# VEGETATED ROOFS: PERFORMANCE AND POLICY IN ATHENS, GA

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**Abstract.** Urban land area in the United States is projected to increase to 8.1% of total land area by the year 2050. These human-dominated environments create conditions that degrade both terrestrial and aquatic ecosystems. If cities are to reduce their environmental impact, innovative practices must be developed that replace ecosystem services lost during the urbanization process. This study evaluated the performance and feasibility of using vegetated or green roof systems for urban ecosystem remediation. The stormwater retention performance of a thin-layer green roof was evaluated using an experimental field test plot. Average stormwater retention was found to be slightly under 78% of rainfall from storm events over the course of one year. The additional stormwater storage created on the rooftop allowed for a curve number of 86 to be developed for the green roof. This curve number was then used in a modeling analysis of Tanyard Branch watershed, a highly urbanized watershed in Athens, Georgia. Spatial analysis demonstrated how impervious surface cover could be reduced in the watershed by using green roofs. Total impervious area in the downtown commercial zone was reduced 20% when all the roofs were greened. Roof greening also resulted in significant hydrologic changes in the watershed. A benefit-cost analysis (BCA) was also performed for the life cycle of the green roof system. In Tanyard Branch, the net present values of green roofs are greater than traditional roofing although expected changes in technology, energy prices, and market conditions were shown to reduce green roof life cycle costs to below traditional roofing costs. A green roof policy was developed for Athens, GA based on the performance and economic analysis of the experimental green roof. This policy uses private incentives and public demonstration sites to promote green roof infrastructure. A stormwater best management practice specification for green roofs was created that may be included in future versions of the Georgia Stormwater Management manual. Green roofs are shown to be a potentially valuable tool for increased sustainability in highly developed urban areas.

## INTRODUCTION

One specific component of the built environment often overlooked is the use of the rooftop as environmentally beneficial space. Rooftops comprise a large proportion of surface land area particularly in downtown regions of the city as building footprints can occupy entire city blocks. Transforming the rooftop space into an environmental amenity can add value to the building owner and perform ecosystem services in the city. This transformation can be accomplished by applying vegetation and engineering growing media to the roof surface and creating a “green” roof. The rooftop is then able to retain and utilize stormwater for plant growth, reduce building temperatures through shading by the plants and evaporative cooling, and increase urban habitat. The practice of designing and building green roofs is becoming increasingly popular with architects, landscape architects, stormwater managers and ecological design firms in densely developed urban areas.

There are two general types of modern green roof systems: intensive and extensive. Intensive systems are characterized by deep (> 6”) growing media, opportunities for a diverse plant palate on the rooftop and high cost and maintenance requirements. Extensive systems are designed to be lightweight and easily retrofitted on existing roof surfaces. They contain thin growing media depths (2-6”) and can support a limited number of drought-tolerant plants that thrive in the limited water and nutrient conditions. Extensive systems are by far the most common in Germany with over 80% of green roofs being extensive in 2002 (Harzmann, 2002)

The objectives of this study were 1) to evaluate the stormwater retention performance of an extensive green roof system, 2) to examine the watershed scale effects of widespread extensive green roof implementation, 3) perform a cost-benefit analysis of extensive green roof systems, and 4) evaluate policy tools that may encourage green roof implementation. The interdisciplinary nature of this study reflects the recognition that urban environments must be studied holistically to include human decision-making as an essential biotic component in the structure of the urban ecosystem for remediation to be successful.

## METHODS

### Study site

The data used in this study were generated from an experimental vegetated roof site established on the campus of the University of Georgia in October, 2002. One part of the roof site contains a 42.64 $m^2$ extensive green roof test plot with an identical gravel roof control plot. Adjacent to the stormwater green roof test plot, a second experimental roof was constructed using a modular extensive green roof system. An analysis of the thermal conductivity of growing media as well as energy load modeling was performed on this roof. Automated measurement of *in situ* micrometeorological parameters such as humidity, air temperature, windspeed, radiation, and soil temperature were combined with laboratory analysis of the engineered growing medium providing local data for simulation modeling. The simulation programs used were eQuest and HYDRUS-1D, a building energy model and a combined heat and moisture simulation, respectively. Additional details of this test plot can be found in Hilten (2005).

### Stormwater performance

The stormwater plots were instrumented with weirs beneath the roof deck and Druck PDCR 1800 pressure transducers were mounted to the bottom of the weir boxes allowing stormwater retention performance of the green roof to be evaluated. Storm events were continuously monitored from November, 2003 – November, 2004. Additional details of this study can be found in Carter and Rasmussen (2005) and Carter and Rasmussen (2006).

A detailed rainfall-runoff analysis was then performed in the Tanyard Branch watershed using ArcView 3.2 and StormNet Builder, a stormwater modeling software package that uses EPA's SWMM 5.0 analysis engine and curve number infiltration method for routing runoff through a watershed. Using a composite curve number method, runoff was modeled at four spatial scales and with all roofs and only flat roofs greened. The scales were at the watershed, subwatershed, zoning level, and parcel level. Additional details of this study can be found in Carter and Jackson (in press).

### Economics and policy

The data collected from the experimental green roof test plots were also used to develop a benefit cost analysis (BCA) for the life cycle of extensive green roof systems in an urban watershed. The net present value of green roofs was then compared to a traditional roofing scenario given private and social benefits generated by the green roof such as stormwater retention, energy savings, air quality benefits, and extension of the roof life. A discount rate of 4% was applied over the roof's life cycle and sensitivity analysis was performed to determine how the model assumptions may affect the results. Additional details of this study can be found in Carter (2006).

To establish a green roof policy in Athens, GA, a comprehensive review of international and domestic green roof policies was performed. Green roof policies fall under four general categories of technology standards, performance standards, direct financial incentives and indirect financial incentives. Necessary conditions for green roof policy implementation were identified and recommended policies then applied to local conditions in Athens, GA. Additional details of this study can be found in Carter (2006).

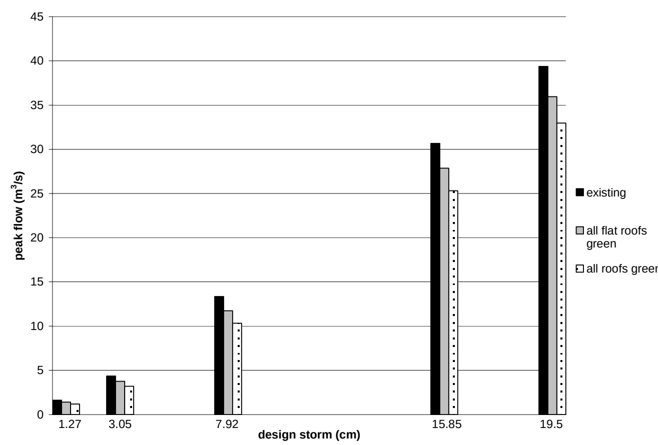


**Figure 1. Peak flow for five design storms with roof greening scenarios**

## RESULTS

### Stormwater performance

Stormwater mitigation performance was monitored for 31 precipitation events, which ranged in depth from 0.28 to 8.43 cm. Green roof precipitation retention decreased with precipitation depth; ranging from just under 90% for small storms (< 2.54 cm) to slight less than 50%for larger storms (> 7.62 cm). Runoff from the green roof was also delayed - average runoff lag times increased from 17.0 minutes for the black roof to 34.9 minutes for the green roof, an average increase of 17.9 minutes. Precipitation and runoff data were also used to estimate the green roof curve number, CN = 86.

Modeling watershed outflow volumes resulted in significant peak flow reductions when all rooftops were greened in the watershed, particularly for smaller storm events. The 1.27 cm storm event resulted in peak flow volumes of 1.62 $m^3/s$ for existing land uses. Greening all the roofs produced a 26% reduction in peak runoff volumes for the 1.27 cm storm resulting in peak flows of 1.19 $m^3/s$ (Figure 1). Greening all the roofs also resulted in a peak flow in the 1 year, 24 hour storm event which was less than the existing 2 year 24 hour storm event peak flow. For larger storms, there was less reduction in peak outflows, although the peak outflow of 32.97 $m^3/s$ from greening all the roofs for the 100 year, 24 hour storm was very similar to the peak outflow of 32.23 $m^3/s$ from the existing 50 year, 24 hour storm. Greening all flat roofs reduced peak flows by about half as much as greening all roofs, similar to CN results for the watershed scenarios. Green roof implementation did not result in any peak flow lag times occurring across the watershed. There was, however, a slight increase in outflow volumes on the falling limb of the green roof hydrographs.

Composite curve numbers modeling revealed dramatic differences particularly in flat green roof stormwater retention performance depending on the scale under evaluation. Existing land use in the watershed produces 0.481 ha-m of stormwater runoff for a 1.27cm storm event. When all the flat roofs are greened, this is reduced to 0.391 ha-m or 18.9%. At the subwatershed scale, reductions range from 7.7% to 36.3% depending on the location of the watershed. The zoning classification ranges from 0% reduction in single family residential zone to 39.9% in the downtown commercial zone. Among individual parcels, wide variation exists even within the same zoning class. For example, one parcel in the downtown commercial zone retained nearly 91% of the 1.27 cm storm event where over 80% of the site was covered in rooftop. Another parcel in the same zone provided no stormwater retention as it contained only surface parking.

**Economics and policy**

Compiling all the discounted costs and benefits associated with green and traditional roofing systems allows for a net present value (NPV) test to be performed. Using a 4% discount rate over 40 years, the total costs of installing thin-layer green roof systems on the flat roofs in the Tanyard Branch watershed are $27,451,153. The total costs of traditional built-up roofing systems the over this same time period is $21,552,206. Social benefits of green roofs equal $3,283,488.37 and a social NPV of $24,167,665 which is 12.14% more than traditional roofing (Table 1).

Private analysis was performed on a 929 $m^2$ roof. This results in a total construction cost of $144,478 for green roofs and 113,353 for conventional roofs at a 4% discount rate on a 929 $m^2$ building. Total private benefits from green roofing for the private building totaled $9,634. This is 18.87% more than typical roofing.

Sensitivity analysis evaluated how changes in energy prices, construction costs, and discount rate affects the NPV of the roofing systems. When these values were allowed to randomly vary over 10,000 trials, the average NPV of green roofs is less than the current NPV of black roofs meaning that over the roof's life cycle it is cheaper to install green roofs than their traditional counterpart (Table 1).

Policy recommendations for Athens, GA include prioritizing areas of the jurisdiction where green roofs will be most effectively used. Density credits and stormwater utility fee credits also are encouraged. Demonstration projects and a commitment to greening publicly-owned buildings will help overcome the educational and institutional roadblocks to green roof installations.

**Table 1. Comparison of green and conventional roof net present value (NPV)**

| | Private roof ($) | | Public watershed ($) | |
|---|---|---|---|---|
| | conservative | average | conservative | average |
| Green roof costs | 144,378.20 | 108,474.13 | 27,451,153.64 | 20,624,589.43 |
| Green roof benefits | 9634.38 | 19,040.24 | 3,283,488.37 | 5,077,495.58 |
| Green roof NPV | 134,743.80 | 89,433.89 | 24,167,665.27 | 15,547,093.85 |
| Conventional Roof NPV | 113,352.95 | 113,352.95 | 21,552,206.10 | 21,552,206.10 |
| Green/black roof cost ratio | 1.19 | 0.79 | 1.12 | 0.72 |

## CONCLUSIONS

The stormwater management capabilities of an extensive green roof system were evaluated in detail. A number of green roof stormwater management functions were documented from this evaluation. This extensive green roof is capable of retaining over 90% of the rainfall from small storm events. In Georgia, these small storms comprise most of the rainfall events that occur annually, with total storm volumes being the key precipitation factor rather than storm intensity.

Using the Tanyard Branch watershed as a case study, spatial analysis applied the green roof hydrologic results to a broader scale and included effects on the receiving water body. The reduction in the amount of total impervious area in the watershed was dramatic for downtown areas near the urban core. It was found that the scale of analysis is critical for prioritizing areas of the watershed which would benefit the most from green roof implementation. In this case, local zoning classifications were found to provide sufficient spatial disaggregation while not being overwhelmingly data intensive. Green roof storage across the watershed was sufficient to mimic the predevelopment abstraction from urban forests. At the parcel scale, initial abstraction values from hydrologic models were met when rooftops covered over 30% of the site.

The cost-benefit analysis shows that under present market conditions, it is understandable why green roofs have not begun to be implemented on a large scale. The net present value of extensive green roof systems costs 12% more to society and 18% more to private interests than traditional roofing practices. Considering reasonable assumptions about the maturation of the green roof industry in this country decreases the premium $0.40 on every dollar resulting in cost savings when green roofs are installed. This sensitivity analysis justifies the use of public funds and policy incentives to encourage green roof implementation.

An evaluation of green roof policies allowed salient and successful features of the policies to be identified and a new model policy to be developed and applied in Athens, GA. A number of voluntary incentive programs including density bonuses and stormwater utility fee credits offer efficient and politically feasible alternatives to the establishment of a green roof technology standard. The public benefits provided by the green roofs, however, give policy makers an opportunity to create public demonstration projects and incorporate green roofing standards in the jurisdiction's existing green building policy.

The practice of extensive roof greening has been shown to have a profound effect at a variety of scales and for a variety of purposes in the urban environment. This study focused primarily on the hydrologic impacts of green roof systems and the consequential stormwater management opportunities provided by the practice. Green roofs were found to be an important stormwater management tool particularly in highly developed areas of a watershed for small storm events. The feasibility of retrofitting extensive green roof systems into the existing urban landscape also allows for environmental mitigation to be performed in areas where this may have been previously been economically impractical. This work integrates the different disciplines of ecology, hydrology, engineering, economics, and environmental policy into a cohesive analysis critical to understanding how future cities may be made more ecologically benign. Using innovative practices such as green roofs may not entirely remove the imprint of humanity on natural systems, but they do provide ecosystem services in the urban landscape that may allow for a levels of sustainability not yet achieved in human-dominated ecosystems.

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