow blades an edge, and keeps cars off the infiltration area. Public works employees seem to like these in contrast to typical swales, for example.

Figure 2.18 Residential Rain Garden - Parkville, MO.
Source: Shockey Consulting

Communities that acquire park land in floodplains must consider how to develop the property to tolerate occasional flooding. Potential maintenance costs associated with how the floodplain property is developed should be included in the decision making process. The use of facilities that are less severely affected by floods, such as non-habitable buildings and structures, is more appropriate.

Utilities and Green Infrastructure

If a community develops utility management policies as part of the comprehensive plan, the community can proactively determine where future utilities can be placed to minimize the impacts on the natural green infrastructure.

The following factors should be considered when planning utility corridors in floodplains:

- Wastewater pipes can leak or break allowing untreated sewage to be discharged to streams.
- Disturbance during construction may result in sediment and other pollutants being carried into streams.
- Installation in major right-of-ways is often too difficult, given the number of utilities therein.
- Construction techniques should be reviewed when putting utilities in stream corridors. Often it is not necessary to "clear cut" a 100-foot swath.

  Native vegetation or other stream restoration practices can be effective in minimizing pavement impacts after construction.
- Utilities can be damaged during flood events.

Green infrastructure opportunities relevant to utility corridors include:

- Distributed infiltration practices, which can minimize the size of collection (grey infrastructure) systems by preventing runoff from entering pipes upstream of the floodplain. Smaller pipes can mean smaller disturbance and in combined sewer communities, infiltration can help prevent overflows during storm events.
- Stream Protection Corridor Zones, or SPCZs, are an administrative control for protecting the riparian area and the floodplain through specifying the allowable type and conditions of utility work in the zone. SCPZs formulas can be a set arbitrary distance from stream center line or can be derived from regional analysis of stream meander width to drainage basin size. Deriving the distance allows the user to enter a drainage area into the formula for a given point in a watershed and yields a width that is appropriate to allow the stream to naturally meander over time. SCPZs are further discussed in Chapter 4.
- Utility corridors typically require maintenance access. Access roads can serve as managed open spaces for use as trails and wildlife habitat, both along streams and in the uplands of a watershed.
- Funding opportunities for natural resource improvements in utility corridors can be in the form of easement fees from private utilities or voluntary donation depositories at trail heads.
- If green infrastructure is going to be placed in existing utility corridors, communities should consider whether any upgrades of existing utilities are needed before installation.

Transportation and Green Infrastructure

Transportation systems, such as roads and parking lots, impact the quantity and quality of stormwater runoff. Large impervious areas created by roadways and parking lots increase the quantity of runoff in urban and suburban areas. Pollutants such as oil, grease, heavy metals, thermal load, salt and sediments will decrease water quality as stormwater runoff from streets, highways and parking lots carries these pollutants into surface water and groundwater.

Municipalities can outline goals, policies and plans to reduce both the volume of stormwater and quantity of pollutants entering water systems from roadways. *Controlling Non point Source Runoff Pollution from Roads, Highways and Bridges* (www.epa.gov/owow/nps/roads.html) is one resource that addresses the impacts of stormwater runoff from transportation systems on water quality. Green infrastructure strategies include:

- Reducing the quantity of impervious surface.
- Allowing narrower street width requirements in residential areas.
- Limiting commercial developments to a maximum amount of parking spaces in addition to minimums.
- Allowing shared parking for adjacent facilities that operate at different hours.
- Allowing vegetated swales or eliminating minimum slope requirements.
- Capturing and treating stormwater at the source.
- Allow or require stormwater control measures in the public right-of-way for all utility or public capital improvement projects.
- Allow or require low-maintenance, hardy, native landscaping on the roadway right-of-way to improve infiltration and filter pollutants.

Figure 2.19 Vegetated Swale - MN.
Source: Ramsey-Washington Watershed District - BMP Descriptions

Housing and Green Infrastructure

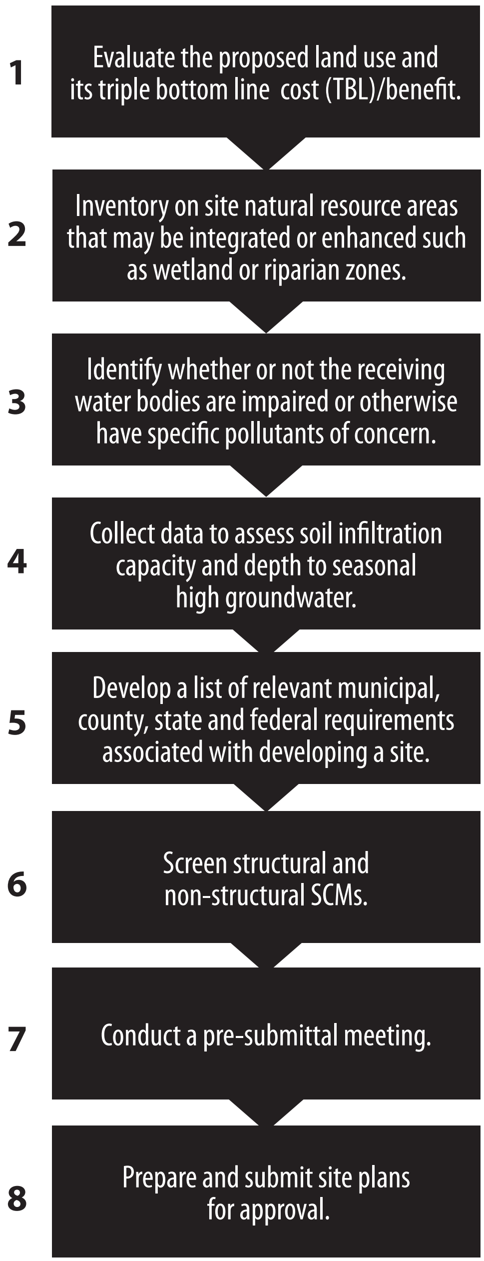
Municipalities can incorporate green infrastructure principles and tools into housing policies outlined in the comprehensive plan. Policies can be developed for the site scale and encouraged at the individual lot scale. Policies that encourage the use of stormwater control measures during the development and redevelopment reduce the stormwater runoff off site which can have positive impacts on local waterways, quality of life and economic development. Details about typical stormwater control measures that are used can be found in Chapter 5.

Create Green Infrastructure Submittal Checklists

Green infrastructure checklists for submittals can help in the preparation and review of plans.

Checklist items may include:

- Evaluate the proposed land use and the triple bottom line cost/benefit against relevant municipal, watershed and regional plan.
- Inventory on-site natural resource areas that may be integrated or enhanced such as wetland or riparian zones.
- Identify whether or not the receiving water bodies are impaired or otherwise have specific pollutants of concern.
- Collect data to assess soil infiltration capacity and depth to seasonal high groundwater.



- Develop a list of relevant municipal, county, state and federal requirements associated with developing a site. Evaluate each for green infrastructure constraint such as prohibitions against stormwater management in the right of way, requirements for direct connection of downspouts to storm sewers and public access restrictions to designated stormwater management areas.
- Screen structural and non-structural stormwater control measures for applicability to the proposed land uses, citing why or why not some stormwater control measures were retained for further consideration.
- Conduct a pre-submittal meeting with local regulatory and plan review personnel to discuss green infrastructure and any atypical design elements.
- Prepare and submit site plans for approval. Include a narrative and supporting graphics showing how the proposed plan compares to issues identified in the checklist.

Additional Green Infrastructure Municipal Planning Opportunities

Municipalities may believe that integrating stormwater management policies and plans into the comprehensive planning is too complex for a small department with limited staff or for municipalities that may not have a planner. In these municipalities, planning can occur at many different levels that may not be as formal as a comprehensive planning process.

The following are some additional examples of planning processes that can incorporate stormwater management into its process.

- Strategic planning or community visioning.
- Budgetary planning.
- Capital improvement program.

Incentives and Credits for Green Infrastructure and Low Impact Development

Incentives and credits can be used to encourage developers to preserve natural resources on their sites, to use st to improve runoff water quality and volume of stormwater runoff. Incentives and credits can also be given to property owners who retrofit green infrastructure improvements on their property. Some incentives for developers may include:

- Allowing an increase in the number of residential lots by reducing lot size requirements. This allows a typical or higher density development the added benefit of increasing the open space and area of resource protection.
- Allowing an increase in the amount of square footage for a commercial development. The footprint of the development is often required to be smaller, but the overall square footage of the development can be larger. This is an incentive to build multiple story units.
- Providing assurances of higher priority and reduced review times. This is accomplished by establishing criteria for receiving the assurances. Some criteria may include providing certain levels of runoff treatment, providing stream buffers and preserving other natural resources beyond levels required in the community's ordinances.
- Providing recognition in a locally-defined program would publicize the efforts of the developers that are employing green infrastructure and low impact development practices. The development could receive an official title such as "Certified Green Development."
- Providing reduced fees or credits. There are many ways credits can be used to reduce the fees paid by developers such as reducing plan review fees for new or redevelopment. However, stormwater utility fees may already be underfunded, making credit programs difficult to implement.
- Education and outreach programs. Programs describing the cost benefit of green infrastructure in context of land development can be provided free of charge.

Some incentives for individual property owners include:

- Providing reimbursements. Some communities have reimbursement programs where individuals receive money for installing stormwater control measures on their property. Many of the reimbursement programs provide a cost-share so that the individual pays for the installation up front and then applies for reimbursement.
- Providing materials and supplies. Some materials that help improve water quality on a property can be provided to property owners at a free or reduced cost. Rain garden planting kits and rain barrels are the most common materials that are provided.
- Providing credits on utility fees. Credits also can be achieved through reduced stormwater utility fees paid by the residents or property owners who have constructed on-site improvements that address site runoff or runoff treatment. Because credit programs may not fully compensate the residents for their investment, this incentive may need to be coupled with other programs described herein.
- Providing recognition. Similar to the incentive provided to developers, property owners can receive recognition by planting a rain garden in their yard. They would then be able to post a sign in their yard and could be added to a database of local rain gardens.

2.3 Green Infrastructure Planning at the Watershed Scale

A watershed is the geographic area where all water running off the land drains from the highest ridges to a given stream, river, lake or wetland. Watershed scale planning can be similar to regional planning (Section 2.4), but areas are specifically defined by their watershed boundaries.

A watershed approach to planning is typically used as a framework where managing water resource quality and quantity within a specified drainage area is the primary goal of the planning agency. Many watersheds have established management programs that encompass multiple towns and other incorporated areas, but also address land use in unincorporated rural areas.

Because a watershed can include multiple government jurisdictions, a watershed management framework can be used to create intergovernmental land development and stormwater runoff management plans (Brown, Claytor, Holland, Kwon, Winer, & Zielinski, 2007).

Figure 2.20 A watershed diagram. Source: Pennsylvania Department of Environmental Protection.

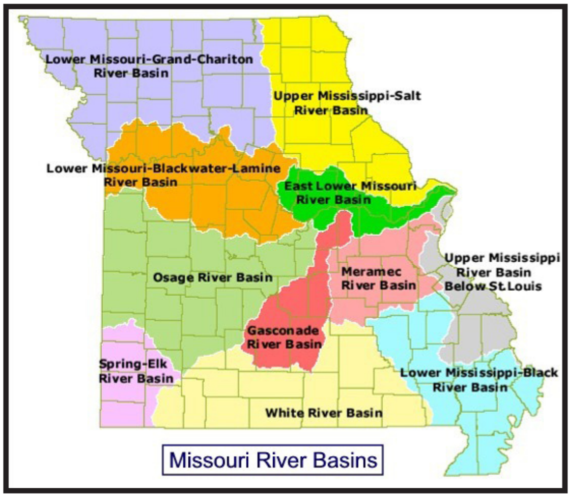


Figure 2.21 Missouri River Basins.
Source: Laclede County SWCD, MO

Watershed-scale planning structures the intergovernmental relationships within a basin or smaller watershed area to promote common interests in water resource management policies and practices. As municipal and site based planning occur, the objectives of those smaller scales should remain consistent with the broader objectives outlined in the regional and watershed planning.

Watersheds can be defined by their hydrological unit codes, or HUC. As of 2010 there are six levels in the HUC hierarchy, from two to 12 digits long, referred to as regions, sub regions, basins, sub basins, watersheds and sub watersheds. Figure 2.21 shows Missouri major river basins.

Watershed plans typically include assessments of current conditions with identification of sources of impairment, estimates of load reductions of identified source impairments to achieve water quality goals, management measures to achieve these goals and estimates of potential capital cost associated with the recommended management measures.

EPA has identified nine elements of a watershed management plan that should be addressed in order to ensure the plan's success:

1. Recognize the causes of impairment and pollutant sources.

2. Estimate pollutant load reductions needed to meet water quality goals.

3. Design management measures that will be needed to achieve load reductions.

4. Estimate amount of technical and financial resources needed and the sources and authorities needed to help.

5. Inform and educate stakeholders to enhance understanding of the project plan and encourage early and continued participation in selecting, designing and implementing nonpoint source management measures.

6. Develop an implementation schedule to manage implementation that is reasonably expeditious.

7. Set interim milestones for measuring implementation progress.

8. Develop criteria for measuring load reductions and progress toward attaining water quality standards.

9. Create monitoring program in accordance with the schedule, implementation milestones and assessment criteria to validate design plan.

2.4 Green Infrastructure Planning at the Regional Scale

Comprehensive land use plans can encompass large geographical areas, address a broad range of topics and cover a long-term time horizon. Regardless of scale, the goal of the process is to determine community goals and aspirations in terms of land use. The outcome is the public policy foundation for infrastructure and economic development.

Regional scale planning is necessary to manage shared resources, such as water or air, so that individuals or groups of individuals acting rationally but in their own self-interest do not degrade or deplete these resources beyond their practical use by others downstream or downwind. As such, regional scale planning areas are defined by political or geographic boundaries that can encompass multiple watersheds, counties, cities and towns. At this scale, no specific entity below the state level is typically regulated, although stakeholders share a common interest in one or more elements of land use planning in their region. See Figure 2.22.

Many varieties of regional agencies have been formed to define region-wide development concerns, prescribe regional strategies and coordinate local actions (Porter, 1997). Examples include state agencies, regional transportation planning agencies and regional economic development corporations.

In Missouri, there are three large metropolitan planning organizations that act as clearinghouses for planning issues and policies in their areas:

- Capital Area Metropolitan Planning Organization.
- East-West Gateway Council.
- Mid-America Regional Council.

In counties that are prohibited from making zoning laws or in small communities with limited planning resources, it may be beneficial to work with an metropolitan planning organization or other regional planning commission (www.macogonline.org/) or refer to guidance from organizations such as the International City / County Management Association (ICMA, http://icma.org/en/icma/home) and the National Nonpoint Education for Municipal Officials Network (http://nemonet.uconn.edu/).

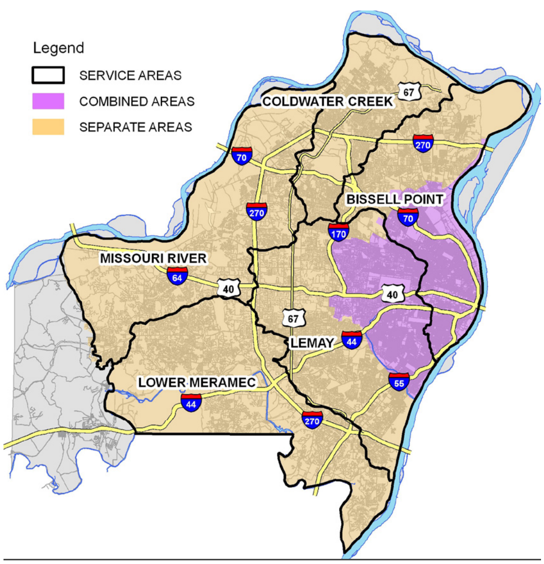


Figure 2.22 St. Louis Area Sewersheds.
Source: Metropolitan St. Louis Sewer Distrct

Regional Planning and Green Infrastructure

In context of green infrastructure, regional planners need to consider TBL costs and benefits to better integrate infrastructure at the regional scale. Example regional green infrastructure can include park systems, transportation networks, water and sewer districts and energy utilities.

Regional park and trail systems and regional transportation networks can be designed to help provide pedestrian connectivity, improve public health, preserve natural resources and wildlife habitat, integrate floodplain and stormwater management and stimulate economic development.

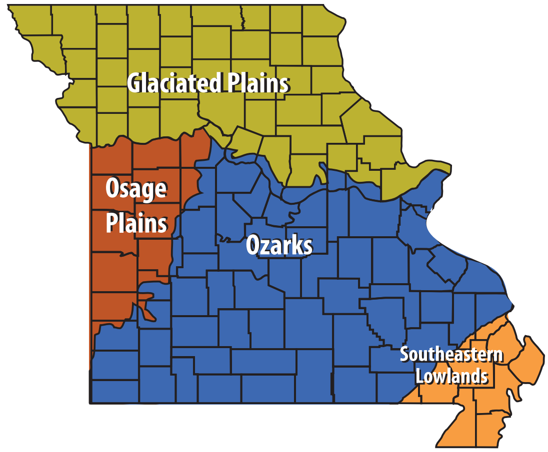


Figure 2.23 Physiographic regions of Missouri.
Source: Department of Natural Resources.

2.5 Physiographic Regions

It is a common misconception that Missouri is home to one soil type – clay. Yet, Missouri is one of the most geologically diverse states in the nation. And its soil types are diverse as well. It's true that urban soils tend to be more compacted and therefore exhibit a higher percentage of clay in areas. However, undisturbed areas can be quite diverse in soil type and they tend to be more permeable without compaction.

Physiographic regions are broad-scale subdivisions based on terrain texture, rock type and geological structure and history. Missouri contains three primary physiographic regions - the Dissected Till or Glaciated Plains, the Ozarks and the Southeastern Lowlands. The Ozarks region is subdivided into the Osage Plains and the Ozarks with several additional subdivisions (DNR, 2002).

Each physiographic region is defined by unique geological strata, soil type, drainage patterns, moisture content, temperature and degree of slope. These conditions often dictate the predominant vegetation and can have significant affect on runoff management techniques.

Dissected Till or Glaciated Plains

Located in the northern part of Missouri, the Dissected Till or Glaciated Plains was created by large glaciers of ice. The topography consists of rolling hills dissected by streams that typically drain south to the Missouri River.

The soils consist of easily erodible glacial tills of clay, silt, sand, gravel and boulders in widely varying amounts. The glacial till has low permeability with limited infiltration capacity. Furthermore, the region is extensively row cropped for the production of corn, soy beans and other grains. The combination of these two factors lead to high suspended sediment loads in many streams and rivers (Vandike, 1995).

Osage Plains and the Ozark Highlands

The Ozarks contain the Osage Plains and the Ozark Highlands. Part of the Great Plains of America, the Osage Plains are relatively flat with thin soils overlying limestone, shale and sandstone bedrock. Runoff in this area is rapid and there is very little groundwater recharge (Missouri, 2002).

Agriculture in the region is a mixture of grain crops and livestock. Coal mining is also important in this region.

The Ozark Highlands is known for its steep hills and rocky soil. It is the largest region in the state and tourism is a large part of the economy. Many people visit the Ozarks to see its beauty, rugged hills, caves, lakes, springs, rivers and forest.

The Ozarks contain large areas of karst topography. Karst topography is formed where the limestone bedrock is soluble. Over time, surface and subsurface water create solution cavities, allowing runoff to enter groundwater and springs quickly with little or no filtering from passage through soils. Aquifers in these areas are vulnerable to pollutants carried in stormwater runoff.

The remainder of the Ozarks region is an area of uplifted bedrock that has variable terrain compared to the other regions of Missouri. Soils are relatively thin and derived from weathered limestone and are generally well-drained and runoff is moderate (Missouri, 2002).

Southeastern or Mississippi Lowlands

The Southeastern or Mississippi Lowlands, also known as the bootheel of Missouri, was once a swamp. The rich, black soil and temperate climate attracted farmers who drained much of the swamp to grow cotton, rice and soybeans. The area is relatively flat, with relatively well drained soils, increasing the effectiveness and ease of installation for many structural stormwater control measures relative to other regions of the state (Missouri, 2002).

Alluvial River Plains

The Alluvial River Plains are relatively small geographic regions located along Missouri's two great rivers: The Missouri River and The Mississippi River. Missouri's two largest cities are partially located in this region: St. Louis and Kansas City.

Figure 2.24 St. Francois State Park - rock outcrop. Photo by Scott Myers, Missouri Department of Natural Resources.

Introduction to Case Studies

Throughout the U.S., there is a growing recognition of the benefits green infrastructure provides to communities. Many municipalities and other jurisdictions have begun to effectively incorporate these practices. The following case studies were selected to showcase both site and landscape scale GI projects which have successfully been implemented. Additional case studies are included in Chapter 6. Readers are encouraged to follow the links or titles provided for each case study to learn more about these projects.

Case Study: 16 Better Site Design Principles (CWP, 2007)

Better Site Design Principles - Center for Watershed Protection

Conservation of Natural Areas

1. Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas and promoting the use of native plants. Wherever practical, manage community open space, street right-of-ways, parking lot islands and other landscaped areas to promote natural vegetation.

2. Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access and provide fire protection. A fixed portion of any community open space should be managed as protected green space in a consolidated manner.

Lot Development

3. Promote open space development that incorporates smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space and promote watershed protection.

4. *Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front setback requirements to minimize driveway lengths and reduce overall lot imperviousness.

Photos source: Center for Watershed Protection, 2007

5. *Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.

6. Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together.

Residential Streets and Parking Lots

7. Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking and emergency maintenance.

8. Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.

9. Residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk and vegetated open channels. Utilities and storm drains should be located within the pavement section of the right-of-way wherever feasible.

Photo source: Center for Watershed Protection, 2007

10. Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.

11. Where density, topography, soils and slope permit, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.

12. *The required parking ratio governing a particular land use or activity should be enforced as both a maximum and a minimum in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance taking into account local and national experience to determine if lower ratios are warranted and feasible.

13. *Parking codes should be revised to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.

14. Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes and using pervious materials in the spillover parking areas where possible.

15. *Provide meaningful incentives to encourage structured and shared parking to make it more economically viable.

16. Provide stormwater treatment for parking lot runoff using bioretention areas, filter strips or other practices that can be integrated into required landscaping areas and traffic islands.

* Practice likely requires action at the municipal level and may not be within the control of the design team.

Case Study: Assessing Conservation Value of Natural Areas

In context of sustainable site design, natural resource inventories can also collect information to better assess conservation value of natural areas (Ratcliffe et al 1997):

Size:	Importance to nature conservation increases with size. Larger areas of trees have higher priority than smaller areas.
Diversity:	The more diverse, the better. Areas with greater numbers of species types of flora and fauna have higher priority than those lower numbers.
Naturalness:	The less anthropogenic modification, the better. Recently timbered areas have lower priority than older timber management stands.
Representation:	Natural communities not well represented locally have higher priority than those that may be common. Although a type of natural community may not be endangered, or threatened, it may not be common in the local area.
Rarity:	Sites containing rare elements have higher priority. Endangered species habitat is one example.
Fragility:	Unusually fragile systems require higher degrees of protection. For example, vernal pool wetlands are more fragile than an open water marsh wetland.
Typicalness:	Maintaining good examples of common species is good. Tree surveys can be performed to improve timber stands and remove diseased or dying specimens or to flag trees to be preserved in areas of development.
Recorded History:	Researching is better than supposition. Using local knowledge, published data or aerial photos can help assess pre-developed conditions and check for degradation of natural resource areas.
Landscape Position:	Contiguous features are better than fragmented ones. Applied to development, bridges or bottomless culverts provide better connectivity within stream habitat than piped culverts.
Potential Value:	Diminished sites that can be restored to previous condition are important. Former wetland areas may have been drained for agriculture and may be readily restored pending proposed development patterns.
Intrinsic Appeal:	Protection of conspicuous specimens such as large live oaks may increase public awareness for nature conservation. Specimen trees also provide signature opportunities for marketing purposes.

Case Study: Campus Master Plan Planning Principles

University of Missouri 2010 Campus

1. Reinforce the University mission and values: organize facilities and places to promote MU's mission and values.

2. Pride of the state: express the importance of the campus to the state, nation and world.

3. Diversity with the unity: create and maintain campus settings that bring together the diversity of people, heritages and culture.

4. Strong 'sense of place': make the campus a distinctively meaningful and memorable place for all members of the university community and for the citizens of Missouri.

5. Respect natural and architectural heritage: Design facilities to respect the scale, materials and textures embodied in the historic architecture and natural landscape of the campus.

6. Environmental sustainability: Embrace suitable strategies in promoting sustainable sites, water efficiency, energy and atmosphere, materials and resources and indoor environmental quality.

7. Recruitment-retention: emphasize the qualities of the campus that help attract and keep students, faculty and staff.

8. Planning and design integrity: provide facilities and grounds that meet the functional needs of the institution and that comply with the intent of the design principles to provide an overall aesthetical and pleasing campus experience.

9. Enhance community spirit: locate campus functions in close proximity to enhance scholarly activities and social interaction within a safe and secure campus.

10. Allow for prudent expansion of campus functions: provide for facilities expansion in ways that respect neighbors and effectively utilize limited land resources, while conserving and protecting natural resources.

11. Pedestrian dominance: maintain a pedestrian-dominant campus recognizing and gracefully accommodating the need for bicycles and vehicles.

12. Transportation and vehicle circulation: maintain a safe, functional and aesthetically compatible system of transportation, vehicle circulation and parking.

13. Respond to accessibility needs: continue the tradition of providing optimal access to persons with disabilities.

14. Facilities and grounds stewardship: preserve the quality and utility of existing facilities for sustainable use of established resources.

(University of Missouri, 2011)

Case Study: Bear Creek Prairie

Columbia, MO

The Bear Creek Prairie development is located in Columbia and is planned and designed using the concepts of conservation design. To facilitate the concept the property was ultimately zoned as a planned unit development where the owner could propose integrating multiple land uses at one property. The owners goal for the development was to build a community using ecologically sensitive development techniques and construction practices to preserve portions of an existing remnant prairie.

After years of consideration the owners and the Missouri University Department of Architectural Studies, assembled an integrated planning team to conduct the initial design charrette. The charrette included planners, architects, natural resource specialists, engineering professionals and home builders from around the country. To obtain a larger range of suggestions and ideas, the owners also included city officials, potential residents, neighbors, other university faculty and state organizations.

- Cluster the homes around common areas to create a setting that is conducive to resident interaction.
- Create quality homes that are visually interesting, in a moderate price range, with low utility costs and minimal maintenance.
- Have a range of unit sizes and styles, such as townhomes, cottages and flats.
- Use all feasible "green" building techniques to create a healthy living environment.
- Preserve a significant portion of the land for native habitat and wildlife as well as for the residents and future generations.

The culmination of the charrettes shaped the design which follows the principles of the conservation community concept, where homes are generally clustered around common green spaces while minimizing infrastructure. This encourages interaction among residents while retaining use of wooded and open areas for trails, gardens, gathering areas and other amenities (Bear Creek Prairie, 2011).

Proposed Bear Creek Prairie Project, Columbia, MO.
Image Courtesy of Andy Guti.

Case Study: Big Darby Watershed

Franklin County, OH

Brown Township. Big Darby Accord. Source: www.brown.twp.franklin.oh.us/big_darby_accord.htm.

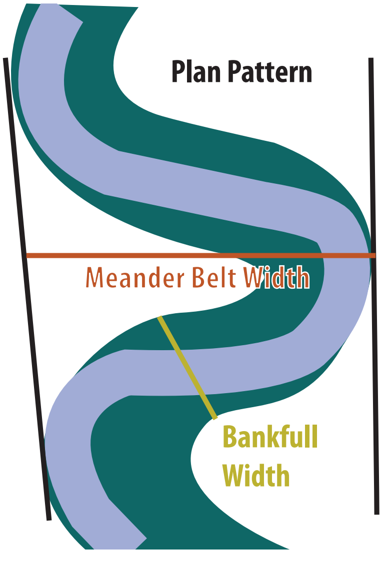
Conservation Planning

The Big Darby Accord performed a qualitative assessment of hydrogeologic, hydrologic and environmental criteria to prioritize the sensitive areas in their planning for the value in maintaining a healthy watershed and to begin to recognize degrees of sensitivity as they relate to proposed future land uses. Based on existing conditions, areas were ranked as high, moderate, low or lacking environmentally significant factors for purposes of watershed health. All areas of high, moderate and low environmental sensitivity should be considered as having important values worthy of preservation.

High Sensitivity Area

- Resources that relate to protecting water quality, both surface and groundwater or critical habitat areas recognized by federal or state agencies.
- Areas with well drained, sandy soils exhibit a high degree of flow exchange or high groundwater pollution potential due to hydrogeologic characteristics.
- Linear features such as 100-year floodplains or meander belt widths for their recognized value in maintaining healthy waterways, providing habitat areas in streams and along water ways and minimizing flood damage and personal property loss.

Meander Width Ratio of Natural Channels



$$\text{Meander Width Ratio} = \frac{\text{Belt Width}}{\text{Bankfull Width}}$$

Moderate Sensitivity Area

- Moderate degree of flow exchange between ground and surface water.
- Wooded areas of three or more acres were assigned a medium value to emphasize their importance in providing habitat areas and creating a network of green corridors

Low Sensitivity Area

- Contain hydric soils.
- Land within the 500 year floodplain and beyond the 100 year floodplain boundary.
- Wooded areas between one half and three acres (EDAW, 2006).

Big Darby – Land Use Planning

The Big Darby Land Use Plan is an example of a watershed land use plan based on a multi-jurisdictional district accord in the Big Darby watershed in Franklin County, Ohio.

The goal of this plan was to balance the needs of development with protection and conservation of a highly valuable resource, the Big Darby Creek.

Land use strategies included:

- Focus on higher density development in a designated town center.
- Incorporate additional areas of higher density adjacent to where utility service is already available.
- Provide designated conservation development areas where future sewer service is unlikely.
- Incorporate sensitive natural areas that should be targeted for protection in Tiers 1, 2 and 3.

The Big Darby Accord also provides definitions and allowable uses of open space. The accord provides guidance on where to locate open space relevant to environmentally sensitive features, topography and other land use features. Allowable open space uses are divided into three categories:

- Permitted uses: passive recreation including trails, vegetative enhancement, reforestation, removal of damaged or diseased trees, stream bank stabilization/restoration, public utilities, non-structural best management practices, minor disturbances related to the construction of the permitted use, land application of waste water effluent (outside SCPZ or wetlands).
- Conditional uses: active recreational uses limited to multi-purpose fields, playgrounds.
- Prohibited uses: grading activities and land uses commonly associated with a development process, development.

(EDAW, 2006)

Case Study: Parks and Stormwater Management

English Landing Park

English Landing Park in Parkville, MO is the largest park in the city's relatively young park system, it is nestled between the overlooking hills, adjacent to the city's downtown historic district and the Missouri River. The 68-acre facility has several amenities including 3 miles of walking trails, a large playground area, boat ramp, picnic shelters, a disc golf course, in addition to baseball and soccer fields.

English Landing Park attracts a wide variety of users, including bicyclists, walkers, runners, and nature enthusiasts. For the young to the old- there is a recreation outlet for all to enjoy. The park's scenic walking trails and athletic fields are close in proximity and are designed to be flood tolerant for when the river overflows. Green infrastructure elements include:

- English Landing in close proximity to historic downtown district.
- Multi-use trail.
- Flood tolerant vegetation.

English Landing Park. Parkville, MO
Source: Shockey Consulting.

Earl Road flood control facility. Photo Source: Williams Creek Consulting.

- Integrated natural resources into open space.

Earl Road Flood Control Facility

The Earl Road Flood Control Facility located in Michigan City, Ind., is designed to manage regional stormwater quantity and improve water quality control during peak flows. The facility also serves the dual purpose of passive recreation while creating the opportunity to demonstrate the need to manage nonpoint source pollutants prior to discharge in Lake Michigan.

Case Study: St. Louis Great Streets Initiative, 2007

The goal of the Great Streets Initiative is to generate economic and social benefits for communities by providing interesting, lively and attractive streets that serve all modes of transportation.

- Great Streets are representative of their places. A Great Street reflects the neighborhood through which it passes and has a scale and design appropriate to the character of the abutting properties and land uses.

- Great Streets allow people to walk comfortably and safely. The pedestrian environment on, along and near the street is well-designed and well-furnished. The relationship between the street and its adjacent buildings is organic, conducive to walking and inviting to people.

- Great Streets contribute to the economic vitality of the city. Great Streets facilitate the interaction of people and the promotion of commerce. They serve as destinations, not just transportation channels. They are good commercial addresses and provide location value to businesses that power the local economy.

- Great Streets are functionally complete. Great Streets support balanced mobility with appropriate provision for safe and convenient travel by all of the ground transportation modes: transit, walking, bicycling, personal motor vehicles and freight movement.

- Great Streets provide mobility. Great Streets strike an appropriate balance among the three elements of modern mobility: through travel, local circulation and access. The right balance varies with the function of the street and the character of its neighborhoods and abutting properties.

- Great Streets facilitate placemaking. Great Streets incorporate within them places that are memorable and interesting. These may include plazas, pocket parks, attractive intersections and corners or simply wide sidewalks fostering an active street life.

- Great Streets are green. Great Streets provide an attractive and refreshing environment by working with natural systems. They incorporate environmentally sensitive design standards and green development techniques, including generous provision of street trees and other plantings and application of modern storm water management practices.

St. Louis Great Streets Initiative. Learn Share Plan Build.
Source: www.greatstreetsstlouis.net/

Case Study: San Mateo County, California

Source: www.ci.sanmateo.ca.us/

Stormwater Management and Transportation

The San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook provides a variety of ideas for methods to minimize runoff from streets and parking lots, including:

1. Streets including narrower streets and on-street parking.

- Narrow travel lanes.
- Consolidate travel lanes/on-street parking.
- Convert unused asphalt space to stormwater management.

2. Parking lots.

- Shorten stall length and include green space between parking stalls.
- Balance parking spaces with green space.

3. Conveyance.

- Use overland flow to convey stormwater.
- Transform traditional landscape areas to stormwater conveyance (depressed green space).

4. Tree canopy

- Trees contribute to slowing, absorbing and filtering stormwater.
- Other benefits include energy, air quality and economic.

These suggestions should be considered or incorporated into site design/layout to facilitate stormwater management through SCM's. SCM's are categorized by vegetated swale, stormwater planter, curb extension, pervious pavers, green gutter and rain gardens.

(Nevue Ngan Associates; Sherwood Design Engineers, 2009)

Case Study: Complete Streets

Complete streets are designed and operated to enable safe access for all users – cars, bikes, pedestrians and public transportation. Complete street policies direct transportation planners and engineers to consistently design with all users in mind, in line with the elements of complete streets policies. An ideal complete streets policy:

- Includes a vision for how and why the community wants to complete its streets.
- Specifies that 'all users' includes pedestrians, bicyclists and transit passengers of all ages and abilities, as well as trucks, buses and automobiles.

- Encourages street connectivity and aims to create a comprehensive, integrated, connected network for all modes.
- Is adoptable by all agencies to cover all roads.
- Applies to both new and retrofit projects, including design, planning, maintenance and operations, for the entire right of way.
- Makes any exceptions specific and sets a clear procedure that requires high-level approval of exceptions.
- Directs the use of the latest and best design criteria and guidelines while recognizing the need for flexibility in balancing user needs.
- Directs that complete streets solutions will complement the context of the community.
- Establishes performance standards with measurable outcomes.
- Includes specific next steps for implementation of the policy.

(National Complete Streets Coalition, 2005-2011)

Before and after images of Lester Intersection located in Orange Beach, AL. Source: Photovisualization created by the WALC Institute for AARP, www.walklive.org

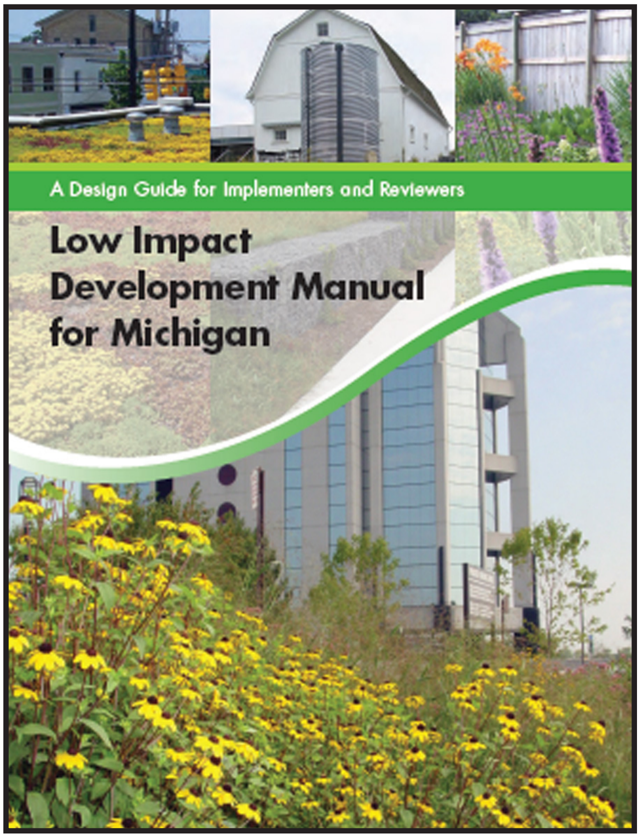
Case Study: SEMCOG Low Impact Development Area

LID Checklist

Southeast Michigan Council of Government has developed a description of the site development process specific to Low Impact Development that provides a checklist of questions to ask. The complete checklist is included in Appendix F, but some example questions that should be asked in the process include (Low, 2008):

- What are the major/minor watersheds?
- What is the state stream use/standards designation/classification?
- Are any streams classified as 303d/ impaired streams?
- Is additional development anticipated for the area that could lead to further opportunities (e.g. partnerships in multi-site or regional water quality or quantity controls)?
- Have the important natural site features been inventoried or mapped?
- Is the development concept consistent with other plans in the community?
- Is development consistent with local existing regulations?
- Will there be concentrated/clustered uses and lots?
- Are the lots/development configured to fit natural topography?
- Does the development connect open space/ sensitive areas with larger community greenways plan?
- Does the development consider re-forestation and re-vegetation opportunities?

(Southeast Michigan Council of Governments, 2008)



Case Study: Stormwater Credit Manuals for Non-Residential Property Owners

Stormwater Credits

Wetland Swale. Source: Olsson Associates

Indianapolis, Ind. and Bloomington, Ill. have similar rate reduction credits for non-residential property owners who discharge a portion of their stormwater directly into a major waterway without sending it through public stormwater facilities or have stormwater control facilities in place to manage runoff and reduce the impact on the drainage system (City of Indianapolis Department of Public Works, 2003; City of Bloomington, Illinois Engineering Department, 2006)

Franklin, Tennessee provides credits to non-residential properties whose impact on the city's stormwater drainage system is significantly limited or has been effectively reduced through specific controls.

The credits available are in four categories:

- Water quantity credits for facilities that convey stormwater runoff.
- Water quality credits for facilities that reduce pollution.
- Education credits for most public and private schools or school systems.
- NPDES stormwater permitted facilities credits for facilities with a Tennessee Department of Environment and Conservation Stormwater Permit on file (Franklin, 2003).

In December 2009, the St. Charles, MO, adopted a green points rating system and incentive program (sustainable zoning ordinance) for non-residential building projects. The program is the product of a partnership formed between the St. Charles and the

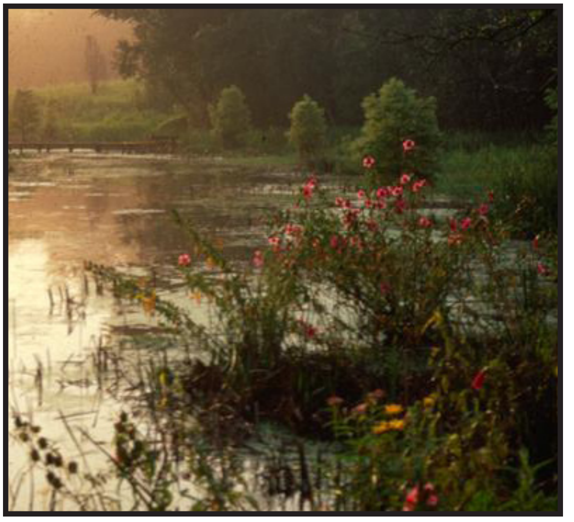
Parking Lot Swale- Kansas City, MO. Source: David Dods

St. Charles County Partners for Progress in early 2009. It is a key piece of a larger effort in the St. Charles to promote environmental sustainability and responsible land use.

The green point rating system is a voluntary program that allows developers and business owners to accumulate points for sustainable building and site enhancements. The number of points accumulated during the planning and development phases determines the types of incentives that are made available for the project. Program incentives include expedited permitting, reduced building permit fees and zoning exceptions that allow for a larger buildable area.

This program is unique in that it does not use LEED designations as a standard and has no requirement for LEED certification. In discussions with small business owners, concerns were expressed that LEED certification requirements would be cost prohibitive. As a result of those discussions, the city devised its own point rating system with the assistance of Partners for Progress and Buro Happold.

This is the first program of its type in the St. Louis metropolitan area and one of a handful in the Midwest region. It has received a great deal of local attention and city staff has presented the program to numerous municipalities and organizations, including the American Planning Association.



Constructed Wetland- Shaw Nature Preserve- Gray Summit, MO.
Source: Missouri Botanical Garden www.shawnature.org

Case Study: Lake of the Ozarks Watershed Alliance or LOWA

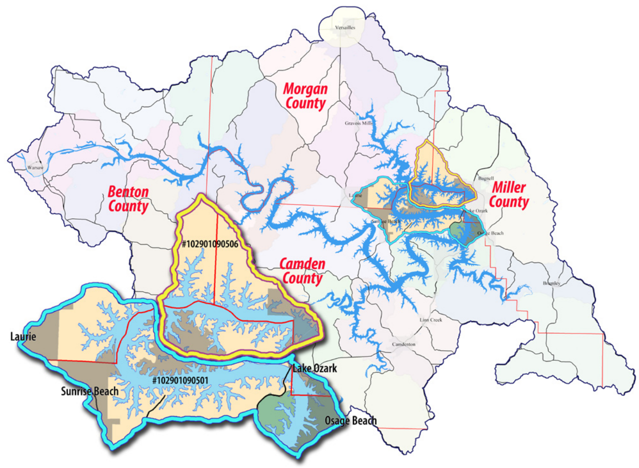
Watershed Planning

The Lake of the Ozarks Watershed Alliance, or LOWA, narrowed to the focus of its watershed management plan from the lake's formidable 14,000 square mile watershed to two densely populated and fast growing areas - The Buck Creek and Lick Branch 12-digit HUCs. Water quality in these watersheds has been affected by waste and pollution from dense populations and largely unregulated development. Stresses include failing septic systems, eroding sediments from land disturbance and other non point source pollution. LOWA adopted the mission statement:

"Citizens will protect, preserve and improve the Lake of the Ozarks, its watershed and natural resources while maintaining our economic, social and environmental health."

The Buck Creek and Lick Branch sub-watersheds encompass the first 18 miles of the main channel of the Lake of the Ozarks, as well as its many side coves. These two areas contain parts of multiple governmental jurisdictions, including Osage Beach, Lake Ozark, Laurie and Sunrise Beach. This densely populated area includes many marinas, businesses, condominiums and single family residences.

Long-term strategy goals are to reduce the bacteria load, the nutrient load and the amount of sediment reaching the lake. A long term goal is to reduce the phosphorus and nitrogen levels to the nutrient criteria levels established for the Lake of the Ozarks by implementing a 20-year strategy to reduce nutrient levels incrementally each year until the nutrient criteria levels are reached. Unlike nutrient loads, the WMP prescribes short term 4-year plans



Lake of the Ozarks watershed and sub-watersheds Buck Creek and Lick Branch. Source: Donna Swall

to reduce sediment loads and an immediate plan to reduce bacteria loads can be reduced significantly within a relatively shorter period of time.

To meet these goals, LOWA plans to establish programs to reduce the amount of wastewater dumped by boats and leaking from inefficient septic tanks, monitor best management practices at land disturbance sites, establish green awards and other incentives for businesses to go beyond their legal requirements and a cost-share incentive program to help citizens create and install rain gardens, rain barrels and LOWA low-impact landscapes. In addition, LOWA established a regional wastewater management system to replace septic systems and address projected economic growth. The WMP also integrates issues beyond water quality, including a designated captain program to improve boating safety and dock slip sizes.

Case Study: Multi-Family Site Design - National Apartments

Urban Redevelopment

National Apartments is located in Indianapolis, Indiana Smart Growth Renewal District. The 2.31 acre site obtained drainage approval for traditional stormwater management design. The project owner contracted both conventional and green infrastructure designs in order to compare and select which provided the most cost and benefit. Both plans were designed to meet city standards for water quality management and peak rate control.

The table below summarizes relevant infrastructure costs for both designs. The proposed green infrastructure drainage improvements on-site consist of 14,000 square feet of permeable paver parking area, 800 square feet of parking lot rain gardens and 500 feet of pervious concrete curb and gutter. It will infiltrate up to 53,000 gallons of stormwater runoff per water quality storm event and control peak release rates from the 10 and 100 year storm events to the two year and 10 year release rate, respectively, prior to discharging to the city combined sewer collection system.

NATIONAL APARTMENTS SITE REDEVELOPMENT
INDIANAPOLIS, INDIANA

Traditional Option **National Apartments Site Redevelopment**			**Sustainable Infrastructure Option** **National Apartments Site Redevelopment**		
Manholes, catch basins, and inlets	$	52,150	Manholes and catch basins	$	5,900
Storm Sewer and Underdrains	$	63,864	GI Storm Sewer and Underdrains	$	10,704
Concrete curb, gutter and walks	$	9,464	Pervious concrete curb, gutter, walks, and parking bumpers	$	28,066
Mechanical Separator and Underground Storage	$	96,000	Bioretention	$	8,000
Light Duty Asphalt pvt (converted area only)(3.5" section @ $90/ton)	$	19,532	Permeable Paver Section	$	60,720
	$	-	Stone Storage under Permeable Paver Section for Water Quality Volume	$	15,225
TOTAL	**$**	**241,010**	**TOTAL**	**$**	**128,615**
			Potential Sustainable Infrastructure Savings	$	112,395

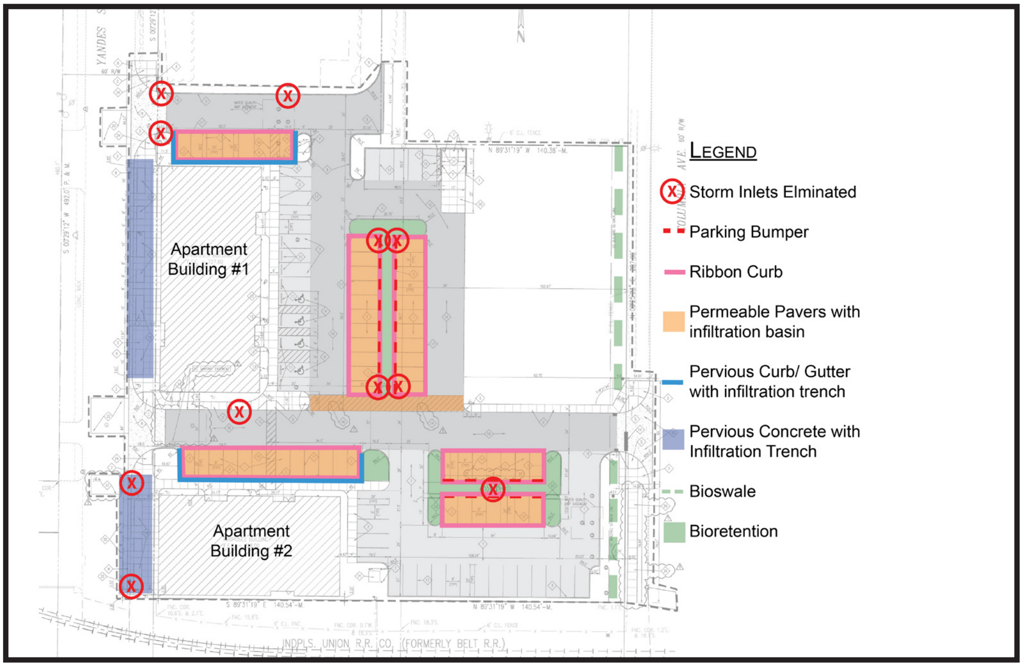
Sustainable Infrastructure Material and Installation cost comparison (only items and quantities altered are included. All other items remain the same between options.)

Comparison based upon best available information for Plans

From Owner:
Site Grading $386,200; Trenching $5,000; Layout $9,500; Paving $93,880; Landscaping $10,000; Temp Fencing $5,130. Total 509,710

Source: Williams Creek Consulting

Green Infrastructure Elements

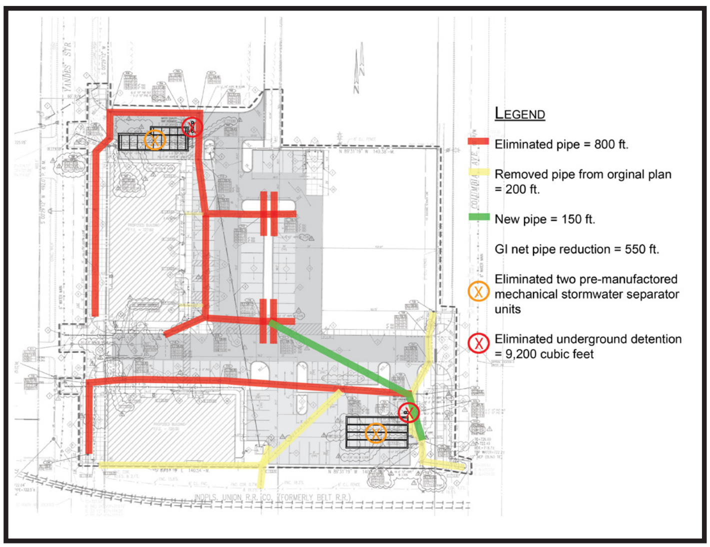


Source: Williams Creek Consulting

Stormwater Collection System Reduction

Benefits:

- Stormwater infiltration – aquifer recharge.
- Eliminated $40,000 in infrastructure cost.
- Added traffic calming elements.
- Increased overall aesthetics.



Source: Williams Creek Consulting

Case Study: Street Retrofit
The Alabama Street Pilot Project

The Alabama Street Pilot Project is in an urban residential neighborhood in Indianapolis, Indiana. The project is located in the city's combined sewer service area adjacent to a boulevard median. The green infrastructure improvements extended and enhanced the existing boulevard median into a previously paved area, introduced bump out rain gardens, pervious concrete curbs and a 2,500 square foot permeable paver pedestrian plaza.

The project was completed as part of a greater Southeast Neighborhood Development revitalization initiative and manages approximately three acres of mixed use runoff. More than 1,000,000 gallons of stormwater are projected to be removed from the CSO annually.

The previously under-utilized median, new plaza streetscape and surrounding rain gardens now function as a neighborhood gathering space, a center to the community, an economic generator to encourage the upkeep of homes which improve the overall neighborhood value and an integrated stormwater management feature. The rain garden bump outs and raised plaza provide traffic calming and safe route for pedestrian connectivity to Lincoln School located across the street from the new plaza.

The retrofit was originally priced at $52,000 to construct and maintain the site for one year. Volunteer labor, material and maintenance agreements through Southeast Neighborhood Development lowered the cost by approximately $8,000.

Source: Williams Creek Consulting

Case Study: Urban Retrofit

Source: Williams Creek Consulting

Ohio Street, Indianapolis, IN

The Ohio Street Green Infrastructure Pilot Project was a partnership effort to improve the East Ohio Street gateway into the downtown area from Interstate 65. The project improved drainage, handicap accessibility and rehabilitated curb and sidewalks to capitalize as a means to continue strengthening the Cole-Noble neighborhood pedestrian environment.

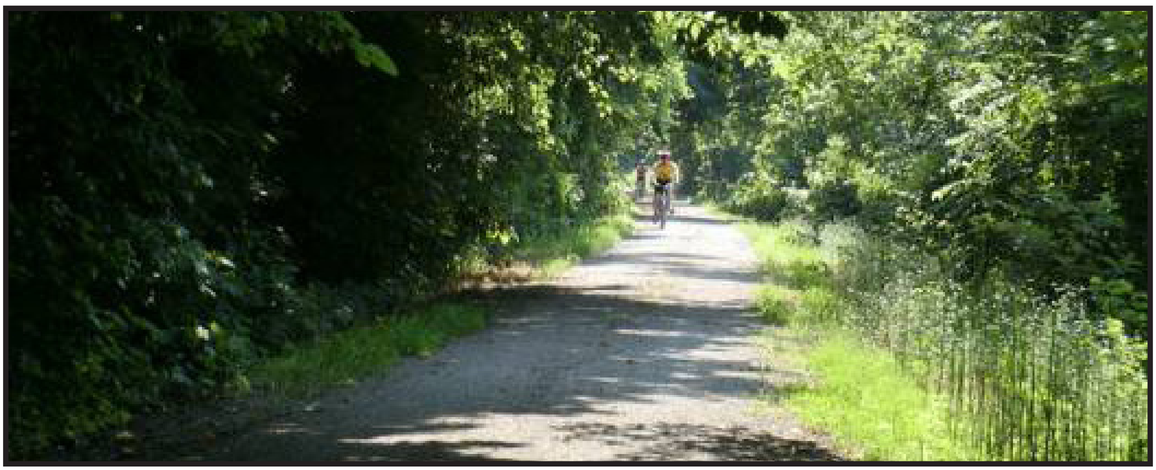
The project incorporated 2,650 square feet of pervious concrete sidewalk, 900 linear feet of pervious concrete curb and gutter and approximately 750 square feet of rain garden. These green infrastructure retrofits manage runoff from approximately 60,000 square feet of impervious surface and will infiltrate more than 1,350,000 gallons of stormwater in a typical year in an area that had no stormwater infrastructure in place, while creating a safer pedestrian corridor.

The $53,000 project included a $5,000 grant from United Water to Indianapolis Downtown Inc. for the construction of the rain garden. The remainder of the project was funded through county-wide stormwater budget.

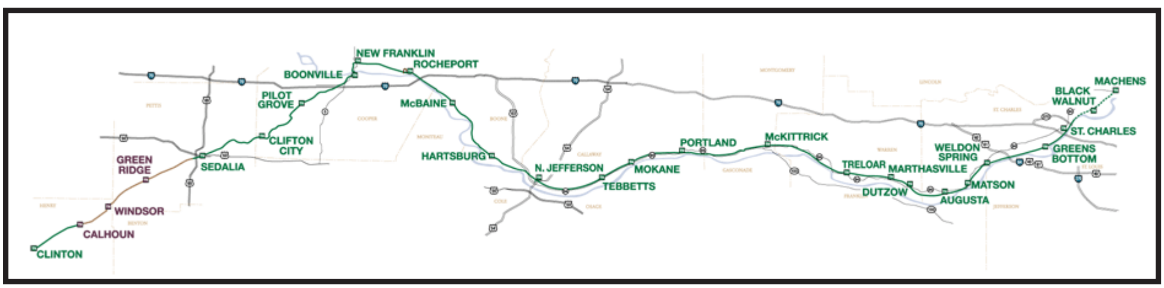
Case Study: Katy Trail State Park

The 225-mile Katy Trail is an example regional park. The trail stretches across most of the state of Missouri, first following the path taken by Lewis and Clark's path up the Missouri River, then through prairies, forests, farmland and small towns. The Katy Trail is the longest "rails-to-trail" project in the country and is ideal for pedestrian travel.

mostateparks.com/page/58605/2011-katy-trail-ride.



Cyclists enjoy a beautiful day on the Katy Trail. mostateparks.com/park/katy-trail-state-park#.



Complete map of the Katy Trail State Park. mostateparks.com/page/57750/entire-trail.

Case Study: MARC - Mid America Regional Council

MetroGreen®

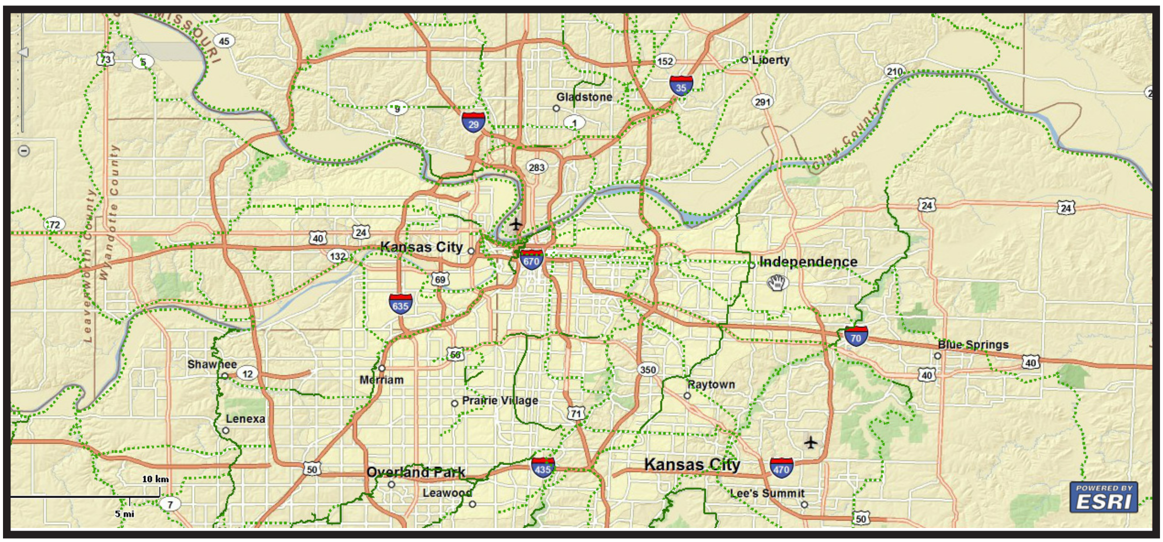
MetroGreen® is an interconnected system of public and private natural areas, greenways and trails linking communities throughout the Kansas City metropolitan area.

The 1,144-mile greenway plan covers Leavenworth, Johnson and Wyandotte counties in Kansas and Cass, Clay, Jackson and Platte counties in Missouri.

The concept of a metro greenway system is not new. MetroGreen extends the "parkways and boulevards" concept of the 1894 Kessler Plan for Kansas City, MO; builds on existing local greenway plans and systems; and is the next step in a project begun in 1991 by the Prairie Gateway Chapter of the American Society of the Landscape Architects. Read more about MetroGreen's history at www.marc.org/metrogreen/about/history.

MetroGreen® identifies more than 75 separate corridors that will form a regional network to connect many of the area's most valuable natural assets. Over 200 miles of the system have been constructed and an additional 100 miles are planned for construction in the next 10 years.

MetroGreen® 2002 defines the critical relationship between environmental stewardship and urban growth management.
(Mid-America. 2002)



Source: Mid America Regional Council, Kansas City MO

3 Green Infrastructure for MS4 Post-Construction Runoff Management

Municipalities that own and manage their own stormwater infrastructure may be regulated under the federal National Pollutant Discharge Elimination System, or NPDES, permit program. The NPDES permit program is a national program designed to reduce pollutants associated with stormwater runoff. This chapter reviews the process for establishing a post-construction stormwater management program utilizing green infrastructure so that regulated Municipal Separate Storm Sewer Systems, or MS4, communities can develop their own program for compliance with state and federal regulations and their MS4 permit. However, this chapter will also be useful to those non-regulated MS4s desiring to incorporate green infrastructure as a matter of good business practice.

Successful implementation of green infrastructure into a stormwater management program plan will require many unique considerations and decisions. Chapter 4 of this guide provides recommendations and examples of how to integrate green infrastructure and other sustainable development concepts into ordinances that support a post-construction runoff management program.

There are many available guides describing the requirements and methods for developing such a post-construction management program. One recommended comprehensive guide can be found in the *Center for Watershed Protection's Managing Stormwater in Your Community, A Guide for Building an Effective Post-Construction Program*.

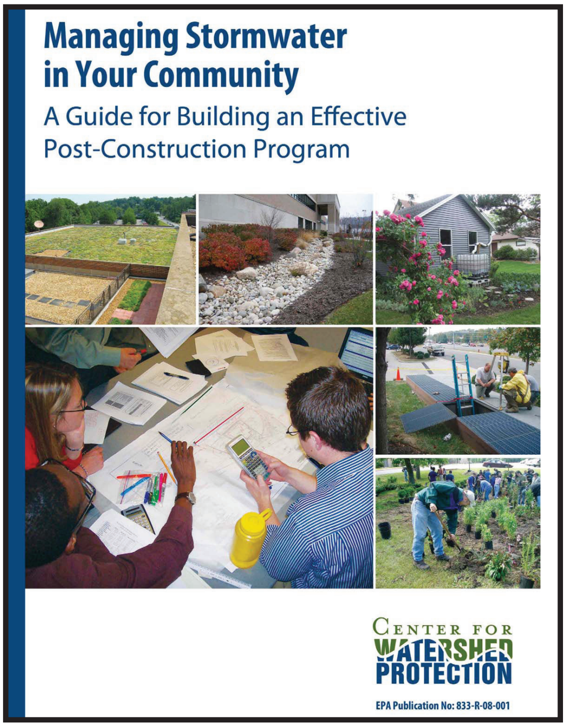


Figure 3.1- *Managing Stormwater in your Community. A Guide for Building an Effective Post-Construction Program*. Source: www.epa.gov/npdes/pubs/stormwaterinthecommunity.pdf

3.1 MS4 Program Requirements

The Missouri Department of Natural Resources is authorized to administer the federal water quality and stormwater laws and regulations through the Missouri Clean Water Law and Revised Statutes of Missouri. As a state agency, the department is responsible for administering the NPDES stormwater permit program for both Phase I and Phase II communities. Phase I communities include those with populations of 100,000 or more per 1990 federal regulation, and Phase II communities include those with populations of 1,000 or more within urbanized areas or 10,000 or more outside of urbanized areas. See the list of regulated municipal separate storm sewer systems (MS4s) at www.dnr.mo.gov/env/wpp/stormwater/sw-phaseii-communities.pdf. For a list of MS4s visit:

- Missouri Department of Natural Resources - Phase II stormwater information: www.dnr.mo.gov/env/wpp/stormwater/sw-phaseii-info.htm
- EPA - National Pollution Discharge Elimination System: www.epa.gov/npdes/stormwater
- EPA, January 2007. MS4 Program Evaluation Guide: www.epa.gov/npdes/stormwater
- NPDES Phase II general permit requirements: www.dnr.mo.gov/env/wpp/permits/issued/R040000.pdf

In Missouri, NPDES permits require MS4 communities to establish a post-construction runoff management program as one part of their comprehensive stormwater management program. At a minimum, a post-construction program must:

1. Determine measurable goals for control of post-construction runoff. Measurable goals gauge program compliance and effectiveness. Goals should reflect the needs and characteristics of the area served by its MS4 and address the water quality management requirements of the permit.

2. Develop and implement structural and/or non-structural stormwater control measures, for meeting established goals.

Non-structural stormwater control measures include planning procedures and site-based stormwater control measures. Planning procedures, such as those described in Chapter 2 of this document, can help minimize impervious surfaces and promote improved water quality.

- Site-based non-structural stormwater control measures include stream buffer setbacks. They also include preserving reparian zones, minimizing areas of disturbance and imperviousness, and maximizing open space.
- Structural stormwater control measures can include practices that infiltrate, evapotranspirate or reuse stormwater.
- Vegetative stormwater control measures are landscaping features that may store, convey, filter, infiltrate or evapotranspire runoff while helping to preserve natural site hydrology, promote healthier habitats, provide recreational opportunities and increase aesthetic appeal. Examples include grass swales, filter strips, constructed wetlands, rain gardens and other bioretention practices.
- Other retention or detention stormwater control measures include wet ponds, dry basins, or multi-chamber catch basins that settle out and retain solids while helping control the rate of runoff to receiving streams.
- Infiltration stormwater control measures facilitate percolation of runoff through infiltration basins, subsurface trenches and pervious pavements to filter pollutants and reduce stormwater runoff quantity.

3. Have an Ordinance:

Develop, revise, adopt ordinances or other regulatory mechanisms requiring the implementation of non-structural and structural post-construction runoff controls to the extent allowable under state, tribal, or local law. Chapter 4 of this guide discusses how to integrate green infrastructure into ordinances.

4. Ensure Adequate Long-Term Operation and Maintenance:

Missouri's Phase II Stormwater Regulations for small MS4s allow three permit options for small MS4 discharges: a general permit, a site specific permit, or a co-permittee option.

The Metropolitan St. Louis Sewer District is the coordinating authority under the St. Louis Metropolitan Small MS4 Stormwater Permit, MO-R040005, issued by the Missouri Department of Natural Resources, Water Pollution Control Program. The district partners with 60 municipalities (co-permittees) to comply with stormwater permit requirements for the St. Louis Metropolitan Small Municipal Separate Storm Sewer System. All co-permittees within St. Louis County operate under a common stormwater management program plan which can be viewed at www.stlmsd.com/educationoutreach/phase2/Phase%20II%20Stormwater%20Plan%20Overview.

"The department encourages cooperation between potential small MS4 applicants when addressing application requirements and in the development, implementation and enforcement of the six minimum measures under issued permits…"
(St. Louis Municipalities Phase II Stormwater Planning Committee , 2008-2013).

In annual MS4 report forms, the department asks the following post-construction questions of MS4 permittees. While it is not necessary to answer "yes" to all questions, answers can help the permittee and the state determine adequacy of the MS4 post-construction program.

F. NEW AND REDEVELOPMENT (POST-CONSTRUCTION) STORM WATER MEASURES

1. Do you have ordinances or other mechanisms to require:
   a. Pre-site design meetings with developers?
      ☐ Yes ☐ No
   b. Site plan reviews for storm water quality of all new and re-development projects of an acre or more?
      ☐ Yes ☐ No
   c. Reasonable mimicking of pre-construction storm water runoff quality in all new development projects of an acre or more?
      ☐ Yes ☐ No
   d. An incremental improvement of existing storm water runoff quality in redevelopment projects of an acre or more?
      ☐ Yes ☐ No
   e. Long-term operation and maintenance of storm water management controls?
      ☐ Yes ☐ No
   f. Retrofitting to incorporate long-term storm water management controls?
      ☐ Yes ☐ No

2. If you have retrofit requirements, what are the circumstances or criteria?

3. What are your criteria for determining which new/re-development storm water plans you will review for water quality? (such as all projects, projects disturbing greater than one acre, etc.)

4. Do your ordinance(s) or other regulatory mechanism(s) allow for:
   a. Non-structural site design options to allow for optimal water quality management in long-term storm water runoff? (such as minimized/disconnected impervious surfaces, cluster housing in exchange for green space, resource protection boundaries, etc.)
      ☐ Yes ☐ No
   b. Structural contemporary, dispersed micro-infiltration/filtration practices such as grassed swales, sand filters, neighborhood roundabouts with rain gardens, etc.?
      ☐ Yes ☐ No

5. Do you require water quality design standards or performance standards, either directly or by reference, be met for new development and re-development?
   ☐ Yes ☐ No

6. Do these design standards/performance measures require pre-construction runoff conditions in new development be met for:
   a. Flow volumes.
      ☐ Yes ☐ No
   b. Peak discharge rates.
      ☐ Yes ☐ No
   c. Discharge frequency.
      ☐ Yes ☐ No
   d. Flow duration.
      ☐ Yes ☐ No
   e. Water quality.
      ☐ Yes ☐ No

7. Please provide the Web address/reference where all post-construction storm water management standards are located.

8. Do your zoning bylaws, ordinances or other regulatory processes allow or enable:
   a. Flexible site design criteria such as smaller lot sizes, reduced setbacks and narrow streets in exchange for functional green space and optimal water quality management in storm water runoff.
      ☐ Yes ☐ No
   b. Established regulatory controls over tree clearance and removal of mature trees or forest stands?
      ☐ Yes ☐ No
   c. Green space residential developments (cluster development or conservation subdivision design)?
      ☐ Yes ☐ No
   d. The location of bioretention areas, rain gardens, filters strips, swales and constructed wetlands in required setback areas?
      ☐ Yes ☐ No
   e. Construction of low impact development, or LID, storm water management techniques (bioretention, swales, filter strips) on land held in common (when appropriate)?
      ☐ Yes ☐ No
   f. Use of permeable paving for parking stalls and spillover parking areas?
      ☐ Yes ☐ No
   g. Limited clearing within the right-of-way to the minimum necessary to construct roadway, drainage, sidewalk and utilities, and to maintain site lines?
      ☐ Yes ☐ No

9. Does your review and approval process include using a water quality checklist?
   - ☐ Yes ☐ No

10. If yes to # 9, please check all of the following checklist items that apply:
    a. Existing and proposed mapping and plans (recommended scale of 1" = 50'.) which illustrate:
       1. Existing and proposed topography (minimum of 2-foot contours recommended).
          ☐ Yes ☐ No
       2. Compatibility with watershed plans, land use plans, comprehensive plans, (contemporary street standards) etc.
          ☐ Yes ☐ No
       3. Perennial and intermittent streams.
          ☐ Yes ☐ No
       4. Mapping of predominant soils from USDA soil surveys as well as location of any site-specific borehole investigations that may have been performed.
          ☐ Yes ☐ No
       5. Boundaries of existing predominant vegetation and proposed limits of clearing.
          ☐ Yes ☐ No
       6. Location and boundaries of resource protection areas such as wetlands, lakes, ponds and other setbacks (e.g., stream buffers, drinking water well setbacks, septic setbacks).
          ☐ Yes ☐ No
       7. Grading plan with location of existing and proposed roads, buildings and other structures.
          ☐ Yes ☐ No
       8. Location of existing and proposed utilities (e.g., water, sewer, gas, electric) and easements.
          ☐ Yes ☐ No
       9. Location of existing and proposed conveyance systems such as grass channels, swales and storm drains.
          ☐ Yes ☐ No
       10. Flow paths.
          ☐ Yes ☐ No
       11. Location of floodplain/floodway limits and relationship of site to upstream and downstream properties and drainages.
          ☐ Yes ☐ No
       12. Location and dimensions of proposed channel modifications, such as bridge or culvert crossings.
          ☐ Yes ☐ No
       13. Location, size, maintenance access and limits of disturbance of proposed structural storm water management practices.
          ☐ Yes ☐ No
       14. Location of proposed community recreation/green space areas.
          ☐ Yes ☐ No
       15. Functional landscape plan.
          ☐ Yes ☐ No

    b. Narrative and supporting calculations describing:
       1. Representative low-impact development techniques (with supporting evidence that technique is compatible with site characteristics) such as on-lot bioretention, tree clearing minimization, minimizing directly connected impervious surfaces, open section roads (also called roadside swales), etc.
          ☐ Yes ☐ No
       2. Zoning, acreage, types and amounts of land uses. (e.g., parking spaces, density, green areas, building footprint areas)
          ☐ Yes ☐ No
       3. Traffic analysis estimating average daily trips for street network and parking requirements.
          ☐ Yes ☐ No
       4. Site impervious area (including effective disconnections).
          ☐ Yes ☐ No
       5. Reforestation and/or resource conservation protection measures.
          ☐ Yes ☐ No
       6. Comparison of proposed development data with allowable density, land use, etc.
          ☐ Yes ☐ No
       7. Development phasing or implementation sequence.
          ☐ Yes ☐ No
       8. Other?

11. How many development and redevelopment project plans were reviewed during the reporting period to assess impacts to water quality and receiving stream protection?

12. How many of the plans identified in # 11 were approved?

13. How many privately owned permanent storm water management practices/facilities were inspected during the reporting period?

14. Location of proposed community recreation/green space areas.
☐ Yes ☐ No
15. Functional landscape plan.
☐ Yes ☐ No

b. Narrative and supporting calculations describing:
1. Representative low-impact development techniques (with supporting evidence that technique is compatible with site characteristics) such as on-lot bioretention, tree clearing minimization, minimizing directly connected impervious surfaces, open section roads (also called roadside swales), etc.
☐ Yes ☐ No
2. Zoning, acreage, types and amounts of land uses. (e.g., parking spaces, density, green areas, building footprint areas)
☐ Yes ☐ No
3. Traffic analysis estimating average daily trips for street network and parking requirements.
☐ Yes ☐ No
4. Site impervious area (including effective disconnections).
☐ Yes ☐ No
5. Reforestation and/or resource conservation protection measures.
☐ Yes ☐ No
6. Comparison of proposed development data with allowable density, land use, etc.
☐ Yes ☐ No
7. Development phasing or implementation sequence.
☐ Yes ☐ No
8. Other?

11. How many development and redevelopment project plans were reviewed during the reporting period to assess impacts to water quality and receiving stream protection?

12. How many of the plans identified in # 11 were approved?

13. How many privately owned permanent storm water management practices/facilities were inspected during the reporting period?

Figure 3.2 Excerpt from Stormwater Annual Report - Small MS4 Permits Addendum - Water Quality Program Assessment, Form MO 780-2049.

3.2 Establishing, Adapting or Adopting Stormwater Control Measure Design Manuals

Some communities have developed or are developing manuals which may include non-structural and structural stormwater control measures to assist planners and designers to implement the community's stormwater management program. In some cases where the resources are not available or official guidance is lacking, communities are referring designers to reference materials and resources that are found outside of the community.

Adopting Manuals

Many communities are faced with the decision to adopt or develop their own post-construction runoff manual. If your community is proposing to adopt a manual then care should be given to adopting a manual to ensure that it "fits" the needs and requirements of the community. In Missouri, the Mid-America Regional Council and the Kansas City Metro Chapter of the American Public Works Association have developed a post-construction stormwater manual that would assist surrounding communities help meet their MS4 post-construction runoff requirements. If your community decides to adopt a manual, then review of other codes and ordinance will likely be necessary to eliminate any potential conflicts.

3.3 Integrating Green Infrastructure into Program Development

Creating or revising an MS4 post-construction stormwater program that includes green infrastructure elements requires:

- Building a multi-disciplined integrated program team.
- Setting and tracking measurable goals.
- Updating land use policies and procedures.
- Planning for long-term funding, implementation and maintenance.

3.3.1 Building the Program Team

The program team should be comprised of multiple disciplines and stakeholder groups. The completed team should include members with relevant knowledge of general challenges encountered while developing a stormwater management program, such as:

- Consistency among municipal codes, ordinances, or agencies.
- Infrastructure needs in rapidly growing areas or redevelopment.
- Retrofitting in areas of existing development.
- Impacts to sensitive natural resource areas.

A. Consistency among code, ordinances or agencies

Coordination of the municipal agencies and departments having purview over stormwater-related issues is fundamental to a successful stormwater management program. Where several MS4s are partnering together to implement the program, a separate regional stormwater management district may be set up to facilitate program development, implementation and maintenance.

Public outreach, education and participation in program development should occur as early as possible in the process and steps should be taken to ensure regular opportunities for stakeholder input.

B. Rapidly Growing Areas

An MS4 may include areas that are undergoing rapid development. These areas typically include large parcels of private development. Including elected officials, relevant agency personnel, developers and major area commercial residents can help address these typical items.

- The need or desire for additional revenue; property and sales tax in a community often leads to quick development decisions that may have impacts on a community's natural resources.

- Political pressure for economic development, services and retail options. As population increases, the demand for rezoning or changes to land use codes to provide employment, services and retail options may arise.
- Pressure from developers to delay implementing new standards or emerging development trends. Financial pressure may create a need to build homes and commercial buildings as quickly as possible. Changes in standards can slow down the development process and increase fees and costs. Educating developers on the financial benefits of green infrastructure may help create new standards.
- Staff limitations for implementing programs, plan reviews and inspections. High growth communities may not have sufficient staff to handle the day-to-day operations for keeping up with the large volume of permits that may be requested. Actively educating or including elected officials responsible for budgets can help ensure adequate levels of qualified staff and inspectors trained in stormwater management techniques are funded as part of the program.

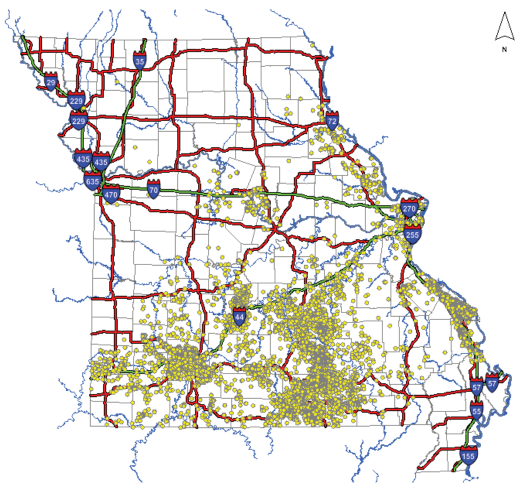
Growth can create pressure on infrastructure and open space. High growth areas may have difficulty funding needed infrastructure to areas of new development. Green infrastructure concepts help to limit erratic growth by encouraging density in areas of proposed development. Many types of structural green infrastructure can meet multiple infrastructure needs to help reduce overall costs of development and long-term maintenance. Actively including program team members with non-stormwater infrastructure responsibilities can help gain support for green infrastructure initiatives.

C. Sensitive Relevant Natural Resource Areas

Coordination with local natural resource agencies, watershed groups, or environmental protection groups can help take into consideration relevant natural resources such as karst geology, wetlands, hardwood forests, soils, impaired or listed waters of the state, or drinking water supplies. Planning with these types of resources in advance of implementation will reduce any roadblocks that may occur at a later date.

Karst Geology

Karst geology features such as springs and sinkholes provide challenges relevant to stormwater. It is important to document these features within and near your community up front to help minimize the risks from unintentionally increasing the rate of sinkhole development or accidental contamination of groundwater. Non-structural solutions for



Known Sinkholes in Missouri

Figure 3.3 Known sinkholes in Missouri. Source: Missouri Department of Natural Resources Division of Geology and Land Survey

Figure 3.4 Known springs in Missouri. Source: Missouri Department of Natural Resources Division of Geology and Land Survey

stormwater management may be needed in sensitive karst areas in order to minimize the need for infiltration stormwater control measures. Figure 3.3 and Figure 3.4 display the known sinkholes and springs in Missouri from the karst, springs and caves website on the Missouri Department of Natural Resources website. Consulting with local Missouri Department of Natural Resources or other knowledgeable natural resource agency offices may help identify areas of special concern within the MS4 related to karst geology. More information on karst and related geology can be found at: www.dnr.mo.gov/env/wrc/springsandcaves.htm

Wetlands

In Missouri, many of the remaining wetlands exist within riparian corridors along streams and rivers. Wetlands are one of nature's tools for water quantity and quality control. Therefore, wetlands within your community's watersheds can be an asset to your stormwater management program. Comprehensive land use plans that identify wetland resources as an asset to be protected and utilized can help you take advantage of these assets.

More information on wetlands can be found at www.dnr.mo.gov/env/wrc/wetlands.htm

Soils

Soils are important natural features that should be taken into consideration when developing a stormwater management program. Soil types vary widely across Missouri and even vary within one community. Communities will need to select stormwater control measures and develop design criteria that are appropriate for the varying soil types in their community, particularly for measures that require greater infiltration rates. Soil maps and general descriptions can be viewed at: www.mo.nrcs.usda.gov/technical/soils.html, websoilsurvey.nrcs.usda.gov/app/HomePage.htm, or www.cares.missouri.edu/.

Impaired or Listed Waters

In Missouri impaired or listed waters are those with documented water quality issues for one or more priority pollutants. Some streams and rivers have total maximum daily loads, or TMDLs, assigned to them. The TMDL limits the overall pollutant load that can be discharged to the receiving water body. When developing or revising a stormwater management program, it is important to reduce and eliminate pollutants that are identified in the TMDL. These restrictions can impact new or additional discharges to the receiving water body. Communities should be proactive in addressing this issue by working closely with stakeholders and the Department of Natural Resources (DNR, 2011).

Drinking Water Supplies

Drinking water supplies within or downhill of a community pose special challenges in stormwater management. Using tools for decision making, such as land use plans, planning and zoning maps, overlay zoning and protection ordinances should be the primary methods to protect and address these community assets.

More information on groundwater and related water supply information can be found at: www.dnr.mo.gov/env/wrc/grdh2o.htm

D. Retrofitting areas of existing development

Built-out or fully developed communities include a variety of stakeholders that can provide positive input to the program. Examples include:

Watershed and Stream Team Organizations

Citizens involved in organizations such as watershed groups or stream teams can participate in the process of goal setting. Citizen inclusion can create buy-in and minimize project opposition. See Missouri Stream Teams at www.mostream.org. Also see the Missouri Stormwater information clearinghouse, local governments page. The post construction page lists several watershed organization. (Missouri. Appendix C.)

Community Development Corporations

Community development corporations are non-profit economic development groups often formed in areas with lower density and lower property values than surrounding areas. Green infrastructure can help revitalize areas where stormwater infrastructure is also rehabilitated with pervious curb, gutter and sidewalks or enhanced landscapes in the form of rain gardens or vegetated boulevards. Abandoned homes and other vacant properties can be converted to pocket parks that manage stormwater while increasing opportunities for public open space, urban farming, or playgrounds.

Combined Sewer Area Programs

Combined sanitary and storm sewers are primarily located in older developed areas. Although these areas are not typically part of an MS4 program because they are exempt per federal regulation and otherwise regulated under sanitary sewer permits, they are often located within an MS4 area. Stormwater programs using green infrastructure infiltration methods can reduce the amount of stormwater entering the combined sewer system, increasing the available capacity of existing and planned collection systems and improve water quality by reducing the probability of sanitary wastewater overflows to receiving streams.

Private Redevelopment Corporations

Private for-profit redevelopment corporations can provide relevant input to the program regarding land value and infrastructure needs. Involving private development stakeholders in plan development can help educate them on whether or not to incorporate green infrastructure into their projects.

3.3.2 Setting and Tracking Measurable Goals

Post-construction stormwater management program goals drive the development of plans, the actions selected and the context of results. Setting program goals is therefore critical for the creation of a program relevant to both compliance and fitting community-specific needs. Program goals should be reviewed regularly for revisions to improve the program and respond to changes in community or regulatory needs. Environmental and other goals indirectly related to water quality should be encouraged.

Measurable goals quantify the progress of program implementation and the performance of your stormwater control measures. EPA recommends for program goals to include:

- A multiple variety of short- and long-term goals.
- Proposed actions, expected results in quantifiable terms and schedules/milestones for each proposed stormwater control measures. http://cfpub.epa.gov/npdes/stormwater/measurablegoals/index.cfm

EPA also recommends establishing a baseline against which progress can be measured. Information on current water quality conditions, numbers of stormwater control measures already implemented and the public's current knowledge/awareness of stormwater management would be useful in establishing a baseline.

Measurable goals can be based on one or more of the following general categories:

- Tracking implementation over time.
- Track how often and where stormwater control measures are implemented.
- Measure and track the effectiveness of stormwater control measures.

Example Goal: Install at least 10 rain gardens per year in a specified area of the watershed. Identify and fund construction of rain gardens on public land. Constructed rain gardens will be tracked in the municipal GIS database. Data will be collected to track capital cost per square foot of each rain garden and the ratio of rain garden area to contributing watershed.

Measuring Progress in Implementing. Some stormwater control measures are developed over time and a measurable goal can be used to track this progress until the control measure implementation is completed.

Example: Develop a residential rain garden incentive program. A residential rain garden guidance document will be published by [DATE 1] in order to facilitate the funding and construction of 1,000 residential on-lot rain gardens by [DATE 2] in order to reduce annual runoff volume to below a predevelopment condition.

Tracking Total Numbers of Stormwater Control Measures Implemented. Measurable goals also can be used to track stormwater control measures implementation numerically.

Example: Construct a rain garden as part of 50 percent or more future American Disability Act, or ADA, sidewalk ramp rehabilitation projects. Proposed transportation design projects in the watershed will be reviewed quarterly for opportunities. Annual summary reports will be issued listing the location and number of rain gardens and number and location of ADA sidewalk ramp improvements to verify progress.

Tracking Program/Stormwater Control Measures Effectiveness. Measurable goals can be developed to evaluate stormwater control measures effectiveness.

Example: Reduce annual runoff volume. Measure collection system flow rates and correlate to rainfall events and relevant stormwater control measures to estimate reductions in runoff volumes through a five year proposed implementation period. Interim progress reports shall be completed annually to monitor progress.

Tracking water quality and other environmental indicators can provide a benchmark against state water quality standards for the receiving waters such as TMDLs.

Example: Reduce nutrient concentrations in an impaired stream to below TMDL criteria. Stormwater control measures will be implemented in the watershed to filter and remove nitrogen and phosphorus according to a five year implementation plan. Samples will be collected quarterly to track improvements.

Administrative goals evaluating the community's capacity to implement a stormwater management program should be a part of developing the community's goals. Community capacity issues can include anticipated growth, funding resources, political and community support, availability of trained personnel to implement the program and integrating the program into other community efforts.

Example: Conduct a study by [DATE 1] to assess funding needs to adequately implement stormwater program and implement the funding program by [DATE 2].

3.3.3 Assess and Update Land Use Policies

Once the program team has formulated measurable goals, existing land use and other natural resource policies should be compared against the measurable goals. Chapter 2 has discussed comprehensive planning at different geographic and political levels and Chapter 4 of this document discusses methods for updating policies to better meet water quality goals. Common policies relevant to stormwater management may include:

A. Zoning prescribes the type and intensity of allowable land use in different areas. Low density zoning helps allow for green infrastructure concepts such as conservation development and increased open space, but may also contribute to suburban sprawl requiring longer runs of road, water, sewer and other utilities that may create additional land disturbance, impervious surface, long-term operation and maintenance costs that may or may not be funded by the taxes generated in the low density area. In contrast, high density zoning helps consolidate utilities and minimize impervious surface per capita, but may be more likely to degrade natural habitats, increase heat island effects and create more localized stream degradation due to changes in hydrology. Areas that may not have specified zoning should follow the most up to date standard of practice for their planning and engineering, or apply zoning requirements from a municipality with reasonably close proximity.

B. Subdivision control and other infrastructure policies address building footprint size, sidewalk and road widths, parking requirements, setbacks and other elements that affect the amount of impervious surface. Compromises may be required to balance needs among local agencies such as public safety, transportation, environmental protection and economic development in order for subdivision control policy to support stormwater program goals that plan to integrate green infrastructure. Despite their stormwater and infrastructure cost benefits, green infrastructure concepts such as narrowing roads may conflict with public safety access, minimizing parking counts may not support peak seasonal shopping and reducing setback distances may limit the appeal for some residential developers.

C. Watershed Plans and other regional natural resource policies may already support program goals. However, these documents may also generate additional requirements for the stormwater program not previously considered.

3.3.4 Funding and Staffing

Effective stormwater management has many economic benefits and could help avoid significant local expenditures such as for repairing washouts, addressing flooding, reducing downstream erosion and stream bank repair. When weighing the cost of a good post-construction program, consider the millions of dollars associated with stream bank restoration projects, basin dredging and maintenance of clogged collection systems and outlets. Many types of green infrastructure capture solids in a way that can be easier to maintain than these other systems.

MS4s need financing plans for stormwater management programs, including creation of regulatory controls and program implementation, technical services for stormwater plan review, staffing, site inspections and enforcement.

Stormwater programs funding options include taxes, fees, bonds and grants. Some funding resources are limited by state and local laws governing revenue generation and can be dependent on the size of the community and method of governance. Be aware of potential exemption riders on proposed funding mechanisms. Often the largest contributors to runoff find ways to be exempted from funding, and therefore compromise the effectiveness of such funding.

Funding could also be distributed among different programs such as transportation for street runoff controls and the parks budget for selected structural stormwater control measures. Examples may include integrating green infrastructure into other infrastructure such as pervious curb and gutter infiltration trenches, parking island rain gardens and dry detention or other basins in parks.

At a minimum, your funding program should:

- Estimate funding needs for each program component.
- Describe administrative and field staff positions.
- Identify funding sources.
- Include a schedule, which may include staff or equipment, when utility fees may be implemented or increased, or when other relevant program phases may occur.
- Provide a large amount of lead time for arranging program financing.
- Identify long-term projects to fund.

Funding maintenance of green infrastructure in the right-of-way should be addressed at the interdepartmental level in most municipalities. Potential maintenance entities include transportation, parks, landscape, or stormwater departments. Green infrastructure is an integral part of a stormwater management system. Volunteer groups are not recommended for maintenance on city stormwater features. However, it is important to work with home owners on maintenance agreements for rain gardens and similar features located on their properties. Some cities have home owners submit annual reports on the status of their rain gardens, in order to minimize encroachment.

Funding methods and mechanisms commonly used for stormwater programs can include:

- General revenue appropriations – using general tax revenues to support stormwater programs.
- Stormwater user (service) fees – creating a stormwater utility to bill and collect user fees to cover some or all of program practices.
- Local parks and stormwater sales tax.

- Plan review fees – dedicated fees collected as part of a project approval process.
- Development inspection fees – dedicated fees collected from HOAs, businesses and other owners of structural stormwater control measures to support inspection programs.
- Special user fees – additional user fees imposed on atypical dischargers, usually associated with other NPDES regulated activities.
- Special assessments – dedicated funding of specific construction projects such as regional stormwater basins.
- Bonding for capital improvements – used to fund large projects that far exceed current revenues.
- In-lieu of construction fees – collected from new developments to construct regional stormwater facilities as substitutes for on-site practices.
- Capitalization recovery fees – collected to recover costs on prior infrastructure installed in anticipation of development.
- Impact fees – collected for actions that contribute to off-site stormwater issues but cannot be effectively mitigated for on-site.
- Developer extension/latecomer fees – collected by a developer as future compensation where oversized systems are tapped into at a later date.
- Federal and state funding opportunities such as grants, loans and cooperative programs.

Stormwater Program Funding Guidance Resources

Guidance manuals and tools available to assist stormwater program managers in developing and implementing funding for a post-construction program include:

- National Association of Flood and Stormwater Management Agencies - Guidance for Municipal Stormwater Funding (Guidance, 2006). www.nafsma.org/Guidance%20Manual%20Version%202X.pdf
- Center for Urban Policy and the Environment at Indiana University - Purdue University Indianapolis - An Internet Guide to Financing Stormwater Management. http://stormwaterfinance.urbancenter.iupui.edu/.
- Prince William County, Virginia Department of Public Works - Stormwater Management Fee (Storm). www.pwcgov.org/default.aspx?topic=010008000780000828
- Reason Public Policy Institute - Preparing for the Storm: Preserving Water Resources with Stormwater Utilities (Preparing, 2001). http://reason.org/news/show/preparing-for-the-storm
- The Center for Watershed Protection has developed some tools that can assist communities with budget assessment (Tool, 2008): www.cwp.org/store/free-downloads.html
- Managing Stormwater in Your Community Tools - Tool 2- Program and Budget Planning Tool: www.cwp.org/store/free-downloads.html
- Managing Stormwater in Your Community Tools - Tool 7 - Performance Bond Tool; http://www.cwp.org/store/free-downloads.html

3.4 Enhancing and Implementing Your Stormwater Management Program

Successful program enhancement with green infrastructure and its implementation will require leadership, training, inspections, enforcement and reporting. Leadership and support from both the political and administrative levels of local government are essential to implement an effective stormwater management and post-construction program. This support is vital for department directors and staff to conduct their duties and responsibilities with integrity, effectiveness and confidence when working with stakeholders.

A. MS4 Leadership

The prime leadership role may be the MS4 coordinator or other "advocates" that are constantly moving the program forward. Leadership may be a staff person, an elected official or long-time member of the community who is highly regarded among stakeholders and should be given adequate decision making authority by the appropriate municipal leadership. MS4 program leaders should be clearly identified by name and title in the program and their ability to make different level of decisions on behalf of program implementation in cooperation with all departments.

B. Training Programs

A training program should include stormwater control measures operations and maintenance, ordinance enforcement, documentation and how to work with the public. Training opportunities for the community may include participation in regional training courses such as those provided by a regional council of governments, training provided

Training Program Example Topics								
Example Trainees	Plans and policies	Ordinances and codes dealing directly and indirectly with stormwater management	NPDES Phase II Program requirements	Stormwater control measures for post-construction control	Stormwater control measures for construction erosion and sediment control	Phase II permit requirements	Phase II regulations	How to work with the public
Elected officials, city administrator, board of zoning, adjustment officials	X	X	X					
Planning and zoning officials, development plan review team	X	X	X	X	X			
Public works staff, community, community development staff, inspectors	X	X	X	X	X	X	X	X

Table 3.1

by local or in-house staff, using purchased programs, or training by an outside consultant. In some cases, the State of Missouri may offer regional training courses through a local organization or government agency.

C. Inspection Program

An inspection program is important for a successful post-construction program because it verifies that the development plans are implemented as approved. Furthermore, it is critical that the designated inspector understands the site drawings and follows through to verify that they are constructed as designed. Some benefits to establishing a new or refining an existing inspection program include:

- Assesses program and ordinance implementation.
- Measures the effectiveness of stormwater control measures (structural and non-structural).
- Identifies the maintenance needs of stormwater control measures.
- Provides knowledge and confidence to staff through the application of the program.
- Assesses the effectiveness of ordinances and codes.
- Provide sease in completion of annual Phase II reports.
- Assures the site drawings are followed.

Elements of an inspection program should define who will conduct the inspections, the methods and tools needed and the frequency of inspections.

Inspectors may represent a single agency within the local government or a shared responsibility. For example, one department could have the legal responsibility for stormwater management while another department has the authority to enforce ordinances, codes and to levy fines for noncompliance. Whether inspection is the sole responsibility of a single department or shared among a group of departments, the responsibility should be identified and specified in the ordinance providing regulatory authority.

An effective tool to use for an inspection program is the revised Missouri Department of Natural Resources' *Protecting Water Quality Manual 2011* provides resources for inspecting construction best management practices that can be adopted for a post-construction program.

Additional tools to support and enforce ordinances include having the necessary equipment such as computers, cameras, transportation and training on how to conduct inspections and how to interact with people.

D. Enforcement

Enforcement plans provide incentives in the form of consequences for non-compliance. Penalties or other consequences should be specified in an ordinance or other enforceable regulation and detailed enough to avoid misinterpretation. A tiered enforcement plan with a combination of actions and imposed fines is a practicable approach.

Example Tiered Enforcement Protocol	
First Offense	Advise on corrections needed, time frame for correction and warn of consequences for non-compliance.
Second Offense	Stop operations and impose fine.
Third Offense	Fines imposed for each violation since first occurrence; place a lien on property until compliance is achieved and fines paid.
Non-compliance after Third Offense	Fines imposed for each violation since first occurrence; place a lien on property until compliance is achieved and fines paid.

Table 3.2

E. Tracking, Record keeping and Reporting

For the post-construction program, there may be overlap in record keeping with other municipal requirements and the Phase II stormwater permit. It is important for a community to develop and maintain an electronic geographical information system, or GIS, database or other documentation protocol and system to track and update program progress.

The MS4 should consult legal counsel regarding their documentation retention procedure and reporting requirements relevant to their NPDES permit.

Monitoring is an important consideration in tracking the success of a program. Without "real" data, performance cannot be evaluated. Tracking indicators alone can be very misleading, but can be used with the monitoring efforts to evaluate performance and determine any necessary changes for program success. (Burten et al. 2002)

The MS4 should ensure documentation, record keeping and reporting are done in accordance with permit requirements and federal and state regulations.

Example Inspection Schedule for Installed Stormwater Control Measures	
During Construction	2 to 3 times following a rain event or as required by code.
Upon Construction	As required by code or design and installation standards.
First year, Post-construction	After average precipitation events, after major precipitation events, upon complaints/comments from public.
Second Year	Biannually, after major precipitation events, upon complaints/comments from public.

Table 3.3

Annual NPDES reporting requirements provide an opportunity to evaluate program progress. Reporting can lead to:

- Shore up weaknesses in specific program areas, such as inspections.
- Clarify portions of policies, plans or ordinances that are ambiguous or open to interpretation.
- Increase or modify training for staff and officials.
- Make system improvements, such as the program tracking and documentation.
- Change ordinances or codes that are inconsistent.

These and additional records that may be tracked include area-wide data specific to the structural stormwater control measures in the MS4 area and administrative program data covering policies, training programs or permit compliance.

Example Area-wide Implementation Records
MS4 Area-Wide Post-Construction Technical Elements

- A GIS database or other system to track:
    - Stormwater control measure description – type, size, location and date of construction of structural control measures.
    - Measurable Goals – what the stormwater control measure is expected to do.
    - Responsible Entity – MS4, transportation department, parks department and homeowners association are all examples of potential responsible entities.
    - Schedule – inspections, training, phased construction, or other relevant schedule specific to the stormwater control measure.

  - Reporting and record keeping – protocol for record retention specific to the stormwater control measure.
  - Relevant minimum control measures addressed – list one or more of the six minimum controls met by the stormwater control measures.
  - Target constituents – residential, commercial, or industrial changes in percent impervious cover.
- Description, function and implementation date of non-structural stormwater control measures.
- Number of development plans submitted and approved under new program.
- Number of developments with low impact development or similar development methods.
- Number of conservation easements negotiated.
- Acreage of riparian corridor protected.
- Water quality and quantity monitoring from stormwater control measure outlets.
- Reduction of flooding in flood-prone areas.
- MS4 Area-wide Inspections.
  - Date, time, location and staff of each inspection.
  - Specific stormwater control measures inspected – notes, photographs, video.
  - Results of each inspection.
  - Follow-up of inspections requiring action by the developer or property owner.
- Project specific plan review process (for each development or redevelopment project).
  - Preliminary meeting with developer or property owner.
  - Preliminary plats and development information.
  - Subsequent meetings with developer or property owner.
  - All communications with developer, property owner, architect and development engineer.
  - Reviews by staff.
  - Reviews by planning and zoning commission or similar board.
  - Approvals and denials of development plans and explanations.
  - Comments from other agencies, the public and other stakeholders.

F. Example Administrative Program Records

Revisions to relevant stormwater management program policies, plans, ordinances and technical design manuals including:

Correspondence and Meeting Logs:

- Meeting notes on development and passage of policies, plans, ordinances and/or manuals.
- Communications with stakeholders regarding development and policies, plans, ordinances and/or manuals.
- Comments from stakeholders on policies, plans, ordinances and/or manuals, including public meetings held.
- Minutes from city council or alderman meetings regarding stormwater management and post-construction policies, plans, ordinances and/or manuals (presentations by staff, discussion, official readings, votes taken).

Training Program:

- Agenda of each training event: topic, time for each topic, instructor and specific training tools used such as videos or publications.
- Attendance sheet for each training event.
- Results of any written exam given during the training.
- Evaluation summaries of the training provided by attendees.

NPDES Post-Construction Program Requirements:

- Permit requirements: measurable goals, tasks, activities.
- Completion or implementation of each task, activity and measurable goal.
- Annual report.
- Inspections or audits by regulatory agencies.
- Communications with regulatory agencies.

Case Study: Small Town USA

Small Town, USA, has substantial existing development and many neighborhoods that are still growing. In existing developed areas, the town plans to disconnect some impervious surfaces and ensure that existing stormwater controls are functioning properly. For new and redevelopment areas, the town plans to enact a new stormwater ordinance and develop supporting design guidance.

Minimum Measure Objective: Reduce the volume and improve the quality of runoff by disconnecting impervious surfaces and installing and maintaining structural stormwater control measures.

- **Stormwater Control Measure:** Reduce directly connected impervious surfaces in new and redevelopment projects by requiring that swales or filter strips be installed along roadsides in lieu of curbs and gutters.

Measurable Goal: Directly connected impervious road surfaces in new developments and redevelopment areas will be reduced by 30 percent compared to traditional scenario.

- **Justification:** This practice would provide on-lot treatment of stormwater, reduce the total volume of stormwater being discharged from sites and increase the time of concentration of runoff generated from road surfaces.
- **Stormwater Control Measure:** Develop a program for maintenance of structural stormwater controls.

Measurable Goals: In year one, conduct an inventory of structural runoff controls. In year two, develop a GIS map to integrate the location of these controls with maintenance and inspection. Conduct four inspections of each structural control per year and conduct regular maintenance as prescribed.

- **Justification:** In order to implement a maintenance plan, the type and location of structural stormwater control measures must be compiled. An inspection and maintenance schedule can be developed to improve efficiency and minimize labor requirements.
- **Stormwater Control Measure:** Develop and implement a stormwater ordinance and design guidance that includes performance standards designed to control runoff.

Measurable Goal: By year three of the permit term, 95 percent of all building permits will include descriptions and plans of stormwater control measures that comply with the criteria in the ordinance and accompanying guidance

- **Justification:** Ordinances are an effective way to establish performance standards for runoff controls. For example, performance standards may include requirements to maintain predevelopment hydrologic conditions.

United States Environmental Protection Agency (2011)

Wetland Swale. Source: Olsson Associates

Sand Filter (Open Basin Design)- North Carolina. Source: *North Carolina Stormwater BMP Manual.*

Excerpt: Missouri Municipal Separate Storm Sewer System Permit for Phase II Communities. June 2008.

4.2.5 Post-Construction Stormwater Management in New Development and Redevelopment

4.2.5.1 Permit requirement. The permittee shall develop, implement, and enforce a program to address the quality of long-term stormwater runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into the permittee's regulated small MS4. The permittee's program shall ensure that controls are in place that have been designed and implemented to prevent or minimize water quality impacts by reasonably mimicking pre-construction runoff conditions on all affected new development projects and by effectively utilizing water quality strategies and technologies on all affected redevelopment projects, to the maximum extent practicable. The permittee shall assess site characteristics at the beginning of the construction design phase to ensure adequate planning for stormwater program compliance....

Introduction to Case Studies

Throughout the U.S., there is a growing recognition of the benefits green infrastructure provides to communities. Many municipalities and other jurisdictions have begun to effectively incorporate these practices. The following case studies were selected to showcase both site and landscape scale GI projects which have successfully been implemented. Additional case studies are included in Chapter 6. Readers are encouraged to follow the links or titles provided for each case study to learn more about these projects.

Case Study: Municipal Stormwater Funding

Charlotte/Mecklenburg County, NC

Charlotte/Mecklenburg County, NC, utility was instituted in 1994 and relies on centralized funding and regional programs for major systems combined with local management of minor stormwater systems. Charlotte and small towns typically employ a blend of funding from several sources while the county relies almost entirely on the service fee. The total stormwater budget for all entities in 2005 was more than $85 million. The fee for a single-family house is $1.06/month throughout the county.

Local stormwater programs of the county, cities and towns are funded by a separate additional rate component which ranges from $0.30/month to $6.72/month in Charlotte. In 2005, the budget of Mecklenburg County was about $750 million and the population of Charlotte was about 650,000.

Charlotte, NC

Bellevue, WA

The Bellevue, WA, stormwater management program was established in 1974. Funding is primarily derived from a user fee that is based on gross property area and a factor reflecting the intensity of development of each property. Residential fees range from $3/month to more than $20 per month with an average of about $10/month. The annual operating budget is approximately $6 million. The population of Bellevue was about 117,000 in 2005.

Tulsa, OK

The Tulsa, OK, Stormwater Management Program budget has recently ranged from $12 million to $14 million per year and includes comprehensive watershed management, dedicated funds for maintenance and operation and a $200 million capital improvements program.

All residential properties are charged a single rate of $3.49/month and fees for other properties are based on the amount of impervious surface on each property. The population of Tulsa was about 400,000 in 2005.

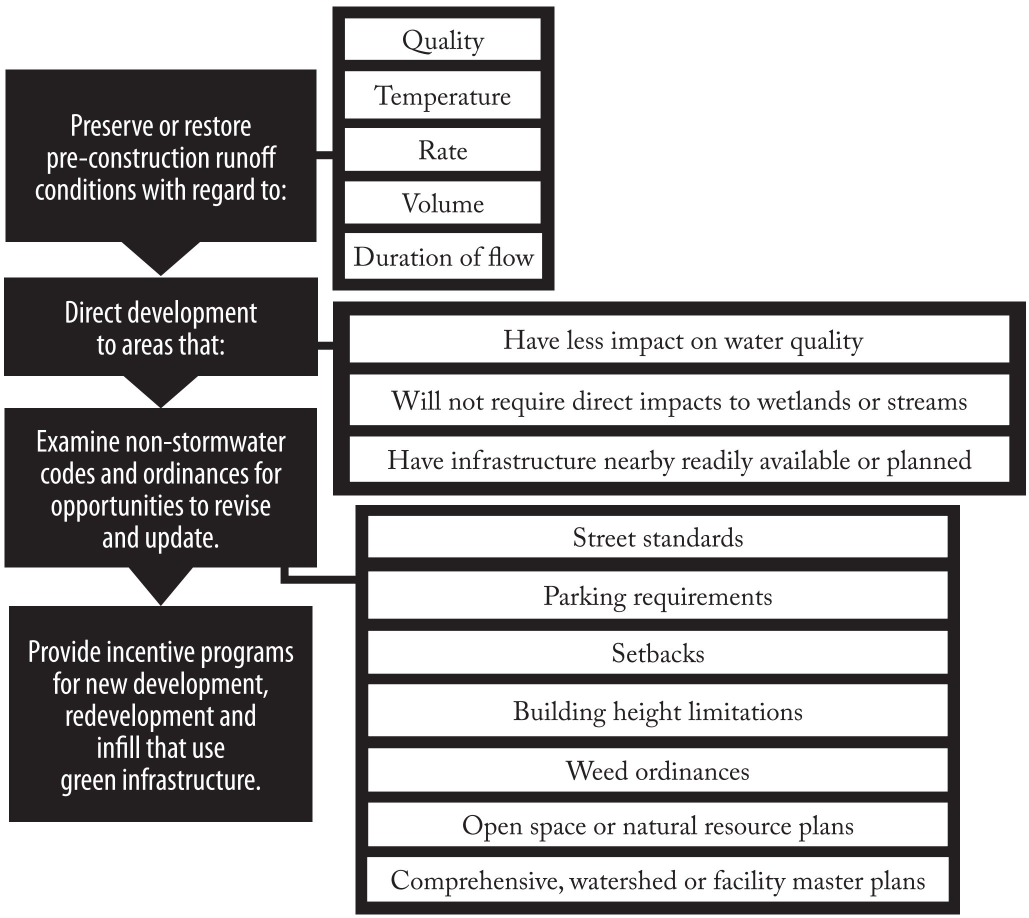
Louisville, KY

Louisville, KY, consolidates flood control and stormwater management with a regional wastewater collection and treatment program provided by the Metropolitan Sewer District. Most of the smaller cities and towns in Jefferson County do not perform stormwater management functions. The district's stormwater fee is based on a flat rate for single-family residential properties and differential rates for other properties based on an impervious area equivalency unit. The single-family residential stormwater service fee in 2005 was $4.41/month. Stormwater service fee revenues in fiscal year 2005 were expected to be nearly $24 million. Louisville had a population of about 700,000 in 2005.

(Tucker, Harrison, Cyre, Burchmore, & Reese, 2006); (Chan, 2009)

4 Integrating Green Infrastructure Into Ordinances

Ordinances and codes are the legal mechanisms for implementing and enforcing a post-construction stormwater runoff program. MS4 communities desiring to integrate green infrastructure into their program may need to create or revise ordinances relevant to infrastructure, land use and natural resources. Relevant procedures to post-construction management of stormwater runoff include policies that:



Water quality problems due to stormwater runoff typically are associated with the smaller storms and not the design storms used by engineers for drainage. (Pitt-Clark. 2008.) The goal of sustainable stormwater management is to select and implement an optimal array of control practices that meet the water quality goals while minimizing detrimental considerations, including cost. These controls should be selected based on-site characteristics, including soils, and on the rainfall and runoff conditions.

Two options for demonstrating the goal of water quality are described below.

1. The first, and most common option, uses a concept sometimes referred to as "water quality volume." In this option, water quality rain events that occur roughly 90 percent of the time over a given period of record in order to address water quality goals in development. Also, stormwater control measures are designed, constructed and maintained to infiltrate, evapotranspire or reuse runoff to the maximum extent practical. This option is a recognized standard of practice based on studies of small storm impact, and they can help restore site hydrology. However, it may not necessarily maintain or restore the pre-construction runoff condition.

2. Option two involves site-specific engineering analysis to design and model on-site stormwater control measures to mimic pre-construction runoff conditions in new development or prevent runoff pollution to the maximum extent practicable in redevelopment/infill projects. Analysis is typically based on site-specific data such as soil type, slope, depth-to-groundwater, land use and local meteorology (including rainfall frequency). Data can be applied in continuous simulation models to show that post-construction stormwater control measures control the rate, volume, frequency, duration or temperature of runoff in a manner that does not exceed pre-construction conditions.

4.1 Develop, Enhance and Implement Policies to Protect, Restore or Enhance Pre-Construction Runoff Conditions

Policies should establish appropriate performance goals to maintain, restore, or enhance pre-construction runoff conditions to the maximum extent practicable. Common options include capture and treatment of the water quality rainfall event, assumed annual infiltration performance based on applied stormwater controls or a site-specific engineering analysis.

In any option, policies may define pre-construction runoff conditions by land use conditions prior to the proposed development. Pre-construction land use is land function prior to new and redevelopment or retrofit applications. Measures more restrictive than mimicking pre-construction runoff conditions may be warranted in areas where streams are currently impaired. It is most cost-effective to reasonably mimic pre-construction runoff conditions in new development projects, also known as "greenfield" projects.

Which Option to Apply?

Policy may direct which design option to use based on whether the designer can be reasonably expected to have the requisite data and resources needed to analyze annual rainfall, infiltration, evapotransipiration, interception and potential harvest and reuse scenarios. Water quality event management may be appropriate for small sites proposed in areas of no obvious direct connection to sensitive areas (not adjacent to lakes, wetlands or streams for example), and more detailed analysis may be appropriate for very large sites or any sites adjacent to environmentally sensitive areas.

Potential Constraints

In some cases, site conditions may prevent post-development conditions from meeting the performance criteria. Conditions that could prevent fully restored pre-construction runoff conditions include:

- Shallow bedrock, karst or heavy clay soils, preventing or minimizing potential infiltration.
- Contaminated soils that require minimal infiltration to prevent transport of pollutants to groundwater.
- Groundwater depths less than two feet below finished grade elevations.
- Lime stabilization requirements of subsoils.
- Water harvesting and reuse are not practical or possible because of local plumbing code requirements.
- Retrofits to existing facilities are not feasible because of structural or operational constraints.
- Retention or use of stormwater on-site or discharge of stormwater on-site via infiltration has a significant adverse effect on the site or the down gradient water balance of surface waters, groundwaters or receiving watershed ecological processes.
- State and local requirements prohibiting stormwater collection.
- State and local requirements prohibiting retention in the public right of way.

Where contaminated runoff from hotspots threaten groundwater quality, minimal infiltration to prevent transport of pollutants to groundwater is recommended.

4.2 Directing Development

Directing land development patterns can be used to minimize the potential for negative impacts on water quality. Land use is a primary cause of water quality degradation and impervious surface in urbanized areas can represent the largest increases to runoff volumes on a per square foot basis. In terms of sediment loads, the national average of sediment runoff from roads, commercial and industrial sites averaged up to one-half ton per acre (University of Wisconsin-Extension and Wisconsin Department of Natural Resources, 1997). For comparison, erosion form agriculture cropland average 2.7 tons per acre per year (USDA-NRCS, 2010) and active construction-sites average 30 tons per acre per year (University of Wisconsin -Extension and Wisconsin et al, 1997).

Integrating a Watershed Plan

Integrating watershed plans into comprehensive plans, ordinances and codes is the one direct way of integrating green infrastructure into land use strategies. A watershed approach is a flexible framework for managing water resource quality and quantity that provides assessment and management information for a geographically defined watershed, including the analyses, actions, participants and resources related to developing and implementing the plan. Watershed plans typically consider the cumulative effect of new development, roads and other associated infrastructure, the loss of natural wetlands and floodplains and their potential compounding affect on streams and other water bodies. A more comprehensive discussion on watershed planning can be referenced in Chapter 2.

Sustainability and Development Strategies

Preserving and restoring natural landscape features (such as forests, floodplains and wetlands) is an integral part of green infrastructure. However, there are other strategies that can indirectly improve or ensure the long term health of water resources in a community such as redeveloping already degraded sites. Strategies may include:

- Direct development to infill and other redevelopment areas to make use of existing infrastructure networks and minimize the addition of new impervious surfaces.
- Create range of housing opportunities and mixed land use choices. Allowing housing for all income levels within a mixed use community can reduce the need and cost for extensive road, utility and other infrastructure and their associated land disturbance.
- Create walkable neighborhoods to decrease the need for road and parking networks, indirectly reducing the amount of new impervious surface in a watershed.
- Provide multi-modal transportation planning to help create linear green infrastructure stormwater management networks and lower the long term need for land disturbance during system upgrades.
- Encourage community and stakeholder collaboration to help gain long term support for green infrastructure funding and maintenance.
- Foster distinctive, attractive communities with a strong sense of place. Green infrastructure can be used to increase landscape architectural beauty and distinctiveness.

Make Development Decisions Predictable, Fair and Cost Effective

Applying performance goals, rather than prescriptive standards, for green infrastructure can help create triple bottom line balanced integration with grey infrastructure. The intent is to set performance goals and allow tools and standards to be developed that are specific to local climate and geology while fitting the socioeconomic needs of the community. For example:

1. Favor performance language over prescriptive language, where possible. Performance language can include guidelines such as "infiltration practices shall take into account the permeability of the anticipated limiting soil layer and contain organic content equal to or greater than topsoil typical to the region." Prescriptive language are mandates such as "a bioretention area shall have 30 inches of biosoil." The distinction is important in terms of material cost. "Biosoil" can cost up to six times that of a less stringent but similarly effective topsoil and sand mix.

2. Preserve Open Space to help increase property values, attract new businesses, preserve sensitive environments and provide outdoor health and recreation opportunities.

3. Plan for Compact or Multi-Story Building, which minimizes the roof top impervious surface and can lessen the physical distance required by road and other infrastructure networks.

New Development Areas

Defining new development versus redevelopment is a local decision. How each is defined may affect their requirements for water quality management. New developments may include restrictions on impervious area or the installation of landscape types or structural stormwater control measures to offset the increase in runoff volume created by the impervious area. Redevelopment requirements may include the reduction in impervious area or the installation of stormwater control measures so runoff water quality is equivalent to a reduction in the impervious area (Maryland Department of the Environment, 2000). In the Kansas City metropolitan area, the *Manual of Best Management Practices for Stormwater Quality* provides a methodology for a community to adopt higher standards for runoff reduction measures instead of just maintaining existing conditions (Mid-American Regional Council; American Public Works Association, 2009).

In any development scenario, reasons to consider setting goals for new development projects that would reduce the volume of runoff or improve runoff water quality from the site include:

- Improving runoff conditions into degraded urban streams.
- Reducing the potential to pollute drinking water sources.
- Improving water quality in impaired waters.
- Meeting requirements/recommendations of total maximum daily load regulations.
- Obtaining public support for the development.
- Reducing the potential for flooding.

These reasons must be weighed against the potential for increased costs of the redevelopment site, reduced land area for redevelopment and the impacts these may have on the development community. The overall vision and goals of the community discussed in Chapter 2 should be a driver in the decision-making process.

4.3 Updating Codes and Ordinances

Some ordinances may be specific to managing stormwater while others address issues with direct or indirect relevance to stormwater. This section describes tools to help communities address:

- Assessment of current codes and ordinances for green infrastructure compatibility.
- Green infrastructure elements in non-stormwater codes and ordinances.
- Legal impediments and considerations.

4.3.1 Assessing Existing Codes and Ordinances

Prior to creating or revising ordinances, a community should perform a self-assessment to determine their current compatibility with green infrastructure principles. Readily available tools for adopting or revising ordinances to better accommodate green infrastructure practices include *EPA's Water Quality Scorecard and the Center for Wartershed Protection's Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*.

Water Quality Scorecard:

Incorporating Green Infrastructure Practices at the Municipal, Neighborhood and Site Scale (United States Environmental Protection Agency, 2010)

EPA's Water Quality Scorecard addresses:

1. Zoning ordinances specify the type and intensity of land uses allowed on a given parcel. A zoning ordinance can dictate single-use low-density zoning, which spreads development throughout the watershed, creating considerable excess impervious surface.

2. Subdivision codes or ordinances specify development elements for a parcel: housing footprint minimums, distance from the house to the road, the width of the road, street configuration, open space requirements and lot size—all of which can lead to excess impervious cover.

3. Street standards or road design guidelines dictate the width of the road, turning radius, street connectivity and intersection design requirements. Often in new subdivisions, roads tend to be too wide, which creates excess impervious cover.

4. Open space or natural resource plans detail land parcels that are or will be set aside for recreation, habitat corridors or preservation. These plans help communities prioritize their conservation, parks and recreation goals.

5. Parking requirements generally set the minimum, not the maximum, number of parking spaces required for retail and office parking. Setting minimums leads to parking lots designed for peak demand periods, such as the day after Thanksgiving, which can create acres of unused pavement during the rest of the year.

6. Comprehensive plans may be required by state law and many cities, towns and counties prepare comprehensive plans to support zoning codes. Most comprehensive plans include elements addressing land use, open space, natural resource protection, transportation, economic development and housing, all of which are important to watershed protection. Increasingly, local governments are defining existing green infrastructure and outlining opportunities to add new green infrastructure throughout the community.

7. Setbacks define the distance between a building and the right-of-way or lot line and can spread development out by leading to longer driveways and larger lots. Establishing maximum setback lines for residential and retail development will bring buildings closer to the street, reducing impervious cover associated with long driveways, walkways and parking lots.

8. Height limitations limit the number of floors in a building. Limiting height can spread development out if square footage is unmet by vertical density.

Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program
(CWP, 2008)

This guide provides stormwater professionals with practical guidance, insights and tools to build effective programs. The guide is accompanied by several downloadable "tools" designed to be used and modified by local stormwater managers to help with program implementation.

Tool 1: Stormwater program self-assessment. The desired outcome for conducting this self-assessment is to generate short-term and long-term action items to build a more effective program.

Tool 2: Program spreadsheet. The program and budget planning tool is a spreadsheet tool that is meant to assist stormwater managers with program planning, goal setting and phasing.

Tool 3: Post-construction stormwater model ordinance. Provides a menu of code language for local, regional, or state stormwater programs to use to craft or update their ordinances. The ordinance is written so that individual sections can be lifted out and modified to suit individual program needs.

Tool 4: Code and ordinance worksheet. The code and ordinance worksheet allows an in-depth review of the standards, ordinances and codes (i.e., the development rules) that shape how development occurs in your community.

4.3.2 Examples of Relevant Stormwater

As indicated by the water quality scorecard method, opportunities and constraints affecting green infrastructure are present within many different sections of ordinances and codes.

A. Incorporating Natural Resource Protection into Codes and Ordinances
Protecting natural resources can provide a zero-cost solution to helping ensure long-term stormwater quality. The Minnesota Department of Natural Resources, Metro Division, has developed the natural resource guidance checklist *Addressing Natural Resources in a Comprehensive Plan* that helps a community incorporate resource protection into a community's comprehensive plan.

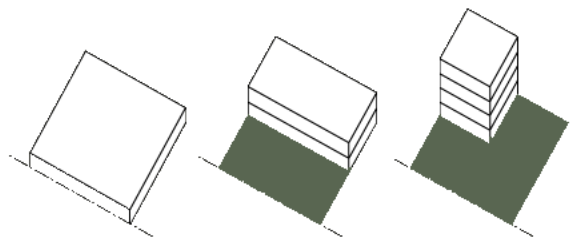


Figure 4.1

B. Overlay Zoning
Overlay zoning is a regulatory tool that creates a special zoning district placed over an existing base zone(s). The overlay district identifies special provisions in addition to those in the underlying base zone. Regulations or incentives are attached to the overlay district to protect a specific resource or guide development within a special area according to the *Center for Watershed Protection's Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (Center, 2008).

For example, overlay zoning can provide for:

- Pervious pavement materials for sidewalks, curbs, or on-street parking in specified areas of town.
- Additional landscaping and open space requirements.
- Irrigation restrictions for potable water use can encourage incorporation of re-use tools such as rain barrels.
- U.S. Green Building Council, LEED or other sustainability rating system requirements.

C. Floodplain Ordinances

Floodplain ordinances are required by communities participating in the National Flood Insurance Program administered by the Federal Emergency Management Agency. Such ordinances can include no net loss provisions to limit the placement of fill within floodplains and create compensatory storage programs for areas requiring fill for economic development.

If communities choose to allow development in the floodplain, there should be no exception from water quality requirements. Because the areas are subject to flooding during large storm events, they are sometimes exempted from large storm flood control. However, water quality events do not produce similarly large volumes and should be captured for treatment prior to discharge.

D. Stream Setbacks and Buffers

Ordinances that include stream setbacks and buffers provide a measurable area of vegetation between the streams and development and help protect the functions and values of aquatic habitat. They typically are designed so that almost all types of development or land clearing are prohibited near the stream, with gradually increased development as the distance from the top of the stream bank increases.

Stream setback or stream buffer requirements typically apply to new development and are effective at preserving the natural benefits of riparian corridors. The Center for Watershed Protection's website, The Stormwater Manager's Resources Center, lists model ordinances for stream buffers. According to the model ordinance for stream buffers a stream setback or buffer ordinance should include a minimum of the following elements:

- Background – defines the benefits of the ordinance.
- Intent – provides the purpose of the ordinance.
- Definitions - relevant technical terms.
- Application – outlines where the ordinance would apply and where it would not.
- Plan requirements – defines the information required on development plans to delineate the limits of the setbacks.
- Standards – defines how the limits of the setback are established.
- Management and maintenance.
- Enforcement procedures.
- Waivers/variances.

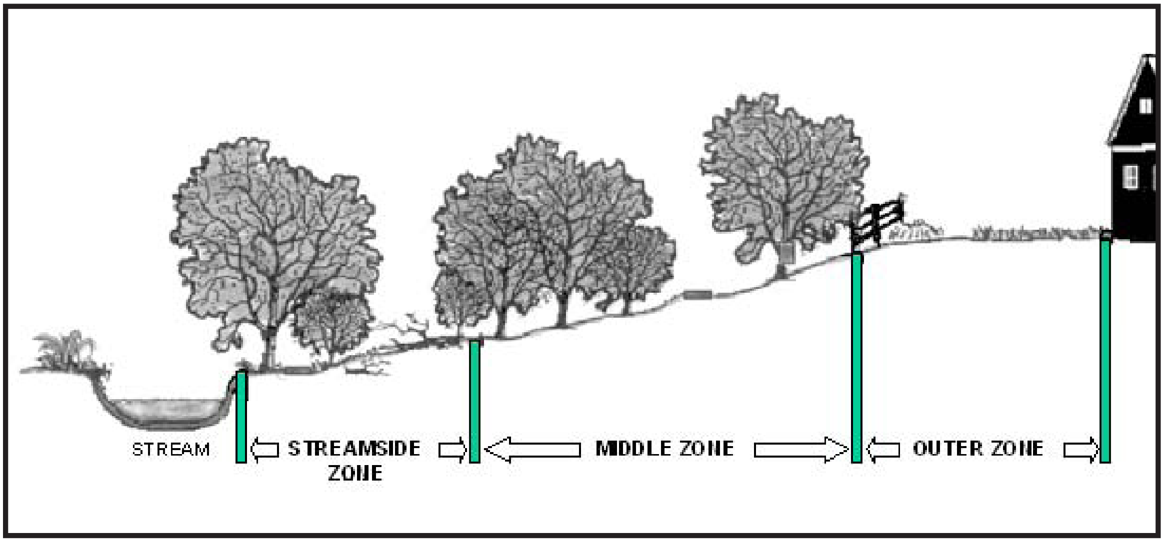


Figure 4.2 Three-Zone Stream Buffer System *Minnesota Stormwater Manual*. November 2005. Source: Adapted from Schueler, 1995.

E. Stream Meander Belt Setbacks

Given the nature of a stream's ability to shift over time, consideration may be given to creating a meander belt setback. Failing to prevent development within the meander belt will eventually put development into conflict with shifting stream banks. Stream bank stabilization requires permitting through state and federal agencies, can be costly to construct, may transfer stabilization problems down or upstream and has no guarantee of success.

Given their physical location, meander setbacks can be incorporated into either stream setback or floodplain ordinances. A meander belt setback is a line drawn parallel at the top of the bank at each existing meander. The setback should be from the meander belt setback line.

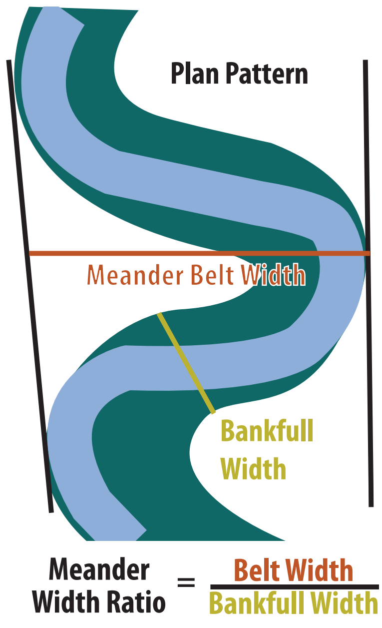


Figure 4.3 Meander width ratio of natural channels.

F. Urban Forestry Management

An urban forestry management ordinance is a municipal scale planning tool for preserving and protecting trees. The ordinance can prescribe goals to protect, preserve and reforest areas to establish a healthy, mature street tree canopy within an urban area. Trees have a higher capacity for uptaking water than smaller plants.

G. Tree Preservation Ordinance

Similar to riparian setbacks and urban forestry ordinances, tree preservation ordinances can assist with preserving trees outside of these corridors.

Trees provide a wide range of benefits for stormwater management as well as other environmental, economic and community benefits. Tree preservation ordinances are designed to mitigate any negative impacts of land development and will assist with other tangible benefits, such as maintaining property values, air pollution, stormwater management, urban heat island cooling and providing a sense of place.

Tree preservation ordinances should provide for protection from salt damage, but should not prevent use of trees in bioretention areas that may be used for storing snow. Careful consideration should be given to planting deciduous trees in areas more likely to be impacted by salt, because their roots go dormant in the wintertime. Evergreens are more susceptible to salt damage as their roots grow all year round.

H. Parking Standards and Ordinances

Non-residential parking can be a large portion of the impervious surface in a watershed, depending on land use. Green infrastructure can be integrated into parking standards or ordinances, including:

- Reduce minimum parking space count requirements, establish maximum parking space counts and allow shared parking. Allow for exceptions where the developer can meet specific compensatory requirements through supplemental stormwater control measures such as pervious pavement, additional rain gardens or other infiltration method.
- Reducing minimum required area per parking space can directly reduce the size of parking lots and length of drive lanes. EPA's water quality scorecard recommends a nine foot wide by 18 foot long parking space (162 square feet). St. Louis County requires a minimum 9 foot wide by 19 foot space (171 square feet)
- Encouraging one-way directional, angled parking minimizes drive lane widths and can decrease parking lot impervious surface by up to 10 percent without reducing parking space counts. Requiring developers to submit four parking layouts using perpendicular and angled parking configurations and applying two-way and one-way drive lanes to each style can help ensure that impervious surface is minimized as part of design.

"Natural stream stability is achieved by allowing the stream to develop a stable dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades or degrades. For a stream to be stable it must be able to consistently transport its sediment load, both in size and type, associated with local deposition and scour. Channel instability occurs when the scouring process leads to degradation, or excessive sediment deposition results in aggradation." (Rosgen, 1996)

Example : St. Louis County Phase II Stormwater BMP Implementation Work Group, 2011

Maximum parking – requirements are based on Chesterfield's City Code, Section 1003.165 Parking, Stacking and Loading Requirements. The recommended model parking ordinance contains a section that requires increases in parking areas over 10 percent of the maximum parking requirement to be reviewed and approved by the Planning and Development Services Director and applicants must include measures to mitigate for the increase, such as, increased open space, pervious pavement, green roofs and more.

Shared parking – City of Maryland Heights Zoning Ordinance, Article 14, Section 25-14.10, Shared Parking allows for shared use of a parking lot where uses are unlikely to produce substantial demand for parking at the same time, based on a parking study and legal agreement between all land owners.

Modifications of Parking Requirements – Chesterfield's City Code states that a Parking Demand Study can modify zoning ordinance requirements to reduce the number of required parking spaces. The request must include various analyses, as prescribed. Parking lot design strategies must use pavement reducing strategies that mitigate stormwater runoff.

Landscape Guidelines – City of Chesterfield's Tree Preservation and Landscape Requirements in Chapter 27.5 of City Code (Ordinance 2512) requires landscaped islands with trees in parking lots. The island size must be a minimum of nine feet wide and 135 square feet of pervious area per parking row. No parking space can be located farther than 50 feet from a tree.

I. Parking Landscape Requirements

Landscape guidelines can be used to require a minimum amount of green space within the parking lot. Green infrastructure elements may include:

- Where practicable, parking landscapes should be constructed to receive and manage stormwater runoff.
- Shade trees should be required to intercept and evapotranspire rainfall.
- Deep rooted native vegetation to increase infiltration capacity of soils.
- Linear parking islands should be encouraged over perpendicular designs to increase opportunities for stormwater management and tree canopy.

J. Weed Ordinances

Ordinances should be checked and updated to address conflicts between weed ordinances prohibiting the use of many native species and stormwater control measures that require their use. To help ensure attractive native plant landscapes, native species lists may be limited or their use otherwise restricted within the landscape guidelines or other relevant municipal technical manual. In general, hardy - deep-rooted species are recommended for stormwater management to help ensure long term infiltration of runoff and high survivability during periods of drought. Multiple species are not required for success relevant to stormwater management, however increasing species variety helps increase habitat diversity and lowers the risk of die off due to species-specific stressors.

Native plants identified by the Missouri Department of Conservation is available at Grow Native at www.grownative.org and the Missouri Botanical Garden's Flora of Missouri Project, at www.tropicos.org/project/mo.

K. Street Standards

Similar to parking standards, street standards should encourage for reduction in widths where practical and allow for stormwater infiltration or retention in the right of way. Issues and ideas to consider include:

- Pervious pavements, pavers or other aggregate may currently be prohibited or not be pre-approved for use as construction materials in existing ordinances.
- Fire code and other public safety access restrictions preclude narrowing streets in some cases. However, alternatives such as stabilized turf shoulders or other pervious media can be used to minimize impervious surface while providing adequate emergency access.
- Prohibiting and enforcing on-street parking restrictions may be needed on narrowed streets.
- Converting two-lane, two-way traffic to one-lane, one-way traffic can reduce street widths by one lane.
- Converting two-lane, two-way traffic to one-way traffic with angled parking can further reduce street width and provide opportunities for rain gardens.

L. Right of Way Uses and Standards

Managing runoff in the right of way generates numerous issues and concerns from competing uses. Transportation, public safety, utilities and stakeholders all have vested interests in designing and managing the right of way for their primary functions.

Most municipalities currently require a variance from existing street design criteria in order to place stormwater control measures in the right of way. Results in the St. Louis County Phase II Stormwater BMP Implementation Work Group, or STLBMPWG, February 2011 report describe several issues and potential solutions:

Right-of-ways – would be limited to the street edge of pavement. Public maintenance of the street would be enabled through a permanent roadway, improvement, maintenance, utility, sewer and sidewalk easement, or PRIMUSSE, up to the former right-of-way limits. For Missouri Department of Transportation streets, the stormwater control measures would be allowed in the Missouri Department of Transportation right-of-way and a maintenance agreement would be executed so the property owners or subdivision trustees would be responsible for maintenance.

PRIMUSSE – shown on the property plats up to 12 feet from the edge of pavement will provide public agencies the access needed to maintain the streets, utilities and sidewalks. Underground utilities should be placed perpendicular to the sidewalk, not parallel under the sidewalk. Coordination with utilities is necessary and utilities may be placed in an additional utility easement located outside the PRIMUSSE.

Sidewalks – can be located in the PRIMUSSE. In some cases, sidewalks can be limited to one side of the street subject to the Americans with Disabilities Act, or ADA, requirements.

Common Ground – would be established for the stormwater control measure's footprint to ensure the subdivision trustees would maintain the stormwater facility so it operates properly. This is a typical arrangement for stormwater control measures located elsewhere in a development. The property plat shows the area as common ground and identified as a stormwater management reserve area. This reserve area is subject to a stormwater control measures maintenance agreement between the metropolitan sewer district and the property owner(s) to ensure the owners maintain the stormwater control measure.

Curb Cuts – allow stormwater from the street to flow into bioretention areas next to the street or through a "bioretention sump" located at the edge of the roadway transitioning into the bioretention area. The sump design can allow for non-erosive flows into the bioretention area and for larger flows to bypass into the curb gutter for management in a storm sewer inlet. Alternatively, an inlet can be located within the bioretention stormwater control measure.

Cul-de-sac Islands – create an excellent location for a bioretention stormwater control measure that would avoid the issues identified above and would typically not require significant changes to current development property plat plans, since these areas are already in common ground that is maintained by the subdivision trustees.

M. Residential Drives and Alleys

Less impervious area used for residential driveways can be accomplished by making the effective width of paved surface in the driveway smaller, by reducing the amount of driveway needed to serve a residential property or by substituting pervious materials for construction.

Two-track driveways – reduce the impervious area of a driveway by providing for green space on the portion of the driveway that is not needed for a vehicle's wheels to travel on. Local American Planning Association members were queried as to their use of this solution. Of the 12 STLBMPWG responders, only one city allows the construction of two-track driveways and three do not allow them. The majority of the responders, eight, do not specifically prohibit or allow. Various additional comments indicate that this solution is not very popular.

Shared driveways – are commonly used in St. Louis County, primarily in duplex properties, where two residences use the same driveway. Also, where off-street parking is provided, such as in lieu of on-street parking along a 20 foot wide street, shared driveways and shared parking can be a tool to reduce the impervious area.

Figure 4.4 Residential alley. Source: Metropolitan St. Louis Sewer District

Figure 4.5 and 4.6 Before and after street edge alternatives (SEA Streets Project) - Seattle, Washington. Source: www.epa.gov/greenkit/stormwater_studies/SEA_Streets_WA.pdf

Smaller driveways – less than nine feet per lane width was deemed not popular with the public or practical for use by the work group and therefore, is not being recommended.

Pervious driveways – can reduce the impervious area by using paving materials and designs that allow rainwater to pass through the surface. Options typically include: pervious asphalt, pervious concrete and pervious pavers.

Residential Alleys – can incorporate two-track, reduced width or pervious material concepts similar to those presented above.

Green Streets Initiatives – can aid the adoption and implementation of stormwater control measures such as bioswales with flat curbed streets, rain gardens, and similar functional and aesthetic landscapeds to manage stormwater quality. See Appendix C for green street resources

4.3.3 Legal Impediments and Considerations

Portions or all of a stormwater community may be subject to oversight or regulation by other jurisdictions. For that reason, it is important to identify other departments or agencies that have jurisdiction over relevant physical areas or operations within a municipality in order to include them as stakeholders in the ordinance review and revision process.

To ensure any proposed stormwater ordinance does not conflict with existing ordinances, the municipality should review and identify issues that may arise with the implementation of green infrastructure. The review should be thorough and included everything from parking and street standards to weed control ordinances.

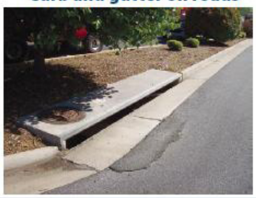
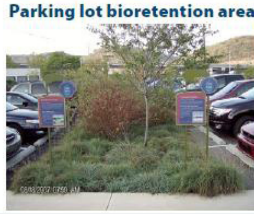
THE LOCAL CODE MAY *REQUIRE* THIS	BUT *NOT ALLOW* THIS
Subdivision with no open space  *Graphic courtesy of Rennaissance Planning Group*	**Open-space design**  *Graphic courtesy of Rennaissance Planning Group*
Curb and gutter on roads 	**Swales and grass channels** 
Parking lot islands not used for stormwater 	**Parking lot bioretention areas**  *Photo courtesy of Sanitation District #1 of Northern Kentucky*
Stormwater BMPs address only flood control 	**Stormwater BMPs address water quality and resource protection** 
Nonstructural BMPs and LID not allowed 	**Nonstructural BMPs and LID given credit** 

Figure 4.7: Existing codes that may conflict with stormwater management ordinances.
Source: Center for Watershed Protection's *Managing Stormwater n Your Community: A Guide for Building and Effective Post-Construction Program*, 2008

Key Local Documents that could Impact Development Regulations
Zoning Ordinance
Subdivision Codes
Street Standards or Road Design Manual
Parking Requirements
Building and Fire Regulations/Standards
Stormwater Management or Drainage Criteria
Buffer or Floodplain Regulations
Environmental Regulations
Tree Protection or Landscaping Ordinance
Erosion and Sediment Control Ordinances
Public Fire Defense Master plans
Grading Ordinances
Weed Ordinance

Table 4.1 Source: Shockey Consulting

To meet the goals of the 2007 Phase II Stormwater Management Plan, St. Louis County assembled a work group to evaluate legal impediments that may occur to meet the water quality requirements set forth by Metropolitan St. Louis Sewer District (St. Louis County Phase II Stormwater BMP Implementation Work Group, 2011).

This section highlights five of the potential challenges to adopting or revising ordinances to better accommodate green infrastructure. Although not binding on Missouri courts and arising out of different constitutional and statutory backdrops, challenges in other states offer insight into the types of challenges that might be raised in Missouri.

A. Authority

The most basic challenge is whether a community even has the authority to enact stormwater ordinances and fees. While there is no statute specifically permitting Missouri cities, towns and villages to adopt a post-construction runoff management ordinance, the Missouri zoning enabling statute 1, as with all development regulations, would seem to provide authority for stormwater regulations during and after development. Other authority such as the general police power (i.e., protection of the welfare, safety, health and even morals of the public), the power to construct and maintain a sewerage system and nuisance authority appear to apply as well.

Additionally, in other states, courts have found authority for these ordinances under the police power. Where there appears to be adequate authority, a municipality should be careful to draft regulations that squarely fit into the municipality's existing authority to control and regulate development and stormwater runoff.

B. Fees

Legal challenges regarding post-construction runoff management ordinances could arise in ordinances where the municipality, in addition to regulation, also provides for a funding mechanism for stormwater projects or programs. In Missouri, the Hancock Amendment (Mo. Const., Art X, §§ 16-24) mandates that any charge made by a municipality that constitutes a "tax, license or fee" can only be imposed after voter approval. The courts have determined, however, that a charge that constitutes a true user fee is not subject to the voting requirement. Generally, under Missouri case law, a charge is a user fee (i.e., not a tax) and could be imposed by a municipality without voter approval:

- A fee charged for an actual service or good; charged only to persons receiving the goods or service; (1 Chapter 89 of the Revised Statutes of Missouri authorizing regulation for "the coordinated development of the city, town or village." See, e.g., §89.410).
- Charged after or at the time the service or good is provided.
- Based on the actual cost of providing the service or good to the specific person charged the fee.
- This is not a service, permission or activity historically and exclusively provided by the government. This concern arises with any charge whether for capital projects or application review.

In other states with similar user fee/tax distinctions, courts generally have held that the fees for stormwater system users are not illegal taxes. For example:

- Densmore et al. v. Jefferson County et al., (Densmore, 2001) where the Alabama court system found that a "stormwater-program fee is a valid fee for the purpose of regulating stormwater discharge and that it is not a tax designed to raise revenue."
- Teter v. Clark County, (Teter, 1985) where the Washington court system found that because "the primary purpose of the stormwater ordinance is regulatory, the charges are properly characterized as 'tools of regulation' rather than taxes."
- Twietmeyer et al. v. City of Hampton, (Twietmeyer, 1998) where the Virginia court system dismissed the argument that the stormwater management fee is a tax because it is "tied directly to the administration of stormwater management and is not meant to raise general revenue."
- Sarasota County v. Sarasota Church of Christ, Inc., et al., (Sarasota, 1996) where the Florida court system found that a "flat fee for the services based on the number of individual dwelling units on the property" for residential property and "non-residential developed property owners pay a fee based on a formula that is designed to create a direct relationship between the method of assessing a non-residential unit and the average residential unit" upheld.
- Bolt v. City of Lansing, (Bolt, 1997) where the Michigan court system heard the case on a landowner's challenge that the city's stormwater service charges were disguised taxes without submitting such charge to the taxpayer's vote failed because charging each parcel for stormwater runoff was a user fee and not a tax.

C. Takings

Another possible challenge is that the municipality's stormwater regulation goes too far and effectively "takes" all use of the owner's property without just compensation. This is known as a "takings" claim. To avoid this challenge, the municipality should draft its ordinance to avoid regulations that effectively deny an owner all economically viable use of the owner's property. For a variety of procedural and substantive reasons, takings claims would be difficult to prove against a municipality as is demonstrated by the fact that not one reported "takings" challenge with respect to stormwater management has been successful.

D. Equal Protection

Municipalities intending to charge a fee to property owners who use the stormwater system should also strive to avoid any irrational distinctions between property owners in the assessment of the fee. Failure to do so could lead to equal protection challenges depending upon how the fee structure is arranged. The most common argument arises when an ordinance distinguishes between different types or classifications of properties. However, an equal protection challenge places a high burden on the challenger because the challenger should show that no rational relationship exists between the classification and a legitimate governmental interest. Most courts faced with this issue have rejected arguments that a classification that applies uniformly to similar properties violates the equal protection clause.

E. Enforcement of Stormwater Ordinances

Clearly defining enforcement procedures and penalties for non-compliance with the requirements of the post-construction runoff management ordinance would help to minimize confusion and challenges to the program's requirements. Development of enforcement procedures and penalties should be closely coordinated with existing enforcement and penalty codes and precedents that have been set. *The Center for Watershed Protection's Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program* (Center, 2008) provides an overview of the types of penalties that a community could choose to employ.

The ordinance should be enforced even-handedly and in all circumstances with limited exceptions and should decide what events would trigger non-compliance with the ordinance and what developments would be considered too far along to be brought within the ordinances' scope. This would avoid claims that enforcement is selective or retroactive.

For example, Heaton v. City of Princeton, et al., (Heaton, 1997) where the court dismissed a selective enforcement challenge because although many developers and businesses had not had to comply with the Stormwater Ordinance Management Control to receive a permit, there is no right to have a law go unenforced, "even if you are the first person against whom it is enforced and even if you think (or can prove) that you are not as culpable as some others who have gone unpunished," and because plaintiffs could not prove that the alleged selective treatment was used "as a means of achieving invidious discrimination because of membership in a protected group or in retaliation for the exercise of a constitutionally protected right," however Myers v. Penn Township, (Myers, 2002) the court ruled for plaintiff finding that the ordinance was retroactively applied to plaintiff who received preliminary approval from the city and installed several stormwater management ponds in accordance with the plan's specifications and then the township rejected plaintiff's offer to dedicate the ponds solely because he would not agree to provide funds pursuant to the newly enacted stormwater ordinance.

The relatively recent governmental focus on water quality has led to challenges by those having to comply with the new laws. Courts seem inclined to uphold these regulations as being necessary for the public health and safety and would only strike them down when the ordinance or fees bear no rational relationship to the purpose of controlling and treating stormwater or are clearly a revenue-generating vehicle with no true service being provided. Minimally, an ordinance should cite the authority and public need for the stormwater regulations. The community should also ensure that any fees charged to property owners are true user-fees that are rationally related to the control and maintenance of the ordinance and that the landowner's use of or benefit received from the ordinance rationally relates to the amount that the landowner should pay. The community should strive to narrowly draft the regulations to ensure that implementation would not be a physical taking or deprive the property owner of all viable use of that property and clearly define to whom and at what point in the development process the stormwater ordinance would be enforced.

Penalities and Remedies for your Community	
Type	**Description**
Notice of violation	Written notice served on the responsible party stating the cause of the violation, and consequences for noncompliance (e.g., stop work, revoke permits, and pursuit of civil and/or criminal penalties.)
Stop work order	Provisions for the enforcing agency to stop work on a site if the responsible party fails to comply with an notice of violation.
Civil penalties or charges	Civil penalties can impose charges for specific violations. The ordinance can include a schedule of civil penalties (specific charges linked to specific types of violations), and inspectors can use this schedule in "ticket book" fashion when in the field. Civil penalties provide more flexibility than criminal penalties.
Criminal penalties	Criminal penalties establish violations as misdemeanors, subject to specific fines and/or imprisonment. Each day the site is not in compliance is considered a separate violation. Although criminal penalties represent the biggest "hammer" in the enforcement toolbox, most programs resort to them rarely and could find it difficult to garner the political support to use such penalties.
Withholding other permits or approvals	Perhaps the biggest motivator to comply during the construction process is withholding certificates of occupancy or other approvals until all measures have been properly installed. This tool would not apply to long-term maintenance, however, and might also present timing challenges for the applicant and jurisdiction (e.g. site work lags behind building and occupancy).
Revoking or suspending other permits or approvals	Revoking or suspending other permits or approvals. This tool is similar to withholding permits, but it applies to permits or approvals that have already been granted (e.g. building or grading permits). The appropriate permit or authorization can be suspended until the required actions are taken, at which point the permit is reinstated. This tool can be quite effective, but implementing it usually takes political support.
Performance bonds	Performance bonds are not an enforcement tool in the strict legal sense, but many programs use them to motivate compliance. Bonds can be particularly useful for a stormwater program because their duration can cover the proper installation of stormwater measures plus a reasonable period thereafter to ensure that practices function properly. The bond concept can also be expanded to maintenance in the form of a maintenance bond, escrow, or other financial guarantee that should be posted by the responsible party. In the ordinance, the performance bond section would likely not be in the penalties section but rather in the plan submission and review section.

Table 4.2. Source: Shockey Consulting

Introduction to Case Studies

Throughout the U.S., there is a growing recognition of the benefits green infrastructure provides to communities. Many municipalities and other jurisdictions have begun to effectively incorporate these practices. The following case studies were selected to showcase both site and landscape scale GI projects which have successfully been implemented. Additional case studies are included in Chapter 6. Readers are encouraged to follow the links or titles provided for each case study to learn more about these projects.

Case Study: The Milwaukee River Basin Overlay Districts

Overlay districts are typically developed in conjunction with the preparation of a comprehensive land-use plan. They can provide significant improvements to overall water quality. Careful consideration of economic impacts, natural impacts and private rights should be exercised when using overlay districts.

An overlay district is an additional zoning requirement that is placed on a geographic area but does not change the underlying zoning. Overlay districts have been used to impose development restrictions in specific locations in a watershed in addition to standard zoning requirements. These districts are created to protect natural resources, promote safety and protect health. Some examples of overlay districts are:

- Airport overlay district.
- Wind energy system overlay district.
- Wireless communication facilities overlay district.
- Shoreland wetland overlay district.
- Floodplain overlay district.
- Agricultural overlay district.
- Aquifer protection overlay district.

Source: Williams Creek Consulting

Shoreland, floodplain, aquifer and agricultural overlay districts have a direct benefit on the water quality of a watershed by imposing additional restrictions on the type of land use allowed within their boundaries. Depending on the environmental conditions, more than one overlay district may apply to a single area.

Floodplain Overlay Districts

It is known that allowing uncontrolled development within floodplains results in damage to private and public facilities, creates safety hazards, impacts the tax base and can lead to expensive floodway improvement projects. Floodplain overlay districts try to minimize these impacts by allowing only uses that will not experience significant impact by floods and will not obstruct flood flows.

These districts do not intend to completely restrict development in this zone. For example, the Dodge County land use code allows uses such as parking lots, roadways, airport landing strips and golf courses to be constructed within the overlay zone.

Case Study: Kansas City, MO Stream Ordinance

Riparian corridors are natural areas located adjacent to linear waterways and typically have trees and herbaceous vegetation adapted to the localized environment. Riparian corridors provide water quality benefits, assist with in-stream stability, are wildlife corridors and often convey flood water. To protect these and other benefits, Kansas City has implemented a stream buffer ordinance. Additionally, the stream buffer ordinance also encompasses public health and safety rules for developing within a potential floodplain. To implement the ordinance, Kansas City developed a natural resource map that assists the public to identify streams that the stream buffer ordinance encompasses. The ordinance includes three zones:

1. Streamside Zone - The streamside zone extends 25 feet landward from the edge of stream.

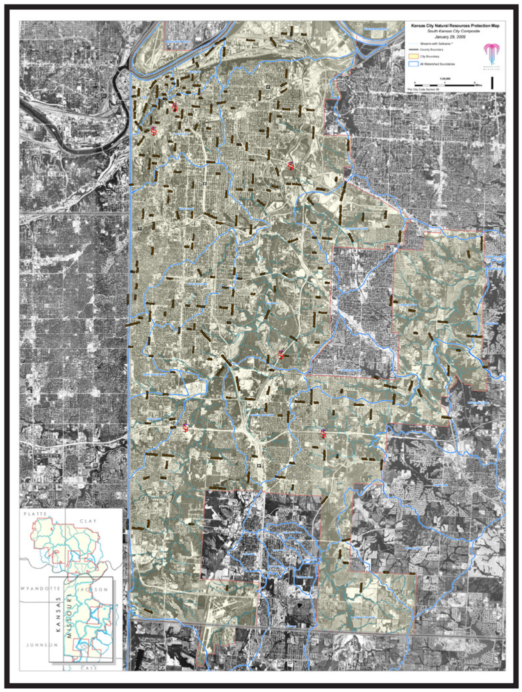
2. Middle Zone - The middle zone extends landward beyond the streamside zone and encompasses the FEMA- or city-designated 100 year floodplain or the limits of the 100 year floodplain as determined by a qualified engineer and any jurisdictional wetlands. The middle zone may be adjusted based on permitting and mitigation requirements.

3. Outer Zone - The outer zone extends landward 75 feet from the outer edge of the middle zone. When slopes exceeding 15 percent or mature riparian vegetation areas are contiguous with the middle zone boundary, the width of the outer zone is expanded to encompass such resource areas.

Although development activities are required to follow the ordinance, some activities are allowed within the stream buffer areas:

- The streamside zone may include vegetation management and trail development with administrative approval.
- The middle zone may include paved and unpaved trails and underground utilities that are restored.
- The outer zone may include middle zone allowances, stormwater management, other described development and variance to include additional building heights and reduces off street parking. In some instances, mitigation may be approved in this zone for projects that require additional land use.

As part of the ordinance, the proposed development must develop a site plan with required information and submit as part of the city approval process.



Kansas City arial.

Case Study: Georgia Forestry Commission Tree Ordinance

The following sample tree ordinance is provided as a tool to help communities develop the initial stages of tree protection ordinances. It provides one example of basic document formatting and verbiage. As a starting point, such an ordinance serves as the baseline for communities to build an ongoing process for community tree care and tree conservation. It should be noted that tree ordinances should be made compatible with bioretention provisions.

PURPOSE: The purpose of this ordinance is to provide for the protection, management, removal and replacement of trees on public property and public rights-of-way.

WHEREAS, the health, safety and general welfare of the public and the conservation and protection of the natural resources of the county/city and their values necessitate the implementation of regulations to guide the planting, maintenance and removal of shade and ornamental trees on public property and rights-of-way within the county/city and

WHEREAS, high growth areas, where natural green spaces are diminishing, have fewer trees remaining to transform the carbon dioxide of ever increasing, harmful vehicular and industrial emissions into oxygen, resulting in severe air quality degradation and

WHEREAS, the removal of forest canopy from urban areas of the state and its replacement with more intensive land uses exacts real costs upon the infrastructure which must be borne by all citizens of the community and

WHEREAS, community forests function to the benefit of the local citizenry as a part of the public infrastructure as much as streets, utilities, stormwater management structures and sewers and integrated forest canopies reduce the costs of maintenance of other co-located parts of the urban infrastructure and

WHEREAS, well-managed urban forest resources increase in value and provide benefits to all the citizens of the community with respect to air quality, water quality, stormwater management, temperature amelioration, community aesthetics and general quality of life and, healthy community forests increase local commercial and residential property values and

WHEREAS, these benefits are crucial to the long-term health, benefit, welfare and safety of the citizens of the community and

WHEREAS, this tree protection law is one part of a dedicated and integrated planning process dealing with land use, impacts of impervious surface, urban hydrology and water quality, air quality, soil erosion, transportation, noise abatement and wildlife habitat and

WHEREAS, the board of commissioners/city council finds that it is in the best interest of the public to provide standards and requirements for the conservation, protection and replacement of trees on public property for the purpose of making this county/city a more attractive and healthier living environment;

(Georgia. 2004)

Case Study: Taylor v. Harmony Township Board of Commissioners

Timber Ordinance

Taylor v. Harmony Township Bd. of Comm'rs, 851 A.2d 1020, 1024-27 (Pa. Commw. Ct. 2004)

Under the Township's local Ordinance No. 335, "…no timber harvesting shall take place in areas determined by the Engineer, with reference to published or commonly accepted guidelines, to be landslide-prone or flood-prone."

Landowner contended that:

- The general "police power" provisions of the Code do not specifically authorize the Township to regulate logging or timber harvesting as the Township suggests.
- The Pennsylvania Municipalities Planning Code, is the enabling statute that controls this case and because the code prohibits unreasonable restrictions on logging and timber harvesting, Ordinance 335 is invalid.

As to the landowner's first argument, the Code has numerous sections referring to general police powers of first class townships. Under Section 1502, cl. X of the Code, first class townships may "take all needful means for securing the safety of persons or property within the township."

In addition, Section 1502, cl. LII of the code provides that a first class township may:

"…make and adopt all such ordinances, by-laws, rules and regulations…as may be deemed expedient or necessary for the proper management, care and control of the township and its finances and

the maintenance of peace, good government and welfare of the township and its trade, commerce and manufactures."

Finally, Section 1502, cl. XLIV of the code provides that first class townships may

"…make such regulations as may be deemed necessary for the health, safety, morals, general welfare, cleanliness, beauty, convenience and comfort of the township and the inhabitants thereof."

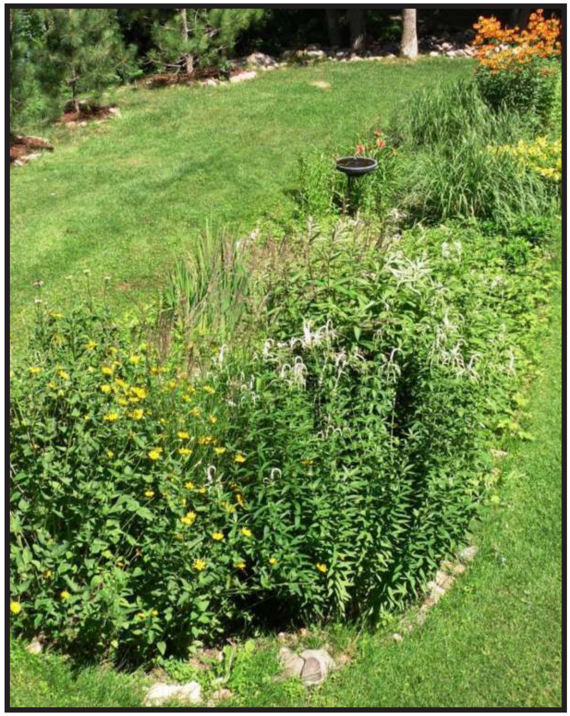
Although police powers are not without limitation, commonwealth courts have recognized that municipalities have the power to enact legislation aimed at protecting the health, safety and welfare of citizens under the general welfare clauses contained in municipal codes.

In conclusion, the judge of the commonwealth court found the township had the authority to enact Ordinance 335 under the First Class Township Code.

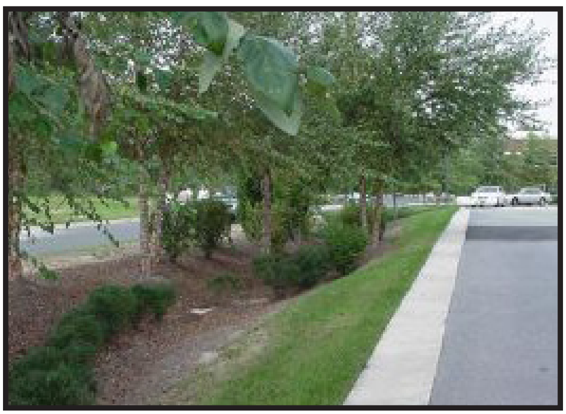
Case Study: Brockman Enterprises LLC v. City of New Haven, 868 N.E.2d 1130, 1134-35 (Ct. App. Ind. 2007)

Plaintiff's equal protection challenge that the ordinance illegally distinguished between residential and non-residential properties by placing a cap on the charge for non-residential properties was rejected, because since the classifications apply uniformly to similarly-sized lots, the cap is rationally related to a governmental interest.

However, requiring one developer or landowner to pay the entire bill for a public improvement may not be rational because the one property owner would not be the only owner to benefit from such an improvement. For example, in Christopher Lake Development Co. v. St. Louis County, (Christopher Lake Development v. St. Louis County, 1994) where the court system overruled a grant of a motion to dismiss, because "although the county's objective to prevent flooding may be rational, it may not be rational to single out the *plaintiff to provide the entire drainage system."



Rain garden.



Flat curb edge with receiving vegetated swale.

Case Study: Lenexa, Kan.

Some communities, such as Lenexa, Kan., incorporated natural resource protection and green infrastructure components into their comprehensive planning strategies. The integration into community planning was driven by the community's value of natural resources. Communities that place a high value on natural resources, setting goals for resource protection at the comprehensive planning scale assist to reinforce good stewardship and sets the foundation for good stormwater management.

Lenexa Vision 2020 discussed both the importance of stormwater management to quality growth and the desire to maintain a balance between Lenexa's natural and man made environments. As a community that promotes the coexistence of the natural environment and quality planned development, the city is leading in developing and following effective stormwater management practices and implementing a long-term, comprehensive stormwater management program that meets the desired balance of the city's environmental and development goals.

The city's stormwater management planning targets the goals of flood reduction and avoidance, water quality protection, stream corridor conservation and the creation of recreational amenities. An overall watershed-based strategy is being developed in cooperation with neighboring jurisdictions and the public will be encouraged to monitor their own activities that may affect the stormwater management goals. All parties will acknowledge that there will always be inherent dangers from extreme storm events and that individuals must exercise responsibility, even as the city plans to manage risks. The city created a stormwater utility in the spring of 2000, which acts as a primary funding source for construction and maintenance of watershed-based stormwater facilities.

A stream setback ordinance was applied to all land or new development within the stream corridor and establishes permanent buffers along most streams and creeks. GIS mapping identifies stream quality and stream order affected by this ordinance.

No development is to occur within a stream corridor unless a development application has been approved authorizing the proposed development and provided that, the development proposed is, in all respects, in conformity with the requirements of this stream setback ordinance.

Stream Setback Requirements: Lenexa, Kan.			
Stream Order	Types 1-2 Sensitive Streams	Type 3 Restorable Streams	Types 4-5 Impacted Streams
1	150 ft.	125 ft.	100 ft.
2	250 ft.	200 ft.	150 ft.
3+	300 ft.	250 ft.	200 ft.

Case Study: Stormwater Best Management Practices Post-Construction Recommendations

A St. Louis County work group reviewed legal impediments to implementing green infrastructure. As a result, the work group developed the *Stormwater Best Management Practices Post-Construction Recommendations* report in 2011.

1. A recommended model property plat for stormwater control measures at the edge of a roadway has been drawn up and is located in Appendix F of this report. This model has been reviewed and agreed to by the work group, which consists of municipal and private engineers and planners and utilities. Each of the individual elements of the model have been approved locally. Also, refer to the recommended Note (5) in Appendix E, Residential Street Design Criteria.

The report can be viewed at www.stlmsd.com by searching legal impediments.

Parking lot with rain garden and overflow, plus permeable pavement and curb cutouts above. Source: Metropolitan St. Louis Sewer District

River de Peres Greenway, St. Louis MO.
Source: Williams Creek Consulting

2. Metropolitan St. Louis Sewer District's Non-Standard Details of Sewer Construction Drawings for Roadway Bioretention located at the edge of street pavement, are located in the Appendix G of this report. These four non-standard detail drawings were reviewed and agreed to by the work group as a recommendation for locating stormwater control measures next to roadways. Details of the bioretention sump are also included.

3. Parking Bioretention Areas – Bioretention areas are used as water quality stormwater control measures under Metropolitan St. Louis Sewer District's Rules and Regulations and in fact, are the most popular post-construction stormwater control measure used in the community. Bioretention stormwater management facilities are ideally suited to being located in cul-de-sacs. If it is necessary to build a cul-de-sac, MSD has developed plans for a stormwater infrastructure project to include bioretention in a cul-de-sac on Chalet Court in Creve Coeur.

5 Green Infrastructure Implementation Methods

As discussed in Chapter 2 of this document, one of the most effective ways to reasonably mimic pre-construction runoff conditions in new development is to employ sustainable site design techniques during planning. Both structural and non-structural stormwater control measures can be integrated into a site design to help meet pre-construction runoff conditions and treat pollutants within the runoff. Non-structural stormwater control measures include protecting existing features, slowing runoff, disconnecting impervious surfaces, etc.

Where site conditions make infiltration impracticable, underdrain systems and extended detention may be used to better simulate pre-construction runoff conditions and return runoff to its pre-construction condition. This is also applicable where potential groundwater contamination is a concern.

This chapter further explores sustainable site design using non-structural and structural methods for managing stormwater runoff, while also creating functions and addressing needs outside of stormwater management.

Figure 5.1 Oakbrook development site plan. Source: Shockey Consulting

5.1 Sustainable Site Design Principles

Reducing pollutant sources and stormwater volume through non-structural stormwater control measures in strategic combination with structural stormwater control measures can be an effective method of managing runoff. Proper application of sustainable design methods require defining the sources of potential runoff issues so appropriate non-structural and structural stormwater control measures can be selected.

The following principles are from the *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers* (Southeast Michigan Council of Governments, 2008):

Plan first.

Planning for runoff management in the earliest stages of the development process helps ensure that natural resources are protected and the impacts are minimized.

Prevent, then mitigate.

Minimizing the amount of runoff generated from the site is the most effective way to manage stormwater. This can include preserving natural features, clustering development and minimizing impervious surfaces. Once prevention as a design strategy is maximized, then the site design — using structural stormwater control measures — can be prepared.

Minimize the disturbance.

Limiting the disturbance of a site reduces the amount of stormwater runoff control needed to maintain the natural hydrology.

Manage stormwater as a resource – not a waste.

Designing sites to take advantage of stormwater runoff can create community amenities, reduce watering needs and protect natural resources. Planning a development around naturalized stormwater areas can help attract residents and adds value to lots near them. See Chapter 2 for benefits of green infrastructure.

Mimic the natural water cycle.

Designing the site to control peak rate, annual volume and water quality flows helps manage the full range of precipitation from small, frequent events to large, infrequent flood events.

Disconnect, decentralize, distribute.

Capturing rainfall where it falls is a very effective stormwater management technique. This is accomplished by disconnecting impervious areas from the drainage system, installing stormwater control measures at individual lots and neighborhoods and spreading them throughout the development.

Integrate natural systems.

Protecting and taking advantage of native soils, vegetation and natural resources minimizes the impacts of a development and can increase its value.

Natural resources are effective stormwater systems that provide water quality benefits and reduce flood peaks.

Maximize multiple benefits.

Designing the site to preserve natural resources and incorporate stormwater control measures using native vegetation can add to the social and economic value of a development and community.

Make maintenance a priority.

Stormwater control measures often require different types of maintenance than typical crews are used to performing. Placing priority on training crews to properly care for stormwater control measures and committing to scheduled maintenance programs is important for their long-term function.

More Sustainable Site Design Resources

The Missouri Department of Natural Resources' *Protecting Water Quality: A field guide to erosion, sediment and stormwater best management practices for development sites in Missouri and Kansas*, contains a section on permanent post construction stormwater control measures including information on their design and application. There are multiple additional resources including:

1. The *Maryland Stormwater Design Manual* includes technical guidance on many types of structural and non-structural stormwater control measures, including those that attempt to meet pre-construction runoff conditions. The Maryland manual is currently adopted with some adaptations by some MS4s in Missouri, including the Metropolitan St. Louis Sewer District.

2. The *APWA/MARC BMP Manual* provides guidance for land development practices within the region. It provides developers, engineers and planners with flexible tools to reduce the volume of stormwater discharge while conserving water quality at the same time. The manual provides specific guidance for planning and implementing stormwater control measures, and describes how to assess alternative site-design approaches to maximize the benefits for individual sites. It also defines stormwater control measures, provides performance goals for site development and describes methods for determining development impacts. (Mid-American Regional Council, 2008).

3. The *Minnesota Stormwater Manual* contains site design regulations based on integrated stormwater management accounting for runoff rate, volume, quality and groundwater impacts. The manual also discusses the "treatment train process" where multiple stormwater control measures are placed in sequence to better manage runoff. (Minnesota Stormwater Steering Committee, 2008)

4. The international best management practices database is available at www.bmpdatabase.org. It is a resource for extracting data on structural stormwater control measure performance. It is focused on providing information about the performance of stormwater control measures and the removal of specific pollution by a range of types of stormwater control measures, but does not make recommendations on which type to use.

5. Other post-construction design manuals such as the *Urban Small Sites Best Management Practice Manual* have developed lists of practices that meet certain performance criteria. www.metrocouncil.org/environment/Water/BMP/manual.htm

6. The EPA System for Urban Stormwater Treatment and Analysis INtegration Model, or SUSTAIN, www.epa.gov/nmrl/wswrd/wq/models/sustain, is a decision support system to facilitate selection and placement of stormwater control measures and low impact development techniques at strategic locations in urban watersheds. It was developed to assist stormwater management professionals in developing implementation plans for flow and pollution control to protect source waters and meet water quality goals. SUSTAIN was designed to help users develop, evaluate, and select optimal best management practice combinations at various watershed scales on the basis of cost and effectiveness.

The EPA Stormwater Management Model or SWMM http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/ works with SUSTAIN to help answer:

- How effective are best management practices in reducing runoff and pollutant loadings?
- What are the most cost-effective solutions for meeting water quality and quantity objectives?
- Where, what type of and how big should best management practices be?

7. Loading and Management Model, or SLAMM, was originally developed to better understand the relationships between sources of urban runoff pollutants and runoff quality (Pitt and Voorhees. 2002). Source It has been continually expanded since the late 1970s and now includes a wide variety of source area and outfall control practices (infiltration practices, wet detention ponds, porous pavement, street cleaning, catch basin cleaning and grass swales). SLAMM is strongly based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control. USGS works with Wisconsin DNR to support SLAMM in their region with their calibration data.

8. EPA's green infrastructure website http://water.epa.gov/infrastructure/greeninfrastructure/gi_modelingtools.cfm has links to additional open source tools and other models. Simp and complex tools exist. The user must decide what tools will meet their needs.

5.2 Defining the Source

Source control requires defining the pollutants of concern. Urban and suburban runoff characteristics are affected by many factors such as rainfall amount, rainfall intensity, land use, geology, season of the year and antecedent condition. Modeling software tools are available to help identify, quantify and address pollutants of concern such as the EPA SUSTAIN Model and SLAMM.

Continuous long-term simulations are needed for stormwater quality analyses. Single event design storms are not effective in covering the wide range of conditions needing attention. Use actual decades of rain data for the area (such as possible with SWMM and WinSLAMM, www.winslamm.com).

1. Design Storms

Selecting a design storm is a critical step. The current standard of practice focuses on small but frequent rain events that account for the great majority of pollutants found in runoff. These small storms generate what is typically defined as a water quality volume. According to the National Research Council, water quality volume (W_{qv}) is the volume needed to capture and treat 90 percent of the average annual stormwater runoff volume equal to 1 inch times the volumetric runoff coefficient (R_v) times the site area. (National Research Council, 2009) Control may also include storms up to 1.5 to 2 inches where channel protection requirements apply. This volume is based on local rainfall data and can vary depending on geographic location.

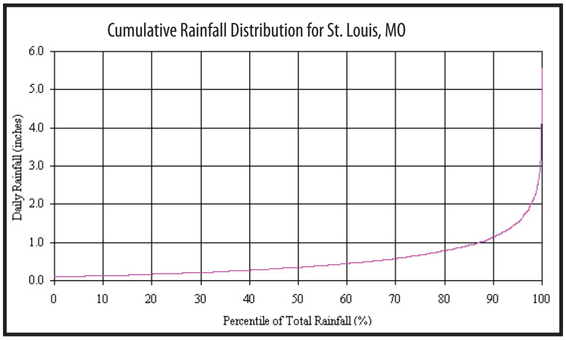


Figure 5.2 Source: Metropolitan St. Louis Sewer District.

Selecting a Design Storm: St. Louis, MO Rainfall Distribution

50 years of rainfall data for St. Louis, indicates that 90 percent of all rainfall events are 1.14 inches or smaller. This value should be determined locally using rainfall records to develop a similar rainfall frequency analysis. Communities with large geographic areas may find it beneficial to obtain data from different areas in a community to account for variability in rainfall patterns. Rainfall data sets and distributions can be derived from weather service organizations such as the United States Geological Survey (http://mo.water.usgs.gov/), National Weather Service, National Oceanic and Atmospheric Administration, or their regional and local affiliates.

2. Land use – Runoff carries pollutants that are primarily a function of land use. For example, commercial parking and dense urban areas can create excess volume and thermal loads, gas stations may contain hydrocarbons and agricultural areas may have high suspended solids loads from dormant croplands.

3. Target Pollutants – In context of source control, regulators and designers need to consider pollutants in context of the receiving streams. According to a recent report completed for EPA, "the rapid conversion of land to urban and suburban area has profoundly altered how water flows during and following storm events, putting higher volumes of water and more pollutants into the nation's rivers, lakes, and estuaries. These changes have degraded water quality and habitat in virtually every urban stream system" (Committee, 2009). Numeric limits for specific pollutants are not common, however target pollutants may include suspended solids, TMDL values, channel protection volumes, or specific pollutants linked to industrial land use.

Summary of Available Stormwater Quality Data Included in NSQD, Version 3.0

Parameter	Residential	Commercial	Industrial	Freeways	Open Space	
Land use and number of samples in the NSQD	TSS (mg/L)	BOD5 (mg/L)	COD (mg/L)	Fecal Coliform (mpn/100 mL)	Fecal Strep. (mpn/100 mL)	Total E. Coli. (mpn/100 mL)
Residential Areas Combined (2,586)	120	15	70	56,000	64,000	6,000
Commercial Areas Combined (916)	120	20	90	26,000	54,000	5,500
Industrial Areas Combined (719)	170	30	100	47,000	63,000	3,100
Freeway Areas Combined (680)	115	15	90	8,500	27,000	6,000
Open Space Areas Combined (79)	40	7	20	7,300		1,550

Table 5.1 Source: National Stormwater Quality Database, version 3, 2007
http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

Summary of Available Stormwater Quality Data Included in NSQD, Version 3.0							
	NH3 (mg/L)	NO2+NO3 (mg/L)	Nitrogen, Total Kjeldahl (mg/L)	Phosphorus, total (mg/L)	Cu, total (µg/L)	Pb, total (µg/L)	Zn, total (µg/L)
Residential Areas Combined (2,586)	0.5	1.0	1.8	0.4	30	20	120
Commercial Areas Combined (916)	0.8	0.8	1.9	0.3	30	30	200
Industrial Areas Combined (719)	0.7	0.9	2.0	0.4	40	60	250
Freeway Areas Combined (680)	1.7	1.9	2.5	0.7	35	75	160
Open Space Areas Combined (79)	0.3	0.6	0.5	0.1	10	50	60

Table 5.2 Source: National Stormwater Quality Database, version 3, 2007 http://www.unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.html

4. Soil Type – Soil type affects both the volume of runoff and type of sediment a watershed may produce. Highly erodible soils may contribute large volumes of post-construction sediment to structural stormwater control measures, making non-structural measures an important preventive maintenance tool. In contrast, cohesive watershed soils may generate less volume of sediment, but contain finer grained sediments that may require filtration based structural stormwater control measures for effective treatment.

Figure 5.3: Theis Park rain garden- Kansas City, MO.
Source: Shockey Consulting.

5.3 Controlling the Source through Sustainable Site Design Methods and Practices

Limiting the volume of runoff and pollutants through site planning is a critical component of green infrastructure. Non-structural stormwater control measures most relevant to source control of volume and other pollutants are minimizing impervious surfaces during design and maintaining good housekeeping practices.

5.3.1 Minimizing Pavement and Direct Connections

Minimizing impervious surface requires designers to evaluate every potential impervious surface and its connection to the stormwater collection system. Roads, curbs, walks, trails, driveways, alleys, rooftops and hardscaped open space all contribute to increased rates and volume of runoff. The impact of each can be minimized through efficient design.

Research in Milwaukee, WI (Pitt, 1999) demonstrates rains between 0.5 and 1.5 inches are responsible for about 75 percent of the runoff pollutant discharges and are key rains when addressing mass pollutant discharges in a given year. The median rainfall depth was about 0.2 inches while 66 percent of all Milwaukee rains were less than 0.5 inches in depth. Pollutant loads closely followed the runoff cumulative probability density function, demonstrating how small but frequent rain events create the majority of the annual runoff volume and the greatest pollutant discharges. Furthermore according to the National Research Council publication Urban Stormwater management in the United States 2009, MS4s have failed to address the more frequent rain events (<2.5 cm). Stormwater control measures designed to address these storms can assist with larger watershed flooding issues.

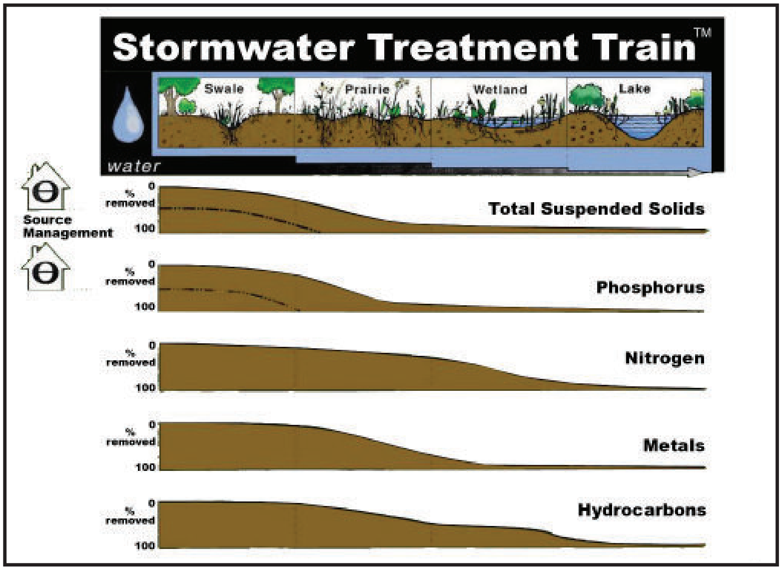
1. Narrowing – Reducing the width of roads create a directly proportional decrease in water quality volumes associated with transportation networks. Narrowing may also create more area for vegetated stormwater control measures within the right of way such as grass swales or rain gardens. Designers may be able to decrease effective road widths through inclusion of pervious pavements in curbs, gutters and shoulders or through adapting some streets and alleys to private drives.

2. Shortening – Concepts should be re-evaluated during design development to help ensure that road lengths cannot be further reduced. Use of cul-de-sacs, clustering homes, or limiting the use of unloaded roads can decrease overall street lengths required in some residential developments.

3. Through streets versus cul-de-sacs – Emergency service chiefs may sometimes negotiate narrower street widths in exchange for through streets versus cul-de-sacs. Narrower streets may be difficult for emergency vehicle drivers to navigate if the street also ends in a cul-de-sac. If cul-de-sacs must be used, they should be designed with functional rain gardens where possible.

4. Walks and trails – Sidewalks can be reduced by using minimum widths (reducing from five to four feet for example) or by substituting a single multi-use trail for streets planned with walks on each side. Pervious concrete may even be used for sidewalks. Trails are not typically directly connected impervious surfaces, so their effect on runoff rates and volumes is not as severe as roads or walks. However, trail networks should be narrowed and shortened where practicable.

5. Disconnection - Conventional designs often include direct connection of runoff to the collection system via downspout connections to sewers, area inlets within paved parking areas and gutter inlets along roadways. Disconnecting this runoff from the impervious surface prior to entering the collection system can effectively reduce impact from these areas on the hydrologic regime. Effective disconnection examples include downspout disconnection or redirection, moving parking area inlets into rain gardens, placing roadway inlets within roadside swales or bioretention areas, or using pervious pavements in gutters in advance of inlets.



The Stormwater Treatment Train,™ or STT, graphic was created by Applied Ecological Services Inc. in the early 1980's. It was developed after working on a study of the Des Plaines river and to study how discharge in the river has changed since mid-1800's. This STT graphic shows the elements developed for the Prairie Crossing project, Grayslake, IL. The dashed line in the graphic is expected reductions in nutrients, road de-icing salts, fertilizers and other contaminant constituents from source control. This aids changing landowner behavior to reduce home lawn fertilizer, herbicide, and pesticide uses. This graphic is stylized modeling output from the USGS HSPF model. Any questions about this graphic or the studies behind it can be directed to Steven I. Apfelbaum (steve@appliedeco.com) at Applied Ecological Services, Inc.

Figure 5.4 Stormwater Treatment Train. Source: Applied Ecological Services. See www.appliedeco.com for more STT information and project examples.

5.3.2 Good Housekeeping

Basic maintenance of pavements, landscapes and stormwater control measures is needed to ensure long-term stormwater control measures performance and help prevent unnecessary pollutants in runoff. Site designers should include specific operation and maintenance manuals for all stormwater control measures and landscape areas. These practices will help the municipality with stormwater compliance. Some good housekeeping strategies may include:

- Regular street sweeping using mechanical or vacuum sweepers to protect downstream stormwater control measures from filling or clogging, The cost effectiveness of street sweeping for stormwater management alone may be low, but is strongly suggested for maintenance of pervious pavements.
- Minimizing material volumes during deicing material applications.
- Prompt pavement repairs.
- Quick cleanup of chemical or other pollutant spills.
- Nuisance geese prevention practices including fencing or vegetated barriers, no feeding signs or ordinances, chemical repellent applications to lawn areas. Dog patrols, capture and relocation and addling eggs may also be used but may require permits or other special permission.
- Vector (mosquito) control.
- Pet waste regulations.
- Trimming vegetation and removing accumulated sediments, floatables and other debris.
- Proper, limited or prohibited application of fertilizers and pesticides.
- Use of moisture sensors in irrigated turf areas.

GOOD HOUSEKEEPING STRATEGY: MODEL MAINTENANCE AGREEMENT

To help ensure maintenance of stormwater control measures, MS4s can provide model maintenance agreements. Example language below is taken from St. Louis Metropolitan Sewer District:

KNOW ALL MEN BY THESE PRESENTS, that, ___________ a Missouri Corporation, for and in consideration of the approval of sewer plans and of the issuance of a sewer permit by The Metropolitan St. Louis Sewer District for stormwater management facilities according to plans to be approved by said District for a development known as ___________ in St. Louis ___________, Missouri, at ___________, and other good and valuable considerations, do hereby agree and promise, as follows:

1. To build and construct stormwater management facilities, including Best Management Practices (BMP), basins, drainage facilities, appurtenances and sewer lines, in accordance with the design, plans and report, submitted to and approved by The Metropolitan St. Louis Sewer District. The stormwater management facilities are to be perpetually located within the dimensioned and reserved area, as shown hachured on the exhibit "A" as attached hereto and made a part hereof.

2. To maintain and operate the stormwater management facilities in conformity with the approved Stormwater Management Facilities Report.

3. To maintain all pipes and drains in good working order and maintain all walls, dikes, vegetation, filter media, and any other requisite appurtenances and improvements for the retention and management of stormwater in good repair.

4. That in the event ____ or its successor in title to said property shall fail to maintain the stormwater management facilities, BMP, basins, drainage facilities, appurtenances and sewer lines in accordance with this agreement, The Metropolitan St. Louis Sewer District shall be permitted to enter onto the property and make the repairs and corrections and perform such maintenance as it deems necessary and bill the owners of said property for the services performed. It is further agreed that in the event said bill or charge for the services performed shall not be paid within a period of 30 days said sum shall become a lien on the real property and shall accrue interest at a rate of eight percent (8 percent) until paid in full.

5. This agreement is irrevocable and shall continue forever.

5.4 Green Infrastructure and Structural Stormwater Control Measures.

Many stormwater control measures are a potential element of green infrastructure if applied in an integrated manner with other necessary infrastructure. Where possible, green infrastructure should be integrated to help meet non-stormwater needs such as landscaping requirements, habitat improvement, pedestrian connectivity, overflow parking surfaces and rooftop improvements. Integration examples include:

- Permeable pavements can be used to minimize the volume of runoff and can also be designed to help control peak rates.
- Green roofs or rainwater harvesting for re-use.
- Rain gardens or bioretention in place of elevated parking islands.
- Infiltration trenches below pervious parking or curb and gutter sections (where site conditions do not pose significant threats to groundwater contamination).
- Vegetated filter strips and flush or "ribbon" curbs adjacent to pavement sections.
- Wetland areas may be used to manage stormwater provided that runoff has been treated prior to entering. This can help maintain wetland hydrology while minimizing the risk of infill to the wetland.

As the selection of stormwater control measures are considered, the potential for groundwater contamination pollution post-construction should also be considered. Overall contamination potential (the combination of the subfactors of mobility,

Primary and Secondary Removal Mechanisms

Best Management Practices Group	Pollutant Removal Mechanisms									
	Water Quality					Water Quantity				
	Screening Filtration	Infiltration/ Recharge	Settling	Biological Uptake	Temperature Control	Soil Adsorption	Volume Control	Rate Control	Velocity Control	Evapotranspiration
Pollution Prevention	Not applicable - pollutants not exposed to stormwater									
Better Site Design/ Low Impact Development	1	2	2	2	2	2	1	2	2	2
Runoff Volume Minimization		2			2		1	2		
Temporary Construction Sediment Control			1					1	2	
Bioretention	1	2	2	2	2	2	2	2		2
Filtration	1	2		2		2		2		2
Infiltration	2	1		2	1	2	2	2		
Stormwater Ponds		2	1	2				1	1	2
Stormwater Wetlands	2	2	1	1		2		1	1	2
Supplemental Treatment	Each supplemental and proprietary device should be carefully studied to learn the primary and secondary pollutant removal functions.									
1 = Primary Pollutant Removal 2 = Secondary Pollutant Removal Mechanism										

Table 5.3 Source: Minnesota Stormwater Control Manual (2008)

abundance, and filterable fraction) is the critical influencing factor in determining whether to use infiltration at a site. The ranking of these three subfactors in assessing contamination potential depends on the type of treatment planned, if any, prior to infiltration. See Table 5.3 for groundwater contamination potential.

Creating a series of stormwater control measures in sequence has a cumulative effect that can be used to meet water quality goals, even where each individual stormwater control measure in the series may be undersized relative to water quality volume.

Groundwater Contamination Potential for Stormwater Pollutants Post-Treatment.

Compound Class	Compounds	Surface Infiltration and No Pretreatment*	Surface Infiltration with Sedimentation*	Subsurface Injection with Minimal Pretreatment
Nutrients	Nitrates	Low/moderate	Low/moderate	Low/moderate
Pesticides	2,4-D	Low	Low	Low
	*-BHC (lindane)	Moderate	Low	Moderate
	Atrazine	Low	Low	Low
	Chlordane	Moderate	Low	Moderate
	Diazinon	Low	Low	Low
Other organics	VOCs	Low	Low	Low
	1,3-dichlorobenzene	Low	Low	High
	Benzo(a) anthracene	Moderate	Low	Moderate
	Bis (2-ethyl-hexyl) phthalate	Moderate	Low	Moderate
	Fluoranthene	Moderate	Moderate	High
	Naphthalene	Low	Low	Low
	Phenanthrene	Moderate	Low	Moderate
	Pyrene	Moderate	Moderate	High
Pathogens	Enteroviruses	High	High	High
	Shigella	Low/moderate	Low/moderate	High
	P. aeruginosa	Low/moderate	Low/moderate	High
	Protozoa	Low	Low	High
Heavy metals	Cadmium	Low	Low	Low
	Chromium	Low/moderate	Low	Moderate
	Lead	Low	Low	Moderate
	Zinc	Low	Low	High
Salts	Chloride	High	High	High

Table 5.4 Source: Dr. Robert Pitt. (Modified from Pitt, R. et al. 1994.)

* Even for those compounds with low contamination potential from surface infiltration, the depth to the groundwater must be considered if it is shallow (1 m or less in a sandy soil). Infiltration may be appropriate in an area with a shallow groundwater table if maintenance is sufficiently frequent to replace contaminated vadose zone soils.

A typical green infrastructure "treatment train" could include:

- Water quality volume rain gardens or subsurface infiltration in advance of the collection system to better distribute infiltration practices throughout a site.
- Surface flow, linear vegetated features to allow infiltration and treatment during conveyance, but also provide pedestrian connectivity.
- Larger stormwater basins to manage larger storm events. These larger basins may be located in ball fields, parks and other common green space areas.

Which stormwater control measure is selected may be a function of where they fit into a development, rather than altering the development to make them fit. General types of structural stormwater control measures include:

1. Bioretention typically includes amended soils to provide improved filtration and increased storage capacity. Bioretention areas can be small streetscape islands or large and extensive parking lot medians. Where site conditions are poorly drained or impermeable, bioretention areas may have underdrains.

Site Level Constraints and Opportunities	
Site Feature	**Constraint or Opportunity**
Floodplains, riparian areas, wetlands, natural and man-made drainage ways	To the extent possible, development should be avoided in floodplain areas, riparian areas, wetlands, and drainage ways. A stream buffer ordinance or other regulations may be in place to limit development in these areas.
Soils and topography	Impact the amount of runoff and infiltration of precipitation that will occur.
Geology, groundwater conditions	Might create limitations on where development can occur if the area is underlain by limestone with fractures and solutions cavities or if the water table is near the ground surface.
Vegetation	Opportunities to eliminate invasive species, improve or restore habitat, and enhance landscaping aesthetics. Use selected vegetation for water quality and quantity controls.
Existing land use	Redevelopment projects may already be paved, have buildings, and buried infrastructure that make implementation of structural stormwater control measures problematic. Opportunities to disconnect downspouts, use existing infrastructure, and decrease impervious surface may all provide low cost stormwater improvements.
Roadways	Stormwater management in the right of way may be prohibited by regulatory agencies. If not, street landscapes, curbs and gutters, and sidewalks all provide potential areas for distributed storage outside the street boundaries. Over widened streets can be narrowed or otherwise redesigned to include less impervious areas.

Table 5.5 Source: Michigan (2008)

Figure 5.5 Wetland Swale. Source: Olsson Associates

2. Subsurface infiltration is an engineered, subsurface trench similar to a septic leach field. It may be placed at the perimeter of paved areas, beneath pervious concrete curb and gutter sections, pervious sidewalk or trail systems, or in pervious parking, drives or alleys.

3. Bioswales may contain engineered backfill that can improve performance, but also increase cost. Wetland swales can be used in zero-slope conditions to help ensure long-term survivability of vegetation.

4. Swales with native vegetation can provide improved long term infiltration, but may not be aesthetically appropriate for some settings.

5. Rain gardens are small, landscaped areas designed to receive and manage small storms. They typically need to be a depressed landscape area planted with vegetation that tolerate flooded as well as dry conditions. They can be placed near downspouts, intersections, or intermittently along streets where space allows.

6. Turf swales with shade trees may be more aesthetically pleasing but require more frequent mowing and provide less effective long-term infiltration and treatment than deeper rooted native or adaptive plants.

7. Linear dry detention allows for the swale to serve both a conveyance and rate control function.

8. Stormwater parks can include a variety of control measures but generally will have a small frequently inundated water quality area (if no stormwater control measures address this upstream) and a large, normally dry, offline detention shelf area that is used as a park.

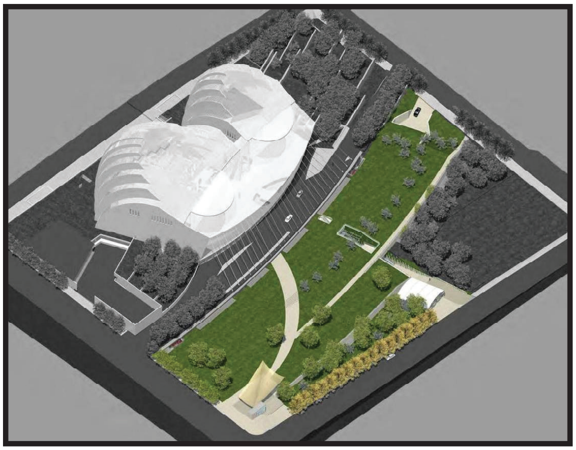
9. Green roofs can offer a combination of benefits, including stormwater management, urban heat island moderation, improved air quality, building energy savings and useable green space.

Figure 5.6 Intensive Rain Garden - Olsson family garden, St. Louis Children's Hospital. Source: www.stlouischildrens.org

Introduction to Case Studies

Throughout the U.S., there is a growing recognition of the benefits green infrastructure provides to communities. Many municipalities and other jurisdictions have begun to effectively incorporate these practices. The following case studies were selected to showcase both site and landscape scale GI projects which have successfully been implemented. Additional case studies are included in Chapter 6. Readers are encouraged to follow the links or titles provided for each case study to learn more about these projects.

Case Study: Kansas City Performing Arts Center Garage Kansas City, MO



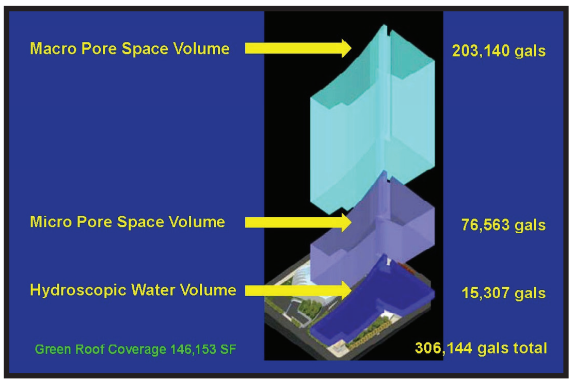
Kansas City Performing Arts Center Garage Green Roof boundary is shown in color.
Source: Jeffrey L. Bruce & Company, Landscape Architects

The Arts District Garage is a $32 million, 1000 car underground parking structure attached to the new Kauffman Performing Arts Center in downtown Kansas City, Missouri. The green roof atop the structure is designed as a 2.63 acre open space park. The 146,000 square foot green roof component of the garage serves as a stormwater collection and detention system with the capability of collecting and detaining 50 percent of a 100 year storm event for the first 24 hours and the system will continue to detain 25 percent of the stormwater for up to the next 66 hours before release into the water harvesting cisterns.

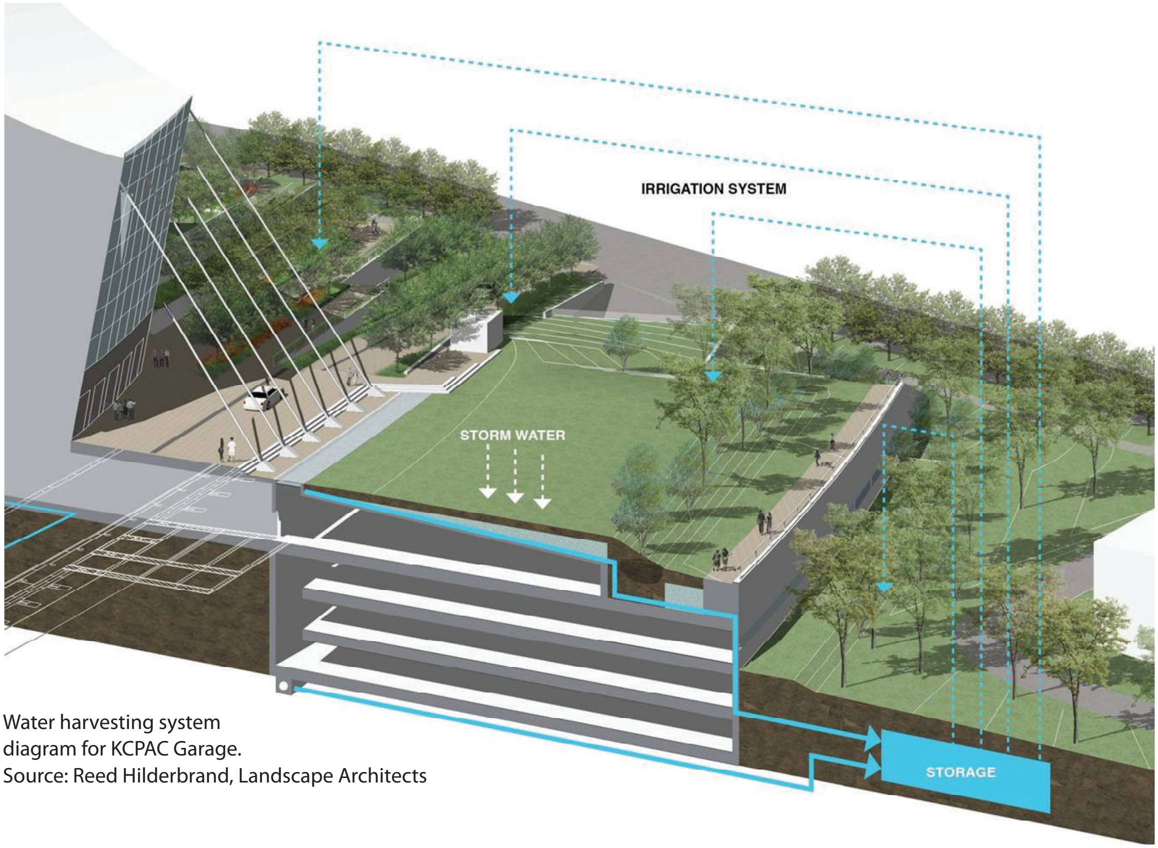
The system captures excess stormwater which exceeds storage capacity of the green roof soils and routes it into underground cistern storage where it is then recycled as irrigation water for the vegetated roof. The Arts District Garage is the first permitted green roof stormwater detention facility in Kansas City, MO.

Green Roof Design

The primary objective for this rooftop park is to provide a grand lawn for the new KCPAC building. The green roof designed as a multipurpose space for events and public gatherings helps to blur the edges of the parking garage by projecting the landforms



Calculation of the volume of water by phase contained on the green roof. Source: Jeffrey L. Bruce & Company, Landscape Architects.



Water harvesting system diagram for KCPAC Garage.
Source: Reed Hilderbrand, Landscape Architects

of the surrounding park onto the parking garage. The unique aspect of this case study is the soil profile design that allows the green roof to replace the mandated stormwater detention facility. The soil profiles were specifically designed to meet the diverse needs of this demanding site. The use of the site by hundreds of thousands of visitors per year required considerable agronomic innovation to ensure sustainability of the landscape under such physical loading and abuse.

Using the sand based media mix designed for the green roof a mock-up of the green roof profile was created to mimic as built conditions so that the designers could gain a precise understanding of water movement and detention in the soil profile.

This experiment was conducted under two scenarios; one with the sand-based soil in a saturated condition and the second with the soil in an unsaturated condition. Using the Kansas City stormwater design parameters that mandate retention of the first 25 percent of a 100 year storm event, the lab simulated a 3" storm event within a 25 minute time period, thus exceeding the city requirements. The measurements were documented over a 120 hour period with the following results:

- 50 percent of the storm event was retained within the soil profile for the first 24 hours.
- 25 percent of the storm event was retained within the soil profile for 66 hours before the soil moisture content returned to an unsaturated condition.

The test results indicated the green roof for the KCPAC Garage contained a total of 306,144 gallons of water storage.

Local ordinances mandated a stormwater detention facility for the garage, but did not mandate a green roof. This component of the design was envisioned by the landscape architect who provided the research data to determine the retention and flow characteristics of the growing media and demonstrated meeting the stormwater ordinance requirements with alternative means.

Based on this data, storm events such as the 2, 10, and 25 year storm events would be retained in the soil making the water available to the plant material or slowly draining to the collection system when the soil profile is in an unsaturated condition thus eliminating runoff. Having the alternative compliance method of meeting the local stormwater ordinance approved the design team was able to remove from the project a $348,000 traditional detention system and replace them with two 50,000 gallon cisterns for $290,000. With the addition of the 2 cisterns the stormwater would be collected and returned to the green roof for reuse as irrigation water further reducing stormwater runoff from the site.

The Arts District Garage green roof is the first green roof project in Missouri to be permitted as a stormwater detention facility. It provides life cycle cost savings by increasing the life of the waterproofing membrane, reducing water cost for the irrigation system and provides a pristine open space within the urban landscape. The creation of this green roof open space also provides a stormwater detention facility that greatly exceeds the local stormwater requirements and serves as part of the structure's infrastructure.

Installation of the water harvesting cisterns.
Source: Jeffrey L. Bruce & Company, Landscape Architects

The benefits to the community will be the addition of a vibrant new open space park within Kansas City's downtown area. It will provide a new venue for patrons of the arts by providing landscaped lawn areas for arts and crafts events and well as outdoor on the lawn concerts. Additionally, the reduction in stormwater runoff to an aging city stormwater system helps to improve the capacity of the existing combine sewer system.

Maroney Commons
Source: Rural Learning Center, Howard, South Dakota

Rural Smart Growth

Maroney Commons at the Rural Learning Center in Howard, South Dakota

With just over 850 residents, Howard is reimagining what it means to be rural with Maroney Commons. The Commons, built with green building techniques, is a mixed-use complex with a hotel, a conference center, a restaurant, and offices that will help rural residents learn about green jobs and technology.

A model for other rural towns

Maroney Commons serves as a model for other rural towns looking to create vibrant community places that strengthen Main Streets, help residents learn new skills to compete in the 21st-century economy, and demonstrate environmentally responsible, energy efficient design. Its message that "Rural is a good investment!" can inspire other towns around the nation.

The story behind Maroney Commons began over a decade ago, when Howard High School students launched a successful "buy local" campaign to increase sales tax revenue in Miner County. The effort generated nearly $16 million in additional gross sales for Howard, the county seat, in its first year and inspired Miner County's residents to engage in a community visioning process. The visioning process, combined with the growth of the wind energy industry in Miner County, led to the development of the Maroney Commons.

Although the town could have built the new facility on 40 acres of donated land outside of town, Howard residents instead chose to reinvest in their downtown by demolishing — and salvaging materials from — dilapidated buildings on Main Street, putting Maroney Commons at the center of the community. Intensive workshops gathered citizens' input throughout the design process.

Maroney Commons
Source: Rural Learning Center, Howard, South Dakota

Roof top garden

The roof top garden is a favorite feature with stormwater consideration. This is located just off the wind turbine tower and just off the elevator on the second floor. The garden is a trench that holds two feet of soil and contains plantings that are indigenous to the state of South Dakota; this feature also helps collect rain water as well as supporting the need to "move" if you have been at meetings or training all day.

Cistern

The building features an underground cistern that holds up to 16,500 gallons of rainwater and snowmelt collected from the roof. This water is used to flush toilets throughout the facility. As a part of the learning corridor, the water from the roof flows through a clear plastic pipe on its way to the cistern to help illustrate this feature. Even a slight rain shower will cause people to stop in the corridor and watch this water moving through the pipe; provides an excellent teaching opportunity!

The building also features a rain collection pond (located next to the parking lot which covers the 44 geothermal wells connected to the project!). This pond holds water during a significant rain storm, etc. which then also moves into the rainwater cistern.

Pail of Reference

Many aspects of the construction and design of the Maroney Rural Learning Center are not obvious as you drive past. Some amazing features of the building are now almost out of sight but continue to serve their purpose in conservation and energy efficiency. One of these is the underground water storage cistern located on the west side of the new building. Rain water and snow melt will be

Cistern Pail of Reference with 8-year old Lane Miller, son of Ryan and Sara Miller. Source: Rural Learning Center, Howard, South Dakota

collected and stored in the underground cement cistern which has a capacity of 16,000 gallons. This water is then reused to flush toilets throughout the building.

It is hard for most of us to imagine what 16,000 gallons looks like. But farm kids think in terms of 5-gallon pails. Lane Miller (aged 8) pointed out that more than 3000 of the 5-gallon pails would fit into the cistern. (He went on to calculate that it's actually 3,200 pails – thanks, Lane!). That's a lot of water saved from the roof and from the roof top garden and adds efficiency and renewal points to the building's "green" certification.

"We've hosted tours for young and not so young visitors and each time we've learned something new, too!" reports the Rural Learning Center staff.

With the community's input, Maroney Commons contains a restaurant, a community kitchen, a fitness center, retail space, a hotel, and meeting space. This multi-use community facility will provide educational, social, and business opportunities for not just Miner County residents, but rural communities all across the region. The facility is expected to create 13 full-time jobs and bring the local economy more than $6 million per year. Profits will likely allow the building to be self-sustaining within three years.

The conference center, which holds up to 300 people, was designed for training in green energy jobs and rural health care. The facility also hosts design: South Dakota, a team of architects and community development experts who travel statewide helping residents reimagine their rural communities through design workshops. Eighty percent of South Dakota's population lives within 100 miles of Howard, making the center accessible to many small-town residents.

Maroney Commons has raised the bar — both through its innovative design and construction and its educational opportunities for rural residents. One of the first LEED Platinum-certified buildings in South Dakota, the building has solar panels, a wind turbine, geothermal heating and cooling, porous outdoor pavement, rainwater capture and storage, and native landscaping. Materials gathered from demolished Main Street buildings were recycled and reused during construction; the wood floor from an old gymnasium is now the floor of the restaurant, and Maroney Commons' siding came from an old American Legion hall. Real-time, touch-screen displays of the wind and solar energy produced at the building help visitors understand these technologies.

Partners include City of Howard; Miner County; U.S. Department of Agriculture; American Institute of Architects South Dakota; and Citi Foundation. Contact the Rural Learning Center at 605-772-5153 to set up a tour or visit http://rurallearningcenter.org/

6 Green Infrastructure Stormwater Control Measures - Strategies, Practices and Tools

This chapter provides general examples green infrastructure strategies, practices and tools, including several case studies. For more comprehensive lists and details, numerous design manuals and other resources are cited throughout this guide and in the appendices. It is essential that long-term operation and maintenance be incorporated into plans for green infrastructure. Operation and maintenance is discussed throughout the numerous design manuals available. There are also operation and maintenance resources available United States Environmental Protection Agency's, or EPA's, website at http://water.epa.gov/infrastructure/greeninfrastructure/gi_design.cfm.

Retrofitting Wet Ponds

Wet ponds are landscape features that readily remove coarser sediments (sand and some silt), and which can reduce biochemical oxygen demand, nutrients and trace metals in stormwater runoff. However, wet ponds constructed prior to water quality regulations may not have included extended detention controls or other design features needed to maximize their water quality benefit. Retrofits to these ponds may include:

1. Modifying the outlet control structure to provide extended detention.

2. Installation of deep rooted native wetland and mesic vegetation to improve infiltration on pond shelf and banks, increase public safety and help control nuisance waterfowl populations.

3. Installation of hydrophytic, high water uptake shade trees such as hybrid poplars on the south bank to decrease thermal pollution and increase evapotranspiration.

ADVANTAGES

- Extended detention outlets increase water quality detention times. The water quality benefits are achieved by creating sufficient residence time to settle out particulates, and by microbial processes that occur over time in sediments and in the water column (Minton, 2005).
- Wetland shelves can be a cost-effective method of increasing pollutant removal potential, discourage nuisance waterfowl and enhance public safety through limiting pedestrian access to the pond.

- Hybrid poplars or other flood-tolerant, but high evapotranspiration species, can evapotranspirate up to 100 gallons per day during the growing season and help shade water surfaces to minimize thermal pollution discharges and algae or phytoplankton blooms that may contribute to organic TSS discharges.

LIMITATIONS

A primary limitation of wet ponds is that they do not typically infiltrate or otherwise remove significant volume from runoff events.

- Existing hydraulic calculations must be checked in order to ensure proper function under retrofitted conditions. Changing the outlet structure to include an extended detention orificy in front of the primary outlet will increase staging depths during larger storm events.
- An adequate supply of runoff shall be available to ensure a minimum average pool depth of six to eight feet throughout the entire year.
- Wet ponds can attract undesired waterfowl populations, leading to increased potential for fecal coliform export. In contrast, wet ponds fitted with wetland shelves can help reduce fecal coliform export. Where fecal coliforms are a target pollutant due to TMDL or other site specific issue, additional stormwater control measures may be needed to filter and provide adequate treatment.
- Heavy storms may cause mixing and subsequent resuspension of solids.
- Seasonal algal blooms can export organic TSS.
- Trees should not be placed in areas where bank stability may be a concern.

Figure 6.1 Extended Wet Detention, Express Scripts Campus, Berely, MO. Source: Metropolitan St. Louis Sewer District.

Integrating Infiltration Stormwater Control Measures

Infiltration-based stormwater control measures function by requiring the water quality volume to filter through a design medium for treatment prior to discharge. Infiltration can be achieved in well-drained soils where seasonal high groundwater does not prevent adequate drainage or infiltration can be simulated in poorly drained soils through use of soil amendments and underdrains. It is important to note that infiltration drains into the subgrade beneath the stormwater control measure and that a percentage of filtration drains through a pipe.

This form of asset-based urban ecology can help drive community revitalization while helping to meet volumetric control standards.

Common names of infiltration stormwater control measures include, but are not limited to:

- Rain gardens.
- Bioretention areas.
- Infiltration trenches and basins.

Some natural subgrade soils and a variety of backfill substrates can create an environment conducive to adsorption and degradation of pollutants. For example, organic substrates provide sites for microbial attachment, which can facilitate degradation of these pollutants (e.g. oil, grease, antifreeze, herbicides). Properly designed infiltration zones can also remove excess nutrients and bacteria, and they should be considered for watersheds that discharge to streams with identified pollutants of concern (TMDL or other data).

Depth of amended soils is critical where specific infiltration volumes are assumed as part of stormwater control measure performance. One example would be where default credits are granted for infiltration practices such as bioretention.

Figure 6.2 Infiltration Basin. Source: David Dods

ADVANTAGES

- Properly constructed infiltration-based stormwater control measures can remove over 95 percent of influent TSS (Minton, 2005).
- Infiltration-based stormwater control measures that incorporate an organic layer such as compost can remove in excess of 90 percent of dissolved metals through cation exchange (EPA, 2004).

Figure 6.3 Biofiltration infiltration trench, Cumberland County, PA. Source: Pennsylvania Department of Environmental Protection

LIMITATIONS

- Where underdrains are needed to achieve adequate drainage in areas with poorly drained subgrade soils, infiltration capacity is limited to the storage volume below the underdrain.
- Class V well status may require additional permitting through state and federal agencies where infiltration systems are deeper than their widest dimension.
- Infiltration systems should consider pretreatment when constructed adjacent to potential stormwater hot spot areas. Pretreatment stormwater control measures may vary, but should be designed to mange the anticipated pollutants associated with the hot spot.
- Unless washed, crushed limestone and other aggregate containing fines should be avoided to help prevent long-term clogging.
- Depth to seasonal or average high groundwater tables may preclude the use of infiltration stormwater control measures.

Green Roofs

Green roofs and roof gardens reduce the rate of stormwater runoff from commercial, industrial and residential buildings. In contrast to traditional roofing materials, green roofs capture, store, absorb and evapotranspire stormwater. Additional non stormwater benefits include thermal insulation and energy efficiency, increased acoustic insulation, reduced heat island effect, and increased durability and lifespan of roofs. These systems are generally classified as extensive or intensive.

- Extensive green roofs are typically lightweight, have 4 inches or less of growing medium, use drought tolerant vegetation, and can structurally support limited uses such as performing necessary operation and maintenance.
- Intensive green roof designs are more elaborate and have 6 to 12 inches of growing medium. Different growth media types and depths allow for a larger selection of plants, including flowering shrubs and trees to promote pedestrian interaction.

Figure 6.4 Green Roof St. Louis Zoo, Animal Nutrition Center Source: SWT Design.

Figure 6.5 Extensive Green Roof- University of Missouri, Life Science Center- Columbia, MO. Source: www.greenroofs.org

Application

Green roofs may be used in new construction or retrofitted to existing structures. They are applicable to residential, commercial, and industrial buildings and are constructed on roofs with up to a 20 percent slope. In highly urbanized locations, green roofs would likely have the most notable effect on stormwater and heat island effect.

Benefits

- Reduces the quantity of runoff entering a storm sewer system by capture and evapotranspiration. Significant impacts can be realized in areas with combined sewer systems.
- Improves water quality.
- Provides additional park, garden and recreation areas provided with intensive green roofs.
- Provides additional thermal insulation and energy efficiency for building.
- Provides increased durability and lifespan of building roof system.

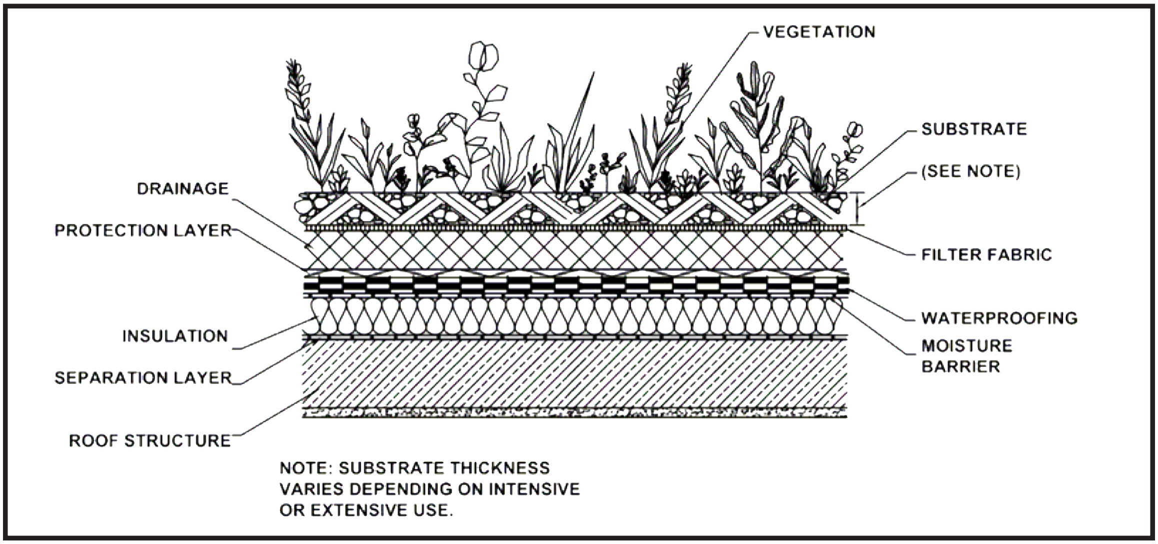


Figure 6.6 Intensive green roof profile example. Source: Center for Watershed Protection

Cost

Depending on the type of green roof, costs for green roofs are estimated to average between $14 to $40 per square foot for all use types, i.e., high density residential, commercial, industrial etc. These costs include all aspects of green roof development, from the waterproofing membrane to soil substrate creation to planting. By far the highest costs associated with green roof creation are the soil substrate/growth medium and the plant components associated with it. Green roof retrofit projects may have increased cost associated with traffic and resource scheduling concerns as well as the on-site availability of equipment and materials. The cost of planting can also increase if plants are placed individually rather than pre-grown on vegetation mats.

- Extensive green roofs range in price from $14 per square foot to $25 per square foot. Life cycle analysis should recognize the significant cost savings associated with reduced energy consumption and extended roof lifespan. www.cnt.org/repository/CNT-LID-paper.pdf
- Intensive green roofs are more costly than extensive green roofs. Estimates range from $20 to $40 per square foot, however the square foot cost may increase depending on the area and type of design. Life cycle analysis should recognize the significant cost savings associated with reducing energy consumption and extended roof lifespan. Intensive green roofs provide recreational and park space and may be justified relative to the price of land in an area.
- Municipalities may have allowances for tax credits, density credits and impervious credits for additional cost benefits. See model tax credit ordinance.

Figure 6.7 Green roof, Chicago city hall. www.cityofchicago.org

From Reduced Building Energy Use:

www.cnt.org/repository/CNT-LID-paper.pdf

Green roofs provide superior insulation compared to conventional roofs, reduce solar radiation reaching the roof surface and reduce roof surface temperatures through evaporative cooling. Estimates of reduced heat flux of a green roof as compared to a conventional roof range from 70 to 90 percent in summer to 10 to 30 percent in winter (Liu and Minor 2005; Liu and Baskaran 2003). The difference in seasonal performance is due to the fact that frozen growing media is a less effective insulator.

Note the advantages of direct shading and evaporative cooling only apply during warm weather. Models of the impact of a green roof on office building energy consumption in Chicago and Houston found a 2 percent reduction in total building electricity consumption in both cities; a 9 percent reduction in natural gas consumption for Chicago and an 11 percent reduction in natural gas consumption for Houston (Sailor 2008).

Another modeling study of an eight-story residential building in Madrid found a 1.2 percent reduction in annual building energy consumption. The bulk of the benefit comes from reduced summer cooling costs, where the authors found a 6 percent reduction compared to the conventional roof (Saiz et al., 2006).

The reduced heating and cooling loads that a green roof can provide depend on local temperatures, the portion of a building's heating and cooling load due to heat flow through the roof, the thickness of the soil layer, extent of foliage, relative humidity and wind speed and moisture content of the growing media. (Clark et al., 2008; Theodosiou 2003; Gaffin 2005)

Siting and Safety Requirements

- A structural engineer should be consulted to determine the correct loading for any proposed buildings.
- If retrofitting an existing roof, then the structural integrity of an existing roof should be inspected and verified by a professional, before proceeding with the design.
- Plants should be well-suited for local climatic conditions.

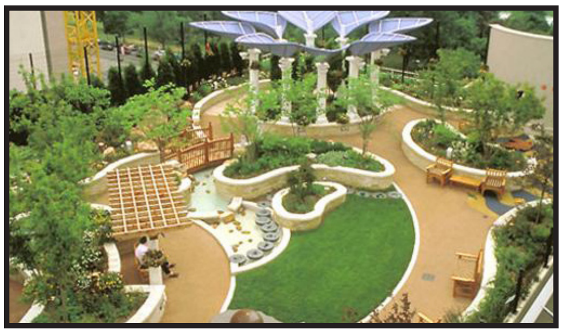


Figure 6.8 Intensive Rain Garden- Olsson Family Garden St. Louis Children's Hospital Source: www.stlouischildrens.org

- Intensive green roofs should have additional safety measures since it will likely be interactive.
- Local building codes should be referenced for roof safety requirements.

Permits

- Codes and permits for installing a green roof will vary in municipalities.

Maintenance

- Minimal to moderate.
- Should be monitored regularly during the first growing season to ensure vegetation establishment.
- Extensive and intensive green roofs should be inspected annually and lightly fertilized as needed and may need irrigation for the first growing season.
- All fertilizer applications should be prescribed by a professional in order to prevent stormwater runoff pollution.
- Intensive green roofs are maintained as landscape areas and may include gardens and irrigation systems.

Greenroof Inspections and Maintenance Checklist

Site name: ______________________________ Owner Change since last inspection? Y N

Owner Name, Address, Phone ______________________________

Number______________________________

Location: ______________________________

Site Status: ______________________________

Date:______________________________ Time: ______________________________

Inspector: ______________________________

Greenroof Type: Extensive Roof Cover ☐ Intensive Roof Garden ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms; G=monthly during April-September growing season only

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Debris Removal				
Gutter inlets blocked by plant debris/trash or plant growth hindered by debris?	*M*			
Vegetation				
Any evidence of additional irrigation needs?	*G*			
Fallen leaves/debris interfering with plant health?	*M*			
Any dead plants to be replaced?	*M*			
Any need for weeding/mowing/trimming?	*G*			
Soil Substrate/Growing Medium				
Any evidence of wind or water erosion?	*A*			
Structural Components				
Any evidence of structural deterioration?	*A*			
Load-bearing walls in good condition?	*A*			
Spalling or cracking of structural parts?	*A*			
Access/maintenance routes maintained and free of debris?	*M*			
Other				
Any locations of standing water that may harbor insect infestations?	*S*			

Inspector Comments:______________________________

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	**Due Date**

The next routine inspection is scheduled for approximately: ___________________
(date)

Inspected by: (signature) ____

Inspected by: (printed) ____

Figure 6.9 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Rain Barrels

The roof of a house may receive between 600 to 1,000 gallons of water, depending on surface area, with just one inch of rainfall. A rain barrel is a small collection system that temporarily stores stormwater runoff from roof areas and is typically located under the downspout of the roof. Soaker hoses that are attached to rain barrel spigots will slowly release the stored volume which can be used for landscape irrigation. The barrel is usually constructed with a 55-gallon drum, and uses a vinyl hose, PVC couplings, and a screen grate to keep debris and insects out.

Rain barrels, given their size will be mostly useful for public education and on-site reuse, although they can provide a small level of volume control. Per stormwater expert Dr. Robert Pitt, PE, four typical rain barrels per home in the central US actually have the greatest potential irrigation use of stormwater due to having precipitation during the same seasons as evapotranspiration (about 15 inches in Kansas City per year.) This would result in only about 40 percent roof runoff reductions (compared to directly connected roofs), or about 15 percent for the whole area. If the goal is to reduce rooftop runoff by ninety percent or more to meet irrigation demands, it would likely require a storage tank about six feet by ten feet per home for example. This also assumes that effective use of the captured water occurs so that storage facilities are drawn down as soon as possible after a rain. See next section on cisterns for cisterns/storage tanks sizing and performance.

Rain barrels are relatively simple and inexpensive to construct, however there are a variety of vendors where they may be purchased as one unit. Properly maintained rain barrels should be fully sealed for vector control.

Application

Rain barrels are typically incorporated at the residential site level; however, they can be used in parks or at small office buildings. Rainwater is routed through the gutter system and diverted to the barrel where it can be stored for use in watering nearby gardens or other landscaping.

Figure 6.10 55-Gallon Rain Barrel. Source: Shockey Consulting

Benefits

- Runoff stored in rain barrels can be used at a future date for landscape watering or gray water systems.
- Reduces the cost of potable water consumption by using rainwater for irrigation.
- Reduces or minimizes stormwater runoff entering a storm sewer system.

Cost

Rain barrel and associated materials usually cost under $100, however depending on the materials and type of system, may range up to $400. Standard materials should be available at a local hardware store.

Siting and Safety

- Locate rain barrel on a flat surface next to or near the downspout.
- Overflow should be directed towards landscaped area or lawn.
- Rain barrel should be fully sealed or openings should be protected with screening for vector control.

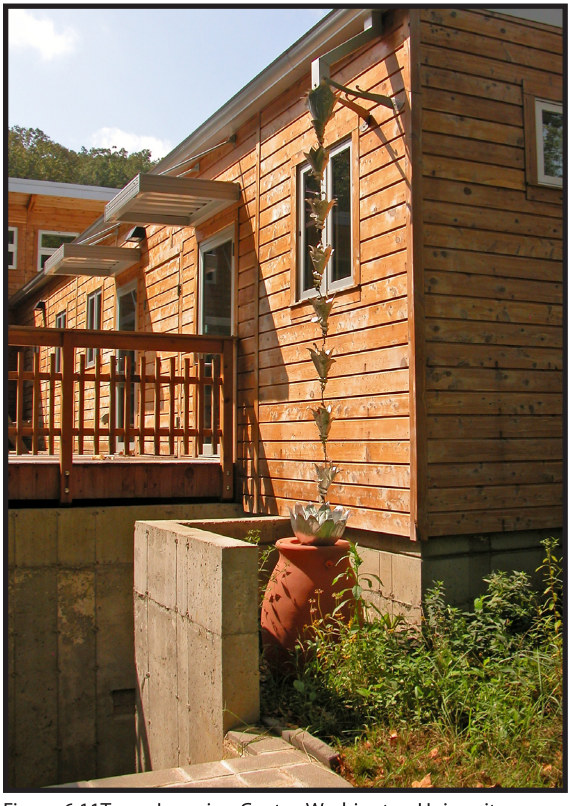


Figure 6.11Tyson Learning Center, Washington University, Eureka, MO. Source: Williams Creek Consulting

Permits

- Most municipalities do not require a permit to add a rain barrel on residential property.
- Zoning codes may prohibit a barrel in the front of the house; consult local zoning ordinances.
- Zoning codes may prohibit the disconnection of downspouts; consult local zoning ordinances.

Maintenance

- Gutters should be cleaned to minimize debris to your rain barrel.
- Periodic removal of accumulated leaves or debris in rain barrel screening.
- Periodic checks of barrel and seals to ensure system is working as designed and intended.
- The barrel interior should be cleaned and disinfected with environmentally friendly cleaner once a year.
- During cold months if freezing could be an issue, downspouts should be disconnected and barrel stored upside down to limit damage.
- To minimize debris in your rain barrel system, filters can be installed over the existing house gutter system.

Cisterns/Storage Tanks

A cistern or storage tank has the same function as a rain barrel, but stores larger volumes of rainwater. Cisterns can be located at grade or below grade. Cisterns are typically manufactured from fiberglass, plastic, concrete, or metal. In general, a 1,000-square-foot roof will produce approximately 600 gallons of rain in a one inch rain event. The cistern can be constructed a screen grate to keep debris and insects out.

Application

Cisterns may be incorporated at the residential, commercial and institutional levels. Rainwater from the roof is routed through the building's collection system and routed to the cistern where it can be stored for irrigation use. Dependent on local codes and restrictions, other uses may include reuse for toilet flushing, or installing a filtration and disinfected system to reuse as potable water. During the initial flush from the roof, the cistern should be cleaned to remove any debris that may be present during installation.

Figure 6.12 Residential Cistern.
Source: Shockey Consulting Services

Figure 6.13 Tyson Learning Center, Washington University, Eureka, MO. Source: Williams Creek Consulting

Benefits

- Reduces municipal supply water usage and associated costs during peak use.
- Can significantly reduce the quantity of runoff entering a storm sewer or receiving stream.
- Runoff stored in cisterns can be used at a future date for watering the landscape or for gray water systems.
- Can be sized to manage rooftop runoff for irrigation or other beneficial reuse.

Cost

For residential, commercial and institutional sites, cistern construction and installation costs are directly related to the volume of storage, type of material and location (above or below ground). Standard sizes are usually associated with manufacturer specifications and could be in excess of 10,000 gallons.

Cistern/Storage Tank Sizing vs. Performance				
Storage per house (ft^3 per ft^2 or roof area)	Reduction in annual roof runoff (%)	Number of 25 gallon rain barrels for 945 ft^2 roof	Tank height size required is 5 ft D (ft)	Tank height size required if 10 ft D (ft)
0.005	24	1	0.24	0.060
0.01	29	2	0.45	0.12
0.02	39	4	0.96	0.24
0.05	56	10	2.4	0.60
0.12	74	25	6.0	1.5
0.50	99	100	24	6.0

Table 6.1 Calculations for KC for using different roof runoff storage systems.
Source: Dr. Robert Pitt, PE., Ph.D., BCEE, D. WRE, Cudworth Professor of Urban Water Systems

Material	Cost - Small System	Cost - Large System
Polyethylene	$160 for 165 gallons	$1,100 for 1800 gallons
Fiberglass	$660 for 350 gallons	$10,000 for 10,000 gallons
Ferro-cement	Price variable upon location	Price variable upon location
Fiberglass/steel composite	$300 for 300 gallons	$10,000 for 5,000 gallons
Aluminum	Cost prohibitive for water use	Cost prohibitive for water use.

Table 6.2 Cistern materials cost estimate. Source: Adapted from www.lid-stormwater.net/raincist_home.htm

Siting and Safety

- Only collect roof water for reuse. Do not collect other surface water for reuse unless treated.
- Underground cisterns should have an overflow pipes. The overflow should be either daylighted to the surface down gradient in poorly drained soils or could potentially be connected to a leach field in well drained soils.
- Underground location should not be near sanitary utilities and care should be taken when proposed cistern location is near existing trees, in order to protect root systems. Maximize distance from existing trees.
- Care should be taken in selecting the type of cistern. For example, galvanized steel dramatically degrades water quality with very high zinc levels in stored water (several mg/l) and should be avoided. Some areas provide for aluminized steel. Polyethylene units are typically less expensive and do not create similar pollution concerns.

- **Permits**
  Local codes should be reviewed to determine if plumbing, electrical and/or building permits are required.
- Water treatment for reuse in the structure (as is sometimes done in commercial buildings) will likely require permits through the health department and other local entities.
- Ensure local requirements allow catchment reuse of rainwater.

Maintenance

- Periodic checks of system to ensure it is functioning as designed.
- Gutters should be cleaned frequently to minimize debris entering the cistern.
- Annual removal of accumulated sediment and debris that may have entered the cistern.
- To minimize debris in your cistern, filters can be installed to the existing house gutter system.

Rain Gardens

Figure 6.14 Theis Park Rain Garden- Kansas City, MO. Source: Shockey Consulting

A rain garden is an attractive, landscaped area built in a shallow depression (low-lying area) and is designed to capture and filter stormwater runoff from impervious surfaces such as rooftops, sidewalks, driveways and even compacted lawns. Rain gardens are typically planted with perennial native or adaptive deep-rooted plants that are selected to tolerate both periods of inundation and drought. Rain gardens function by slowing stormwater runoff, reducing runoff volume through infiltration and filtering pollutants from stormwater runoff before it enters local waterways. These gardens can help alleviate drainage issues. Rain gardens provide habitat and food for wildlife including butterflies and birds and enhance the beauty of an individual yard or a community.

Application

Rain gardens can be used to improve stormwater quality and reduce peak runoff rates for small drainage areas, typically less than one acre. They are typically constructed on residential sites but may also be incorporated into the landscaping of small commercial areas, parks and neighborhood common areas. Due to their relatively small surface area, care should be taken in providing for pretreatment and maintenance to help prevent clogging. Vegetation should also be selected to account for anticipated water quality concerns such as salt and other deciding practices.

Benefits

Rain gardens reduce the rate and quantity of stormwater runoff entering a storm sewer system. Temporary storage of initial runoff as well as interception of the storm flow both increase the time of concentration and promote infiltration.

Rain gardens can provide infiltration, filtration and removal of suspended sediments and associated pollutants, such as heavy metals. Rain gardens are designed gardens that contain aesthetically pleasing deep rooting native plants into landscape designs. Rain gardens also often provide habitat that can attract beneficial wildlife such as butterflies and hummingbirds.

Cost

The cost of a residential rain gardens can be as low as the price of necessary materials, however, they can vary considerably based on the proposed application and design. For example:

Residential Rain Garden

The following cost information is the average cost per garden installed, assuming a 100 lot subdivision. All of the facilities have an underdrain system and many of the facilities will be constructed simultaneously. Planning, designing and construction costs are all pro-rated as a portion of the overall site cost work, and sediment control, permits, fees and technical plan approval are required.

Planning phase	$95
Design phase	$340
Construction phase	$3225
Closeout phase	$130
TOTAL ESTIMATED COST:	$3,790

Source for cost: www.lid-stormwater.net/bio_costs.htm

Residential Lot in a Subdivision

This is applicable if the project is a shallow rain garden incorporating in-situ soils and no underdrain system. Homeowner, garden group, or volunteers provide the labor and no heavy construction equipment is used (most of the labor is done by hand). The disturbed area is small enough to avoid permits and fees and the rain garden is seen as a homeowner landscaping project.

Planning phase	$25
Design phase	$100
Construction phase	$950
TOTAL ESTIMATED COST:	$1,075

Source for cost: www.lid-stormwater.net/bio_costs.htm

Permits

Most municipalities do not require a permit to voluntarily construct a rain garden on residential property. Zoning codes should be consulted as many municipalities do require direct connection of downspouts. Additionally, overland flow paths need to be considered for larger storm events to prevent flooding on to neighboring properties.

Some municipalities may offer tax or fee incentives if rain gardens are committed to permanent function via deed restrictions.

Siting and Safety

- Locate at least ten feet from foundation, because moisture can damage foundation.
- Do not locate near lateral sewer lines, in order to avoid inflow and infiltration problems in lines.
- Do not divert excess water to neighbor's property where it can cause damage.

Figure 6.15 Rain garden. Source: StormwaterPA.org, a project of GreenTreks Network, Inc.

Maintenance

With the use of native vegetation and an appropriately planned design, long term maintenance in a rain garden is low relative to conventional landscaping. During the establishment period of the first three years, watering and weeding may be required on a more frequent basis. Successive years required less weeding and once established, watering should not be necessary at all except in cases of extreme drought. Annual maintenance is not necessarily different than traditional landscaping and includes removal of dead vegetation each spring, addition of mulch, unless designed with a 'green mulch' of dense ground cover vegetation and periodic inspection of soil erosion, plant health and removal of litter as needed. However, it is important to pass along information to new home/office owners on the importance of the rain garden and its continued maintenance.

Infiltration Trenches

Infiltration trenches are excavated trenches filled with granular material. Infiltration trenches are designed to intercept and capture stormwater during smaller storm events to promote groundwater recharge. Infiltration trenches remove suspended solids, bacteria, organics, soluble metals, and nutrients through mechanisms of filtration, absorption and microbial decomposition.

Green Infrastructure Application Strategy and Design Issues

Infiltration trenches are best applied in linear, well spaced patterns where possible. They are effective where soil allows an adequate infiltration rate.

Long linear applications help prevent groundwater mounding from reducing the rate of potential infiltration and they make infiltration trenches ideal for application beneath curbs, gutters, sidewalks and parking area perimeters.

Benefits

Some pollutant removal efficiency is assumed with infiltration trenches. Stormwater runoff that enters them is filtered through in-situ soils and does not directly discharge to surface waters. The runoff that enters the infiltration trench should provide groundwater recharge and eventually discharge to nearby streams.

When applied as part of a larger treatment train, infiltration trenches can help reduce the need for large, contiguous flood control stormwater control measures.

Trenches help:

- Reduce impervious surface area and associated increased volumes of runoff.
- Provide storage of initial runoff, helping to prevent thermal loading to receiving ponds or streams.

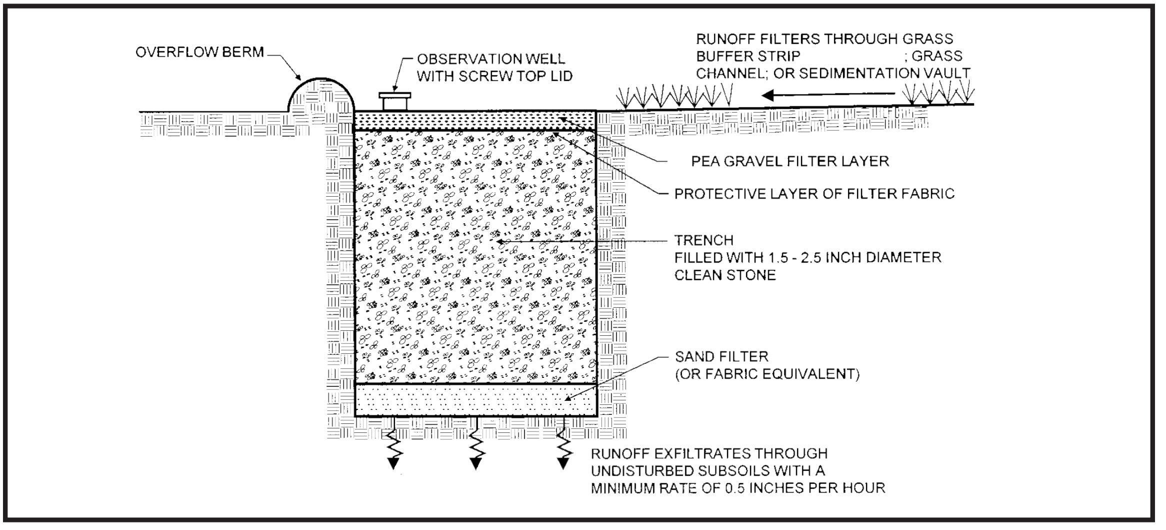


Figure 6.16 Infiltration Trench Schematic. Source: Center for Watershed Protection.

Limitations

Dry wells (or exposed infiltration trenches) basically are injection wells and can be a major contaminant source to the groundwater. Roof runoff (with no galvanized or copper roofing materials!) is probably a safe source water, but limit runoff from other source areas. Seasonal high water tables (or interfering mounding) can greatly hinder infiltration performance also. Horizontal filter fabrics also should not be used in any stormwater device as they commonly clog with the silts.

If the trench is deeper than it is wide, it may be considered an injection well that requires a stormwater discharge permit. Contact the Missouri Department of Natural Resources in your region for more information. http://dnr.mo.gov/regions/regions.htm

Relative Cost

Construction costs for infiltration trenches can vary greatly depending on site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that infiltration trench unit storage cost is not strongly correlated to storage volume increases. Relative to other stormwater control measures in the study, infiltration trench unit volume costs were in a similar range as bioretention but an order of magnitude higher than constructed wetlands, dry basins and wet ponds.

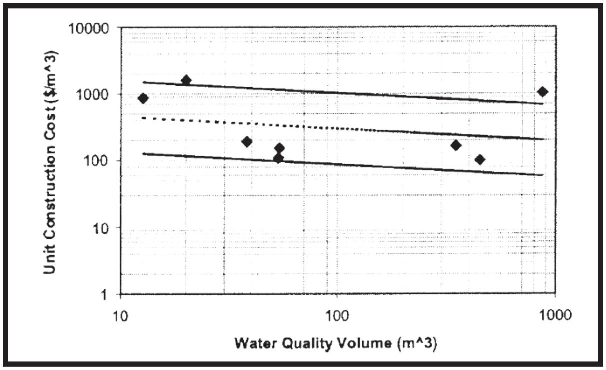


Figure 6.17 Infiltration Trench Unit Cost of Storage.
Source: Weiss et al, 2007

Figure 6.18 Infiltration Trench - Bellingham, WA.
Source: Williams Creek Consulting.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating at $9 per cubic yard and backfilling with a washed gravel at $27 per cubic yard and a one-third porosity in the gravel, yields a cost of $4 per cubic foot of storage, or approximately $175,000 per acre foot. This cost may be cut by as much as half where the trench is part of already necessary gravel subgrade, such as a curb, gutter or sidewalk.

Siting and Safety Requirements

- Runoff from non-paved areas can increase clogging risks. Therefore, infiltration trenches are more amenable to treating directly connected impervious area.
- Infiltration trench bottom should be level, but the slope of the surface may vary.

- The length and slope of the area draining to the trench affects the volume and velocity of runoff. Designers can widen a trench to accommodate higher velocities or deepen it to increase storage volumes pending site conditions.
- Soil type affects infiltration rates. Infiltration rates, textural class and other relevant soil characteristics can be confirmed in the field by a geotechnical engineer or qualified soil scientist.
- Consideration should be given to the proximity to sensitive groundwater areas. Depending on local conditions, infiltration without pretreatment may not be appropriate when near a drinking water aquifer well head protection zone or aquifers overlain by thin or highly permeable soils or areas of shallow ground water tables.
- Infiltration trenches can sometimes be applied in the ultra-urban environment.
- Infiltration trenches should not be used in stormwater hot spots (highly contaminated areas) unless the runoff has been pre-treated by another stormwater control measure.
- In regions of karst geology, infiltration trenches might not be applied due to concerns of sinkhole formation and groundwater contamination.

Permits

Review local requirements for site grading, drainage structures, and erosion and sediment control.

Figure 6.19 Pervious Gutter, Louisville KY.
Source: Williams Creek Consulting.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

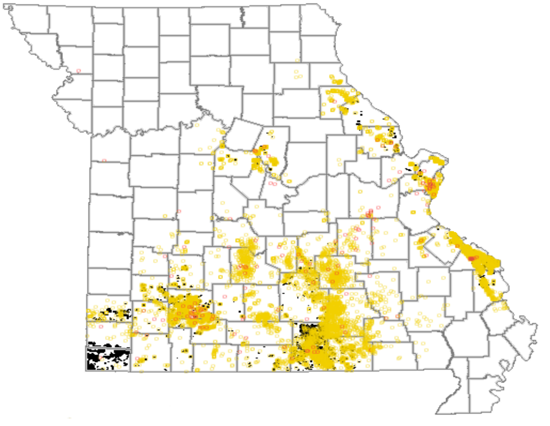


Figure 6.20 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Maintenance

Maintenance on infiltration trenches can be moderate to high:

- Conduct semi-annual inspections of observation wells following three days of dry weather. Failure to percolate may indicate clogging.
- Pervious concrete or vegetated filter strips can be used as pre-treatment to reduce clogging. Pervious concrete can be mechanically or vacuum swept.
- Inspection of pretreatment devices and diversion structures for sediment build-up and structural damage.

INSPECTION CHECKLIST AND MAINTENANCE GUIDANCE
INFILTRATION TRENCH INSPECTION CHECKLIST

Location: ____ Owner Change since last inspection? Y N

Owner Name, Address, Phone: ____

Date: __________ Time: ____________ Site conditions:____

Inspection Items	Satisfactory (S) or Unsatisfactory (U)	Comments/Corrective Action
Inspection List		
Complete drainage of the filter in about 24 to 72 hours after a rain event?		
Clogging of trench surface?		
Clogging of inlet/outlet structures?		
Standing water in observation well when no water should be present?		
Trench clear of debris and functional?		
Evidence of leaks or seeps?		
Animal burrows in trench?		
Cracking, spalling, bulging or deterioration of concrete?		
Erosion in area draining to trench?		
Erosion around inlets, trench, or outlets?		
Pipes and other structures in good condition?		
Undesirable vegetation growth?		
Other (describe)?		
Hazards		
Have there been complaints from residents?		
Public hazards noted?		

If any of the above inspection items are **UNSATISFACTORY**, list corrective actions and the corresponding completion dates below:

Corrective Action Needed	Due Date

Inspector Signature:______________________________ Inspector Name (printed)__________________________

Figure 6.21 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Pervious Pavements

Pervious Pavements

Pervious pavements are any system of surface improvement that allows vehicular traffic while maintaining some degree of permeability to allow rainfall to percolate prior to running off. They can include block, turf, or gravel paver systems or can be monolithic forms of pervious concrete or asphalt.

Although pervious pavements may not provide adequate pollutant removal as a stand alone stormwater control measure, they can provide pretreatment for TSS in advance of infiltration systems. Pervious pavements can also allow for reductions in impervious surface used to calculate water quality volumes and help mimic predevelopment runoff conditions.

Pervious Pavers

Pervious pavers are blocks made of brick, stone or concrete where the joints between the blocks are filled with sand or gravel to allow stormwater to percolate downward into the sub-grade. Pervious pavers may also have an over deepened sub-grade to allow for detention and additional infiltration for groundwater recharge. Although pervious pavers can be used for high volume traffic areas, most applications are in low traffic areas, such as walks, alleys, residential neighborhood roads, driveways and parking.

Figure 6.22 River de Peres Greenway, St. Louis MO.
Source: Williams Creek Consulting

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids		■	
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological		■	
Hydrocarbons		■	■

Table 6.3 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

Turf or Gravel Pavers

Turf or gravel pavers consists of interlocking concrete or plastic reinforced cells filled with soil and planted with turf grass or filled with gravel. Water passes through the system into a subgrade reservoir of crushed aggregate, then infiltrates into the native soil or drains into an underdrain. Turf and gravel pavers is best suited for low-vehicular traffic areas such as emergency access routes, infrequent or overflow parking areas and street shoulders. Pedestrian uses may include patios, walkways, terraces and residential driveways.

Pervious Concrete or Asphalt

Pervious pavements consist of concrete or asphalt made with cements that contain little or no fines. Water passes through the system into a subgrade reservoir of crushed aggregate, then infiltrates into the native soil or drains into an underdrain. Pervious concrete and asphalt can be designed for moderate traffic conditions.

Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to allow water movement.

A typical porous asphalt pavement consists of a top porous asphalt course, a filter course, a reservoir course (designed for runoff detention and frost penetration) and existing soil or sub-base material.

Porous concrete typically consists of specially formulated mixtures of Portland cement, open-graded coarse aggregate and water.

A typical pervious concrete pavement consists of a top pervious concrete course, a filter course, a reservoir course (designed for runoff detention and frost penetration) and existing soil or sub-base material.

Green Infrastructure Application Strategy and Design Issues

Pervious pavements are a very site-adaptable stormwater control measure that can be used to replace impervious surfaces in roads, walks, drives and parking areas. In areas of special groundwater or karst concern, pervious pavements can be used above subsurface storage areas fitted with liners and underdrain systems. However, pervious pavements are not recommended near stormwater hot spots.

Figure 6.23 Porous Asphalt Alley, St. Louis, MO. Source: Metropolitan St. Louis Sewer District.

Figure 6.24 Turf pavers. Source: Williams Creek Consulting.

Benefits

- Applied in a well distributed form, pervious pavements can provide retention to help improve groundwater recharge and mimic predevelopment surface runoff volume.
- Suitable for cold-climate applications, maintains recharge capacity when frozen.
- No standing water or black ice development during winter weather conditions.
- Maintains traction while wet.
- Reduced surface temperatures; pervious concrete minimizes the urban heat island effect.
- Extended pavement life due to well drained base and reduced freeze-thaw.
- Less lighting needed due to highly reflective pavement surface (pervious concrete).
- Can minimize the need for land dedicated to stormwater control measures and increase the area available for development.
- Can help minimize the size and length of stormwater pipes and reduce the need for mass grading.

FAIRFAX, VIRGINIA
Hydrologic and Hydraulic Parameters for Pervious Concrete

For hydrologic computations using the rational method, the runoff coefficient C for pervious concrete shall be computed as follows: $C = (I - kp) / I$

Where:
I = design rainfall intensity (in/hr)
Kp = coefficient of permeability = 4.0 in/hr for pervious concrete

For hydrologic computations using the NRCS method, use a curve number of 40 for pervious concrete. For hydraulic computations, use a roughness coefficient (manning's n value) of 0.03 for pervious concrete.

SOURCE: County of Fairfax, Virginia.
Dec. 21, 2007. Letter 08-01 Pervious Concrete – Use under the innovative best management practices provisions of the Public Facilities Manual

Siting and Safety

Pervious pavements are a very large investment, occupying a large portion of the landscape relative to other stormwater control measures. Proper siting, safety, design and construction are essential to a successful application, as post-construction corrections can be problematic.

- Where recycled fly ash is used in concrete, material should be tested for leachable mercury prior to use.
- Underlying soils should not be impermeable. Michigan Division of Environmental Quality recommends a minimum infiltration rate of 0.27 in/hr. In general, the subgrade should be designed to drain or exfiltrate within 72 hours. Underdrains can be used where the subgrade infiltration rate is inadequate.
- Areas of special groundwater concern, well head protection areas, karst or other subsurface limitation may require liners or underdrains.
- Mild slopes (<5 percent) are typically necessary for proper function.
- Concerns with freezing are often expressed relevant to pervious pavement and other infiltration methods. While the subgrade drainage system should be designed to account for freeze heaving and thawing effects, the effect of freezing conditions is little to no different than the effect on normally pervious soil conditions.
- Use on sites with relatively high impervious cover in strategic locations such as parking strips or curb and gutter areas. Application to larger areas may result in unnecessarily intensive maintenance.

- Winter road treatments such as sand may require more frequent vacuuming during spring. Use of salt should be minimized to prevent excessive chlorides in groundwater. However, University of New Hampshire studies indicate that pervious concrete does not suffer from standing water or black ice conditions to the extent of traditional pavements.
- The durability and maintenance cost of alternate pavements should be evaluated against conventional surfaces.
- Construction issues include:
    - Recommends a certified pervious concrete craftsman on-site during installation (NRMCA or other).
    - Proper soil stabilization and erosion control are required to prevent clogging.
    - Quality control for material production and installation are essential for success.
    - Concrete must cure under plastic for 7-days after installation.
- Pervious pavements will require more intensive maintenance where they receive runoff from unstabilized silt or clay soils.
- To help ensure future function, signs should be placed to identify pervious pavement areas.
- High commercial traffic areas should be avoided for pervious pavement applications.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in Karstic geographic regions.

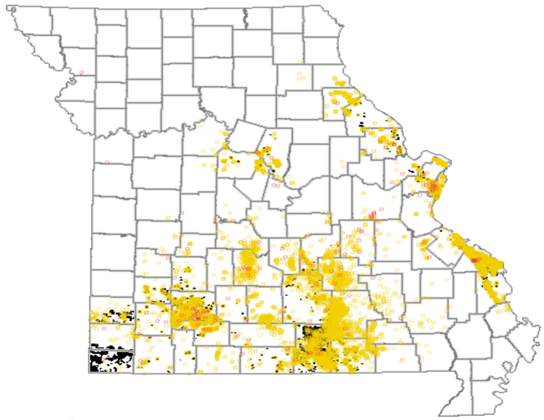


Figure 6.25 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Special Construction Sequencing

Due to the nature of construction sites, the Missouri Protecting Water Quality field guide recommends construction sequencing criteria where pervious pavement is proposed (Missouri, 2011). Infiltration beds under pervious pavement may be used as temporary sediment basins or traps, but require excavation after the site is stabilized and sediment storage is no longer required. For example:

- The existing subgrade under the bed areas should not be compacted or subject to excessive construction equipment prior to geotextile and stone bed placement.

- Where erosion of the subgrade has caused accumulation of fine materials or surface ponding, this material shall be removed with light equipment and the underlying soils should be scarified to a minimum depth of six inches. All fine grading should be done by hand and the bottom of the bed should be at a level grade to prevent localized ponding.
- Earthen berms between infiltration beds should be left in place during excavation. These berms do not require compaction if proven stable during construction.
- If an underdrain system is designed, it should be installed before the subgrade for the infiltration bed is prepared.
- Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation and in accordance with manufacturer's recommendations and specifications when needed, excess geotextile along bed edges can be cut back when all bare soils adjacent to beds are stabilized and vegetated.
- Clean, washed graded aggregate should be placed into the prepared bed in specified lifts. Each layer should be lightly compacted, with the construction equipment kept off the bed bottom as much as possible. After bed aggregate is installed to the desired grade, a 1 inch layer of base course such as AASHTO M-43 #57 aggregate could be installed uniformly over the surface in order to provide an even surface for paving.
- The pervious pavement materials (pervious concrete or asphalt) or pavers should be installed in accordance with relevant and applicable standards and specifications.

Cost

Cost of pervious pavements vary widely due to the wide variety of pavement types and design conditions. Each potential application should be evaluated on a site-by-site basis and compared to the cost of traditional paving systems. For comparison during design, a range of cost estimates for the basic installation of permeable paver materials is given in the table below for comparison purposes. Premiums assume that the pervious pavement is substituted for a traditional pavement.

Costs			
Pervious Pavement	**Traditional Pavement Cost/Ft^2**	**Pervious Pave-ment Cost/Ft^2**	**Premium Cost for Pervious /Ft^2**
Asphalt	\$3.50- \$5	\$4 -\$6	\$0.50 - \$1
Porous Concrete	\$5 - \$6	\$6-\$8	\$0 - \$3
Grass/Gravel Pavers	\$0.50 - \$1	\$1.50 - \$5.75	\$0.50 - \$5.25
Interlocking Concrete Paving Blocks	\$3.50 - \$6	\$8 - \$12	\$2 - \$8.50

Table 6.4 Source: Williams Creek Consulting

Maintenance

- Ensure adjacent areas are stabilized with no soil erosion to pervious surfaces.
- Lawn debris should be removed to prevent clogging.
- Keep surfaces and overflow devices free of debris.
- Vacuum or mechanically sweep curb and gutter applications every six to 12 weeks and in larger areas with less intense sediment loads can be maintained less frequently (as needed).
- Repair failed areas as needed.
- Turf Pavers
    - Lawn clipping shall be removed.
    - Reseed as needed.
    - Water as needed.
    - Chemical and fertilizer application should be minimized.

Figure 6.26 Pervious concrete and asphalt.
Source: Williams Creek Consulting.

Figure 6.27 Pervious pavement types.
Source: Williams Creek Consulting.

Permeable Pavement Inspection and Maintenance Checklist

Site Name: ______________________________ Owner Change since last inspection? Y N

Location: ______________________________

Owner Name: ______________________________

____

Address ______________________________ Phone Number ______________________________

Site Status: ______________________________

Date: ____________ Time: ______________ Site conditions:

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Pavement Area				
Pavement area free of debris?	*M*			
Inlets and outlets unobstructed?	*M*			
Is water standing after a storm event?	*S*			
Any evidence of clogged pores that require vacuum-sweeping?	*M*			
Access to pervious pavement (egress and ingress routes) safe and efficient?	*M*			
Vegetation				
Adjacent area fully stabilized (no evidence of eroding material into or from pervious pavement area)?	*A*			
Any noticeable irrigation needs?	*M*			
Fallen leaves/plant debris collecting in paving area?	*M*			
Grass height over 4 inches?	*M*			
Vegetation health affected by oil/grease from vehicles?	*A*			
Other	*A*			
Hazards				
Obstructions or debris affecting overflows/emergency spillways?	*M*			
Load-bearing capability of pavement intact?	*M*			

Inspector Comments: ______________________________

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

Figure 6.28 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments, (City of Memphis, 2007)

Tree Box and Tree Vault

A tree box or tree vault is a stormwater control measure that combines the bioretention stormwater control measure with street plantings to provide sufficient soil volume for healthy tree growth as well. A tree box is for a single tree, a vault is where several trees are planted within the same trenched area. The stormwater control measure consists of a structural box or vault with an underdrain filled with bio-engineered soils of sufficient volume to provide flow through water quality control and long term tree health. Stormwater can be accepted either through pervious pavement above the box/vault, or if placed along a street, can receive street runoff.

Figure 6.29 Post-Construction Image - Tree Box.
Source: Urban Design Tools. Low Impact Development
www.lid.stormwater.net/

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			■
Nitrogen			■
Phosphorous			■
Metals			■
Bacteriological			■
Hydrocarbons			

Table 6.5 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

Green Infrastructure Application Strategy and Design Issues

Healthy mature street trees can provide significant amenities to a community such as reduced heat island effect; reduced stormwater volume through interception on leaves, branches and bark; increased time of concentration of stormwater flows; and increased property value. For a tree to remain healthy and reach the growth potential necessary to provide these amenities, it must have sufficient soil volume, which may or may not be provided in traditional urban tree plantings.

Substituting stormwater tree boxes for traditional street tree planters is an effective way of improving runoff control. Tree boxes/vaults are a site-adaptable stormwater control measure, particularly in dense urban areas, that can be cost comparable to traditional tree planters. Systems are generally applied to small drainage areas and can be applied both along roads under sidewalks and in public plazas where large trees would be favorable.

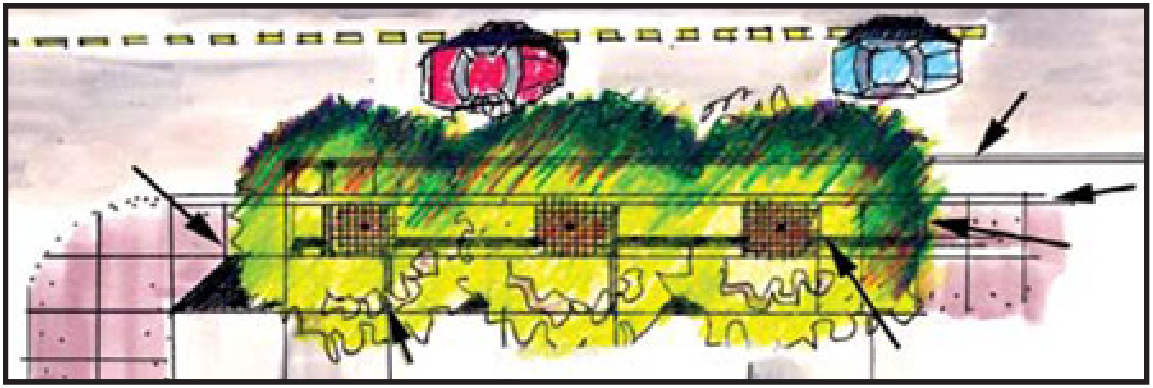


Figure 6.30 A linear storm water tree pit, Source: Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites.

Benefits

- Tree box/vaults use bioretention- type soils and have similar high nutrient and pollutant removal efficiencies.
- Tree box/vaults can be used in street ROWs particularly in heavy traffic areas with no on-street parking where few other stormwater control measures can.
- Tree box/vaults can be incorporated into a treatment train approach, including those preferring pretreatment such as dry detention/ retention basins.
- Mature trees provide aesthetic enhancement to property, lower air temperature in paved urban areas and clean the air.
- Properly designed systems can reduce the size of piped stormwater collection systems.

Siting Issues

- 625 square feet of soil area are typically recommended per tree for long term viability.
- Overhead lines and buried utilities should be avoided or considered when selecting plant material.

Cost

Tree boxes/vault costs can range considerably depending on size of the box/vault and whether proprietary systems are used. Costs can start at the low end at $2,500 per tree box and escalate up to $10,000 per tree box. Consideration should be given to the life-cycle cost-benefit over time due to the increase in stormwater control and property value as the trees grow in size and value each year.

Permits

Tree boxes/vaults typically do not require any specific permitting but it often requires review and approval by municipal authorities if it is to be incorporated into the regulated stormwater collection system. Review local requirements for site grading, drainage structures, erosion and sediment control and potential invasive vegetation.

Landscaping

Selecting plant material for tree box/vault areas are a critical design element to improve both the function and aesthetics. Native trees, are well adapted to or have evolved under local climate conditions.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying trees suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland, or OBL: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative wetland, or FACW: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but are occasionally found in non wetlands.
- Facultative, or FAC: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative upland, or FACU: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland, or UPL: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Note: A given indicator status shown with a "+" or a "-" means that the species is more or less often found in wetlands than other plants with the same indicator status without the "+" or "-" designation.

Indicator Status Website: www.plants.usda.gov

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Maintenance

Maintenance is low. Watering during establishment is often necessary. Maintenance decreases in successive years. Semi-annual inspection of sediment build up, plant health, and removal of litter will maintain bioretention soil functions and services. Tree box/vaults may actually lower utility costs by requiring less watering than similarly landscaped areas.

Figure 6.31 Tree vault, Arlington, VA.
Source: www.arlingtonva.us/departments/EnvironmentalServices

Bioretention

Bioretention is a landscape feature built in a natural or constructed depression that filters stormwater runoff using the pollutant removal mechanisms that operate in natural ecosystems. During water quality and other small storm events, stormwater filters through the engineered or native soil media. Runoff from larger storms generally ponds and overflows to a structure that drains to the storm system. Filtered runoff can be collected in a perforated underdrain and returned to the storm system or allowed to infiltrate into the subsoil. Larger storm events will likely overflow into a catch basin and enter the stormwater conveyance system.

Green Infrastructure Application Strategy and Design Issues

Bioretention is a very site-adaptable stormwater control measure that can be used to replace other landscape options such as parking lot islands, streetscapes, or on-lot landscapes. Bioretention can also be used to treat stormwater hot spots with design modifications specific to the pollutant of concern.

Figure 6.32 Bioretention - Delaware Health Village, Delaware, OH. Source: Williams Creek Consulting

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids		■	■
Nitrogen		■	
Phosphorous		■	
Metals		■	
Bacteriological			■
Hydrocarbons		■	

Table 6.6 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

If applied at a great enough level of frequency and intensity, bioretention can also minimize the need for large, contiguous flood and stormwater control measures. Bioretention soil mixes vary widely. When developing local standards for "biosoil," consideration should be given to:

- Local availability of material.
- Biosoil depth, pH and nutrient content relative to water quality goals, not necessarily a universal growing medium.
- Minimum and maximum infiltration capacity.

Many design manuals prescribe design criteria for different types of bioretention areas. Pending site characteristics and anticipated target pollutants, these design criteria may be excessive and unnecessarily increase construction costs.

(*Rethinking Bioretention Design Concepts*, M. Clar, E. Laramore, H. Ryan, Department of Land Use, New Castle County, DE). However, depth of amended soils is critical where specific infiltration volumes are assumed as part of stormwater control measure performance. One example would be where default credits are granted for infiltration practices such as bioretention.

Where no default infiltration credit is assumed, the 2008 Clar research indicates:

- Maximum allowable ponding depths should be a function of vegetation type, adjacent land use, allowable drawdown times, or other defined condition. Increasing allowable stage depth from six inches to depths of 12 or 18 inches could increase the cost effectiveness of bioretention areas by two to three times and make them more effective at mimicking pre-construction runoff conditions.
- Underdrains may be needed where subgrade soils are poorly drained. In areas where the subgrade is capable of infiltrating design volumes within 72 hours, consideration should be given to not requiring underdrains. Removing the underdrains can help increase the infiltration capacity of a bioretention area.

Benefits

- Significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation, soil absorption and biogeochemical activity in the soil column. Vegetation in the bioretention area also filters and helps prevent resuspension of sediment.

Figure 6.33 Bioretention System - medical facility in Ohio.
Source: Williams Creek Consulting

- Similar to any constructed landscape, bioretention can be low to high maintenance, pending the aesthetic requirements of the landscape. Relevant to upland ornamental landscapes, a mature bioretention area is generally more resistant to colonization by upland nuisance weeds, better adapted to thrive in saturated and flooded conditions and more tolerant to droughts.
- Can provide retention to help improve groundwater recharge and mimic pre-construction surface runoff volumes.
- Can be applied in large areas such as boulevards or parking area buffers, bioretention can decrease downstream channel erosion and reduce peak runoff rates.
- Can provide increased aesthetic value.
- Provides public outreach opportunities along greenways.

Siting and Safety

- Bioretention areas should be placed at least ten feet from building foundations and designed not to stage to a depth that may flood the structure. Where bioretention is designed nearer foundations, the architect or structural engineer should be consulted regarding underdrains and other drainage improvements to help ensure building safety and flood protection.
- As needed, river rocks or a grass filter strip may be used to dissipate energy where water enters the treatment cell.

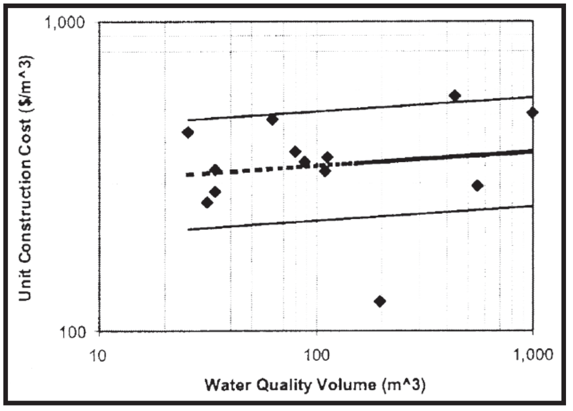
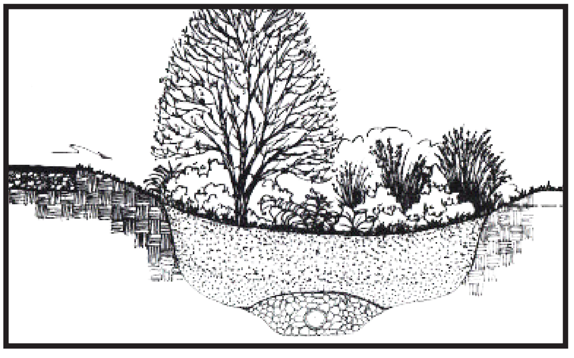


Figure 6.34 Bioretention Unit Cost of Storage.
Source: Weiss et al, 2007.



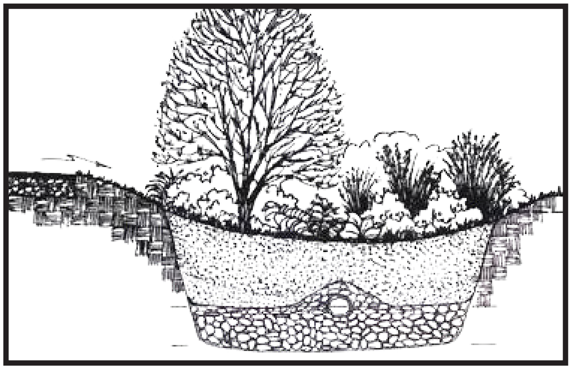


Figure 6.35 Infiltration/filtration/recharge.
Source: Bioretention manual - Environmental Services Division Department of Environmental Resources - the Prince George's County, Maryland.

Relative Cost

Construction costs can vary greatly depending on site characteristics. However, an equation was developed to estimate the cost of bioretention prior to design (Brown and Schueler, 1997).

C = 7.3V0.99 where:

C = Construction, design and permitting cost
V = Treatment volume (ft3)

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. The above formula yields a value of approximately $6.50 per cubic foot of treatment volume.

Case Study Cost

National databases or local case studies can be used to estimate costs. An EPA case study (EPA, Office of Water, Bioretention Applications, 2000, EPA-841-B-00-005A) done in Inglewood, Maryland, constructed a 38 feet by 12 feet bioretention to manage approximately one-half acre of impervious surface. This bioretention cell represents only two percent of a watershed area that is nearly 100 percent impervious. The cost was reported to be $4,500, or approximately $10 per square foot.

Permits

Bioretention typically does not require any specific permitting but it often requires review and approval by municipal authorities if it is to be incorporated into the regulated stormwater collection system or is to be constructed in public owned right-of-way.

Primary Cost Components for Bioretention			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Soil preparation	Soil cost ($/acre) x Seeding/planting area (1-ft average depth per acre	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding or sodding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2/1 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor cost ($/hr) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1/5 yr)	
	Erosion repair	Repair cost ($/acre) x Affected area	
	Gate/Valve operation	Operation cost ($) x Operation Frequency (2/1 yr)	
	Inspection	Inspection cost ($) x Inspection Frequency (2/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (4/1 yr)	

Table 6.7 Source: Minnesota Stormwater Manual Version 2, 2008.

Landscaping

Landscaping of bioretention areas are a critical design element to improve both the function and aesthetics of bioretention areas. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because deep-rooted native and adaptive species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants nearly always (more than 99 percent of the time) found in wetlands under natural conditions.
- Facultative wetland: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative upland: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Common Name	Latin Name
Broad-leaved cattail	*Typha latifolia*
Narrow-leaved cattail	*Typha angustifolia*
Hybrid cattail	*Typha x glauca*
Common Reed	*Phragmites australis*
Purple loosestrife	*Lythrum salicaria*
Johnson Grass	*Sorghum halepense*

Maintenance

- Similar to traditional landscaping.
- Irrigate as necessary while plants are establishing.
- Cut and remove dead vegetation in the spring.
- Annual addition of mulch may be required unless designed with dense groundcover.
- Semi annual inspection should be conducted for erosion, plant health and litter removal.

Bioretention and Organic Filters Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																																						
Andropogon gerardii	Big bluestem			x	x	x	4-6	2	plum	x	x							x	x	x	x	x				x	x		x		x	x	M	12	2		M	
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan							x	x	x	x	x		x	x			x	x		x			x	L				L	
Carex praegracilis*	Tollway sedge		x		x	x	1-2	1.5	tan				x	x	x							x	x			x	x	x	x				H	12	2	H	H	H
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x							x	x	x	x		x	x	x				H	24	3		L	
Carex shortiana	Short's sedge		x		x	x	2	1.5	bluish				x	x	x							x	x	x		x	x	x	x			x	M	24	3		L	
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x			x	x				x	H	24	3	L	L	
Chasmanthium latifolium	River oats			x	x	x	2-4	1.5	green						x	x	x	x	x	x			x	x	x	x	x		x		x	x	M	12	1		H	
Schizachyrium scoparium	Little bluestem			x		x	2-3	1.5	bronze	x	x						x	x	x	x	x	x				x	x		x		x	x	L			M	L	L
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan								x	x	x	x	x	x				x	x		x			x	L				L	
Forbs																																						
Amsonia illustris	Shining bluestar		x	x	x		2-3	2.5	lt. blue				x	x								x	x	x		x	x	x		x	x		H	36	5		L	H
Aster novae-angliae	New England aster		x		x		3-4	2	violet								x	x				x	x				x	x		x	x		M	24	3	L	H	
Chelone obliqua	Rose turtlehead		x		x		3-4	2	rose/purple								x	x	x			x	x	x	x		x	x					M	12	1		M	
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow			x	x	x								x	x			x	x			x			L		1		L	
Echinacea pallida	Pale purple coneflower					x	2-3	1.5	violet						x	x						x	x			x	x		x				L				L	
Echinacea purpurea	Purple coneflower					x	2-3	1.5	lt. purple						x	x	x						x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green						x	x	x	x				x				x	x			x		x	M	12	2	M	L	
Eupatorium coelestinum	Mist flower; wild ageratum		x	x	x		1-2	1.5	lavender							x	x	x	x			x	x				x	x		x			H	12	3		M	H
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x			x	x	x			x	x		x	x		H	36	5		M	M
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x					x	x					x	x			x	H	36	4		M	M
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white							x	x	x				x	x	x		x	x						L		1		M	
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow						x	x	x					x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia fulgida	Orange coneflower				x		2	2	yellow						x	x	x	x				x	x			x	x			x		x	L				M	
Rudbeckia hirta	Black-eyed Susan						2-3	1.5	yellow						x	x	x	x				x				x	x			x			L				M	
Solidago rugosa	Rough-leaved goldenrod				x	x	2-3	1.5	yellow								x	x				x	x	x	x	x	x			x		x	L			M	H	L
Solidago speciosa	Showy goldenrod				x	x	2-3	1.5	yellow								x	x				x	x	x		x	x			x		x	L			M	H	L
Verbesina helianthoides	Yellow wingstem						2-3	1.5	yellow						x							x	x	x		x	x		x	x			L				M	
Zizia aurea	Golden alexander					x	1-3	1.5	yellow					x	x							x	x	x		x	x			x			L			M	H	
Trees/Shrubs																																						
Carpinus caroliniana	Musclewood				x	x	15-20	20	yellow	x	x	x							x	x	x	x	x	x		x	x				x	x	M	6	1		L	
Cercis canadensis	Redbud			x	x	x	10-20	15	pink			x	x									x	x	x		x	x						L			L	M	L
Hamamelis virginiana	Eastern witchazel		x		x	x	10-15	15	yellow										x	x	x		x	x	x	x	x				x	x	L			L	L	
Quercus alba	White oak				x	x	40-60	30	green			x	x						x	x		x	x	x	x	x	x		x	x	x	x	L			H	L	

Requirements

Local Ecotype Rule: Plants of Missouri or Southern Illinois ecotype are required.

Must use a minimum of 5 grass/sedge species and 8 forb species for each BMP. It is recommended that this list be provided to landscape contractors/buyers in case substitutions are required.

Each species must consist of between 5% - 15% of the total plant count for each BMP.

Refer to Planting, Water, and Mulch Requirements for Stormwater BMP's for plant sizes and irrigation requirements

Biodegradable erosion blanket must be used on slopes greater than 10%.

Erosion blankets must be coarse to allow varying leaf sizes (examples include Geojute, Curlex #1 and NorthAmerican Green S75 single net straw blanket, or equivalent)

*Experimental for practice and/or limited availability in commercial trade

Figure 6.36 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Bioretention Inspections and Maintenance Checklist

Site Name: ______________________________ Owner Change since last inspection? Y N

Location: ______________________________

Owner Name: ______________________________

____

Address ______________________________ Phone Number ______________

Site Status: ______________________________

Date:__________ Time: ____________ Site conditions:

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Treatment Area				
Treatment area free of debris?	*M*			
Inlets and outlets unobstructed?	*M*			
Is there standing water longer than 24 hours after a storm event?	*S*			
Evidence or erosion?	*M/S*			
Vegetation				
Adjacent area fully stabilized (no evidence of eroding material into Bioretention area)?	*A*			
Plant height not less than design ponding depth?	*A*			
Plant composition according to approved plan?	*A*			
Grass height not more than 6 inches?	*M*			
Vegetation overgrown?	*A*			
Other	*A*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:______________________________

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

Figure 6.37 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Bioswales

Bioswales (Vegetative Swales)

Wetland swales, dry swales with filter media and filter strips can be flow-through channels or have characteristics that allow them to retain and infiltrate runoff. The vegetation in the filters can range from turf to native grasses and may include woody plants. Pending their design, they are sometimes only suitable as pre-treatment practices as part of a larger treatment train.

1. Dry swales with filter media are broad and shallow channels with native vegetation covering the side slopes and channel bottom. As opposed to wetland swales, these swales, natural or constructed, include an engineered soil matrix and underdrain system for improved drainage and filtration. Specified vegetation should be able to tolerate drought and saturated soil conditions. They convey stormwater runoff slowly, promoting infiltration and water quality treatment.

2. Wetland swales are flat or shallow sloped channels with hydrophytic vegetation in the channel base. Stormwater runoff is slowly conveyed resulting in higher rates of infiltration, increased plant transpiration, adsorption of pollutants, settling of suspended solids, and microbial breakdown of nutrients and hydrocarbons. They can also be designed with check dams to increase their stormwater retention capabilities.

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			■
Nitrogen		■	
Phosphorous	■	■	
Metals		■	■
Bacteriological		■	■
Hydrocarbons			■

Table 6.8 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

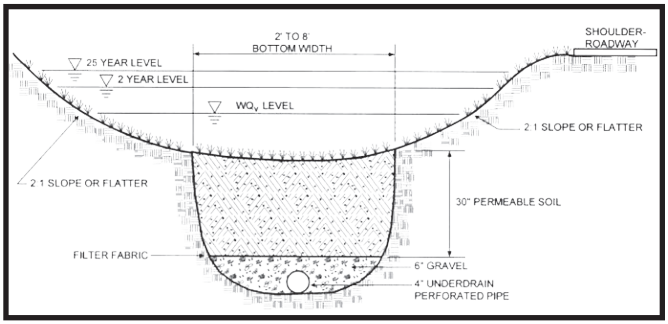


Figure 6.38 Dry swale. Source: Center for Watershed Protection

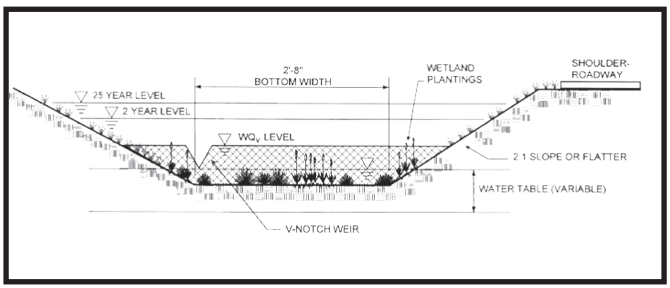


Figure 6.39 Wetland swale. Source: Center for Watershed Protection

3. Turf swales and vegetated filter strips are primarily a pre-treatment stormwater control measure designed to treat sheet flow from adjacent impervious surfaces. They function by reducing runoff velocity and filtering sediment and other pollutants. Filter strips are often adjacent to parking areas, incorporated as the outer zone of a stream buffer, or located upstream of other stormwater control measures and are not typically a stand alone practice. Depending on the condition of underlying soils, filter strips can provide limited infiltration.

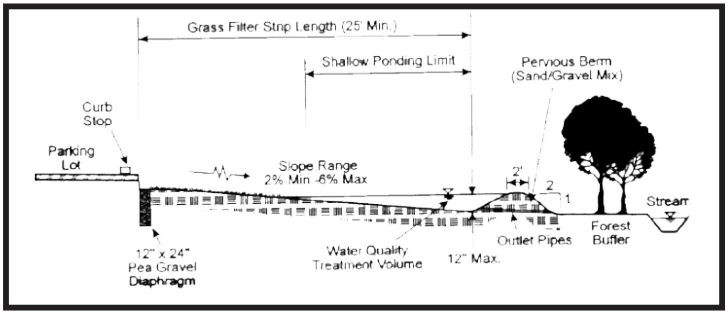


Figure 6.40 Turf Swale. Source: Center for Watershed Protection, 1996

Vegetative filters, designed as grass channels or swales, may be used as the primary conveyance between or out of best management practices, as well as providing some treatment for stormwater runoff. Native plant swales perform better than turf due to deeper root systems.

Figure 6.41 Bioswale - Clifty Creek, Ind. Source: Williams Creek Consulting.

Green Infrastructure Application Strategies

Many codes and ordinances require that swales have a minimum slope in order to maintain well drained conditions. In context of green infrastructure, swales do not necessarily need to have slope and can sometimes produce greater benefits where they have zero slope.

The conveyance potential inherent to all vegetated filters makes their application well suited to sustainable infrastructure.
Example applications include:

- Parking lots - Turf swales and filter strips can be installed at the perimeter of the parking area and vegetated to serve as landscape buffers from adjacent developments.
- Streetscapes – Filter strips and swales can follow street topography. They can be used in combination with rain gardens or other bioretention to create a network of vegetated conveyance and distributed storage systems similar to natural drainage patterns.
- Green space – swales can be used as low flow channels in dry detention basins to keep the balance of the basin available for passive recreation.

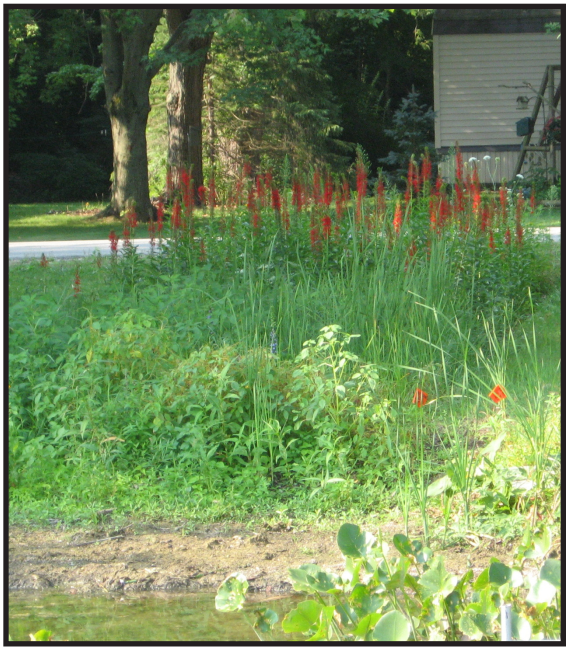


Figure 6.42 Bioswale - Loon Lake, IN.
Source: Williams Creek Consulting

Benefits

- Significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation and microbiological processes. Vegetation physically filters out sediments and helps prevent resuspension.
- Can provide limited retention and detention.
- Increases the time of concentration relative to conventional pipe collection systems, which can help reduce peak runoff rates and mimic the predevelopment hydrograph.
- Can increase biodiversity relative to other centralized stormwater control measures such as dry detention or wet ponds.
- Does not suffer seasonal maintenance issues such as wet pond spring or fall algae blooms or dry basin mowing.
- Creates opportunities for a linear network of common area that can be used for pedestrian trails, maintenance access and emergency vehicle access.
- Can help minimize mass earthwork requirements where used to maintain predevelopment drainage patterns.

Primary Cost Components for Bioswales			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Under-drains	Under-drain cost ($/lineal ft.) x length of device	Pipes, catch basins, manholes, valves.
	Vault structure (for media filters)	$/Structure	
	Media (for media filters)	Media cost ($/cubic yard) x filter volume (cubic yard)	
	Inlet structure (for vegetative filters)	$/Structure	Tree protection, soil amendments, seed bed preparation, trails.
	Outlet structure (for vegetative filters)	$/Structure	
Site Restoration	Filter Strip	Sod cost ($/sq. ft.) x Filter strip area	Vegetation maintenance, cleaning of structures.
	Soil preparation	Soil cost ($/acre) x Seeding/planting area (1-ft average depth per acre	
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2x/1 yr)	Vegetation maintenance, cleaning of structures.
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (5x/1 yr)	
	Gate/Valve operation	Operation cost ($) x Operation Frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection Frequency (6x/1 yr)	
	Mowing (for vegetative filters)	Mowing cost ($) x Mowing frequency (4x/1 yr)	

Table 6.9 Source: Minnesota Stormwater Manual Version 2, 2008.

Siting Considerations

- Swales are well suited for roadside applications or along the property boundaries of development.
- Side slopes should not be steeper than 3:1 for maintenance and safety considerations.
- Concrete maintenance surfaces can be used at inlets for ease of maintenance
- To help maintain slow velocities and increase opportunities for infiltration during conveyance, swales should be designed with minimal or no slope. In steeper topographic areas, check dams can be used to help slow small storm runoff velocities and protect the swale against erosion.

Cost

Cost is dependent upon the size of the swale, use of seeds or plugs, presence of a pretreatment forebay and the extent of necessary excavation during construction. Capital cost varies between $10 to $50 dollars per linear foot depending on these factors (Storm, 1999). For similar sized applications, wet swales can be less expensive than bioswales due to no requirement for special backfill or underdrains.

Permits

Review local requirements for site grading, drainage structures, erosion and sediment control and potential invasive vegetation.

Landscaping

Landscaping of vegetated filters is a critical design element to improve both the function and aesthetics. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland, or OBL: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland, or FACW: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative, or FAC: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland, or FACU: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland, or UPL: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Indicator status can be reviewed at www. plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Johnson Grass	Sorghum *halepense*

Maintenance

- Relatively low to medium, depending on the type of vegetation and mowing frequency.
- Sediment should be removed as needed near inlets to prevent blocking or clogging.
- Remove trash as needed.
- Invasive and exotic species should be removed.
- Mowing of turf swales will be necessary.
- Semiannual inspection for:
    - Sediment accumulation.
- Invasive and exotic species vegetation.
    - Integrity of the slopes and center line.
    - Corrective actions in areas of erosion.

Bioretention and Organic Filters Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D
Grasses/Sedges																					
Andropogon virginicus	Broomsedge			x		x	1-2	1.5	orange								x	x	x	x	x
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan							x	x	x	x	x	
Carex muskingumensis	Palm sedge		x	x	x		1-2	1.5	tan					x	x	x	x				
Carex praegracilis*	Tollway sedge		x		x	x	1-2	2	tan				x	x	x						
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x					
Panicum virgatum	Switchgrass			x	x	x	3-6	2.5	pink	x	x					x	x	x	x	x	x
Schizachyrium scoparium	Little bluestem			x		x	2-4	1.5	bronze								x	x	x	x	x
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan								x	x	x	x	x
Forbs																					
Asclepias tuberosa	Butterfly milkweed			x		x	1-2	1.5	orange						x	x	x				
Baptisia australis	Blue wild indigo						3-4	3-4	blue					x	x						
Blephilia ciliata	Ohio horsemint					x	1-2	1.5	pink				x	x							
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow			x	x	x							
Echinacea purpurea	Purple coneflower					x	2-3	1.5	t. purple						x	x	x				
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green						x	x	x	x			
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white							x	x	x			
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow						x	x	x				
Rudbeckia subtomentosa	Sweet coneflower				x	x	3-4	2	yellow						x	x	x	x			
Scutellaria incana	Hoary skullcap				x		2-3	2	blue						x	x	x				
Solidago rigida	Stiff goldenrod				x	x	3-5	1.5	yellow								x	x			
Verbesina helianthoides	Yellow wingstem			x	x	x	2-3	1.5	yellow						x	x					
Zizia aurea	Golden alexander					x	1-3	1.5	yellow				x	x							
Trees/Shrubs																					
Cornus florida	Flowering dogwood			x	x	x	10-20	15	white			x	x					x	x	x	x
Diospyros virginiana	Persimmon			x	x	x	30-40	20	orange				x	x				x	x	x	
Ostrya virginiana	Hophornbeam				x	x	20-30	20	green									x	x		
Quercus muhlenbergii	Chinquapin oak				x	x	40-50	35	green									x	x		

Latin Name	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																	
Andropogon virginicus	x				x			x		x	x	L		1		M	L
Bouteloua curtipendula	x				x	x		x			x	L		1		L	L
Carex muskingumensis	x	x	x	x	x	x	x	x				H	24	3+		M	H
Carex praegracilis*	x	x			x	x	x	x				H	12	2	H	H	H
Carex vulpinoidea	x	x	x			x	x					H	24	3+	L	L	H
Panicum virgatum	x	x	x			x	x	x		x		M	12	2	M	M	M
Schizachyrium scoparium	x				x	x		x		x	x	L	12	1	M	L	L
Sporobolus heterolepis	x				x	x		x			x	L				L	
Forbs																	
Asclepias tuberosa	x				x	x			x			L			V	M	
Baptisia australis	x	x	x		x	x			x			L				M	
Blephilia ciliata		x	x	x	x	x			x		x	L					
Coreopsis lanceolata	x	x			x	x			x			L		1		L	
Echinacea purpurea		x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	x				x	x			x		x	M	12	2	M	L	
Pycnanthemum tenuifolium	x	x	x		x	x						L		1		M	
Ratibida pinnata	x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia subtomentosa	x	x				x	x		x		x	H	12	2		M	
Scutellaria incana			x	x	x	x			x			L					L
Solidago rigida	x					x					x	L	12	2	M	H	L
Verbesina helianthoides	x	x	x		x	x		x	x							M	
Zizia aurea	x	x	x			x			x			H	12	1	M	H	U
Trees/Shrubs																	
Cornus florida		x	x	x	x	x		x		x	x	L			L	L	L
Diospyros virginiana	x	x	x		x	x		x		x	x	M	12	1		M	M
Ostrya virginiana		x	x	x	x	x						L				L	L
Quercus muhlenbergii		x	x	x	x	x					x	L			H	L	L

Requirements

Local Ecotype Rule: Plants of Missouri or Southern Illinois ecotype are required.

Must use a minimum of 5 grass/sedge species and 8 forb species for each BMP. It is recommended that this list be provided to landscape contractors/buyers in case substitutions are required.

Each species must consist of between 5% - 15% of the total plant count for each BMP.

Refer to Planting, Water, and Mulch Requirements for Stormwater BMP's for plant sizes and irrigation requirements

Biodegradable erosion blanket must be used on slopes greater than 10%.

Erosion blankets must be coarse to allow varying leaf sizes (examples include Geojute, Curlex #1 and NorthAmerican Green S75 single net straw blanket, or equivalent)

*Experimental for practice and/or limited availability in commercial trade

Figure 6.43 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Enhanced Swales/ Grass Channels/ Filter Strips Inspections and Maintenance Checklist

Site name: ________________________________ Owner Change since last inspection? Y N

Owner Name, Address, Phone ________________________________

Number________________________________

Location: ________________________________

Site Status: ________________________________

Date:________________________________ Time: ________________________________

Inspector: ________________________

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Debris Removal				
Facility and adjacent area free of debris?	*M*			
Inlets and outlets free of debris?	*M*			
Any dumping of yard wastes into facility?				
Litter (branches) removed?	*M*			
Vegetation				
Surrounding area fully stabilized? (no evidence of eroding material into swale, channel or filter strip)	*M*			
Grass mowed?	*M*			
Plant height not less than design water depth?	*M*			
Fertilized per specifications?	*M*			
Plan composition according to approved plan?	*M*			
Unauthorized or inappropriate plantings?	*A*			
Plants healthy? (no diseased or dying vegetation)	*M*			
Evidence of plants stressed from inadequate watering?	*M*			
Filtration Capacity				
Clogging from oil or grease?	*M*			
Facility dewaters between storms?	*M*			
Check dams and energy dissipators/sumps				
Any evidence of sedimentation build up	*A,S*			
Are sumps greater than 50% full of sediment?	*A,S*			
Any evidence of erosion and down stream toe of drop structures?	*A,S*			
Sediment Deposition				
Swale clean of sediments	*A*			
Sediment not > 20% of swale design depth	*A*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Outlet/Overflow Spillway				
In good condition?	A			
Any evidence of erosion?				
Any evidence of blockages?	A			
Has facility been filled or blocked inappropriately?	A			

Inspector Comments:____

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: ___________________
(date)

Inspected by: (signature) ________________________________
Inspected by: (printed) ________________________________

Figure 6.44 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Wet Retention and Detention Basins

Wet Ponds

Wet ponds are a type of detention basin typically designed for large storm management and can be designed with extended detention controls to improve small storm management. Ponds rely on physical, biological and chemical processes to remove pollutants from incoming stormwater runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants. Algae and aquatic vegetation can help manage nutrients, however many nutrients in ponds are released when these organisms die. Volatilization and chemical activity can also occur, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons, however lighter hydrocarbons such as gasoline will float and may pass through ponds untreated.

Wet and dry ponds perform very differently (see the International BMP Database) dry ponds are not very effective pollutant control devices (low to medium), while wet ponds are usually highly effective for particulate bound pollutants. Both can be the most effective control for energy reductions though (needed for habitat protection), to balance the flow-duration distribution for a site (after upland infiltration).

Benefits
Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids		■	■
Nitrogen		■	
Phosphorous		■	
Metals		■	
Bacteriological			■
Hydrocarbons		■	

Table 6.10 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

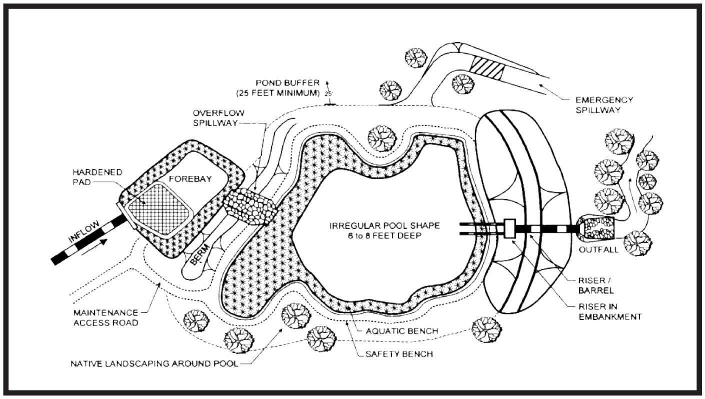


Figure 6.45 Flow-through wet detention pond. Source: Center for Watershed Protection, 1996

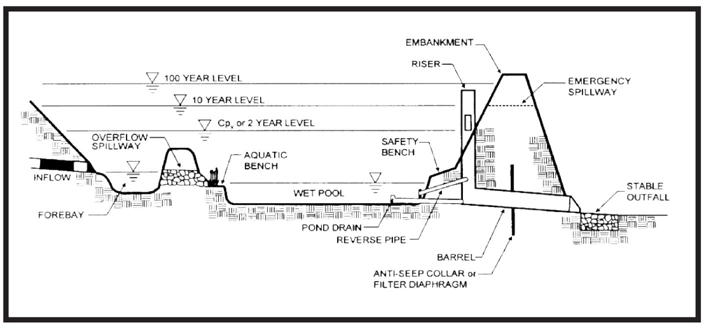


Figure 6.46 Flow-through wet detention pond. Source: Center for Watershed Protection, 1996

Variants in wet pond design include:

1. Flow-through Wet Detention Ponds typically have a weir or single orifice outlet control to slow the release of runoff from large, infrequent storms such as 10-year or 100-year storms. Designers need to consider drawdown times when designing slopes above normal pool. Rapid drawdown times can contribute to slope instability and bank failure.

2. Extended Detention Wet Ponds use a multiple orifice outlet to provide extended detention of small storms. Designers need to consider drawdown times when designing vegetation on slopes near the normal water surface, as these areas may be inundated for extended periods unsuitable for turf grasses.

3. Pond/Wetland Systems are combinations of deep open water areas and wetland shelves. This combination can share the advantages of both systems.

3. Water reuse ponds used primarily for irrigation.

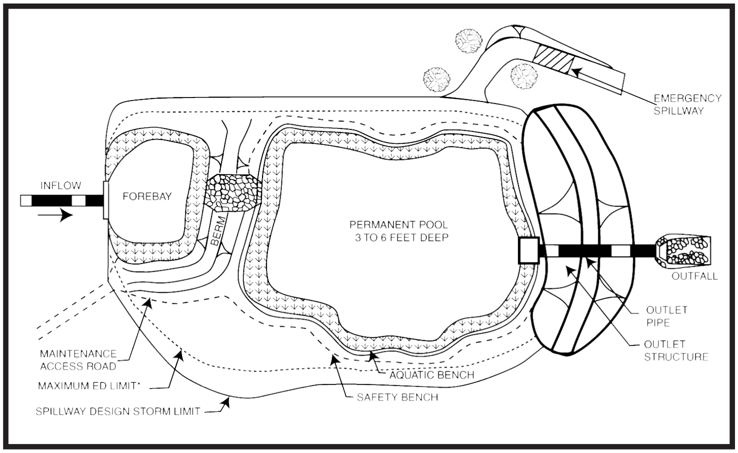


Figure 6.47 Extended wet detention. Source: Center for Watershed Protection, 1996

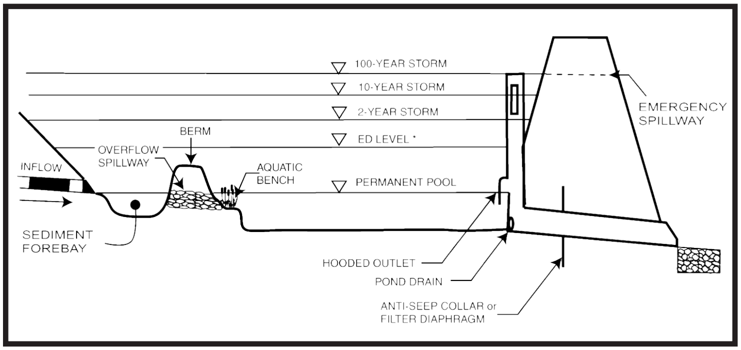


Figure 6.48 Extended wet detention. Source: Center for Watershed Protection, 1996

Green Infrastructure Application Strategy

Wet ponds are well suited to regional stormwater management applications. The large footprint of regional basins create opportunities for trails, fishing areas and other amenities.

Wet ponds can also be retrofitted with extended detention controls and/or wetland shelves. Extended detention controls can be designed to improve an existing wet pond's management of multiple design storms. Wetland shelves can help provide a safety barrier between open water and the shoreline, and help control waterfowl populations and associated fecal coliform issues, although coliform removal rates vary widely and do not necessarily meet pollutant removal requirements alone.

Figure 6.49 IntelliPlex - Shelbyville, IN. Source: Williams Creek Consulting

Water balance calculators are recommended where wet ponds are at the end of a green infrastructure treatment train. The infiltration capacity of many green infrastructure stormwater control measures and the reduced runoff from non-structural stormwater control measure practices may not provide adequate volumes of water to maintain wet pond design pool elevations and result in stagnant or otherwise reduced pond health.

Benefits

- Efficient control of peak discharge rates to help decrease downstream channel erosion and reduce peak runoff rates.
- Long term sequestering of sediments.
- When designed with wetland shelves, wet ponds can increase biodiversity and aquatic habitat.
- Less construction cost than similarly sized constructed wetland systems.

Potential Drawbacks

- Can have seasonal algae blooms.
- Can become clogged with invasive and exotic vegetation such as milfoil.
- Pose a drowning safety risk.
- Can create a net export of suspended solids where nutrients cause phytoplankton and algae blooms.
- Can attract nuisance waterfowl populations.
- Have difficulty settling fine grained particles.

Minimal infiltration is typically provided by wet ponds. However, exceptions may occur where a wet pond normal pool elevation is equal to the seasonal high groundwater table. This is a difficult condition to achieve and attempting but failing to execute properly can result in:

- Normal pool set above the seasonal high water table. This condition can result in exposed pond shelves, making the safety ledge ineffective at preventing pedestrian access to steep, submerged slopes.

Figure 6.50 Corporate headquarters - Plainfield, IN.
Source: Williams Creek Consulting

- Normal pool set below the seasonal high water table. This condition can result in dewatering of the shallow aquifer through continuous discharge. Lowering of the water table results in a long-term increase in discharge volumes to receiving streams and can damage or kill trees and other vegetation unable to reach the depressed water table elevation.

Safety

Due to drowning risk, public safety is important in wet pond design. Issues to address include:

- The principal outlet or spillway should not permit access by small children.
- Endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard Access to open water should be limited using fencing or vegetation.
- Prohibited use signs should be posted.
- Setbacks from roads should be set to minimize risks to vehicular accidents.
- Shallow shelves should extend into the pond prior to dropping off to deep depths.
- Dam safety regulations should be strictly followed where relevant and applicable.

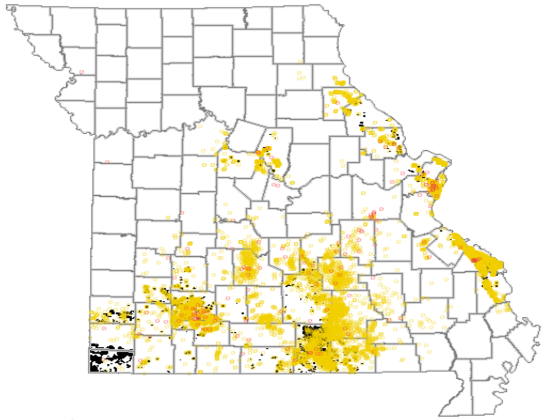


Figure 6.51 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

Siting Considerations

- Minimum average depths of 6 to 8 feet help provide long term storage capacity for sediment.
- Ponds may require liners to prevent leaking.

Relative Cost

Construction costs for surface wet ponds can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that wetland unit storage cost decreases as storage volume increases (see figure). Relative to other stormwater control measures in the study, constructed wet pond unit volume costs are similar in magnitude to dry basins and wetlands, but an order of magnitude lower than bioretention. However, these costs do not consider the expense of setting aside land, which can be significant.

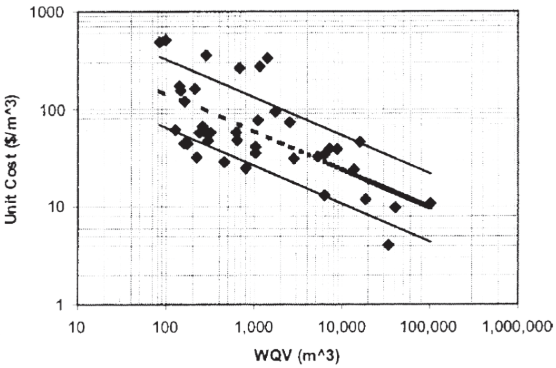


Figure 6.52 Bioretention Unit Cost of Storage.
Source: Weiss et al, 2007.

Construction costs can vary greatly pending site characteristics. However, an equation was developed to estimate the cost of extended detention wetlands prior to design (Brown and Schueler, 1997).

C = 24.5 V(0.705) Where:

C = Construction, design and permitting cost.
V = Volume needed to control the 10-year storm (ft3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. For example, the same study that provides a formula for wetlands indicates wet ponds cost approximately 20 percent less than a similarly sized wetland.

Case Study Cost

National databases or local case studies can be used to estimate costs. The 2008 Minnesota Stormwater Manual estimates that wet ponds cost from $30,000 to $60,000 per acre-foot of storage. This study projects the annual cost of routine maintenance to be approximately five percent of the construction cost and that the typical design life is longer than 20 years.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating 12 feet below existing grade at $9 per cubic yard yields a cost of $0.44 per square foot of wet pond area. Assuming this wet pond stages approximately three to four feet, the cost of storage is approximately $4,800 to $6,400 per acre foot, much less than the Minnesota manual indicates. However, these costs do not include dewatering, inlet and outlet controls, or other considerations that may have affected the Minnesota manual study.

Primary Cost Components for Wet Ponds			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Seeding	Seeding cost ($/acre) x Seeded area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2x/1 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor Cost ($/) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	
	Gate/Valve operation	Operation cost ($) x Operation frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (2x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (4x/1 yr)	

Table 6.11 Source: Minnesota Stormwater Manual Version 2, 2008.

Landscaping

Landscaping of ponds is a design element to improve both the function and aesthetics of stormwater ponds. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season. Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Eurasian water-milfoil	Myriophyllum *spicatum*
Johnson grass	Sorghum *halepense*

Maintenance

- Inlets and outlets should be kept clear of debris to prevent blocking or clogging.
- Remove trash as needed.
- Invasive and exotic species should be removed from pond banks and shelves.
- Semiannual inspection for sediment accumulation.
- Invasive and exotic species vegetation management.
- Integrity of the outfall structures.
- Inspect berms for nuisance wildlife damage.

Wet Retention and Detention Basins Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																																						
Carex annectans	Yellow fruited sedge		x		x		2-3	1.5	tan				x	x	x							x	x	x			x	x	x			x	H	12	3		L	
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x								x	x	x		x	x	x				M	12	2		L	M
Carex crinita	Fringed sedge		x		x		2-3	1.5	brown					x	x							x	x	x			x	x	x				H	12	3	U	L	
Carex muskingumensis	Palm sedge		x	x	x		2-3	1.5	tan				x	x	x	x	x					x	x	x	x		x	x	x			x	H	24	3		M	M
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x			x	x				x	H	24	3	L	L	
Juncus effusus	Soft rush	0-1	x				2-3	1.5	green									x	x	x	x	x	x				x	x	x			x	H	24	4	L	M	M
Scirpus atrovirens	Great green bullrush		x	x	x		2-3	1.5	green				x	x	x							x	x				x	x	x			x	M	12	3		L	
Scirpus cyperinus*	Wool grass		x				3-4	1.5	orange					x	x	x	x	x	x	x	x	x	x					x	x		x	x	H	24	3		M	
Forbs																																						
Asclepias incarnata	Marsh milkweed		x	x	x		2-4	2	pink							x	x	x	x			x	x				x	x		x			M	18	3	M	M	
Chelone obliqua	Rose turtlehead		x		x		3-4	2	rose/purple								x	x	x			x	x	x	x		x	x					M	12	1		M	
Equisetum hyemale	Horsetail		x	x	x		2-4	2.5	green				x	x					x	x		x	x	x			x	x			x	x	H	36	5		H	H
Helenium autumnale	Sneezeweed		x		x		3-4	2	yellow							x	x	x	x			x	x	x			x	x	x	x			M	18	3	M	M	
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x			x	x	x			x	x		x	x		H	36	5		M	M
Iris fulva	Copper iris		x	x	x		2-3	1.5	copper					x	x							x	x				x	x	x				M	12	1		M	
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x					x	x					x	x			x	H	36	4		M	M
Lobelia cardinalis	Cardinal flower		x	x	x		2-3	1.5	red							x	x	x				x	x	x	x		x	x	x	x			H	18	5	L	M	U
Mimulus ringens*	Allegehny monkey flower		x	x	x		1-2	1.5	lavender							x	x	x				x	x				x	x					M	24	1		M	
Nymphaea odorata	Fragrant water lily	1-5					1	10	white							x	x	x				x						x					H	36			H	
Pontedaria cordata	Pickeral weed	0-1	x				1-2	2.5	blue						x	x	x	x	x			x	x	x				x					M	12	4	L	L	U
Sagittaria latifolia	Arrowleaf	0-1	x				1-4	2.5	white							x	x	x				x						x	x				M	18	3	M	M	L
Saururus cernuus	Lizard tail	0-1	x				1-2	2.5	white						x	x	x	x				x	x	x	x			x					H	24			H	
Thalia dealbata	Wild canna	0-2	x				4-7	5	purple							x	x	x				x						x					H	24			M	H
Trees/Shrubs																																						
Aesculus pavia	Red buckeye		x		x		10-20	15	red			x	x									x	x	x			x	x	x				H	18	2		L	M
Cephalanthus occidentalis	Buttonbush	x	x		x		5-10	7.5	white						x	x	x					x	x	x			x	x		x			H	36	7		M	H
Quercus macrocarpa	Bur oak		x		x	x	40-60	35	green										x	x		x	x	x			x	x				x	H	36	5	H	L	H
Taxodium disticum	Bald cypress	x	x	x	x		40-60	20	orange										x	x		x	x	x			x	x			x	x	H	36	7		L	H

Figure 6.53 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Storm Water Pond Inspections and Maintenance Checklist

Site Name: ____ Owner Change since last inspection? Y N

Location: ____

Owner Name:

Address____Phone Number

Site Status: ____

Date:___________ Time: ______________ Site conditions:

Storm Water Pond Type: Wet Pond ☐ Wet ED Pond ☐ Micropool Pond ☐ Multiple Pond System ☐ Dry Pond ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels functioning, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Permanent Pool Areas (if applicable)				
Undesirable vegetation growth?	*M*			
Visible pollution?	*M*			
Shoreline erosion?	*M*			
Erosion at outfalls into pond?	*M*			
Headwalls and endwalls in good condition?	*M*			
Encroachment into pond or easement area by other activities?	*M*			
Evidence of sediment accumulation?	*A*			
Dry Pond Areas (if applicable)				
Vegetation adequate?	*M*			
Undesirable vegetation or woody plant growth?	*M*			
Excessive sedimentation?	*A*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:____

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: ____________________
(date)

Inspected by: (signature) ____
Inspected by: (printed) ____

Figure 6.54 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Dry Ponds and Extended Dry Detention Basins

Dry Ponds and Extended Dry Detention Basins

Traditional dry ponds were historically used for large storm management and located at the end of a piped collection system with little or no pretreatment. These types of basins were normally turfed, dry, fitted with a low flow concrete channel and viewed as providing little water quality benefit relative to other stormwater control measures. If pollutant removal efficiency is an important consideration, then dry detention ponds may not be the most appropriate choice. If water quality treatment is a goal of dry detention basin design and construction, a wet or extended stormwater pond design should be incorporated. If dry ponds are used, they should be used in conjunction with other practices, as part of an overall treatment series; they should include enhancements such as a sediment forebay, extended storage, a micropool at the outlet, a long shape to minimize short-circuiting or a combination of these features. Effectiveness of dry ponds varies significantly depending on design, incorporation of companion water quality practices and maintenance.

Figure 6.55 Detention basin with concrete conveyance channel.
Source: Metropolitan St. Louis Sewer District

Wet and dry ponds perform very differently (see the International BMP Database; dry ponds are not very effective pollutant control devices (low to medium), while wet ponds are usually highly effective for particulate bound pollutants. Both can be the most effective control for energy reductions though (needed for habitat protection), to balance the flow-duration distribution for a site (after upland infiltration).

Green Infrastructure Application Strategy and Design Issues

Green infrastructure application strategies may include:

- Stormwater control measures constructed upstream to filter sediment and other pollutants so that the dry retention basin need only serve to manage peak rates of discharge.
- Installing "micro-stormwater control measures" such as constructed wetlands or wet pond micropools near inlets and outlets within dry basins to sequester sediment and improve pollutant removal.
- Constructing vegetated micro-stormwater control measures such as swales, rain gardens or filter strips to manage smaller storms around the perimeter of the dry basin. Larger, infrequent storms may stage into the remainder of the dry basin, making it available for recreational use in all but severe storm events. This practice is similar to many municipal parks located within the 100-year floodplain or other intermittently flooded area.

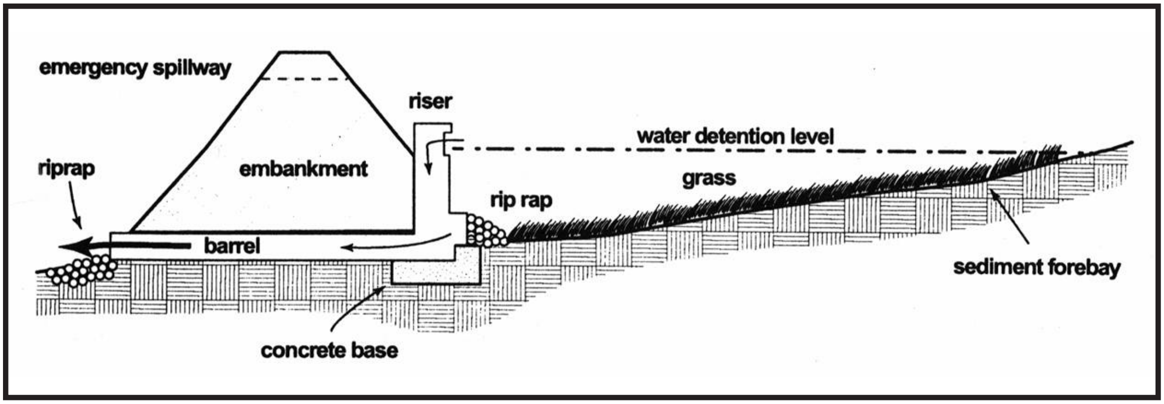


Figure 6.56 Example profile view of a dry pond design. Source: EPA Dry Detention Pond fact sheet.
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=67&minmeasure=5

- Installing soil amendments and underdrains to incorporate many of the biofiltration benefits of bioretention areas into a dry basin design.
- Dry detention basins can be constructed as long linear features that can store, treat and convey runoff. Linear stormwater control measure practices can greatly reduce grading and stormwater pipe requirements while improving pedestrian greenway connectivity.

Benefits

- Potential for significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation, soil absorption and biogeochemical activity in the soil column. Vegetation in the micro-stormwater control measures within the basin can filter and help prevent resuspension of sediment.
- Dry basins can be low to high maintenance, depending on the aesthetic requirements of the landscape or the overloading of sediments from neighboring construction projects. Relevant to upland ornamental landscapes, a mature dry basin area is generally more resistant to colonization by upland nuisance weeds, better adapted to thrive in saturated and flooded conditions and more tolerant to droughts.
- In some cases, where soil conditions allow, it can provide retention to help improve groundwater recharge and mimic predevelopment surface runoff volumes.

Figure 6.57 Dry detention basin. Source: ABC's of BMP's, LLC

- Can decrease downstream channel erosion and reduce peak runoff rates from large storm events.
- Can provide passive or active recreation open space opportunities.
- Can be among the most cost effective approaches to runoff management.

Limitations

(Minnesota, 2008)

- Limited monitoring data are available and field longevity is not well documented.
- Failure can occur due to improper siting, design, construction and maintenance.
- Systems are susceptible to clogging by sediment and organic debris.
- There is a risk of groundwater contamination depending on subsurface conditions, land use and aquifer susceptibility.
- They are not ideal for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads.
- They are not recommended for areas with steep slopes.

Even though there are potential pollution and physical clogging problems with infiltration, it is one of the most important elements in the stormwater runoff treatment train. Fear of the limitations should not prevent well designed systems from being used.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

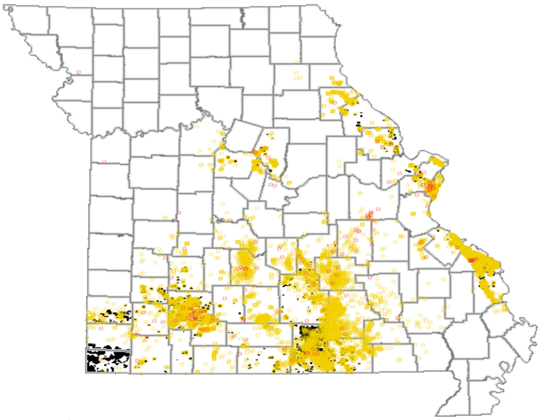


Figure 6.58 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

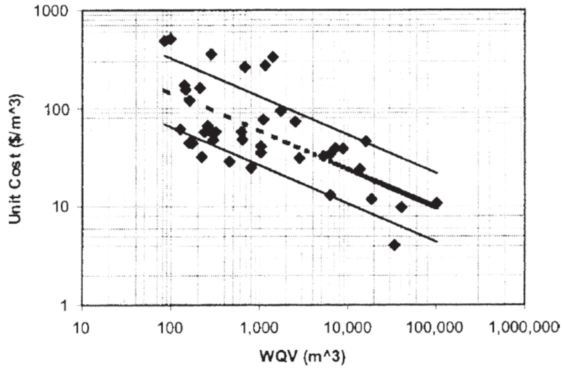


Figure 6.59 Dry detention unit cost of storage.
Source: Weiss et al. 2007

Relative Cost

Construction costs for dry basins can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that dry basin unit storage cost decreases as storage volume increases (see Figure 6.59). Relative to other stormwater control measures in the study, dry basin unit volume costs were similar to constructed wetlands and wet ponds, but an order of magnitude lower than bioretention or infiltration trenches. However, these costs do not include the cost to set aside the larger area of land required to construct a pond.

Another study developed an equation to estimate the cost of dry detention prior to design (Brown and Schueler, 1997):

C = 12.4V(0.76) where:

C = Construction, design and permitting cost.
V = Volume needed to control the 10-year storm (ft^3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. The above formula yields a value of approximately $42,000 per acre-foot of volume.

In a comparative study shown in Table 6.13, results indicate that dry detention basins are among the most inexpensive stormwater control measures to maintain; however, dry basins designed for infiltration may require slightly more maintenance. This assumes the basin is not inundated with neighboring construction runoff.

Annual O&M as a Percent of Construction Cost

Stormwater Control Measure	EPA, 1999	Weiss, 2007
Retention basins and constructed wetlands.	3-6%	Not reported.
Detention basins	<1%	1.8-2.7%
Constructed wetlands	2%	4-14.1%
Infiltration trench	5-20%	5.1-126%
Sand filters	11-13%	0.9-9.5%
Swales	5-7%	4.0-178%
Bioretention	5-7%	0.7-10.9%
Filter strips	$320/acre (maintained)	Not reported
Wet Ponds	Not reported	1.9-10.2%

Table 6.12 Source: Weiss et al. 2007

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, mass excavating five feet below existing grade at $6,000 per acre foot, and installing turf or native seed at $4,000 per acre, yields a cost of $34,000 per acre. Assuming this dry basin area stages approximately three to four feet, a simplified cost of storage is approximately $9,000 to $11,000 per acre foot.

Infiltration Practices Cost Components			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Infiltration area protection	Silt fence cost ($/ft.) x Perimeter of infiltration area	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Vault structure (for underground infiltration)	$/Structure	Pipes, catch basins, manholes, valves.
	Media (for infiltration trenches)	Media cost ($/cubic yd.) x filter volume (cubic yd.)	
	Geotextile	Geotextile cost ($/cubic yd.) x area of trench, including walls	
	Inlet structure	$/Structure	
	Overflow structure	$/Structure	
	Observation well	$/Structure	
Site Restoration	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Filter strip	Sod cost ($/sq. ft) x filter strip	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	Vegetation maintenance, cleaning of structures.
	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/2 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (6x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (6x/1 yr)	

Table 6.13 Source: Minnesota Stormwater Manual Version 2, 2008.

Figure 6.60 Dry Detention- Shelbyville, IN.
Source: William Creek Consulting.

Landscaping

Landscaping of dry detention can improve both the function and aesthetics. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

In general plant roots improve the permeability of the soil mixture (Lucas and Greenway, 2007). Vegetation roots can penetrate confining layers, open up soil structure and promotes the formation of macropores. The beneficial effects of native plants on infiltration rates is reported to persist even in depositional situations where sediments accumulates. The Lucas and Greenway study concludes that native vegetation can result in infiltration rates several orders of magnitude higher than predicted by underlying soil properties.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Johnson Grass	Sorghum *halepense*

Permits

Review local requirements for site grading, erosion and sediment control and potential invasive vegetation.

Maintenance

- Semi-annual inspection of erosion on banks and near inlets and outlets.
- Annual monitoring of sediment accumulation near inlets.
- Invasive species control.
- Outlet inspection and clearing.
- Repair of damaged vegetation or embankments as needed.
- Where dry basins are used as a construction phase best management practice, they must be rehabilitated to design conditions prior to serving as a post-construction stormwater control measure.

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D
Grasses/Sedges																					
Andropogon virginicus	Broomsedge			x		x	1-2	1.5	orange								x	x	x	x	x
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan							x	x	x	x	x	
Carex muskingumensis	Palm sedge		x	x	x		1-2	1.5	tan					x	x	x	x				
Carex praegracilis*	Tollway sedge		x		x	x	1-2	2	tan				x	x	x						
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x					
Panicum virgatum	Switchgrass			x	x	x	3-6	2.5	pink	x	x					x	x	x	x	x	x
Schizachyrium scoparium	Little bluestem			x		x	2-4	1.5	bronze								x	x	x	x	x
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan								x	x	x	x	x
Forbs																					
Asclepias tuberosa	Butterfly milkweed			x		x	1-2	1.5	orange						x	x	x				
Baptisia australis	Blue wild indigo						3-4	3-4	blue					x	x						
Blephilia ciliata	Ohio horsemint					x	1-2	1.5	pink				x	x							
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow			x	x	x							
Echinacea purpurea	Purple coneflower					x	2-3	1.5	t. purple						x	x	x				
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green						x	x	x	x			
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white							x	x	x			
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow						x	x	x				
Rudbeckia subtomentosa	Sweet coneflower				x	x	3-4	2	yellow						x	x	x	x			
Scutellaria incana	Hoary skullcap				x		2-3	2	blue						x	x	x				
Solidago rigida	Stiff goldenrod				x	x	3-5	1.5	yellow								x	x			
Verbesina helianthoides	Yellow wingstem			x	x	x	2-3	1.5	yellow						x	x					
Zizia aurea	Golden alexander					x	1-3	1.5	yellow				x	x							
Trees/Shrubs																					
Cornus florida	Flowering dogwood			x	x	x	10-20	15	white			x	x					x	x	x	x
Diospyros virginiana	Persimmon			x	x	x	30-40	20	orange				x	x				x	x	x	
Ostrya virginiana	Hophornbeam				x	x	20-30	20	green									x	x		
Quercus muhlenbergii	Chinquapin oak				x	x	40-50	35	green									x	x		

Latin Name	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																	
Andropogon virginicus	x				x			x		x	x	L		1		M	L
Bouteloua curtipendula	x				x	x		x			x	L		1		L	L
Carex muskingumensis	x	x	x	x	x	x	x	x				H	24	3+		M	H
Carex praegracilis*	x	x			x	x	x	x				H	12	2	H	H	H
Carex vulpinoidea	x	x	x			x	x					H	24	3+	L	L	H
Panicum virgatum	x	x	x			x	x	x		x		M	12	2	M	M	M
Schizachyrium scoparium	x				x	x		x		x	x	L	12	1	M	L	L
Sporobolus heterolepis	x				x	x		x			x	L				L	
Forbs																	
Asclepias tuberosa	x				x	x			x			L			V	M	
Baptisia australis	x	x	x		x	x			x			L				M	
Blephilia ciliata		x	x	x	x	x			x		x	L					
Coreopsis lanceolata	x	x			x	x			x			L		1		L	
Echinacea purpurea		x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	x				x	x			x		x	M	12	2	M	L	
Pycnanthemum tenuifolium	x	x	x		x	x						L		1		M	
Ratibida pinnata	x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia subtomentosa	x	x				x	x		x		x	H	12	2		M	
Scutellaria incana			x	x	x	x			x			L					L
Solidago rigida	x					x					x	L	12	2	M	H	L
Verbesina helianthoides	x	x	x		x	x		x	x							M	
Zizia aurea	x	x	x			x			x			H	12	1	M	H	U
Trees/Shrubs																	
Cornus florida		x	x	x	x	x		x		x	x	L			L	L	L
Diospyros virginiana	x	x	x		x	x		x		x	x	M	12	1		M	M
Ostrya virginiana		x	x	x	x	x						L				L	L
Quercus muhlenbergii		x	x	x	x	x					x	L			H	L	L

Figure 6.61 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Storm Water Pond Inspections and Maintenance Checklist

Site Name: ____ Owner Change since last inspection? Y N

Location: ____

Owner Name:

Address____Phone Number

Site Status: ____

Date:___________ Time: ______________ Site conditions:

Storm Water Pond Type: Wet Pond ☐ Wet ED Pond ☐ Micropool Pond ☐ Multiple Pond System ☐ Dry Pond ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels functioning, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Outlet/Overflow Spillway				
In good condition?	A			
Any evidence of erosion?				
Any evidence of blockages?	A			
Has facility been filled or blocked inappropriately?	A			

Inspector Comments:____

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: ________________
(date)

Inspected by: (signature) ______________________________
Inspected by: (printed) ______________________________

Figure 6.62 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Stormwater Wetlands

Constructed Stormwater Wetlands

Stormwater wetlands are adaptable to small or large storm management and can be designed with or without extended detention controls. Stormwater wetlands can be designed to retain, detain or treat runoff by mimicking the functions and values of natural wetlands. Wetlands provide both aerobic and anaerobic conditions that help degrade hydrocarbons, retain sediment and metals and reduce colonization opportunities for nuisance weeds. Wetlands also manage annual volume through infiltration, increase biodiversity of both flora and fauna and can control peak runoff rates during large storms. Five variants in wetland design include:

1. Shallow Marsh Wetland has different areas of terrestrial, emergent and submergent vegetation. Deep micropools may be located at inlets to manage sediments and at outlets to help with thermal pollution.

2. Pond/Wetland Systems are combinations of deep open water areas and wetland shelves. This combination can share the advantages of both systems.

3. Extended Detention Shallow Wetland includes a multiple orifice outlet to provide extended detention of small storms. Designers need to consider drawdown times when selecting vegetation.

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			■
Nitrogen		■	
Phosphorous	■	■	
Metals		■	■
Bacteriological		■	■
Hydrocarbons			■

Table 6.14 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

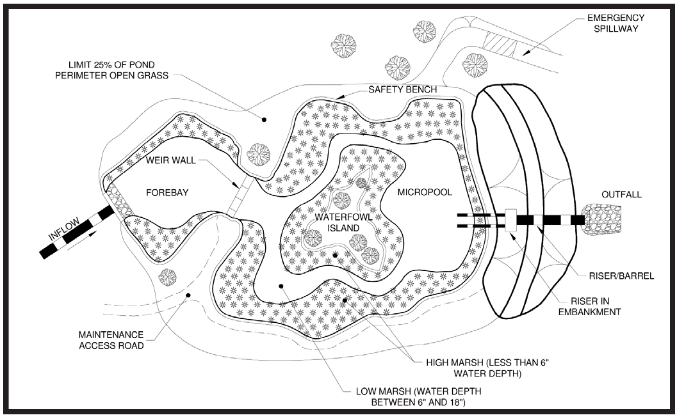


Figure 6.63 Constructed stormwater wetland.
Source: Center for Watershed Protection

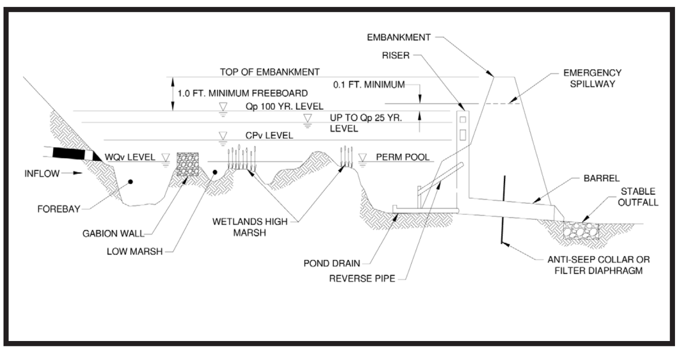


Figure 6.64 Constructed stormwater wetland.
Source: Center for Watershed Protection

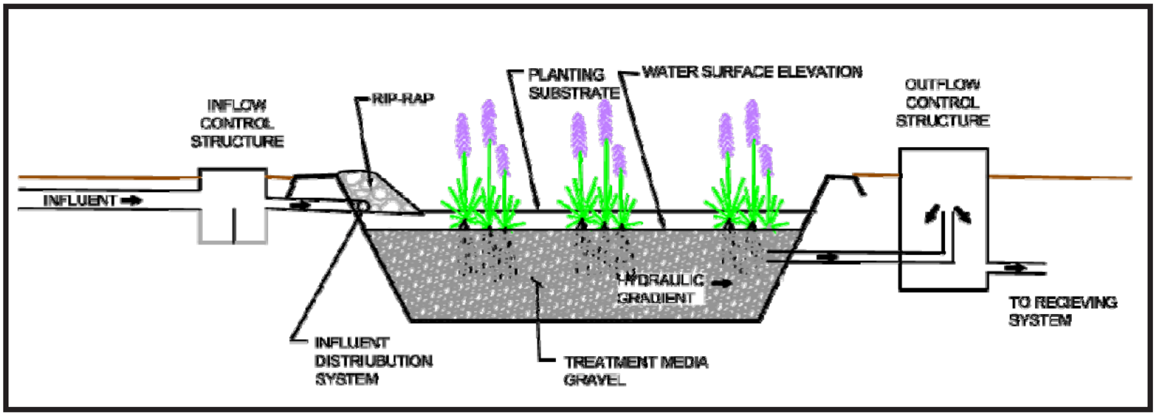


Figure 6.65 Source: Maryland Design Manual Chapter 5 (2009).

4. **Submerged Gravel Wetlands** are one or more treatment cells backfilled with gravel that allow stormwater to flow subsurface through the root zone of the vegetation. This is beneficial in areas where vector control is an issue, such as urban areas.

5. **Pocket Wetland** is intended for smaller drainage areas of two to ten acres and typically requires excavation down to the water table for a reliable water source to support the wetland system.

Green Infrastructure Application Strategy

Surface stormwater wetlands can provide stormwater control, public education and recreation opportunities and increased habitat value. A type of wetland green infrastructure strategy is to retrofit stormwater control measures by installing wetland plants in the low, frequently inundated areas of dry basins or along the shelves of wet ponds.

Surface stormwater wetlands are also well suited to regional stormwater management applications. The large footprint of regional basins create opportunities for trails, observation decks and other amenities to allow the public to take advantage of the many wildlife features found in a large diverse wetland.

Submerged gravel wetlands function as water quality treatment through filtering in highly urbanized sites with space restrictions.

Benefits

- Surface wetlands provide significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by wetland vegetation, algae and bacterial. Vegetation filters and helps prevent resuspension of sediment. Volatilization and chemical break down of other stormwater contaminants such as hydrocarbons also occurs.
- Wetland vegetation is low maintenance, resists colonization by upland nuisance weeds, is adapted to thrive in saturated and flooded conditions and can be drought tolerant once established.
- Submerged gravel wetlands provide for the opportunity to treat stormwater runoff in areas with space limitation such as highly urbanized sites.

- Surface wetlands can provide both retention and detention to help improve groundwater recharge, decrease downstream channel erosion and reduce peak runoff rates.
- Can increase biodiversity relative to other centralized stormwater control measures such as dry detention or wet ponds.
- Surface wetlands do not suffer seasonal maintenance issues such as wet pond spring or fall algae blooms or dry basin mowing.
- Surface wetlands can provide aesthetic and recreational value.
- Surface wetlands provide aquatic habitat and long term sediment storage without the drowning safety risks associated with wet ponds.
- Provides public outreach opportunities.

Siting Considerations for Surface Flow Constructed Wetlands

- Large areas are recommended, but not necessary, for surface constructed wetlands. Large wetlands provide greater opportunity for large storm management and increased habitat value. Smaller or "pocket wetlands" provide many of the same benefits as bioretention but may not significantly reduce runoff volume (by infiltration).
- Loamy soils are preferred, but not necessary, for most wetland plants. Alternate species may be needed for "drier" wetlands, and live plant material may be needed in lieu of seed in "tight" soils in order to help ensure propagation.
- Surface constructed wetland bottoms should not be flat. Microtopography helps encourage biodiversity, which helps create a more resilient plant community. To help ensure long-term diversity and performance under varying climate conditions (droughts to very wet years), a wetland can be designed with four zones:
    - Open water zone: Greater than 18 inches deep, this zone can be planted with submergent species and help provide long term sediment storage.
    - Low marsh zone: 6 to 18 inches deep, this zone is suitable for emergent wetland plant species, provides substrate for biological activity on plant stems.
    - High marsh zone: Up to 6 inches deep, this zone will support a greater density and diversity of wetland species than the low marsh zone.
- Semi-wet zone: Areas above the permanent pool that are inundated during frequent small storms can be planted with wet-mesic or mesic species pending the depth, duration and frequency of inundation to help stabilize banks at the normal pool water line.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in Karstic geographic regions.

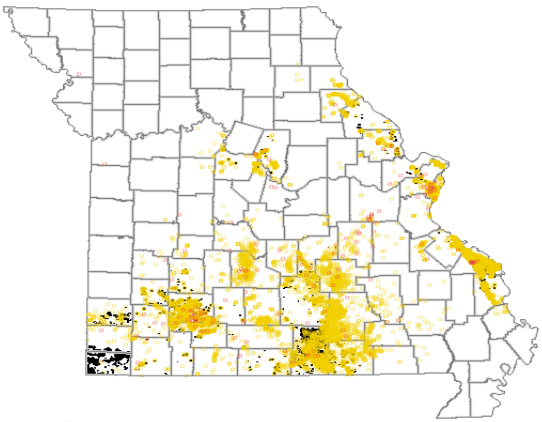


Figure 6.66 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Relative Cost

Construction costs for surface wetlands can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that wetland unit storage cost decreases as storage volume increases (see figure). Relative to other stormwater control measures in the study, constructed wetlands unit volume costs are similar in magnitude to dry basins and wet ponds, but an order of magnitude lower than bioretention.

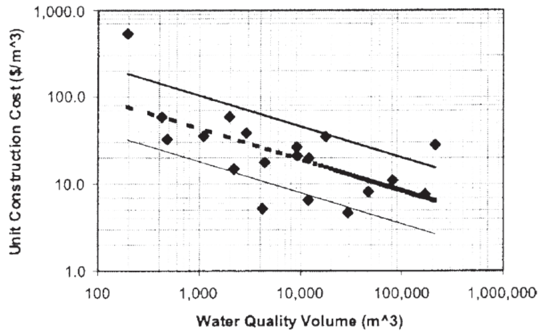


Figure 6.67 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

C = 30.6V(0.705) where:

C = Construction, design and permitting cost.
V = Wetland volume needed to control the 10-yr storm (ft3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. For example, the same study provides a formula for wet pond cost that indicates wetlands cost approximately 25 percent more than a similarly sized wet pond.

Case Study Cost

National databases or local case studies can be used to estimate costs. The 2008 Minnesota Stormwater Manual estimates that constructed wetlands cost from $30,000 to $60,000 per acre-foot of storage. This study projects the annual cost of routine maintenance to be approximately 5 percent of the construction cost and the typical design life is longer than 20 years. These costs do not include the cost of land, which can be extensive.

Primary Cost Components for Surface Stormwater Wetlands			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/2 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor cost ($/hr) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	
	Erosion repair	Repair cost ($/acre) x Affected area	
	Gate/Valve operation	Operation cost ($) x Operation frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (6x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (6x/1 yr)	

Table 6.15 Source: Minnesota Stormwater Manual Version 2, 2008.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating three feet below existing grade at $9 per cubic yard and installing live wetland plugs on two foot centers at $4 each, yields a cost of $2 per square foot of wetland. Assuming this wetland stages approximately 1.5 to three per acre-foot, the cost of storage is approximately $30,000 to $60,000 per acre foot of storage (similar to the Minnesota study previously discussed).

For comparison, a submerged gravel wetland has similar excavation and planting requirements ($2 per square foot), but costs an additional $2 per square foot for a liner and $3 per square foot for gravel and can only store one cubic foot per square foot below its surface. These values yield a cost of storage of approximately $300,000 per acre foot (five to ten times greater than a surface flow wetland.

Permits

Review local requirements for site grading, drainage structures, erosion and sediment control, vector control and potential invasive vegetation.

Landscaping

Landscaping of wetlands is a critical design element to improve both the function and aesthetics of stormwater wetlands. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants, which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland: Plants, which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants, which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland: Plants, which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants, which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season. Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Eurasian water-milfoil	Myriophyllum *spicatum*
Johnson Grass	Sorghum *halepense*

Maintenance

- Sediment should be removed as needed near inlets and outlets to prevent blocking or clogging.
- Outlet structure should be kept free of debris to prevent blocking.
- Remove trash as needed.
- Invasive and exotic species should be removed.
- Inspect berms for nuisance wildlife damage.
- Inspect berms for erosion.

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D
Grasses/Sedges																					
Carex annectans	Yellow fruited sedge		x		x		2-3	1.5	tan				x	x	x						
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x						
Carex crinita	Fringed sedge		x		x		2-3	1.5	brown					x	x						
Carex muskingumensis	Palm sedge		x	x	x		2-3	1.5	tan				x	x	x	x	x				
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x					
Juncus effusus	Soft rush	0-1	x				2-3	1.5	green									x	x	x	x
Scirpus atrovirens	Great green bullrush		x	x	x		2-3	1.5	green				x	x	x						
Scirpus cyperinus*	Wool grass		x				3-4	1.5	orange					x	x	x	x	x	x	x	x
Forbs																					
Asclepias incarnata	Marsh milkweed		x	x	x		2-4	2	pink							x	x	x	x		
Chelone obliqua	Rose turtlehead		x		x		3-4	2	rose/purple								x	x	x		
Equisetum hyemale	Horsetail		x	x	x		2-4	2.5	green				x	x					x	x	
Helenium autumnale	Sneezeweed		x		x		3-4	2	yellow							x	x	x	x		
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x		
Iris fulva	Copper iris		x	x	x		2-3	1.5	copper					x	x						
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x				
Lobelia cardinalis	Cardinal flower		x	x	x		2-3	1.5	red							x	x	x			
Mimulus ringens*	Allegheny monkey flower		x	x	x		1-2	1.5	lavender							x	x	x			
Nymphaea odorata	Fragrant water lily	1-5					1	10	white							x	x	x			
Pontedaria cordata	Pickeral weed	0-1	x				1-2	2.5	blue						x	x	x	x	x		
Sagittaria latifolia	Arrowleaf	0-1	x				1-4	2.5	white							x	x	x			
Saururus cernuus	Lizard tail	0-1	x				1-2	2.5	white						x	x	x	x			
Thalia dealbata	Wild canna	0-2	x				4-7	5	purple							x	x	x			
Trees/Shrubs																					
Aesculus pavia	Red buckeye		x		x		10-20	15	red			x	x								
Cephalanthus occidentalis	Buttonbush	x	x		x		5-10	7.5	white						x	x	x				
Quercus macrocarpa	Bur oak		x		x	x	40-60	35	green										x	x	
Taxodium disticum	Bald cypress	x	x	x	x		40-60	20	orange										x	x	

Latin Name	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																	
Carex annectans	x	x	x			x	x	x			x	H	12	3		L	
Carex grayi		x	x	x		x	x	x				M	12	2		L	M
Carex crinita	x	x	x			x	x	x				H	12	3	U	L	
Carex muskingumensis	x	x	x	x		x	x	x			x	H	24	3		M	M
Carex vulpinoidea	x	x	x			x	x				x	H	24	3	L	L	
Juncus effusus	x	x				x	x	x			x	H	24	4	L	M	M
Scirpus atrovirens	x	x				x	x	x			x	M	12	3		L	
Scirpus cyperinus*	x	x					x	x		x	x	H	24	3		M	
Forbs																	
Asclepias incarnata	x	x				x	x		x			M	18	3	M	M	
Chelone obliqua	x	x	x	x		x	x					M	12	1		M	
Equisetum hyemale	x	x	x			x	x			x	x	H	36	5		H	H
Helenium autumnale	x	x	x			x	x	x	x			M	18	3	M	M	
Hibiscus lasiocarpos	x	x	x			x	x		x	x		H	36	5		M	M
Iris fulva	x	x				x	x	x				M	12	1		M	
Iris virginica	x	x					x	x			x	H	36	4		M	M
Lobelia cardinalis	x	x	x	x		x	x	x	x			H	18	5	L	M	U
Mimulus ringens*	x	x				x	x					M	24	1		M	
Nymphaea odorata	x						x					H	36			H	
Pontedaria cordata	x	x	x				x					M	12	4	L	L	U
Sagittaria latifolia	x						x	x				M	18	3	M	M	L
Saururus cernuus	x	x	x	x			x					H	24			H	
Thalia dealbata	x						x					H	24			M	H
Trees/Shrubs																	
Aesculus pavia	x	x	x			x	x	x				H	18	2		L	M
Cephalanthus occidentalis	x	x	x			x	x		x			H	36	7		M	H
Quercus macrocarpa	x	x	x			x	x				x	H	36	5	H	L	H
Taxodium disticum	x	x	x			x	x			x	x	H	36	7		L	H

Figure 6.68 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Constructed Wetlands Inspections and Maintenance Checklist

Site Name: ______________________________ Owner Change since last inspection? Y N

Location: ______________________________

Owner Name: ______________________________

Address______________________________Phone Number ______________

Site Status: ______________________________

Date:__________ Time: ___________ Site conditions:

Constructed Wetland Type: ED Wetland ☐ Pocket Wetland ☐ Wetland ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels function, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Constructed Wetland Ponding Areas				
Wetland vegetation present and healthy?	*M*			
Vegetation removal needed?	*A/M*			
Floatable debris removal needed?	*M*			
Visible pollution?	*M*			
Shoreline problem?	*M*			
Erosion at outfalls into pond?	*M*			
Headwalls and endwalls in good condition?	*M*			
Encroachment into pond or easement area?	*M*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:____

____

____

____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: ________________
(date)

Inspected by: (signature) ____________________________
Inspected by: (printed) ____________________________

Figure 6.69 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

A Appendix A- Glossary

Alluvium: sediment deposited by streams and rivers in the stream channel and floodplain areas.

Baffle boxes: underground retention systems designed to remove settleable solids. There are several water quality inlet designs but most contain one to three chambers. The first chamber provides removal of coarse particles; the second chamber provides separation of oil, grease, and gasoline; and the third chamber provides safety relief if blockage occurs. Frequent maintenance and disposal of trapped residuals and hydrocarbons are necessary for these devices to continuously and effectively remove pollutants.

Best Management Practice (BMP): stormwater management practice used during construction to prevent or control the discharge of pollutants and minimize runoff to waterways. BMPs may include structural or non-structural solutions, a schedule of activities, prohibition of practices, maintenance procedures, or other management practices.

Bioretention: small engineered and landscaped basins intended to provide water quality management by filtering stormwater runoff before release into stormdrain systems.

Biogeochemical: the chemical exchanges between living and no-living ecosystem components.

Bioswale: an open vegetated channel with an engineered soil matrix and underdrain system designed to filter runoff.

Catch basin inserts: catch basin inserts consist of a frame that fits below the inlet grate of a catch basin and can be fitted with various trays that target specific pollutants. Typically the frame and trays are made of stainless steel, cast iron, or aluminum to resist corrosion. The device is typically designed to accept the design flow rate of the inlet grate with bypasses as the trays become clogged with debris.

Charrette: a rapid, intensive, and creative work session, usually lasting a week or more, in which a design team focuses on a particular design problem [with diverse goals] to arrive at a collaborative solution. Charrettes are product-oriented. The public charrette is fast becoming a preferred way to face the planning challenges confronting American cities. (Source: University of Georgia's College of Environment and Design)

Clean Water Act: legislation passed by the U.S. Congress in 1971 that regulates the discharge of pollutants into surface and groundwater (streams, rivers, lakes, estuaries, oceans, aquifers). The regulations cover point source or end-of-pipe discharges and nonpoint source discharges primarily from stormwater runoff.

Combined Sewer Overflow (CSO): overflow or bypass of wastewater from a sewage collection system that conveys both wastewater and stormwater and is piped to a wastewater treatment plant. Generally located in older sections of cities; this was the standard practice during the early and mid 1900s.

Comprehensive Land Use Plan: guiding document for a community that sets the vision and goals for future actions. Some states require communities to develop comprehensive plans to guide future land use, economic development, and budget expenditures. Land use regulations are often outlined in the plan for development to achieve continuity, quality, economic, industrial and residential goals. A planning and zoning map is usually part of the plan, showing where each type of development or land use can be built within the community.

Detention Storage: the volume occupied by water below the level of the emergency spillway crest during operation of a stormwater detention facility.

Dry Well: a subsurface storage facility that receives and temporarily stores stormwater runoff from rooftops, discharging through infiltration into surrounding soils.

Emergency Spillway: a device or devices for discharging water when inflow exceeds designed outflow from a detention facility. The emergency spillway can prevent damage to the detention facility from sudden release of impounded water.

Erosion and Sediment Control (ESC): tools and methods that manage or abate the erosion of soil from bare surfaces during construction.

Evapotranspiration: the water lost to the atmosphere by two processes-overall evaporation and plant transpiration. Evaporation is the loss of moisture from lakes and reservoirs, wetlands, soil, and snow cover; transpiration is the loss from living-plant surfaces.

Extended Dry Detention Basin: any detention facility, vegetated with native plants, designed to permit no permanent impoundment of water but designed to detain the water quality volume for 40 hours.

Extended Detention Wetland: a land area that is permanently wet or periodically flooded by surface or groundwater, and has developed hydric soil properties that support vegetation growth under saturated soil conditions. It may have been engineered with adequate capacity to detain large storm flows.

Extended Wet Detention Basin: any detention facility designed to include a permanent pool and designed to detain the water quality volume for 40 hours.

Filter Strip: a grassed area that accepts sheet flow runoff from adjacent surfaces. It slows runoff velocities and filters out sediment and other pollutants. Filter strips may be used to treat shallow, concentrated, and evenly distributed storm flows.

First Flush: the initial runoff (after a dry spell) from a storm or snowmelt event that commonly contains elevated pollutant concentrations. Often the first flush contains most of the pollutants in drainage waters produced by the storm event.

Floodplain: a relatively level surface that is submerged during times of flooding. Located at either side of a waterway, it is composed of stratified alluvial soils built up by silt and sand carried out of the main channel. Activities within floodplains are often regulated by the Federal Emergency Management Agency (FEMA) or other regulatory agency.

Forebay: a storage basin upstream from the inlet to a larger storage basin designed to capture and settle sediments.

Frost Penetration: The layer of soil that freezes during winter season often defined as the frost penetration depth. The depth of soil at which the earth will freeze and swell. This depth varies in different parts of the country. For example, see Missouri River Basin Depth of Frost Penetration Map. National Weather Service River Forecast Center National Oceanic and Atmospheric Administration (NOAA.) http://www.crh.noaa.gov/mbrfc/?n=frost For frost depth calculation example, visit http://www.pavementinteractive.org/article/Calculation-of-Frost-Depth/

GIS: Geographical Information System: an electronic system for storing and arranging data, often used to generate layers of informative maps.

Green Infrastructure: systems and practices that use or mimic natural processes to infiltrate, evapotranspirate, or reuse stormwater or runoff on the site where it is generated. It is an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations. As a stormwater treatment approach, green infrastructure uses natural and engineered systems to cleanse water and reduce excess volumes by filtering and treating using plants, soils, and microbes.

Groundwater Mounding: commonly, an outward and upward expansion of the free water table caused by shallow re-injection, percolation below an impoundment, or other surface recharge method (essentially, the reverse of the core of depression effect created by a pumping well.) Mounding can alter groundwater flow rates and direction; however the effects are usually localized and may be temporary, depending upon the frequency and duration of the surface recharge events. (Alabama State Water Program.)

Hydrodynamic Devices: hydrodynamic devices are engineered systems with an internal component that creates a swirling motion as runoff flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as runoff moves in this swirling path. Typically these devices are prefabricated and come in a range of sizes targeted at specific flow rates. Maintenance requirements include the periodic removal of oil, greases, and sediments, typically by using a vacuum truck.

Hydorphitic: water loving.

Hydrologic Soil Group (HSG): Natural Resources Conservation Service soil grouping according to minimum infiltration rate, or the capacity of soil (absent vegetation) to permit infiltration. Soils are grouped from HSG A (greatest infiltration and least runoff) to D (least infiltration and greatest runoff).

Impact Stilling Basin: a pool placed below an outlet spillway and designed for reducing discharge energies in order to minimize downstream erosive effects.

Impervious Surface: natural or manmade ground surfaces that are hard and cannot be readily penetrated by water and other fluids. Natural ground surfaces that are compacted from human or equipment traffic result in an impervious surface.

Infiltration: percolation of water into the ground.

Infiltration Basins: earthen structures that capture a certain stormwater runoff volume, hold this volume, and infiltrate it into the ground over a period of days.

Infiltration Practices: a system allowing percolation of water into the subsurface of the soil. This may recharge shallow or deep groundwater. Basins or trenches may serve as key components of this system.

Infiltration Trench: small, excavated trenches filled with coarse granular material; they collect first flush runoff for temporary storage and infiltration.

Karst Geology: a specific terrain where weathering of the bedrock has created solution cavities allowing interconnection between subsurface and surface drainage ways (8).

Leadership in Energy and Environmental Design (LEED): an internationally recognized certification system that measures how well a building or community performs across all the metrics that matter most: energy savings, water efficiency, carbon dioxide emission reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts. LEED addresses stormwater management through water efficiency, stewardship of resources and sensitivity to their impacts.

Level of Service: the level of water quality protection recommended for a development or provided by a post development stormwater management system. The level of service requirement for the development is determined by the change in runoff from the predevelopment condition. The level of service provided by the stormwater management system is determined by a combination of detention and water quality treatment.

Level Spreader: a structural practice of redistributing concentrated flows to sheet flow over a wide area to minimize erosive velocities and increase infiltration and treatment potential.

Low Impact Development (LID): a set of approaches and practices designed to reduce runoff of water and pollutants from the site at which they are generated. It is the application of techniques that are modeled after nature: manage rainfall by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source.

Media Filtration Practices: suitable only for runoff from highly impervious stabilized areas, these filters consist of a pretreatment area or chamber in conjunction with a self-contained bed of media (i.e. sand) used to treat wastewater or diverted stormwater runoff. The water subsequently is collected in underground pipes for additional treatment or discharge.

Municipal Separate Storm Sewer System (MS4): separate collection systems for wastewater and stormwater used by municipalities, local governments, and local entities to manage wastewater.

Native Soil and Vegetation Preservation: the practice of preserving land areas containing soil profiles and vegetation that have adapted to the climate, hydrology and ecology of the area to minimize the impacts of development.

Native Vegetation: this term refers to plant types historically located in this geographic area as part of the tall grass prairie, riparian woodland, and oak-hickory forest plant communities. These plant species have not undergone change or improvement by humans, and are still found growing in uncultivated or relatively undisturbed areas within this region. Due to their historic presence, these plant species are extremely well adapted to the climate and natural disturbances (e.g., fire, grazing, and flooding) of the region.

Natural Channel: any river, creek, channel, or drainageway that has an alignment, bed and bank materials, profile, bed configuration, and channel shape predominately formed by the action of moving water, sediment migration, and biological activity. The natural channel's form results from regional geology, geography, ecology and climate.

National Pollutant Discharge Elimination System (NPDES): defined in Section 402 of the Clean Water Act, this provides for the permit system that is key for enforcing the effluent limitations and water quality standards of the Act. The Phase II Final Rule published in the Federal Register on Dec. 8, 1999 requires NPDES permit coverage for stormwater discharges from certain regulated, small, municipal separate storm sewer systems (MS4s) and from land areas greater than 1 acre disturbed by construction.

Native Vegetation Swale: native grasses and forbes planted in a swale to reduce velocity of runoff and promote infiltration.

Non-structural Best Management Practice or Stormwater Control Measure: particular policies, plans, ordinances, and procedures that are not built structures.

Overlay Zoning: specific class of land use or zoning that is enforced in addition to a base zoning classification. It is often used for regulating or protecting special assets in the community, such as areas of prime habitat or conservation management.

Peak flow rate: maximum discharge measured during a precipitation event.

Pervious Pavement: a type of pavement that allows water to infiltrate the surface layer and enter into a high-void, aggregate, sub-base layer. The captured water is stored in the sub-base layer until it infiltrates the underlying soil.

Physiographic: physical and geological characteristics particular to a landscape environment.

Post-construction stormwater: management of stormwater runoff in built environments, after site development is completed. It includes retrofits of stormwater management systems during redevelopment of property.

Predevelopment: the time period prior to a proposed or actual development activity at a site. Predevelopment may refer an undeveloped site or a developed site that will be redeveloped or expanded: also referred to as pre-construction.

Proprietary Systems: configured and designed system that removes pollutants from stormwater runoff by filtering stormwater through a bed of media. One class of media is chemically inert and targets suspended solids and associated pollutants. The second class of media utilizes ion exchange or adsorption processes to remove dissolved contaminants. Proprietary systems may include baffle boxes, catch basin inserts, hydrodynamic devices, and media filtration devices.

Rain Garden: a small depression planted with native wetland and prairie vegetation where runoff collects and infiltrates, rather than a turfgrass lawn.

Riparian Corridor: strips of herbaceous and woody vegetation located parallel to perennial and intermittent streams and adjacent to open bodies of water. Riparian buffers capture sediment and other pollutants in runoff before it enters the adjoining surface waterbody.

Seasonal High Water Table: Also Seasonal High Groundwater Table: A seasonal high water table, or SHWT, is the shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (more than a few weeks) (Watts and Hurt, 1991) According to Rule 40C-42, Florida Administrative Code, the SHWT elevation means the highest level of the saturated zone in the soil in a year with normal rainfall.

State-of-the-practice: most current methods for implementing policies and practices, in this case referring to the management of stormwater runoff.

Stormwater Control Measure (SCM): permanent stormwater management practice used post-construction to prevent or control the discharge of pollutants and minimize runoff to waterways. SCMs may include structural or nonstructural solutions, a schedule of activities, prohibition of practices, maintenance procedures, or other management practices.

Stormwater Detention Facility: any structure, device, or combination thereof with a controlled discharge rate less than its inflow rate.

Stormwater Pollution Prevention Plan or SWPPP: a plan written to manage erosion and sediment runoff into drainages and streams during construction.

Stream Buffer: an area defined by regulatory agencies or municipalities for the protection of riparian corridors and floodplains.

Structural Best Management Practice or Stormwater Control Measure: refers to stormwater management structures, designed and constructed to achieve a certain goal and are permanent structures in the landscape.

Submergent Plants: plants that grow wholly or partly in water, such as water lillies or pickerel weed.

Swale: a depressed area used for stormwater conveyance or short term storage. Types of swales may include bioswales, native vegetation swales, turf grass swales, and wetland swales.

Time of Concentration: The time period necessary for surface runoff to reach the outlet of a subbasin from the hydraulically most remote point in the tributary drainage area.

Total Maximum Daily Load (TMDL): the maximum amount of a specific pollutant allowed in a water body over a 24-hour period. TMDLs are designed to limit the increase of pollutants discharged to streams with degraded water quality. Regulatory limits are established for each pollutant.

Total Suspended Solids (TSS): matter suspended in stormwater excluding litter, debris, and other gross solids exceeding one millimeter in diameter.

Treatment Train: the series of stormwater control measures (or other treatments) used to achieve biological and physical treatment efficiencies necessary for removing pollutants from stormwater (or other wastewater flows).

Tree Preservation: maintenance of existing trees and shrubs.

Turf Grass Swale: a swale designed to convey stormwater planted with turf grass. Turf grass swales are meant to be used as a substitute for closed drainage systems.

Uplands: lands elevated above the floodplain that are seldom or never inundated.

Value Rating (VR): the assumed water quality improvement value of a cover type or BMP, based on its ability to improve water quality and mitigate runoff volume.

Water Quality: the chemical, physical, and biological characteristics of water. This term also can refer to regulatory concerns about water's suitability for swimming, fishing, drinking, agriculture, industrial activity, and healthy aquatic ecosystems.

Water Quality Volume (WQv): the storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. It is calculated by multiplying the water quality storm by the volumetric runoff coefficient and site area.

Watershed: all the land area that drains to a given point (also described as a basin, catchment and drainage area).

B Appendix B - References

Association of State Floodplain Managers. (2008). NAI-No Adverse Impact Floodplain Management.
Atlanta Regional Commission. (2012). *State of Georgia Stormwater Manual.* www.georgiastormwater.com.

Bear Creek Prairie. (2011). Bear Creek Prairie Conservation Community. www.bearcreekprairie.com/ index.html.

Belan, G. and B. Otto. (September 2004). *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management*, American Rivers: www.americanrivers.org/assets/pdfs/CatchingTheRaine4a1.pdf.

Benedict, M. A., & E.T. McMahon, (2006). *Green Infrastructure: Linking Landscapes and Communities*. Island Press.

Benedict, M. A., & E.T. McMahon, *Green Infrastructure: Smart Conservation for the 21st Century*. Sprawl Watch Clearinghouse Monograph Series.

Bolt v. City of Lansing, 561 N.W.2d 423, 425-27 (Mich. App. 1997)

Bouwer, H., J.C. Lance, & M.S. Riggs, (1974). *High-rate Land Treatment: Water Quality and Economic Aspects of the Flushing Meadows Project*. Journal of the Water Pollution Control Federation 46:844-859.

Brown, K., R. Claytor, H. Holland, H.Y. Kwon, R. Winer & J. Zielinski, (2007). *Better Site Design: An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act.* Center for Watershed Protection.

Brown, W. and T. Schueler, (1997). *Economics of Stormwater Best Management Practices in the Mid-Atlantic Region*. Center for Watershed Protection, Ellicott City, MD.

Burchmore, D., H. Cyre, D. Harrison, A. Reese, S. Tucker, (January 2006). *Guidance for Municipal Stormwater Funding*, National Association of Flood and Stormwater Management Agencies: www.nafsma.org/Guidance%20Manual%20Version%20 2X.pdf.

Burgess, J. & U.I. Forester, (2005). *Tree Ordinance Development Guidebook*. Georgia Forestry Commission.

Burton, G.A, Jr., and R. Pitt. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists and Engineers.* ISBN 0-87371-924-7. CRC Press, Inc. Boca Raton, FL. 2002. 911 pages.

Center for Watershed Protection (CWP), (2008). *Managing Stormwater in Your Community, A Guide to Building an Effective Post-Contruction Program*. United States Environmental Protection Agency.

Center for Neighborhood Technology, American Rivers, (2010). *The Value of Green Infrastructure – A Guide to Recognizing Its Economic, Environmental and Social Benefits.* www.cnt.org.

Chan, A. L. (2009). *Stormwater Financing*. AMEC.

Christopher Lake Development v. St. Louis County, 35 F. 3d 1269, 1275 (8th Cir. 1994).

City of Bloomington, Illinois Engineering Department. (2006). *Storm Water Credit Manual. Bloomington*, City of Bloomington, Illinois Engineering Department.

City of Indianapolis Department of Public Works. (2003, Revised January 2006). *Stormwater Credit Manual. Indianapolis*, City of Indianapolis Department of Public Works.

City of Memphis. (2007). *Storm Water Management Manual*, City of Memphis Division of Public Works and Division of Engineering, Shelby County Public Works Department. Volume 1. Version 1. February 2007. www.memphistn.gov/pdf_forms/001-Volume1_PolicyManual.pdf

Clar, M. (1993). *Design Manual for Use of Bioretention in Stormwater Management*. Prince George's County: Engineering Technologies Associates Inc. and Biohabitats Inc.

Clar, M., E. Laramore, & H. Ryan. *Rethinking Bioretention Design Concepts*. (2007). Low Impact Development: New and Continuing Applications Proceedings of the 2nd Annual Low Impact Developmennt Conference.

Clark, C., P. Adrianes, F.B. Talbot, (2008). *Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits*. Environmental Science and Technology, (2008) 42, 2155-2161.

Committee on Reducing Stormwater Discharge Contributions to Water Pollution, National Research Council. (2009). *Urban Stormwater Management in the United States.* The National Academies Press, Washington, D. C.

Commonwealth Court of Pennsylvania. (2004, May - June). Taylor v. Harmony Township Board of Commissioners. Retrieved 2011, from http://caselaw.findlaw.com/pa-commonwealth-court/1471903.html.

Densmore et al. v. Jefferson County et al., 813 So.2d 844, 854 (Al. 2001).

EDAW, Inc. (2006.) Big Darby Accord Watershed Master Plan. http://prairietownship.org/darby/06_Appendix_Final.pdf and www.darbywatershed.com

FCM - Centre for Sustainable Community Development (2001). *Green Municipalities, A Guide to Green Infrastructure for Canadian Municipalities*. FCM - Centre for Sustainable Community Development.

Gaffin, S., C. Rosenzweig, L. Parshall, D. Beattie, R. Berghage, G. O'Keefe, D. Braman. (2005). *Energy Balance Modeling Applied to a Comparison of White and Green Roof Cooling Efficiency*. Proceedings of the 3rd Annual Greening Rooftops for Sustainable Cities Conference, May 4-6, 2005, Washington, DC.

Georgia Forestry Commission. (2004.) The Framework of Community Tree Ordinances. www.gfc.state.ga.us/communityforests/documents/FrameworkofOrdinances2004-revised.pdf

Geosyntec Consultants, Inc. and Wright Water Engineers Inc. for the International BMP Database. (June 2008). *Analysis of Treatment System Performance Overview of Performance by BMP Category and Common Pollutant Type.*
www.bmpdatabase.org/Docs/Performance%20Summary%20Cut%20Sheet%20June%202008.pdf.

Goldshore, L. and M. Wolf, (February 2004). Amendments to Stormwater Management Rules Address Water Quality and Smart Growth, 175 Nj.Lj.402.

Heaton v. City of Princeton, et al., 47 F.Supp.2d 841, 843 (W.D. Ky. 1997)

Iowa State University (2009.) *Iowa Stormwater Management Manual*. Version 3; Oct. 28, 2009. www.ctre.iastate.edu/pubs/stormwater/index.cfm

Kloss, C. and C. Crystal. (2006). *Rooftops to Rivers - Green Strategies for Controlling Stormwater and Combined Sewer Overflows*. Natural Resources Defence Council.

Lake of the Ozarks Watershed Alliance. (2011). Lake of the Ozarks Watershed Management Plan. Missouri.

Lucas, W.C. and M. Greenway. (2007). *A Study of Hydraulic Nutrient Retention Dynamics, in Vegetated and Non-Vegetated Bioretention Mesocosms*, paper Environmental and Water Resources Congress, 2007, Tampa, Florida, Environmental and Water Resources Institute, American Society of Civil Engineers, Reston, VA.

Maryland Department of the Environment: *Maryland Stormwater Design Manual,* Volumes I & II (Effective October 2000, Revised May 2009). www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/Programs/WaterPrograms/SedimentandStormwater/stormwater_design

McMahon, E. T. (2000). *Green Infrastructure*. Planning Commissioners Journal, 1-4.

McDonald (King), L, A. William, M. Benedict and K. O'Conner, (2005) *Green Infrastructure Plan Evaluation Frameworks*. Journal of Conservation Planning, Vol 1 (2005) 6-25.

Metropolitan St. Louis Sewer District (MSD), Missouri Department of Conservaton, Missouri Botanical Garden, Shaw Nature Reserve, Missouri Department of Agriculture, Grow Native! (August, 2010) *Landscape Guide for Stormwater Best Management Practice Design*,
www.stlmsd.com/portal/pls/portal/!PORTAL.wwpob_ page.show?_docname=356309.PDF.

Metropolitan St. Louis Sewer District (MSD) and the St Louis Municipalities Phase II Storm Water Steering Committee. (April, 2009). *Site Design Guidance - Tools for Incorporating Post-Construction Stormwater Quality Protection into Concept Plans and Land Disturbance Permitting.*

Mid-America Regional Council and American Public Works Association. (August 2009, 2nd Edition). *Manual of Best Management Practices for Stormwater Quality*.
http://kcmetro.apwa.net/chapters/kcmetro/specs/APWA_BMP_ManualAUG09.pdf

Minnesota Stormwater Steering Committee. (2008). *The Minnesota Stormwater Manual - Version 2*. Minnesota Pollution Control Agency.
www.pca.state.mn.us/index.php/view-document. html?gid=8937

Minton, G. (2005). *Stormwater Treatment: Biological, Chemical and Engineering Principles, Second Edition*. Seattle: Resource Planning Associates Press.

Missouri Botanical Garden's Flora of Missouri Project. http://www.tropicos.org/Project/MO

Missouri Department of Natural Resources. (2002). Division of Geology and Land Survey *Physiographic Regions of Missouri. www.dnr.mo.gov/geology/adm/publications/map-ShdRelief.pdf*

Missouri Department of Natural Resources. (2011). *Protecting Water Quality: A field guide to erosion, sediment and stormwater best management practices for development sites in Missouri and Kansas.*
www.dnr.mo.gov/env/wpp/wpcp-guide.htm

Missouri Department of Natural Resources. (2011). Water Protection Program. 303(d) list.
www.dnr. mo.gov/env/wpp/waterquality/303d.htm.

Myers v. Penn Township, 812 A.2d 766, 767 (Pa. Commw. 2002)

National Complete Streets Coalition. (2005-2011). *Complete Streets*. Retrieved July 2011, from www.completestreets.org.

National Research Council Committee on Reducing Stormwater Discharge Contributions to Water Pollution. (2009). *Urban Stormwater Management in the United States*. The National Academies Press, Washington, D. C.

Nevue Ngan Associates and Sherwood Design Engineers. (2009). *San Mateo County Sustainalbe Green Strees and Parking Lots Design Guidebook*. San Mateo: San Mateo Pollution Prevention Program.

Pitt, R., A. Maestre and R. Morquecho, Department of Civil and Environmental Engineering, University of Alabama. "National Stormwater Quality Database (NSQD, version 1.1)" Table 1. version 3, 2007

Pitt, R., S.E. Clark. (2008). *Integrated Storm-Water Management for Watershed Sustainability J. Irrig*. Drain Eng. 134, 548 (2008); doi:10.1061/(ASCE)0733- 9437(2008)134:5(548) (8 pages)
http://ascelibrary.org/iro/resource/1/jidedh/v134/i5/p548_s1.

Pitt, R.(1999.) *Small storm hydrology and why it is important for the design of stormwater control practices*. In: *Advances in Modeling the Management of Stormwater Impacts, Volume 7*. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. 1999. Pp 61 – 91.

Pitt, R. and T. Voorhees. (2002). "SLAMM." Leading and Management Model in L Wet-Wether Flow in the Urban Watershed. (Edited by Richard Field and Daniel Sullivan) CRC Press, Boca Raton, FL. Pp. 103-139, 2002.

Poff, N., A. Leroy, J. David J., M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. (December 1997). The Natural Flow Regime: A paradigm for river conservation and restoration. BioScience Vol. 47 No.11, Page 782.

Porter, D. R. (1997). *Managing Growth in America's Communities*. Washington DC: Island Press.

Ratcliffe, D.A. (1977). T. Kendle and S. Forbes. (1997). Adapted from D.A. Ratcliffe, *A Nature Conservation Review*, Cambridge, UK: Cambridge University Press, 1977; and T. Kendle and S. Forbes, *Urban Nature Conservation*. London: Spon, 1997.

Reich, S., E. MacMullan, L. Juntunen and A. Hollingshead. (June, 2011) *Managing Stormwater in Redevelopment and Greenfield Development Projects Using Green Infrastructure - Economic Factors that Influence Developers' Decisions.* ECONorthwest, www.econw.com.

Rosgen, D.L. 1996. Applied river morphology. Pagosa Springs, CO: Wildland Hydrology. 352 p p.

Sailor Dj., 2008. *A green roof model for building energy simulation programs*, Energy and Buildings, vol.40, pp 1466-1478.

Saiz, S., C. Kennedy, B. Bass and K. Pressnail. (2006). *Comparative Life Cycle Assessment of Standard and Green Roofs*. Environmental Science and Technology, 40:4312-4316.

Sarasota County v. Sarasota Church of Christ, Inc., et al., 667 So.2d 180, 186 (Fla. 1996)

Sierra Club (2006). *Building Better II, A Guide to America's Best New Development Projects.* Sierra Club
St. Louis Great Streets Initiative. (2007). Retrieved July 2011, from www.greatstreetsstlouis.net

Southeast Michigan Council of Governments (SEMCOG): *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers.* (December 2008.)
http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf

St. Louis County Phase II Stormwater BMP Implementation Work Group. (2011). *Stormwater Best Management Practices Post-Construction Recommendations*. St. Louis.

St. Louis Municipalities Phase II Stormwater Planning Committee. (2008-2013). *St. Louis County Phase II Stormwater Management Plan*. St. Louis County Municipalities.

The Milwaukee River Basin Partnership. (2003, August). *Protecting Our Waters: Overlay Districts.* Retrieved 2011, from http://clean-water.uwex.edu/plan/overlay.htm.

The Sheltair Group. (2001). *Green Municipalities: A Guide to Green Infrastructure for Canadian Municipalities.* Center for Sustainable Communities Development.

Theodosiou, T.G., 'Summer period analysis of the performance of a planted roof as a passive cooling technique', *Energy and Buildings*, 35, pp. 909-917, 2003.

Tucker, S., D. Harrison, H. Cyre, D. Burchmore and A. Reese. (2006). *Guidance for Municipal Stormwater Funding*. National Association of Flood and Stormwater Management Agencies.

United States Department of Agriculture. (2006). *Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites*. Forest Service, Northeastern Area State and Private Forestry. NA-TP-01-06. May 2006. www.na.fs.fed.us/watershed/pdf/Urban%20Watershed%20Forestry%20Manual%20Part%202.pdf

United States Department of Agriculture, Natural Resource Conservation Service (USDA-NRCS). (April 2010). *Soil Erosion on Cropland*. www.nrcs.usda.gov/internet/FSE_Documents/NRCS143_012269

United States Environmental Protection Agency. (2011.) *Measurable Goals Guidance for Phase II Small MS4s.* http://www.epa.gov/npdes/pubs/measurablegoals.pdf

United States Environmental Protection Agency. (2004.) National Risk Management Research Laboratory, Office of Research and Development. Clar, M., B. Barfield and T. O'Connor. *Stormwater Best Management Practice Design Guide Volume 2 Vegetative Biofilters*. EPA/600/R-04/121A September 2004. http://www.epa.gov/nrmrl/pubs/600r04121/600r04121.htm

United States Environmental Protection Agency. (October, 2009). Office of Research and Development (8101R) 1301 Constitution Ave. NW Room 1408 Washington, DC 20004. *Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scale.* EPA231-B-09-001 www.epa.gov/smartgrowth/water_scorecard.htm.

United States Environmental Protection Agency. (1999.) *Preliminary Studies, Preliminary Data Summary of Urban Stormwater Best Management Practices* EPA-821-R-99-012; August 1999. http://water.epa.gov/scitech/wastetech/guide/stormwater

United States Environmental Protection Agency. (2010, Oct. 14). *Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scale.* www.epa.gov/smartgrowth/water_scorecard.htm

United States Environmental Protection Agency. EPA – *Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scale.* Managing Wet Weather with Green Infrastructure: Municipal Handbook Series (EPA 231-B-09-001). http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm

University of Arkansas Community Design Center. (2010). *Low Impact Development: a Design Manual for Urban Areas*. Fay Jones School of Architecture and University of Arkansas Press.

University of Missouri. (2011, July). University of Missouri Campus Facilities. Retrieved July 2011, from www.cf.missouri.edu/masterplan/principles/plannprinc.html.

University of Wisconsin-Extension and Wisconsin Department of Natural Resources. (1997). *Polluted Urban Runoff: A Source of Concern. Madison.* University of Wisconsin-Extension and Wisconsin Department of Natural Resources. GWQ020 Polluted Urban Runoff - A Source of Concern I-02-97-5M-20-S DNR:WT-483-97. http://clean-water.uwex.edu/pubs/pdf/urban.pdf.

Urban Design Tools: Low Impact Development. (1999-2007). *Bioretention Costs.* www.lid-stormwater.net/bio_costs.htm.

Vandike, J. E. (1995). Missouri State Water Plan Series Vol. 1-*Surface Water Resources of Missouri.* Rolla: Missouri Department of Natural Resources.

Virginia Department of Conservation & Recreation. (2008). *Virginia Stormwater Management Handbook*. Virginia Department of Conservation & Recreation.

Watts, F.C., and G.W. Hurt. *Determining Depths to the Seasonal High Water Table and Hydric Soils in Florida*. Soil Survey Horizons, Vol. 32, No. 4, pp. 117-120, Winter 1991.

Weiss, P.T., J.S. Gullivar and A.J. Erickson. (October, 2007.) *Cost and Pollutant Removal of Storm-Water Treatment and Practices*. Journal of Water Resources Planning and Management © ASCE/MAY/JUNE 2007.

Winterset Valley. (2011). Winterset Valley. Retrieved July 2011, from www.wintersetpark.com/docs/ developer_profile.asp.

Wise, S., J. Braden, D. Ghalayini, J. Grant, C. Kloss, E. MacMullan, S. Morse, F. Montalto, D. Nees, D. Nowak, S. Peck, S. Shaikh, and C. Yu. *Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits. Center for Neighborhood Technology.* www.cnt.org

C Appendix C - Additional Resources

American Society of Landscape Architects, www.asla.org American Public Works Association, www.apwa.net

An Internet Guide to Financing Stormwater Management, Center for Urban Policy and the Environment at Indiana University-Purdue University Indianapolis: http://stormwaterfinance.urbancenter.iupui.edu/

APWA/Marc Stormwater Design Manual - www.marc.org/Environment/water/bmp_manual.htm.

Center for Watershed Protection, www.cwp.org

Center for Watershed Protection, Stormwater Managers Resource Center: www.stormwatercenter.net

Program Builder - "Financing Stormwater Programs"

Manual Builder – "Stormwater Credits"

Cisterns, City of Portland fact sheet, www.portlandonline.com/bes/index.cfm?a=127468&c=31870

Comprehensive Plan, May (2000.) City of Lenexa, Kansas: http://www.lenexa.com/commdev/compplan/compplan.htm

Conover Commons Cottages- Redmond, Washington. (2010.) The Cottage Company: www.cottagecompany.com/Communities/Conover-Commons-Cottages/Conover-Commons-Cottages-SitePlan.aspx

DeBusk, K., W. Hunt and D. Line. (March, 2011) Technical Note - Bioretention Outflow: Does it Mimic Non-Urban Watershed Shallow Interflow? Journal of Hydrolic Engineering, ASCE.

Delaware Valley Green Building Council, www.dvgbc.org/files/resources/Green%20Roof%Tax%20credit.pdf Developer Resources Stormwater Design Criteria. www.springfieldmo.gov/stormwater/developer.html

EPA - *Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (Guiding Principles*). http://www.epa.gov/greeningepa/stormwater/requirements.htm#gps

EPA - *Handbook for Developing Watershed Plans to Restore and Protect Our Waters.* (March 2008). United States Environmental Protection Agency: United States Environmental Protection Agency Office of Water, Nonpoint Source Control Branch, Washington, DC 20460, EPA 841-B-08-002. www.epa.gov/nps/watershed_handbook/pdf/handbook.pdf

EPA – *Integrating Green Infrastructure into Regulatory Programs* http://cfpub.epa.gov/npdes/greeninfrastructure/regulators.cfm

EPA - *Managing Wet Weather with Green Infrastructure*, http://cfpub.epa.gov/npdes/home.cfm?program_id=298

EPA – Low Impact Development, www.epa.gov/owow/NPS/lid

EPA - Managing Wet Weather with Green Infrastructure: http://cfpub.epa.gov/npdes/home.cfm?program_id=298

EPA - MS4 Program Evaluation Guidance, January 2007. EPA-833-R-07-003 (Municipal, 2007) http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1007BZP.txt

EPA - National Menu of Sormwater Best Management Practices, http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

EPA - National Pollutant Discharge Elimination System, www.epa.gov/npdes/stormwater

EPA - *Post Construction Runoff Control Minimum Control Measure* fact sheet 2.7. (December 2005). United States Environmental Protection Agency, Stormwater Phase II Final Rule Fact Sheet Series: www.epa.gov/npdes/pubs/fact2-7.pdf

EPA - *Reducing Stormwater costs through Low Impact Development (LID) Strategies and Practice*s, December 2007. United States Environmental Protection Agency: www.epa.gov/owow/nps/lid/costs07/documents/reducingstormwatercosts.pdf

EPA - Planning for Sustainability: A Handbook for Water and Wastewater Utilities. (February 2012.) EPA-832-R-12-001. http://water.epa.gov/infrastructure/sustain/upload/EPA-s-Planning-for-Sustainability-Handbook.pdf

EPA – *Proposed National Rulemaking to Strengthen the Stormwater Program*, http://cfpub.epa.gov/npdes/stormwater/rulemaking.cfm

EPA – *Stormwater Control Operation and Maintenance*, www.epa.gov/owow/NPS/ordinance/stormwater.htm

EPA – *Stormwater Discharges from Municipal Separate Storm Sewer Systems (MS4s)* http://cfpub.epa.gov/npdes/stormwater/munic.cfm

EPA – *Stormwater Phase II Final Rule* fact sheet, http://cfpub.epa.gov/npdes/stormwater/swfinal.cfm

EPA – Stormwater Program, http://cfpub.epa.gov/npdes/home.cfm?program_id=6

EPA - *Stormwater Discharges From Municipal Separate Storm Sewer Systems (MS4s), National Pollutant Discharge Elimination System (NPDES),*
Municipal website: http://cfpub.epa.gov/npdes/stormwater/munic.cfm

EPA – *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act.* (December, 2009) www.epa.gov/owow/nps/lid/section438

EPA – Urban Stormwater Retrofit Guide

EPA -*Using Green Infrastructure to Protect Water Quality in Stormwater, CSO, Nonpoint Source and other Water Program*s – EPA Memo from Benjamin Grumbles, EPA Assistant Administrator (Using, 2007): http://www.epa.gov/reg3wapd/npdes/pdf/dcms4_guidance.pdf

EPA – Water Quality Scorecard, http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm

Green Roofs for Healthy Cities: www.greenroofs.org

Green Roof and Wall Projects Database: http://www.greenroofs.com/projects/plist.php

Green Values®: National Stormwater Management Calculator. Green Values Stormwater Toolbox®. Copyright 2006-9 Center for Neighborhood Technology.
http://greenvalues.cnt.org/national/benefits_detail.php

High Point Right of Way and Open Space Landscape Design Guidelines. (December 2006). SvR Design Company, City of Seattle, Washington: www.svrdesign.com/docs/High%20Point%20ROW%20and%20Landscape%20Maintenance%20Guidelines%20-%2012-21-06.pdf

Innovative/Flexible Zoning, Lancaster County (Pennsylvania) Smart Growth Toolbox:
www.co.lancaster.pa.us/toolbox/cwp/view.asp?a=3&q=618817

Integrated Storm-Water Management for Watershed Sustainability, Pitt, R. and S. Clark. (September/October 2008). *Journal of Irrigation and Drainage Engineering*, Vol. 134, No. 5, pp. 548-555.
http://ascelibrary.org/iro/resource/1/jidedh/v134/i5/p548_s1

International Stormwater Database, www.bmpdatabase.org

Kansas City 10,000 Rain Gardens, www.rainkc.com

Karst, Springs and Caves in Missouri. Missouri Department of Natural Resources:
www.dnr.mo.gov/env/wrc/springsandcaves.htm

Low Impact Development Center Inc. (2011). *Low Impact Development Center*. Retrieved July 2011, from www.lowimpactdevelopment.org.

Measurable Goals Guidance for Phase II Small MS4's, Part 1- Background and Regulatory Context and Part 2- Process for Developing Measurable Goals Under a General Permit. (October 2007). United States Environmental Protection Agency. http://cfpub.epa.gov/npdes/stormwater/measurablegoals/index.cfm

Miami OH Conservancy District,
www.miamiconservancy.org/Water_Data/StormwaterBMPs/infiltrationtrench.asp

Military Sustainability Library, www.p2sustainabilitylibrary.mil/P2_Opportunity_Handbook/10-4.html
Milwaukee River Basin Partnership, http://dnr.wi.gov/water/basin/milw/

Minnesota Stormwater Manual - Version 2. (January 2008). www.pca.state.mn.us/index.php/water/watertypes-and-programs/stormwater/stormwater-management/minnesota-s-stormwater-manual.html

Missouri Aggregate Producers: http://dnr.mo.gov/asp/lrp/impermits/search.asp

Missouri Department of Conservation GrowNative! www.grownative.org

Missouri Department of Natural Resources - 319 Nonpoint Source Grant Program Implementation Program, for grants for nonpoint source runoff pollution control. www.dnr.mo.gov/env/wpp/nps/

Missouri Department of Natural Resources - Small MS4 General Permit www.dnr.mo.gov/env/wpp/permits/issued/R040000.pdf

Missouri Department of Natural Resources - Land Reclamation Program, Search for Missouri Aggregate Producers - http://dnr.mo.gov/asp/lrp/impermits/search.asp

Missouri Department of Natural Resources – Stormwater Information Clearinghouse http://dnr.mo.gov/env/wpp/stormwater

Missouri Department of Natural Resources, Water Protection Financial Assistance Center for grants and low interest loans for sewer and water infrastructure -http://www.dnr.mo.gov/env/wpp/srf/

Missouri Department of Natural Resources – Water Protection Program www.dnr.mo.gov/env/wpp/index.html

Missouri Department of Natural Resources – Water Protection Program; Phase II Background, Highlights and Governance: www.dnr.mo.gov/env/wpp/stormwater/sw-phaseii-info.htm

Missouri Major Land Resource Areas, The Cooperative Soil Survey Static Mapping: http://soils.missouri.edu/maps/mlra.asp

Missouri State Water Plan Series Volume 1, Surface Water Resources of Missouri, Vandike, James E. 1995, Missouri Department of Natural Resources- Division of Geology and Land Survey: www.dnr.mo.gov/env/wrc/statewaterplanMain.htm

Municipal Separate Storm Sewer System Program Evaluation Guidance, Chapter 4.5 and Appendix B, January 2007. United States Environmental Protection Agency. www.epa.gov/npdes/pubs/ms4guide_withappendixa.pdf; http://www.epa.gov/npdes/pubs/ms4guide_appendicesb-d.pdf

Municipal Stormwater Program Effectiveness Assessment Guidance document, May 2007. California Stormwater Quality Association: www.casqa.org/store/products/tabid/154/p-7-effectiveness-assessment-guide.aspx

Municipal Stormwater Management, Second Edition. (2003). Debo, T.N. and A.J. Reece: CRC Press, LLC.

National Stormwater Quality Database (NSQD, version 1.1) Pitt, R., A. Maestre and R. Morquecho, Table 1. (February 2004). Department of Civil and Environmental Engineering, University of Alabama. unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html

Native Landscaping Manual: A Guide to Native Landscaping in Missouri, Missouri Department of Conservation and the Shaw Nature Preserve, http://www.missouribotanicalgarden.org/visit/family-of-attractions/shaw-nature-reserve/gardens-gardening-at-shaw-nature-reserve/native-landscaping-for-the-home-gardener/native-landscaping-manual.aspx

Natural Resource Guidance Checklist: Addressing Natural Resources in a Comprehensive Plan. (December 2001.) Minnesota Department of Natural Resources
http://files.dnr.state.mn.us/assistance/nrplanning/ community/nrchecklists/compplan.pdf

Pitt, R. Research web site for Dr. Pitt's on-line stormwater publications (to be updated soon): http://www. unix.eng.ua.edu/~rpitt/Publications/Publications.shtml

Pitt, R., L. Talebi. R. Bean, and S. Clark. (2011.) Stormwater Non-Potable Beneficial Uses and Effects on Urban Infrastructure, Water Environment Research Foundation, Report No. INFR3SG09. Alexandria, VA. November 2011. 224 pgs.

Phase II Stormwater Management Plan, Metropolitan St. Louis Sewer District,
www.stlmsd.com/ educationoutreach/phase2

Physiographic Regions (2003): USGS. A Tapestry of Time and Terrain: The Union of Two Maps: Geology and Topography. http://tapestry.usgs.gov/physiogr/physio.html

Planning for Agriculture: A Guide for Connecticut Municipalities, September 2008.
American Farmland Trust and Connecticut Conference of Municipalities:
www.ctplanningforagriculture.com/guide/AFT_ guide_web9-29.pdf

Preparing a Natural Resource Protection Plan, City of Minnetonka, Minnesota Public Works website: www.eminnetonka.com/public_works/natural_resources/construction_projects/grading_building_permits/natural_resource_protection_plan.cfm

Protecting the Property Rights of All: No Adverse Impact and Stormwater Management, Thomas, E.A., Esq. (January 2008). Rocky Mountain Land Use Institute: http://www.floods.org/PDF/NAI%20_No%20Adverse%20Impact%20Floodplain%20and%20Stormwater%20Management.pdf

Preparing for the Storm: Preserving Water *Resources with Stormwater Utilities*. (January 2001).
Walker, Barrett., Reason Public Policy Institute: http://reason.org/news/show/127738.html

Portland Green Streets: www.portlandgreenstreets.org

Rain Barrels and Cisterns, Low Impact Development Center Inc., Urban Design Tools- LID Techniques: http://www.lid-stormwater.net/raincist_cost.htm

Rain Gardens of West Michigan, www.raingardens.org

A Regional Natural Resources Protection Plan for the Toms River Corridor, Jackson and Manchester Townships, Ocean City, New Jersey, Toms River Corridor Task Force. (February 2004),
www.state.nj.us/pinelands/infor/broch/toms_river_corridor.pdf

San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook. (January 2009). San Mateo County, California- Nevue Ngan Associates and Sherwood Design Engineers, www.flowstobay.org/ms_sustainable_guidebook.php

Seattle's Natural Drainage Systems Booklet, City of Seattle, Washington: www.seattle.gov/util/stellent/groups/public/@spu/@usm/documents/webcontent/spu02_019984.pdf

Small Storm Hydrology and Why it is Important for the Design of Storm Water Control Practices, Pitt, R. (1999). *Advances in Modeling the Management of Stormwater Impacts, Volume 7,* Computational Hydraulics International: http://rpitt.eng.ua.edu/Publications/UrbanHyandCompsoils/small%20storm%20 hydrology%20Pitt%20james98.pdf

Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. Federal Highway Administration. (2006). http://environment.fhwa.dot.gov/ecosystems/ultraurb/index.asp

St. Louis Great Streets Initiative, East-West Gateway Council: www.greatstreets-stl.org

Sustainability and Conservation. Missouri Botanical Gardens, www.missouribotanicalgarden.org/ sustainability-conservation.aspx

Stormwater Credit Manual, January 2003. City of Indianapolis, Indiana: www.indy.gov/eGov/City/DPW/ Environment/CleanStream/Solutions/Flooding/Documents/CreditManualRevised1103.pdf

Storm Water Credit Manual, (Revised January 2006). City of Bloomington, Illinois, www.cityblm.org/ upload/images/eng/pdfs/Storm%20Water%20Credit%20Manual.pdf

Storm Water Management Fee, Prince William County, Virginia Department of Public Works website: www.pwcgov.org/government/dept/publicworks/environment/Pages/Storm-Water-Management-Fee.aspx

Stormwater Management Manual, Chapter 2, (Revised August 2008). City of Portland, Oregon. www.portlandonline.com/BES/index.cfm?c=47954

Stormwater Solutions Handbook, (November 2006). City of Portland, Oregon Environmental Services: www. portlandonline.com/bes/index.cfm?c=43110

Sustainable Sites Initiative: an interdisciplinary effort by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at The University of Texas at Austin and the United States Botanic Garden to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices. www.sustainablesites.org/

Storm Water Management Model User's Manual, Version 5.0. Rossman, LE. (Revised July 2010). Water Supply and Water Resources Division, National Risk Managemnt Research Laboratory, Cincinatti, OH 45628. EPA/600-R-05/040.

Tool 1- Stormwater Program Self-Assessment, Tool 2- Program and Budget Planning Tool and Tool 7- Performance Bond Tool, 2008. Center for Watershed Protection: www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm

Tool 4- Code and Ordinance Worksheet, (2008). Center for Watershed Protection: www.cwp.org/Resource_Library/Center_Docs/SW/pcguidance/Tool4.pdf

What about Flood Control?, Low Impact Development Center Inc., Urban Design Tools- Introduction to LID: www.lid-stormwater.net/background.htm#floodctrl_LID

Urban Watershed Forestry Manual Part 1: Methods for Increasing Forest Cover in a Watershed, Cappiella, Karen, Tom Schueler, and Tiffany Wright, page 7. July 2005, United States Department of Agriculture, www.na.fs.fed.us/watershed/pdf/Urban%20Watershed%20Forestry%20Manual%20Part%201.pdf

Using Green Infrastructure to Protect Water Quality in Stormwater, CSO, Nonpoint Source and other Water Programs, Grumbles, Benjamin. (March 2007): United States Environmental Protection Agency, Office of Water. www.epa.gov/reg3wapd/npdes/pdf/dcms4_guidance.pdf Trout Creek Stormwater Overlay District Ordinance. Tredyffrin Township, Chester County Pennsylvania, www.tredyffrin.org.

Urban Design Tools, www.lid-stormwater.net/greenroofs_maintain.htm

Urban Design Tools, www.lid-stormwater.net/raincist_home.htm

Urban Land Institute. www.uli.org/

United State Green Building Council, www.usgbc.org

Urban BMP Performance Tool http://cfpub.epa.gov/npdes/stormwater/urbanbmp/bmpeffectiveness.cfm

Urban Land Institute, www.uli.org

Virginia Department of Forestry Rain Garden Guide - www.dof.virginia.gov/mgt/resources/pub-Rain-Garden-Tech-Guide_2008-05.pdf

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www.dnr.mo.gov