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EFFECT OF GREEN ROOF MEDIA DEPTH ON CURVE NUMBER CALCULATION

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ABSTRACT

Green roofs are one of the green infrastructure techniques that can be an effective tool in stormwater management. The curve number method can be used to estimate the volume of stormwater runoff if the type and depth of the growth media are considered. For a study period of 25 months and 175 rainfall events, the curve number of planted model built-in-place green roof systems (BIPS) of 5cm, 10cm, 15cm, and 20cm growth media depths were tested. Also, the curve number for a tray system of growth media (Green Roof Blocks™), and a conventional membrane roof were tested during the same period. The growth media consisted of 80% by volume arkalyte (expanded clay) and 20% by volume composted pine bark. In green roof systems containing 10 cm of growth media, curve number of 92 can be used for the BIPS and curve number 95 for the tray system.

Keywords: green roof, stormwater runoff, curve number.

INTRODUCTION

Green roof

Impervious surfaces that arise with urbanization represent major environmental problems. In urban areas, rooftops can contribute a high percentage of total impervious surfaces which contribute to increasing stormwater runoff and nonpoint source pollution. There are different kinds of physical, biological and chemical treatment processes that filter pollutants and reduce the rate and volume of precipitation runoff. Green roofs are considered to be one of the at-source technologies to reduce the amount of pollution delivered to the local drainage system and, ultimately, to receiving waters (Sayre *et al.*, 2006). A green roof (also known as an eco-roof or living roof) is a technology that can change impervious roof surface into green space. Green roofs have been utilized since the Hanging Gardens in ancient Babylon (Kuhne, 2005). Nowadays, it has been reconsidered as a method to address non-point source pollution reduction and energy savings.

Currently, green roofs' primary benefits are considered increased roof longevity by protecting the underlying roof membrane, reduced stormwater runoff, visual enhancement, improved air quality, reduced energy consumption of buildings, reduced urban heat island effect, decreased noise pollution, and increased quality habitats for insects and birds (Alyaseri, 2010). A green roof is a system that uses vegetation planted in growth media installed over a waterproofing membrane. A green roof may also include additional layers such as a root barrier, drainage system, and filter mat.

Many studies have shown the ability of green roofs to retain storm water (e.g. Moran, 2004; VanWoert *et al.*, 2005; Carter and Rasmussen, 2006; Mentens *et al.*, 2006; Forrester, 2007; Villarreal *et al.*, 2004; Woods, 2009; Richter *et al.*, 2009; Alyaseri, 2010; and Stovin *et al,* 2012). Liptan (2003) showed that 10% to 35% reduction in volume during the wet season and 65% to 100% reduction in volume in the dry season can be achieved by using green roof technology. Kolb (2004) showed that a green roof can reduce annual runoff by 45% to 70%, while Moran *et al.* (2004) showed that 60% of total rainfall can be retained and 85% of the peak flow rate can be reduced when applying a green roof.

Curve number

Curve Number (CN) is the Natural Resources Conservation Service (NRCS) method of estimating direct runoff from a precipitation event. The NRCS runoff equation was developed to estimate total storm runoff from total storm rainfall. These curve numbers reflect the effect of the hydrologic soil-cover complex on the amount of rainfall that runs off. The number is an index of hydrologic soil group contribution, and land use. Empirical analyses suggested that curve number is a function of soil group, cover complex, and antecedent moisture condition (McCuen, 2005). According to U.S. Soil Conservation Services (U.S. SCS), soils were classified into four groups (A, B, C, and D) based on soil characteristics and/or soil infiltration rate. The hydrologic condition is related to land management, and it is classified into three classes: poor, fair, and good. Curve number for different land uses, treatment, and hydrologic conditions usually obtained from tables available in books of hydrology.

The simplicity of this method contributes to its popularity for stormwater management. A CN equal to 100 means that all the precipitation turned to surface runoff and no infiltration occurred. A CN of 0 means that all precipitation infiltrated, so there was no runoff. Impervious surfaces were assigned a CN of 98 (NRCS, 2008).

Studies to estimate the curve number for roofs that are covered with vegetation are still limited. Carter and Rasmussen (2005) conducted an experiment to estimate curve number for a green roof in the State of Georgia. They established the CN value for green roof from the median of 11 storm events data. Spatial information was used to model changes in stormwater

volume for different scenarios and different design storms. Factors such as; weather and special conditions, green roof media, depth of media, and roof characteristics (such as slope) may affect the curve number calculated for a green roof. With the current increase in the number of green roofs around world's cities, calculating curve number for various regions is essential.

MATERIALS AND METHODS

Green roof models

Forrester, 2007 and Woods 2009 conducted a study on multiple green roof depths. The study used twenty-eight built-in-place systems (BIPS), four modular trays (Green Roof Blocks™), and four control roofs (black EPDM membrane only) up on four tables in a completely randomized design, at the Southern Illinois University Edwardsville campus in Edwardsville, Illinois. Each table included four planted and one unplanted BIPS at four growth media depths (5, 10, 15, and 20 cm), one 10 cm planted tray, and one control roof. Each of the 28 BIPS and the control roof consisted of a 61 cm x 61 cm wood frame with wafer board substrate and adhered EPDM roofing membrane. The four Green Roof Blocks™ were 61 cm x 61 cm containers made with 8 millimeter anodized aluminum and contained 10 cm of growth media. The growth medium used in both green roof systems was comprised of 80% by volume arkalyte and 20% by volume composted pine bark. Five Sedum hybridum 'Immergrunchen' plugs were used for planting (Forrester, 2007 and Woods, 2009).

Curve number method

For curve number calculation, the Forrester (2007) and Woods (2009) study at the campus of Southern Illinois University Edwardsville (SIUE) was selected for data of rainfall and runoff as this study was long enough to cover different seasons (the study was conducted between September 2005 and June 2008) (Forrester, 2007 and Woods 2009). Evaluation based on the data from this long-term experiment on green roof stormwater retention, was used to estimate the curve number CN for each growth media depth.

The NRCS equation used to estimate direct runoff (Q) from a 24-hour precipitation (P) event is:

$$\mathrm{Q} = \frac{(P - Ia)^2}{\mathrm{P} - \mathrm{Ia} + \mathrm{S}} \qquad (1)$$

where: Q=actual accumulated runoff in inches, P=actual accumulated precipitation in inches, Ia=initial abstraction by soil in inches, and S=maximum potential retention height by soil in inches.

For Ia estimation, it is usually assumed to be a function of soil maximum potential retention, S, expressed as Ia = 0.2S (NRCS, 2004). So, the precipitation-runoff relationship can be rewritten after substituting Ia in Equation 1 as follows:

$$\mathrm{Q} = \frac{(P - 0.2S)^2}{\mathrm{P} + 0.8\mathrm{S}} \qquad \text{For P} > Ia \qquad (2)$$

This equation was used to determine the relationship between precipitation in inches and direct runoff from the green roof models for selected curve numbers in Figures 1 through 5. The maximum soil retention value (S) substituted in Equation 2 was derived from the relationship between CN and maximum soil retention using the following equation (NRCS, 2008):

$$\mathrm{S} = \frac{1000}{\mathrm{CN}} - 10 \qquad (3)$$

Equation 2 can be rearranged so the curve number can be estimated if rainfall and runoff volume are known. The equation then becomes (NRCS, 2008):

$$\mathrm{CN} = [1000/\ [10 + 5\mathrm{P} + 10\mathrm{Q} - 10(\mathrm{Q}^2 + 1.25\mathrm{Q}*\mathrm{P})\ ½] \qquad (4)$$

Using the relationship between CN and maximum soil retention, Carter and Rasmussen, (2005) calculated a CN of 88 for green roofs by taking the median curve numbers of eleven storms. Their study defined the storm event as rainfall greater than 0.1 inch with an antecedent dry period of 24 hours.

RESULTS AND DISCUSSIONS

Figures 1 through 5 show the relationship between measured rainfall and measured runoff in inches for different depths of the growth media. The best fit line that represents the relationship is a second order polynomial. The figures also include the curve numbers from 100 to 50. In all figures, there are some data that lay above CN 100. These were the cases when snow or ice from previous snow or rainfall events melted with the next rainfall event so the collected runoff became higher than the rainfall at that event.

Equation 4 was used to calculate the actual curve number for all 175 precipitation events. The median and average curve numbers for each growth media depth are arranged in Table-1.

Table-1. Calculated median and average curve number for different green roof depths.

Green roof depth	Median CN	Average CN
5 cm BIPS	95.1	93.9
10 cm BIPS	94.2	91.9
15 cm BIPS	94.4	91.3
20 cm BIPS	94.7	91.4
10 cm Tray	96.1	94.9

Figures 1 through 5 show that the best fit line ranges between CN 90 to 95, which is consistent with the curve numbers calculated by Equation 4.

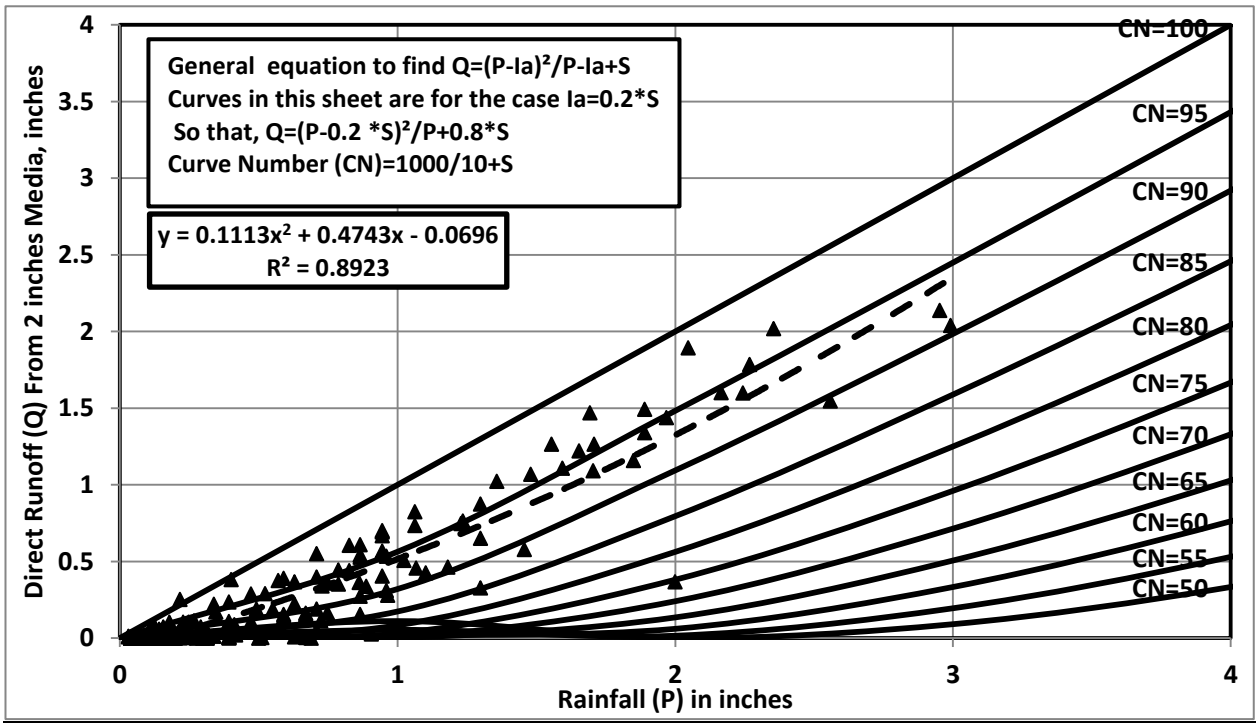

Figure-1. Relationship between rainfall and runoff in the 5 cm (2 in) BIPs. The dashed line represents the best fit CN. Lines of equal curve number are shown for comparison.

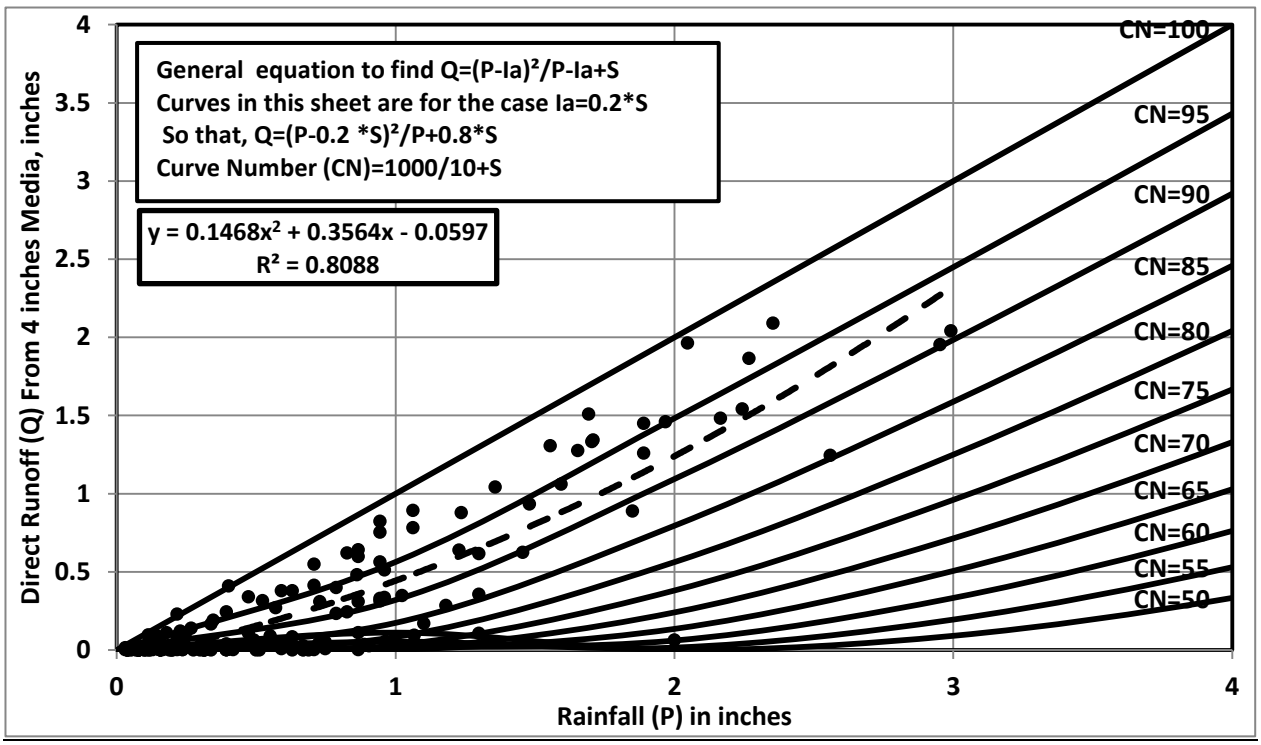

Figure-2. Relationship between rainfall and runoff in the 10 cm (4 in) BIPs showing lines of equal curve number.

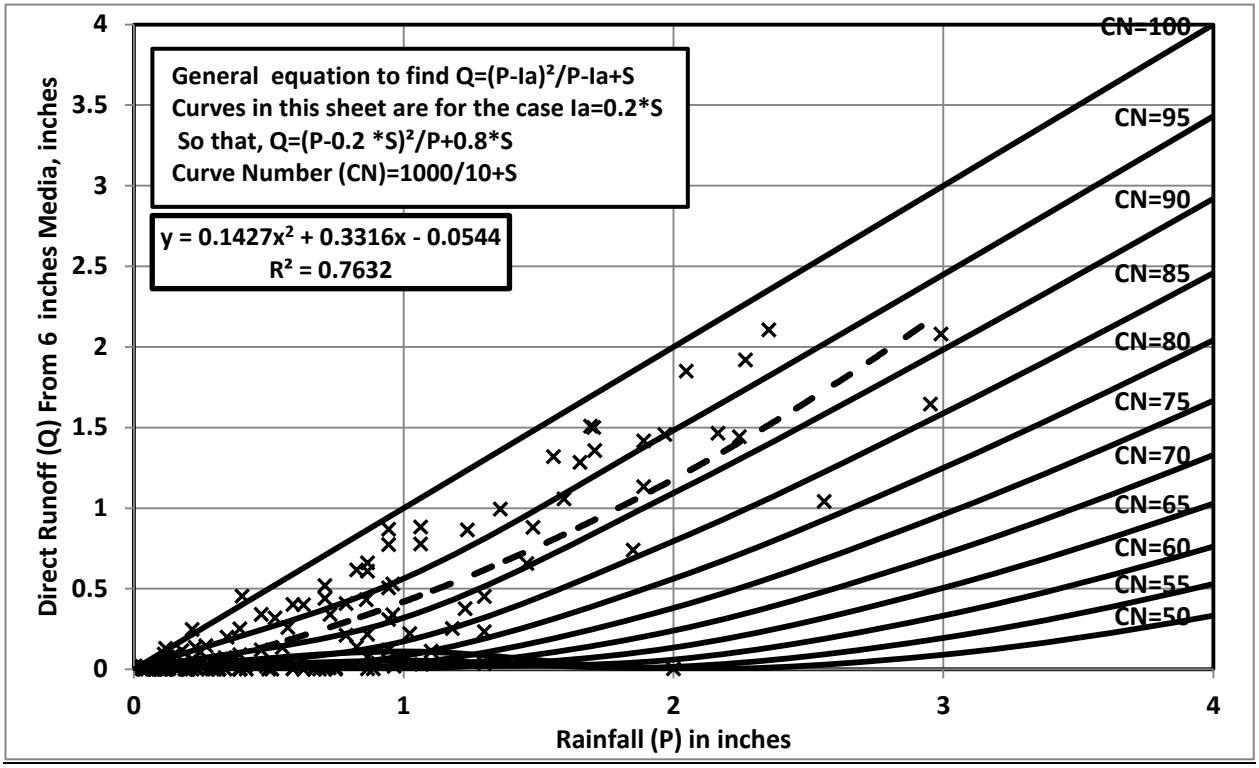

Figure-3. Relationship between rainfall and runoff in the 15 cm (6 in) BIPs showing lines of equal curve number.

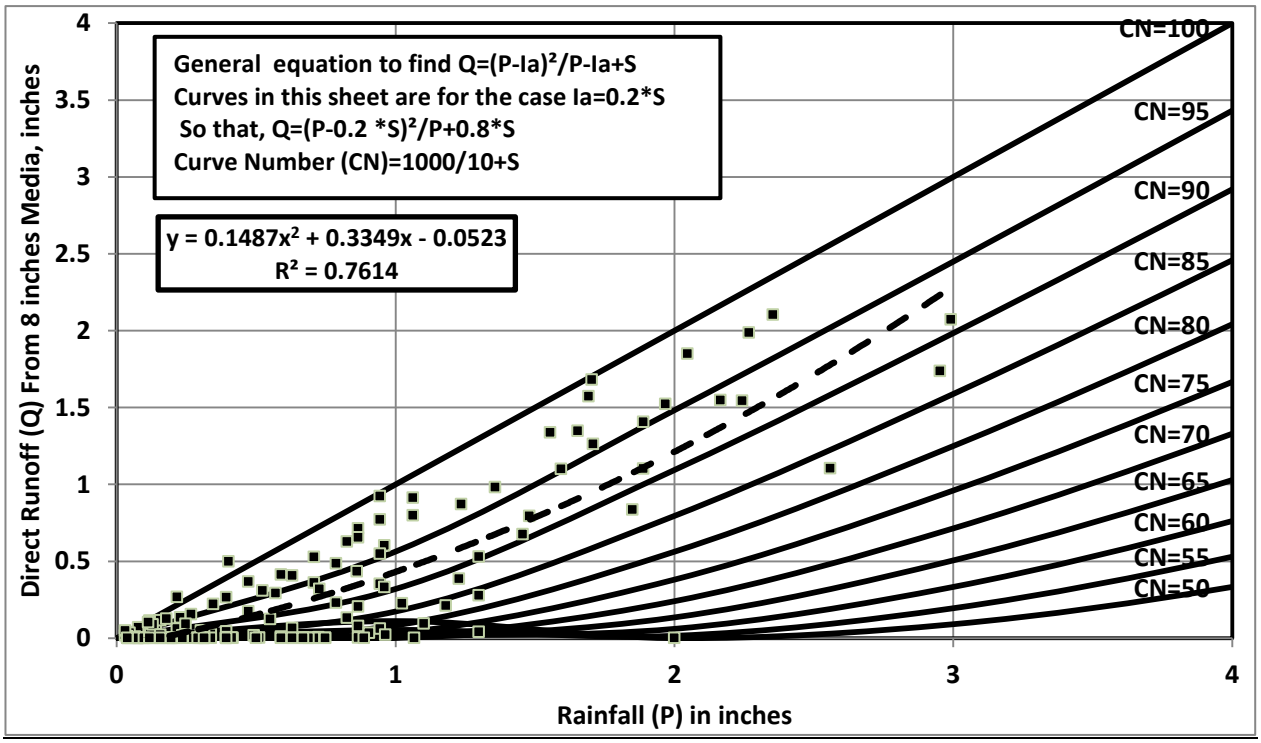

Figure-4. Relationship between rainfall and runoff in the 20 cm (8 in) BIPs showing lines of equal curve number.

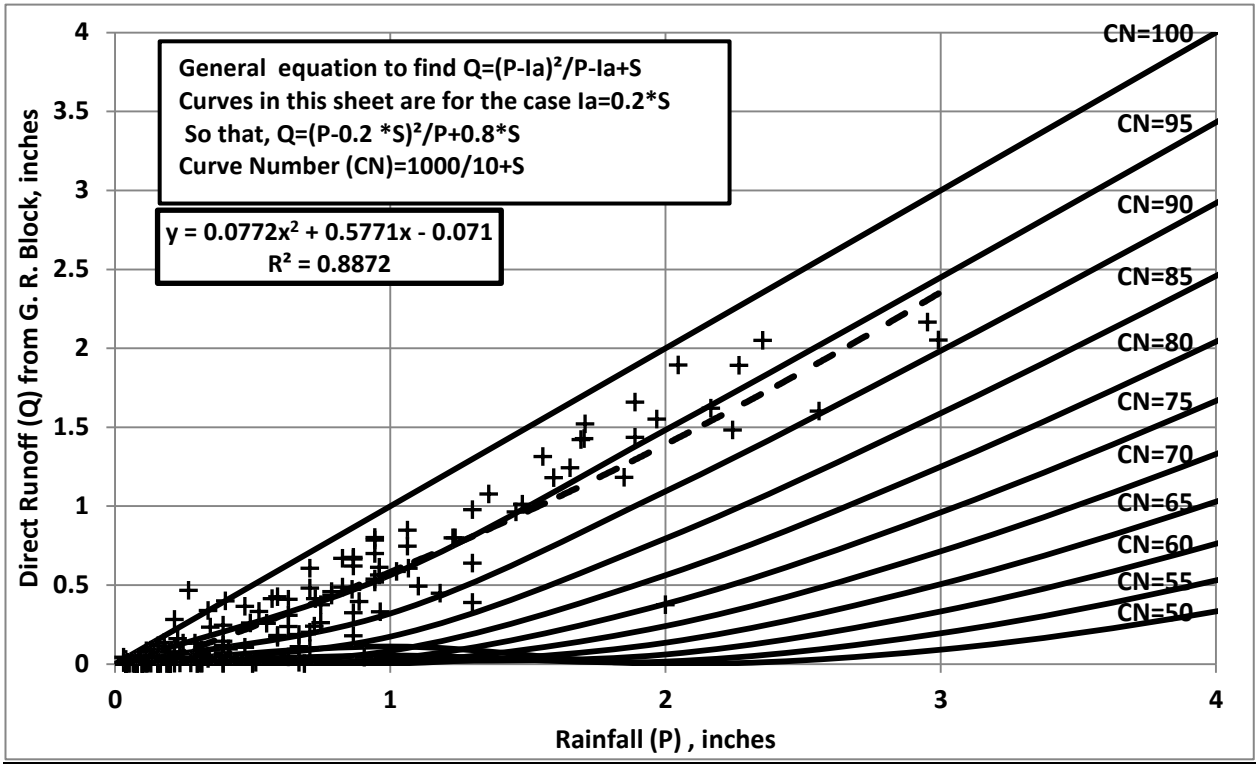

Figure-5. Relationship between rainfall and runoff in the 10 cm (4 in) tray system showing lines of equal curve number.

The initial abstraction (Ia) in regular soil includes the interception, surface depression storage, and infiltration during the early parts of the storm event (NRCS, 2004). Green roof growth media is different from regular soil so the interception and surface depression storage would be different as the rainfall is passing through the roof and running under the growth media instead of running above.

Infiltration during the early part of the storm is highly dependent of factors such as moisture content, duration since last rain, depth of the growth media, vegetation type and coverage, and rainfall intensity.

The type of the media used in the green roof may also affect the curve number used for runoff calculations. Carter and Rasmussen (2005) used a mix of Stalite (expanded slate), sand, and composted organic matter at a ratio of 55:30:15. The current study used a growth media comprised of arkalyte (expanded clay) and composted pine bark at a ratio of 80:20. The curve numbers calculated in this study are inconsistent with Carter and Rasmussen, 2005 study most likely due to differences in growth media. The variation between the curve numbers for each depth in Table-1, and between this study and Carter and Rasmussen study, indicate that the depth and type of green roof's growth media needs to be considered when using curve number method in stormwater management. The CN of the green roof and the maximum amount of rain that can be retained may vary between different types of media. Wet sieve analysis shows that arkalyte has a low percentage of pores in its structure when compared to lava or haydite (Alyaseri, 2010). Media with a greater percentage of pores are expected to have lower CN.

However, the spread of runoff and precipitation data shows that the interval between storm events is important. The data near the x-axis occurred when there was enough time between the storm events for the roof to absorb all the rain and result in zero runoff. Hence, the curve number method is not very effective when the antecedent dry period exerts a significant effect and more studies need to be conducted to address this factor.

CONCLUSIONS

Curve Number (CN) is one method used for estimation of runoff after rainfall event. The current evaluation shows various curve numbers due to the variation in depth of the BIPS and the tray system (ranging between 91.4 for the 20 cm BIPS to 94.9 for the tray system) which indicate that green roof depth has to be considered when assign a CN in stormwater management.

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