

# A Review on the Controlling Factors that Affecting the Stormwater Retention Performance of Green Roof

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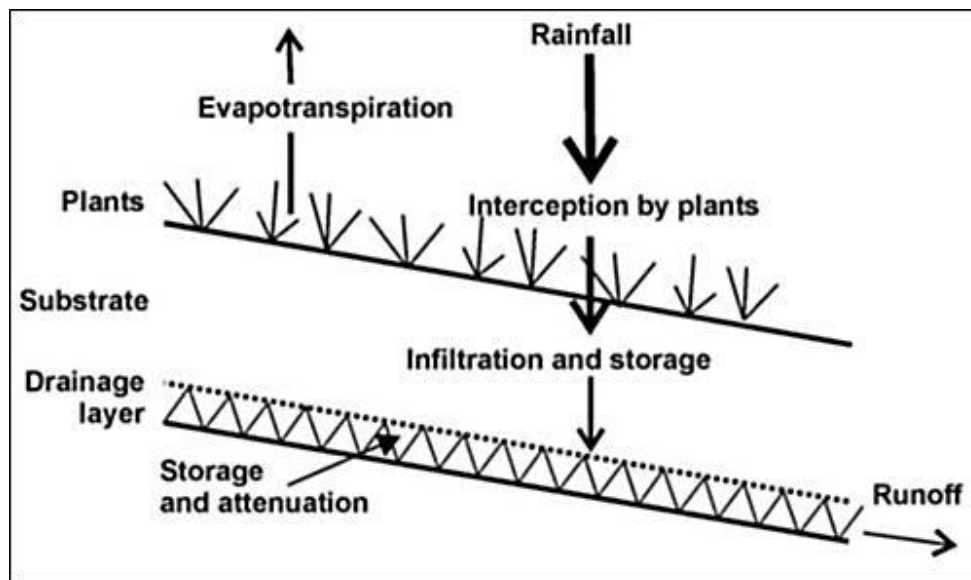
**Abstract.** Green roofs have become a popular strategy in urban stormwater management in the recent years. However, the hydrological performance of green roofs can vary substantially due to design characteristics and environmental conditions. This study is aimed to review all the controlling factors that affecting the stormwater retention performance of green roofs. Current hydrological research on green roofs involving different plant species, substrate types and environmental conditions are reviewed and evaluated in detail. Better understandings on the controlling factors that affecting the hydrological performance of extensive green roofs will be benefiting to the successful implementation of green roof system in the future.

## 1. Introduction

Nowadays, urban development is expected to grow with increasing population in the urban area. Green roof has been widely implemented as a sustainable urban stormwater management around the world in the past few decades. According to previous studies, design of green roofs should have high hydraulic conductivity which the infiltration rate exceeds the precipitation rate in most rainfall events that likely to be experienced by that particular site [1]-[3]. Total amount of runoff is usually used as a variable to assess the hydrological response of a green roof. The amount of water that does not flow out from the green roof is considered as water retained. In general, the depth of water retained plus the runoff depth must be equal to the total depth of rainfall. If a rainfall exceeds the maximum water storage capacity of a green roof, runoff may not begin immediately because it also depends on the intensity of rainfall event. Green roofs may detain an additional depth of water more than its storage capacity. The maximum water detention capacity of a green roof is greatly depends on the growing media composition and the response is usually dynamic to the rainfall intensity [3], [4]. Thus, green roof can delay and reduce the peak flow of runoff during a storm event [5]-[10]. The available storage capacity would allow the rainwater to infiltrate into the growing media. Once the volume of rainwater exceeds the maximum storage capacity of green roof, the rainwater will be drained out from the growing media. The excessive rainwater would percolate into growing media and passing down the filter and drainage layers (bottom layer) before flowing out to the drainage system. Drainage layer often consists of high amount of lateral hydraulic conductivity that ensures all rainwater beyond the storage capacity of growing media is able to flow out [1], [2]. Detained water can continuously to drain for a few hours after a rainfall event until the water level is reduced to the maximum storage capacity of green roof [11]. The whole hydrological processes in green roof system are illustrated in Figure 1. The hydrological performance of green roofs can vary substantially due to design



characteristics and environmental conditions. Better understandings of the influencing factors on the hydrological performance of extensive green roofs are important in order to assure the successful implementation of green roofs. Therefore, this study is aimed to review all the controlling factors that affecting the stormwater retention performance of green roofs.



**Figure 1.** The hydrological processes in green roof system.

## 2. Factors that affecting retention performance of green roof

### 2.1. Vegetation

Many studies had agreed that plant species have significant effect on the stormwater retention capacity in green roofs [12]. Green roof vegetation generally retains the rain water through evapotranspiration, interception by leaves, water uptake and retention by root system. Thus, plant selection on a green roof should consider its vegetation coverage, root uptake, root pathways in the substrate, water storage in plant tissue, transpiration, interception, evaporation and shading of media. Generally, plant species with bigger diameter, larger root biomass and taller height would increase the stormwater retention capacity of a green roof [12]. Morgan et al. [13] suggested that the stormwater retention capacity can be increased if the vegetation coverage reaches up to 20-25 %. According to White and Snodgrass [14], the plant species for extensive green roofs are required to show the characteristics of rapid establishment, high ground cover density and easy propagation. Hutchinson et al. [11] also stated that maturity of vegetation was considered as an important factor that leading to the increasing of runoff retention. Nagase and Dunnett [12] studied the differences of plant species types on the stormwater retention performance and found grasses were the most significant vegetation for decreasing runoff volume, followed by forbs and sedum. Succulent plant especially sedum has been identified as the most effective plant in extensive green roofs due to its potential for keeping excessive water, controlling transpiration, drought tolerance and shallow substrate adaptability [15]-[17]. Jarrett et al. [16] stated that sedum has the potential to capture one millimeter of rainfall depth in green roof. Ouldboukhitine et al. [18] stated that evapotranspiration for grass was 60% higher than that of sedum and almost twice fold than the bare substrate. Voyde et al. [19] reported that both *Sedum mexicanum* and *Disphyma australe* accounted for approximately 50% of stormwater reduction through evapotranspiration during water abundant conditions. Drought tolerance of sedum species has been well investigated. Lassalle [20] found that *S. album* L. (white stonecrop) could survive more than 100 days without water. Others also have confirmed that *S. album* is a drought-hardy species [21], along with *S. acre* L. (biting stonecrop), *S. kamtschaticum* Fischer & Meyer (orange stonecrop) and *S. reflexum* L. All of these plant species can survive for 88 day without water [22].

Liesecke [23] in Germany stated that more than five tuberous plant species would be the good selection for extensive green roofs. In Michigan, nine sedum and eighteen native taxa were evaluated for its growing, survival during both establishment and overwintering, and visual appearance in a non-irrigated extensive green roof over 3 years period [24], [25]. The results confirmed that all these nine sedum species were suitable for green roof in Midwestern climatic condition. In United Kingdom, Graceson et al. [26] found that sedum species averagely retained 40% while meadow plant retained 48%, respectively. In Malaysia, Johari et al. [27] had conducted a study on plant selection for green roof. The results identified that Portulacaceae, Neoregelia and Carssulaceae are the suitable plant species that can survive in tropical climate. In other study, Ismail et al. [28] indicated that green roof system planted with cardinal creeper (*ipomoeahorsfalliae* /*jasminumsambac*), sweet potato (*ipomoea batatas*), arrowhead plants (*syngoniumpodophyllum*), and beach morning glory (*ipomoea pes-caprae*) would led to decreasing of indoor and outdoor temperatures compared to black bare roof and white roof. Raymond and Ahmad [29] found that native fern species outperformed the other non-native sedum species in term of plant coverage and visual appearance during withheld watering test. On the other hand, Chow et al. [30] stated that monoculture of sedum was the most effective single species for retaining water runoff with 55.5%, followed by fern (50.9%), cow grass (34.8%) and manila grass (28.3%). Ayub et al. [31] showed that *A. compressus* performed the highest runoff reduction percentage in all experiments. Data recorded showed this species managed to attenuate peak flow in the ranges of 30.5% to 67%.

## 2.2 Substrate depth and composition

Substrate composition has a major significant effect on green roof water retention capacity than plan types and cover [22], [32], [33]. The water storage capacity of substrate is always depends on depth, composition and maximum water holding capacity [1], [22], [34], [35]. Many researchers have confirmed that increased substrate depth will improve the stormwater retention performance of green roof [36,33,24,37,38,39]. Mentens et al. [36] concluded that extensive green roofs have capability to retain 45% stormwater runoff (substrate depth: 10 cm) while for intensive green roofs can retain 75% of stormwater runoff (substrate depth: 15 cm), compared to gravel and traditional roof which only retain 25% and 15%, respectively. VanWoert et al. [22] also reported that the substrate depth will affect the water retention capacity of green roof. The effect of growing media depth on the storm water retention performance of green roof was investigated for different depths (2.5, 4.0, and 6.0 cm) and slopes (2% and 6.5%) in their study. For all combined rainfall events, green roof platforms at 2% slope with a 4-cm growing media depth had the greatest mean rainwater retention percentage of 87%. Mineral contained in substrate will support the growth of vegetation. The selection of substrate composition will be subjected to the availability of materials locally and substrate composition can be formulated for the intended plant selection, anticipated level of maintenance and climatic zone. Vijayaraghavan and Raja [40] have used mixture of expanded perlite, coco-peat (29% moisture content), crushed bricks, exfoliated vermiculite, and sand in the green roof substrate development. They identified that the best soil characteristics of substrate that used in green roof were particle size ranges between 0.25 mm to 4 mm, water holding capacity of 39.4% , bulk density (at maximum water holding capacity) of 912 kg/m<sup>3</sup>, dry bulk density of 431 kg/m<sup>3</sup> and air filled porosity of 19.5%. Recycled wastes also can be used as a substrate in green roof development. Chloe et al. [41] in London, UK have tested four recycled materials which including crushed red brick (the U.K. industry standard substrate base and then used as a control) and three alternative pellets made from: paper ash (from recycled newspaper), clay and sewage sludge (fly ash, sewage sludge and waste clay from excavation), and carbonated limestone (from quarry fines). The outcomes of this study showed the significant interactions between four aggregates and the amount of added organic material, whereby organic material addition did not have the same effect on the plant growth in each aggregate. Eksi et al. [42] in Turkey stated that decomposed material can be used as a green roof substrate. Their result showed that 60% and 80% compost substrate produced the greatest plant growth and fruit yield, respectively. These amounts are much higher than that recommended for standard extensive green roofs planted with succulents or other herbaceous perennials. High compost material will cause negative consequences of substrate shrinkage and nutrient runoff.

Organic content plays an important role in the selection of substrate type in green roof. Amount of organic content will determine the growth of plant. Nagase and Dunnett [43] had carried out a study to examine the relationship between percentage of organic matter in substrate and plant growth in extensive green roof, particularly at the establishment stages. From their results, it can be concluded that addition of 10% organic matter was optimal for all plant species in the study as the plant showed stable growth regardless of the watering regime. Meanwhile, increased organic matter did not result in increased growth in the wet regime of green roof. Nadine et al. [44] had carried out a study to assess whether ECM fungi can enhance *P.pinaster* growth in the burned soil of green roof. The results showed that inoculation has significantly enhanced the growth of *P.pinaster*, which *R.roseolus* exhibited to be the most effective fungi isolate in burned soil with an 8-fold increase in plant fresh weight.

### *2.3. Rainfall characteristics and seasonal climate*

Many green roofs studies showed that the rainfall characteristics have great effects on stormwater runoff retention performance [22], [45], [46]. Carter and Rasmussen [45] stated that an inverse relationship between the retention percentage of stormwater runoff and rainfall depth. Researcher observed 88% rainwater was retained for small storms (<25.4mm), 54% for medium storms (25.4-76.2 mm) and 48% for large storm (>76.2mm). Similarly, Simmons et al. [46] found that rainwater in small storm events (<10mm) were all retained in the green roofs. However, the retention percentage decreased to 8-43% for rain events with depth greater than 28 mm. VanWoert et al. [22] also reported that more than 95 % of total light rainfall (<0.2cm) can be retained by extensive green roof, followed by more than 80% of moderate rainfall event can be retained (0.2-0.6 cm), and only 52% of total heavy rainfall can be retained (>0.6 cm). It was observed that the green roof retention performance also depended on rainfall intensity not just on storm size. Villarreal and Bengtsson [3] mentioned that lower rainfall intensity will result in higher water retention in green roofs. Their results showed that the rainwater retention was 62% for rainfall intensity of 0.4 mm/min but only 21% for rainfall intensity of 1.3 mm/min. Getter et al. [47] also stated that light rainfall event recorded the highest retention percentage of 94% while heavy rainfall recorded the lowest retention percentage of 63%. Lee et al. [48] and Bengtsson et al. [4] both stated similar contrary relationship between rainfall intensity and water retention capacity of green roof. Seasonal conditions may also influence the water retention performance in green roofs as plant evapotranspiration is influenced by climatic aspects such as solar radiation and temperature [36]. The summer season records greater evapotranspiration rate and thus increases the retention capacity of green roof [36,49]. Bengtsson et al. [4] reported that the highest runoff reduction in extensive vegetated roofs was observed for June (88%) while the lowest for February (19%). Meanwhile, Villarreal and Bengtsson [3] found the retention capacities of studied green roof were varied between 34% during September – February and 67% during March-August.

### *2.4. Slope*

Various studies had reported different results on the effect of slope on green roofs runoff retention capacity. Some studies found no correlation between roof slope and runoff retention [6,36,50], while others had observed runoff retention may depend on the slope of green roofs [3,22,47]. Villarreal and Bengtsson [3] found that peak flow and runoff volume increased as slope increased. It was observed that 2% slope has double retention volume recorded compared with 14% slope. Similar results were stated by Getter et al. [47] that runoff volume reduction decreased as roof slope increased. The lowest stormwater retention capacity of 75% was observed for 25% slope while the highest retention capacity of 85% was observed for 2% slope. VanWoert et al. [22] also studied the influences of slope (2% and 6.5%) and substrate depth (2.5, 4.0 and 6.0 cm) on runoff retention capacity of green roofs. In the study, they found the greatest overall retention was 87% for green roof at 2% gradient with 40 cm substrate. Bengtsson [6] examined the influences of slope and length of green roofs on the runoff peak flow retention but found that there are no significant changes on the runoff distributions. Schade [51] in Germany also found no significant difference in runoff retention amounts across different sloped roofs. The contradicting results may be caused by the rainfall patterns in different environments. Many

researchers have observed that dry substrate conditions prior to storm event will result in higher stormwater retention compared with initially wet condition in green roof [3,52].

### 2.5. Age of the green roof

Certain studies claimed that the age of green roofs will affect the rainwater retention efficiency [47,53]. Berndtsson [51] stated that the substrates of green roof experienced several physical and chemical changes over time such as loss of soil particle, washout of dissolvable substances, changes of organic content and changes of soil porosity due to roots development. These changes would influence the hydrology dynamics in the green roof. The water holding capacity increased from 16% to 68% while pore volume and organic content increased twice after 5 years usage of green roofs (from 41% to 82% and from 2% to 4%, respectively) [47]. However, Mentens et al. [36] did not find any significant relationship between the age of green roof and annual runoff volume reduction.

### 3. Conclusion

This paper has identified all the controlling factors that affecting the hydrological performance of green roofs. The effects of vegetation, substrate composition, physical properties of substrates, climate condition, rainfall pattern, structure and design of green roof have been reviewed thoroughly in this paper. The information provided in this paper are beneficial to the improvement of green roof system in the future.

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