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PAS MEMO

# The Effectiveness of Green Infrastructure for Urban Stormwater Management

*By Martin Jaffe*

Green infrastructure — development practices that preserve, emulate, or restore a site's natural hydrology — is becoming an increasingly popular strategy to manage stormwater runoff.

The U.S. Environmental Protection Agency, for example, has been championing green infrastructure as part of its Municipal Separate Stormwater Sewer System (MS4) permit program, and Smart Growth advocates have also been promoting these practices as part of their low-impact development initiatives.

Planners need to know how to evaluate these innovative practices when they are proposed to supplement or replace conventional stormwater sewer and detention infrastructure in new development, or when proposals are made to retrofit them to existing development in order to address existing water pollution and flood-hazard risks.

This *PAS Memo* explores the effectiveness and some of the economic implications of many common green infrastructure practices that are used to manage the water quality and flood risks associated with urban stormwater runoff. Many of its insights and findings arose in a study undertaken for the Illinois Environmental Protection Agency in 2010 by a research team from the University of Illinois at Chicago, the Center for Neighborhood Technology, the Chicago Metropolitan Agency for Planning, and the Illinois-Indiana Sea Grant College Program at the University of Illinois and Purdue University. This study, the Illinois Green Infrastructure Study, examined the best practices for green infrastructure in the United States and the effectiveness of these practices when compared with conventional stormwater management approaches, making its findings relevant to a national planning audience.

## Background

"Green infrastructure" was a term originally used to define a network of open spaces that provide adequate habitat to support biodiversity (Benedict and McMahon 2006). This is the definition still employed by the consortium of 230 environmental groups, local governments, and corporations that comprise Chicago Wilderness, a nonprofit organization that created a biodiversity recovery plan and mapped a "Green Infrastructure Vision" for the tri-state Chicago metro region (Chicago Wilderness 1999). In both the plan and map, Chicago Wilderness used the term "green infrastructure" to denote the critical habitats and open-space corridors it identified as management priorities in southeast Wisconsin, northeast Illinois, and northwest Indiana.

In the 21st century, however, the biodiversity functions of green infrastructure have moved from a central concept to a more subsidiary role. Instead of being used solely to define critical habitats, the phrase has evolved to define a variety of best management practices for urban stormwater management in order to maintain or improve the ambient water quality of urban streams.

For the purposes of this article, the phrases "stormwater control measures," "best management practices," and "low-impact or conservation development" are all synonymous with the underlying concepts of green infrastructure: urban stormwater management practices that preserve, restore, or mimic natural hydrology, especially the infiltration of stormwater into soils, its evaporation, and its transpiration by vegetation.

Using natural systems and processes to manage precipitation and snowmelt on site in order to replicate predevelopment hydrology has become an increasingly popular option for urban stormwater management. Part of this popularity is because environmental managers recognize that the increased regulation of point sources of pollution under the Clean Water Act still has not allowed many urban streams to attain their desired uses. This has shifted attention to better management of indirect pollution sources such as stormwater runoff. Reducing the runoff contributions to urban streams also reduces downstream flood risks while improving aquatic and riparian habitat (NRC 2008).

Stormwater runoff contributions to urban streams increase with the amount of impervious surface in a watershed (see Figure 1). The Center for Watershed Protection (CWP) has found, for example, that stream quality is affected when only 10 percent of an urbanized watershed consists of impervious surfaces (such as roofs and paving) and that streams become severely degraded when impervious surfaces in a watershed exceed 25 percent (CWP 2003).

**Figure 1. Changes in hydrology from increased impervious surface**

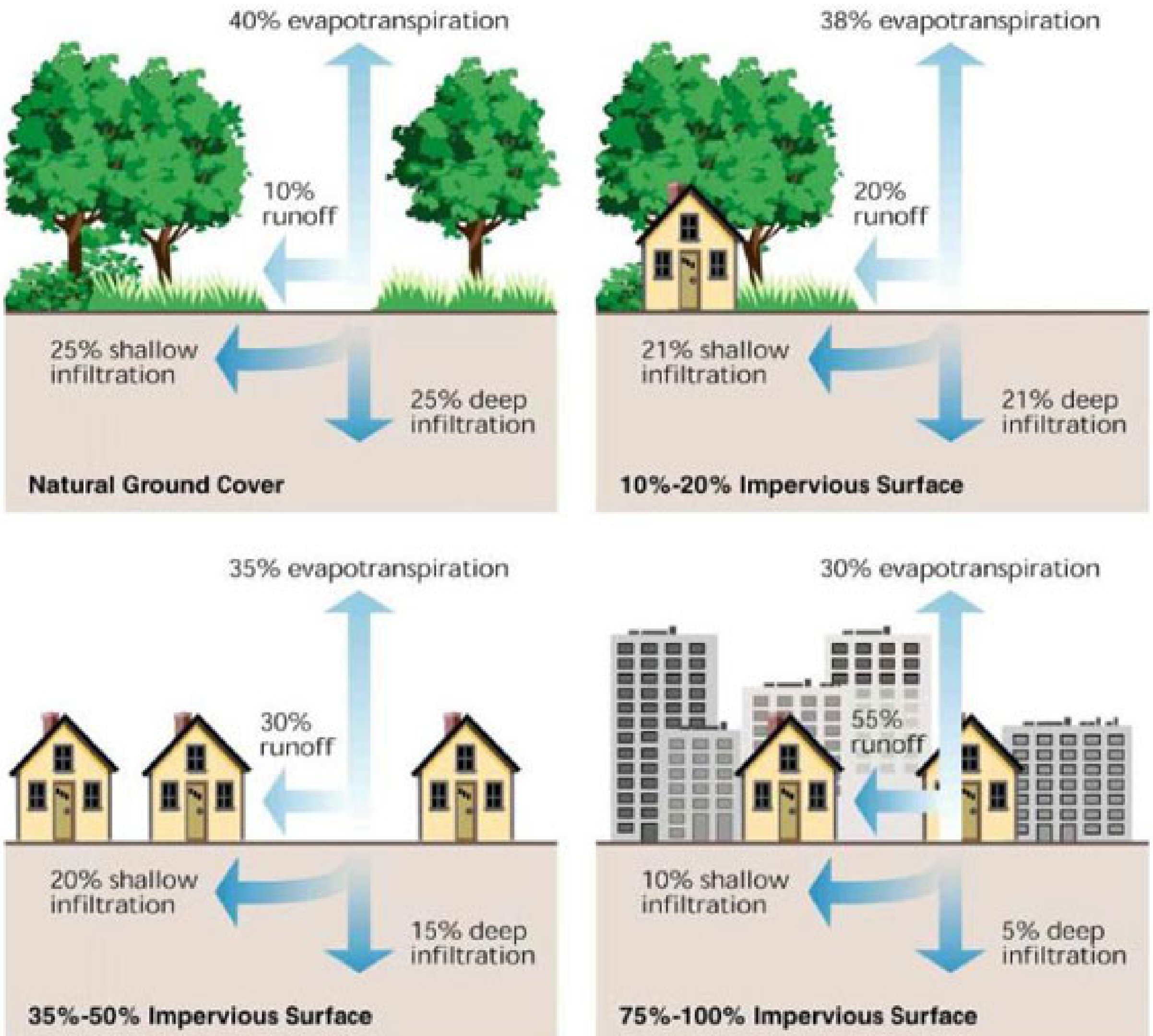


Image from *Stream Corridor Restoration: Principles, Processes, and Practices*, Federal Interagency Stream Restoration Working Group, October 1998.

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By using green infrastructure, planners hope to encourage a greater percentage of stormwater to infiltrate into soils or be taken up by plants. Green infrastructure is used to reduce both the peak streamflow and the pollutant loading of a stream after rainstorms or, in the case of melted winter snow cover, after spring or winter thaws. Snowmelt runoff has the potential for higher pollutant loadings to waterways because of the sudden release of pollutants trapped in the snow. It may also become a more significant water-quality threat in the future as global climate change increases the number of freeze-thaw cycles during increasingly warmer winters in northern latitudes when frozen soils impair infiltration.

The federal government has shown interest in promoting green infrastructure practices, much of it sparked by recent legislation. Section 438 of the federal Energy Independence and Security Act of 2007 (EISA) requires all federal agencies to use "site planning, design, construction and maintenance practices to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume and duration of flow" when developing facilities with footprints exceeding 5,000 square feet. This statutory mandate is supported by two presidential Executive Orders: E.O. 13423 (signed on January 24, 2007) and E.O. 13514 (signed on October 5, 2009), both requiring that federal agencies "lead by example" to try and achieve more stringent greenhouse gas, building performance, water and energy conservation, stormwater management, and other sustainability goals (U.S. EPA 2009b).

The U.S. Environmental Protection Agency has been the major federal proponent of green infrastructure , developing guidance on how agencies can meet their EISA mandates, promoting low-impact development as part of its sustainable development initiatives, and adopting the Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure (U.S. EPA 2011a) to provide assistance to local governments to encourage better urban stormwater management practices. The U.S. EPA has also recently issued a joint memorandum between its Office of Water and Office of Enforcement and Compliance Assurance that specifically promotes green infrastructure as legitimate techniques that can be used by municipalities to meet the stormwater discharge control requirements of state MS4 permits under the Clean Water Act (U.S. EPA 2011b).

Innovative stormwater management practices that employ green infrastructure are being promoted by state environmental protection agencies as well. Pennsylvania's and New Jersey's departments of environmental protection both promote structural and nonstructural stormwater best management practices, many employing green infrastructure techniques (PDEP 2006; NJDEP 2009). The Minnesota Pollution Control Agency's comprehensive Minnesota Stormwater Manual also encourages the use of a wide range of green infrastructure practices that can be considered by communities to meet the requirements of the state's MS4 permit program (MPCA 2008).

Finally, local governments are also beginning to pay more attention to the use of green infrastructure to better manage water-quality threats to their urban streams and to reduce associated flooding risks to downstream communities. In 2011 , the Illinois Environmental Protection Agency made available $5 million in grant money to promote the use of green infrastructure for urban stormwater management (IEPA 2012). The agency received 154 applications from local governments requesting over $51 million in funds, but was ultimately able to fund only 14 proposals. Given the strong response from local officials to this initiative, IEPA decided to commit another $5 million in FY 2012 to continue its Illinois Green Infrastructure Grant Program.

Planners need to know more about these practices to better advise their communities regarding the emerging issues associated with these new stormwater management approaches.

**Planning Resources**

The U.S. EPA has developed several recent guidebooks on low-impact development and green infrastructure use, including one that provides a number of case studies of local governments that are promoting green infrastructure practices, including Philadelphia ; Chicago ; Portland, Oregon; Seattle ; and San Jose and Santa Monica, California (U.S. EPA 2010). U.S. EPA's Office of Sustainable Communities also distributes a Water Quality Scorecard to enable local planners to better gauge how green infrastructure practices can be incorporated into development projects at the municipal, neighborhood and local scales (U.S. EPA 2009a). Both resources provide an excellent overview of green infrastructure practices and also provide numerous case studies of how these practices can be applied by local planners in development review and approval processes.

## Green Infrastructure Effectiveness

Common green infrastructure practices that can reduce the volume and pollutant loads of stormwater reaching urban streams include bioinfiltration (by rain gardens, vegetated buffer strips, or vegetated swales), sand filtration, green roofs, tree planting, capturing rainwater (also called rainwater harvesting), the use of pervious paving, and the use of artificial wetlands for stormwater detention. All of these practices are alternatives for, or supplements to, conventional stormwater management technologies using separate stormwater sewer systems and detention basins (also called " gray infrastructure").

The National Research Council (NRC) has identified 19 strategies for managing urban stormwater, including not only the green infrastructure practices mentioned above but also preventive practices, such as conservation of natural areas, employing erosion and sedimentation controls during construction, reforestation, impervious surface minimization, watershed and land use planning, and education, and pollutant-removal measures, such as municipal street sweeping and the regular clearing of storm drains (NRC 2008).

A significant impediment to the greater use of green infrastructure practices is that little is known about their relative performance in reducing pollutant loads and stormwater discharge volumes when compared with conventional gray-infrastructure detention technologies commonly used in urban areas. For example, the NRC found that adequate performance studies existed for only two techniques: the use of stormwater wetlands and dry or wet ponds for peak reduction and runoff treatment, and stormwater treatment using sand filters (NRC 2008, Table 5-2). The other 17 strategies — including all of the most common green infrastructure practices — were found to have either "very few" or "limited" performance assessments available (with "very few" meaning that too few studies existed from which to generalize performance, and "limited" meaning that though numerous studies were available, they were either inconsistent or too variable to be used to generalize performance).

Our 2010 Green Infrastructure Study for the Illinois Environmental Protection Agency generally confirmed the NRC's 2008 assessment that relatively little is known about green infrastructure performance, but we attempted to remedy this shortcoming by developing more specific performance measures through assessing the peer-reviewed scientific literature on green infrastructure practices (Jaffe et al. 2010). Only 57 articles (representing 173 sites) out of the 490 scientific articles assessing green infrastructure practices we reviewed contained enough data to allow us to estimate the effectiveness of bioinfiltration, filtration, pervious paving, green roofs, and constructed wetlands.

We focused on examining runoff volume and peak flow reduction as the best measures of how green infrastructure affects hydrology. Likewise, we selected the removal of total suspended solids (TSS) and total nitrogen (TN) as the best measures of how green infrastructure affects meeting water-quality objectives for urban waterways. TSS serves as a surrogate for sedimentation and particulate pollutants such as phosphorus and heavy metals, while TN is a good surrogate for various dissolved pollutants such as chlorides and nutrients. Nutrients are particularly important to monitor because excess nitrogen can cause eutrophication and algal blooms, often leading to reductions in dissolved oxygen and degradation of aquatic communities.

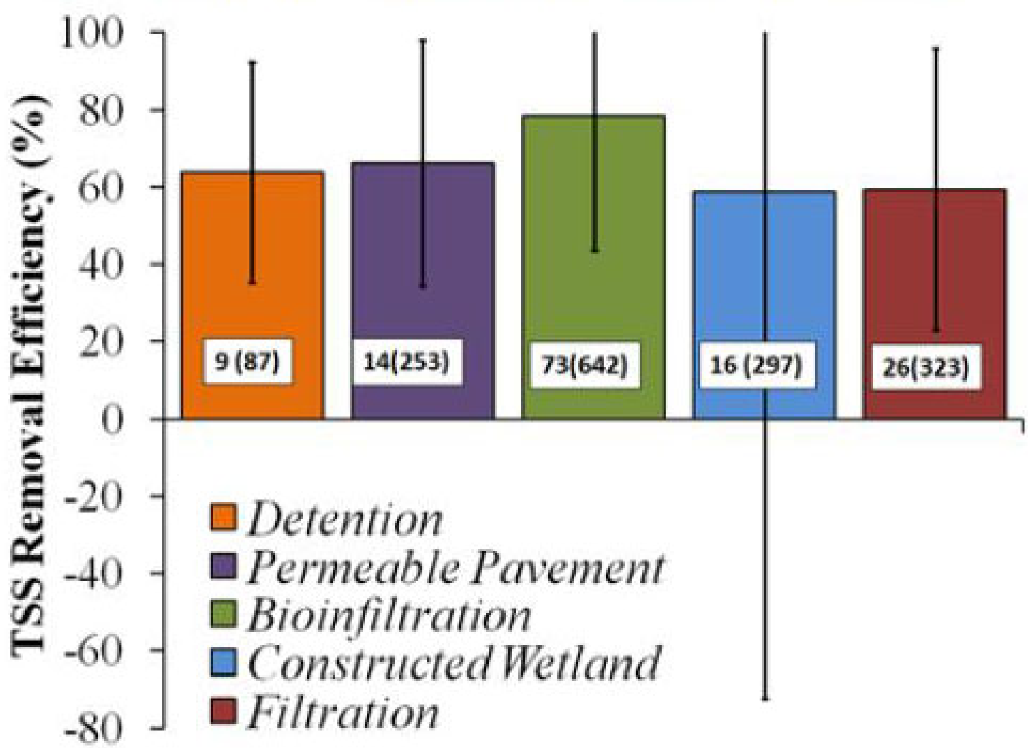
Our team derived average removal efficiencies — or percentage reductions of mean TSS and TN pollutant concentrations in stormwater before and after passing through a green infrastructure treatment ,— for each of the five green-infrastructure techniques, weighted by the number of storm events monitored for each site. We also calculated storm-weighted average reductions in runoff volumes and peak flows, along with weighted standard deviations, since reducing the amount of urban runoff entering a stream also tends to reduce the total amount of pollution being carried to the stream by the runoff.

The results of these calculations for each practice are summarized in Figure 2. The values on each bar show the number of sites included in the analysis, and the total number of storm events monitored are listed in parentheses.

We found that the performance of the five green-infrastructure practices was, *on average*, about equivalent to conventional stormwater detention in reducing TSS concentrations. The performance of the green infrastructure techniques, however, was more variable than that of conventional detention (especially with respect to constructed wetlands). Green infrastructure was also somewhat less effective in removing TN pollutant loads than in removing TSS.

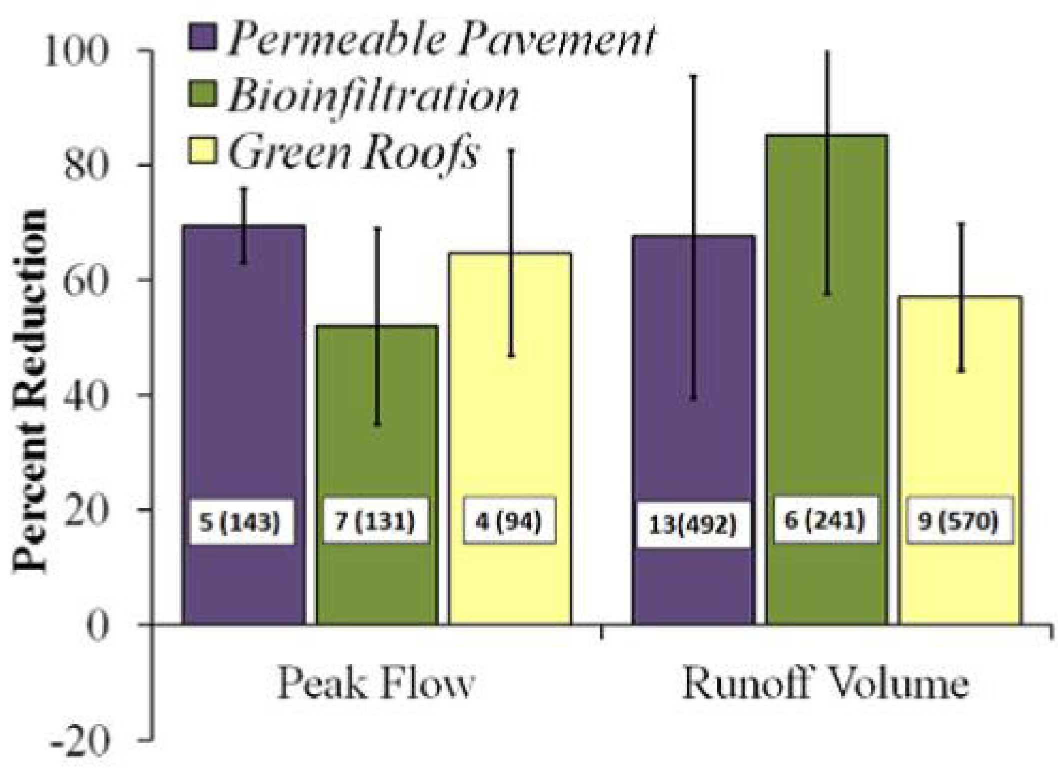
In addition, we found that permeable pavement, bioinfiltration, and green roofs generally reduced both peak flow and runoff volume, but we had insufficient data available to be able to compare their performance to detention. There were also insufficient data available to calculate weighted average removal efficiency for either TSS or TN by buffers or green roofs or for TN removal by bioinfiltration (Jaffe et al. 2010, page 34).

**Figure 2A. Effectiveness of green infrastructure in removing total suspended solids**



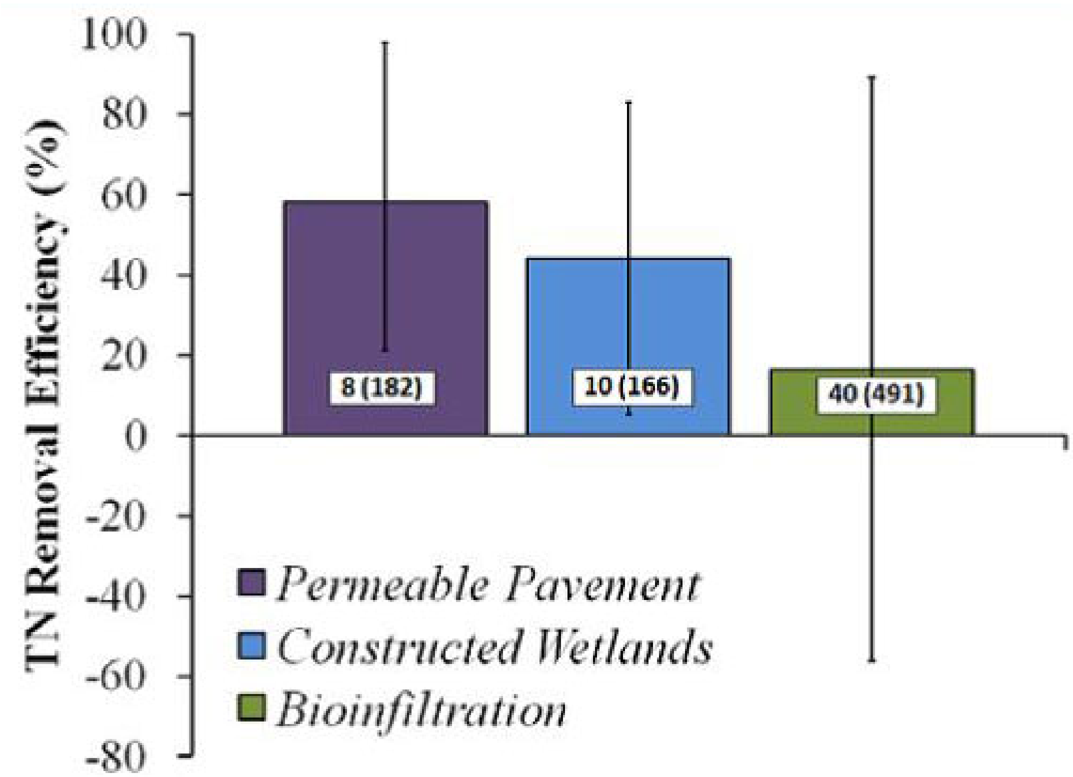

Source: Jaffe et al. 2010.

**Figure 2b. Effectiveness of green infrastructure in reducing peak flows and runoff volumes**




Source: Jaffe et al. 2010.

**Figure 2c. Effectiveness of green infrastructure in removing total nitrogen**




Source: Jaffe et al. 2010.

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Evaluating green infrastructure performance turned out to be a surprisingly complicated enterprise. For example, the International Stormwater BMP Database (**www.bmpdatabase.org**), an online collection of approximately 450 case studies maintained by the U.S. EPA and the American Society of Civil Engineers, among others, expressly rejects the use of percentage removal efficiency to gauge BMP performance. Instead, it offers information only on the storm-weighted average reduction in pollutant loading (as measured by the different quantities of pollutants found in monitored influent and effluent) by the BMPs employed within each case study. The BMP Database does not estimate the removal efficiencies of each type of BMP, as we chose to do in the Illinois Green Infrastructure Study, because of problems involving measuring the differences in influent and effluent concentrations between different case studies, the high variability of monitored results, and methodological inconsistencies in monitoring and reporting the case study data, among other factors (Wright Water Engineers, Inc. and Geosyntec Consultants, Inc. 2007, 2011).

The bottom line is that both our study and the International BMP Database have too much variability in their findings to enable one to say with any great confidence that one specific green infrastructure practice consistently outperforms another in either pollutant removal or in reducing runoff flow or volume reduction, whether one is using a quantity-reduction or removal-efficiency approach. What we can conclude from the data is that *all* the green infrastructure practices can probably reduce some types of pollution (TSS) better than other types (TN) and that *all* the green infrastructure practices can reduce runoff volumes and flow rates to urban streams, if designed, sited, and maintained correctly. Our own independent research confirmed the NRC's earlier finding that, despite being strongly promoted by state and federal agencies and by environmental groups, relatively little is still known about green infrastructure's performance in reducing runoff pollutant and volume contributions to urban waterways.

## Economic Issues of Green Infrastructure

Even if one assumes that green infrastructure practices are roughly as effective, on average, as gray infrastructure in managing some stormwater pollution and flood risks, additional questions remain. How do they fare *economically* when compared with traditional stormwater detention facilities? Are green infrastructure practices cheaper or more expensive than gray infrastructure for a given level of performance, be it measured by removal efficiency or by pollutant load reduction? This also turns out to be a surprisingly difficult question to answer because of the different methods that are used to calculate the costs (as well as the benefits) of green infrastructure practices.

One reason that environmental advocates promote the greater use of green infrastructure is that it is likely a cheaper stormwater management option than gray infrastructure under many conditions, but especially when stormwater inflow and infiltration can exceed the distribution and wastewater treatment capacities of a combined sewer system (i.e., systems where both stormwater and wastewater are conveyed in the same pipes, the kind often found in older cities and suburbs). When the capacity is exceeded, usually after large storms, either combined sewer overflow (CSO) discharges end up in urban waterways in violation of state Clean Water Act permits or, worse, the sewers back up stormwater-diluted sewage into basements. Since larger storms may become more common in the future as a result of climate change, CSO has remained a hot topic in urban stormwater management.

There are essentially three very expensive management alternatives that can be used to mitigate CSO events:

(1) expanding a sewer system's overall storage and treatment capacity (for example, the multibillion dollar "deep tunnel" projects in Chicago and Milwaukee);

(2) reducing the wastewater component of the combined wet-weather flow to increase sewer system capacity, by promoting the use of water conservation fixtures and appliances in order to provide more "headroom" for stormwater within the combined sewer system; or

(3) reducing the stormwater component of the combined wet-weather flow, thereby preserving the capacity of the combined sewer system to transport and treat the less-diluted wastewater.

Stormwater runoff contributions to combined sewer systems can be reduced by diverting or storing a substantial amount of the stormwater on site or off site before it can reach a sewer grate or waterway. This can be accomplished by encouraging more stormwater to be managed on site through infiltration, such as by rain gardens or by using permeable paving, or by retention, such as through the installation of green roofs or water harvesting systems. It can also be collected and managed off site, by installing conventional detention basins or artificial wetlands, for example, or by designing and using common open space for stormwater bioinfiltration.

One useful tool that can assess the costs and benefits of reducing stormwater loading to municipal sewer systems is the Center for Neighborhood Technology (CNT)'s online Green Values Calculator (**greenvalues.cnt.org**). This online "toolbox" can estimate the life-cycle costs of various green infrastructure practices at different scales and can calculate the economic consequences of employing these practices as a substitute for installing conventional stormwater detention or treating larger volumes of wastewater diluted by stormwater inflow. The model is especially useful for promoting green infrastructure because it can calculate the "out -of -pocket" costs and savings (the metrics most people use to gauge cost-effectiveness) of various stormwater BMPs at different scales, and it also shows that using green infrastructure practices to manage stormwater runoff usually saves landowners money.

Despite its utility, CNT's Green Values Calculator has some limitations . It ignores the greater variability in volume and pollution reduction in some green infrastructure practices when compared to conventional gray infrastructure, and it also assumes that the green infrastructure practices are applied in new development and are not retrofitted (thus ignoring the added costs of duplicating or digging up and replacing existing infrastructure). The savings that are calculated for the green infrastructure BMPs are derived largely from reduced construction and life-cycle maintenance costs, compared with gray infrastructure, and the averted wastewater treatment costs for each gallon of stormwater diverted.

The costs of managing stormwater are reasonably clear ; one can calculate how much it costs to install and maintain a rain garden or detention basin, for example, that is sized and built to intercept and infiltrate a given amount of stormwater runoff. However, it is much harder to calculate all of the benefits, especially since many green infrastructure practices provide a variety of environmental benefits to society besides the averted sewage treatment and lowered life-cycle installation and maintenance costs calculated by CNT's model. Moreover, many of these environmental services and improvements (such as increasing aquatic or riparian biodiversity or improving the clarity of the receiving stream) can be very difficult to monetize.

Nonetheless, NRC identified some approaches that could be used to value the benefits of preserving or enhancing these environmental goods and services (NRC 2004). These valuation techniques are often used in the cost-benefit analyses employed in evaluating environmental policies and regulations (where the policy or regulation with the highest benefit-cost ratio is the preferred one, from society's perspective) and include, for example, various contingent valuation and willingness-to-pay studies, hedonic pricing studies, and recreational travel studies.

Some of the NRC's economic approaches have already been used to enable researchers to better assess the benefits of green infrastructure. For example, a recent study by CNT and American Rivers surveyed the environmental economics literature to examine the different ways that the environmental benefits to society of green roofs, tree planting, bioretention and infiltration, permeable paving, and water harvesting could be valued (CNT 2010). The environmental benefits that could be monetized included averted water-treatment, reduced gray infrastructure, improved water quality, reduced flooding, reduced energy use and associated improved air quality, reduced greenhouse-gas emissions, and reduced urban heat island impacts.

Another study that examined the broader economic benefits to society of managing stormwater discharges from low-impact developments using green infrastructure practices found that reducing flood risks increased downstream residential property values by 2 to 5 percent, and that associated water-quality improvements increased riparian housing values by up to 15 percent (Braden and Johnson 2004). Other societal benefits identified in this study included the need for smaller bridges, culverts, and wastewater treatment facilities and increased aquifer recharge.

The choice of what to count as a benefit or a cost has important consequences. For example, one study of green roofs that examined their air-quality and averted stormwater-infrastructure benefits calculated a net present value savings of 24.5–40.2 percent over their useful lives compared with conventional roofs (Clark, Adriaens, and Talbot 2008). In contrast, the CNT's Green Values Calculator , which analyzes only the difference between the out-of-pocket construction and maintenance costs of green roofs compared with their projected savings in wastewater treatment costs and ignores their broader environmental benefits (such as providing habitat or reducing flood risks and energy use), finds few if any life-cycle savings from the use of green roofs at almost any scale and under almost any development scenario. These various economic impact studies of the same stormwater management practices monetize different benefits and different costs, giving planners and local officials little consistent guidance as to the preferred options.

What one counts as "benefits," as well as how one values them, significantly frames our understanding of green infrastructure economics and our calculation of its costs and benefits. Generally, the greater the scope of the environmental services that are accounted for in evaluating different stormwater management approaches, the more that these intangible environmental benefits will be used to offset the tangible "out-of-pocket" costs of building and maintaining stormwater infrastructure (whether green or gray). The NRC's 2004 report on valuing ecosystem services proposes that a much wider variety of environmental services and benefits be monetized and incorporated into cost-benefit analyses, an approach that will likely further encourage policymakers to promote green infrastructure practices over conventional detention.

**Economic Resources**

An excellent overview of the recent literature on the economics of green infrastructure and low-impact development has been compiled by the U.S. EPA and is available at **http://water.epa.gov/infrastructure/greeninfrastructure/gi_costbenefits.cfm**. CNT's report surveying green infrastructure economics also included several municipal case studies along with an appendix listing recent models and tools for calculating the economic benefits of some of the practices (CNT 2010).

## Green Infrastructure Design and Maintenance Issues

As part of our 2010 Illinois Green Infrastructure Study, staff of the Chicago Metropolitan Agency for Planning interviewed engineers and stormwater managers about their perceptions concerning the efficacy of green infrastructure (Jaffe et al. 2010). Four issues were identified in focus group meetings: variability in green infrastructure performance under diverse conditions (including poorly drained soils and frozen ground), maintenance issues, potentially higher costs for green infrastructure, and lack of public acceptance. The economic and public acceptance issues can be resolved through education (using CNT's Green Values Calculator , for example, to show that most of the green infrastructure BMPs are cheaper than conventional gray infrastructure) and public outreach, but the performance variability and maintenance issues require a bit more attention.

The Center for Watershed Protection identified a number of design issues that can affect green infrastructure performance through an audit of green infrastructure facilities (including those employing bioinfiltration) installed in Virginia's James River watershed (CWP 2009). Problems found by the audit included inadvertent "short-circuiting" of treatment pathways and bypassing of drains, clogged underdrains and soil media (where fine sediment carried by stormwater fills the pores between soil particles, reducing its ability to infiltrate runoff), erosion issues, poor vegetation quality, and failing structures. These problems are not insurmountable, however, and the report provides a concise summary of the specific design, construction, and maintenance recommendations needed to address and resolve these issues. The University of Minnesota has also developed both detailed design and technical criteria that can be considered in designing and developing a formal process to audit and assess green infrastructure performance and maintenance (Gulliver and Anderson 2008).

In addition, the Center for Watershed Protection has developed a manual addressing the post-construction maintenance of stormwater facilities, including green infrastructure practices, in great detail and has researched winter performance issues (CWP 2008, 1997). Winter constraints on green and gray stormwater infrastructure include pipe freezing, reduced biological activity and shorter growing seasons, reduced soil infiltration, increased flow and pollutant loading from spring snowmelt, loss of storage capacity by ice formation, and the impacts of road salting on facility vegetation and discharges. Again, these concerns can be readily addressed in the design and sizing of the green infrastructure, which can be oversized or modified to provide communities with an appropriate margin of safety for winter performance. Maintenance can be assured by periodic inspections of green and gray infrastructure performance, with the administrative burden perhaps funded through annual fees or by the creation of a local stormwater utility.

## Promoting Green Infrastructure at the Local Level

One of the main findings of the Illinois Green Infrastructure Study was that a major impediment to the wider adoption of green infrastructure for stormwater management is a simple lack of knowledge, especially on the part of municipal engineers, about how green infrastructure practices are designed, sized, and maintained, and how they function under various site conditions. In comparing green to gray infrastructure, it is important to realize that a green infrastructure practice, such as a rain garden, is not just an area in a backyard or along a parking lot that is planted with some native landscaping material, but rather an engineered facility that is sited, designed, and sized to manage a specific volume of stormwater runoff, much the same as gray infrastructure is sited, sized, and designed.

If expertise is required in designing green infrastructure, then similar professional rigor is also needed to review development projects proposing these practices. The increasing number of technical manuals and hydrologic models addressing green infrastructure practices becoming available through federal and state environmental protection agencies and environmental organizations (such as the Center for Watershed Protection) can help planners build the technical expertise needed to assess such BMPs, but local officials and developers will also have to be brought up to speed on these green technologies.

To promote green infrastructure , planners can incorporate these practices into public facilities as local pilot projects in order to reassure municipal engineers and local officials of their effectiveness in managing stormwater runoff. They can then encourage their use in private developments by moving from specific engineering standards for the design of stormwater facilities to performance-based standards that establish volumetric or release rates for stormwater, leaving it up to the landowner to choose the mix of BMPs and strategies that achieves the standard. This, for example, is the strategy that the City of Chicago used in promoting green infrastructure practices as part of its environmental initiatives. The city first funded a variety of pilot projects that were monitored for their performance (including the famous green roof on city hall) and then adopted a stormwater ordinance in 2006 incorporating a stormwater performance standard requiring commercial developments with threshold amounts of impervious surface to capture the first half-inch of stormwater on site (City of Chicago 2011).

Increased familiarity with green infrastructure practices on the part of municipal planners should lead to less uncertainty in development review, a process that may lead to increased familiarity and greater acceptance by the development community. Only with this increased familiarity, shared on both sides of the table, can green infrastructure finally come of age and become more commonly used as a cost-effective strategy to address both water pollution and flooding risks, to the benefit of individual landowners, society, and the environment.

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