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Establishing Green Roof Infrastructure Through Environmental Policy Instruments

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Abstract Traditional construction practices provide little opportunity for environmental remediation to occur in urban areas. As concerns for environmental improvement in urban areas become more prevalent, innovative practices which create ecosystem services and ecologically functional land cover in cities will be in higher demand. Green roofs are a prime example of one of these practices. The past decade has seen the North American green roof industry rapidly expand through international green roof conferences, demonstration sites, case studies, and scientific research. This study evaluates existing international and North American green roof policies at the federal, municipal, and community levels. Green roof policies fall into a number of general categories, including direct and indirect regulation, direct and indirect financial incentives, and funding of demonstration or research projects. Advantages and disadvantages of each category are discussed. Salient features and a list of prompting standards common to successfully implemented green roof strategies are then distilled from these existing policies. By combining these features with data collected from an experimental green roof site in Athens, Georgia, the planning and regulatory framework for widespread green roof infrastructure can be developed. The authors propose policy instruments be multi-faceted and spatially focused, and also propose the following recommendations: (1) Identification of green roof overlay zones with specifications for green roofs built in these zones. This spatial analysis is important for prioritizing areas of the jurisdiction where green roofs will most efficiently function; (2) Offer financial incentives in the form of density credits and stormwater utility fee credits to help overcome the barriers to entry of the new technology; (3) Construct demonstration projects and institutionalize a commitment greening roofs on publicly-owned buildings as an effective way of establishing an educated roofing industry and experienced installers for future green roof construction.

Keywords Green roof · Urbanization · Urban ecology · Ecosystem services

Introduction

Urban land area in the United States is projected to increase to 8.1% of total land area by the year 2050 (Nowak and Walton 2005). Urbanization is a phenomenon that affects the environment in profound ways. One of the most detrimental effects is that the ecological processes in urban areas can be irreversibly altered and the ecosystem services provided by these processes are often lost (Farber and others 2006). Covering the ground with impervious surface, a ubiquitous feature of urban areas, greatly reduces the infiltration capacity of the soil and dramatically alters urban hydrology causing increased flooding, aquatic ecosystem degradation, and water quality impairment (Paul and Meyer 2001). These services provided by the soil are costly to replace. Conventionally-engineered stormwater systems typically only function to reduce flooding while exacerbating the other environmental problems associated with urbanization. Erosion of stream bed and banks from high storm flows, elevated pollutant transport capacity

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during storm events, and the culverting and burying of urban headwater streams are all common results of this type of stormwater management.

One way to prevent this type of environmental decline in urban areas is to simply preserve patches of land in cities for parks and other green space, thus maintaining many of the ecosystem services in these isolated areas (Pincetl and Gearin 2005). Another method is to develop engineered systems which mimic and replace forms and functions which have been altered due to the impact of human development. While theoretically there is nothing inherently inferior about constructed systems, the complexity and multi-functional components of undisturbed environments are difficult to replicate with functional trade-off occurring during "domestication" of the ecosystem (Kareiva and others 2007). Investing in the natural capital of natural systems, such as protecting a watershed to preserve water quality, rather than built capital is often cost effective as well (Salzman 2005). These "designer ecosystems," however, are becoming an important component of the urban landscape (Palmer and others 2004) and can function not only ecologically, but also as urban ecological research sites, public education venues, and potentially add aesthetic value (Felson and Pickett 2005).

One example of these designer ecosystems is vegetated or green roofs. Green roofs typically contain layers of engineered growing media and drainage materials which are incorporated into a roof membrane and support plant communities which are tolerant of the extreme weather conditions found on rooftops. Researchers have likened green roofs to rock outcrop ecosystems and have begun to treat them as habitat templates where unique biotic assemblages adapted to the harsh rooftop conditions are expected to colonize (Larson and others 2004).

Green roofs are often characterized as falling within one of two general categories: intensive and extensive. Intensive roofs contain deep layers of growing media, can support diverse plant communities, and are suitable for particularly sturdy structures, such as new commercial buildings and parking decks, given the significant additional weight added by the intensive green roof system. In contrast, extensive systems have a much thinner profile which limits plant diversity on the roof, but can easily be retrofitted onto many existing structures. While this categorization is useful for communication purposes, not all green roofs can be considered simply extensive or intensive and thus a third category of semi-intensive bridges the gap between the two extremes (Dunnett and Kingsbury 2004). Extensive systems are by far the most common in Germany due to the ease of implementation and relatively low cost (Harzmann 2002). Extensive green roofs are the most likely to become widespread in North America due to existing market conditions where the additional expense of green roofs and limited installation experience has relegated them to specialized applications (Beattie and Berghage 2004).

There are numerous social and private benefits provided by intensive and extensive green roof systems. Stormwater retention is one of the most frequently cited and heavily studied green roof benefits (Getter and others 2007; Moran and others 2005; VanWoert and others 2005; Villarreal and Bengtsson 2005). Green roofs retain significant amounts of rainfall from small storm events which would typically be discharged quickly into the nearest receiving water body or storm sewer system (Carter and Rasmussen 2006). In areas with combined sewer systems, large rainfall events cause combined sewer overflows (CSOs), resulting in untreated sewage being discharged into local streams and rivers. By retaining significant amounts of stormwater, green roofs can prevent CSOs (Doshi 2006). The pollutant transport capacity and peak discharge rates of stormwater are also reduced, as are nuisance flooding and streambed and bank erosion (Carter and Jackson 2007).

Another environmental benefit of green roofs involves the thermal performance of the roof membrane. Reduction in the roof's temperature through shading and evaporative cooling lessen the heat flux into the building resulting in decreased HVAC costs (Wong and others 2003a). The vegetation also acts as an insulative barrier in the winter, provided the growing media does not freeze for extended periods of time (Liu and Baskaran 2003).

Air quality is also improved as the plants will uptake NO_x and CO_2, common greenhouse gases, from the atmosphere (Clark 2005). Aesthetic improvements, habitat provision, and increased urban biodiversity are all environmental benefits that green roofs can provide (Peck and others 1999; Firth and Gedge 2005).

Many of these benefits are not only internalized by the building owner, but shared with the public. Public benefits relating to green roofs include: stormwater retention that minimizes impacts to aquatic ecosystems, mitigation of urban heat island effects, and increasing levels of urban biodiversity (Deutsch and others 2007). Public benefits are, by definition, not fully realized by the party bearing the cost of the green roof installation and therefore justify public intervention through the development of green roof policies.

Installing green roof systems also involves costs in the form of additional expense for the North American building owner due to the novel nature of these systems. Extensive green roofs add anywhere from \$5–10/ft^2 (in 2005 \$s) onto roof construction costs depending on site conditions (Carter and Keeler 2007). Total costs, including waterproofing, for extensive green roof systems average \$12–18/ft^2 (Carter and Keeler 2007). When the entire life cycle costs of the roof are calculated, however, the private and public benefits such as stormwater retention, building energy savings, and improved air quality offset much of the additional up-front roof construction costs. Some studies show a net savings over the life of the roof when green roofs are used (Wong and others 2003b). Risk aversion may also be an impediment to adoption as building owners may see their roof as leak-prone if greening were to occur.

The goal of this article is to evaluate the best policies for establishing a green roof infrastructure given the wide variation in physical characteristics, regulatory infrastructure, and social dynamics found in urban areas. The authors look first at the legal and federal policy background establishing green roof infrastructure in the United States. Existing policies that have recently been developed in select major North American cities are then evaluated. These existing policies fall into a number of distinct categories, including technology standards, performance standards, direct financial incentives, and indirect financial incentives. Advantages, disadvantages, and key features of existing green roof policies are then discussed. Finally, these policy lessons are applied in Athens, Georgia as a case study.

Legal Foundation for Green Roofs at the Federal Level

Federal Statutes

Stormwater management provisions in the Federal Water Pollution Control Act or Clean Water Act (CWA) have direct application for green roof systems. Approval for National Pollutant Discharge Elimination System (NPDES) permits is contingent upon the development of stormwater management programs that include provisions to treat stormwater runoff using best management practices. These best management practices include green roofs. The CSOs policy of the CWA, codified at Section 402(q), requires that communities serviced by combined storm sewer systems implement BMPs as part of a pollution prevention program to reduce contaminants. Research has shown that green roofs have the potential to reduce combined sewer volumes by more than 18% (Doshi and others 2005). Green roofs could therefore be a key component in a jurisdiction's CSO control plan.

Section 303(d) of the CWA requires states to create water quality standards for receiving water bodies and develop total maximum daily loads (TMDLs) for those water bodies not meeting their assigned standard. TMDLs may apply to both point and nonpoint sources of pollution. Controls, such as green roofs, may be part of TMDL implementation plans to reduce pollutant loading in a specified water body particularly impacted by stormwater runoff.

Additionally, Section 319 of the CWA addresses nonpoint source pollution controls, including stormwater management. This section requires states to identify waterways which cannot meet water quality standards without control of nonpoint source pollution. The categories of nonpoint pollution sources must be identified and the state must recommend best management practices for control of these sources of pollution. Section 319 also establishes a grant program whereby federal and state funds are allocated to local governments and other entities to fund nonpoint source pollution control. As of 2006, twelve projects to construct green roofs had been funded from Section 319 across the United States (Table 1).

Other Federal Policies

Various federal agencies have adopted "green" initiatives that indirectly encourage green roof installation through green building requirements. In 2003, the U.S. General Services Administration, for example, began requiring all new building projects to be LEED certified and they are encouraged to exceed basic certification to achieve LEED Silver. Additionally, the Department of Defense now requires all buildings to meet the LEED Silver standard (http://www.wbdg.org). As discussed below, green roofs are an excellent way of acquiring the LEED points necessary to reach this certification.

U.S. Environmental Protection Agency (EPA) is promoting green roofs as well. The Statement of Intent of its Green Infrastructure Initiative, which includes a partnership with four national environmental groups "…formalize[s] a collaborative effort… in order to promote the benefits of using green infrastructure in protecting drinking water supplies and public health, mitigating…and to encourage the use of green infrastructure by cities and wastewater treatment plants…" (http://www.epa.gov).

Table 1 Green roof projects funded by CWA Section 319

Location	Year	Amount($)
Tennessee	2006	53,025
North Carolina	2006	N/A
Michigan	2006	N/A
Washington DC	2006	625,300
Washington DC	2005	625,301
Iowa	2005	25,000
Idaho	2004	200,00
Illinois	2004	316,430
Illinois	2003	532,136
Illinois	2003	181,200
Oregon	2002	75,600
Illinois	2002	211,523

Green roofs are explicitly mentioned as a green infrastructure practice to accomplish the goals of this initiative.

Municipal and Community Level Green Roof Policies

At more localized levels of government, policies have been specifically crafted to encourage new green roof projects. This is where the most detailed green roof policies are found and the scale at which our study site was evaluated. There are a number of general categories of green roof policies which directly and indirectly encourage new green roof installations. Some policies take the form of a "command and control" approach through performance or technology standards while others utilize a market-based approach using tax incentives or government subsidies. When determining which type of approach to use, it is important to recognize whether the costs of implementation are homogenous across the industry or if there is a significant degree of heterogeneity. If costs are relatively similar, then a policy based on standards can be just as efficient as market-based approaches (Revesz and Stavins 2004).

Technology standards include building code requirements that mandate the use of green roofs over all or part of a building's rooftop. Performance standards may specify an amount of on-site stormwater retention which may be met through the use of green roof technology. Direct economic incentives involve subsidies specifically for new green roof installations as well as for broader urban greening programs that include green roofs. Density bonuses for roof greening and stormwater fee credits are common forms of indirect economic benefits. Table 2 provides a summary of the forms of green roof policies along with summaries of case studies of jurisdictions in the United States that have implemented these policies.

Technology Standards

One option to encourage green roof implementation is to directly mandate in the building code that all buildings of a certain type must green all or part of their roof. Public buildings or large commercial buildings with flat roofs are often identified as candidates for this regulation. Design specifications may also be included, such as the depth of growing media, amount of plant coverage, water retention capacity, and/or roof surface reflectance.

This technology standard approach has been implemented in Tokyo, Japan where private buildings larger than 1000 m^2 and public buildings larger than 250 m^2 are required to have 20% of the rooftop greened. Due to this ordinance, 54.5ha of rooftops have been greened in the city as of January 1, 2005 (http://www2.kankyo.metro.tokyo.jp). The city of Linz, Austria requires green roofs on all new buildings larger than 100 m^2 and a slope of up to 20%, as well as the roof surfaces of all underground structures, such as subsurface parking decks (Ngan 2004). In response to loss of biodiversity in urban areas, Basel, Switzerland has mandated green roofs on all new buildings with flat roofs and for roofs over 500 m^2, substrate composition and depth requirements are imposed (Brenneisen 2006).

North American municipalities have also recently adopted green roofing requirements in their building policy. The city of Toronto, Canada approved a policy stating that, "…where feasible and practical, green roofs with a coverage of 50–75% of the building footprint be constructed on all new City-owned buildings…on existing City-owned buildings…when roofs are due to be replaced" (Toronto City Clerk 2006). Toronto's green roof projects must fit within the City's capital and operating budgets and occur on roofs which have low-slopes, adequate structural capacity, and are easily maintained to qualify as "feasible and practical" conditions for the project. A green building policy was also enacted in Portland, Oregon which mandates that all new city-owned facilities include a green roof with 70% coverage unless the green roof is impractical (PDC 2005). In Portland, there is little additional policy guidance as to what specifically constitutes practicality. In one case in Portland, however, a train station owned by the city which normally would have required a green roof was exempted because it is on the National Historic Registry.

Table 2 Policies to encourage green roof implementation

Type of green roof policy	Example	Location	Key features
Technology standard	Mandatory green roofs on buildings of a particular type	Portland	All new city-owned facilities include green roof unless it is "impractical"
Performance standard	Require cool roof technology	Chicago	Use of green roof exempts building from reflectance and emittance requirements
Direct economic incentive	Subsidy or grants for construction	Chicago	$100,00 for 20 projects
Indirect economic incentive	Stormwater utility fee credit	Minneapolis	100% credit for green roofs that replace impervious surface

Minneapolis, Minnesota has also explicitly incorporated green roof standards into their site plan review for certain zoning classifications. Land uses, such as Planned Unit Developments (PUDs), may use green roofs to receive alternative compliance certification when site conditions make code compliance difficult. Additionally, government staff has allowed developers to satisfy greenspace requirements by installing green roofs where land is scarce (B. Sporlein personal communication October 17, 2007).

Performance Standards

A number of jurisdictions have identified sections of their city or areas of new development to be bound to tighter environmental controls. These environmental controls are based on stormwater management goals, urban greening requirements, or rooftop reflectance values. In Berlin, an inner-city area named Potsdamer Platz was redeveloped after decades of neglect. The Berlin city council passed a mandate requiring the project to manage 99% of its stormwater on-site. The development used a combination of stormwater tools, including extensive green roofs, to accomplish this goal (Kohler and Keeley 2005).

In North America, a number of states have adopted or drafted stormwater management manuals which identify stormwater management standards primarily for new development. Green roofs are sometimes specified as a stormwater best management practice (BMP) that can be used to meet these standards. Pennsylvania, New Jersey, and North Carolina have included green roofs in their structural BMP section and it is expected that as green roofs become more common, they will be included in future stormwater manuals.

Urban areas are notorious for a lack of green space and biodiversity with new attention being paid to strategies that integrate urban infrastructure and green areas (Pincetl and Gearin 2005). Areas of a city may be prioritized or a simple standard may apply across a particular jurisdiction. A sophisticated urban greening policy which encourages green roofs exists both in Berlin, Germany and Malmö, Sweden and is generally known as the Biotope Area Factor (BAF). The objective of this policy is to improve an ecosystem's functionality and promote the development of biotopes in the city center (http://www.stadtentwicklung.berlin.de). BAF is defined as:

$$\mathrm{BAF} = \frac{\text{ecologically} - \text{effective surface areas}}{\text{total land area}}$$

Different surfaces have different BAFs according to the ecosystem services provided, such as stormwater retention, habitat creation, or connection with existing environmental features of the site. BAF targets are based on the type of land under development, the amount of additional construction on the site, and whether construction is new or is an extension of existing coverage. The target BAF is then achieved using a combination of practices which are weighted according to their individual BAF.

A final green roof performance standard applies to green building standards. One type of green building standard relating to roofing is a minimum reflectivity standard for rooftops. This standard derives from a well-known phenomenon that occurs in urban areas known as the urban heat island effect where temperatures of urban areas can be 6–8° hotter than the surrounding landscape due to dark impervious surface cover, such as asphalt rooftops (Bornstein 1968). Roofing materials which have lower roof reflectivity help to mitigate the thermal impact of developed areas. The U.S. EPA has created an Energy Star labeling system for roofing materials which have a reflectance value of greater than .65 and the Leadership in Energy and Environmental Design (LEED) Green Building Rating System assigns points for using Energy Star rated roofing products. Green roofs can also directly earn LEED points through the following categories:

Reduced site disturbance, protect or restore open space
Landscape design that reduces urban heat islands, roof
Stormwater management
Water efficient landscaping
Innovative wastewater technologies
Innovation in design

Green roofs may count for up to 15 points under the LEED system depending upon how well the roof is integrated into other building systems (Kula 2005).

Green roofs can be used as a surrogate for these highly reflective roof coatings due to the evaporative cooling potential of the plants and growing media. The city of Chicago has directly incorporated green roof language into their municipal energy code for the purposes of mitigating the urban heat island:

18.13.303. Urban heat island provisions. The reflectance and emittance requirements…are intended to minimize the urban heat island effect

…

1. The portion of the roof that is covered by a rooftop deck covering 1/3 or less of the aggregate area of the roof, or a rooftop garden, or a green roof, is exempted from the requirements of this section.

Direct Financial Incentives

One of the most straightforward green roof financial policies is the use of a subsidy or direct financing to encourage new green roof construction. These types of direct financial incentives help overcome the barrier of adopting new technology. Particularly in the North American market where the green roof industry is not robust, reducing market friction in the form of an increased green roof installation cost is important to encourage socially desirable behavior (Revesz and Stavins 2004).

Green roof projects can qualify for a subsidy by meeting certain specifications, such as a minimum depth of growing media, minimum maintenance agreements, and minimum vegetation coverage. The subsidy is then credited in a $/m^2 amount. German subsidies occur at the state and municipal levels of government and they typically range from 10–50% of initial construction costs (Ngan 2004; Keeley 2004). Approximately 50% of German cities offer some form of direct subsidy to building owners for installing green roof systems (http://www.greenroofs.com; http://www.fbb.de).

Berlin enacted a green roof subsidy program from 1983–1997 which reimbursed residents approximately 50% of green roof construction costs and resulted in approximately 63,500 m^2 of green roofs built in the city (Kohler and Keeley 2005). A region in Germany, North Rhine Westphalia, currently has a subsidy for practices controlling stormwater. The subsidy includes 15 Euro/m^2 for removal of impervious surfaces, 15 Euro/m^2 for infiltration systems, and 15 Euro/m^2 for green roofing insulation, drainage layers, substrate, and plants. The green roofs eligible for the subsidy must also have a runoff coefficient of at least 0.3 according to German national green roof guidelines (FLL 2000).

In North America, subsidies and grants are used sparingly and typically over a limited time horizon. Toronto has recently adopted a Green Roof Incentive Pilot Program which offers a grant of up to $10 Cdn/m^2 to eligible green roofs (http://www.toronto.ca). In the United States, there are currently no government programs offering direct subsidies for the unit costs ($/m^2) of green roof installations across a jurisdiction. Instead, there are green roof grant programs which offer lump sum payments under a competitive selection process. In 2005, the city of Chicago allocated $100,000 to be distributed to 20 green roof projects on residential and small commercial applications. The projects ranged from an 800 ft^2 vegetable garden to a 1750 ft^2 green roof and selection criteria were based on project location and visibility as well as environmental benefit (http://www.cityofchicago.org). Additionally, private foundations in the U.S. have created grant programs to directly fund green roof implementation. With funding from a lawsuit settlement, the Chesapeake Bay Foundation oversaw a small grants program for green roof projects in the Anacostia River watershed in the District of Columbia. The grants covered approximately 20% of the capital cost of green roof installation. Seven green roof projects were funded under this program (Johnson 2007). The Home Depot Foundation has also provided funding to groups in the U.S. to hold conferences, execute workshops, and implement research projects to advance the green roof industry.

Indirect Financial Incentives

The most prevalent green roof policy is the use of some form of indirect financial incentive to support construction of green roofs. Of these indirect incentives, a credit towards a municipality's stormwater utility fee is popular for encouraging green roof installation. Stormwater utilities are typically based on the amount of impervious surface which is found on a given site. Measures to minimize or mitigate for impervious surface, such as green roofs, are given credit towards a portion of the stormwater utility fee. Stormwater utilities are being used increasingly in the United States to fund stormwater programs with some researchers estimating there will be over 2500 utilities in the U.S. in the next decade (Woolson 2004).

Portland's Clean River Incentive and Discount program (CRID) illustrates how green roofs can be used to offset a stormwater utility fee. The city's base stormwater management charge for single family residences is $14.26 per month. CRID allows for up to a 35% reduction of this stormwater charge depending on the effectiveness of the site owner's private stormwater management. Preliminary reports show that a green roof covering over 70% of the rooftop will allow the site owner to receive the total amount of credit available under the program (Liptan 2003). Minneapolis has recently enacted a stormwater utility and provides 100% fee credit under the utility for stormwater quantity management including green roof systems. In the Minneapolis policy, green roofs receive credit simply as replacements of impervious area and the roof's stormwater retention is not the determining factor in receiving the credit. While this program should encourage green roof installations in theory, in actuality it has had limited success. This is due, among other things, to the relatively low cost of the base charge which makes the green roof payback over 80 years based on the credit (Welch 2007).

Another indirect incentive is allowing an increase in building density bonuses when green roofs are installed on the building. This policy is implemented in both Portland and Chicago. The basic form of the policy involves designating areas of the city or building which are eligible for density bonuses and then determining the amount of bonus for each ft^2 of green roof. In the case of Portland, for green roofs that cover up to 30% of the roof area, one ft^2 of bonus is allowed for each ft^2 of green roof. For green roof coverage of up to 60% of the roof area, two ft^2 of bonus is allowed for each ft^2 of green roof. For green roof coverage of greater than 60% each ft^2 of green roof will allow three ft^2 of bonus (Liptan 2003).

Chicago has also incorporated green roofs into section 17-4-1015 of their zoning ordinance which allows for floor area bonuses to developers who provide public amenities that improve the quality of life for the public. The following formula is used when calculating the floor area bonus in Chicago:

$$\text{Bonus floor area ratio (FAR)} = (\text{area of roof landscaping in excess of } 50\% \text{ of net roof area} \div \textit{lot area}) * 0.30 * \text{Base FAR}.$$

Minimum criteria for buildings to be eligible for the bonus include location within specific districts where the policy applies, minimum coverage of the green roof over the net roof area, provisions for maintenance over the life of the building, and demonstration that the building can support the additional weight.

Advantages and Disadvantages of Green Roof Policies

There are distinct advantages to utilizing certain types of green roof policies over others based on the goals of the green roof program, landscape features of the jurisdiction, and institutional support. Direct financial incentives in the form of subsidies have the advantage of providing building owners compensation for initial construction costs of the roof, which is often the limiting factor in determining whether or not to install a green roof system. Jurisdictions must have adequate funding sources to provide this subsidy, however, and many of these sources may vary from year to year based on annual budgets. In several jurisdictions in Germany, green roof subsidy programs were implemented for a number of years but were eventually terminated because of budget constraints (Ngan 2004).

Indirect financial incentives and performance standards have the advantage of being voluntary, favoring those owners who can install green roofs in a cost-effective manner based on their site conditions. This may be accomplished in both new construction and retrofit situations. A disadvantage is that it is difficult to guarantee green roofs will be installed, particularly when other more familiar management practices may also be used to accomplish the same environmental goal.

Mandating green roofs through the building code provides the highest level of insurance that buildings which qualify for roof greening will, in fact, install a system as defined by the agency in charge of oversight. The standards must clearly define installation procedures guaranteeing builders will install quality green roof systems. Some drawbacks to this approach are that it is likely to be politically unpopular and this is why it is sometimes implemented only on publicly owned buildings or buildings receiving public funds. An additional disadvantage to the technology standard approach is that it can stifle innovation if installers are bound to rigid criteria for each green roof they install.

Prompting Standards and Features of Successfully Implemented Green Roof Policies

A review of the policies of those jurisdictions currently promoting green roofs indicate there are some conditions necessary for the adoption of green roof policy and other conditions that should be addressed in the policy itself.

Environmental Concern in Highly Developed Areas

Green roof policy is always driven by some environmental concern found in urban areas. Some of the green roof policies are embedded in green building resolutions and, therefore, environmental concerns stem from the problems associated with development and construction practices in general, not specifically rooftop contributions. These issues cover a wide spectrum from air and water pollution, deforestation, toxic emissions, climate change, depletion of natural resources, energy consumption, and solid waste disposal. Three environmental issues typically used to justify green roof policy are the effects of stormwater runoff in urban areas, thermal impacts of traditional rooftops, and the lack of greenspace or biodiversity in highly developed areas. Without one of these three drivers, there is often little political footing for roof greening initiatives.

Well Defined Standards for Qualifying Green Roofs

In Germany, the Landscaping and Landscape Development Research Society (FLL) has developed a comprehensive green roof standard book called the "Guideline for the Planning, Execution and Upkeep of Green-Roof sites" (2000). This guide, which has been translated into English, provides a standard for German green roof implementation which both the green roof installers and the government regulators can refer to when developing their green roof projects, reviewing submitted plans, and creating incentives for new implementation. Uniform green roof standards have only recently begun to be developed in the U.S. The American Society for Testing and Materials (ASTM) has developed a number of standard test methods for green roofs including water permeability in the media, determination of dead and live loads, and a plant selection guide (http://www.astm.org).

Jurisdictions which have initiated green roof policies use various standards for what constitutes a green roof or what type of green roof qualifies for credit under the policy. At a minimum, these standards should address minimum continuous coverage of the growing media, minimum depth of growing media, key features of qualifying buildings (e.g., roof slope, building class, zoning class), and maintenance agreements.

Targeted Areas for Roof Greening

An important feature of using green roofs for environmental remediation is that they are limited in their application for society to receive the maximum benefit they can provide. Green roof policies are most effective in areas where a drainage basin contains high proportions of rooftop area, which often corresponds with areas containing high levels of impervious area. In less heavily urbanized areas, other management strategies may be more easily implemented. This has meant that green roof policies are found in cities with large populations and dense urban cores where high levels of impervious surface are found. Leading cities promoting green roofs often have dense populations and established urban centers including: Tokyo, London, Toronto, Chicago, and Portland.

Population size is not a prerequisite for a drainage area to contain high levels of rooftop or total impervious surface area. Commercial sites containing "big box" stores, urban centers of small municipalities, or industrial sites all can fit the mold for a targeted green roof policy to be efficiently implemented. Identifying whether the policy applies to new and/or existing structures can further refine the type of policy used. Doshi (2007) used a GIS-based approach to target areas of Toronto and rank potential green roof sites according to three major environmental benefits: energy conservation, stormwater reduction, and air quality improvement. While quantification of benefits in this way may be limited based on a jurisdiction's GIS data, this type of analysis allows policy-makers an opportunity to maximize efficiency of green roof regulatory tools to encourage implementation.

Advocacy Groups or Local Individuals to Promote Green Roofs

Both European and North American green roof policies were initiated by a small group or number of individuals. In Germany, modern green roofs began in the 1960's when researchers began to investigate some of the rooftop vegetation which had begun to naturally occur around Berlin. This research and subsequent public and private interest led to the formation of the FLL in 1975 which helped solidify the core of green roof interests in the country and paved the way for innovation both in the construction of green roofs and in the policies used to promote them.

In North America, the largest advocacy group is the Toronto-based nonprofit organization named "Green Roofs for Healthy Cities" (GRHC) which was founded in 1999 after the release of a green roof feasibility study by the group's founders, a consortium of public and private researchers. For the past four years the group has organized large international green roof conferences bringing together researchers, policy makers and members of the green industry to explore the current and future state of roof greening around the world.

Individuals also play a crucial role in establishing green roof programs in their communities. A classic example of the power of the individual is found in Portland, Oregon where in 1994 an employee of the Portland Bureau of Environmental Services took an interest in green roofs, built some test plots over his garage and provided data to the city which spawned larger test plots. This has blossomed into Portland becoming one of the leaders in green roof installations in North America including being the host city for GRHC's annual conference in 2004.

Institutional Authority to Oversee Green Roof Program Implementation

In all cases in North America, the jurisdictions which have implemented green roof policies have sufficient institutional support for staffing and technical assistance. In Toronto, the policy development process specifically identified "green roof resource person[s]" to be housed in five separate divisions (Toronto City Clerk 2006). While technical knowledge can often be left to the private firms responsible for green roof installations, adequate knowledge must be present in the regulatory agency's staff so that green roof installations will meet the goals expressed by the enacting legislation.

Application of Green Roof Policy: Athens, GA

Study Site and Data Collection

In order to apply the lessons learned from existing green roof policies, the jurisdiction of Athens, GA was selected as a test case. Athens is located in northeast Georgia approximately 100 km east of Atlanta and contains a population in 2005 of approximately 108,000 (http://www.athensclarkecounty.com). Athens-Clarke County is a unified city and county government. Land use in the watershed is typical of an urban area with high densities of impervious surface in the urban core of the city, commercial areas along major road arteries, isolated industrial parks, residential subdivisions, and designated agricultural zones. The University of Georgia is located in Athens and a large tract of land downtown is dedicated to the campus.

A thin-layer green roof test plot was established on campus in October, 2003 and was monitored for its ability to retain stormwater and mitigate rooftop temperatures (See Carter and Rasmussen 2006; Carter and Jackson 2007; Carter and Keeler 2007; Hilten 2005; and Prowell 2006 for more details). This green roof was designed to be cost-effective and easily replicated and therefore was considered as the model for new green roofs in the watershed. The data collected from this site was used to establish policy recommendations given the principles previously discussed and lessons learned in other jurisdictions.

Built Infrastructure

Athens' stormwater system is separate from its sanitary sewer system. This type of infrastructure has advantages and disadvantages for green roof implementation. The advantage is that it allows for a stormwater utility to be easily created as maintenance and repair of the stormwater infrastructure is often contained in a stormwater department with an independent budget allocation. The disadvantage is that one of the quantifiable benefits that can be realized with green roofs is the reduction of combined sewer overflows due to stormwater volume attenuation. This benefit is not accounted for given ACC's infrastructure.

Regulatory Infrastructure

The ACC Mayor and Commission voted to create a stormwater utility in 2004. This utility charges parcel owners a fee based on the amount of impervious surface on the parcel and zoned land use. The fee is divided into three parts, a base fee, stormwater quantity fee, and stormwater quality fee. If parcel owners can demonstrate they have instituted practices that reduce either the stormwater quality or quantity, credit will be given on their bill. Practices must be approved by a stormwater engineer according to specifications found in the Georgia Stormwater Management Manual (GSMM). The program is used to fund ACC's federally mandated stormwater management program.

General building permit fees are based on the value of the proposed construction. Currently the fees associated with construction contain no stipulations for credits based on environmentally beneficial construction practices. The Athens-Clarke County zoning code identifies limits to the floor area ratio (FAR) for commercial buildings depending on zoning class. FAR is the result of dividing the total floor area of a structure by the area of the lot on which it is located. For the downtown core of the city, maximum FAR is 5.0 whereas for areas zoned commercial-rural, the maximum FAR is .25 (Table 3).

Policy Recommendations

The current institutional framework and landscape characteristics of ACC allows for many green roof policy options to be investigated. It is important before selecting or prioritizing policies in the watershed that the jurisdiction clearly defines the goals it wants to accomplish. In the case of ACC, the recently enacted stormwater utility indicates the jurisdiction considers stormwater management important to both comply with federal regulations and protect the integrity of streams and rivers in the jurisdiction. ACC urban greening initiatives have not focused explicitly on green construction practices with the policy makers in the area placing most emphasis on riparian buffers and green corridors. A notable exception is found in a recent internal policy requiring all public buildings to be designed to meet the minimum standards for LEED certification. This does not necessarily result in green roof construction, however, as four buildings have been completed since the policy went into effect and none have green roofs.

Given these goals and the landscape characteristics of the jurisdiction, the most effective green roof policy in ACC should be both spatially focused and multifaceted. The spatial targets for roof greening are areas zoned "government," "commercial," and "industrial" (Figs. 1 and 2). In areas zoned residential or agricultural, impervious surface levels and relative amounts of rooftop to land cover are significantly lower at the parcel level than in the designated target areas. Also, the impervious surfaces which are found on a low-density lot are typically not fully connected to the storm sewer system as they are in more densely developed zones. This lack of direct connection allows for stormwater mitigation to be performed easily using management methods other than green roofs.

Creation of green roof district overlay zones allows for all new and existing development to fall under the same guidelines and receive the same benefits for green roof installation. Specifications for green roof construction in the overlay zone may be as follows:

Roofs which are flat or nearly flat (approximately 2% slope) are eligible to participate in the credit programs for roof greening.

Minimum thickness of growing media is 3″ for stormwater retention credit.

The vegetation, growing media, and specialized roofing layers must be installed according to manufacturer specifications.

A green roof maintenance plan must be submitted.

While modular green roof systems are allowed, a minimum area of 50% must be greened for roofs to qualify for credit programs.

Table 3 Maximum floor area ratios (FAR) and green roof FAR bonuses for a property with 100% building coverage in Athens, GA

Zoning class	Commercial					Industrial
	General	Downtown	Office	Neighborhood	Residential	
Current maximum FAR	1.5	5.0	.75	.75	.25	2.5
Bonus FAR with 100% green roof coverage	.6	2.0	.3	.3	.1	1.0
Total FAR with green roof FAR bonus	2.1	7.0	1.05	1.05	.35	3.5

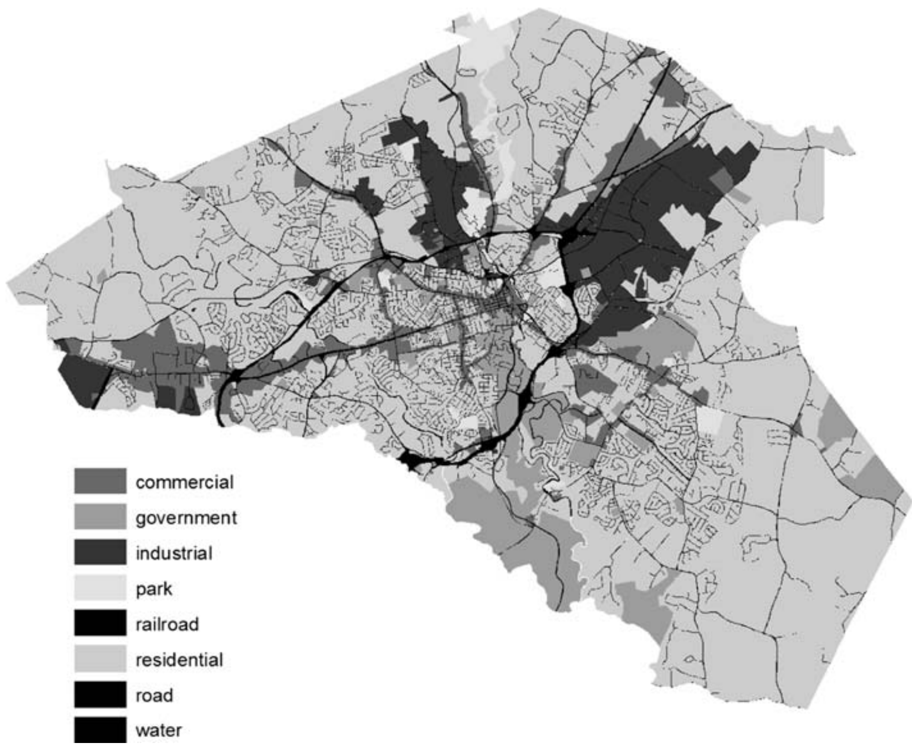

Fig. 1 ACC zoning classifications generalized from ACC zoning code

Technology Standards

Mandating roof greening on public buildings in Athens is recommended. Public roof greening should be clarified to include only buildings where green roofs are feasible, meaning the buildings matching stipulations found in the ACC green roof district overlay zone guidelines described earlier. This policy would serve a number of purposes. Greening the roofs of public buildings would generate all the positive ecosystem services that green roofs provide on any site. It also would establish local green roof examples which would serve as references for future private installations. There are currently only three examples in the ACC area where green roofs have been installed. An elementary school had a green roof constructed in the early 1970's as part of an earth building project. The green roof was constructed with topsoil and grasses and is not similar to the highly engineered systems recommended for use in ACC. The other two green roofs are research plots, one of which was previously described and the other is a small 4 × 8-ft test plot constructed over a shed at a private residence.

Local industry connections would also be established with potential job creation opportunities if the industry expands. The commitment to build publicly owned buildings in an environmentally sensitive manner already exists for new public construction in ACC and green roof demonstration sites may easily be incorporated into this LEED standard or directly mandated for specific buildings.

Indirect Financial Incentives

A stormwater utility credit for green roof installation is a recommended indirect financial incentive. Since ACC currently allows credits for practices in the GSMM and the GSMM currently does not reference green roofs as a stormwater volume mitigation tool, either an addendum to the GSMM must be created or a change to the credit system must be made to include green roofs as a BMP. Regional supplements to the GSMM as well as other state manuals

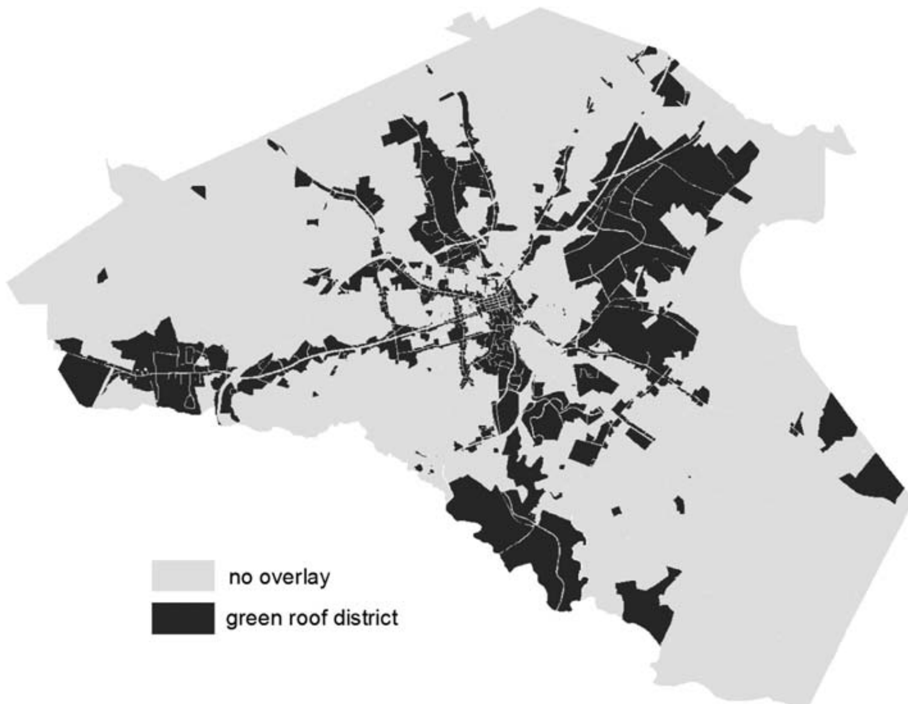

Fig. 2 Green roof district overlay zones

have included green roofs as a stormwater management practice (http://www.etowahhcp.org) and it is reasonable to consider them as existing in a revised version of the GSMM. A model green roof specification is included in supplementary material.

In practice, allowing for green roofs to count towards the stormwater volume credit independent of the GSMM may be an easier task. This involves documentation that post-development peak flow mitigation from various storm events will occur. Analysis of the runoff data collected at the green roof site allowed for a water quantity credit to be applied. Crediting stormwater customers with a water quantity credit results in a savings of approximately $1.78/month for average single family homes. Since the fee is based on the size of the property, larger buildings could realize much greater savings. Athens City Hall, for example, would save nearly $27/month in its stormwater utility fee. As previously discussed, this credit alone may not provide sufficient incentive for widespread green roof construction and therefore this policy is recommended in combination with other financial policy tools.

A second form of an indirect financial incentive for ACC is floor area bonuses, a form of density credits when green roofs are installed in the green roof district overlays. This policy will most likely play the largest role in the downtown and commercial areas where lots are small relative to the building footprint and additional floor space may be extremely valuable. The density formula is based on Chicago's policy which calculates credits based on the floor area ratio of the zoned property:

$$\text{FAR bonus} = (\text{area of green roof/total lot area}) \times (0.4) \times (\text{current FAR})$$

In the case of a green roof on a 20,000 ft^2 building in the downtown commercial area entirely covering a lot, the bonus would allow for an additional two units of FAR for a total of seven units, thus adding an additional 40,000 ft^2 to the proposed structure.

By creating a voluntary program based on the possibility of increased floor area, it is assumed that the areas with the highest value per square foot of floor area would take advantage of the density credits. This most costly property in the jurisdiction is in the downtown commercial zone. The downtown commercial area is also the part of the jurisdiction with the highest density of impervious surfaces, averaging over 77% total impervious area. This makes green roofs one of the few viable environmental mitigation tools with this incentive program encouraging the tool where green roofs are needed most.

Discussion and Conclusion

Finding ways to repair the damaged environment in the urban landscape is difficult. The more tools that urban planners, landscape designers, policy makers, and engineers have in their proverbial toolbox, the more flexibility they will have to determine what practices may work best given the constraints of the local landscape. Designer ecosystems, like green roofs, fit well with jurisdictions that see the built environment as ripe with opportunities for management.

Policies at various levels of government have been initiated to promote the use of green roofs. Federal policies can mandate the control of stormwater or other kinds of environmental protection and provide direct green roof funding through grants or subsidization through tax relief for green roof installation. Local governments can mandate or encourage the use of green roofs as a means of controlling stormwater or achieving other environmental goals in specific locations or circumstances. Jurisdictions may use both voluntary economic policy incentives and performance standards to encourage private green roof installations. Without adequate education and on-the-ground examples, however, the regulated community may have a difficult time changing established roofing practices. By mandating green roof policies for public buildings, jurisdictions can demonstrate their commitment to sustainable building practices as well as provide local green roof reference sites for other builders.

Despite the theoretical underpinning that would suggest green roof policies would encourage green roof installations, it is unclear whether United States green roof policies have resulted in more on-the-ground projects. The lack of evidence is primarily due to a lack of green roof project data. A limited database can be found at http://www.greenroofs.com but without comprehensive jurisdictional surveys, policy effects are difficult to track. Surprisingly, Chicago, one of the leading jurisdictions in green roof policy, does not have accessible up-to-date databases with dates of green roof installations. Portland, however, does have a better tracking system. From 2001–2006, 26 green roofs were installed to meet stormwater management requirements. The CRID program went into effect for green roofs on October 30, 2006 and from 2006–2007, 23 green roofs were constructed to receive this discount on their stormwater fee (T. Liptan personal communication January 17, 2008). This would suggest that there is a market response to the credit policy either in anticipation of the policy being enacted during 2006 or in direct response to the credit in 2007.

Despite the increased up-front costs, a number of high profile private projects, such as the 454,000 ft^2 green roof on Ford's Dearborn Truck Assembly Plant and the 12,000 ft^2 Heinz 57 Center green roof in downtown Pittsburgh, PA, occurred independently of policy initiatives or government incentives for installations. In these cases private benefits, such as marketing opportunities, building energy savings, "functional space" for meetings or gatherings, and/or consistency with a company's "green" initiatives were enough to overcome the premiums associated with green roof installation. Since private green roof projects are continuing to be done in areas where there is little government support, the policy recommendations provided here would only serve to boost the industry in these areas while helping to internalize the public benefits that the early adopters of the technology are providing to their local communities.

Green roofs have the potential to provide benefits to both the public and private sectors given realistic limitations currently found in the technology like the additional expense of greening sloped roofs and the opportunities for cheaper alternative management practices to be used in low-density residential areas. Additionally, as demonstrated by the lack of a combined sewer system in Athens, local conditions will define benefits resulting from a green roof policy program. Throughout urban areas, land cover may vary dramatically from highly impervious to relatively undeveloped. When prescribing environmental management practices, consideration must be paid to the spatial variation within jurisdictions and the appropriate management tools which may vary with location. Because the technology is still considered novel, it should be encouraged with directed policies.

Once a commitment is made to develop green roof policies in a local jurisdiction, the case study of Athens demonstrates both the importance of customizing policy to local conditions. Athens' relatively sophisticated stormwater administrative infrastructure, including a stormwater utility, internal policies to green public buildings, lack of a combined sewer system, and clearly defined locations where green roof priority areas could be targeted, allow for policy priorities to be determined.

Additionally, this study demonstrated the value of integrating locally collected green roof data into policy recommendations. Scientific data was incorporated into policy recommendations in a number of ways. The hydrologic data demonstrated that rooftops located on highly impervious sites could retain significant amounts of rainfall and thus the stormwater utility fee credit was recommended. To maximize green roof benefits, spatial analysis demonstrated roof greening scenarios to be most effective in the commercial and industrial corridors with a corresponding policy recommendation for green roof district overlay zones.

The future of the green roof industry will be driven both by public initiatives and private enterprise. The ability of green roof policy instruments to function effectively depends on a jurisdiction's ability to account for green roof public benefits and recognize the limiting factors that influence green roof installations. While this urban greening tool is rapidly gaining in popularity, it is important that limitations of the current technology be recognized so that public green roof support and policy can maintain a strong linkage to the functional components of the green roof systems. Using innovative practices, such as green roofs, may not completely mitigate for the ecological footprint of buildings in urban ecosystems, but they do create ecosystem services and can be a viable tool in a broader plan to establish green infrastructure in urban environments.

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