United States Environmental Protection Agency

Greening CSO Plans:

Planning and Modeling Green Infrastructure for Combined Sewer Overflow (CSO) Control

U.S. Environmental Protection Agency

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Photo courtesy of Abbey Hall, U.S. EPA

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Chapter 1: Introduction

Purpose of this Resource

This technical resource is intended to assist communities in developing and evaluating Combined Sewer Overflow (CSO) control alternatives that include green infrastructure. It is designed to provide municipal officials as well as sewer authorities with tools to help quantify green infrastructure contributions to an overall CSO control plan. This document is the result of a joint effort between EPA's Office of Water (OW) and Office of Research and Development (ORD), and is intended for use by both policy-oriented as well as technical professionals working to incorporate green infrastructure into CSO Long Term Control Plans (LTCPs). This resource contains three main parts:

- General overview of the regulatory and policy context for incorporating green infrastructure into CSO control programs.
- Description of how municipalities may develop and assess control alternatives that include green infrastructure.
- Brief demonstration of a modeling tool, the Storm Water Management Model v. 5.0 (SWMM5), that can help quantify green infrastructure contributions to an overall CSO control plan.

Chapter 1 describes how green infrastructure approaches fit into the Federal regulatory framework for CSO control. Chapter 2 highlights general opportunities for integrating green infrastructure into CSO LTCPs. Chapter 3 explains how to develop and evaluate control alternatives that incorporate green infrastructure practices. Chapter 4 presents a case study demonstrating how a specific model, SWMM5, may quantify green infrastructure contributions to a total CSO control program.

Environmental and Public Health Impacts of CSOs

Across the United States, more than 700 cities rely on combined sewer systems (CSSs) to collect and convey both sanitary sewage and stormwater to wastewater treatment facilities. Most of these communities are older cities in the Northeast, the Great Lakes region, and the Pacific Northwest. When wet weather flows exceed the capacity of CSSs and treatment facilities, stormwater, untreated human, commercial and industrial waste, toxic materials, and debris are diverted to CSO outfalls and discharged directly into surface waters. These CSOs carry microbial pathogens, suspended solids, floatables, and other pollutants, and can lead to beach closures, shellfish bed closures, contamination of drinking water supplies, and other environmental and human health impacts. For many cities with combined sewer systems, CSOs remain one of the greatest challenges to meeting water quality standards.

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Rain barrel captures roof runoff in Santa Monica, CA.

In 1994, EPA published the CSO Control Policy (59 FR 18688 (April 19, 1994) available at [http://www.epa.gov/npdes/pubs/owm0111. pdf](http://www.epa.gov/npdes/pubs/owm0111.pdf)). The CSO Control Policy provides guidance to municipalities and State and Federal permitting authorities on controlling discharges from

CSOs through the National Pollutant Discharge Elimination System (NDPES) permit program under the Clean Water Act. In 2000, Congress amended section 402 of the Clean Water Act to require both NPDES permits and enforcement orders for CSO discharges to conform to the CSO Control Policy (33 USC § 1342(q)). Under their NPDES permits, communities are required to implement nine minimum controls (NMC) and to develop and implement Long Term Control Plans (LTCPs). Many communities are still searching for cost effective ways to implement their LTCPs.

Despite the progress achieved to date, significant infrastructure investments are still needed to address CSOs. Although funding assistance is available from federal and state sources, local ratepayers ultimately fund most CSO control projects. Therefore, CSO control programs represent a significant municipal investment that competes with other local programs.

Climate change could further amplify investments required to mitigate CSOs. The frequency and severity of CSO events is largely determined by climatic factors, including the form, quantity, and intensity of precipitation. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that changing trends in climate are evident from historical observations (IPCC, 2013[1]). In the United States, observed climate change in the 20th century varied regionally, but generally included warming temperatures and an increased frequency of heavy precipitation events. Anticipated changes in the 21st century also vary regionally and are not yet certain, but research suggests continued warming and changes in precipitation throughout much of the United States (Christensen et al., 2007)[2]. Though the extent of the risk is unknown, these changes could significantly affect the efficacy of CSO mitigation efforts.

Available Controls

CSO controls may be grouped into four broad categories: operation and maintenance practices, collection system controls, storage facilities, and treatment technologies. Most of the early efforts to control CSOs emphasized what we refer to in this document as “gray infrastructure,” which describes traditional practices for stormwater management that involve pipes, sewers and other structures involving concrete and steel. One of the most commonly implemented types of gray infrastructure is off-line storage. Off-line storage facilities store wet weather combined sewer flows in tanks, basins, or deep tunnels located adjacent to the sewer system until a wastewater treatment plant (WWT) of a publicly owned treatment works (POTW) has the capacity to treat the stored wastewater.

CSO Control Technologies:

1. Operation and maintenance practices
2. Collection system controls
   - Conventional Approaches, and
   - Green Infrastructure Approaches
     - Retention, and
     - Runoff Control
3. Storage facilities
4. Treatment technologies

[1] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Green Infrastructure Controls

Green infrastructure practices mimic natural hydrologic processes to reduce the quantity and/or rate of stormwater flows into the the combined sewer system (CSS). By controlling stormwater runoff through the processes of infiltration, evapotranspiration, and capture and use (rainwater harvesting), green infrastructure can help keep stormwater out of the CSS. Green infrastructure also supports the principals of Low Impact Development (LID), an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible.

Green infrastructure can be utilized at varying scales—both at the site and watershed level. For example, small source control practices such as rain gardens, bioswales, porous pavements, green roofs, infiltration planters, trees, and rainwater harvesting can fit into individual development, redevelopment or retrofit sites. Larger scale management strategies such as riparian buffers, flood plain preservation or restoration, open space, wetland and forest preservation and restoration, and large infiltration systems can be used at the subwatershed or watershed level.

Drain collects runoff from impervious surface and directs it to rain gardens in Saint Paul, MN.

Multiple Benefits of Green Infrastructure

Green infrastructure can contribute to CSO control while providing multiple environmental and social benefits. Although green infrastructure alone is often unlikely to fully control CSOs, it may be able to reduce the size of more capital-intensive, "downstream" gray infrastructure control measures, such as storage facilities or treatment technologies. It may also reduce operating and energy expenditures due to the passive nature of typical green infrastructure practices. Green infrastructure can improve community livability, air quality, reduce urban heat island effects, improve water quality, reduce energy use, and create green jobs. Larger scale green infrastructure strategies can also increase recreational opportunities, improve wildlife habitat and biodiversity, and help mitigate flooding. For further information on the multiple benefits of green infrastructure, see: http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm.

EPA recognizes the particular importance of ensuring resilient water infrastructure in the face of climate change. Green infrastructure is one useful approach. Green infrastructure can provide flexibility in addressing uncertainties surrounding future droughts and increased precipitation resulting from climate change. It may also be incrementally and relatively rapidly expanded and adapted as necessary. EPA already has a number of resources and tools available to communities to help assess and address the impacts of climate change. The National Water Program Climate Change Strategy lays out goals and actions for protecting our nation's water resources, and EPA has already made significant progress in the areas of improving resiliency in water infrastructure, watersheds and wetlands, coastal and ocean waters, and water quality (http://water.epa.gov/scitech/climatechange/2012-National-Water-Program-Strategy.cfm). EPA's Climate Ready Water Utilities program assists the water sector, including drinking water, wastewater, and stormwater utilities, in addressing climate change impacts and has a number of resources and tools available to water utilities and the public at http://water.epa.gov/infrastructure/watersecurity/climate/. EPA also has publicly available resources and tools to assist water utilities in addressing energy efficiency at http://water.epa.gov/infrastructure/sustain/energyefficiency.cfm.

Figure 1-1. Green infrastructure practices commonly used in urban areas.

Green Infrastructure Practice	Description
 **Disconnection**	Disconnection refers to the practice of directing runoff from impervious areas such as roofs or parking lots onto pervious areas such as lawns or vegetative strips, rather than directly into storm drains.
 **Rain Harvesting**	Rain harvesting systems collect runoff from rooftops and convey it to a cistern tank where the water is available for uses that do not depend on potable water, like irrigation.
 **Rain Gardens**	Rain gardens are shallow depressions filled with an engineered soil mix that supports vegetative growth. They are designed to store and infiltrate captured runoff, and retain water for plant uptake. They are commonly used on individual home lots to capture roof runoff.
 **Green Roofs**	Green roofs (also known as vegetated roofs or ecoroofs) are vegetated detention systems placed on roof surfaces that capture and temporarily store rainwater in a soil medium. They typically have a waterproof membrane, a drainage layer, and a lightweight growing medium populated with plants that absorb and evaporate water
 **Infiltration Trench**	Infiltration trenches are gravel-filled excavations that are used to collect runoff from impervious surfaces and infiltrate the runoff into the native soil. Some systems are designed to filter runoff and reduce clogging by routing water across grassed buffer strips.
 **Street Planters**	Street planters are typically placed along sidewalks or parking areas. They consist of concrete boxes filled with an engineered soil that supports vegetative growth. Beneath the soil is a gravel bed that provides additional storage as the captured runoff infiltrates into the existing soil below. Street planters also can be designed with underdrains to avoid ponding on sites with inadequate infiltration capacity.
 **Porous Pavement**	Permeable pavement and paver systems are excavated areas filled with gravel and paved over with a permeable concrete or asphalt mix. They may also be overset with a layer of pavers. Rainfall passes through the pavement or pavers into the gravel storage layer below where it can infiltrate at natural rates into the site's native soil.

Chapter 2: Integrating Green Infrastructure into the Federal Regulatory Framework for CSO Control

The 1994 CSO Policy provides guidance to EPA and State NPDES authorities on how to develop NPDES permits for CSO discharges, as well as how to conduct enforcement actions against violators with CSOs. Although the processes and practices for meeting the CWA and CSO Policy requirements with gray infrastructure are generally well understood, the process for meeting them with a combination of gray and green infrastructure is less well defined.

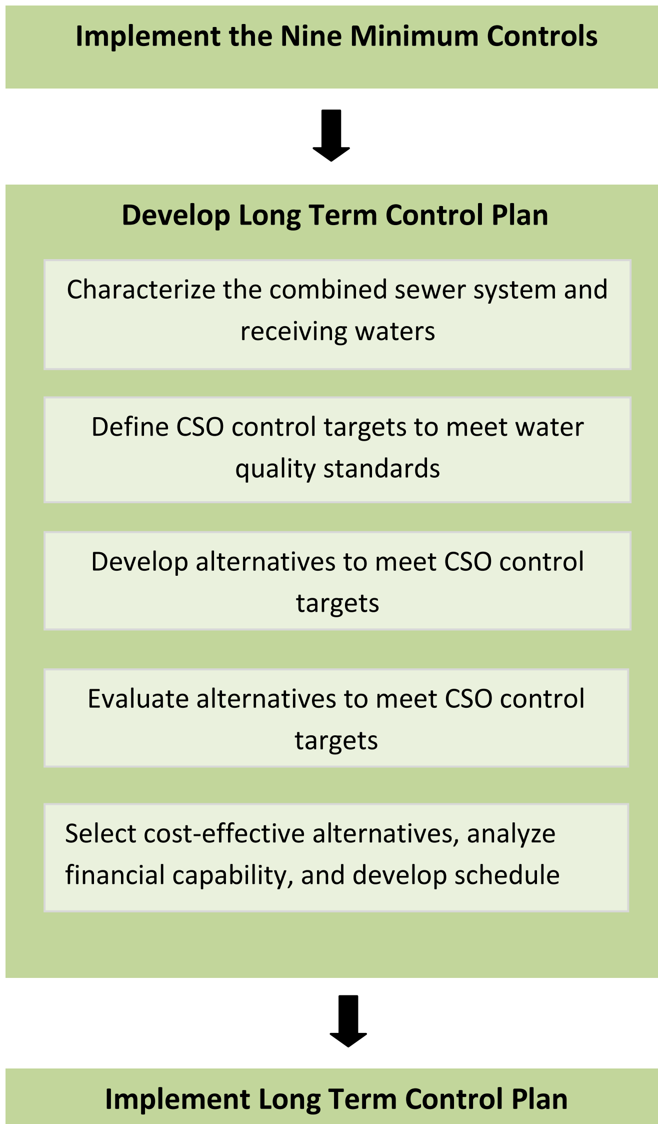

Figure 2-1. The process for meeting federal requirements for CSO controls generally follows the series of steps shown here.

Implementing the CSO Control Policy

Phase I: Green Infrastructure and the Nine Minimum Controls

The Nine Minimum Controls (NMCs) are minimum technology-based requirements that municipalities must take to address combined sewer overflows:

Nine Minimum Controls:

1. Proper operation and regular maintenance programs for the sewer system and the CSOs
2. Maximum use of the collection system for storage
3. Review and modification of pretreatment requirements to assure CSO impacts are minimized
4. Maximization of flow to the publicly owned treatment works for treatment
5. Prohibition of CSOs during dry weather
6. Control of solid and floatable materials in CSOs
7. Pollution prevention
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls

Green infrastructure approaches are adaptable in several components of the NMCs. For example, green infrastructure practices can retain and control runoff for a period of time before slowly releasing it to the sewer system. Green infrastructure practices can also increase available storage capacity in the collection system, which reduces the likelihood of overflows and maximizes the amount of stormwater treated at a publicly owned treatment works (POTW). The full text of EPA's 1995 Guidance for Nine Minimum Controls is available at http://www.epa.gov/npdes/pubs/owm0030.pdf.

Phase II: Developing the Long Term Control Plan

CSO communities are generally required under their NPDES permits to develop and implement a Long Term Control Plan (LTCP). LTCPs set out plans for specific measures to meet the requirements of the Clean Water Act, including the attainment of water quality standards. Detailed information on developing and implementing LTCPs can be found at http://cfpub.epa.gov/npdes/cso/guidedocs.cfm?program_id=5.

The first two steps in developing an LTCP include characterization of the CSS and receiving waters, and the development of CSO control targets to meet water quality standards (WQS). These two steps are independent of the types of controls under consideration. Regardless of the types of controls considered, pursuant to the CSO Control Policy, CSO communities are expected to develop a LTCP that adopts either the demonstration or presumption approach to define targets for CSO control that achieve compliance with the Clean Water Act (CWA).

Once a community defines CSO control targets, they may develop and evaluate control alternatives to meet these targets. The 1995 EPA Guidance for Long Term Control Plans identifies four categories of CSO control measures, and includes specific green infrastructure measures in the category labeled "Source Controls" (1995 EPA Guidance for LTCPs, Section 3.3.5.1). The measures discussed in this guidance include permeable pavements, flow detention, downspout disconnection, and infiltration-based practices. The guidance also recognizes that, "since source controls reduce the volumes, peak flows, or pollutant loads entering the collection system, the size of more capital-intensive downstream measures can be reduced or, in some cases, the need for downstream facilities eliminated."

Elements of a Long Term CSO Control Plan:

1. Characterization, monitoring, and modeling of the Combined Sewer System (CSS)
2. Public Participation
3. Consideration of sensitive areas
4. Evaluation of alternatives
5. Cost/performance considerations
6. Operational plan
7. Maximization of treatment at the existing POTW treatment plant
8. Implementation schedule for CSO controls
9. Post-construction compliance monitoring program

The complete CSO Control Policy is available at:
http://cfpub.epa.gov/npdes/cso/guidedocs.cfm?program_id=5

Implementing the Long Term CSO Control Plan

Regardless of the type of controls included, LTCPs are expected to result in compliance with the requirements of the CWA. To assess progress toward compliance, the CSO Policy requires development of a post-construction compliance-monitoring program that adequately measures and evaluates the effectiveness of CSO controls, protects designated uses, and complies with water quality standards (WQS).

For LTCPs incorporating green infrastructure approaches, an **adaptive management** approach can be employed during the implementation process. Adaptive management means monitoring and evaluating green infrastructure projects and practices as work proceeds, and adapting or revising plans and designs as appropriate based on lessons learned. Evaluating practices as work proceeds can often be a more effective approach than adopting a monitoring program confined to the post-construction phase.

Photo: Permeable paver retrofits help to infiltrate urban runoff in a Chicago alley. © Abby Hall, U.S. EPA.

Importance of Monitoring

As the previous section suggests, the installation of green infrastructure controls may occur incrementally over time. By monitoring the effectiveness of green infrastructure controls as they are installed, municipalities can compare observed performance to modeled performance. If necessary, they can modify designs of remaining planned projects to meet a CSO control goal, or retrofit existing practices as necessary.

Green Infrastructure in EPA Enforcement

Given the multiple environmental, economic and social benefits associated with green infrastructure, EPA has supported and encouraged the implementation of green infrastructure for stormwater runoff and sewer overflow management to the maximum extent possible. EPA enforcement in particular has taken a leadership role in the incorporation of green infrastructure remedies in municipal Clean Water Act (CWA) settlements. Many cities have used green infrastructure to effectively manage stormwater. Runoff reductions from green infrastructure are demonstrable, may be less expensive than traditional stormwater management approaches in many cases, and provide a wide variety of community benefits (http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm). Based on this evidence, EPA enforcement has incorporated green infrastructure as part of injunctive relief, the measures and actions legally required to bring an entity back into compliance with the law, in a growing number of municipal CWA cases. Although communities are given discretion over how they want to comply with the CWA, EPA encourages the use of green infrastructure wherever appropriate. It has become common practice for green infrastructure to be included as injunctive relief in many municipal CWA settlements.

Many recently settled green infrastructure matters include an option for communities to study the feasibility for green infrastructure approaches, and to propose the replacement of specific gray infrastructure projects with green infrastructure on a case by case basis as a result of a feasibility analysis. Other settlements call for a commitment to a certain level of green infrastructure implementation up front while still offering the opportunity to scale up green infrastructure in the future, as appropriate.

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A green roof captures stormwater in Chicago, IL. Under a U.S. EPA Consent Decree, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is required to develop a detailed Green Infrastructure Program.

➢ More Enforcement Resources

An index of recent enforcement actions incorporating green infrastructure is available on EPA's website here: http://water.epa.gov/infrastructure/greeninfrastructure/gi_regulatory.cfm#csoplans

For more information on incorporating green infrastructure in EPA enforcement actions, see the U.S. EPA Green Infrastructure *Permitting and Enforcement Factsheet Series* here*:* http://water.epa.gov/infrastructure/greeninfrastructure/gi_regulatory.cfm#permittingseries

Chapter 3: Quantifying Green Infrastructure Controls as a Component of CSO Long Term Control Plans

Once a community defines its CSO control targets, the next step is to develop a set of alternative CSO control programs, and to evaluate these alternatives in order to select a preferred program. The development and evaluation processes are closely linked, and rely on many of the same factors, including sizing, cost, performance, and siting considerations. In assessing the performance of different control scenarios, Hydrologic and Hydraulic (H&H) models are often used to simulate how a municipal collection and conveyance system will respond to infrastructure changes. H&H models can evaluate the impact of a variety of infrastructure changes, such as the addition of off-line storage or construction of a tunnel to convey and store wet weather flows. More recently, these models have been adapted to simulate the effects of green infrastructure in a CSO service area.

Quantifying Green Infrastructure Implementation

Before beginning to model the effects of green infrastructure, it is important to understand the *amount* and *types* of green infrastructure that can be implemented, realistically and cost-effectively, in a given catchment. If green infrastructure opportunities are over-estimated, model results will over-estimate the potential for CSO reductions. Over-estimation of the degree of green infrastructure implementation can also lead to under-sizing gray infrastructure components downstream.

Green infrastructure opportunities within a catchment largely depend on soil characteristics, topography and land use. For example, if there are a large number of sizable industrial and/or commercial properties within a given catchment, there may be opportunities to add green roofs to both existing and future rooftops. Single-family residential lots with sufficient yard area offer opportunities to capture runoff off from rooftops, patios, driveways, and streets using residential rain gardens. Planned road improvements present opportunities to include green infrastructure practices in the redesign/reconstruction of right-of-way areas. Estimating the maximum or optimal amount of green infrastructure implementation also requires consideration of institutional factors that will affect the degree of implementation.

"It is important to understand the amount and types of green infrastructure that can be implemented, realistically and cost effectively, in a given catchment."

Curbside raingarden installation in Portland, Oregon.

Any proposal for the incorporation of green infrastructure into an LTCP should include, at a minimum, robust analyses in the following two areas:

1. **Community and Political Support for Green Infrastructure**
The municipality or sewer authority responsible for implementing the LTCP should solicit initial buy-in from the community and relevant political powers. Developing a substantial green infrastructure program will involve iterative interaction with both the community and local government officials. Meaningful local buy-in is essential for long-term success.

2. **Realistic Potential for Green Infrastructure Implementation**
The municipality or sewer authority responsible for implementing the LTCP should adequately investigate local factors that may limit the implementation of green infrastructure, including physical factors (e.g. soils, topography and land availability), regulatory factors (e.g. codes and ordinances), and social and political factors (e.g. ability to enact incentives and/or regulatory drivers for green infrastructure).

When simulating the performance of green infrastructure measures using H&H modeling, the technical characteristics utilized for each type of green infrastructure measure should reflect those likely to be **realistically** achieved, given both costs and physical, regulatory and/or social and political factors.

Factors to consider when evaluating the degree of green infrastructure implementation potential within a catchment should minimally include:

Soil characteristics. Many green infrastructure practices rely on infiltration as a means of stormwater disposition. Areas with very tight soils (e.g., clay soils not conducive to infiltration of water) will reduce the infiltration potential of many green infrastructure measures. In some situations it may be appropriate to amend soils to enhance storage and infiltration, and to promote plant growth.

Land Use and Ownership. How much land is residential, commercial, and industrial? What are the lot sizes? Are there vacant lots? Who owns them? How much land in the catchment is publicly owned or controlled (e.g., are there parkways in the public right-of-way)? What is the configuration of the existing street drainage system? Weaving green infrastructure into the existing landscape requires an understanding of current land use, as well as the local codes, plans and ordinances that will shape future land use patterns. Since impervious cover tends to vary across land use type, parcel-level land use data can help estimate green infrastructure potential. Detailed land use data can also determine what types of green infrastructure approaches are most appropriate for a given catchment. Commercial or publicly owned buildings, for example, may be better suited for green roof installations. Industrial parks with large minimum lot sizes exhibit potential for larger retention basins or constructed wetlands.

Local Buy-in. Will landowners be receptive or resistant to green infrastructure practices in the neighborhood or on their property? How will green infrastructure fit into the existing fabric of the neighborhood? Drawing on the knowledge and experience of community leaders, as well as key groups such as home owner associations, land trusts, etc., will help inform outreach strategies.

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Seattle's Street Edge Alternatives (SEA) program installed curbside stormwater features in residential neighborhoods.

Topography. Green infrastructure practices should ideally be located on slopes of less than 5%. Steeper terrain tends to make implementation more difficult and less cost-effective. For example, detention basins built on slopes over 5% are often difficult to design, plant and berm effectively. In response many communities prohibit the construction of green infrastructure in areas with slopes greater than 25%. GIS software can help identify and map steeper slopes, as well as areas with low infiltration potential (i.e., poorly drained soils).

Financing and Institutional Factors. Are there financial incentives to promote green infrastructure practices on private property? What incentives would effectively encourage property owners to construct and maintain green infrastructure practices? Do codes and ordinances require green practices at existing sites or redevelopment sites? What is the budget for green infrastructure implementation on public properties? Are there institutional barriers or impediments to requiring or incentivizing green infrastructure? Does the jurisdiction have the legal authority and the institutional capacity to require or incentivize green infrastructure?

Redevelopment Rate. Will there be redevelopment and reuse of many parcels, allowing new green infrastructure practices to be constructed as part of the redevelopment process? Some localities require new and re- development to meet onsite retention standards. If this is the case, the CSO authority may use redevelopment rates to predict degree of new green infrastructure installation over time. If mandatory requirements do not exist, communities may consider incentives that encourage developers to install green infrastructure.

Green Infrastructure on Private Property. Privately-owned properties such as corporate campuses or shopping malls can be good locations for green infrastructure practices in terms of the availability of space and/or the location in a sewershed. However, implementing green infrastructure on private property as part of a CSO control plan presents special challenges. Questions can arise as to who is responsible for maintenance, as wells as weather the sewer authority has the right to come onto the property for inspections or maintenance. In some cases, easements, deed restrictions, covenants, stormwater development standards, or other programmatic elements can be used to retain benefits gained. If a sewer authority is planning green infrastructure on private property as part of the long-term control plan, careful consideration of maintenance and preservation measures is essential; otherwise, model results could overestimate the actual flow reductions that will be achieved through green infrastructure practices.

Opportunities Presented by Partnerships. Opportunities for partnerships can help CSO communities plan what green infrastructure measures can be placed where. In some cases, CSO communities may be able to capitalize on opportunities presented by partners to work collaboratively on projects. Such partnerships potentially could include:

- **Public-public partnerships**– For example, the sewer authority could work with the streets department, park district or school district to implement green infrastructure in streets, at parks or on school grounds. Partnership opportunities may make public sites available for green infrastructure implementation, and/or there may be opportunities to share green infrastructure maintenance responsibilities across different departments or jurisdictions. Integrating green infrastructure into Capital Improvement Plans can allow different government departments to identify the most impactful and/or cost effective opportunities for green practices. For example, coordinating green infrastructure efforts with scheduled Department of Transportation improvements provides an opportunity to implement green streets at a much lower cost than traditional stormwater retrofits.
- **Public-private partnerships**—The CSO authority may engage the private sector in construction financing efforts to support the installation of green infrastructure. They might also partner with local Business Improvement Districts (BIDs) or other private entities to support the maintenance and operation of existing green infrastructure practices.
- **Partnerships with non-profits and neighborhood groups** – Working with not-for-profit organizations and community groups can help garner input from citizens on green infrastructure planning, gaining public acceptance, recruiting volunteers, and providing a sense of ownership once the practices are in place.

Green Infrastructure Planning on Multiple Scales

The process of analyzing green infrastructure strategies for site-specific conditions should be carefully planned and scaled. For example, a regional sewer district might first assess which sewersheds provide the most opportunity for green infrastructure, and then focus on identifying what type of green infrastructure can realistically and cost-effectively be implemented in those areas.

Another approach is to categorize sewersheds into groups, based on land use, soils, and topography, and then develop green infrastructure templates for the various types/categories of sewersheds. Geographic Information Systems (GIS) can help integrate land use, ownership, soil and slope data into a simple ranking system. A basic GIS ranking model estimates green infrastructure implementation potential across a given service area using local spatial data. Specific factors that can be brought into a ranking analysis include:

- open space
- slope
- soil characteristics
- publicly owned parking lots/buildings
- commercial/industrial ownership
- residential housing (for downspout disconnection)
- existing vegetation

Examples of Green Infrastructure Planning

Several CSO communities have planned for green infrastructure as part of their stormwater runoff management strategies. Four different approaches are presented below.

Planning Case Study #1: Northeast Ohio Regional Sewer District

The Northeast Ohio Regional Sewer District (NEORSD) performed a systematic evaluation of where to best implement green infrastructure measures within their service area. Under the terms of a Consent Decree agreement with U.S. EPA and the State of Ohio, NEORSD committed to implementing green infrastructure as part of its CSO control program. The District needs to plan for the construction of green infrastructure to meet a performance criterion of reducing CSOs by 44 million gallons in a typical year, beyond the reductions achieved by planned gray infrastructure control measures. NEORSD performed a geographic screening of neighborhoods within the combined sewer service area using a *Green Infrastructure Index* to identify locations most suitable for green infrastructure projects. Factors involved in the *Index* ranking are described in the NEORSD Green Infrastructure Plan here: http://neorsd.org/projectcleanlake.php.

Permeable pavers infiltrate street runoff in Portland, OR.

NEORSD's *Green Infrastructure Index* has two separate components. The first component, referred to as the Baseline Index, provides a numeric score that characterizes general opportunities, space, and potential effects of green infrastructure projects. The second component is specific to the 44 million gallon performance criterion, and provides a numeric score that characterizes projected impacts of green infrastructure on CSO volume reduction. The *Green Infrastructure Index* repressents a sum of these two scores. Factors taken into account in the Index include development and redevelopment opportunities, soils, open space and imperviousness, partnership opportunities, and environmental justice. The District assessed CSO volume reductions for the second component by running H&H model simulations where directly connected impervious areas (DCIAs) were reduced by fixed amounts. After determining which sub-catchments received the highest combined GI Index scores, staff identified 38 “priority” sub-catchments across the district.

The District then developed, evaluated, and prioritized green infrastructure projects in each priority sub-catchment. Using a ranking-based tool such as NEORSD’s *Green Infrastructure Index* can provide a systematic approach for identifying the most promising sewersheds and most appropriate practices within a given service area.

Planning Case Study #2: San Francisco Public Utilities Commission

The San Francisco Public Utilities Commission also used a GIS-based analysis to identify maximum potential for specific green infrastructure practices across its sewershed based on physical constraints (see Section 3.2 and Table 6 of http://sfwater.org/modules/showdocument.aspx?documentid=560). The results of this analysis estimated a maximum of 38% of the total city area was available for conversion to green roofs, downspout disconnection, bioretention, urban trees, and permeable pavement. Modeling scenarios for San Francisco later incorporated goals related to this maximum potential for green infrastructure. A watershed-based planning process called *The Urban Watershed Assessment* will use this information to inform San Francisco’s Sewer System Improvement Program (SSIP).

Planning Case Study #3: Metropolitan Sewer District of Greater Cincinnati

The Metropolitan Sewer District of Greater Cincinnati (http://msdgc.org/) conducted a green infrastructure planning effort in a single pilot area, the Lick Run sub-sewershed. Lick Run is a 2,600 acre sub-sewershed with primarily single-family residential, commercial and undeveloped/open space. The District selected Lick Run for evaluation because its drainage area contains a mix of topography, land use, and surficial soil characteristics. In total, approximately 24% of the sewershed is impervious. The analysis focused on three classes of impervious areas: roofs, parking lots/driveways, and streets.

GIS polygons representing roof footprints facilitated analysis of green roof potential. Both green roofs and roof top cisterns were considered for larger commercial, industrial, and multifamily residential buildings. For smaller single-family residential buildings, downspout disconnection to a rain garden was the selected green infrastructure practice. GIS data was unavailable for parking lots and sidewalks, so boundaries had to be delineated by hand from aerial photos. Bioretention and permeable pavement were the selected alternatives for these impervious surfaces. For roadways, GIS data was only available as street centerlines. As such, the District estimated associated impervious area for roads based on width estimates for each street type. Curbside bioretention and infiltration swales were the chosen practices for local roads where road narrowing was feasible.

The district created a range of scenarios in which green infrastructure practices would manage 10-35% of roadways, 20-50% of rooftops, and 25-50% of parking lots and sidewalks. Once the inputs were appropriately set up, they ran a CSO model individually for three separate rainfall events, using a continuous simulation of a typical year in order to characterize the effects of the various levels of green infrastructure implementation.

Planning Case Study #4: City of Toledo

The City of Toledo, Ohio kicked off a significant green infrastructure retrofit project by first installing and monitoring bioswales along a residential street (http://www.estormwater.com/maywood-avenue-storm-water-volume-reduction-project). The City conducted monitoring of runoff from the street before and after installing bioswales, and then monitored a nearby non-retrofitted street for comparison purposes. The monitoring study provided data on the amount of stormwater stored or infiltrated at both test sites. The City then used this data to calibrate its stormwater management model (SWMM). Finally, the City used this model to simulate flow reductions provided by the green street upgrades. Long-term simulations using the SWMM model indicate an annual average reduction of runoff volume from the bioswales of approximately 64%. Long-term simulation results showed that during the fifth-largest storm event bioswales removed 70,000-80,000 gallons of flow from the CSS. Toledo was also able to calculate a cost per gallon of stormwater removed by the bioswales. With this data the city is now able to evaluate the cost effectiveness of implementing bioswales as an element of its CSO control program.

After green infrastructure implementation sites and control measures have been selected, hydrologic and hydraulic (H&H) modeling can be used to quantify how green infrastructure will change runoff characteristics and, in combination with gray infrastructure, help reduce CSOs. More details about the methods for using H&H models for these purposes will be covered in the following section of this report. Note that green infrastructure planning and H&H modeling is an iterative process. For example, hydrologic modeling reflecting green infrastructure practices might reveal opportunities to downsize downstream gray infrastructure. H&H modeling can thus help evaluate varying combinations of green and gray infrastructure to identify what combination of alternatives is most cost-effective.

Using Green LTCP-EZ, a Simplified Tool for Small Communities

Once analyses such as those mentioned above identify what green infrastructure practices can realistically be implemented in a given service area, modeling work can simulate the effects of the green infrastructure on reducing flows into the system. One tool that communities can use for developing a CSO long-term control plan that includes green infrastructure is the *Green LTCP-EZ Template*. This tool was developed by EPA and is posted on the Agency's website here: http://water.epa.gov/infrastructure/greeninfrastructure/upload/final_green_ltcpez_instructions withpoecacomments.pdf.

The *Green LTCP-EZ Template* is a planning tool for communities that wish to develop an LTCP to address CSOs using, at least in part, green infrastructure. The template provides a framework for organizing and completing an LTCP. Schedules 5A and 5B of the template lay out a process for communities to evaluate the ability of a set of widely used green infrastructure runoff controls, as well as pipe network CSO controls to meet a CSO reduction target.

Schedule 5A estimates the number of green infrastructure practices required to meet a runoff reduction goal. The schedule estimates the number of practices that will need to be implemented to achieve the level of CSO control required for Clean Water Act compliance, but it does not assess the capacity of the landscape to accommodate those practices. While the actual volumetric reductions achieved by using different green infrastructure practices

The volume of runoff reduction achieved for each practice category is calculated using a variation of the following equation for volume of runoff reduction:

$$V = kAP24RR$$

V = runoff reduction volume (gallons or million gallons [MG])
k = unit conversion factor
A = area of impervious surface managed (acres)
P24 = depth of 24-hour design storm rainfall (inches)
RR = average volumetric reduction rates (per practice)

Five general green infrastructure controls are considered in the 5A Schedule:

- Green roofs
- Bioretention
- Vegetated swales
- Permeable pavement
- Rain barrels and cisterns

will vary based on local conditions as well as sizing and design considerations, Green LTCP-EZ uses a simplified approach that includes practice-specific volumetric reduction rates to provide an estimate of the volumetric reductions achieved through implementation of green practices. Before making a final determination on the approach to control overflows, the user would need to ensure that the green infrastructure practices are suitable for a given catchment.

Green LTCP-EZ is suitable for small communities and situations that are relatively simple to assess. However, Schedules 5A and 5B may be a resource for others as well in that they are an example of a way to quantify the ability of green infrastructure practices to keep water out of a CSS.

To further quantify the impacts of green infrastructure on CSO frequency and volume in a sewershed, more complex hydrologic & hydraulic (H&H) modeling tools are needed that simulate the processes involved in stormwater runoff across the landscape as well as those involved in routing of storm and wastewater through CSS infrastructure and outfalls.

Using Hydrologic & Hydraulic Models in Planning CSO Control Programs

H&H models are frequently developed and used to simulate how a municipal sewer system will respond to rainfall events. Models are mathematical approaches that calculate estimated water flows through a sewer system. Simulation models are critical for CSO planning because they can project the effects of alternative control scenarios and identify the combination of control measures likely to result in the achievement of CSO control goals.

H&H models are particularly well suited to municipalities with large, complex, combined sewer areas. H&H models include detailed representations of catchments, conveyance systems, and storage and treatment facilities, and simulate how these elements respond to local meteorological data.
In general, H&H models are developed in two stages: the baseline stage, and the future scenarios stage. Prior to assessing alternative future scenarios, the current situation or baseline condition is modeled. Observed results are then compared to simulated results in order to calibrate and validate the model. Several H&H models are available today (see Green Infrastructure Permitting and Enforcement Series, Supplement 3 "Green infrastructure Models and Calculators" at http://water.epa.gov/infrastructure/greeninfrastructure/upload/EPA-Green-Infrastructure-Supplement-3-061212-1-PJ.pdf.

Once a model is built and tested with existing conditions, a community can then run the model and add in various proposed control devices with varying capacities and capabilities at different locations. The model will estimate how the system will perform, and what the resultant CSO event frequencies and discharge volumes will be under various alternative scenarios. There are a variety of approaches to developing alternative scenarios. Communities can then select a cost-effective combination

The H's in H&H Models:

Hydrology
Where does rainwater go and how much will flow into the sewer network?

Hydraulics
What will be the volume and velocity of flow in the sewer network? How will the constructed infrastructure manage and treat the flows?

What Models Can Estimate for Proposed Control Devices:

- How the system will perform
- Resultant CSO event frequencies
- Resultant CSO discharge volumes

of control measures by finding combinations that meet established goals (e.g., no more than four CSO events in a typical year) at the lowest cost.

There are two key components to an H&H model:

- *Hydrology* - The hydrologic component of an H&H model looks at the catchment areas – how big are they, what are the soils like, what land uses they contain – in order to estimate *how much* runoff will drain into the sewer system over *what time frame* when there is a precipitation event. For precipitation that falls on the land surface, hydrologic models predict how this water will redistribute into the soil, groundwater, and atmosphere; and how much will flow into the sewer network. For the purposes of CSO modeling, the final output of interest from hydrological modeling is the volume and timing of water that flows into the CSS through storm drains.

- *Hydraulics* - The hydraulic component of the model is used to simulate how the flows in a sewer system will move through the sewer network. Information from the hydrology component of the H&H model is an input to the hydraulic component of the model. Once flow is delivered to a sewer or another conveyance such as a channel, hydraulic modeling is used to estimate the volume and velocity of flow through the sewer. The complete drainage network needs to be represented in the hydraulic modeling, including factors such as storage facilities or inflatable dams, to simulate the movement of water through all the connected channels as it is transported to the wastewater treatment plants, or to overflow outfalls if the volume of flows exceeds capacity of the system. In CSO contexts, an output of interest from hydraulic modeling is the frequency and volume of these overflows.

The results that emerge from H&H model runs reflect the volume and timing of stormwater runoff that enters the CSS as predicted by the hydrology model, as well as ways the CSO infrastructure system components will store, convey, and treat flows, as simulated by the hydraulic model.

A **dynamic H&H model** is necessary for accurately describing the temporal and spatial variability of an urban catchment's response to rainfall events. Dynamic models can simulate varying conditions over time by calculating the system's state iteratively in short time steps. Commonly used dynamic models are listed below.

Examples of Dynamic H&H Models:

- EPA's SWMM http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/
- Related commercial products such as Info-SWMM (http://www.innovyze.com/products/infoswmm/), PCSWMM (http://www.chiwater.com/Software/PCSWMM.NET/index.asp), XP-SWMM (http://www.xpsoftware.com/products/xpswmm/), and MikeSWMM (http://www.dhisoftware.com/mikeswmm/index.htm)
- InfoWorks (http://www.innovyze.com/products/infoworks_cs/)
- Mike Urban (http://www.dhisoftware.com/Products/Cities/MIKEURBAN.aspx)
- SewerGems (http://www.bentley.com/en-US/Products/SewerGEMS/)

For more information on dynamic models is available reference:
http://water.epa.gov/infrastructure/greeninfrastructure/gi_modelingtools.cfm

Many communities in the U.S. use dynamic models when planning their CSO control programs to demonstrate how specific control measures will alter the frequency and volume of CSO events.

CSO control measures that are modeled using H&H models can include gray infrastructure modifications such as increasing sewer line capacity, addition of storage or treatment devices, and/or expansion of treatment plant capacity. Gray infrastructure controls are typically reflected in the hydraulic component of the model. One can use these models to predict effects on untreated discharge volumes during CSO events if defined gray infrastructure controls are put in place. Many CSO communities already have experience modeling gray infrastructure control measures.

H&H models can also be used to evaluate green infrastructure control practices. In some cases modelers can use green infrastructure to represent stormwater storage. An example of this might be a constructed wetland basin. Where proposed green infrastructure control measures provide a storage function for a defined storm size, modelers can route runoff through a storage node. However, in many cases green infrastructure can perform functions beyond providing storage. For example, practices such as rain gardens can allow for infiltration and evapotranspiration, which increase the performance of the practice in terms of keeping water out of the sewer system. Functions of green infrastructure can also be reflected in the hydrology component of the model. Care must be taken to appropriately quantify the effects of green infrastructure practices in terms of flow quantities and timing in order for the H&H model to produce reliable results. Three case studies at the conclusion of this section point to specific examples of modeling the contribution of green infrastructure practices to CSO reductions.

The hydrology component of the model, if set up to reflect planned green infrastructure practices in a catchment, can also provide information on flow quantities and timing that can be useful in sizing gray infrastructure components downstream. In other words, if green infrastructure practices are integrated into modeling prior to planning the gray infrastructure measures, gray infrastructure will be "right-sized". Running the model with planned green and gray infrastructure measures can estimate the combined effects of the green and gray together, providing a way to determine if CSO control goals will be met.

The Role of Monitoring

Monitoring is an essential part of integrating green infrastructure into the CSO control plan process. Whenever possible, monitoring should be performed to validate CSO models. For example, the Metropolitan Sewer District of Greater Cincinnati (MSDGC) conducted monitoring of CSO flows and discharges during a year that closely resembled a typical rainfall year. Using this data the District was able to compare actual CSO results with model predictions to validate their model. For more information on MSGD's monitoring effort, see: http://projectgroundwork.org/.

Monitoring should also play a role as green infrastructure implementation proceeds. Conducting monitoring during implementation allows for assessment of whether practices are performing as anticipated. If monitoring data indicates control measures are not performing as anticipated, adjustments to factors in the model might be needed. Monitoring during the implementation process can also reveal what practices or designs are working or not working well. This information can inform an adaptive management strategy to either modify or enhance future activities to help ensure CSO control goals are met.

Examples of Communities Using H&H Models to Estimate Green Infrastructure Contributions to CSO Reductions

As illustrated by the case studies described above, a growing number of municipalities have used H&H models to estimate the extent to which proposed green infrastructure measures will reduce CSOs. In most cases, land cover or storage parameters in an existing H&H model were adjusted to reflect green infrastructure measures. Examples of other ways in which municipalities have represented green infrastructure within models include:

- Making broad changes to the representation of catchment hydrology (e.g., defining separate catchments to represent areas treated with green infrastructure);
- Conversion of directly connected impervious areas to disconnected impervious areas;
- Modifying depression storage value parameters;
- Adjusting the amount of storage in individual nodes.

In some cases, modelers evaluated the impact of specific green infrastructure practices by creating a more detailed representation of the system. Details can include defining catchments for individual practices, and reflecting changes in infiltration, evapotranspiration, and storage components. Some of these efforts used separate platforms or evaluations for catchment areas, whereas others performed this evaluation within the primary collection system model. In all cases, the goal was to reflect how stormwater volumes and timing have changed or would change as the result of green infrastructure implementation in the hydrology component of the H&H model. Several communities, three of which are described below, have used modeling as an important tool in their green infrastructure planning.

Modeling Case Study #1: Metropolitan Sewer District of Greater Cincinnati

The Metropolitan Sewer District of Greater Cincinnati (MSDGC) modified its existing model, which was based on MikeSWMM, to model the effects of green infrastructure implementation in the Lick Run sewershed. Modelers extracted this smaller sewershed from the larger system-wide model to streamline the modeling effort. They then redefined the catchment to better distinguish various land use categories and improve hydrologic parameters. Lastly, they recalibrated the model using existing historic flow data.

With the updated baseline model set up and calibrated, staff introduced the effect of green infrastructure practices by removing green infrastructure-managed areas from the baseline model catchments and adding them to newly created catchments. Changes in the hydrology component of the model to reflect green infrastructure practices included the following: Modifications to amount of impervious surface area, addition of depression storage areas, addition of parallel pipes to represent a daylighted stream, and removal of impervious area from the catchment area for downspout disconnection. Scenarios were evaluated using two approaches. The first approach used variations in the amount of managed impervious area, and the second used variations in the amount of captured volume and the release rate associated with each type of practice. Modeling results considered a range of green infrastructure implementation scenarios based on storm sewer separation and stream daylighting, detention basins, and downspout disconnection. Suggested reductions of CSO volume ranged from 39 to 46 percent control of CSO events for a typical rainfall year. (See Table 3.04-1 in http://projectgroundwork.org/downloads/cfac/Lick_run_strategic_integration_plan_July2011_Final_Full_Report.pdf).

Modeling Case Study #2: San Francisco Public Utilities Commission

The San Francisco Public Utilities Commission (SFPUC) modified its baseline collection system model, which is based on the InfoWorks Collection System software including SWMM, for estimating the hydrology and runoff portion of its CSS model. Modelers altered impervious area to represent select green infrastructure practices (e.g., green roofs, street trees, bioretention, and permeable pavement). Manning roughness number and depression storage values, which are used in the runoff calculation, were altered for the areas where green infrastructure practices were added in the model, except for the downspout disconnections that were excluded by removing roof top areas from the catchment. The results of the modeling based on SFPUC's 30-year target for green infrastructure implementation would reduce annual CSO amounts by 200 to 400 million gallons or 14 to 27 percent. See http://sfwater.org/modules/showdocument.aspx?documentid=560.

Modeling Case Study #3: Milwaukee Metropolitan Sewerage District

To evaluate the potential for green infrastructure to reduce average annual stormwater runoff and peak flows that typically result in CSOs, the Milwaukee Metropolitan Sewerage District (MMSD) conducted numerous modeling exercises (http://v3.mmsd.com/assetsclient/documents/sustainability/SustainBookletweb1209.pdf). MMSD developed a hydrologic simulation program Fortran (HSPF) model to represent five- to six-acre residential and commercial city blocks. The model initially established baseline conditions, then evaluated the impact of green infrastructure practices. Modeled results indicated that introducing green infrastructure in residential areas could reduce peak flows by 5 to 36 percent. After initial modeling showed reduced stormwater flows into the combined system within the hydrology component of the H&H model, MMSD was able to use the hydraulic component of its model to simulate the overall response of the District's conveyance and treatment system. MMSD's modeling confirmed the potential of green infrastructure to have a significant impact on average annual CSO volumes (12 to 38 percent).

These and other case studies provide examples of how H&H model can be set up to reflect green infrastructure practices. EPA's new SWMM Version 5.0 can incorporate a variety of green infrastructure practices *explicitly* rather than making indirect modifications to reflect the effects of green infrastructure practices. Chapter 4 contains a step-by-step, detailed case study describing how SWMM version 5.0 can model the effects of green infrastructure implementation in a theoretical sewershed. Chapter 4 also includes information on how to compare model results to a baseline simulation in order to quantify the degree to which green infrastructure practices contribute to total reduction of CSO events.

"A growing number of municipalities have used H&H models to estimate the extent to which proposed green infrastructure measures will reduce CSOs."

Volunteers maintain a curbside planter capturing street runoff in Gresham, Oregon.

Chapter 4: Detailed Case Study of Incorporating Green Infrastructure into a CSO Model using SWMM v. 5.0

This chapter presents a hypothetical case study developed by EPA to illustrate how a community might use H&H modeling to explore tradeoffs between gray and green infrastructure for CSO control. H & H modeling can assist with scoping, planning and prioritization of different green infrastructure control scenarios. This case walks the reader through four major steps: 1) characterizing the CSS, 2) defining a baseline scenario, 3) developing a gray infrastructure control scenario, 4) developing green infrastructure alternatives, and 5) analyzing alternative gray/green CSO control scenarios.

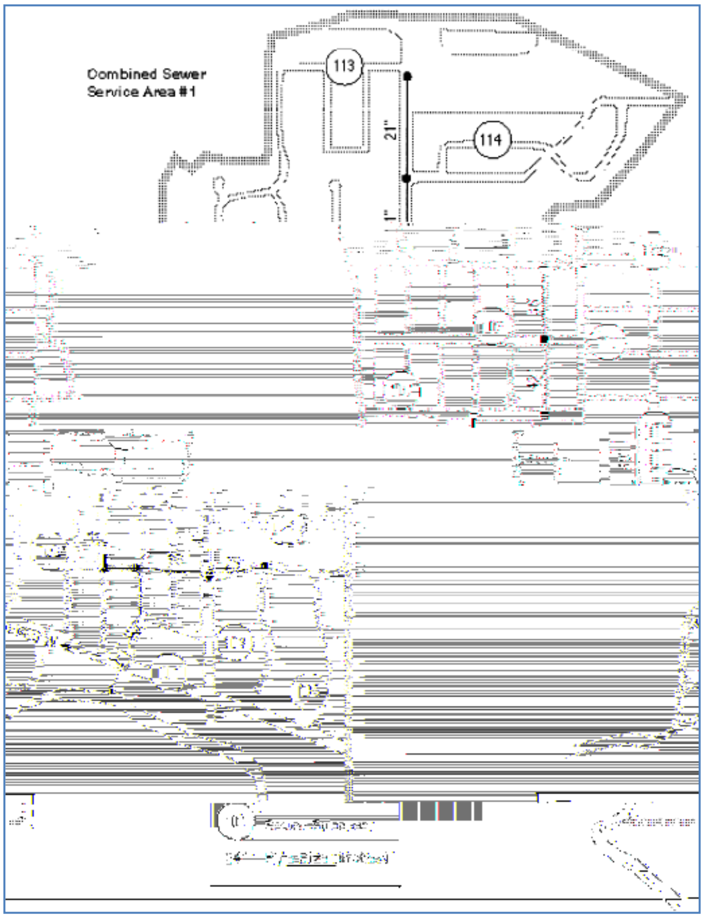


Figure 4-1. Hypothetical sewershed modeled in the case study.

This same theoretical system was used in the 1999 EPA publication "Combined Sewer Overflows - Guidance for Monitoring and Modeling" (EPA 832-B-99-002; http://www.epa.gov/npdes/pubs/sewer.pdf). Readers can refer to that report for a detailed discussion of how one selects, builds, and calibrates a CSS H&H model. It also contains information specific to the current case study - soil infiltration properties, land surface characteristics, the layout, size, and slope of the sewer pipes, and the average dry weather sanitary flows generated.

The original case study in the 1999 publication modeled the baseline condition of an existing overflow structure with no controls in place. This example will now be extended to consider both gray and green infrastructure approaches for reducing CSO frequency and volume. The H&H software used in this case study is the freely available EPA Storm Water Management Model v. 5 (SWMM5), although any of the other modeling packages listed in Chapter 3 could also be used.

Step 1: Characterize the System

Figure 4-1 is a map of a hypothetical CSS that covers a 500-acre service area. There is a diversion structure located at the bottom of the system that sends excess flows to a receiving stream. Larger systems can be comprised of several such sewersheds that might be tied into one or more interceptor lines with various overflow points before ending at a treatment works.

Figure 4-2 shows the SWMM5 representation of the sewershed. The service area is divided into 14 separate sub-areas (the polygon areas in the figure) that discharge both dry weather sanitary and wet weather runoff flow at different locations along the sewer network (the line segments in the figure). The boundaries of these sub-areas were primarily determined by the natural drainage contours of the land surface. They each contain different mixtures of land cover types (roofs, pavement, lawn areas, shrub, and forest). The percentage of each sub-area covered by impervious surfaces ranges from 17 to 75 percent and is displayed in color-coded fashion. The pervious portions of the sewershed consist of Group B soils (a moderately well-draining sandy loam). The CSS network contains pipes ranging in diameter from 21–54 inches. Their slopes vary from 0.7 to 5 percent. The total average dry weather sanitary flow is 1 million gallons per day (MGD).

A key component of any CSS model is the flow diversion (or regulator) device used to divert wet weather flow away from the main interceptor and discharge it directly into a watercourse to avoid surcharge and flooding of the CSS. There are several different types of regulators in common use. One example is the *transverse weir with orifice regulator* (Figure 4-3). Actual diversion structures can be considerably more complex than the one shown here. For this case study, the diversion structure is modeled using SWMM5's Flow Splitter element. The Splitter sends flows of up to 5 cfs (3 MGD or three times the average dry weather flow) to the sewage treatment plant through a two-foot diameter interceptor. Any excess flow above this is directly discharged to the receiving stream.

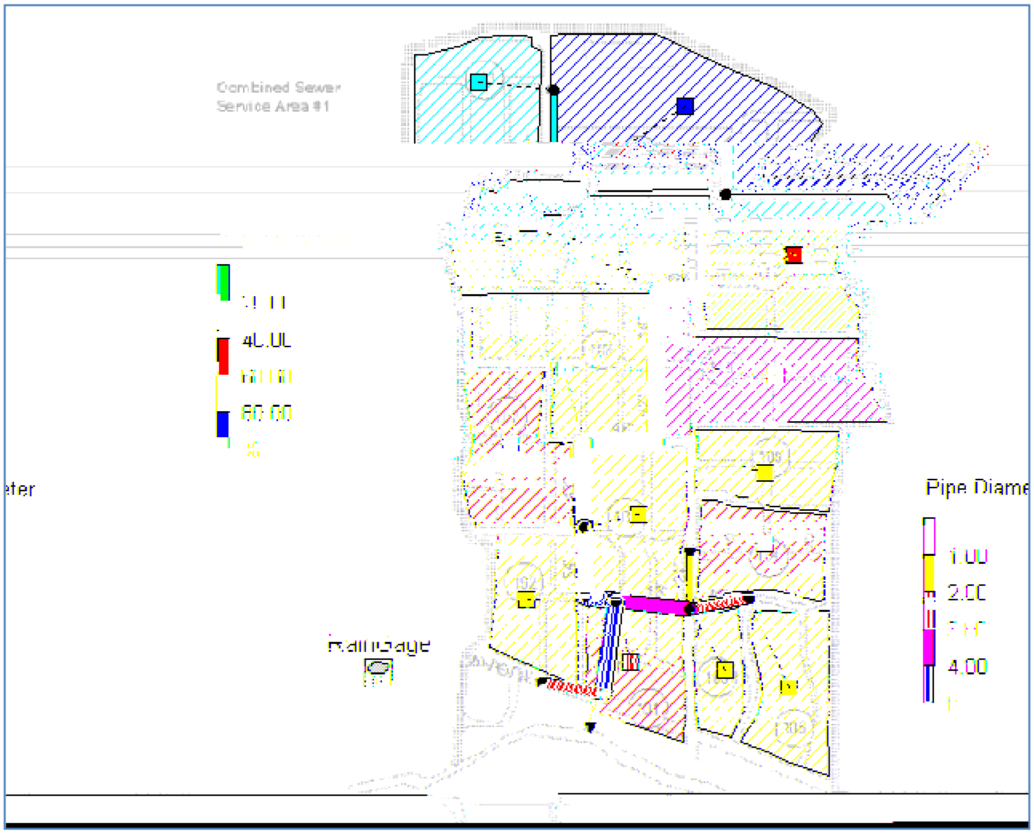


Figure 4-2. SWMM5 representation of the hypothetical case study CSS.

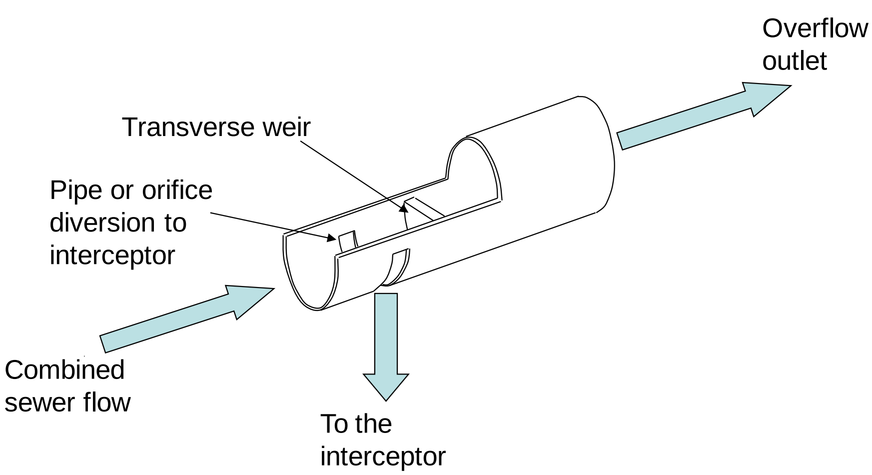


Figure 4-3. A typical transverse weir flow regulator.

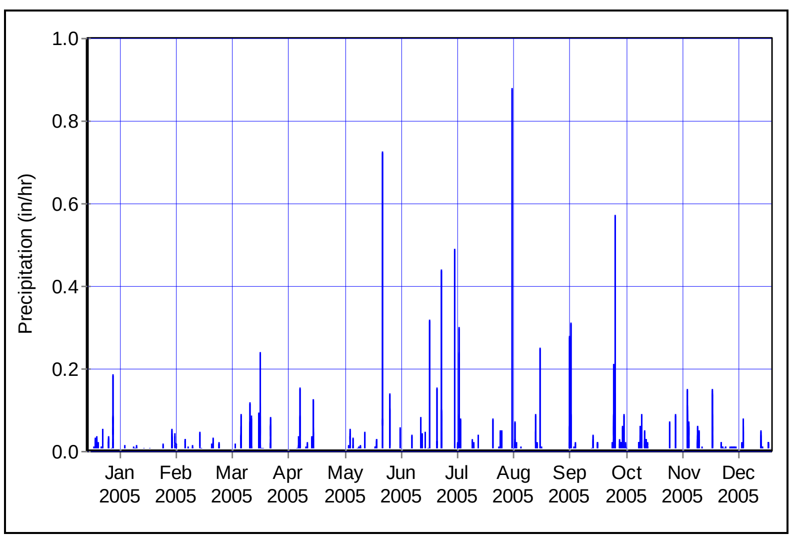
Step 2: Define a Baseline Scenario

The next step is to determine the frequency and magnitude of overflows under current baseline conditions with no CSO controls applied. To do this, the model was run with one year's worth of long-term hourly rainfall data at a nearby rain gage. This particular year was deemed to represent a typical year and serves as a reasonable compromise between running the model over the full historical rainfall record (which consumes a large amount of processing time) and using just a single "design storm" event (which fails to capture a meaningful range of storm magnitudes, durations and antecedent conditions).

The resulting time series of rainfall, interceptor flow, and CSO flow are shown in Figure 4-4. These figures were directly generated from the SWMM5 software. It appears that any rainfall above about 0.1 inches/hour is enough to trigger an overflow. The overall behavior of this baseline scenario is summarized in Table 4-1. The total volume values listed in the table came directly from SWMM5's Status Report listing. The number of days with overflows was determined by using SWMM5's statistics tool, which counts number of days when peak overflow from the regulator was above 0.01 cfs. Under the baseline scenario with no CSO controls there are 64 days with CSOs resulting in a discharge of 28 million gallons of untreated combined sewage in a typical year.

Table 4-1. CSS flow volumes for the case study area in a typical year.

Annual Statistic	
Dry Weather Inflow (MG)	386
Stormwater Inflow (MG)	70
Combined System Inflow (MG)	456
Treated Outflow (MG)	428
Untreated Overflow (MG)	28
Number of Days with Overflows	64



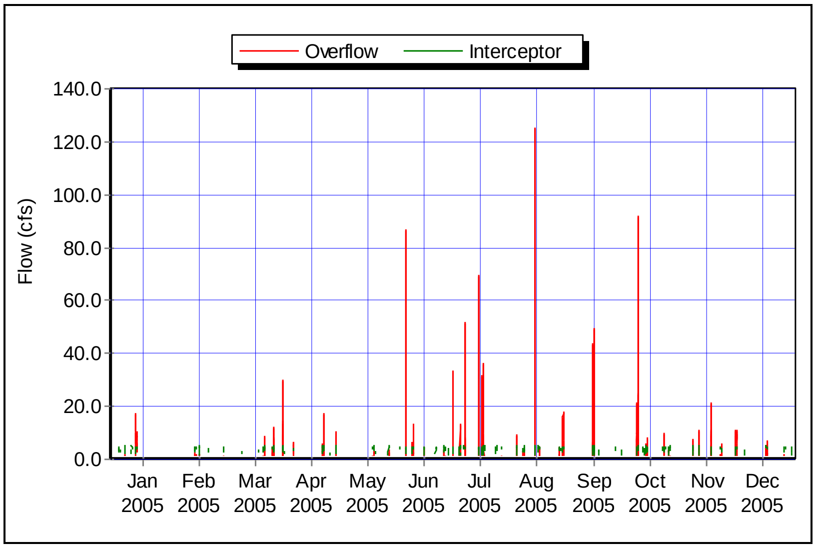


Figure 4-4. Precipitation, interceptor flow, and CSO flow for the baseline scenario.

Step 3: Develop a Gray Infrastructure CSO Control Scenario

Sewer separation, treatment plant expansion, in-line storage, and off-line storage/treatment are traditional approaches to controlling CSOs. These gray infrastructure alternatives all involve adding to, replacing or modifying the existing wastewater collection and treatment system to provide more capacity to handle existing wet weather flows in an environmentally protective manner.

This case study will next consider the effect that different amounts of off-line storage capacity would have in reducing the frequency and magnitude of CSOs. Off-line storage is one of the simplest and most commonly used CSO mitigation measures. Figure 4-5 is a conceptual drawing of how a storage facility works, accepting overflows from the CSO regulator and storing them until such time when the main interceptor once again has enough capacity to accept additional flow.

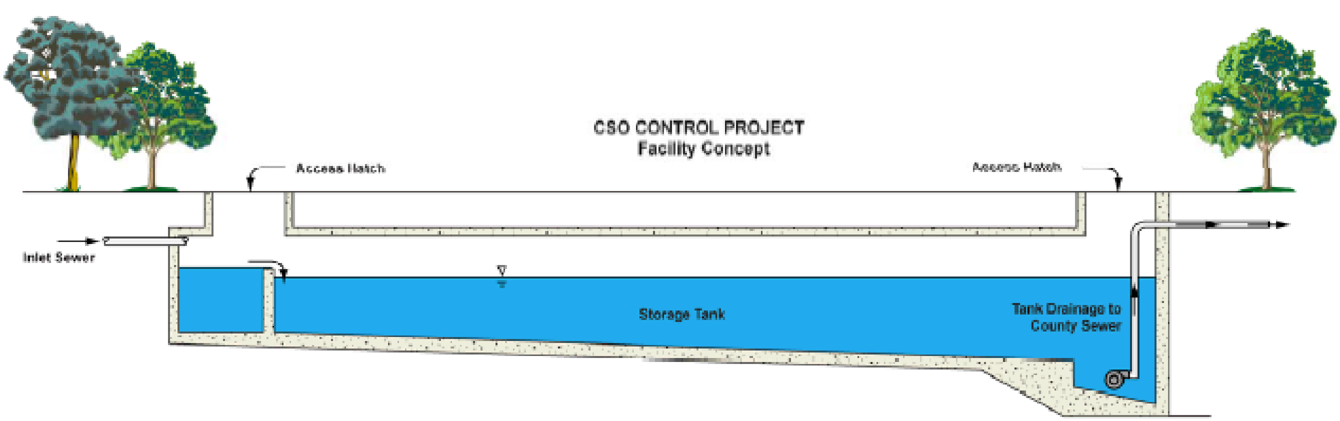


Figure 4-5. Conceptual drawing of a CSO storage facility.

Figure 4-6 shows how an off-line storage facility can be added into the SWMM5 model. The facility is represented here as a SWMM5 Storage Unit element. The diversion leg of the regulator serves as the inlet line to the facility. There are two outlet lines. One is a Weir element placed along the top rim of the unit to discharge any excess overflow from the facility to the CSO outfall. The second outlet line is a Pump element used to empty the contents of the storage unit when capacity becomes available in the interceptor to the treatment plant.

The storage unit is configured to be 10 feet high, 20 feet wide, with a length that can vary from 250–2500 ft., depending on the targeted level of CSO control. This provides 0.4–4 MG of storage depending on the length chosen. The pump used to dewater the unit does so at a constant flow of 3 cubic feet per second (cfs) when the flow in the interceptor drops below 2 cfs (so as not to exceed the 5 cfs capacity of the interceptor). Otherwise, the pump remains off. In the SWMM5 model, a Control Rule element is used to express this pumping policy.

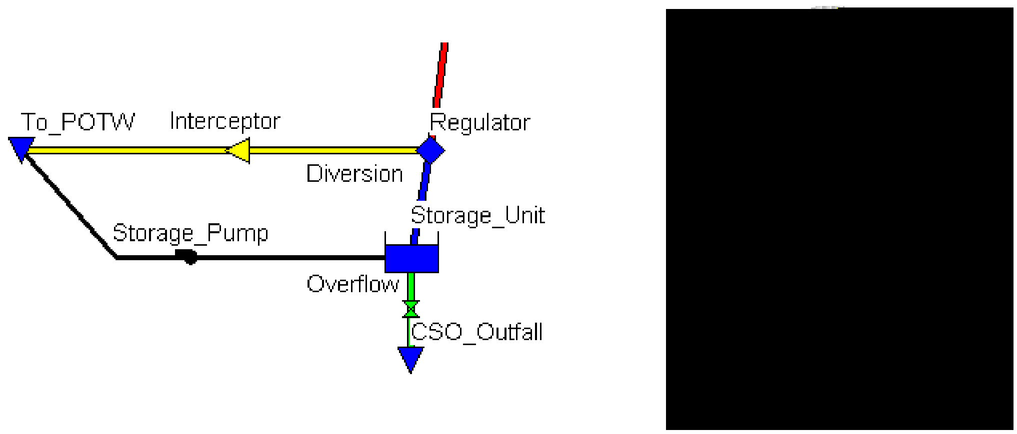


Figure 4-6. Detail of the case study model with CSO storage added.

The case study model can be run with varying levels of off-line CSO storage provided over the same year of rainfall (as was used for the baseline analysis). Figure 4-7 shows how the number and total volume of CSOs varies in this example with the amount of storage provided. Note how the curves flatten out beyond 2 MG of storage (producing four overflow days with a total CSO volume of 5 MG) indicating how additional increments of storage volume become less effective in reducing CSOs beyond this point.

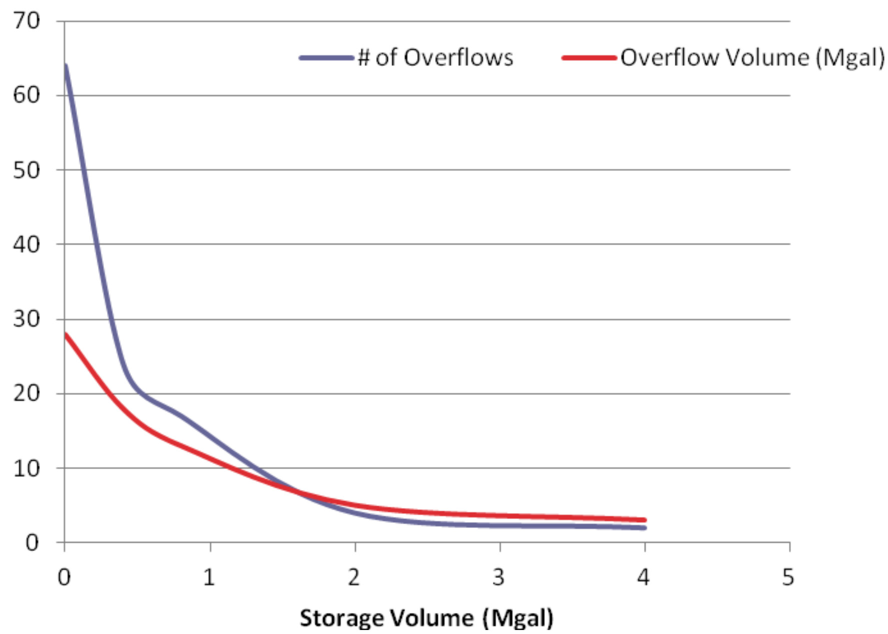


Figure 4-7. CSO frequency and volume with increasing amounts of off-line storage volume.

Step 4: Develop Green Infrastructure Alternatives

Although it is relatively straightforward to model gray infrastructure solutions because of the limited number of feasible alternatives and locations, analyzing the opportunities afforded by green infrastructure requires additional modeling considerations. Green infrastructure utilizes a variety of distributed practices deployed at many locations throughout a service area to reduce stormwater runoff at its source (see Chapter 1). Decisions regarding the type, number, location, sizing, and capture area of each control throughout the entire service area must somehow be conveyed to the H&H model. In addition, the model must be capable of estimating how much reduction in runoff results from utilizing these controls over a long-term sequence of rainfall events.

For planning purposes, it is acceptable to employ some level of aggregation and abstraction when modeling the numerous types and locations of green infrastructure controls that comprise a green solution. One simplified approach is to represent the combined effect of all green infrastructure controls within a particular sub-area by either reducing the amount of impervious area or by having some fraction of the impervious area's runoff be routed onto its pervious area (thus simulating the disconnection practice shown in Table 1-1). Although this method is easily applied, this method fails to account for the intricate dynamics between the rates of surface capture, surface infiltration, evapotranspiration, soil percolation, sub-surface storage, and native soil infiltration that characterize the hydrologic behavior of many green infrastructure controls.

Some H&H modeling packages (including SWMM5) now have the ability to model the hydrologic performance of green practices on an individual unit basis. Here is how one can use this feature to provide a more accurate way to model green infrastructure within a sewershed without having to explicitly represent each individual green infrastructure installation:

1. Select an appropriate sub-set of green infrastructure practices and establish a generic design template for each.
2. For each CSS model sub-area, determine the total amount of impervious area that will be treated by each generic green infrastructure design.
3. Add this information into the CSS model.
4. Run the green infrastructure-augmented CSS model with varying levels of gray control utilized to see the combined effect that a green/gray solution has on CSO frequency and volume.
5. Modify the choices made in step 2 and repeat steps 3 and 4 to see the effect that different green control scenarios have in reducing CSOs.

The key to this approach is recognizing that green infrastructure controls of the same design but different sizing will perform the same as long as their capture ratios (ratio of green infrastructure area to treated impervious area) are the same. This allows many otherwise geographically dispersed green infrastructure units within a sub-area to be treated as one large unit within the H&H model.

In applying this approach to our case study example, three types of generic green infrastructure controls were selected as most suitable for the conditions within the service area. These were permeable pavements (to capture street and parking lot runoff), street planters (to capture runoff from roofs and sidewalks in high-density areas), and rain gardens (to capture roof runoff from individual home lots). A template for designing each type of green infrastructure control on a per unit area basis was then established (see Table 4-2). Note that each control's Capture Ratio parameter allows one to determine its actual size once the amount of impervious area it treats is established.

Table 4-2. Design parameters for the generic green infrastructure controls used within the case study.

Parameter	**Permeable Pavement**	**Street Planter**	**Rain Garden**
Surface Layer			
Capture Ratio (percent)[1]	25	5	5
Ponding Depth (inches)	0	6	6
Soil / Pavement Layer			
Thickness (inches)	4	18	12
Porosity (percent)	11	50	50
Conductivity (in/hr)	100	10	10
Storage Layer			
Thickness (inches)	18	12	0
Porosity (percent)	43	43	0

[1]Ratio of green infrastructure control area to impervious area treated.

The next step is to perform a detailed analysis of the land surfaces and contours within each model sub-area to determine how much of its impervious area could feasibly be treated by a most suitable type of generic green infrastructure control. This assignment of green infrastructure practices to land areas was made for both publicly owned and privately owned land because in many cases it may be easier to implement a green infrastructure program on the former as compared to the latter. Recognizing this distinction results in two green scenarios to consider – public land only and public plus private.

The result of this suitability analysis, shown in Table 4-3, summarizes what percent of the impervious area in each modeled sub-area could be treated by each type of green infrastructure control on both publicly and privately owned land. As an example of how to interpret the numbers in the table, consider the permeable pavement entry for Sub-Area 101. The value of 10 means it was considered feasible to treat 10% of the total impervious area with permeable pavement applied to public land. Because the capture ratio of our generic permeable pavement design is 25%, this means that only 2.5% of the impervious area in Sub-Area 101 is actually replaced with permeable pavement. Summing together the various entries in the table reveals that public green infrastructure could be applied to 20% of the sewershed's impervious area. Another 15% could be treated with controls placed on private land.

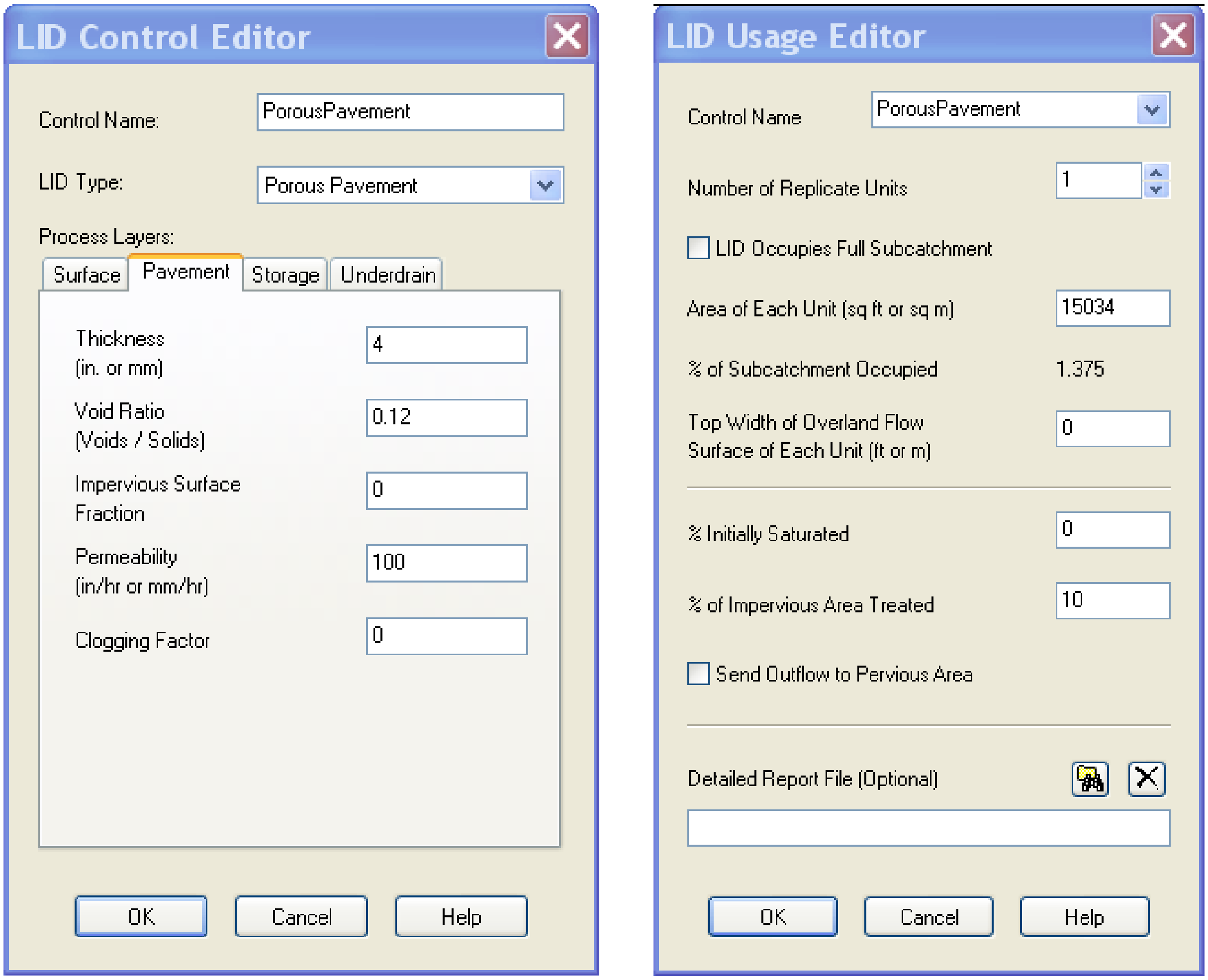
Table 4-3. Percentage of impervious area treatable by different green infrastructure controls.

Sub-Area	Percent Impervious	Public Permeable Pavement	Public Street Planters	Private Rain Gardens
101	55	10	10	15
102	35	10	5	15
103	28	10	5	15
104	55	10	10	20
105	22	10	5	15
106	31	10	5	15
107	46	10	10	15
108	38	10	5	15
109	35	10	5	15
110	75	20	20	10
111	17	0	5	25
112	59	15	10	10
113	39	10	5	15
114	29	10	5	15

Assembling a "green infrastructure treatability" table like this is not a simple task. It would likely require many hours spent on GIS analysis of aerial and contour maps along with walking tours of the service area. However once compiled in this fashion, it is then relatively straightforward to use this information along with the generic green infrastructure control designs to populate the H&H model with a green infrastructure control plan, and then analyze the impact on controlling CSOs.

Step 5: Analyze Gray/Green CSO Control Scenarios

The case study SWMM5 model with the CSO storage unit can be expanded to include green infrastructure by first defining within the model the three generic green infrastructure control templates listed in Table 4-2. Figure 4-8a shows the SWMM5 dialog used to do this for the permeable pavement option. Note that this generic design applies to all permeable pavement installed within the sewershed, but does not specify the actual amount (or area) used. That is done for each sub-area using the LID Usage editor shown in Figure 4-8b. Here one specifies the actual number of square feet of permeable pavement applied and the amount of impervious area whose runoff it captures and treats using the information contained in Table 4-3. A similar sequence of steps (defining the generic design first and then defining its usage in each model sub-area) was used in this example for street planters placed on public land.



(a) (b)

Figure 4-8. SWMM5's LID control editor (a) and LID usage editor (b).

At this point, the model contains both a gray CSO control option (the storage unit) and a green option (permeable pavement and street planters applied to public land). As was done before for the gray-only option, the model can be run for a series of different storage unit sizes to see what the combined effect of gray and public green control would have on the number and volume of combined sewerage overflows during a typical year. After these runs, the model can be updated to add an additional increment of green infrastructure – rain gardens applied to private land. Multiple runs at different storage unit sizes are once again made to determine the effect of adding more green infrastructure to the mix. The overall results of these model runs are summarized in Figure 4-9 for CSO frequency and in Figure 4-10 for CSO volume.

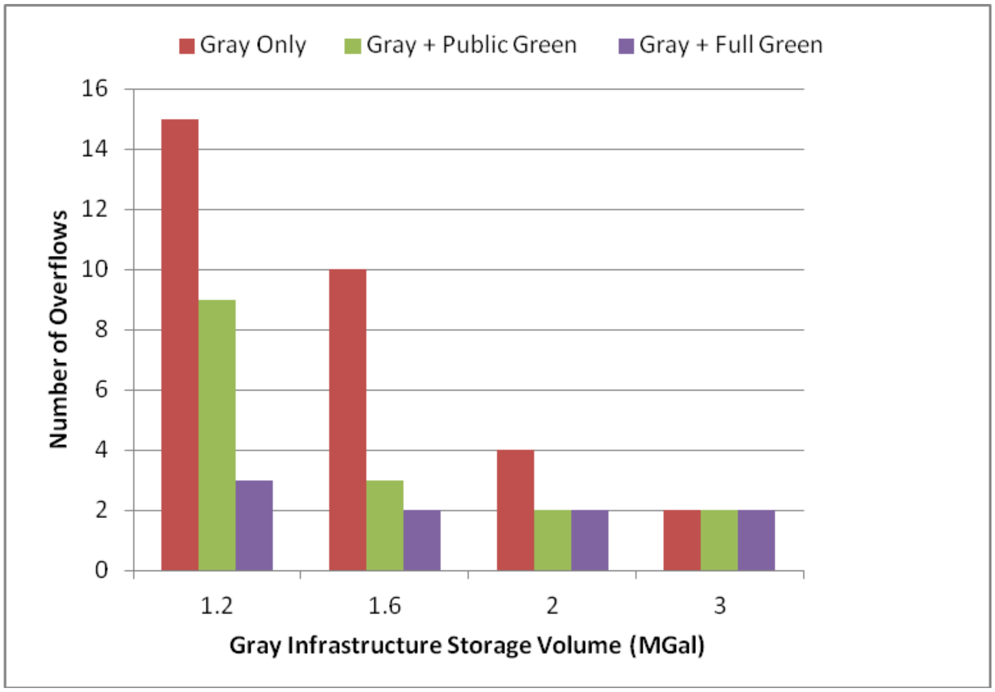


Figure 4-9. Number of overflows with varying gray infrastructure storage volumes with different gray and green CSO controls.

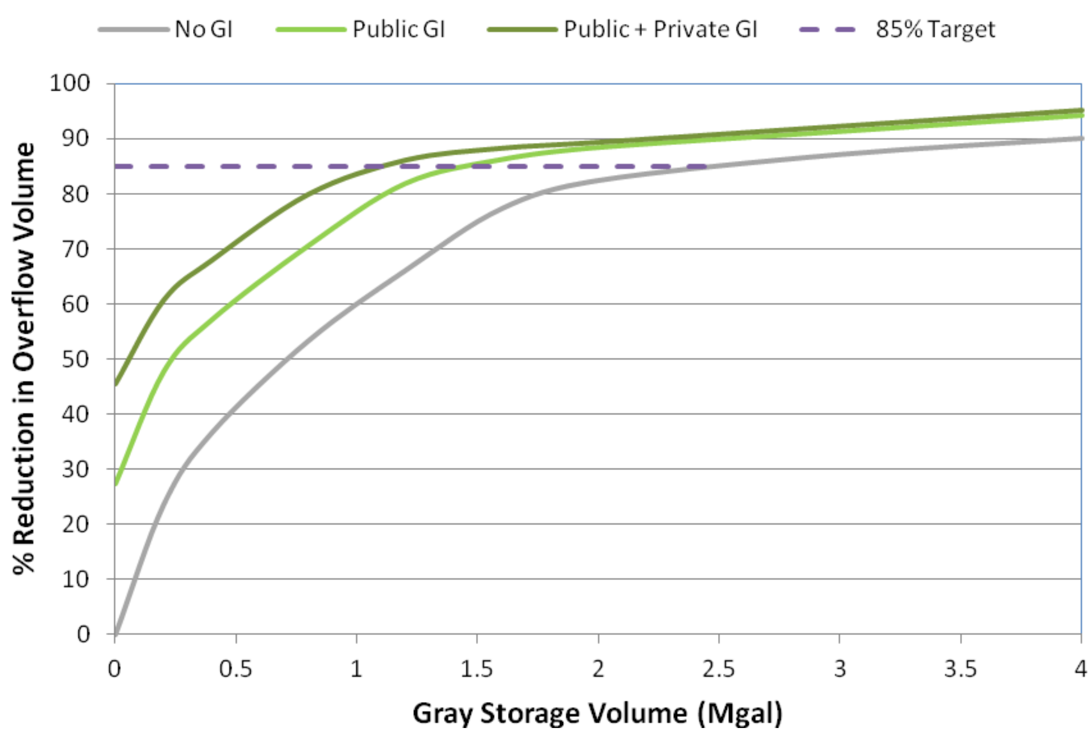


Figure 4-10. Percent reduction in overflow volume using gray and green CSO controls.

Model Outputs

For the purposes of CSO decision-making, the final output of interest from the hydrological component of an H&H model is the volume and timing of water flowing into the CSS through storm drains. Linking planned green infrastructure control measures to their effects is accomplished by quantifying the volume and timing of stormwater runoff entering the CSS as predicted by the hydrology model, and the overflow volume and frequency discharged from the CSS as predicted by the hydraulic model.

Several important results in this particular case study are worth noting. First, for this particular model, green infrastructure appears to have had a greater impact in reducing CSO volumes than CSO frequencies. This follows from the fact that the green infrastructure controls were only designed to treat a limited fraction of the sewershed's impervious area (20–35%) and that the green infrastructure system or practices have a fixed capacity to accept stormwater runoff. This capacity can be exceeded during large storm events or situations where successive storms saturate green infrastructure practices, so overflow events may still result. This example illustrates that in most cases some combination of green infrastructure and gray infrastructure is necessary to reduce or eliminate overflows.

A second result to emphasize is that an all-green solution (i.e., no gray infrastructure storage provided and both public plus private green infrastructure) only treats a fraction (e.g., 35%) of the total impervious area. Yet, it can still provide some significant reductions in CSOs. Overflow frequency can be reduced by 30%, and overflow volumes by 45%.

Finally, green solutions may also help reduce the size and cost of the gray solution needed to meet higher CSO control targets. For example, meeting an overflow volume reduction target of 85% (5 MG) would require a 2.5 MG storage unit without any green infrastructure. This system can be reduced to store 1.3 MG if public green infrastructure controls are used and down to 1 MG (a 60% reduction) if both public and private controls are utilized based on an estimated adoption rate and coverage. Reduced volume of stormwater entering the waste water treatment plant may also translate to additional cost savings, or avoid additional capital costs if expanded treatment capacity would be needed to treat additional stored flows. Here we find that utilizing a dynamic H&H model can help decision makers scope, plan and prioritize a variety of different control options.

Chapter 5: Conclusion

Controlling CSOs is an important element of restoring and protecting water resources in many metropolitan areas. CSO controls often involve a significant financial investment for both sewer districts and municipalities. Today, many communities are investigating the potential for green infrastructure control measures as an element of their overall CSO control strategy. The green infrastructure practices described in this document can help reduce flows going into the sewer system, which may in turn reduce capital and operational costs. Green infrastructure investments also serve as amenities for neighborhoods, providing both social and economic benefits.

Green practices must be planned and scheduled, and implementation tracked and evaluated, similar in concept to how gray infrastructure projects are planned and tracked. In turn green infrastructure should be planned hand-in-hand with gray infrastructure, as these components of an overall CSO control plan are strongly inter-related.

The level of green infrastructure that can realistically be achieved in a given catchment should take into account key sewershed characteristics, such as land use, soil types, topography and the expected degree of buy-in from local stakeholders. Care must be taken in projecting green infrastructure implementation based on these varying factors, such that model outputs provide a strong, realistic basis for future decision-making around green infrastructure investments.

This resource has shown that H&H models are particularly useful tools to help evaluate combinations of gray and green infrastructure. H&H models can also help assess whether planned level of technologies will meet established CSO control objectives. While larger green infrastructure practices that fulfill a storage function can be modeled in the hydraulic component of an H&H model, smaller green infrastructure practices are typically modeled in the hydrologic component. Several techniques can make the model reflect both reduction of flow into the system, as well as extending the time of concentration. The detailed case study provided in Chapter 4 illustrates how changing hydrology parameters within a model (e.g., the conversion of impervious area to pervious area, conversion of directly connected impervious areas to disconnected impervious areas, and modifying depression storage value parameters) can all be used to account for the effects of green infrastructure.

Using these techniques, models such as EPA's SWMM Version 5.0 can help represent the hydrologic response of a variety of green infrastructure practices. Use of this model or others like it can help simplify and standardize the impacts of green infrastructure practices within combined sewer systems.

For more in depth information on integrating green infrastructure into CSO Long Term Control Plans (LTCPs), see: Review of Green Infrastructure (GI) in CSO Long Term Control Plans: A Training Tool produced by EPA Region 5 and EPA's Office of Enforcement and Compliance Assurance (OECA). This resource provides additional insight into how to assess the practicality and likely performance of green infrastructure measures within CSO Long Term Control Plans. The document is available at: http://water.epa.gov/infrastructure/greeninfrastructure/gi_regulatory.cfm#csoplan

FURTHER RESOURCES

Greening CSO Plans is part of a series of technical resources for integrating green infrastructure into permitting and enforcement actions: http://water.epa.gov/infrastructure/greeninfrastructure/gi_regulatory.cfm

For additional resources on green infrastructure, access EPA's Green Infrastructure web page at: http://water.epa.gov/infrastructure/greeninfrastructure

EPA United States Environmental Protection Agency