USE OF GREEN ROOFS FOR ULTRA-URBAN STREAM RESTORATION IN THE GEORGIA PIEDMONT (USA)

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REFERENCE: Proceedings of the 2005 Georgia Water Resources Conference, held April 25-27, 2005, at The University of Georgia, Kathryn J. Hatcher, Editor, Institute of Ecology, The University of Georgia, Athens GA 30602.

Abstract. Stormwater management has traditionally focused on the use of conveyances to quickly move stormwater runoff from urban centers into nearby rivers, streams, and lakes. The increased flow caused by impervious surface cover (ISC) leads to runoff rates that are amplified by kinematic processes as they travel through the municipality's stormwater system. Elevated runoff volumes and rates lead to high pollutant transfer and altered hydrology that adversely affects urban stream ecosystems, water quality, and human health.

Vegetated roof cover provides a means for reducing stormwater runoff, while providing additional aesthetic and environmental benefits. We tested vegetated roof plots at the Boyd Graduate Studies Building on the campus of the University of Georgia from October 2003 to the present for their effectiveness in reducing stormwater flows. Performance results were found for a large range of storm events. Spatial analysis was performed in an urban watershed (Tanyard Branch watershed in Athens, GA) to evaluate widespread green roof implementation. Resulting management scenarios are discussed.

INTRODUCTION

The built environment is often implicated as a causal agent in degradation of stream ecosystems which are found in and around urban areas (2, 3, 10, 13, 14). As additional impervious surfaces are created, there is an increase in stormwater runoff and anthropogenic pollutants that are responsible for urban aquatic environmental problems (5). These surfaces eliminate stormwater infiltration creating an altered hydrology which quickly transports anthropogenic contaminants into the receiving water body. The physical characteristics of urban streams are often found to be dramatically altered as buffers are eliminated, stream banks are armored, and channels are straightened (4). The biotic community is frequently dominated by a few tolerant species of fish and macroinvertebrates (11).

These detrimental effects of urbanization on the chemical, physical, and biological properties of stream ecosystems have resulted in regulations at the federal, state and local levels requiring government agencies to develop management strategies to mitigate the negative environmental impacts of development.

The Clean Water Act established the National Pollutant Discharge Elimination System (NPDES) permitting which authorizes the federal or state government to implement a stormwater discharge permitting system (9). Under Georgia Environmental Protection Division's Municipal Separate Storm Sewer System (MS4) permit program, local governments are required to develop a stormwater management program which includes structural and nonstructural stormwater controls. Non-structural controls are primarily encompassed in better site design practices. Structural controls are "constructed stormwater management facilities designed to treat stormwater runoff and/or mitigate the effects of increased stormwater runoff peak rate, volume, and velocity due to urbanization" (1). These stormwater best management practices (BMPs) are sized for a variety of goals including water quality, channel protection, overbank flood protection, and extreme flood protection. These practices include stormwater ponds and wetlands, bioretention areas, and vegetated filter strips.

Traditional BMPs are useful in urbanizing areas and where land is readily available. In many metropolitan areas, however, undeveloped land is scarce and stormwater management must be retrofitted into the built environment. Vegetated, or green, roofs use engineered growing media, drought-tolerant plants, and specialized roofing materials that can be installed on existing structures. This creates a rooftop which can absorb and utilize precipitation rather than shedding it into the stormwater system. While green roofs have been used in Europe for decades, they have only recently been used in North America and little research exists on their performance for regional rainfall conditions.

The goals of this study were to: 1) Install a large green roof test plot that would be monitored for its stormwater retention performance relative to a typical gravel roof; 2) Model this performance data across an urban watershed in the Piedmont region of Georgia; and 3) Examine how widespread green roof implementation may be used to accomplish statewide stormwater management goals.

STUDY AREA

The project study area is the Tanyard Branch watershed in the Piedmont region of Georgia. This is a highly urbanized watershed, occupying over 585 acres in downtown Athens, GA. Nearly 54% of the watershed is covered in some type of impervious surface. Tanyard Branch is a second-order urban stream which flows into the North Oconee River. It was recently listed on Georgia's 303(d) list of waters not supporting their designated use due to urban runoff.

Two test sites have been retrofitted onto an existing flat ($< 2\%$ slope) roof on the campus of the University of Georgia (UGA) to evaluate green roof performance. The roof was selected for its accessibility, ability to accommodate additional weight, and high visibility for public education. The original built-up roof components include a concrete deck overlaid with approximately ten inches of perlite insulation, a water-proofing layer of asphalt and fiberglass-reinforced, asphalt-saturated felt, and approximately 2" of gravel ballast. The roof drains to the existing stormwater system.

METHODS

Green roof stormwater retention Two existing roof areas were isolated using pressure treated lumber and additional waterproofing (Figure 1). This allowed for the drains to be isolated and monitored. The sites are identical in size (459 ft^2) and shape. The control plot was left in its original state. The vegetated section uses a design from American Hydrotech, Inc., primarily comprised of loose-laid layers underneath the growing media and plant material. The specialized layers include a WSF40 root-protection sheet, a SSM 45 moisture-retention mat, a Floradrain FD40 synthetic drainage panel, and a Systemfilter SF geotextile-filter sheet. The growing media was provided by ItSaul Natural, LLC, and is a blend of 55% expanded slate, 30% USGA sand, and 15% organic matter composed primarily of worm castings. Six xeriphytic plant species were selected for their ability to survive drought and low nutrient conditions.

Figure 1: Test (left) and control (right) plots after nine months.

The drains beneath the test plot sections were diverted to $4' \times 1' \times 1'$ stainless-steel box containing a 1" open orifice located six inches from the bottom and a rectangular weir at the top to accommodate runoff from extreme storm events (Figure 2). The boxes then drained back to the main stormwater system. A pressure transducer was mounted in the base of both boxes to measure the height of the water above of the point of the instrument. The pressure transducers were connected to a datalogger that was programmed to record water levels every 30 seconds during a storm event. A tipping-bucket rain gauge located within the test plots was also linked to the same datalogger.

Storm events were continuously monitored from November 2003 to December 2004. A storm event was defined as rainfall greater than 0.1" with an antecedent dry period of 24 hours (8). Runoff was determined using the weir equation, $Q = C\sqrt{h}$, where Q is the flow in cm^3/s, C is the weir coefficient, and h is the height of water above the weir outlet, cm.

Watershed application and modeling Spatial analyses coupled with hydrologic modeling were used to evaluate how widespread green roof performance affects the hydrology in the Tanyard Branch watershed. Spatial analysis was performed using geographic information system software (ArcView 3.2). 2003 full color aerial photographs with one-half foot pixel resolution were obtained to digitize the land coverage at a scale of 1:500. Land uses were clas-

Figure 2: Weirs used for determining stormwater volume.

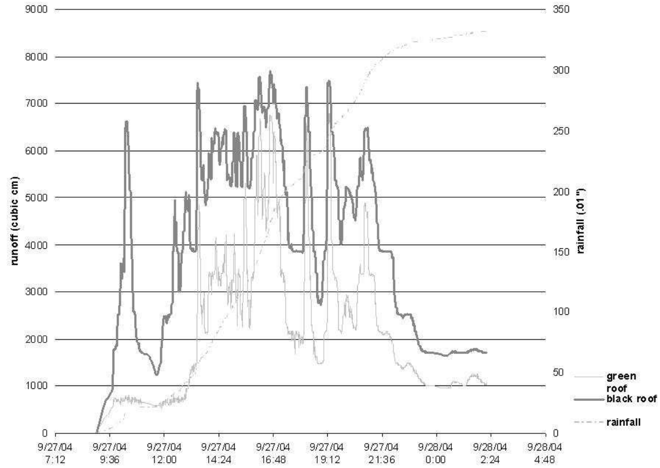

Figure 3: Representative stormwater hydrograph.

sified as roofs, roads, parking, sidewalks, sports, or greenspace. Stormwater maps and a watershed mapping extension were also used to determine the subwatersheds of the two first-order sections of the stream. This detailed spatial information allowed for different green roofing scenarios to be explored across the watershed. Total impervious area (TIA) was then calculated for the entire watershed and the two subwatersheds. Impervious surfaces were also classified as connected or unconnected based on their linkage to the stormwater system. Only surfaces that were directly connected to the system were considered part of the effective impervious surface area (EIA).

The Curve Number (CN) method was selected for its simplicity and widespread use. Curve numbers are assigned for a range of land uses according to their runoff characteristics. Impervious areas are typically assigned a value of 98. The CN method is also recommended in the Georgia Stormwater Management Manual for use in urban watersheds similar to our study area. We first established the CN value for our green roof runoff data. Runoff volumes from the traditional (black) roof were calibrated using the CN calculations found in the manual. The percentage of stormwater retained by the green roof was multiplied by the modeled amount of runoff from the black roof to develop a model CN for the green roof test plot.

Green roof curve numbers were found for 11 storm events and the median value was used as the modeled green roof curve number. Composite curve numbers were then established for different scenarios in the watershed using the spatial information compiled in ArcView. These composite curve numbers then were used to model changes in stormwater volume for three scenarios (existing land cover, all roofs greened, and all flat roofs greened) and four design storm volumes (*water quality* event, 1 year-24 hour, 25 year-24 hour, 100 year-24 hour).

RESULTS

Stormwater retention For 32 storm events recorded from November 2003 to November 2004, green roof stormwater retention ranged from 39–100% with an average retention just under 78%. Nearly all of the storm events less than 0.5" retained over 90%, with one event of 0.16" retaining 100% of the precipitation. The smallest retention amount occurred during a 2.12" storm event on 11/19/03 where 39% of the stormwater was retained. A negative relationship exists between the amount of rainfall and the percent of the storm that is retained. A sample hydrograph illustrates how the amount of runoff from a green roof differs from the control roof over the duration of a storm event (Figure 3).

Spatial analysis and curve number modeling Spatial analysis revealed that 53.8% of the Tanyard Branch watershed has some form of impervious surface. Roofs accounted for 15.9% of the watershed area and 29.5% of impervious surfaces. Similar values were found for both first-order subwatersheds. Only parking lots constituted more impervious area.

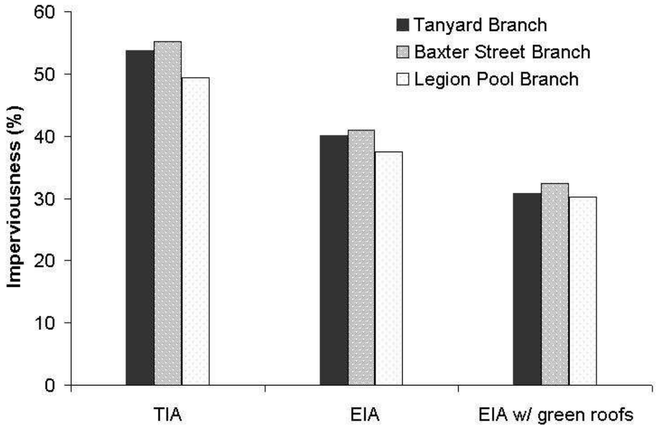

Figure 4: Total Impervious Area (TIA) and Effective Impervious Area (EIA) for three watersheds.

Flat roofs formed nearly half of all roofs in the watershed. Under the two different green scenarios, green roofs were converted from what was previously impervious surfaces into pervious surfaces. This lowered the TIA to 38% when all roofs were greened and 46% when flat roofs were greened. EIA was also affected as green roofs decouple rooftops from the stormwater system (Figure 4).

A median CN=88 was found using data from 11 sample storms, and was used in subsequent hydrologic modeling. A CN=88 is equivalent to 1.36" of water storage, which is consistent with the depth of growing media and specialized roofing materials. Over the watershed, applying green roofs to all the buildings lowered the composite CN by one point from 89 to 88. This translates into a 15% reduction in stormwater volume from the 1.2" storm event, 7% reduction for the 1 year, 24-hour event, 4% reduction for the 25 year, 24-hour event, and 3% for the 100 year 24-hour event.

DISCUSSION

While modern green roof technology has existed in Europe for decades and is beginning to see widespread use in North America, few studies have quantified stormwater retention ability of green roof systems. One possible explanation for this is the difficulty of experimentally designing and monitoring large field test plots. In order to be cost-effective - even for relatively small storm events - the volume of stormwater shed by our 459-ft^2 plots demands a system which allows flow-through, yet not complete containment of the runoff. We found the use of a two-stage riser system to be sensitive to small rainfall events. The use of an open orifice design led to some challenges during calibration, however, as the calculations needed to convert water level height into flow and volume measurements became exceedingly complex. Other researchers have used a v-notch weir for runoff measurements and this may help to simplify the calibration process (12). We also found that using a control and experimental plot design was helpful to find the relative green roof runoff measurements.

The stormwater retention performance at the roof scale demonstrated two important features of thin-layer green roof systems. First, the roof retained nearly all of the rainfall from most frequent, smaller storm events. This initially could be viewed as a detriment to the watershed as the water cycle is disconnected at this point and streams lose what, in a forested watershed, would be infiltrated rainfall translating over time into sustained stream baseflow (7). In highly urban environments, however, the vast majority of this rainfall does not infiltrate and return to the stream slowly as baseflow, but is transported quickly to the receiving water body and results in flashy, elevated stormflow and the direct transport of urban pollutant loads even after small rainfall events (6). For this reason, retention and use of this rainfall by the vegetation is considered a benefit. For infill projects where complete retention of small storms is required, there is great potential for green roofs to be used as a stormwater retention tool.

A second feature is that the majority of stormwater retention is found at the beginning of storms. The growing media absorbs the initial rainfall until it reaches saturation at which point the black and green roof hydrographs look relatively similar. This indicates that the roof operates essentially as a retention instrument for a particular water volume rather than detaining and slowly releasing significant amounts of stormwater after percolation through the soil. The green roof system we used has porous growing media and a synthetic drainage mat and water retention fabric which allows the media to drain and water to runoff during large events, but may retain most of the residual moisture released from the soil after the rainfall is complete.

In applying the green roof performance to the watershed scale, a less dramatic change in stormwater hydrology emerges, particularly for large storm events. Urban landscapes are complex mosaics of land uses, both impervious and pervious. Roofs make up about 16% of the land cover in the Tanyard Branch watershed. Even with widespread green roof installation, change in hydrology across the watershed will be minimal for storm events greater than the 1 year, 24-hour event. For smaller events across the watershed, the modeled results across the watershed indicate that green roofs still have a significant, although small, effect on treatment volumes. For example, the manual recommends interception and treatment of all the runoff from 85% of the storms that occur during the course of a year. In the case of Tanyard Branch, a volumetric runoff coefficient of 0.53 is multiplied by the 85^{th}-percentile rain event (1.2") giving a water quality volume of 31.25 acre-feet. Green roofs would retain approximately 8 acre-feet or one-quarter of the volume needed to be intercepted and treated. No treatment and re-release is actually occurring on this volume, however, as the water cycle is short-circuited at the roof.

CONCLUSIONS

We found green roofs to be effective at providing stormwater management at the roof scale, particularly for small, frequent storm events in the Georgia Piedmont. For architects, this provides a way for new structures to have stormwater management *built in* to their designs. Our project also showed that retrofitting existing buildings with a green roof can significantly reduce and - in some cases - eliminate the stormwater contribution from the existing structure.

Using the Tanyard Branch watershed as a case study, hydrologic modeling suggests that green roofs alone cannot provide the minimum recommended stormwater management at the watershed scale. Although roofs constitute nearly 30% of the total impervious area in the watershed, the amount of other land coverage lessens the impact of widespread roof greening. In watersheds of larger metropolitan areas which contain a proportionally larger percentage of rooftops relative to other land coverage a different conclusion may be reached.

A first step in rehabilitating urban streams is to examine the hydrologic characteristics in the watershed and examine the tools necessary to lessen the impact that altered hydrology has on receiving water bodies. One way to accomplish this is to reduce the amount of impervious surfaces found in the watershed. Green roofs can replace a surface typically seen as a contributor to stormwater problems and cause of urban stream degradation. Green roofs must be used with other management strategies in a comprehensive watershed management plan if effective rehabilitation is to be considered.

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