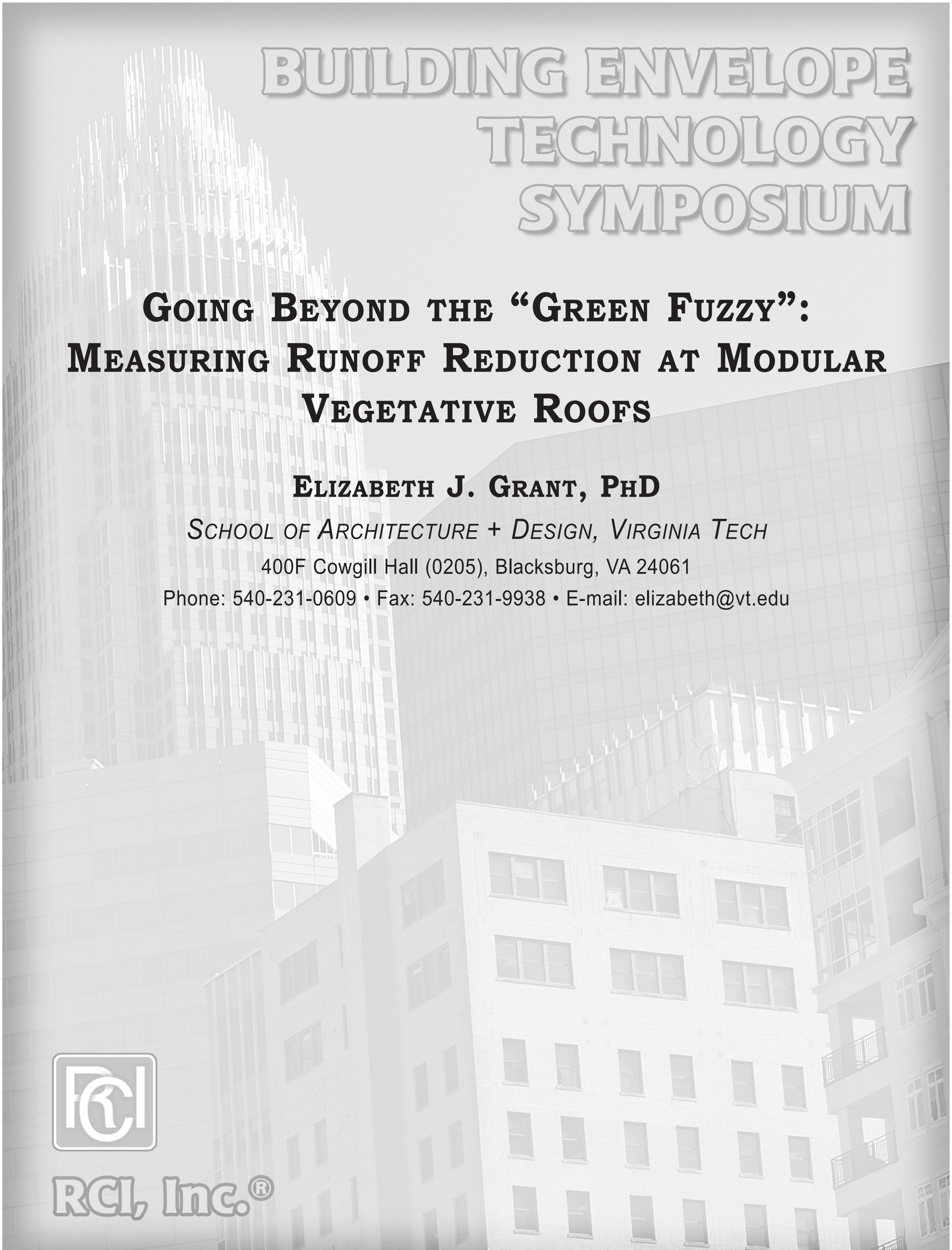

BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

Going Beyond the "Green Fuzzy": Measuring Runoff Reduction at Modular Vegetative Roofs

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ABSTRACT

Vegetative roofs' capacity to decrease the rate and volume of roof runoff is dependent on a range of factors related to climate and roof system characteristics. An experimental setup constructed by the author at Virginia Tech is testing the effects of system depth and presence of vegetation on runoff reduction. Data collection began in April 2011, and results from selected storms will be presented. The expected outcome of the study is a model that will enable vegetative roof system designers, building owners, and policymakers to more confidently anticipate the benefits of installing modular vegetative roof systems for stormwater mitigation.

SPEAKER

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Going Beyond the "Green Fuzzy": Measuring Runoff Reduction at Modular Vegetative Roofs

ABSTRACT

The capacity of vegetative roofs to decrease the rate and volume of roof runoff is dependent on a range of factors related to climate and roof system characteristics. An experimental setup constructed by the author at the Research and Demonstration Facility at Virginia Tech's College of Architecture and Urban Studies is testing the effects of system depth and presence of vegetation on runoff reduction. Five 8-ft x 8-ft (2.4-m x 2.4-m) test plots have been built to simulate low-slope roofs. Three plots are filled with prevegetated modular roof systems of differing depths. A fourth plot contains only growing medium, and a fifth is a control. Rain gauges connected to downspouts from each test plot are being used to measure runoff, while a sixth rain gauge measures rainfall. A weather station simultaneously measures ambient air temperature, relative humidity, solar radiation, and wind speed and direction. Data collection began in April 2011, and results from selected storms are presented. The expected long-term outcome of the study is a model predicting runoff reduction for modular vegetative roof systems. This model will enable vegetative roof system designers, building owners, and policymakers to more confidently anticipate the benefits of installing modular vegetative roof systems for stormwater mitigation.

BACKGROUND

In the roofing trade, claims about the benefits of new technologies tend to precede their thorough vetting in the field. Failures of first-generation green roofs in North America are a testament to this phenomenon (Osmundson, 1999). One of the solutions to this problem is to import technology that has been proven elsewhere and implement it in a new context. Vegetative roofs have largely followed this trajectory, with many North American companies partnering with German organizations with years of experience. While this tactic may have taken some of the risk out of green roofing, the performance benefits that have been proven overseas remain to be tested locally. Several institutions, both commercial and academic, have taken on this burden of proof through research projects that attempt to give an unbiased comparison of green roof systems to one another and to more typical roof configurations. The widely touted benefits of green roofs include runoff retention, pollutant mitigation, reduction of heat flux through the roof assembly, acoustic protection, and air quality improvement. This paper will address perhaps the most compelling and defensible benefit of green roofs: their ability to reduce roof runoff as compared to traditional roofing systems.

There have been multiple studies conducted in North America documenting the ability of green roofs to reduce roof runoff. Results of these studies vary greatly with local weather, the time period studied, and system characteristics; but the general consensus has been that green roofs retain somewhere between half and all of the precipitation incident upon them. Because this range is so wide, further research is needed to more closely predict results. Another critical factor related to runoff mitigation is peak flow reduction, which helps to reduce erosion and the overtaxing of storm sewer systems that can result in urban flooding. Many of the studies conducted in North America have aimed to identify variables, including the time of year, the interval between storms, and the intensity and duration of storms, to determine their effects on the capacity of green roofs to retain and delay stormwater. Architectural factors such as roof slope, distance between drains, the depth and makeup of green roof medium, and the variety of vegetation selected also have an influence on the success of green roofs as stormwater management devices. Efforts are ongoing to establish the influence of each of these parameters and provide a reliable, useful measure of performance that may be used to quantify the impact of green roofs in stormwater calculations.

INTRODUCTION AND DESCRIPTION OF MODULAR SYSTEM

The research installation described in this paper is located at the College of Architecture and Urban Studies' Research and Demonstration Facility on the campus of Virginia Tech in southwest Virginia. A modular green roof system was chosen for study because of its local availability and recent implementation as the first residential green roof project in Blacksburg. The system was easily installed by a team of students without special equipment or expertise. The system used is composed of 1-ft x 2-ft (0.3-m x 0.6-m) interlocking black plastic trays of varying depths: a "Deep" system with 6 in (152 mm) of medium, a "Standard" system with 4.25 in (108 mm) of medium, and a "Lite" system with 2.5 in (64 mm) of medium. The medium is a proprietary blend of inorganic and organic components sourced locally; in this case, the inorganic component is rotary-kiln-expanded slate lightweight aggregate. The blend contains approximately 94% inorganic material by dry weight and conforms to German FLL granulometric standards. A fully saturated Standard module weighs between 27 and 29 pounds per sq ft (130 and 140 kg per sq m) when fully vegetated.

It was hypothesized that the medium alone would have some runoff retention properties; to test this hypothesis, a set of Standard modules was filled with medium and not planted. The modules with plants

Sedum kam ellacombium
Sedum album murale
Sedum stefco
Sedum spurium 'Fuldaglut'
Sedum spurium 'John Creech'
Sedum rupestre 'Angelina'
Sedum sexangulare 'Utah'

Table 1 – Plant list for vegetated modules

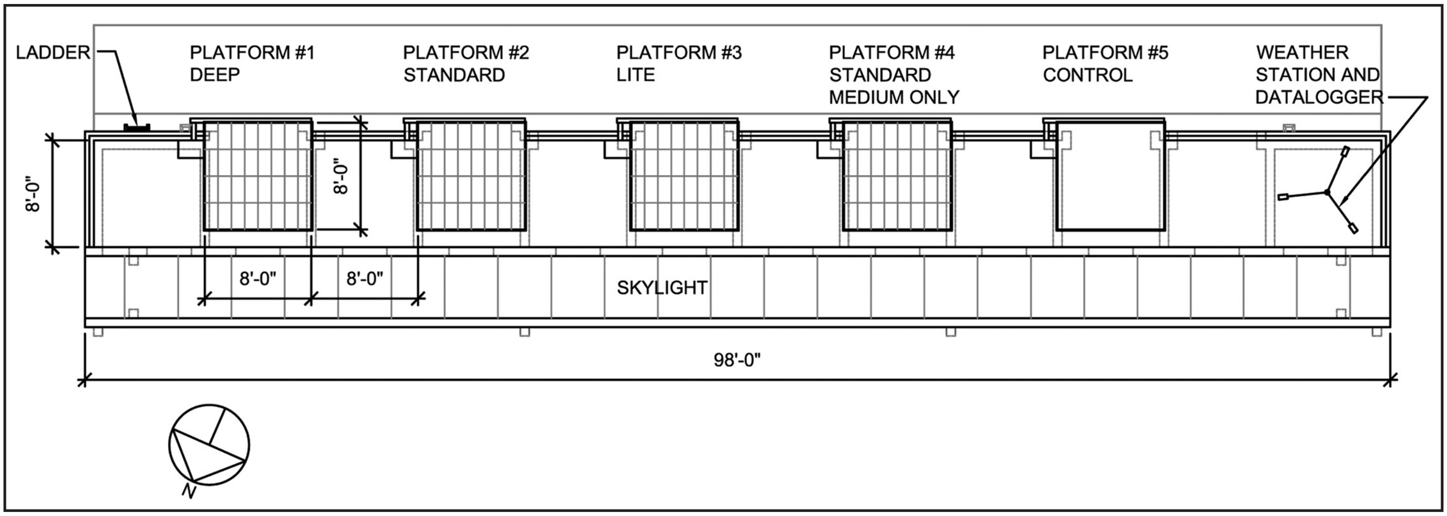

Figure 1 – Research setup (base plan courtesy of Bill Galloway).

were fully vegetated when delivered to the research site, and all were planted with the same mix of species listed in *Table 1*. The bottoms of all of the modules are articulated and slotted for drainage, and no filter fabric was included.

PROJECT SETUP

Five platforms were constructed on the roof of the one-story Test Cell Building, immediately to the south of the main Research and Demonstration Facility. The Test Cell Building was purpose-built for student and faculty experiments. The existing roof is covered with concrete pavers. This location allowed for easy transfer of the modules from grade to roof.

Platforms were constructed of dimensional lumber and plywood in lieu of placing the modules on the existing roof surface. This was done for several practical reasons. First, it was necessary to provide enough vertical clearance to attach a standard gutter to a downspout running to a tipping bucket to catch and record the amount of runoff. Attaching gutters to each platform avoided the difficulty of modifying the building's existing concealed gutter to isolate drainage for each treatment condition. Second, elevating the experimental platforms avoided potential damage to the existing roof system. Third, the platforms permit relatively simple removal or relocation of the project at the end of the study period, if necessary. Fourth, the area under the platforms allows access to the underside of the roof assembly, which may prove useful in future thermal evaluations of the vegetative roof systems. Finally, other design projects coexist with this experiment, and the platforms' rooftop location puts them at lower risk of accidental or deliberate disruption.

The 8-ft x 8-ft (2.4-m x 2.4-m) platforms were spaced 8 ft (2.4 m) apart on the roof to ensure that their supports rest on the bearing walls of the building below and to allow for access on three sides for installation, observation, and irrigation of the plants. The setup is shown in *Figure 1*.

The platforms were built and protected with tarps on July 6, 2010, and covered

Figure 2 – Waterproofed platforms awaiting vegetated module installation.

Figure 3 – Modules brought to platforms via forklift.

Figure 4 – Student volunteers installing prevegetated modules.

with 45-mil TPO membrane on August 11, 2010. In a typical vegetative roof installation, this membrane would have been covered with a slip sheet, but here this was omitted due to the relatively short duration of the project and the absence of foot traffic on the platforms. Membrane flashing was adhered to solid aluminum angles on the three nondraining sides of the platforms to form watertight curbs, as shown in *Figure 2*. The platforms were leveled to slope toward the gutters at ¼ in per ft (1:48).

On October 12, 2010, the vegetated modules were brought to the site on a nursery truck, driven, and lifted to the rooftop via forklift as shown in *Figure 3* and installed by student volunteers as shown in *Figure 4*.

The draining sides were fitted with slotted angles to help hold the modules in place while allowing runoff to reach the gutters.

INSTRUMENTATION AND LIMITATIONS

A Campbell Scientific weather station was erected on the west side of the roof, comprising the following equipment: a Vaisala HMP50 temperature and relative humidity probe, a LI-COR LI90SB photosynthetically active radiation sensor, a RM Young 03002 wind sentry set measuring wind speed and direction, and a Hydrological Services TB6 tipping bucket rain gauge. A Campbell Scientific CR1000 data logger in a weatherproof enclosure was attached to the weather station's tripod. The data logger

Figure 5 – Vegetated platforms after pruning on June 13, 2011. The Deep system is in the foreground.

records signals from the above-mentioned sensors along with tipping buckets at each of the five platforms and CS616 soil moisture sensors at the three vegetated platforms. Data are downloaded to the researcher's laptop every week during site inspections.

Hydrological Services TB1L tipping buckets with 0.5-L tipping volumes were hooked to the end of short lengths of downspout at each of the five platforms. These large tipping buckets were chosen because they can handle the considerable amount of runoff from a 64-sq-ft (5.9-sq-m) area during a heavy storm while also being three times as sensitive, on a rainfall-per-area basis, as the TB6 rain gauge used to record rainfall. Because of the relatively large tipping volume of the TB1L, residual water sitting in the bucket between storms may slightly skew the data for the completed storm, or for the next storm in the data set. Because it was unrealistic to travel to the research site to empty and reset the tipping buckets prior to every storm, this is a potential source of error in the reported data.

MAINTAINING THE RESEARCH SITE

Like any roof, this project cannot be left unattended. Weekly visits are necessary to examine the condition of the tipping buckets, check on the health of the plants, and download the data. While green roofs are designed to be largely self-sustaining, watering is required during warm periods of drought exceeding two weeks and, in the height of summer, one week. Knowing when plants must be watered is, at present, more of an art than a science, and an interesting future research direction would be to develop an algorithm to direct manual or automatic irrigation schedules for green roofs. For this project, the watering regimen has been conducted according to the advice of

Date rainfall recorded (at 0:00)	Total rainfall (mm)	Rainfall equivalent (L)	Runoff per platform (L)				
			#1 Deep	#2 Standard	#3 Lite	#4 Std. Med.	#5 Control
6/6/2011	5.3	31.8	0.5	1.0	0.5	1.0	27.5
6/8/2011	0.3	1.5	0.0	0.0	0.0	0.0	3.0[a]
6/11/2011	25.7	152.9	56.5	19.0	88.0	55.0	137.0
6/13/2011	7.6	45.4	1.0	1.0	3.0	1.5	40.0
6/14/2011	0.3	1.5	0.0	0.0	0.0	0.0	0.5
6/19/2011	14.0	83.3	5.0	4.0	16.0	15.5	69.5
6/21/2011	1.3	7.6	0.0	0.0	0.5	0.0	7.0
Total for period	**54.4**	**324.0**	**63.0**	**24.5**	**108.0**	**73.0**	**284.5**
Total % of rainfall retained			**81**	**92**	**67**	**77**	**12**

[a]The runoff from platform #5 is greater than the rainfall due to the greater sensitivity of the tipping bucket at the platform versus the rain gauge, and also likely due to residual water left in the tipping bucket from the previous storm.

Table 2 – Runoff and rainfall data for seven storms from June 1 to June 21, 2011

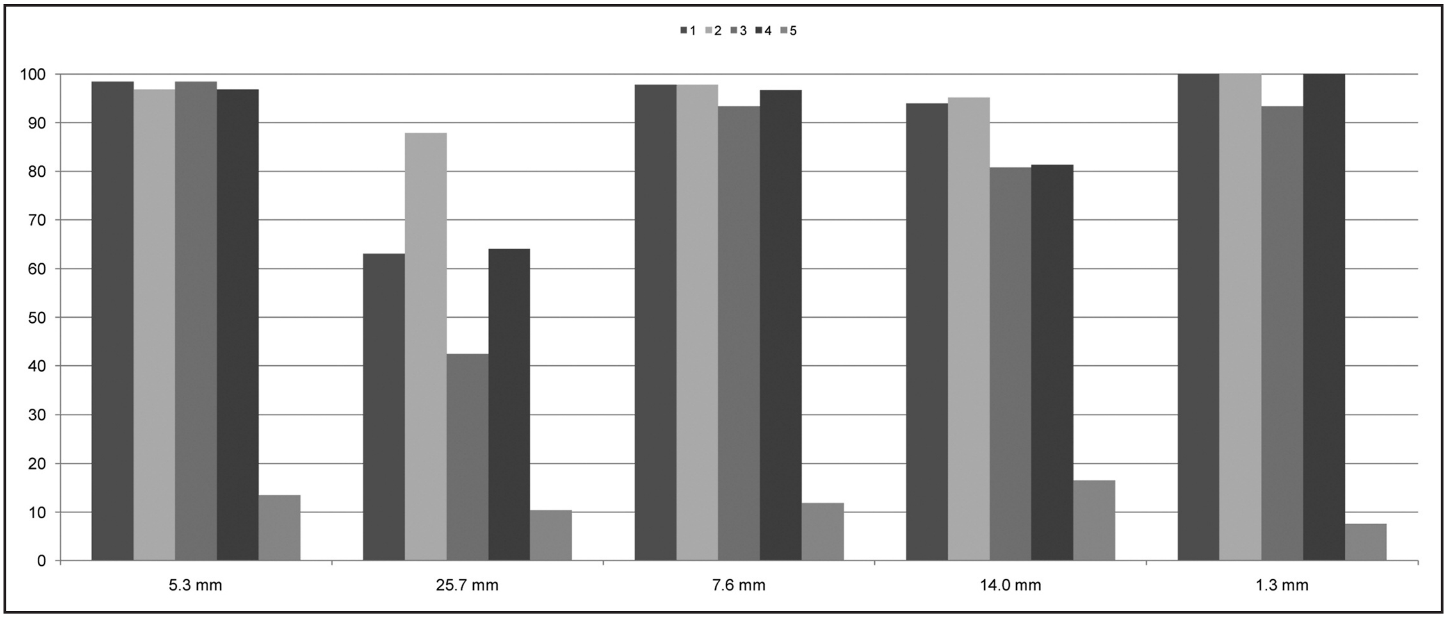

Figure 6 – Roof runoff retained as a percentage of total incident rainfall for five storms from June 1 to June 21, 2011, where #1 is Deep, #2 is Standard, #3 is Lite, #4 is Standard medium only, and #5 is Control.

the landscaping firm supplying the vegetated modules. Plants were hand-watered with a garden sprayer at a rate of 1.25 gallons (4.73 liters) per module upon installation, with additional irrigation on November 9, 2010, and June 2, 2011.

The spring of 2011 was rainy, which meant little irrigation was needed, and the plants thrived. Because of this, the landscape supplier recommended that the vegetation be cut back to avoid a humid environment with low light that can harbor fungal infections such as botrytis. All three vegetated platforms were lightly pruned on Monday, June 13, 2011. Cuttings were left on platforms #2 and #3 to help fill in small bare spots but removed from the fully covered platform #1, again at the advice of the landscape supplier. Though no formal evaluations were made, a positive correlation was observed between the depth of the medium and the vigor, size, coverage, and height of the plants. *Figure 5* shows the platforms after the modules were pruned, with the most aggressive growth on the Deep system in the foreground.

RESULTS

Data collection began in April 2011; and after an initial period of troubleshooting, flow data were recorded starting on June 1, 2011. Results from June 1 through June 21 are presented in this paper. Seven total rain events occurred during this period. Rainfall events were combined when rain from a second storm occurred within six hours of rain or runoff from the first storm. Tabulated results for the study period are presented in *Table 2*. "Rainfall equivalents," or the amount of rainfall incident on each of the platforms in liters, was estimated by taking measurements from the TB6 rain gauge and extrapolating these to a 64-sq-ft (5.9-sq-m) platform. The final row of *Table 2* gives the percentage of rainfall retained by each platform for the study period, calculated as follows:

(1 – Total runoff per platform for period /Total rainfall equivalent for period) x 100

Figure 6 shows the amount of roof runoff retained on each platform as a percentage of total incident rainfall on that platform during each storm event, to illustrate the difference in performance on a per-storm basis. The two storms in the reported period with less than 0.05 in (1.3 mm) of rainfall are not graphed in *Figure 6*, since the four treatment platforms showed no runoff during these two events.

CONCLUSIONS

The small sample size makes sweeping conclusions premature, but several trends have emerged. First, it was clear that all of the vegetated platforms and the medium-only platform retained considerably more runoff than the control platform. Second, it was apparent that the greater the amount of precipitation, the greater the difference between the treatment platforms and the control platform, as seen in *Figure 6*. In lighter storms, the amount of runoff from the treatment platforms became almost negligible. Third, the differences among the vegetated treatments–Deep, Standard, and Lite–were somewhat inconclusive. The Lite system underperformed the Deep and Standard systems in four of the five storms with rainfall totals of 0.05 in (1.3 mm) or more, but the Deep system did not consistently outperform the Standard system, as might have been expected. In fact, the total runoff retained by the Standard system (92%) exceeded that retained by the Deep system (81%) for the reported period. Fourth, the Standard medium-only system yielded somewhat surprising results. It retained more runoff than the Lite system in four out of the five storms with 0.05 inches (1.3 mm) or more rainfall. Precedent for this outcome was found by VanWoert et al. (2005) who reported no significant difference between vegetated and medium-only treatments when storms were grouped by intensity, leading them to suggest that the characteristics of the growing medium and (in their case) the retention fabric have the greatest effect on runoff reduction. Fifth, the control platform retained 12% of the total rainfall for the studied period, which is higher than expected for a membrane roof and may be due to the differing sensitivities of the tipping bucket at the control platform versus the rain gauge. As data collection progresses, further investigation with a larger number of storms may clarify the preliminary findings presented here and allow for meaningful interpretations.

CONTINUATION

To develop a fuller picture of modular vegetative roofs' contribution to stormwater mitigation, reduction of peak flows will be calculated when a significant number of heavy storms have been recorded. The interrelationships among temperature, humidity, solar radiation, wind speed, soil moisture, storm intensity, time between storms, and green roof runoff reduction will also be explored as this project progresses. The study will be continued for a full year, after which analysis of the data will support construction of an algorithm useful for predicting future performance of modular vegetated roofing systems. Upon completion of this phase of the study, the platforms may be modified to measure the influence of other variables, such as roof slope, on green roof performance. Further, pollution mitigation may be investigated, along with thermal impacts of vegetative roofs, as the research agenda expands.

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