

A Proposal for Standard Reporting of Extensive Modular Green Roof Hydraulic Performance Parameters

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ABSTRACT. Green roofs are becoming increasingly popular due to their reported benefits with regard to building thermal performance, urban heat island mitigation, improved local air quality, improved stormwater runoff water quality, and reduction in total runoff. They are also a component of some green scoring systems such as the LEED program. However, there is still a great deal of uncertainty in how to model the hydraulic performance of green roofs. This is particularly important when green roofs are part of a broader low impact development (LID) stormwater design. The inclusion of green roofs in performance based stormwater designs can only be achieved if a reliable method for routing flow through a green roof is achieved. Unfortunately, this is currently very hard to achieve as there is little in the way of standardized data on their hydraulic performance. In this paper we propose a simple routing model for extensive modular green roof systems with high porosity engineered soil. We also propose a standard set of data that should be provided to the stormwater design engineer by green roof vendors. The model assumes that, after an initial abstraction due to moisture absorption into the soil, the green roof module behaves as a detention pond with a series of orifice outlets at the base of the soil layer and a weir outlet at the top of the module. Standard pond routing equations can then be used with the stage storage relationship being modified to account for the soil porosity. The model would require green roof vendors to publish data on the volume of rainfall retained by the soil, the soil porosity, the effective area of the basal orifice outlets, and the effective weir length. Examples of the application of this model will be presented showing the potential efficacy of green roofs in stormwater quantity management.

INTRODUCTION

While green roofs are becoming more popular due to their numerous benefits (thermal performance, urban heat island mitigation, improved local air quality, improved stormwater runoff water quality, and reduction in total

runoff), there are limited methods available to quantify their performance in terms of stormwater management. While there are numerous green roof case studies that document the long-term, overall performance of green roofs, this paper presents a generic routing model for modular green roofs that allows designers to easily model the hydrologic behavior in response to an individual rain event.

Having a model of how a modular green roof routes individual storms will enable the use of performance based design which can be used to optimize the overall stormwater system. Additionally, having a standard generic routing model would enable a manufacturer to provide a standard set of product performance parameters which allows designers and regulators to easily compare products and see which are hydrologically suitable for their project. All these benefits will add up to less barriers in the design process, more effective use of a green roof's hydrologic properties, and potentially a wider adoption of green roofs in South Carolina.

PROJECT DESCRIPTION

A number of case studies (Morgan et al. 2013; Stovin et al. 2013; Voyde et al. 2010) have looked at long-term benefits of green roofs with these results often being reported as a percentage of rainfall that was retained. While these studies and results are important, the studies acknowledge that the percent reductions are an average for all the storms but can vary for individual storms from 100% retention (frequent storms with small depths) to less than 10% retention for storms with return periods longer than a year. Because of this variability, these percent reductions cannot be used to calculate the runoff for any given storm much less provide routing or timing information.

While there have been some attempts at creating routing models (Vesuviano and Stovin 2013), most of these are focused on larger non-modular installations. While the concept and materials are similar between non-modular and modular green roofs, the hydraulic behavior

of the two varies due to the module boxes controlling the flow.

Modular green roof installations have certain advantages such as being easier to install and more cost effective for smaller areas, providing established plant cover from the time of installation to limit the initial maintenance and improve initial performance, and giving building owners the flexibility to easily add capacity over time. Therefore, the objective of this research was to create a simple, generic model that can be easily used in stormwater modeling software to model the routing behavior of modular green roofs. This model provides a framework for a standardized set of values or parameters for manufacturers of modular green roof systems to provide to consumers which will make the process of design and the selection of a particular green roof modular system much easier and more accurate.

Experimental Design

The model presented was implemented for a site based on a large big-box store to verify the model's behavior and measure the sensitivity of the runoff rate to the different parameters to see how manufacturers could optimize their modules to achieve different hydrologic results. After the implementation of the case study, the required parameters necessary for the green roof to be modeled are defined and discussed.

METHODS

Model

While a modular green roof is one component, it must be modeled in two parts, as a sub-basin and detention pond, due to the constraints of the HEC-HMS stormwater modelling software used. A schematic of the model is given in Figure 1.

The tributary area of a single downspout is modeled using a sub-basin with a curve number (CN) of 100. It is assumed that the time it takes for the water to pass through the engineered soil is negligible compared to other time scales so the time of concentration was taken as 1 min (this is the minimum allowable time of concentration in HEC-HMS). The runoff from this sub-basin is routed directly to a detention pond which represents the effective storage capacity (total volume multiplied by the porosity of the engineered soil) of the modular green roof element.

The main outlet of this detention pond is an orifice representing the specific outlet design of a modular system. This can be defined simply as a discharge coefficient and effective orifice area or the manufacturer could provide a more general stage – storage – discharge relationship. This outlet allows the detention pond to drain during and after the storm, though if during the

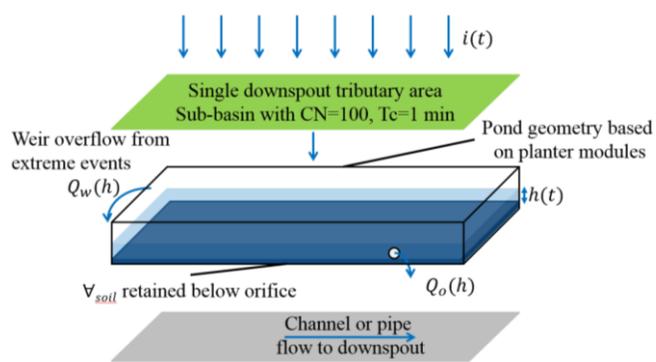


Figure 1: Schematic of the green roof model implemented in HEC-HMS. T_c is the time of concentration, Q is the outflow from the green roof module from the orifice, o , and weir, w , V_{soil} is the volume of water retained by the soil and plant material, and $h(t)$ is the height of water in the module as a function of time.

storm it becomes overwhelmed and the module completely fills, the excess water discharges as weir flow over the edges of the modules. The specific design of the modules will dictate if the length of the weir is the total boundary length of the roof (if the seams between modules are practically water tight) or if it is the sum of all the edges of all the individual modules (if there is a gap between the edges of adjacent boxes).

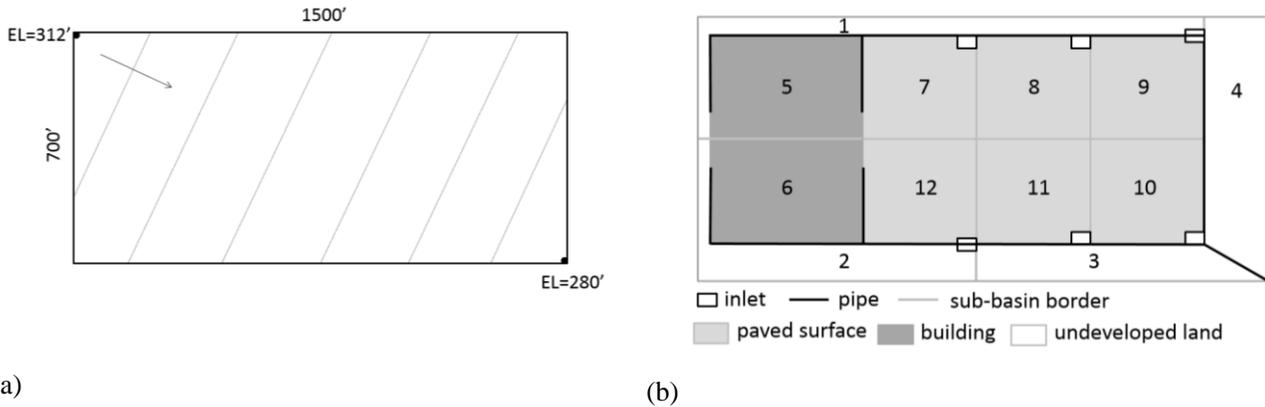
The height of the orifice is set such that the storage depth below the orifice accounts for the water that will be retained by the soil and plant material after the green roof has completely drained. Because the volume that is retained is dependent on a number of variables (type of soil length of time since previous rain, season, temperature, plant variety etc.) a standard value must be given by the green roof manufacture based on the roof composition and installation location.

The outflow from the detention pond is then routed as a channel or pipe flow as it travels from under the green roof module to the nearest roof drain.

Case Study

The case study used to demonstrate this model was based on a big-box store (550 x 400 feet) with a large parking area (550 x 900 feet) in front. The pre-development site has a curve number of 67, a slope of 2%, and a time of concentration of 26 minutes (Figure 2a). The developed site has the same slope for the pavement and for all the stormwater collection drains (Figure 2b). A standard design for the post-development site was completed to appropriately size the collection system and to provide peak flow values to compare to when the building has a green roof.

For the green roof implementation, two of the parameters were varied to measure their effect on the



(a) (b)
Figure 2: (a) The initial site topography and (b) the building, paved area, and stormwater collection networked used as the case study.

overall performance. The first parameter was the stage-discharge relationship which was controlled by adjusting the discharge coefficient and orifice area. The second parameter that was varied is the volume of the storage below the orifice. While the stage-discharge relationship is a function of the module dimensions and should be constant for a particular module design, the retention volume is much more variable as it is a function of the module depth, soil characteristics, plant selection, time of year, and weather conditions. Retention volumes of 2, 5, and 8 mm were used as representative values based on Potential Evapotranspiration (PET) values from Stovin et al. (2013) over a three day period. The choice of 3 days was based on the 3 day drawdown requirement for ponds.

For the pre-development, post-development, and post-development with green roof cases, the peak runoff rate and was calculated to compare the performance.

RESULTS

Simulations were run using HEC-HMS for the undeveloped site, developed site without the green roof and the developed site with the green roof. Simulations were run for 2 and 10 year storm depths for Columbia SC (91 mm and 134 mm respectively) though only the 10 year storm results are presented. The green roof simulations were run assuming that the roof was split into two sections. The green roof was 102 mm deep with a soil porosity of 50%. The outlet orifice effective area ($C_D A_o$) was sized to achieve drawdown times ranging from 3 days to 1 hour.

The reference green roof case had a PET of 5 mm over three days and a drawdown time of 24 hours. The 5 mm PET was achieved in HEC-HMS by placing the orifice 5 mm above the base of the module. A plot of the site runoff hydrographs for the undeveloped, developed with

no green roof, and reference green roof are shown in Figure 3.

The presence of the green roof substantially reduces the post development peak runoff from 104 cfs to 80 cfs by detaining much of the rain that falls on the roof in the green roof module ponds as seen in Figure 4. The total runoff is virtually unchanged however.

The influence of the water retention in the soil was investigated by running simulations for a green roof module with a 24 hour drawdown time and 2, 5, and 8 mm of water retention. For each case the peak runoff was unchanged at 80 cfs. This is to be expected as the reduction in flow rate is due to detention not permanent retention. The retention of water in the soil would have to be substantially larger to significantly influence peak runoff from a design storm.

The influence of drawdown time on the peak discharge is shown in Figure 5. The plot shows the whole site peak discharge as a function of the module drawdown time for a module with 5 mm of water retention. As the drawdown time increases the peak

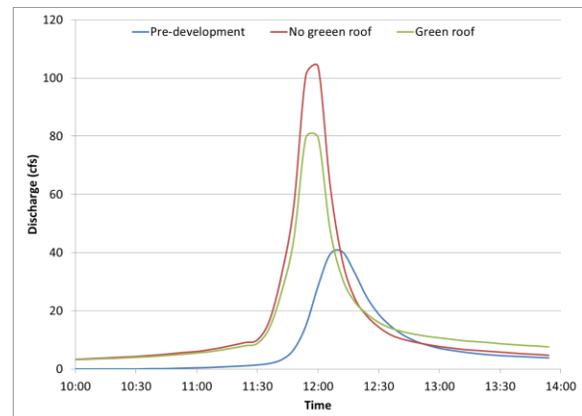


Figure 3: Site runoff hydrographs for the pre-developed, no green roof and reference green roof cases for a 10 year storm.

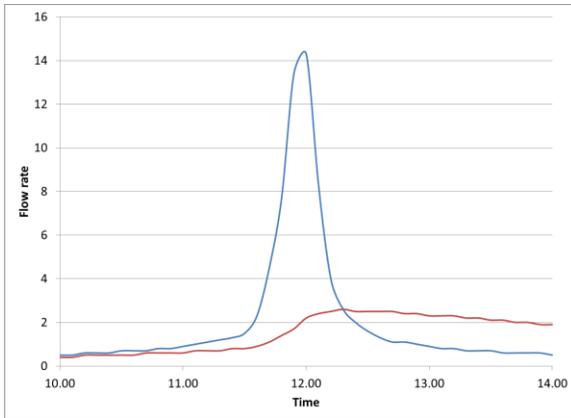


Figure 4: Inflow (blue) and outflow (red) hydrographs for one of the two reference green roof modules for a 10 year storm.

discharge from the green roof module decreases and the time at which the module outflow peaks is delayed. However, the reduction in peak runoff stabilizes once the drawdown time exceeds 12 hours. The difference in peak discharge between drawdown times of 12 and 72 hours is only 4 cfs compared to a difference of 7 cfs between drawdown times of 6 and 12 hours. Once the peak outflow has been delayed enough that it occurs well after the peak discharge of the rest of the site, a further delay in peak discharge will have only a small impact in the whole site peak discharge.

DISCUSSION

Modular green roofs have many benefits. However, it is currently difficult to include them as part of a performance based design for managing peak runoff from a development because there is no standard method for including green roofs in storm routing calculations. This paper presents a simple conceptual routing model for modular green roofs with high porosity engineered soils. Such modular green roofs behave as detention ponds and should be modeled accordingly.

Simulation results from a case study of a generic big-box store development indicate that green roofs can provide substantial reduction in peak runoff provided that the drawdown time for the roof modules is large enough (12 hours or more for the case study presented). This reduction in peak runoff could potentially reduce the amount of land required for a detention pond opening up more land for development. As such, modular green roof designers would be advised to consider module designs with large drawdown times.

The simulation results indicate that, for typical values

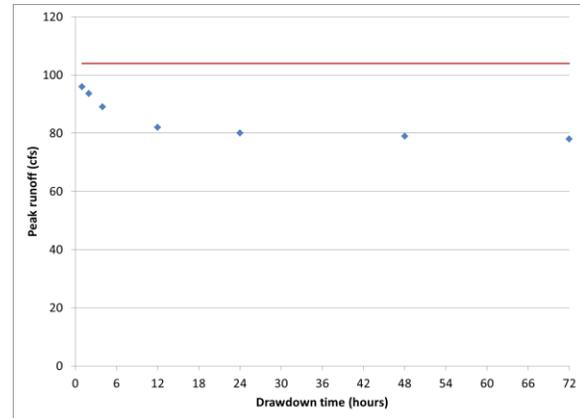


Figure 5: Peak runoff for a 10 year storm as a function of the drawdown time for the green roof modules (blue diamonds). The red line is the peak runoff for the no green roof case.

of PET over a 3 day drawdown period, water retention in the soil contributes very little to the reduction in peak discharge, though it will have some influence on total runoff.

In order to apply this model to an actual green roof installation the modular green roof manufacturer needs to supply the stage – storage and stage – discharge relationships for their module as installed. This would allow stormwater engineers to include the reduction in peak runoff into their overall site design. If the manufacturers were also able to supply typical n day PET value (where n is the local required drawdown time in days) for their modules then the reduction in total runoff could also be incorporated into the whole site routing model.

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