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# Retention performance of green roofs in three different climate regions

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ABSTRACT

Green roofs are becoming increasingly popular for moderating stormwater runoff in urban areas. This study investigated the impact different climates have on the retention performance of identical green roofs installed in London Ontario (humid continental), Calgary Alberta (semi-arid, continental), and Halifax Nova Scotia (humid, maritime). Drier climates were found to have greater percent cumulative stormwater retention with Calgary (67%) having significantly better percent retention than both London (48%) and Halifax (34%). However, over the same study period the green roof in London retained the greatest depth of stormwater (598 mm), followed by the green roof in Halifax (471 mm) and then Calgary (411 mm). The impact of climate was largest for medium sized storms where the antecedent moisture condition (AMC) at the beginning of a rainfall event governs retention performance. Importantly AMC was a very good predictor of stormwater retention, with similar retention at all three sites for a given AMC, emphasizing that AMC is a relevant indicator of retention performance in any climate. For large rainfall events (i.e., >45 mm) green roof average retention ranged between 16% and 29% in all cities. Overall, drier climates have superior retention due to lower AMC in the media. However, moderate and wet climates still provide substantial total volume reduction benefits.


## 1. Introduction

Urban rooftops generally constitute 40–50% of all urban impervious surface area (Mentens et al., 2006). Therefore, retrofitting roofs provides considerable opportunity to mitigate the effects of stormwater runoff. Excessive stormwater contributes to the pollution and erosion of streams, as well as flood and infrastructure damage arising from surcharged storm sewers (P'ng et al., 2003).

Green roofs retain stormwater by storing water in the growth medium and to a lesser extent in the vegetation canopy (Stovin et al., 2012). Water is held in the soil or growth media pore space by capillary forces until it is transpired through the vegetation or evaporated to the atmosphere. Evapotranspiration (ET) evacuates water from growth media pore space, making pore space available for retention (Bengtsson et al., 2005). During a precipitation event a finite amount of water is held in the pore space. Once the storage capacity of the green roof growth media is full, runoff or drainage will occur (Bengtsson et al., 2005). The point at which the storage capacity of the growth media becomes full is referred to as field capacity (Bengtsson et al., 2005). This value, along with the growth media soil moisture condition or deficit (i.e., availability of pore space to store precipitation) prior to a precipitation event, herein referred to as antecedent moisture condition (AMC), directly influences the amount of retention a green roof will experience for any given rainfall event. The retention performance of a green roof is determined through quantification of the volume of precipitation that is retained in the growth medium, where increasing retention corresponds to an improved retention performance. Improved green roof retention performance reduces stormwater runoff, as such an understanding of this metric is crucial to guide the implementation of this technology as a low impact development (LID) control.

Studies on green roof hydrology have been conducted worldwide from Europe (Bengtsson et al., 2005; Palla et al., 2009; Stovin et al., 2012) to North America (Hutchinson et al., 2003; Volder and Dvorak, 2014) and Asia/Oceania (Lee et al., 2013; Razzaghmanesh et al., 2014; Voyde et al., 2010), with a focus on

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the impact of growth medium depth (Nardini et al., 2012; VanWoert et al., 2005), roof slope (VanWoert et al., 2005), vegetation type (Nagase and Dunnett, 2012; Razzaghmanesh et al., 2014; Wolf and Lundholm, 2008), and age (Berndtsson, 2010; Perelli, 2014). Despite the increase in global application of green roofs as a stormwater management tool, the influence of climate on retention performance and applicability of results from different locations is uncertain. Previous studies typically have differing green roof design components (e.g. media depth and slope) and study duration (e.g. one season or on an annual basis) in addition to study location, generating inconsistent retention statistics. For example Mentens et al. (2006) reported annual retention values ranging from 27% to 81%, when compiling results from 18 different studies. Similarly Gregoire and Clausen (2011) reported retention between 34% and 69% based on 13 green roof studies. Retention differences may, in part, be due to climatic differences in the study areas. For example Stovin et al. (2012) found 50% annual retention in Sheffield, England, and Fassman-Beck et al. (2013) reported 39% retention for a green roof in Auckland, New Zealand. Alternatively, Hutchinson et al. (2003) and Carpenter and Kaluvakolanu (2011) reported consistent retention of 69% and 68% in Portland, Oregon and Southfield, Michigan, respectively; two quite different climates. Although retention performance differences may be due to climate, it is not possible to isolate and evaluate the effects of climate from the current literature due to the differing green roof design parameters and durations of these studies.

Stormwater green roof retention studies in the literature range in duration from 2 months (DeNardo et al., 2005) to greater than 18 months (Fassman-Beck et al., 2013; Moran et al., 2005; Stovin et al., 2012). Study duration is important for the reported retention performance, as the degree to which ET replenishes storage capacity between storms is a function of season (e.g. ET rates are typically greater in summer compared to late fall). Additionally, longer duration studies are more likely to represent the historical climate normal, whereas a short-term study is vulnerable to abnormal weather conditions. For example, using four months of monitoring data Stovin (2010) obtained retention of 34%, whereas after continued monitoring for 29 months Stovin et al. (2012) reported retention of 50%. Similarly, Voyde et al. (2010) found a retention of 66% for 91 events over 12 months of monitoring in Auckland New Zealand while Fassman-Beck et al. (2013) reported a long term retention of 56% over 28 months of monitoring 396 events at the same sites. It is important to consider multiple seasons (i.e. spring through fall, and winter if relevant) to provide a representative event sample size.

In general, literature studies report greater percentage retention for smaller size events, as there is greater probability that the storm size will be smaller than the available storage capacity. For example, a study conducted in Lansing, Michigan over 430 days, quantified retention for 83 rainfall events using green roof platforms (0.67 m × 2.44 m) of depths from 2.5 to 6 cm (VanWoert et al., 2005). They found 97% retention for light events (i.e. <2 mm), 83% for medium events (i.e. 2–6 mm) and 52% for heavy events (i.e. >6 mm). Similar trends were also found in other studies (Carpenter and Kaluvakolanu, 2011; Carter and Rasmussen, 2006; Getter et al., 2007; Fassman-Beck et al., 2013). However, each study grouped event size differently and found varying amounts of retention. Carpenter and Kaluvakolanu (2011) studied a green roof in Southfield Michigan (100 mm depth), in close proximity to VanWoert et al., (2005), and found 98.6% retention for small events (i.e. <12.6 mm), 90.2% retention for medium events (i.e. 12.7–25.4 mm) and 52.7% retention for large events (i.e. >25.4 mm). Carpenter and Kaluvakolanu (2011) had a study period of 6 months and observed 21 events, only 3 of which were in the large size category. The influence of study durations and green roof design parameters are evident in the disparity between the results of VanWoert et al. (2005) and Carpenter and Kaluvakolanu (2011) considering the different storm size classifications adopted. Additionally, Speak et al. (2013) conducted a similar analysis on an intensive 170 mm deep green roof in Manchester UK. They found higher average event retention for medium events (i.e. 2–10 mm) than for small events (i.e. <2 mm), a result that is unique in green roof literature. Studies in close proximity have yielded differing results due to different study duration and design components, and studies in different climates also yield differing results. To effectively evaluate the impact of climate on retention a consistent green roof design is needed as well as common study duration.

In addition to quantification of retention for different event sizes, there is a particular need to understand retention for significant events with large return periods. These events generally overwhelm stormwater management systems and result in flooding. Stovin et al. (2013) quantified retention performance for 'significant' events (i.e., in their case, defined as greater than 1-year return period). They used a 3 m × 1 m × 0.08 m green roof test bed in Sheffield, England, over a 29-month period to measure 21 significant events and reported a total retention of 30% for these events. Other groups have quantified retention for large events (i.e. >45 mm) and reported retention ranging from 0 to 60% (Carpenter and Kaluvakolanu, 2011; Carter and Rasmussen, 2006; Speak et al., 2013; Stovin et al., 2012). With the large range of results reported, additional information on green roof performance under significant rainfall events is required.

There exists a gap in empirical data quantifying the effect of climate variability on green roof retention performance, without the influence of changing green roof designs or study duration. The aim of this study is to quantify the response from similar green roofs in different climate regions to isolate and evaluate the impact of climate on retention performance. As such, this study assesses the retention response of three green roofs in distinctively different climates. The green roof design was replicated at each site (i.e. depth, vegetation, age) with identical instrumentation and monitoring periods. The retention performance of the green roofs in different climates is compared based on storm event size retention and annual retention. The factors controlling retention performance as well as the climate conditions for which green roofs provide optimal performance are considered. Finally, large design storms (i.e. storms with return periods greater than 2-years consistent with that used in North America for stormwater management (SWM) design) are assessed to evaluate green roof retention for large events.

## 2. Material and methods

### 2.1. Site description

Three experimental green roofs were installed in July 2012 in London (Ontario), Calgary (Alberta), and Halifax (Nova Scotia), all of which are cities with limited implementation of urban green roofs. Although the studies sites are in Canada, similar climatic conditions are experienced throughout the world (e.g., Europe, Asia and USA). The site and climate characteristics are shown in Table 1 and layouts are shown in Fig. 1. The green roof installed in London is on Talbot College at Western University (approximately 12 m above ground level). The green roof in Calgary was placed on the Earth Sciences building at the University of Calgary (approximately 10 m above ground level). Lastly, the Halifax green roof was installed on an office building in a business park (approximately 20 m above ground level). The monthly average weather for each site can be seen in Fig. 2 for the study period. London displays moderate temperatures, relative humidity and depth of rainfall, while Halifax tends towards slightly cooler temperatures and a