ROOFTOPS TO RIVERS

Green Strategies for Controlling Stormwater and Combined Sewer Overflows

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EXECUTIVE SUMMARY

As an environmental strategy, green infrastructure addresses the root cause of stormwater and combined sewer overflow (CSO) pollution: the conversion of rain and snow into runoff. This pollution is responsible for health threats, beach closings, swimming and fishing advisories, and habitat degradation. Water quality standards are unlikely to be met without effectively managing stormwater and CSO discharges. Green infrastructure—trees, vegetation, wetlands, and open space preserved or created in developed and urban areas—is a strategy for stopping this water pollution at its source.

The urban landscape, with its large areas of impermeable roadways and buildings—known as impervious surfaces—has significantly altered the movement of water through the environment. Over 100 million acres of land have been developed in the United States, and with development and sprawl increasing at a rate faster than population growth, urbanization's negative impact on water quality is a problem that won't be going away. To counteract the effects of urbanization, green infrastructure is beginning to be used to intercept precipitation and allow it to infiltrate rather than being collected on and conveyed from impervious surfaces.

Each year, the rain and snow that falls on urban areas in the United States results in billions of gallons of stormwater runoff and CSOs. Reducing runoff with green infrastructure decreases the amount of pollution introduced into waterways and relieves the strain on stormwater and wastewater infrastructure. Efforts in many cities have shown that green infrastructure can be used to reduce the amount of stormwater discharged or entering combined sewer systems and that it can be cost-competitive with conventional stormwater and CSO controls. Additional environmental benefits include improved air quality, mitigation of the urban heat island effect, and better urban aesthetics.

Green infrastructure is also unique because it offers an alternative land development approach. New developments that use green infrastructure often cost less to build because of decreased site development and conventional infrastructure costs, and such developments are often more attractive to buyers because of environmental amenities. The flexible and decentralized qualities of green infrastructure also allow it to be retrofitted into developed areas to provide stormwater control on a site-specific basis. Green infrastructure can be integrated into redevelopment efforts ranging from a single lot to an entire citywide plan.

Case Study Program Elements and Green Infrastructure Techniques

	PROGRAM ELEMENTS		TYPE OF GREEN INFRASTRUCTURE USED				
City	**Used for Direct CSO Control**	**Established Municipal Programs & Public Funding**	**Green Roofs**	**Rain Gardens/ Vegetated Swales & Landscape**	**Permeable Pavement**	**Downspout Disconnection/ Rainwater Collection**	**Wetlands/ Riparian Protection/ Urban Forests**
Chicago	✔	✔	✔	✔	✔	✔	
Milwaukee	✔	✔	✔	✔			✔
Pittsburgh	✔		✔	✔		✔	✔
Portland	✔	✔	✔	✔		✔	
Rouge River Watershed			✔	✔	✔		✔
Seattle	✔	✔	✔	✔		✔	
Toronto		✔	✔			✔	✔
Vancouver		✔	✔	✔	✔		✔
Washington			✔	✔	✔		

The aerial photograph at left of Washington, DC, shows the amount of green space and vegetation present in 2002. The photo at right shows how this same area would look in 2025 after a proposed 20-year program to install green roofs on 20% of city buildings over 10,000 square feet. PHOTOS COURTESY OF THE CASEY TREES ENDOWMENT FUND

Nonetheless, wider adoption of green infrastructure still faces obstacles. Among these is the economic investment that is required across the country for adequate stormwater and CSO control. Although green infrastructure is in many cases less costly than traditional methods of stormwater and sewer overflow control, some municipalities persist in investing only in existing conventional controls rather than trying an alternative approach. Local decision makers and organizations must take the lead in promoting a cleaner, more environmentally attractive method of reducing the water pollution that reaches their communities. NRDC recommends a number of policy steps local decision makers can take to promote the use of green infrastructure:

1. Develop with green infrastructure and pollution management in mind. Build green space into new development plans and preserve existing vegetation.

2. Incorporate green infrastructure into long-term control plans for managing combined sewer overflows. Green techniques can be incorporated into plans for infrastructure repairs and upgrades.

3. Revise state and local stormwater regulations to encourage green design. A policy emphasis should be placed on reducing impervious surfaces, preserving vegetation, and providing water quality improvements.

The case studies that begin on page 17 offer nine examples of successful communities that have reaped environmental, aesthetic, and economic benefits from a number of green infrastructure initiatives.

The table on page v provides a summary of information contained within the case studies.

Introduction

Water pollution problems in the United States have evolved since the days when Ohio's Cuyahoga River was on fire. Increasingly, water pollution from discrete sources such as factory pipes is being overshadowed by overland flows from streets, rooftops, and parking lots, which engorge downstream waterways every time it rains. This stormwater has nowhere to go because the natural vegetation and soils that could absorb it have been paved over. Instead, it becomes a high-speed, high-velocity conduit for pollution into rivers, lakes, and coastal waters.

Most U.S. cities have separate stormwater sewer systems through which contaminated stormwater flows directly into waterways through underground pipes, causing streambank scouring and erosion and dumping pet waste, road runoff, pesticides, fertilizer, and other pollutants directly into waterways. In older cities, particularly in the Northeast and Great Lakes regions, stormwater flows into the same pipes as sewage and causes these combined pipes to overflow—dumping untreated human, commercial, and industrial waste into waterways. Stormwater pollution has been problematic to some extent for as long as there have been cities, but the volume of stormwater continues to grow as development replaces porous surfaces with impervious blacktop, rooftop, and concrete.

Contaminated stormwater and raw sewage discharges from combined sewer overflows (CSOs) are required to be controlled under the Clean Water Act, but progress is slow because the problems are large and multi-faceted and because the solutions are often expensive. A substantial influx of additional resources is needed at the federal, state, and local levels, but fresh thinking is needed also. Some U.S. cities are already taking steps to successfully build green infrastructure into their communities.

The green roof at Ford Motor Company's Premier Automotive North American Headquarters in Irvine, CA, was designed to visually mimic the natural landscape. PHOTO COURTESY OF ROOFSCAPES, INC.

Emerging green infrastructure techniques present a new pollution-control philosophy based on the known benefits of natural systems that provide multimedia pollution reduction and use soil and vegetation to trap, filter, and infiltrate stormwater. The cities already using green infrastructure are finding that it is a viable alternative to conventional stormwater management. Although used widely overseas, particularly in Germany and Japan, the use of green infrastructure in the United States is still in its infancy; however, data indicate that it can effectively reduce stormwater runoff and remove stormwater pollutants, and cities that have implemented green design are already reaping the benefits (see the case studies on page 17).

CHAPTER 2

THE GROWING PROBLEM OF URBAN STORMWATER

Development as we have come to know it in the United States—large metropolitan centers surrounded by sprawling suburban regions—has contributed greatly to the pollution of the nation's waters. As previously undeveloped land is paved over and built upon, the amount of stormwater running off roofs, streets, and other impervious surfaces into nearby waterways increases. The increased volume of stormwater runoff and the pollutants carried within it continue to degrade the quality of local and regional water bodies. As development continues, nature's ability to maintain a natural water balance is lost to a changing landscape and new impervious surfaces.

The trees, vegetation, and open space typical of undeveloped land capture rain and snowmelt, allowing it to largely infiltrate where it falls. Under natural conditions, the amount of rain that is converted to runoff is less than 10% of the rainfall volume.[1,2] Replacing natural vegetation and landscape with impervious surfaces has significant environmental impacts. The level of imperviousness in a watershed has been shown to be directly related to the health of its rivers, lakes, and estuaries. Research indicates that water quality in receiving water bodies is degraded when watershed imperviousness levels are at or above 10% and that aquatic species can be harmed at even lower levels.[3]

TABLE 1: Effects of Imperviousness on Local Water Bodies[a,b,c]

Watershed Impervious Level	Effect
10%	• Degraded water quality
25%	• Inadequate fish and insect habitat • Shoreline and stream channel erosion
35%–50%	• Runoff equals 30% of rainfall volume
>75%	• Runoff equals 55% of rainfall volume

[a] Environmental Science and Technology, *Is Smart Growth Better for Water Quality?*, August 25, 2004, http://pubs.acs.org/subscribe/journals/estjag-w/2004/policy/jp_smartgrowth.html (accessed December 6, 2004).
[b] U.S. EPA, *Protecting Water Quality from Urban Runoff*, Nonpoint Source Control Branch, EPA 841-F-03-003, February 2003.
[c] Prince George's County, Maryland Department of Environmental Resources, *Low-Impact Development Design Strategies*, January 2000.

Both the National Oceanic and Atmospheric Administration (NOAA) and Pennsylvania State University estimate that there are 25 million acres of impervious surfaces in the continental United States.[4] This quantity represents nearly one-quarter of the more than 107 million acres—almost 8% of non-federal land in the contiguous United States—that had been developed by 2002.[5] In urban areas, it is not uncommon for impervious surfaces to account for 45% or more of the land cover.

This combination of developed land and impervious surfaces presents the primary challenge of stormwater mitigation. Existing stormwater and wastewater infrastructure is unable to manage stormwater in a manner adequate to protect and improve water quality. Standard infrastructure and controls fail to reduce the amount of stormwater runoff from urban environments or effectively remove pollutants.

THE DEFICIENCIES OF CURRENT URBAN STORMWATER INFRASTRUCTURE

Stormwater management in urban areas primarily consists of efficiently collecting and conveying stormwater. Two systems are currently used: separate

Bioswales on Portland's Division Street infiltrate and treat stormwater runoff.
Photo courtesy of the Portland Bureau of Environmental Services

stormwater sewer systems and combined sewer systems. Separate stormwater sewer systems collect only stormwater and transmit it with little or no treatment to a receiving stream, where stormwater and its pollutants are released into the water. Combined sewer systems collect stormwater in the same set of pipes that are used to collect sewage, sending the mixture to a municipal wastewater treatment plant.

Separate Stormwater Sewer Systems

The large quantities of stormwater that wash across urban surfaces and discharge from separate stormwater sewer systems contain a mix of pollutants, shown in Table 2, deposited from a number of sources.[6,7] Stormwater pollution from separate systems affects all types of water bodies in the country and continues to pose a largely unaddressed threat. In 2002, 21% of all swimming beach advisories and closings were attributed to stormwater runoff.[8] Table 3 shows the percentage of assessed (monitored) waters in the United States for which stormwater has been identified as a significant source of pollution.[9]

Combined Sewer Systems

While pollution from separate sewer systems is a problem affecting a large majority of the country, pollution from combined sewer systems tends to be a more regional problem concentrated in the older urban sections of the Northeast, the Great Lakes

TABLE 2: Urban Stormwater Pollutants

Pollutant	Source
Bacteria	Pet waste, wastewater collection systems
Metals	Automobiles, roof shingles
Nutrients	Lawns, gardens, atmospheric deposition
Oil and grease	Automobiles
Oxygen-depleting substances	Organic matter, trash
Pesticides	Lawns, gardens
Sediment	Construction sites, roadways
Toxic chemicals	Automobiles, industrial facilities
Trash and debris	Multiple sources

TABLE 3: Urban Stormwater's Impact on Water Quality

Water Body Type	Stormwater's Rank as Pollution Source	% of Impaired Waters Affected
Ocean shoreline	1st	55% (miles)
Estuaries	2nd	32% (sq. miles)
Great Lakes shoreline	2nd	4% (miles)
Lakes	3rd	18% (acres)
Rivers	4th	13% (miles)

TABLE 4: Pollutants in CSO Discharges[a]

Pollutant	Median CSO Concentration	Treated Wastewater Concentration
Pathogenic bacteria, viruses, parasites • Fecal coliform (indicator bacteria)	215,000 colonies/100 mL	< 200 colonies/100mL
Oxygen depleting substances (BOD_5)	43 mg/L	30 mg/L
Suspended solids	127 mg/L	30 mg/L
Toxics		
• Cadmium	2 μg/L	0.04 μg/L
• Copper	40 μg/L	5.2 μg/L
• Lead	48 μg/L	0.6 μg/L
• Zinc	156 μg/L	51.9 μg/L
Nutrients		
• Total Phosphorus	0.7 mg/L	1.7 mg/L
• Total Kjeldahl Nitrogen	3.6 mg/L	4 mg/L
Trash and debris	Varies	None

[a] U.S. EPA, Report to Congress: Impacts and Control of CSOs and SSOs, Office of Water, EPA-833-R-04-001, August 2004.

region, and the Pacific Northwest. Combined sewers, installed before the mid-twentieth century and prior to the use of municipal wastewater treatment, are present in 746 municipalities in 31 states and the District of Columbia.[10] They were originally used as a cost-effective method of transporting sewage and stormwater away from cities and delivering them to receiving streams. As municipal wastewater treatment plants were installed to treat sewage and protect water quality, the limited capacity of combined sewers during wet weather events became apparent.[11]

During dry periods or small wet weather events, combined sewer systems carry untreated sewage and stormwater to a municipal wastewater treatment plant where the combination is treated prior to being discharged. Larger wet weather events overwhelm a combined sewer system by introducing more stormwater than the collection system or wastewater treatment plant is able to handle. In these situations, rather than backing up sewage and stormwater into basements and onto streets, the system is designed to discharge untreated sewage and stormwater directly to nearby water bodies through a system of combined sewer overflows (CSOs). In certain instances, despite the presence of sewer overflow points, basement and street overflows still occur. Even small amounts of rainfall can trigger a CSO event; Washington D.C.'s combined sewer system can overflow with as little as 0.2 inch of rainfall.[12]

Because CSOs discharge a mix of stormwater and sewage, they are a significant environmental and health concern. CSOs contain both expected stormwater pollutants and pollutants typical of untreated sewage, like bacteria, viruses, nutrients, and oxygen-depleting substances. CSOs pose a direct health threat in the areas surrounding the CSO discharge location because of the potential exposure to bacteria and viruses. Estimates indicate that CSO discharges are typically composed of 15–20% sewage and 80–85% stormwater.[13,14] An estimated 850 billion gallons of untreated sewage and stormwater are discharged nationally each year as combined sewer overflows.[15] Table 4 shows the concentration of pollutants in CSO discharges.

POPULATION GROWTH AND NEW DEVELOPMENT CREATE MORE IMPERVIOUS SURFACES

Current levels of development and imperviousness are a major, and largely unabated, source of water pollution. Projections of population growth and new development indicate that this problem will get worse over time and that mitigation efforts will become more costly and difficult. Although the nation has collectively failed to adequately address the current levels of stormwater runoff and pollution, we have also failed to implement emerging strategies that would minimize further pollution increases. Absent the use of state-of-the-art stormwater controls, each new acre of land developed and each new parcel of impervious surface will introduce new pollution into our waterways.

Recent studies also indicate that stormwater pollution may soon start to increase at a higher rate than in the past. Over the past two decades, the rate of land development has been two times greater than the rate of population growth. Between 1982 and 1997, while the U.S. population grew 15%, the amount of developed land in the continental United States grew 34%, an increase of 25 million acres.[16,17] The 25 million acres developed during this 15-year period represent nearly 25% of the total amount of developed land in the contiguous states. This rapid development pattern is alarming not only because of the conversion of a large and growing percentage of the remaining undeveloped land, but also because of the increase in stormwater runoff that accompanies development.

If the relationship between land development and population growth continues, a significant amount of land will be developed in the coming decades. The anticipated 22% growth in U.S. population from 2000 to 2025 will add an additional 68 million acres of development.[18] By 2030, half of the total square footage of buildings—200 billion square feet—will have been built after the year 2000.[19]

Much of this population growth and new development will occur in coastal regions, a particular concern because urban stormwater runoff is already the largest source of ocean shoreline water pollution. Although coastal counties comprise only 17% of the total acreage of the contiguous United States they are home to more than 50% of the U.S. population. Because of high population concentrations on limited land areas, coastal counties contain a higher percentage of development than interior counties. In 1997, 27 million acres of coastal counties had been developed, accounting for nearly 14% of the total land area. By contrast, 71 million acres, about 4% of the total land area of interior counties, had been developed.[20] Based on these trends, increased population and development in these coastal environments is likely to not only lead to greater amounts of impervious surfaces in coastal watersheds, but also higher percentages of imperviousness. Conventional methods of stormwater control will not be able to adequately manage the higher amount of stormwater pollution implied by this increased imperviousness.

CHAPTER 3

Controlling Stormwater in Urban Environments

The foremost challenge of reducing stormwater pollution and CSO discharges is finding an effective method of reducing the amount of stormwater created in urban environments. Methods currently used to manage stormwater largely fail to address the underlying problem of imperviousness.

Stormwater collected in separate systems typically is not treated before being discharged. In instances where treatment is provided, it usually consists of filtration to remove suspended solids, debris, and floatables. Because dissolved materials and nutrients are difficult to treat in urban stormwater and little has been done to abate the scouring, erosion, and other physical impacts of stormwater discharges, treatment efforts have been largely ineffective at diminishing stormwater-related water pollution.

Most municipal stormwater discharges are regulated as point sources under the Clean Water Act (CWA) and require a National Pollutant Discharge Elimination System (NPDES) permit. However, end-of-pipe treatment and control typical of other permitted point-source discharges are often impractical for urban stormwater, because of the large volumes of stormwater; generated and space constraints in urban areas. Permits for urban stormwater require municipalities to develop a stormwater management plan and to implement best management practices.[1] These management measures are typically used in lieu of specific pollutant removal requirements. "Performance-based" standards are generally not required, and minimum control measures are sufficient for compliance.

As a result, compliance with urban stormwater permits does not necessarily result in improved water quality. Municipalities that develop programs to actually reduce stormwater pollution are motivated to do so because of their proximity to unique or valued water bodies or because of a need to protect drinking water supplies. Some of the more aggressive and innovative stormwater programs are located around sensitive or important water bodies like the Chesapeake Bay, the Great Lakes, or Puget Sound. Federal regulations require states to identify quality-limited waterways and determine the reduction in the Total Maximum Daily Load (TMDL) of those pollutants necessary to meet water quality standards, but these pollutant load-reduction requirements are not often translated into effective stormwater management programs.[2]

Municipalities are required to implement short-term and long-term strategies to reduce overflows from combined sewer systems, but significant numbers of overflows continue to occur. The CWA prohibits the dry weather discharge of untreated sewage and requires wet weather CSO discharges to be limited and to control discharges of solids and floatables. Federal regulations also require that municipalities develop long-term CSO control plans that detail procedures and infrastructure modifications necessary to minimize wet weather overflows and meet water quality standards.[3] The long-term control plans focus primarily on managing stormwater impacts on combined sewer systems.

Mitigating CSOs is costly. The 2000 Clean Watersheds Needs Survey (CWNS) estimated that $56 billion (2005 dollars) in capital investment was needed for CSO control.[4] Separating combined sewer lines and building deep storage tunnels are the two currently preferred methods of CSO control. The costs for separating combined sewers, disconnecting stormwater inlets from the combined sewer system, and directing them to a newly installed separate storm sewer system range from $500 to $600 per foot of sewer separated, or $2.6 million to $3.2 million for each mile of combined sewer to be separated.[5] While sewer separation will eliminate CSO discharges and the release of untreated sewage, the trade-off is an increase in the volume of untreated stormwater discharges.

Deep storage systems are large underground tunnels with millions of gallons of storage capacity that are built to hold the excess surge of combined sewer stormwater during wet weather events. These systems eventually direct the detained wastewater to the municipal treatment plant as combined sewer flow rates subside. If sized, constructed, and operated properly, deep tunnels can significantly reduce CSO discharges. However, deep tunnels take many years to build and are very costly. Several cities have begun or plan to begin deep tunnel projects costing hundreds of millions or billions of dollars, as outlined in Table 5.

Current stormwater management for separate and combined sewer systems is ineffective because it focuses on the symptoms (large stormwater volumes) rather than the problem (development patterns and imperviousness). Capturing, retaining, and trying to improve the quality of vast quantities of urban stormwater runoff is often more difficult and expensive than reducing the amount of stormwater generated from the outset through strategies to reduce imperviousness and maximize infiltration and filtration. On a municipal level, costs can be decreased when these techniques are incorporated into redevelopment and ongoing infrastructure replacement efforts. Comprehensive stormwater management programs can be used to minimize the effect of impervious surfaces and manage precipitation and stormwater with the use of natural processes. These "green" approaches are often less expensive and more effective than current stormwater and CSO controls.

GREEN ALTERNATIVES

Newer, flexible, and more effective urban stormwater and CSO strategies are being adopted in North America. Cities are beginning to introduce green infrastructure as a component of comprehensive stormwater management plans aimed at reducing stormwater runoff, CSOs or both. This approach is significant in that it can be used to address the stormwater problem "at the source" through efforts aimed at restoring some of the

TABLE 5: Examples of Deep Storage Tunnel Projects

City	Project Duration	Completion Date	Storage Capacity	Cost
Chicago, IL[a,b]	40+ years	2019	18 billion gallons	$3.4 billion
Milwaukee, WI[c,d]	17 years (Phase 1)	1994	405 million gallons	$2.3 billion
	8 years (Phase 2)	2005	88 million gallons	$130 million
Portland, OR[e]	20 years	2011	123 million gallons	$1.4 billion
Washington, DC[f]	20 years after construction begins	n/a	193.5 million gallons (proposed)	$1.9 billion (projected)

a Tudor Hampton, "Chicago Engineers Move Fast to Finish Epic Tunneling Feat," *Engineering News-Record,* August 18, 2003, http://www.enr.com/news/environment/archives/030818a.asp (accessed February 16, 2005).
b Metropolitan Water Reclamation District of Greater Chicago, *Combined Sewer Overflow Public Notification Plan*, http://www.mwrd.org/mo/csoapp/CSO/cso.htm (accessed December 15, 2005).
c Milwaukee Metropolitan Sewerage District, *Collection System: Deep Tunnel System*, http://www.mmsd.com/projects/collection8.cfm (accessed November 11, 2004).
d Milwaukee Metropolitan Sewerage District, *Overflow Reduction Plan*, http://www.mmsd.com/overflows/reduction.cfm (accessed November 11, 2004).
e Portland Bureau of Environmental Services, *Working for Clean Rivers*, http://www.portlandonline.com/bes/index.cfm?c=32123 (accessed November 15, 2004).
f D.C. Water and Sewer Authority, "WASA Proposes Plan to Control Combined Sewer Overflows to Local Waterways: Combined Sewer Long Term Control Plan," *The Reporter,* Summer 2001.

Street planters in Portland, OR, are used in highly developed urban areas to introduce green space and manage stormwater runoff.
Photo courtesy of the Portland Bureau of Environmental Services

natural hydrologic function of areas that have been urbanized. Green infrastructure can also be used to limit development in sensitive headwaters regions and groundwater recharge areas to avoid the segmentation and isolation of natural environmental areas and resources.

Green infrastructure can be applied in many forms. It traditionally has been thought of as the interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas that maintain natural ecological processes.[6] In practice, installing green infrastructure means preserving, creating, or restoring vegetated areas and natural corridors such as greenways, parks, conservation easements, and riparian buffers. When linked together through an urban environment, these lands provide rain management benefits similar to natural undeveloped systems, thereby reducing the volume of stormwater runoff. With green infrastructure, stormwater management is accomplished by letting the environment manage water naturally: capturing and retaining rainfall, infiltrating runoff, and trapping and absorbing pollutants. For example, the Village Homes community in Davis, California, uses a system of vegetated swales and meandering streams to manage stormwater. The natural drainage system is able to infiltrate and retain a rainfall volume greater than the 10-year storm without discharging to the municipal storm sewer system.

Green infrastructure can be used to restore vegetation and green space in highly impervious city areas. Planting street trees and other urban forestry initiatives can reduce stormwater runoff because urban tree canopies intercept rainfall before it hits the pavement and is converted to stormwater. Trees with mature canopies can absorb the first half-inch of rainfall.[7]

Recently the concept of green infrastructure has been broadened to include decentralized, engineered stormwater controls. These green techniques are designed to mimic the functions of the natural environment and are installed to offset the impacts of urbanization and imperviousness. Green management techniques are used to minimize, capture, and treat stormwater at the location at which it is created and before it has the opportunity to reach the collection system. Engineered systems commonly used in urban areas include green roofs, rain gardens, rain barrels and cisterns, vegetated swales, pocket wetlands, and permeable pavements.

Most green stormwater controls actually consist of green growth, including vegetated systems like green roofs and rain gardens, but other "green"

Urban trees intercept rainfall before it hits the ground and is converted to stormwater runoff.
PHOTO COURTESY OF THE LOW IMPACT DEVELOPMENT CENTER

controls, like permeable pavements, are not vegetated but designed to provide the water detention and retention capabilities of natural systems. Green infrastructure also encourages downspout disconnection programs that redirect stormwater from collection systems to vegetated areas or that capture and reuse stormwater, such as rain barrels. Downspout disconnection removes stormwater volume from collection systems and allows green infrastructure components to manage the runoff.

Green infrastructure offers numerous benefits when used to manage stormwater runoff. Many green techniques reduce both stormwater volume and pollutant concentrations and, in contrast to conventional centralized controls, provide flexibility in how and where stormwater management is accomplished. The use of green infrastructure protects natural resources and lessens the environmental impacts of development by not only addressing stormwater, but also by improving air quality and community aesthetics.

1. Stormwater volume control and pollutant removal. Green infrastructure is effective for managing stormwater runoff because it is able to reduce the volume of stormwater and remove stormwater pollutants. Reducing the amount of urban runoff is the most effective stormwater pollution control. This reduces the amount of stormwater discharged from separate stormwater sewer systems and aids combined sewer systems by decreasing the overall volume of water entering the system, thus reducing the number and size of overflows. Another large benefit of green infrastructure is that nearly every green technique results in the removal of stormwater pollutants. The natural processes employed by green infrastructure allow pollutants to be filtered or biologically or chemically degraded, which is especially advantageous for separate storm sewer systems that do not provide additional treatment before discharging stormwater. The combination of runoff reduction and pollutant removal is an effective means of reducing the total mass of pollution released to the environment. Because of this, open areas and buffer zones are often designated around urban streams and rivers to provide treatment and management of overland flow before it reaches the waterway.

2. Decentralized, flexible, site-specific solution. Green infrastructure differs from other stormwater management methods because it provides the opportunity to manage and treat stormwater where it is generated. This decentralized approach allows green infrastructure

A RiverSafe RainBarrel installed at the Jane Holmes nursing residence in Pittsburgh, PA, by the Nine Mile Run RainBarrel Initiative. PHOTO COURTESY OF RIVERSIDES

techniques to be installed at numerous locations throughout the city. Green infrastructure is flexible, allowing it to be applied in a wide range of locations and circumstances, and can be tailored to newly developed land or retrofitted to existing developed areas. This enables green infrastructure to be used on individual sites or in individual neighborhoods to address localized stormwater or CSO problems, or incorporated into a more widespread municipal stormwater management program.

3. Green design and the development problem. Projected population growth and development will strain an aged and often inadequate infrastructure system by introducing new areas of imperviousness and additional volumes of stormwater. Strategies will need to be adopted to manage urban growth and its impacts on water quality. The use of green infrastructure offers an alternative to existing development patterns and a new method of developing urban areas. Green infrastructure currently is being used to manage existing stormwater problems, but has the potential to significantly effect how future development contributes to stormwater and sewer overflow problems by preserving and incorporating green space into newly developed areas and by addressing the established connection between imperviousness and stormwater pollution.

4. Ancillary benefit. Green infrastructure is also attractive because it can be used to achieve multiple environmental goals. Funds spent on conventional stormwater management are used only for water infrastructure. In addition to stormwater management benefits, green infrastructure improves air quality by filtering air pollution and helps to counteract urban heat island effect by lowering surface temperatures. For example, many of the green infrastructure projects in Chicago, while also providing stormwater management, were initially installed to mitigate urban temperature increases and improve energy efficiency. Green infrastructure also improves urban aesthetics, has been shown to increase property values, and provides wildlife habitat and recreational space for urban residents. This multi-benefit environmental approach ultimately provides control programs that are more diverse and cost-effective than projects aimed solely at stormwater control.

CHAPTER 4

Economic Benefits of Green Solutions

The cost of stormwater control is a major factor in the successful implementation of pollution control programs. A large investment is required to adequately address CSOs and stormwater runoff. In addition to the $56 billion necessary to control CSOs, the Environmental Protection Agency (EPA) has identified $6 billion of documented needs for municipalities to develop and implement stormwater management programs required by the Phase I and II stormwater regulations, as well as $5 billion in documented needs for urban runoff control.[1,2] However, the EPA estimates that while $5 billion has been documented, up to $16 billion may be needed for urban runoff control.[3] These costs present a significant burden to municipal governments challenged with funding these programs.

Of course, natural stormwater retention and filtration is provided by Mother Nature for free. The high costs associated with urban stormwater result from the destruction of free, natural stormwater treatment systems—trees, meadows, wetlands, and other forms of soil and vegetation. For example, researchers at the University of California at Davis have estimated that for every 1,000 deciduous trees in California's Central Valley, stormwater runoff is reduced nearly 1 million gallons—a value of almost $7,000.[4] Clearly, preserving trees reduces polluted stormwater discharges and the need for engineered controls to replace those lost functions. When those trees are cut down and their functions are lost, those costs are passed on to municipal governments, which then pass them on to their citizens. So, while the bulk of this report is about how to integrate green infrastructure into the developed world, protecting and enhancing those areas that have not yet been developed is often the cheapest, most effective way to keep contaminated stormwater out of urban and suburban streams.

The Nine Mile Run RainBarrel Initiative used 500 RainBarrels to achieve CSO reduction for the ALCOSAN treatment plant in Pittsburgh. PHOTO COURTESY OF RIVERSIDES

THE COSTS OF BUILDING GREEN IN NEW DEVELOPMENTS

Green infrastructure in many instances is less costly than conventional stormwater management programs or centralized CSO approaches and may provide an opportunity to decrease the economic burden of stormwater management. Studies in Maryland and Illinois show that new residential developments using green infrastructure stormwater controls saved $3,500 to $4,500 per lot (quarter- to half-acre lots) when compared to new developments with conventional stormwater controls.[5,6] These developments were conceived and designed to reduce and manage stormwater runoff by preserving natural vegetation and landscaping, reducing overall site imperviousness, and installing green stormwater controls. Cost savings for these developments resulted from less conventional stormwater infrastructure and paving and lower site preparation costs. Importantly, in addition to lowering costs, each of the sites discharges less stormwater than conventional developments. Adding to the cost savings, developments utilizing green infrastructure normally yield more lots for sale by eliminating land-consuming conventional stormwater controls, and lots in green developments generally have a higher sale price because of the premium that buyers place on vegetation and conservation development.[7,8]

OUTFITTING EXISTING DEVELOPMENTS WITH GREEN INFRASTRUCTURE

The economics of retrofitting existing urban areas with stormwater controls differ from new development. Urban stormwater retrofits can be expensive and complicated by space constraints, although this is not always the case. Based upon the costs of their pilot projects, city officials in Seattle and Vancouver (discussed in the case studies on pages 29 and 33), believe that the costs of future green infrastructure installations will be similar to or slightly more than conventional stormwater controls.[9,10] The analysis conducted by the city of Vancouver indicates that retrofitting green infrastructure into locations with existing conventional stormwater controls will cost only marginally more than rehabilitating the conventional system, but introducing green infrastructure into new development will cost less.[11] However, while green infrastructure may be more expensive in some instances, municipalities believe that the additional benefits of green controls—including the creation of more aesthetic city space and the significant reduction in water pollution—justify the added cost. In addition, green infrastructure can be incrementally introduced into urban environments, allowing the costs to be incurred over a longer period of time.

TABLE 6: Cost of Conventional Urban Stormwater and CSO Controls[a]

Control	Cost Equation[b]	Cost to Manage 10 Million Gallons
Surface storage	$C = 5.184V^{0.826}$	$35 million
Deep tunnels	$C = 7.103V^{0.795}$	$44 million
Detention basins	$C = 62,728V^{0.69}$	$300,000
Retention basins	$C = 69,572V^{0.75}$	$390,000

[a] James Heaney, et al., *Costs of Urban Stormwater Control*, National Risk Management Research Laboratory, Office of Research and Development, EPA-600/R-02/021, January 2002.

[b] Cost equations adjusted to 2005 dollars. Volume equals millions of gallons. Cost for surface storage and deep tunnels is millions of dollars.

The EPA has developed cost curves for conventional urban stormwater controls relating stormwater storage capacity to control cost. The costs in Table 6 do not include any associated costs for construction and infrastructure. These costs represent the generally accepted costs of stormwater control and provide a baseline to which green infrastructure costs can be compared.

In many instances, green infrastructure costs compare favorably with the costs of conventional controls. However, cost comparisons for individual, small-scale retrofit projects are not likely to favor green controls. In urban areas, green infrastructure will be most cost-effective when it is incorporated as part of an overall redevelopment effort or when large improvements to infrastructure are required. In these instances, the costs of green infrastructure are minimized relative to the scope and costs of the overall project. While green infrastructure may be more costly than conventional stormwater or CSO controls in certain instances, the added costs should be weighed against the enhanced stormwater control and other environmental benefits gained from their use.

CHAPTER 5

Policy Recommendations for Local Decision Makers

Although green infrastructure has been shown to reduce stormwater runoff and combined sewer overflows and improve water quality, its adoption across the country has been slow. Cities that have incorporated green infrastructure into their stormwater management programs have often done so because of direct efforts to encourage alternative stormwater approaches. The following recommendations can be used to encourage the use of green infrastructure in municipalities.

1. Get development right the first time. Reducing or preventing stormwater runoff is the most effective way to minimize pollution because it prevents pollutants from being transported to water bodies. Incorporating green infrastructure into the earliest stages of community development can negate or limit the need for larger-scale, more expensive stormwater controls. Minimizing imperviousness, preserving existing vegetation, and incorporating green space into designs all decrease the impact that urbanization has on water quality. Used in this way, green infrastructure design is a more cost-effective strategy, often costing less to develop per lot while yielding more lots at an increased sale price.[1,2]

2. Incorporate green infrastructure into long-term control plans for managing combined sewer overflows. Cities with combined sewer systems are required to develop long-term plans to reduce sewer overflows enough to meet water quality standards.[3] Green infrastructure has proven to be valuable in reducing inflows into combined sewer systems and should be integrated into such plans. Rather than relying solely on conventional, centralized storage projects to reduce CSO volumes, municipalities should considering using green techniques, which can be integrated into redevelopment projects and infrastructure repairs and upgrades. Each year Portland, Oregon's downspout disconnection program diverts 1 billion gallons of stormwater from the collection system and has been used to help alleviate localized combined sewer system backups in city neighborhoods.[4]

3. Revise state and local stormwater regulations to encourage green design. Most state and local stormwater regulations focus on peak flow rate control. To encourage more effective stormwater management, these regulations should be revised to require minimizing and reducing impervious surfaces, protecting existing vegetation, maintaining predevelopment runoff volume and infiltration rates, and providing water quality improvements. These requirements encourage green infrastructure because it can meet each of these objectives. Portland, Oregon, requires on-site stormwater management for new development and redevelopment in both CSO and separate sewer areas of the city and encourages use of green infrastructure to comply with the regulation (more details about Portland's development regulations can be found in the case study on page 24).

New Jersey's stormwater management standards require 300-foot riparian buffers and stipulate a preference for nonstructural best management

The vegetated infiltration basins in the Buckman Heights Apartments courtyard in Portland, OR, receive and infiltrate stormwater from building roofs and sidewalks.
Photo courtesy of Portland Bureau of Environmental Services

practices (BMPs). These standards also institute water quantity as well as *quality* regulations. The water quantity standards require no change in groundwater recharge volume following construction and that infiltration be used to maintain pre-development runoff volumes and peak flow rates. Any increase in runoff volume must be offset by a decrease in post-construction peak flow rate. Water quality standards require a reduction in stormwater nutrient loads to the "maximum extent feasible" and total suspended solids (TSS) reductions of 80%. If the receiving water body is a high-quality water or tributary, the required TSS reduction is 95%.[5]

Berlin, Germany, has incorporated the Green Area Factor (GAF) into its regulations. Based on land use and zoning, the GAF sets a greening target for each property that provides the required ratio of vegetated elements to impervious surface. Once property owners apply for a building permit, they are required to satisfy the green target goal. Property owners select green infrastructure practices from an approved list and determine compliance by calculating the proportion of the property dedicated to the greening target. Selected green infrastructure practices are weighted according to their effectiveness at meeting environmental goals.[6]

To date, the U.S. federal government has declined to set performance standards for stormwater discharges from development or to add specifics to the "maximum extent practicable" standard set by the Clean Water Act for discharges from municipalities.[7] Since the federal government has failed to show leadership in this area, state and local entities must do so.

4. Establish dedicated funding for stormwater management that rewards green design. Adequate funding is critical for successful stormwater management programs. The billions of dollars necessary to mitigate stormwater pollution and combined sewer overflows require federal funding to augment state and municipal funding. To encourage its use, dedicated stormwater funding sources could identify a preference for green infrastructure or establish a funding scale based upon the relative use of green management techniques.

Many jurisdictions are creating stormwater utilities similar in function to water and wastewater utilities. Stormwater utilities allow for the assessment and collection of a user fee dedicated to a stormwater management program. Other jurisdictions dedicate a certain portion of collected local tax revenue to a stormwater fund. Establishing a dedicated fund removes stormwater management from general revenue funding, which is subject to variable funding and competes with other general taxation programs for money. Stormwater utilities, where allowed by enabling legislation, are popular because of the ability to determine a user rate structure and as a complement to incentive programs.[8,9]

5. Provide incentives for residential and commercial use of green infrastructure. Various incentives are already in place to encourage green infrastructure use in a number of cities. For example, Portland, Oregon, allows additional building square footage for buildings with green roofs, and Chicago provides a density bonus option for buildings with vegetative cover on the roof.[10,11] The city of Chicago also provided 20 $5,000 grants to install small-scale commercial or residential green roofs in early 2006.[12] Also beginning in 2006, Portland will provide up to a 35% discount in its stormwater utility fee for properties with on-site stormwater management.[13] Maryland provides credits for using green infrastructure when determining compliance with its stormwater regulatory requirements. Six different credits, all related to green infrastructure design, are available.[14] Several cities fund or subsidize downspout disconnection programs; Portland's program pays homeowners $53 per downspout disconnected or the city will disconnect the downspouts for free.

6. Review and revise local development ordinances. Local zoning requirements and building codes often inadvertently discourage the use of green infrastructure. Provisions requiring downspouts to be connected to the stormwater collection system prohibit disconnection programs and the use of green space for treatment of rooftop runoff. Mandatory street widths and building setbacks can unnecessarily increase imperviousness. Stormwater treatment requirements that favor centralized collection and treatment and prescribe treatment options offer little opportunity or incentive to use green infrastructure. Jurisdictions should review their applicable stormwater and wastewater ordinances and revise them to remove barriers to green infrastructure use and encourage more environmentally friendly regulations.[15]

7. Preserve existing trees, open space, and stream buffers. Too often, development removes nearly all existing natural features. Simply preserving trees, open space, and stream buffers and incorporating them into the community will help maintain water quality and manage stormwater runoff while lessening the need for additional stormwater controls. For example, New Jersey's stormwater management standards require 300-foot riparian buffers for new developments and redevelopments to protect water quality.[16]

8. Encourage and use smart growth. Smart growth can be used to limit sprawl and reduce the introduction of impervious surfaces. Smart growth policies can identify and protect sensitive environmental areas and direct development to locations with adequate infrastructure. By limiting sprawl and discouraging development in sensitive areas, smart growth may increase population densities and imperviousness in previously urbanized areas. Smart growth strategies should be coupled with green infrastructure to limit the stormwater and infrastructure effects of a potential increase in urbanization.

9. Get the community involved. Green infrastructure presents an opportunity for community outreach and education. Downspout disconnections, rain barrels, rain gardens, and green roofs may individually manage a relatively small volume of stormwater but collectively can have a significant impact. Portland's downspout disconnection program, for example, now diverts 1 billion gallons of stormwater away from the combined sewer system each year. Green infrastructure can be introduced into a community one lot at a time.

CHAPTER 6

Conclusion

While development, imperviousness, and urbanization have all taken their toll on downstream waterways, current stormwater and combined sewer overflow (CSO) mitigation efforts have failed to adequately address the problem or improve water quality because they are focused on end-of-pipe solutions. Current levels of development and imperviousness have degraded the nation's water quality, and future population growth and development will only exacerbate the problem. Additional development will make stormwater and CSO control solutions even more difficult and costly.

Green infrastructure offers the opportunity to not only develop new areas in a more environmentally efficient manner, but also to rehabilitate existing developed areas. Urbanization and development alter how water is distributed throughout the environment. Much greater volumes of stormwater are generated and discharged to receiving water bodies in developed areas than would be in the natural environment. Green infrastructure is providing measurable water quality improvements, most notably in stormwater volume reduction and CSO mitigation.

Some jurisdictions and cities have chosen green infrastructure as a preferable method of stormwater or CSO control based upon the specific needs and goals of the municipality. Others have installed green infrastructure to experiment with innovative stormwater or combined sewer overflow pilot projects. But all of these efforts demonstrate how it can be successfully integrated into urban communities.

A common driver among the cities using green infrastructure is compliance with regulatory requirements. The catalyst for Portland, Oregon's active program, for example, is a need to satisfy a number of environmental commitments, including a consent decree to limit CSO discharges, Safe Drinking Water Act standards influencing the quality of infiltrated stormwater, and emerging TMDL load and waste load allocations.[1] Other cities with combined sewer systems, or those that discharge stormwater to sensitive receiving waters, face similar requirements. Such regulations only increase the opportunities for creativity and willingness on the part of municipal decision makers to actively promote and introduce green infrastructure. City leaders are finding that when faced with the simultaneous challenges of regulatory requirements, infrastructure limitations, and financial constraints, green infrastructure often emerges as an appropriate means of satisfying each.

Another commonality among cities that have incorporated green infrastructure into their stormwater and CSO control plans is a commitment from city personnel. Whether elected officials or professional staff, these city leaders have recognized the benefits of green infrastructure and have successfully communicated its value to the public. These cities have also been innovative with their regulations and environmental policies, looking for existing and alternative avenues to encourage adoption of new stormwater and CSO control strategies. These efforts are often popular because of the public's positive response to the "greenscaping" that has accompanied the programs. As many local decision makers have already found, using green infrastructure in place of or in combination with less effective conventional methods of handling stormwater runoff can have benefits beyond just economic cost savings and reduced pollution.

CHAPTER 7

Case Studies

The following nine case studies illustrate efforts in North America to incorporate green infrastructure into urban stormwater and combined sewer overflow (CSO) control strategies, but this is not an exhaustive list. Several factors were used to select case-study cities. Among them were extent and duration of program efforts, availability of information and quantifiable data, geographic location, and the number and type of green infrastructure elements practiced.

Chicago, Illinois

Progressive environmental change through creative use of green infrastructure

Population: 2.9 million

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; permeable pavement; downspout disconnection/rainwater collection

Program elements: used for direct CSO control; established municipal programs and public funding

Historically, Chicago has been known more for its industrial horsepower than for progressive environmental ideas. Rivers like Bubbly Creek still bear the names they earned from the pollution they once contained. Stories of the city's sewage and pollution problems from as early as the 1880s still persist as popular legends. However, recent initiatives show that Chicago is emerging as a leader in green development, with an extensive green roof program, environmentally sensitive demonstration projects, and municipal policies that encourage decentralized stormwater management. The city has been particularly creative in its approach, using green infrastructure projects to not only manage stormwater runoff but also to address other environmental issues, such as mitigating urban heat island effects and improving energy efficiency in buildings.

Stormwater Collection Through Expansion of the Combined Sewer System

While the city's past environmental infrastructure projects have had dubious goals, the water quality of Lake Michigan, the city's drinking water source, has long been a concern. In the early 1900s, sewage and stockyard pollution from the Chicago River prompted Chicago officials to reverse the course of the South Branch of the river away from Lake Michigan and to the Mississippi River in an effort to improve the lake's water quality.[1] Water issues remain a concern for the city more than a century later. The city manages one of the largest wastewater collection and treatment systems in the world and contends with flooding, surface water quality impairment, and CSOs. Urban runoff challenges are exacerbated by the magnitude of infrastructure needed to serve Chicago's population. The city itself has over 4,400 miles of sewage infrastructure that cost about $50 million annually to maintain.[2] Approximately 3 million people call Chicago home, and the population of the entire six-county metro region surrounding the city exceeds 8 million; the region's population is projected to increase 20% by 2030.[3] Impervious surfaces cover approximately 58% of the city.[4]

Chicago has pursued a number of initiatives to improve stormwater collection, the most ambitious being a $3.4 billion project to collect and store stormwater and sewage from the combined sewer system.[5]

The green roof at Chicago's City Hall introduces vegetation in the heart of downtown. Temperatures above the Chicago City Hall green roof average 10° to 15°F lower than a nearby black tar roof. During the month of August this temperature difference may be as great as 50°F. The associated energy savings are estimated to be $3,600 per year.
Photo courtesy of Roofscapes, Inc.

In the 1970s, the Metropolitan Water Reclamation District began construction of the primary control solution for CSOs—the Tunnel and Reservoir Plan (TARP). In 2003, with only part of the system operational, more than 44 billion gallons of stormwater were captured; 10 billion gallons, however, were released as CSOs.[6] Approximately 2.5 billion gallons of storage are currently available in the TARP system. An additional 15.6 billion gallons of storage will be available when two more reservoirs are added to the system; construction is scheduled for completion in 2019.[7,8] When complete, the system will handle most of Chicago's CSO discharges, storing combined runoff and sewage until it can be sent for secondary treatment at a wastewater treatment plant.

Chicago's Green Roof Program

Although the Metropolitan Water Reclamation District has committed to this massive public works project, the city has also pursued several initiatives to install green infrastructure that promotes on-site stormwater management, including green roofs, permeable paving projects, rain barrels, and green buildings. Much of this investment in green infrastructure has paralleled the increase in population and building within the city over the last decade. And, unlike the past, the Chicago River is now seen as a public amenity rather than a liability.

Chicago's thriving green roof program began with a 20,300 square foot demonstration roof on its own city hall. The green roof retains more than 75% of the volume from a one-inch storm, preventing this water from reaching the combined sewer system.[9] The program has led to more than 80 green roofs in the city, totaling over one million square feet.[10] A 2003 Chicago Department of the Environment study found that runoff from green roof test plots was less than half of the runoff from conventional stone and black tar roof plots; the difference was even larger for small storms. The city encourages the use of green roofs by sponsoring installations and demonstration sites and by providing incentives. A density bonus is offered to developers who cover 50% or 2,000 square feet (whichever is greater) of a roof with vegetation. In early 2006, the city provided 20 $5,000 grants for green roof installations on small-scale commercial and residential properties.[11]

Other Green Infrastructure Innovations: Chicago's Citywide Commitment

Chicago has employed other green technologies to reduce urban runoff. To address localized flooding caused by runoff from one alley, the city removed the asphalt from the 630 foot long, 16 foot wide alley and replaced it with a permeable paving system. Now, instead of generating stormwater runoff, the alley will infiltrate and retain the volume of a three-inch, one-hour rain event.[12] The permeable pavement requires little maintenance and has a life expectancy of 25 to 35 years.[13] In this same ward, vegetated swales are also being used for stormwater management.

In June 2004, Chicago has embarked on a city-wide green building effort. Chicago Mayor Richard M. Daley presented The Chicago Standard, a set of construction principles designed for municipal buildings. The standards are based on the Leadership in Energy and Environmental Design (LEED™) Green Building Ration System[14] and emphasize sustainability, water efficiency, energy effects, and indoor air quality as well as stormwater management. For both the green roof and green building efforts, Chicago has created municipal demonstration projects to develop professional expertise in the city on these technologies.

Chicago Center for Green Technology. The centerpiece of the city's green building efforts is the Chicago Center for Green Technology. The Chicago Department of Environment transformed this property from a 17-acre brownfield full of construction debris to the first municipal building to receive the LEED™ platinum rating.[15] The 34,000 square foot center serves as an educational facility and rental space for organizations and businesses with an environmental commitment. Four 3,000 gallon cisterns capture stormwater that is used for watering the landscaping. The site also features a green roof, bioswales, permeable paving, and a rain garden. Chicago Department of Environment models indicate that Green Tech's stormwater management technologies retain more than 50% of stormwater on site—for a three-inch storm, the site releases 85,000 gallons of stormwater to the sewer system instead of the expected 175,000 gallons.[16] The success of the Green Tech project spurred several other green building projects, including three new green libraries; a new police station to be monitored for a national case study; green renovations on a firehouse and police headquarters; and the Green Bungalow Initiative, a pilot project to affordably retrofit four of Chicago's historic bungalows with green technologies and monitor any corresponding energy savings. The program has thus far shown average energy savings for the green bungalows of 15% to 49%.[17]

The city has also pursued public outreach programs, engaging homeowners through its recent rain barrel and rain garden programs. In the fall of 2004 city residents purchased more than 400 55-gallon rain barrels for $15 each.[18] The program cost the city $40,000 excluding city labor. The Department of Environment estimates the pilot project has the potential to divert 760,000 gallons annually from the combined sewer system, a relatively small number compared to the total amount of stormwater runoff in the city. However, the program was targeted to areas with a high frequency of basement flooding, meaning the program may have a more significant impact in these localized areas. Since the water in rain barrels can be used for other purposes such as landscaping, this program has additional conservation benefits as well. The city also began a complementary rain garden program, planting four rain gardens along with signage explaining benefits.

Chicago has also complemented its ground-level initiatives with two studies on the effectiveness of green infrastructure technologies. The first is the monitoring study of the green roof box plots. The second is a 2004 Department of Environment Stormwater Reduction Practices Feasibility Study that used hydraulic modeling to assess the effectiveness of best management practices for the Norwood Park sewershed. The study found that downspout disconnection would achieve peak flow reductions in the 1,370-acre area by 30% for a six-month or one-year storm if all homes in the 80% residential area disconnected their downspouts from the sewer system.[19,20] This would potentially reduce peak flow in the CSO outfall pipe by 20% and water levels in the sewer system by eight inches to two feet. The study also showed that three-inch and six-inch-deep rain gardens installed at each home could reduce total runoff by approximately 4%

and 7%, respectively, for the same six-month or one-year storm events.

For Additional Information

Chicago Department of the Environment: http://egov.cityofchicago.org/city/webportal/portalEntityHomeAction.do?entityName=Environment&entityNameEnumValue=05

Milwaukee, Wisconsin

Investing in green infrastructure to improve water quality

Population: 587,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; wetlands, riparian protection, or urban forests

Program elements: used for direct CSO control; established municipal programs and public funding

Like many municipalities with a combined sewer system, Milwaukee has a history of exposure to frequent CSO events and was faced with finding a viable overflow control strategy. To reduce the number of CSOs and their impact on the water quality of Lake Michigan and its tributaries, the Milwaukee Metropolitan Sewerage District (MMSD), the regional wastewater treatment agency, built a deep tunnel storage system in the 1980s and 1990s. MMSD invested $3 billion during this period to reduce overflows. As a complement to this large capital investment, MMSD is investing in green infrastructure projects to reduce stormwater inflow into the combined sewer system and mitigate stormwater runoff.

MMSD manages wastewater from 28 municipalities with a combined population of about 1.1 million people in a 420 square mile service area. All 28 communities own and operate their own sewer systems, which drain into 300 miles of regional sewers owned by MMSD. The district's two wastewater treatment plants each process about 80 to 100 million gallons of wastewater on a dry day.[21] Treated wastewater is discharged to Lake Michigan, which also serves as the city's drinking water supply.[22] The city of Milwaukee and the village of Shorewood own and operate combined sewers, which make up 5% of MMSD's total service area. Combined sewer overflow points are located along rivers that flow into Lake Michigan.[23] The $2.3 billion Deep Tunnel System project, completed by MMSD in 1994, provided 405 million gallons of underground sewer storage. Begun in 1986, the 19.4-mile-long system collects and temporarily stores the large quantities of stormwater and wastewater that are conveyed through the sewers during wet weather events.[24]

Prior to the system becoming operational, Milwaukee averaged 50 to 60 CSO events a year, which discharged 8 to 9 billion gallons of sewage and stormwater. The Deep Tunnel System was designed to limit CSOs to 1.4 events per year; in the first 10 years of operation, from 1994 until 2003, annual average CSO discharges were 1.2 billion gallons from 2.5 average annual events.[25,26] Heavy rains in the spring of 2004 resulted in 1 billion gallons of CSO discharges during a two-week period.[27] Although the Deep Tunnel System has substantially reduced CSO events, excessive quantities of stormwater can still trigger overflows, and MMSD has committed an additional $900 million to an overflow reduction plan.[28]

Milwaukee's Green Infrastructure Approach

As an additional strategy to limit CSO discharges, MMSD has begun to install green infrastructure within the combined sewer area to decrease the volume of stormwater entering the system. One of the first initiatives was a disconnection program that redirected building downspouts from the combined sewer system to rain barrels. Overflow from the rain barrels is directed to pervious areas and rain gardens. In a cooperative cost-sharing arrangement with public entities and private businesses in the city, MMSD partnered with others to install more than 60 rain gardens to receive and treat roof runoff. The total combined cost of these pilot projects was approximately $170,000.[29]

The Highland Gardens housing project. Seven green roofs have been installed in the Milwaukee region.

The green roof atop MMSD's headquarters, shown just after installation, demonstrates how stormwater flow into the city's sewer system could be reduced.
PHOTO COURTESY OF MMSD

One of these is at the Highland Gardens housing project, a 114-unit mid-rise for senior citizens and people with disabilities. A 20,000 square foot green roof was installed at a cost of $380,000. The roof will retain 85% of a two-inch rainfall. The remaining 15% of the water volume is directed to rain gardens and a retention basin used for on-site irrigation.[30] These management strategies prevent stormwater from being discharged to the collection system.

MMSD has installed or helped finance four other green roofs to reduce stormwater runoff. The first was a 3,500 square foot structure on the roof of MMSD's headquarters building in downtown Milwaukee. Native species of grasses and flowering plants were selected for the roof vegetation. The cost of the green roof was just under $70,000.[31] A second green roof was installed on the University of Wisconsin-Milwaukee's Great Lakes Water Institute. MMSD contributed $110,000 of the $233,000 needed to install the 10,000 square foot unit. A third green roof was installed on the city's Urban Ecology Center, with MMSD contributing $40,000 of the total project cost. The fourth green roof is at the Milwaukee County Zoo, to which MMSD contributed half of the $73,000 cost.[32]

Measuring the Effectiveness of Milwaukee's Green Infrastructure

The rain gardens and MMSD-financed green roofs were installed in 2003 and 2004. A monitoring program evaluating the effectiveness of the systems at managing stormwater is being conducted with initial results expected in early 2006. To determine the potential impacts of the green infrastructure program, MMSD conducted a modeling analysis. The modeling effort showed that application of downspout disconnection, rain barrels, and rain gardens in residential areas would reduce each neighborhood's contribution to the annual CSO volume 14% to 38%. Additional modeling results showed the volume of stormwater sent to the treatment plants from the neighborhoods was reduced 31% to 37% and stormwater peak flow rates were reduced 5% to 36%, depending upon the size of the rain event.[33] (The model assumed a high participation rate for residential areas. Volume and peak flow reductions would not be as great with a lower participation rate.)

The effect of green infrastructure in commercial areas was also modeled. The use of green roofs, rain gardens, and green parking lots is predicted to reduce commercial area contributions to CSO volume by 22% to 76%, but would not decrease—and could even increase—the volume of stormwater sent to the treatment plants. Stormwater peak flow rates from commercial areas are predicted to be reduced 13% to 69% with the introduction of green infrastructure.[34]

MMSD has allocated more than $5.5 million for fiscal years 2002 through 2014 for rain water rerouting programs intended to prevent stormwater from entering the combined sewer system. An additional $4.5 million has been allocated for fiscal years 2003 through 2009 to promote, install, and monitor green infrastructure practices aimed at reducing stormwater.[35]

MMSD is also purchasing and protecting open space to reduce stormwater runoff and improve water quality in its urban waterways. The capital budget designates funds to purchase privately owned wetlands to prevent development and establish conservation easements. More than $27 million has been allocated for fiscal years 2000 through 2011. As of fiscal year 2005, 775 acres had been purchased in three watersheds for just under $5.8 million.[36] A greenways initiative will identify lands that compose greenway connections, linkages between sites, delineated environmental corridors, isolated natural wetlands, open space, and riparian wetlands. Linkages between these areas will be acquired to protect and establish greenways along jurisdictional waterways or their tributaries. Preferential consideration is given to land that provides stormwater or flood management benefit.[37]

For Additional Information

Milwaukee Metropolitan Sewerage District:
http://www.mmsd.com/home/index.cfm

Pittsburgh, Pennsylvania

"Restorative development" beautifies land and cleans water

Population: 325,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; downspout disconnection/rainwater collection; wetlands, riparian protection, or urban forests

Program elements: used for direct CSO control

Pittsburgh is a postindustrial city struggling to repair the environmental degradation wrought by its manufacturing past. The city's development as a steel powerhouse and mining center is intrinsically tied to its geographic and hydrologic setting. The city has developed around the confluence of three rivers—the Allegheny, the Monongahela, and the Ohio. Over the past two decades Pittsburgh's metropolitan population has declined, partly due to the collapse of the steel industry. The city's population decreased by 9.5% in the 1990s and the entire metropolitan area saw a decline of 1.5%, trends that were significantly greater than other same-size cities in the northeastern central area.[38] The "steel city" is left with pollution nuisances like brownfields and slag heaps, as well as a shrinking urban center and a considerable sewage overflow problem.

It is precisely because of this industrial reputation and declining urban center that Pittsburgh has had the opportunity and the incentive to redevelop and reclaim large land parcels and turn them into greenways and parks. The restoration, described as "restorative redevelopment," is motivated by a desire to restore habitat, beautify land, increase parkland, and raise property values—in all, generally making Pittsburgh a more attractive city.[39] Pittsburgh's efforts in alternative stormwater management have been a combination of government-sponsored restoration of green space and privately funded demonstration sites. The impetus for Pittsburgh's green restoration comes largely from the private sector, charitable foundations, and citizens' groups.

Water Pollution from Pittsburgh's Sewer System

Pittsburgh clearly has a need for supplemental stormwater management projects. The city's stormwater runoff contributes to frequent CSOs. In 2003, red-flag advisories for impaired water quality were issued on 111 out of 139 summer recreation days (from May 15 to October 1). In 2004, 125 red-flag advisories were issued.[40] The metropolitan area contains more than 300 combined sewer outfalls and over 4,000 miles of underground pipes. Many of these outfalls are upstream of drinking water intakes. Solving Pittsburgh's wet weather sewage problems is a complicated problem that is

The green roof surrounding the executive offices on the Heinz 57 Center in Pittsburgh not only provides environmental benefits, but also creates green space for outdoor meetings and employee enjoyment 14 stories above the ground.
Photo courtesy of Roofscapes, Inc.

exacerbated by the fragmented nature of the collection and treatment system. While there is one treatment plant operated by the Allegheny County Sanitary Authority (ALCOSAN) in the metro area, there are 83 separate municipalities, each responsible for maintaining their own collection system. Many pipes are in a state of disrepair, and ALCOSAN estimates that repairing the system using traditional sewage infrastructure strategies will cost more than $3 billion. This investment includes an expansion of the wastewater treatment plant capacity over the next 20 years from 225 million gallons per day (mgd) to 875 mgd to reduce CSOs. However, 565 mgd of this increased capacity would only provide primary treatment.[41]

Against this troubled environmental background, the private sector and citizens' groups in Pittsburgh have taken an active role to design and implement green infrastructure projects. Several demonstration projects have focused specifically on stormwater capture or treatment.

Pittsburgh's Green Infrastructure Commitment

Pittsburgh's Phipps Conservatory and Botanical Gardens is undergoing a major expansion and, when complete, will boast over 15,000 square feet of green roofs.[42] The conservatory will capture rainwater from its glass roofs and store it in a cistern to be used later to regulate water levels in ornamental ponds. The facility will feature a green roof test garden and a 30-by-100-foot rain garden in a low-lying site near the impervious parking areas.[43]

The McGowan Institute for Regenerative Medicine, built on a brownfield site, collects rainwater from the roof for gray water needs and irrigation. The facility reuses 57% of rainwater falling on the site, retaining 168,000 gallons of stormwater annually.[44]

As a LEED™ Gold certified building, Pittsburgh's David L. Lawrence Center is the world's first certified green convention center. Through stormwater reclamation, the facility reduces its potable water use by approximately 60%. It has an in-house water treatment plant to recycle black water and features a stainless steel roof that reduces total suspended solids in stormwater runoff.[45] By capturing and reusing rainwater on-site, each of these projects decreases the amount of stormwater that would have otherwise entered the combined sewer system.

Nine Mile Run and Frick Park. One of Pittsburgh's key restoration efforts is the $7.7 million project currently under way at Nine Mile Run, one of the last remaining daylit streams in the city. [46] The stream flows underground through several neighborhoods and daylights in Frick Park, a 455-acre natural and recreation area. Before its confluence with the Monongahela River, Nine Mile Run collects stormwater runoff from a seven-mile watershed with 43% impervious surfaces.[47] A number of environmental problems contribute to the stream's impairment. To accommodate development, Nine Mile Run was culverted and no longer flows in its natural meandering pattern, inhibiting its function as a wildlife habitat. In wet weather conditions, stormwater discharges increased stream flow in Nine Mile Run, eroding much of the stream bank. The altered hydrology in the watershed leaves little water in the stream during dry weather conditions, making it unable to support aquatic life. The stream also borders a 238-acre mountain of slag; runoff from the slag increased the natural pH of the stream. As with most Pittsburgh waterways, Nine Mile Run is also the conduit for many combined sewer overflows.

The Army Corps of Engineers is undertaking the main portion of the project to clean up Nine Mile Run under authority of Section 206 of the Water Resources Development Act of 1996. The project is a large-scale effort that will include the construction of woody and herbaceous wetlands to provide both wildlife habitat and stormwater filtration. The stormwater management component of the project takes advantage of Pittsburgh's porous and permeable soils to capture recharge and attempts to prevent pollutants in stormwater from reaching the stream. In an effort to repair the stream and re-create more natural conditions, the new river design adds meanders and pool and riffle sequences, undoing channelization. The project also fits into the city of Pittsburgh's larger Riverfront Development Plan, which includes land conservation along stream banks to prevent runoff and erosion and increased set-asides for recreational trails along Nine Mile Run.[48] The restoration effort will add an estimated 100 acres to Frick Park.

The restoration would not be as effective without corresponding attempts to reduce sources of wet weather pollution to Nine Mile Run. The municipal contribution to the project, $2.7 million, is designated to repair sewer lines, preventing leakages due to old, failing pipes. The city has also partnered with a developer to transform the slag heap, a brownfield site, into a 710-home residential development. Aiding in this effort are groups like 3 Rivers Wet Weather Demonstration Program and the Nine Mile Run Watershed Association. The community groups commissioned an engineering study to determine where rain barrels would be most effective in reducing the stormwater runoff that contributes to CSOs. The organizations installed 500 large rain barrels (132 gallons each) in critical neighborhoods.[49] The groups focused on the educational component of the project to make homeowners aware of lot-level solutions to stormwater management.

For Additional Information

Nine Mile Run Watershed Association:
http://www.ninemilerun.org/

PORTLAND

Portland, Oregon

Making green infrastructure a policy priority

Population: 539,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; downspout disconnection/rainwater collection

Program elements: used for direct CSO control; established municipal programs and public funding

Portland has actively promoted funding and education for innovative stormwater management since 1998 and boasts numerous green applications throughout the city. These projects feature many types of green infrastructure technologies, including bioswales, green roofs, infiltration planters, and sustainable street design. The city has been at the leading edge of the green infrastructure movement and is beginning to accumulate significant data on the effectiveness of decentralized stormwater management technologies.

As with many cities, part of the motivation to achieve more successful stormwater strategies comes from a history of pollution and a desire to repair nearby ecosystems. One of Portland's primary

Vegetated curb extensions decrease stormwater runoff in Portland neighborhoods.
Photo courtesy of the Portland Bureau of Environmental Services

ecological concerns is the Willamette River, which in the course of its flow takes with it a considerable volume of combined sewer overflow. In 2004, Portland experienced 50 overflow events and discharged 2.8 billion gallons of combined overflow into local waterways.[50] In some areas, undersize combined sewers cause basement sewer backups, requiring homeowners to sanitize their basements after sewage backs up into their homes. Stormwater has also transported toxic pollution into area water bodies. Portland Harbor, the industrialized lower portion of the Willamette, was designated an EPA superfund site for contaminated sediments. Investigations into the contribution of overland stormwater flow and other sources of this heavy-metal pollution are under way.

Portland's Dual Approach to Managing CSOs

To alleviate these pressing CSO management problems, Portland has pursued a dual approach, expanding its public infrastructure and pursuing lot-level strategies to manage stormwater.[51] The "Big Pipe" is Portland's primary combined sewage control solution, adding capacity to the overloaded sewer system. In recent years, the city has made considerable progress toward reducing overflows. The constructed capacity, along with other projects, has virtually eliminated CSOs to the Columbia Slough, which discharges into the Willamette River, and has eliminated or controlled eight Willamette River CSO outfalls. When the projects are completed in 2011, CSOs to the Willamette will be reduced by 94%.[52] These strategies are estimated to cost around $1.4 billion and are funded by local sewer charges.[53]

To complement the large infrastructure projects, Portland is installing green infrastructure as an innovative stormwater management approach. Green infrastructure is gaining popularity in Portland for several reasons, including climate, development patterns, and policy institutionalization. Portland's rainfall occurs mostly in small frequent storms, exactly the type of precipitation event green infrastructure technologies are most successful at mitigating. About half of Portland's land area is impervious, 25% attributable to streets, and 40% attributable to rooftops.[54,55] These surfaces create an opportunity and a need for green infrastructure development.

Portland has also encouraged sustainable stormwater management through a series of policy initiatives. City code now requires on-site stormwater management for new development and redevelopment. Portland's stormwater manual encourages the use of green infrastructure techniques to meet this objective. Together, the city of Portland's Bureau of Environmental Services (BES) and the EPA jointly fund the Innovative Wet Weather Program, a grant program for stormwater management projects that focus on water quality improvement. In 2004, budgeted expenditures for a long list of proposed projects totaled almost $3 million.[56] New city-owned buildings are required to have a green roof that covers at least 70% of the roof area; the remaining roof area must be covered with Energy Star roofing material.[57] The city offers a zoning bonus, allowing for additional square footage for buildings featuring a green roof, and in 2006 it will begin offering a stormwater fee discount of up to 35% for properties with on-site stormwater management.[58,59] These programs are built upon the successful participation in the downspout disconnection program, in which homeowners can receive $53 per downspout disconnected from the combined sewer system. The city estimates that more than 45,000 households participate in the program, allowing infiltration of more than 1 billion gallons of stormwater annually.[60,61] The on-site stormwater management requirement, along with incentive programs for installing green infrastructure, will likely lead to more widespread applications throughout the city.

Street-level stormwater management. In 2003, Portland installed the Northeast Siskiyou Street vegetated curb extensions to capture stormwater while creating an attractive landscaped area. To assess the effectiveness of the technology and gather data for future projects, the city conducted flow tests to ensure water would be infiltrated in the right-of-way. The vegetated curb extensions reduced peak flow from a 25-year storm event (approximately two inches in six hours) by 88%.[62] This is enough retention to protect local basements from flooding. The curb extensions also reduced total runoff (2,000 gallons in the simulation) to the combined sewer system by 85%.[63] The project took about two weeks to install and cost approximately $15,000.[64] Portland has also installed curb extensions on Southeast Ankeny Street and is planning additional green street projects at the intersection of Southwest 12th Avenue and SW Montgomery Street and the intersection of Northeast 131st Avenue and Northeast Fremont Street.

Portland's "ecoroofs." In 1996, the first green roof in Portland was installed. In the years since, Portland has begun an initiative to install and monitor green roofs at sites throughout the city. The city prefers the term "ecoroofs" to illustrate that even in the dry season when roofs are not as green, the roofs can still perform well.[65] Portland also uses the term to emphasize the economic benefits of the vegetated technology. The city conducted extensive monitoring studies on Hamilton West Apartments, a 10-story building with two ecoroof components, one measuring 2,520 square feet and the other 2,620 square feet. Based on two years of monitoring data, BES found that the four- to five-inch thick, 25-pound-per-square-foot ecoroof retained 58% of rainfall, preventing it from becoming stormwater runoff. Monitoring has also shown that the ecoroofs absorb almost 100% of the rainfall from Portland's warm season precipitation events.[66]

Some of Portland's other interesting stormwater sites include the Oregon Museum of Science and Industry, where swaled medians were installed around the museum parking lot to capture stormwater. The museum saved $78,000 by installing the green infrastructure technology over a traditional collection system.[67] The Liberty Centre Parking Garage installed infiltration planters as a stormwater retrofit. These planters accept runoff from more than 36,000 square feet of impervious surfaces and can retain the entire volume of a storm slightly smaller than the typical two-year storm event. The cost for this retrofit was $75,500.[68] The Oregon Convention Center rainwater garden collects stormwater from 5.5 acres of roof area.[69] The garden simulates a mountain stream, doubling as an attractive landscape space. The project is designed to handle the runoff from a 25-year storm. A recent stormwater management project is a ring of interconnected bioswales around the New Seasons Market at Seven Corners Southeast Division Street. This project reduces impervious surfaces and will remove 1 million gallons of stormwater annually from the combined sewer system.[70] All of these projects will be eligible to apply for the stormwater fee discount when it is fully implemented in mid-2006.

New Directions in Portland's Green Infrastructure: The Stormwater Trading Program

The city was recently awarded a $288,000 U.S. EPA grant for a feasibility study to determine the viability of a stormwater trading program. As conceptualized, the trading program would allow developers who were unable to satisfy the on-site stormwater management requirement to privately finance or buy credits for stormwater mitigation elsewhere within the city, provided that the purchased credit met water quality and discharge volume requirements. The initial cost of the stormwater credits would likely be based on the cost of a publicly financed program. The first phase of the study will determine if the approach is economically beneficial and if the program can provide acceptable environmental results. If the trading approach is determined to be feasible, later phases of the study will outline the model approach, determine the geographic trading area, select appropriate best management practices, and develop economic models for program valuation. In later phases, the city also plans to demonstrate the operation of the trading system through pilot program implementation.[71]

For Additional Information

Portland Bureau of Environmental Services: http://www.portlandonline.com/bes

Rouge River Watershed, Michigan

Cleaning up the watershed with green approaches to stormwater management

Population: 1.5 million

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; permeable pavement; wetlands, riparian protection, or urban forests

The Rouge River Watershed in southeast Michigan covers nearly 450 square miles and is home to the historically industrial city of Detroit. Fifty percent of the watershed is urbanized, and more than 1.5 million people live within its boundaries.[72] As a tributary and major pollution source to the Detroit River, the Rouge River was designated an Area of Concern by the International Joint Commission in the Great Lakes.[73,74] With industrial and municipal wastewater discharges believed to be effectively permitted and controlled, the focus of the water restoration efforts in the watershed has shifted to addressing wet weather pollution. Stormwater runoff was responsible for creating excessive flow within the river, damaging stream banks and riparian habitat, introducing pollutants, and causing CSOs.

In 1992, the Wayne County, Michigan Department of the Environment initiated the Rouge River Project to address wet weather pollution within the watershed. The project is funded by U.S. EPA grants and municipal funding and serves as a national demonstration project for reclaiming degraded urban rivers.[75] An assessment of the watershed in the mid-1990s found that stormwater runoff had many deleterious effects on water quality and river health. Increased river flows from stormwater discharges had eroded 60% to 90% of the river banks on the Rouge River's major branches.[76] Soil washed from the river banks was deposited along the river bottom downstream, degrading natural stream habitats. Stormwater runoff and pollution had not only contributed to a decline in river fish populations, but also a number of consumption bans and advisories. Nutrient loadings caused seasonal decreases in river oxygen levels, and increased river bacteria counts and resulted in swimming advisories.[77]

Evaluating the most effective means of improving the water quality of the river, the Rouge River Project adopted a watershed-based approach for wet weather pollution control. The first step in this approach was the 1997 adoption of the Michigan NPDES General Stormwater Permit. The permit is unique because the watershed communities requested permission from the U.S. District Court overseeing the river cleanup to develop a draft permit acceptable to the communities and state and federal regulators. The

At more than 10 acres, the largest green roof in the world sits atop Ford's Rouge River Manufacturing Complex. The green roof is one component of a renovation designed to make the facility more environmentally sustainable. Photos courtesy of Green Roofs for Healthy Cities

consensus effort resulted in a watershed-based permit that required each community to develop a watershed management plan and stormwater pollution prevention initiative. The U.S. EPA has supported Michigan's request to continue to use the general permit in lieu of permits that would be required by the Phase II regulations.[78,79]

Watershed Restoration Through Green Infrastructure

Green infrastructure practices have been used as part of watershed management plans to address stormwater pollution. Although highly urbanized, more than 50 miles of riparian parklands are publicly maintained with the watershed.[80] Watershed restoration efforts have also included the use of created and existing wetlands for stormwater management. The Inkster Wetlands demonstration project uses 14 acres of wetlands adjacent to the Rouge River to treat stormwater before it enters the river. Three separate wetlands areas are part of the project and are composed of forested, emergent, scrub, and open water wetlands. Approximately nine of the 14 acres are constructed wetlands.[81] Prior to the project, discharge pipes routed stormwater past the existing wetlands and directly to the river. In addition to creating new wetlands for stormwater treatment, the demonstration project rerouted stormwater through the existing wetlands. The project was completed in 1997 at a cost of $465,000.[82] A five-year monitoring study evaluated the effectiveness of the wetlands at improving the quality of the stormwater runoff. In addition to dampening stormwater flows, the wetlands reduced concentrations of total suspended solids by 80%, total phosphorus by 70%, BOD by 60%, and heavy metals by 60%.[83]

Ford Motor Company's green roof. Located along the Rouge River, Ford Motor Company's 88-year-old, 600-acre Rouge River Manufacturing Complex in Dearborn, Michigan, recently underwent a $2 billion renovation. The renovation of Rouge River was unique because of Ford's decision to make the manufacturing plant a more environmentally sustainable facility. Green infrastructure was an important component of this effort. The complex includes a 450,000 square foot green roof to retain stormwater, lower energy costs, and extend roof life.[84,85] At over 10 acres, the green roof is the largest in the world and is anticipated to absorb the first inch of rainfall.[86] Vegetated swales, planted with indigenous species, are used throughout the site to reduce stormwater discharges and encourage infiltration. New trucks rolling off the assembly line are taken to an outdoor parking lot paved with permeable pavement. A two- to three-foot gravel storage bed beneath the lot filters pollutants from the stormwater and provides storage capacity.[87] The renovation of the site also included the planting of more than 1,500 trees, 20,000 bushes, and 85,000 flowering perennials.[88,89]

For Additional Information

Rouge River Wet Weather Demonstration Project: http://www.rougeriver.com

Seattle, Washington

Using green infrastructure solutions to save sensitive waters

Population: 587,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; downspout disconnection/rainwater collection

Program elements: used for direct CSO control; established municipal programs and public funding

Located along the shores of Puget Sound and home to rivers and creeks that serve as salmon spawning grounds, Seattle is connected to the vitality of its water bodies. The 84 square mile city is highly urbanized and has an average annual rainfall of 37 inches, which occurs primarily during the region's wet months from November to February.[90] Stormwater runoff has long been identified as a threat to the aquatic habitat of Puget Sound and the sensitive salmon streams. Controlling stormwater in the urban watersheds is a complicated task in a city where the majority of development predated stormwater regulations.[91] Consequently, water quality in the region has been impaired and the hydrology of rivers and creeks has been altered because of increased stormwater volumes and flow rates.

Using Natural Drainage Systems to Manage Stormwater Runoff

In the late 1990s, the city decided to install green infrastructure in an effort to mitigate urban stormwater runoff. Seattle Public Utilities (SPU), the agency responsible for water and stormwater programs, developed pilot projects using the concept of natural drainage systems (NDS). The NDS program's goal was to develop a stormwater management system that resembled natural hydrologic functions lost to urbanization.[92] The initial outcome of this program has been innovative neighborhood and stormwater system designs with results exceeding initial expectations.

The Viewlands Cascade. Early this decade four NDS pilot projects were completed and have since been monitored to determine their effectiveness. These projects were designed to reduce stormwater runoff to Pipers Creek, a tributary of Puget Sound and home to wild coho salmon and both steelhead and cutthroat trout. The Viewlands Cascade was the first of these projects and uses a series of 16 stepped vegetated cells to collect stormwater runoff from approximately 72 acres. The system was designed to reduce the volume and flow rate of stormwater runoff by encouraging infiltration and vegetative uptake. The estimated construction cost was $225,000.[93]

Hydrologic monitoring of the Viewlands Cascade indicates that the system decreases stormwater runoff volume 75% to 80% and peak flow rates by 60%.[94] Performance is greater than average for small and medium storm events and considerably less than average for large events. Overall, during a three-year monitoring period, half of the total volume of stormwater that entered the cascade system was retained and not discharged to Pipers Creek.[95] The Viewlands Cascade replaced a partially concrete drainage ditch. Modeling indicates that the new cascade system retained three times as much stormwater volume and held stormwater in the system over 2.5 times longer when compared to the original drainage ditch.[96] In addition, the water quality of the stormwater discharged has improved because of the natural vegetation's biological and chemical removal capabilities.

The SEA Street Project. The 2nd Avenue Street Edge Alternative (SEA) Street project was the second pilot project and one of the better known green infrastructure projects in the country. The project redesigned an entire 660-foot block of 2nd Avenue with a number of green infrastructure techniques, with the goals of reducing stormwater runoff and providing a livable community. SPU worked collaboratively with residents during the process to develop the final street design.

The original 25-foot-wide straight street was replaced with a 14-foot-wide curvilinear street. Vegetated swales, designed to infiltrate and treat

This private residence in Seattle, WA, incorporates stormwater controls and vegetative gardens.
Photo courtesy of Seattle Public Utilities

stormwater, were installed within the right-of-way on both sides of the street. Street parking was replaced with designated angled parking slots, and a sidewalk was installed on one side of the street. The final constructed design reduced imperviousness more than 18% and added 100 evergreen trees and 1,100 shrubs.[97] The original construction cost bid was $244,000. The final total project cost was approximately $850,000, with the substantial increase attributed to costs associated with significant community outreach and coordination as well as design modifications to address community concerns.[98]

Hydrologic monitoring of the project indicates a 99% reduction in total potential surface runoff. Stormwater retention capacity has increased since the project was completed. Stormwater runoff has not been recorded at the site since December 2002, a period that included the highest ever 24-hour recorded rainfall at SeaTac Airport. Reasons for the increased stormwater retention are unclear, but it is speculated that the maturing vegetation takes up more water and increasingly aids infiltration.[99]

Design estimates originally anticipated that the site would attenuate up to 0.75 inches of rain. Monitoring has indicated that the site is able to attenuate a substantially larger rainfall amount. The SEA Street design was expected to reduce total stormwater discharge from the site by 42% and by 66% when compared to a conventional Seattle street with curb and gutter. A modeling analysis indicates that if a conventional curb and gutter system had been installed along 2nd Avenue instead of the SEA Street design, 98 times more stormwater would have been discharged from the site.[100] The SEA Street design has been so popular that local residents have requested that their traditional streets be retrofitted.

Both the Viewlands Cascade and 2nd Avenue SEA Street have been successful at managing stormwater runoff. There is, however, a large functional difference between the two projects. The Viewlands Cascade collects and treats runoff from a designated drainage area once it has been generated as an end-of-pipe treatment focused on reducing peak stormwater flows; the 2nd Avenue SEA Street is designed as a source control strategy intended to prevent the discharge of stormwater from the project site. The success of both projects demonstrates that green infrastructure is adaptable and may be used in various capacities. SPU has incorporated both designs into a number of projects recently completed or currently under construction.

The 110th Street Cascade. The 110th Street Cascade is also located in the Pipers Creek Watershed and is designed to treat runoff from a 28-acre drainage basin. Monitoring at the cascade is measuring flow rate and water quality.[101] Completed in early 2005, the Broadview Green Grid project reconstructed an entire neighborhood's drainage system in a 32-acre sub-basin in the Pipers Creek Watershed. The project used both SEA Street designs and cascade systems. The north-south streets in the project area were reconstructed using the SEA Street design. Each of these streets discharges to an east-west flowing system of vegetated swales and cascades.[102] The Pinehurst Green Grid, a second neighborhood scale reconstruction project, is in the construction phase.

The High Point Redevelopment is under construction and is one of the city's largest recent redevelopment efforts. Forty blocks will be redeveloped in a 129-acre mixed income housing area to eventually contain 1,600 units. The project area is 65% impervious and densely populated. The NDS design will incorporate approximately 22,000 feet of vegetated and grassy swales and is scheduled for completion in 2007.[103] In 2004, the NDS program received an Innovations in American Government Award from Harvard University's Kennedy School of Government. The award, accompanied by a $100,000 grant, highlights effective government projects.[104]

In addition to the NDS design concept, the city of Seattle also promotes rainwater harvesting. The 327,000 square foot King Street Center uses three 5,400 gallon tanks to collect rainwater from the building's roof. The collected rainwater is filtered and pumped through a dedicated piping system for toilet flushing and landscaping needs. The system provides 1.4 million of the approximately 2.2 million gallons—60%—of the toilet flushing water needed annually and reduces the stormwater discharged from the building by the same amount.[105]

In March 2005, SPU began the second phase of a subsidized rain barrel and cistern program intended to distribute the rainwater-harvesting devices throughout the city. The first phase of the program distributed 1,500 rain barrels at a reduced rate to private homeowners.[106] In addition, SPU initiated the Freemont rainwater harvesting study on March 1, 2005. The project, conducted with the cooperation of 10 single-family residential homeowners in the combined sewer area, is studying the effectiveness of slowly draining cisterns to retain peak stormwater runoff. The costs of the program will be compared to the costs of detaining an equal volume of wastewater in centralized vaults before being metered out to the municipal wastewater treatment plant. The project will also test the acceptance and effectiveness of rain gardens in the residential area.[107]

Another approach to mitigating stormwater runoff is green roofs. The city of Seattle has installed four green roofs over the past several years. In order to evaluate the ability of these green roofs to reduce stormwater runoff, the city is embarking on a multiple-year data collection initiative. The goal is to provide information that can be used to modify the city's stormwater code and potentially provide incentives to encourage the construction of green roofs in both public and commercial applications.

Seattle has also begun an urban forestry initiative to reduce stormwater runoff. A master plan for planting trees on city streets implemented in 1999 established a goal of increasing the city's tree canopy from 27% of city surface area to 40%.[108]

For Additional Information

Seattle Public Utilities Natural Drainage Systems: http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Projects/Natural_Drainage_Systems/NATURALDR_20031203121352.asp

Toronto, Ontario, Canada

A long-term "Water Pollution Solution" focuses on green infrastructure

Population: 2.5 million

Type of green infrastructure used: green roofs; downspout disconnection/rainwater collection; wetlands, riparian protection, or urban forests

Program elements: established municipal programs and public funding

Covering 240 square miles along the shores of Lake Ontario, Toronto is the largest city in Canada, with 2.5 million residents. The entire Toronto metropolitan region has a population of 4.5 million people spread out over 560 square miles. This vast urban expanse is also home to an extensive infrastructure network with 2,800 miles of storm sewers and over 2,600 outfalls.[109] Like the Great Lakes cities in the United States, Toronto's urban stormwater is a leading cause of water pollution in Lake Ontario and its tributaries and necessitates expensive investments directed toward CSO mitigation and stormwater management. Toronto and its surrounding watersheds are part of an Area of Concern under a Remedial Action Plan (RAP), a policy designation derived from amendments to the 1972 bilateral Canada-U.S. Great Lakes Water Quality Agreement. The Toronto RAP covers Toronto Bay and six watersheds: Etobicoke Creek, Mimico Creek, Humber River, Don River, Highland Creek, and Rouge River. Goals include the restoration of drinkable, fishable, swimmable, and aesthetically pleasing water and habitat areas.[110] The RAP explicitly highlights pollution from urban stormwater runoff as one of the primary sources of ecosystem degradation to this region.[111]

Faced with the difficult challenge of limiting stormwater runoff and pollution, Toronto has developed a unique policy approach for managing stormwater with the goal of eliminating adverse effects of wet weather flows and achieving measurable improvement in ecosystem health within the watershed.[112] In July 2003, Toronto's City Council approved a 25-year stormwater plan, the Water Pollution Solution, formerly called the Wet Weather Flow Management Plan. This plan is a comprehensive strategy to deal with surface water quality and quantity, sewage overflows, and habitat protection. Toronto's approach includes increasing traditional methods of stormwater storage capacity and improving conveyance structures, but it also includes greener approaches, especially for some short-term solutions.

Toronto's Four Principles of Stormwater Management

The Wet Weather Plan is explicitly based on four innovative principles for stormwater management: (1) recognizing rainwater and snowmelt as a valuable resource; (2) managing wet weather flows on a watershed basis; (3) implementing the hierarchy of wet weather practices beginning with "source," then "conveyance," and lastly, "end-of pipe" solutions; and (4) educating communities and involving the public.[113] Capital costs for the program are estimated to be around \$800 million; operational and maintenance costs are expected to be around \$13 million annually.[114] The city has earmarked \$200,000 annually for community projects that contribute to the Water Pollution Solution.[115]

Toronto's program involves a significant downspout disconnection effort to prevent runoff from entering both the stormwater and combined sewer systems. The city will disconnect residences for free and provide splash guards or rain barrels to protect residential foundations. As of June 2000, Toronto estimated that approximately 20,000 homes had been disconnected.[116] Downspout disconnection efforts have been targeted at areas that either experience localized flooding or have a significant runoff impact on Toronto's beaches.

Toronto has made extensive use of the natural filtering and flood control capacity of wetlands and vegetated areas to help achieve the goals of the RAP. The city has embarked on wetland and stream restoration programs to facilitate stormwater management that will achieve cleaner streams and enhanced wildlife habitat. Toronto is committing \$106 million for the capital costs to restore over 40 miles of streams, and expects operation and maintenance costs for this stream restoration to be roughly \$500,000 per year.[117] Several wetlands have already been restored, including Chester Springs Marsh, a 7.5 -acre wetland restored on the site of an old landfill. This particular wetland was restored specifically to prevent nutrients and pollutants from reaching the Don River. Wetlands originally performed this filtering function before the Don was channeled in the late 19th century.[118] The recovered area has witnessed a substantial increase in the number of species that visit the site, spurring city plans to build and restore several more wetlands.

Toronto's green roofs. Toronto has also become a center for green roof technologies. While not explicitly part of the stormwater plan, the green roof initiatives are expected to have an impact on stormwater mitigation. Based on an Environment Canada study, the nonprofit industry association Green Roofs for Healthy Cities estimates that greening 6% of Toronto's roofs would cost about $36 million over 10 years and would retain almost 1 billion gallons of stormwater annually.[119] In 2002, several Canadian organizations announced the Green Roof Infrastructure Demonstration Project, a public-private partnership that will fund more than $800,000 in green roof costs.[120]

Toronto currently has over 100 green roofs, including an intensive installation on the Toronto City Hall and an extensive installation on the gymnasium roof of the Eastview Neighbourhood Community Centre.[121] The National Research Council's Institute for Research in Construction installed a monitoring system on the Eastview roof to measure both quality and quantity of stormwater runoff.[122] Early findings from an upcoming study to investigate the potential for widespread green roof installations in Toronto (*The Municipal Cost Savings Benefits of Green Roofs*) indicate 57% average annual flow reductions from the Eastview green roof plots compared to traditional roofs.[123] The plots also showed peak flow rates of 25% to 60% during summer and 10% to 30% in late fall of those measured from conventional roofs.[124] These preliminary monitoring results were achieved before vegetation had reached maturity.

A Ryerson University study evaluated the municipal level benefits and costs of wide-scale implementation of green roofs in Toronto. For the study, a Geographic Information Systems (GIS) database was used to model and aggregate environmental benefits and a methodology was developed to monetize these benefits. The study assumed that green roofs would be installed on all city flat roofs more than 3,750 square feet and would cover at least 75% of the roof. Using this assumption, more than 12,000 acres of green roofs, representing 8% of the total land area in the city, could be installed in Toronto.[125]

The study findings estimated nearly $270 million of municipal capital cost savings and more than $30 million in annual savings with this number of installed green roofs. Five primary benefits were quantified in the study: (1) reduced stormwater flows into the separate storm sewer system, (2) reduced stormwater flows into the combined sewer system, (3) improved air quality, (4) mitigated urban heat island effects, and (5) reduced energy consumption. The study estimated more than $100 million in stormwater capital cost savings, $40 million in CSO capital cost savings and nearly $650,000 in CSO annual cost savings.

The researchers anticipate that the only costs to the city will be those to promote green roofs, although the city will also likely incur costs to monitor design and construction of the green roofs. The cost to retrofit existing roofs with green roofs is likely to be borne by private industry during the normal maintenance cycle. Recent green roof projects in Canada have averaged $6 to $7 per square foot, suggesting a total cost of $3 billion to $3.7 billion for 12,000 acres of green roofs.[126,127] While the total cost to install the green roofs is large, it would be spread across numerous building owners and developers. The additional cost of a green roof for the minimum area roof in the study, 3,750 square feet, would be $22,000 to $27,000.

For Additional Information

City of Toronto—Protecting Water Quality: http://www.toronto.ca/water/protecting_quality/index.htm

Vancouver, B.C., Canada

Creative green design for city parks and roads

Population: 600,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; permeable pavement; wetlands, riparian protection, or urban forests

Program elements: established municipal programs and public funding

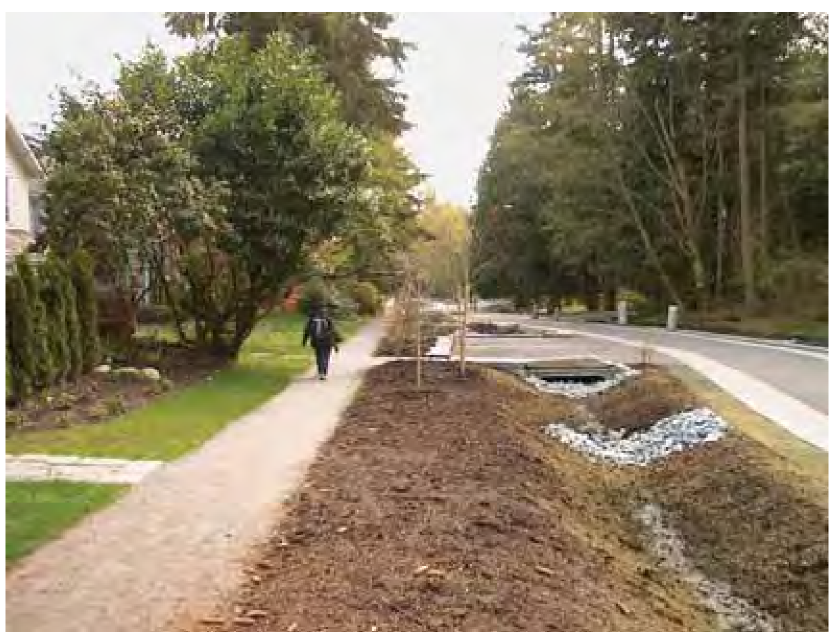
Situated 25 miles north of the U.S.-Canadian border and bounded on three sides by water, Vancouver is the third largest city in Canada. While the city covers an area of 44 square miles, the entire metropolitan area is nearly 1,100 square miles and home to approximately 2 million people.[128] Almost 90% of the 44 square mile city center is developed.[129] Often recognized as one of the best cities in the world in which to live, Vancouver was ranked third in a 2005 survey assessing the quality of life in 215 cities worldwide.[130] However, even one of the world's most highly regarded cities is not immune to the effects of urbanization and stormwater runoff.

Vancouver sits in the Fraser River Valley, the most productive salmon fishery in the world. An estimated 800 million juvenile salmon from five different species migrate along the Fraser River each year. Eighty additional species of fish and 79 species of birds rely on the Fraser River and its estuary for critical habitat and migratory routes.[131,132] With Rocky Mountain snow melt composing the majority of the source water in Vancouver, good water quality has historically been an attribute of Vancouver area watersheds. But within the past half century, urbanization and stormwater have begun to degrade the area's waters. Combined sewers constitute more than 60% of the city's collection system, and combined sewer overflows and separate stormwater runoff have been identified as leading causes of local water pollution.

Creating More Permeable, Pedestrian-Friendly Green Space

The city has begun using green infrastructure to address a range of environmental problems. Because Canada is a signatory of the Kyoto Protocol, many of Vancouver's green infrastructure efforts are focused on climate and air benefits, but some are specifically targeted at stormwater. To address stormwater runoff from roadways, Vancouver has initiated a number of innovative street design projects as part of the city's Greenways Program. The program is focused on introducing pedestrian-friendly green space into the city to connect trails, environmental areas, and urban space. This greenway initiative has also developed innovative strategies to manage roadway stormwater. One of these projects is the Crown Street redevelopment project.

Prior to the redevelopment project, stormwater runoff from Crown Street flowed untreated into the last two remaining salmon-bearing creeks in Vancouver.[133] In 2001, residents along a 1,100-foot block of the street petitioned the city to rehabilitate the deteriorating street using conventional curb and gutter. In response, the city recommended a naturalized streetscape



Crown Street just after construction and prior to swale planting.

Photo courtesy of City of Vancouver Greenways program

VANCOUVER

Vancouver's first Country Lane installed in 2002.
Photo courtesy of City of Vancouver Greenways program

design modeled after the Seattle SEA Street design. The naturalized design narrowed the impervious street width from 28 feet to 21 feet (certain one-way sections of the road were narrowed to 10 feet) and incorporated roadside swales with structurally supported grass to collect and treat stormwater through infiltration. The redesigned street will retain 90% of the annual rainfall volume on site; the remaining 10% of runoff will be treated through a system of vegetated swales before discharging.[134,135] Construction was completed in early 2005 at a cost of $707,000.[136] A conventional curb and gutter design would have cost approximately $364,000; however, because Crown Street was the first of its kind in the city, an estimated $311,000 was spent on additional aesthetic design features and consultant fees that would not be necessary for future projects. Eliminating the project-specific additional costs would bring the cost of retrofitting existing streets with naturalized street design projects in line with conventional drainage systems; however, the city estimates that installing naturalized street designs in new developments will be less expensive than conventional drainage systems.[137,138] In cooperation with the University of British Columbia, Vancouver will monitor the street for the next five years to assess the quality of stormwater runoff. Results will be compared with a nearby curb and gutter street to confirm modeling projections.

The Country Lane Program. Another example of green design within Vancouver's Streets Department is the Country Lane Program to replace traditional highly impervious alleys and lanes with a more permeable alternative. Asphalt lanes are replaced with two concrete or gravel strips surrounded by structural grass (structural grass is supported by a grid and soil structure that prevents soil compaction and root damage). Connections from the country lane to residences are constructed of permeable materials, including paving blocks, broken concrete sections, and structural grass or gravel. Three Country Lanes were installed as a pilot project to introduce green space and encourage on-site infiltration of stormwater. The initial cost of a Country Lane was approximately $71 per linear foot, which is four times greater than the typical alley cost of $18 per foot.[139,140] The city estimates that the cost of a Country Lane in 2006 will decrease to $30 per linear foot.[141,142]

The city is also installing infiltration bulges along roadways to collect and infiltrate street stormwater runoff. These installations are being done in conjunction with the Greenways program's efforts to improve

Infiltration bulges capture and infiltrate stormwater before it reaches the collection system.
Photo courtesy of City of Vancouver Greenways program

transportation corridors by making them more pedestrian friendly. The city is extending curbs at intersections out into the street to lessen the crossing distance and improve the line of sight for pedestrians. The city's stormwater catch basins are located at roadway intersections; when the bulges were constructed, the city was initially relocating these catch basins outside of the bulges. Now, in certain instances, the Streets Department is installing permeable soils and vegetation within these bulged sections to introduce green space and collect stormwater. The catch basins are left in place within the bulges and any stormwater that does not infiltrate into the soil overflows into the stormwater system. This new design not only reduces the amount of stormwater runoff, but is also less costly for the city. Because the stormwater infiltration bulges are installed in conjunction with planned roadway improvements, the only additional costs associated with the stormwater project are the costs of a steel curb insert to allow stormwater to enter the bulge and additional soil excavation costs. These additional costs are more than offset by the $2,400 to $4,000 cost of relocating the catch basins. To date, the city has installed nine infiltration bulges, three of which are maintained by local volunteers as part of a Green Streets program where local residents adopt city green space.[143]

Vancouver's green roofs. In addition to the street initiatives, Vancouver has also used green infrastructure in other applications. Green roofs have been used extensively in the greater Vancouver area, with more than 30 installations.[144] One of the best known of these roofs is installed on the Vancouver Public Library's Central Branch building. The 20,000 square foot green roof was installed in 1995 and planted as an artistic representation of the Fraser River. Monitoring of the roof during an eight-month period in 2003 and 2004 showed a 48% reduction in the volume of stormwater runoff from the roof when compared to a conventional roof. Peak stormwater flows were also reduced between 5% and 30% during the region's wet winter months; in the drier summer, peak flows were reduced more than 80%. As with other green roofs, peak reductions were the greatest for smaller, less intense storms and least for larger rain events.[145]

Biofiltration in Vancouver's parks. Vancouver has designed and installed two biofiltration systems, utilizing natural and reclaimed green space to treat stormwater runoff. One hundred sixty-seven acres of neglected, largely paved land were reclaimed and re-greened to create Hastings Park. The park provides Vancouver residents with green space in a highly urbanized section of the city. Within the park is the biofiltration system referred to as the Sanctuary. This system receives stormwater runoff from a 300-acre residential area to the south of the park and uses natural biological processes to treat the runoff prior to discharging it to the Burrard Inlet.[146] The biofiltration pond was designed in conjunction with the sewer separation project that installed a new separate stormwater collection system in the neighborhood bordering the park. The Sanctuary also provides additional aesthetic and environmental benefits by serving as valuable habitat for wildlife and birds.[147,148]

A second biofiltration system is used in Stanley Park, a 1,000-acre urban park in Vancouver. The park is bisected by the Stanley Park Causeway, a major commuter route. Prior to the construction of the biofiltration wetlands, causeway runoff flowed untreated into the Lost Lagoon, Beaver Lake, and adjacent forests. To manage and treat this stormwater, runoff was directed to a wetland constructed within the Lost Lagoon. The wetland uses natural filtration and biological processes to treat the stormwater before it is discharged to the lagoon. The innovative stormwater wetland was built to harmonize with the existing green space of the park and to provide habitat for plants and wildlife. Areas of the wetland not open to the public provide necessary space for birds to remain undisturbed by human activity.[149,150]

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Washington, D.C.

Using green infrastructure to combat years of river pollution

Population: 563,000

Type of green infrastructure used: green roofs; rain gardens, vegetated swales, and landscape; permeable pavement

Washington, D.C., sits at the confluence of the Potomac and Anacostia rivers and is home to a third, Rock Creek. These rivers in the nation's capital have historical and symbolic importance. The Potomac River is designated an American Heritage River and is often synonymous with the seat of the country's federal government. Unfortunately, Washington's rivers are also significantly affected by the large amount of urbanization surrounding them. Approximately 65% of the District is covered with impervious surfaces.[151] Development and urbanization have taken a toll on the natural features within the city; over the past 30 years, the District has lost 64% of its areas with heavy tree cover and experienced a 34% increase in stormwater runoff.[152]

Cleaning Up Washington's Most Polluted Waters Through Green Infrastructure

One-third of the city is served by a combined sewer system dating to the beginning of the 1900s and earlier. Estimated annual CSO discharges to the city's three rivers are 2.5 billion gallons.[153,154] The Anacostia River, which receives 60% of the CSO discharges, is one of the most polluted in the nation. Fifty percent of brown bullhead catfish collected for study from the river had cancerous liver tumors and approximately 25% had cancerous skin tumors.[155] The city's approved long-term CSO control plan (LTCP) will cost approximately $1.9 billion and focuses primarily on a deep tunnel system and sewer separation, but also recognizes the importance of incorporating green infrastructure within the city.

Low Impact Development at the Navy Yard on the Anacostia River. The Washington Navy Yard, along the banks of the Anacostia River, has been a notorious source of the river's water quality problems. The base has been subject to decades of military pollution and has been a main source of toxic water pollution. In 2001, the Navy Yard installed a number of green infrastructure pilot projects to manage stormwater runoff. Downspouts were disconnected and directed to rain barrels, and permeable pavement, rain gardens, and tree box filters were installed. These

The first commercial high-elevation green roof in Washington, DC, will be monitored to determine how much it lowers air temperature.
Photo courtesy of the Casey Trees Endowment Fund

retrofits cost approximately $500,000 and are providing on-site management of stormwater previously directed to the combined sewer system. Monitoring of the site is ongoing and is determining the stormwater volume reductions, stormwater discharge frequency, and water quality improvements.[156]

Washington's green roofs. Washington's first commercial high-elevation green roof was installed in 2004. The 3,500 square foot green roof was a collaborative effort between two nonprofit organizations and the real estate company that owns the building. The air temperature of the green roof is being monitored and compared to the temperature of a 1,000 square foot section of the roof that was not converted.

Installing green roofs across the District is projected to provide a significant reduction of stormwater runoff and CSO volume. Based on computer modeling by Limno-Tech, Inc., Casey Trees has measured the effects of installing 20 million square feet of green roofs, 20% of the roof area for all city buildings over 10,000 square feet, over the next 20 years. Modeling results based on this coverage scenario show a citywide reduction in runoff of 1% and CSO discharges of 15%. The green roofs are anticipated to retain and store 430 million gallons of rainwater annually and increase proposed deep tunnel storage capacity by 30 million gallons because of the decrease in rooftop runoff.[157]

Incorporating green infrastructure into DC's CSO and stormwater programs. The District's efforts with green infrastructure have not progressed as far as those in other case-study cities. However, a convergence of events presents the city with an opportunity to integrate green approaches into its overall stormwater and CSO control efforts. The 20-year implementation schedule to complete the LTCP provides an ideal window to incorporate green infrastructure into the District's pollution control plans. The District of Columbia Water and Sewer Authority (WASA), the regional agency responsible for implementing the LTCP, has allocated $3 million of the overall LTCP budget for advocating and assisting with green infrastructure retrofits.[158] Major redevelopment is also planned along the Anacostia River to complement the construction of the city's new baseball stadium.

Some of the most significant barriers to incorporating green infrastructure, or any stormwater or CSO controls, into existing urban areas are the cost and challenge of retrofitting these systems into built-out and space-constrained areas. The LTCP work and

Anacostia redevelopment lower these barriers because of the large capital investment that will accompany the projects and substantial overhaul and upgrade of associated infrastructure. These projects offer the opportunity to integrate green infrastructure from the start and take advantage of the associated cost savings. The city will also have the opportunity to learn from several major cities that have been successfully integrating green infrastructure into stormwater and CSO mitigation plans.

A number of the policy recommendations described earlier in this report could be used effectively to encourage green infrastructure. The District currently charges a nominal stormwater fee to its residents and commercial properties located in the separate sewer area. The stormwater fee could be restructured, similar to Portland, Oregon's model, to allow a rate reduction for those properties that install green infrastructure or manage stormwater on site. To be an adequate incentive, the current annual stormwater fee would need to be significantly increased. A similar system could be adopted in the combined sewer area as well. Private grant programs, like the Chesapeake Bay Foundation's green roof grant program, currently exist as an incentive to install green infrastructure in the city. The District should complement these efforts with a city-administered financial assistance program for green infrastructure.

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