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A Tale of Many Cities: Using Low-Impact Development to Reduce Urban Water Pollution

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Over 80% of the U.S. population lives in urban areas, a number that is projected to increase to almost 89% by 2050 (United Nations, 2011). Increasing urbanization puts pressure on centralized stormwater systems, which are expensive to expand and focused on just one task—conveying stormwater to a treatment plant. Urban stormwater is, however, as polluted as untreated domestic wastewater and urban runoff is estimated to be responsible for 47% of the miles of impaired ocean shoreline, 22% of seriously polluted lakes, and 14% of seriously polluted rivers (U.S. Environmental Protection Agency (EPA), 2006; p. 4-23). In addition, many older cities have combined sewers that convey both sewage and stormwater; they were a significant improvement over the above-ground sewer ditches that existed before combined sewer systems were created in the mid-1800s, but many combined sewers discharge harmful waste when storms overload the system (Tibbetts, 2005).

Table 1: Benefits of LID Stormwater Management

- Less water pollution, better surface water quality
  - Fewer combined-sewer overflows (CSOs)
  - Lower levels of pollution flows during regular storms
- Improved aquatic habitat
- Reduced flooding
- Groundwater recharge
- Energy savings (if eco-roofs are used)
- Open space
- Wildlife habitat
- Improved air quality and reduced urban heat island effect
- Better human health

Green infrastructure projects—such as green roofs (or eco-roofs), bioswales, permeable surfaces, and rain gardens—are decentralized approaches that may generate multiple benefits such as the reduction of urban water pollution, provision of open space, reduction of air pollution, and improvements in human health. This article describes new approaches being used to control urban stormwater on public and private property, discusses insights from economic theory about optimal stormwater policy design, and provides examples of projects being implemented in several U.S. cities.

Costs and Benefits of Next Generation Stormwater Management

Many terms are used in discussions of modern stormwater management—often imprecisely—to refer to a suite of stormwater solutions. Low Impact Development (LID) approaches, green infrastructure, decentralized approaches, and best management practices (BMPs)—are all terms that appear in discussions of stormwater control alternatives to traditional, centralized, concrete, engineered "grey" infrastructure—sometimes interchangeably. The terms do, however, vary in connotation. For example, LID is a style of development that also includes design to reduce other facets of the environmental footprint of a building such as energy use (EPA, 2000), and green infrastructure can refer to projects such as wetland restoration that do not occur on developed lands themselves (Weber et al., 2004).

Research indicates that LID-style stormwater management can yield better outcomes than grey infrastructure for water quality and the quality of aquatic habitat

Table 2: Stormwater Management Definitions

Term	Definition
Low-Impact Development (LID)	A development approach that uses nature to manage stormwater by emphasizing on-site stormwater management.
Green Infrastructure	An approach for managing stormwater that uses natural systems or engineered systems that mimic the natural environment.
Grey Infrastructure	Engineered systems that manage stormwater, for example, pipes and gutters.
Best Management Practices (BMPs)	Structural or nonstructural measures taken to control the quantity and quality of stormwater runoff.
Bioswales	A long, narrow, shallow drainage course designed to capture stormwater runoff and treat it before release
Cistern (or rain barrel)	Container that collects and stores stormwater runoff from rooftops
Green Roofs (or eco-roofs)	Vegetated roof that is designed to reduce the volume and velocity of stormwater runoff
Permeable Surfaces (or porous pavements)	Surfaces that allow water to penetrate the ground; for example, pervious concrete
Rain Gardens	An area planted with vegetation to intercept and infiltrate stormwater runoff
Green Street	Street that is designed with vegetated areas (and sometime porous pavement) to intercept stormwater runoff

(EPA, 2000). A design that includes significant onsite stormwater use, treatment, and infiltration from features such as pervious concrete, green roofs, cisterns, rain gardens, and bioswales can greatly reduce stormwater flows during storms and, thus, reduce the introduction of pollution into local waterways from both combined sewer overflows and simple flushing of contaminants from the ground into water bodies via storm sewers. LID can also reduce the "flashiness" of stream flows, with better flow volume during dry times and less severe peaks of water flows during storms; this reduces streambed scouring and provides more stable aquatic habitat in rivers and streams (Williams and Wise, 2006).

Implementing LID management strategies can yield improvements for which the public has value, including open space (Lutzenhiser and Netusil, 2001); improved aquatic habitat (Cadavid and Ando, 2013); groundwater recharge (Cutter, 2007); reduced pollution and, consequently, improved surface water quality, and flood mitigation (Braden and Johnston, 2004). The private benefits of green roofs are sometimes sufficient to offset the added installation costs relative to a conventional roof; when public benefits are included, the net benefits are very often positive (Carter and Keeler, 2008). A survey of research on the expected costs and benefits of a national policy that would induce widespread adoption of LID stormwater solutions found that the benefits would exceed the costs by at least $34 million per year (Braden and Ando, 2012) and a review of case studies found that LID stormwater management yielded better environmental outcomes at an average of 25% lower costs than conventional infrastructure (EPA, 2007).

LID stormwater management is not a panacea. Many impediments slow adoption of sustainable stormwater management practices (Roy et al., 2007) including transaction costs in the process of changing local building codes and training personnel in the construction to make LID development possible (Braden and Ando, 2012). In places with existing construction, retrofits of LID solutions can yield benefits, but retrofits are usually more expensive than new LID construction (MacMullen and Reich, 2007). Decentralized stormwater management (especially if some elements are on private property) may necessarily entail decentralized and volunteer maintenance, with a range of problems associated with monitoring and enforcement (National Research Council (NRC), 2009; 450-452). The effectiveness of LID approaches is likely to vary across cities and with the nature of climatic conditions and soils in the area. Finally, stormwater engineers are sometimes reluctant to design a stormwater management plan with no grey infrastructure at all for fear that LID elements and green infrastructure alone might provide insufficient protection against flooding in major storms (EPA, 2000). However, the bulk of the evidence suggests that there would be net positive social benefits in many cities to controlling water pollution by increasing LID adoption.

Optimal Stormwater Policy

Evidence indicates that new development with impervious surfaces inflicts costs on society from pollution, flooding, and hydrological disruption, and those costs are not entirely borne by the developers or property owners. In other words, there is a negative externality from new, conventional development (Barnard, 1978). Conversely, in areas where old, established developments are already in place, retrofits of LID-style stormwater management can yield benefits to society by reducing pollution and other problems related to impervious surfaces; there is a positive externality to LID adoption. In the face of externalities, policy intervention can make society, as a whole, better off.

Cities could respond to stormwater pollution problems with a uniform regulation requiring that all new developments be designed to manage a minimum amount of rainfall from every storm onsite (for example, Chicago has an ordinance requiring that new construction manage the first inch of rainfall during a storm onsite). However, if the costs of stormwater abatement vary widely across the program area, this uniform approach will not be cost-effective (Thurston, 2006). Sites with high abatement costs will be forced to manage the same amount of stormwater as low-cost sites; total costs could be reduced by reallocating abatement among sites.

Theory in environmental economics (Tietenberg and Lewis, 2010) tells us that the optimal level of private stormwater management can be achieved with a tax on stormwater runoff (or a subsidy for LID installations) equal to the marginal external cost (MEC) associated with runoff (or the marginal external benefit to LID). Furthermore, runoff reduction will be distributed across the city in a manner that minimizes total costs—landowners for whom stormwater abatement is expensive will just pay the tax, while those who can abate at a low cost will do so to reduce their payments. A city could charge landowners a stormwater fee per unit of stormwater estimated to be produced by their property, where the fee is equal to the MEC of runoff. Landowners then have incentives to install retrofitted LID solutions on their previously developed property to reduce runoff (and their total fee) and to design new development to have efficient runoff levels. Many cities have used stormwater fees (Doll, Scodari, and Lindsey, 1998). However, those fees have typically been too low to accomplish socially optimal levels of stormwater controls (Thurston, 2006). Note that the level of the optimal fee is determined by the "polluter pays" principle and depends on the total costs to the community of the last unit of runoff (including the disamenities of water pollution, flooding, and degraded aquatic habitat), not on the costs to the city of putting in grey infrastructure to divert it.

An alternative, cost-effective policy design could be a system of tradable runoff permits. A quantity of permits equal to the total amount of runoff that is optimal for the area would be distributed to landowners, and landowners would have to make sure their properties did not produce more stormwater runoff than the number of permits held. Landowners with low abatement costs will have an incentive to reduce runoff more than they need to in order to sell the extra permits to landowners for whom abatement is costly. Efficient stormwater control will result if the total number of permits is set at the point where the MEC to society of the last unit of runoff is equal to the marginal cost to a landowner to abate it.

Various papers (Thurston et al., 2003; Thurston et al., 2004; Parikh et al., 2005; and Thurston, 2006) have explored and demonstrated the potential for both tradable permits and fee/rebate policies to accomplish efficient levels of stormwater abatement in a cost-effective manner. Economic incentive policies can be modified to accommodate situations where the damage done by stormwater varies across the program area, and they can be designed to minimize resistance from current landowners by giving out permits or using two-part fee/rebate programs to reduce payments from previously developed lots. However, municipalities face many challenges in trying to implement optimal stormwater incentive policies. A plan must be designed for ongoing monitoring and enforcement that is not so costly that it cancels out the benefits of the policy itself. It is also very difficult to estimate the MEC of stormwater to set the efficient fee and to gather the additional information about marginal stormwater abatement costs needed to set the efficient number of permits for a tradable permit scheme. It may be, as Feitelson and Rotem (2004) argue, that a stormwater fee levied on a subset of impervious surfaces equal to a subset of the external costs can have significant social benefits with the advantage of administrative simplicity.

Approaches Used by Cities

Many U.S. cities are aggressively incorporating green infrastructure techniques based on projected cost savings and the multiple benefits generated by some projects (EPA, 2010). Federal statutes generally support the use of green infrastructure to meet Clean Water Act stormwater management goals (EPA, 2008; and EPA, 2013a) and the EPA is actively promoting the use of green infrastructure as a "win-win-win approach and a fundamental component of the U.S. Environmental Protection Agency's (EPA) sustainable community efforts." (EPA, 2011; 1)

Portland, Ore., uses a combination of education, regulations, and incentive-based policies to reduce stormwater runoff. Ratepayers pay a separate stormwater utility fee to cover the cost of stormwater management, but the on-site management portion of the fee can be reduced up to 100% for residential property owners who manage runoff from roof areas and for commercial properties that manage runoff from roofs and paved areas (Environmental Services, 2013a). Payments from the Clean River Rewards program are guaranteed through June 2017.

Other green infrastructure projects in Portland include the installation of green street facilities, the purchase and restoration of open space, and a subsidy of 50% on the purchase of a tree (up to a maximum of $50) in target areas between September 1, 2013, and April 30, 2014 (Environmental Services, 2013b). An eco-roof program, which was discontinued at the start of the 2013 fiscal year due to a lack of funding, provided private developers with a subsidy of up to $5 per square foot and the potential to qualify for a building density bonus.

Philadelphia, Pa., has a Green City, Clean Waters program. It is a 25-year plan that is described as the largest green infrastructure program in the United States (Philadelphia Water Department, 2011). Major initiatives include the use of green infrastructure on public land, requirements and incentives to use green infrastructure on private land, a street tree program, open space acquisition, and stream restoration.

A new parcel-based stormwater fee, which was created in 2010, is based on a non-residential property's impervious area with discounts available for property owners who incorporate green infrastructure techniques. Residential properties are assessed a uniform monthly charge based on the average impervious area for residential properties. New regulations encourage infill to reduce the amount of impervious surface area and stormwater runoff in the region. A "triple bottom line" approach focusing on the environmental, social, and economic benefits of the program is being used with benefits from the program—which include reduced energy usage and greater employment, recreation, property values, air quality, water quality, and wildlife habitat—estimated to exceed costs after 45 years (Philadelphia Water Department, 2011).

Portland and Philadelphia have a combined sewer system, which is a driver for adopting green infrastructure. But cities without these systems are also adopting this approach. Project scales vary from specific sites—such as Pelham and Greenland, N.H. with LID projects in commercial and residential developments—to neighborhood projects—such as Burnsville, Minn., efforts to retrofit a suburban neighborhood with rain gardens. Citywide initiatives also exist—such as Kansas City, Mo., and its "10,000 Rain Gardens" and Orlando, Fla., with its use of wet ponds. Orlando also has a stormwater utility fee and a credit system that allows multi-family and commercial owners to receive credits (up to 42%) that reduce their stormwater utility fee by adopting an onsite management plan (EPA, 2013b; and Water Environment Research Foundation, 2013).

Next Steps

Research shows that LID can cost less than traditional approaches, but few studies have successfully investigated all the private and public benefits from these programs. In order to implement cost-effective, efficient, and equitable stormwater policies and programs, municipalities need to have access to key information on program benefits and how the costs (and benefits) of these programs are distributed among residents.

While cities are showing strong leadership in experimenting and implementing LID approaches, city finances can be volatile and may be more likely to change than policies set at the state or Federal level. Importantly, the decentralized nature of these projects means that cities are expecting residents to take a more active role in reducing stormwater runoff, so it is important to continuously educate residents about their central role in achieving stormwater objectives. With more time, urban efforts to use stormwater policy to control nonpoint urban water pollution could be facilitated by future research to understand how green infrastructure projects are performing and when an LID approach is the most efficient solution to urban water quality problems.

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