Applying Green Roof Research to Detail Design Decisions

A Review of Four North American Research Studies

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ABSTRACT Green roofs are an important design tool landscape architects can use to help mitigate stormwater runoff within dense urban centers. Scientific studies are an integral source in determining how to design for maximimum stormwater retention. This paper summarizes and reviews four green roof water retention studies from research stations in North America which have looked at various plants, soils, slopes, water quality, and other factors that contribute to a green roof's effectiveness. By reviewing this data, a set of recommendations have been derived for green roof design that pertain to seasonal and yearly storm trends, soil depth, media composition, vegetation, green roof slope, and materials.

INTRODUCTION

In cities with limited space for water infiltration, green roofs are found to be one solution for reducing stormwater runoff. Research has found that green roofs reduce stormwater runoff volume and peak flow by retaining water in the growing medium (Connelly et. al., 2005), making them a potent tool for reducing runoff. This raises the question: How might green roofs be designed to maximize stormwater retention? The best sources of information on this topic are from scientific experiments performed at various green roof research stations. Controlled experiments provide scientific data on the performance of green roofs under conditions of limited variability, allowing the researcher to test individual water retention variables.

Four research stations were chosen for analysis: Vancouver, BC; Portland, OR; University Park, PA; and Lancing, MI. Each station studied how green roofs mitigate stormwater runoff; however, different variables were tested at each research facility in an attempt to discern which components are more efficient in reducing runoff. Research from the four studies modified particular conditions of green roofs and compared the results in regards to stormwater retention over time. Two research stations also observed the water quality of the runoff after filtration through the green roofs.

This paper looks at the work from each of these experiments and discusses how seasonal and yearly storm trends, soil depth, vegetation, slope, and materials all affect a green roof's capacity for stormwater retention. The collection and comparison of data has helped devise a set of simple recommendations for the general design of green roofs in order to maximize stormwater retention.

VANCOUVER, BC RESEARCH STATION

The research in Vancouver, BC was performed at the BCIT Green Roof Research Facility at the Great Northern Way Campus. The facility was constructed in 2003 with a focus on calculating differences in stormwater retention in wet and dry seasons. Soil depth and vegetation varieties were also among the primary considerations of this research.

The research facility was comprised of three aligned 22 square meter roofs separated by parapets. The two outer roofs were vegetated, while the centre roof acted as a reference that prevented plant species from migrating between the two outer roofs. All roofs had a consistent 2% slope and were tested for a full year from January 1st to December 21st in 2005 (Connelly et. al., 2005). (See Figure 1)

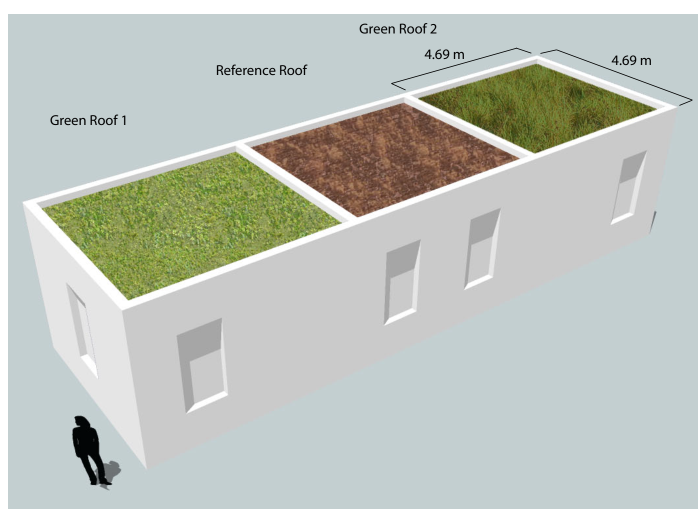

Figure 1. Diagram of BCIT Green Roof Research Facility

The major conditions tested in Vancouver were plant species and soil depth:

Green roof 1 contained 75 mm of growing medium with the following plant species: *Sedum acre, Sedum floriferum*, and *Sedum lydium* which was later replaced with *Sedum sexangulare* due to failure.

Green roof 2 contained 150 mm of growing medium with grasses and fescues indcluding: *Festuca scoparia, Bouteoua gracilis*, and *Carex glauca*.

Each roof was designed to act as a specific ecosystem and plants were chosen for the relative amount of soil they require. The growing medium consisted of 1/3 white pumice, 1/3 sand, and 1/3 organic compost (Connelly et. al., 2005). Sensors were embedded in the roof to measure heat exchange through the different roof components. Soil moisture content and stormwater runoff were measured on the roofs while a weather station measured air temp, humidity, rainfall, solar radiation, and wind speed (Connelly, 2005).

The experiment confirmed that green roofs delay the start of runoff and reduce peak flow and amount of runoff; however, the results differed greatly between the wet and dry seasons. During the dry season (mid-April through late September), green roof 1 retained 86% of stormwater while green roof 2 retained 94% of stormwater. During the wet season, green roof 1 performed better with a 19% retention while green roof 2 retained 14% of stormwater. (See Figure 2)

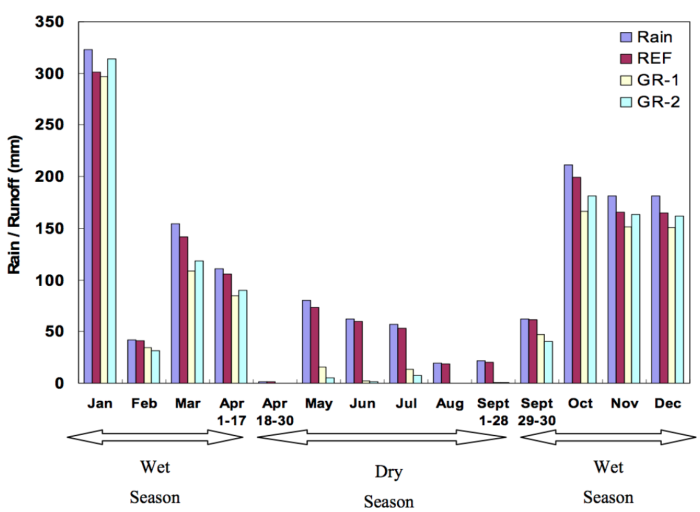

Figure 2. BCIT graph referencing the wet and dry seasons of rainfall and amount of stormwater retention (Connelly et. al., 2005).

Researchers concluded that a deeper growing medium requires longer drying periods to restore its water carrying capacity. During the wet season, water retention was influenced by the amount of rainfall in the preceding days, not the duration or intensity of rainfall. In total, green roof 1 had 29% stormater retention while green roof 2 had 26% stormwater retention. This is not a significant difference overall. In comparing the financial return of each roof, green roof 1, with 75 mm of substrate, was a better financial investment compared to green roof 2 (Connelly et. al., 2005).

PORTLAND, OR RESEARCH STATION

The green roof research station in Portland, called the Hamilton Ecoroof Project, was built on top of the Hamilton Apartments, a ten story 8,700 square foot building. The roof was installed in September 1999. (See Figure 3)

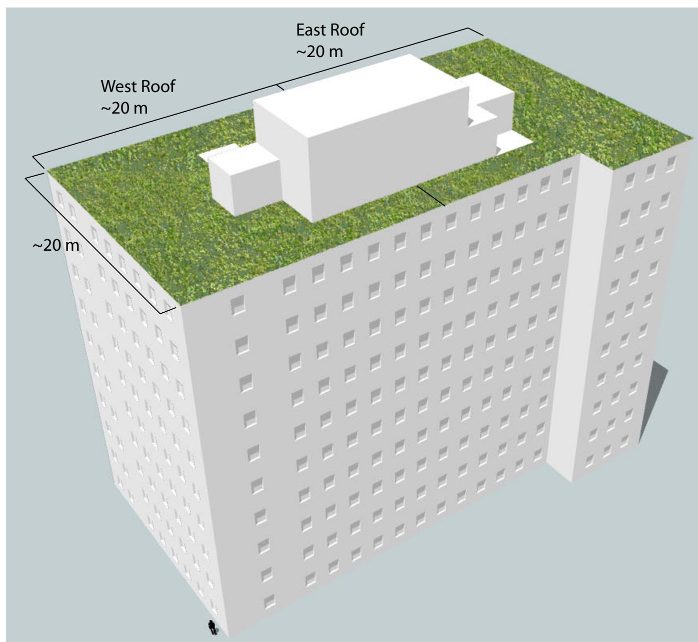

Figure 3. Diagram of the Hamilton Ecoroof Project

This research facility tested how substrate depths and substrate mixes effect stormwater retention and water quality. The study also examined how weather patterns affected stormwater retention. It was completed between January 2002 and April 2003 (Hutchinson, 2003).

The green roof was divided into 2 sides, an East and West.
The East roof was 2,520 square feet, had 2 inches of substrate, and was comprised of 15% digested fiber, 25% encapsulated styrofoam, 15% perlite, 15% coarse peat moss and 15% compost.

The West roof was 2,620 square feet, had 5 inches of substrate, and was comprised of 20% digested fiber, 22% coarse perlite, 28% sandy loam, and 10% compost.

Each roof had similar plants installed. Over 75 species were planted, including a variety of sedum, delospema, sempervivum grasses, and other herbaceous species. Over time, each green roof developed different plant communities due to deaths and re-colonization (Hutchinson et. al., 2003).

The roof rainwater was monitored before draining and samples were analysed for dissolved oxygen, pH, conductance, and temperature. Water was also tested for nitrogen, dissolved metals, and colour. Other data collection included visual observation and photos of human activities (Hutchinson et. al., 2003).

Over the 15 month period there was an overall rainfall retention of 69%. There were significant reductions in peak flows during both winter and summer months. There were major differences in stormwater retention in comparing January through March in 2002 with the same period in 2003 even though rainfall quantities were similar. In 2002 there was a 20% retention of 14.3 inches of rain in that period, while 2003 had a 59% retention with 13.3 inches of rain. Researchers concluded this difference was due to the maturation of the vegetation as well as the different rainfall patterns. Data showed that 2002 had a more even distribution of rainfall while 2003 had longer dry periods between storms. These longer dry periods allowed greater evaporation and drying of the soil for increased water holding capacity (Hutchinson et. al., 2003). (See Figures 4 & 5)

Research on water quality found the west roof had higher concentrations of chemicals in the stormwater runoff that included: copper lead, zinc, nitrate, ammonia, and phosphorous. Researchers assumed poorer water quality was due to differing roof materials, as well as gutters, downspouts, and treated lumber used for edging materials. Phosphorous levels were also a major concern (Hutchinson et. al., 2003).

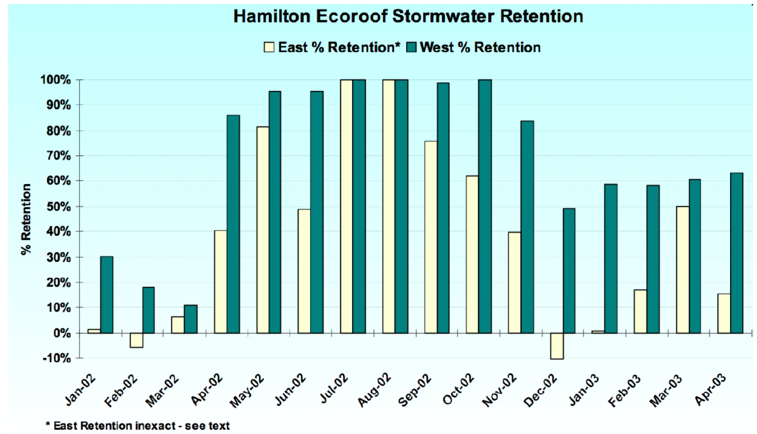

Figure 4. Graph showing the stormwater retention of the Hamilton Ecoroof Project between Jan. 2002 and Apr, 2003 (Hutchinson et. al., 2003).

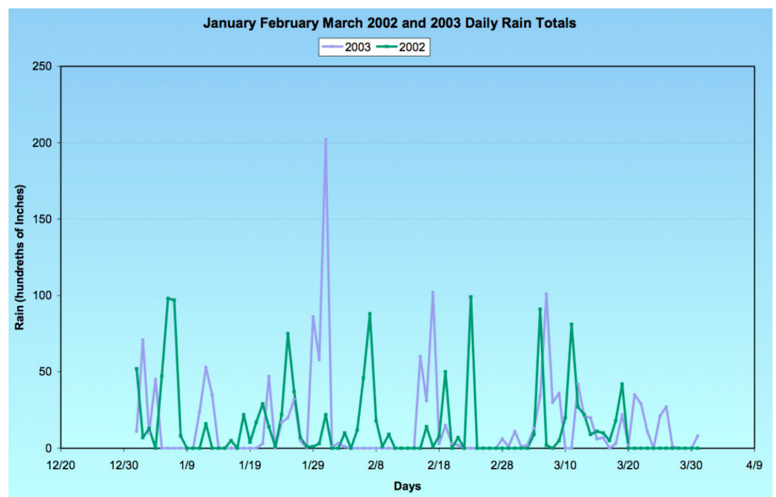

Figure 5. Graph showing the difference in stormwater retention for two different years during the same season (Hutchinson et. al., 2003).

UNIVERSITY PARK, PA RESEARCH STATION

The research at University Park was conducted by Pennsylvania State University and was part of the National Decentralized Water Resources Capacity Development Project. The project was built in 2001, and the study was interested in identifying percentages of stormwater reduction, water holding capacity of the substrate, and criteria to control stormwater volume control. The study also looked at the quality of green roof runoff compared to regular roofs, the evapotranspiration rates of vegetation, and ability to neutraize acid runoff. Data was analyzed for the months of January 2005 through November 2005. Two types of experiments were set up: one as a field study and the other in a controlled greenhouse (Berghage, 2009).

The Field Study was set up as 3 green roofs, 2 substrate roofs, and 1 roof with 1/2 substrate and 1/2 detention. All roofs were 1.8 x 2.4 meters with a 8% pitch. The substrate was comprised of primarily expanded clay with some compost amendment and vegetation was 90% Sedum spurium and 5% Sedum album (Berghage et. al., 2009). (See Figure 6)

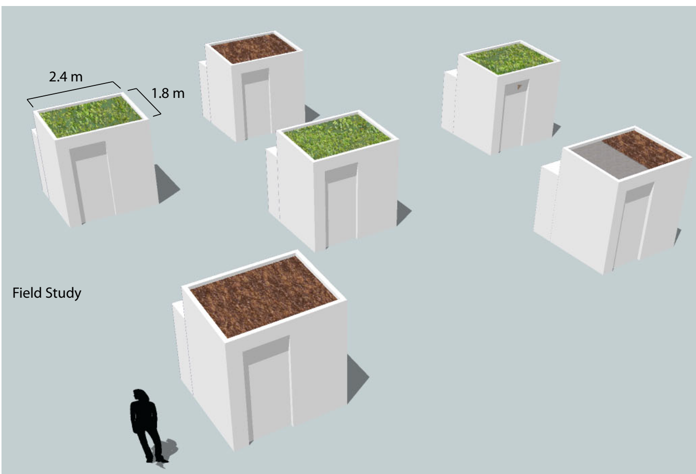

Figure 6. Diagram of the University Park Field Study.

Data was collected on runoff amount and temperature every 5 minutes. A weather station also collected information on rain, temperature, light, humidity, and wind speed. Samples were taken to analyse the water quality including turbidity, salts, nitrate, ammonia, calcium, iron, potassium, manganese, sodium, phosphorous, zinc, and sulphur (Berghage et. al., 2009).

The Greenhouse Experiments tested background information on the media. Tests researched the water storage capacity and retention and detention characteristics with and without plants. Evapotranspiration, plant growth rates, temperature, light, and vapour pressure deficit were also tested.

The controlled greenhouse experiments were located in the Penn State Horticultural Science Greenhouses. Eight planting beds were suspended to measure weight differences due to water gain or loss. Each bed was 1.05 x .54 x .2 m, had a 8% pitch, 89 mm of commercial green roof growing medium, and a drainage layer. Only four beds were planted with *Sedum album* and *Delosperma nubigenum* (Berghage et. al., 2009). (See Figure 7)

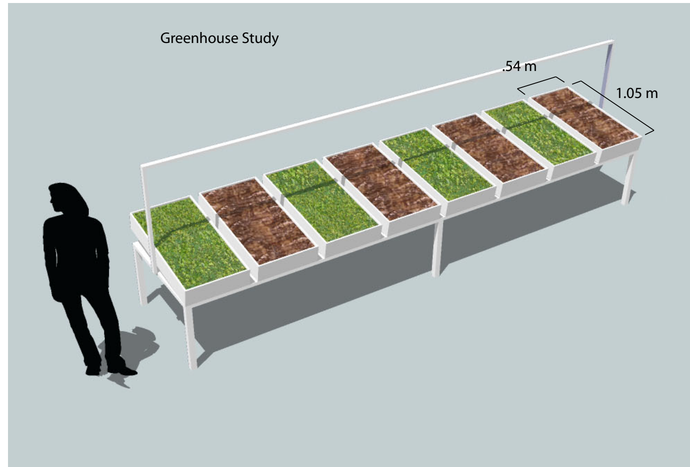

Figure 7. Diagram of the University Park Greenhouse Experiments.

The results found 8 to 10 cm of media can retain 50% or more of annual precipitation. During the summer months there was consistent retention, but it was variable during the winter due to saturation. 95% of precipitation was retained in summer while 20% was retained in winter. Throughout the year, the green roof consistently delayed peak flow (Berghage et. al., 2009). (See Figure 8)

The vegetation had an effect in runoff retention during summer months when it was actively growing and transpiring, but during the cooler months, vegetated beds performed the same as non-vegetated beds. Planted media allowed for continuous water removal deep in the media to recharge the stormwater runoff reduction potential, while non-vegetated only allowed for evaporation of water on the surface of the substrate. Plants had the greatest effect in increasing media's water-holding potential during the first five days of rainfall (Berghage et. al., 2009). (see figure 9)

Green roof runoff contained equal or greater concentrations of phosphorous, potassium, calcium, and magnesium as flat asphalt roofs. Increases in phosphorous and potassium were from green roof materials that provide nutrients for the plants (Berghage et. al., 2009).

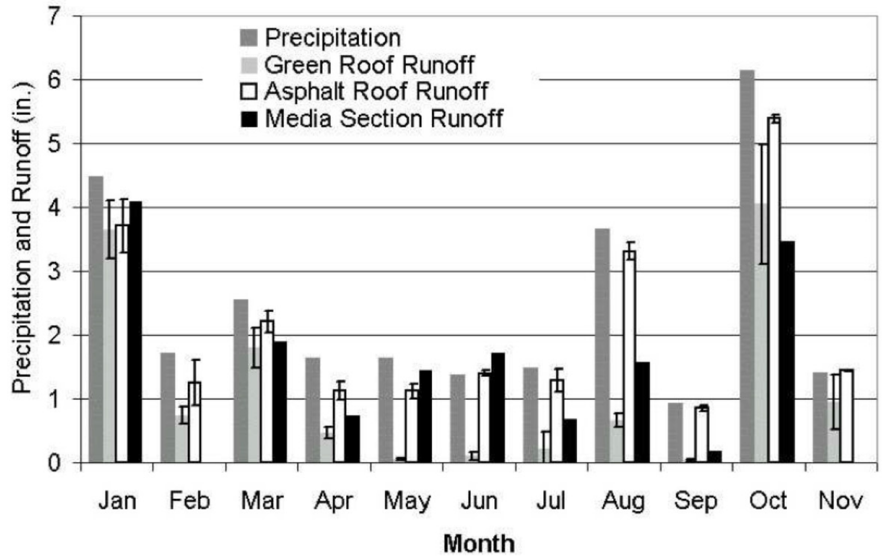

Figure 8. Graph from the University Park study showing the precipitation and runoff from a green roof, an asphalt roof, and a media-only roof (Berghage et. al., 2009).

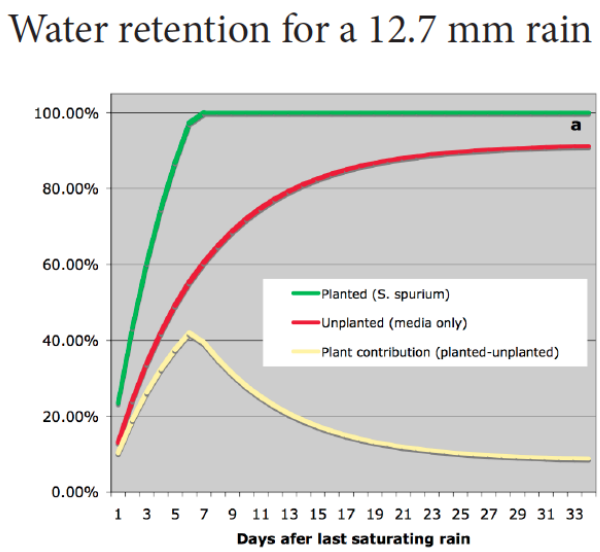

Figure 9. Graph from the University Park greenhouse experiments showing how vegetation affects a substrate's water holding capacity (Berghage et. al., 2009).

LANCING, MI RESEARCH STATION

The research performed in Lancing, MI was performed by the Michigan State University Horticulture Teaching and Research Center. Study 1 was interested in comparing the percentage of stormwater retention between gravel, soil, and vegetated roofs. Light, medium, and heavy rainstorms were factored into this comparison. Study 2 experimented with soil depth and slope and their impacts on stormwater retention (Getter et. al., 2007).

Roof platforms were 2.44 x 2.44 m. The roofs simulated commercial roofs and contained an insulation layer, protective layers, waterproofing membrane, and a drainage layer. Media consisted of 40% heat expanded slate, 40% USGA grade sand, 19% peat 5% dolomite, 3.33% yard waste, and 1.67% composted poultry litter. A controlled release fertilizer, Nutricote Type 100, was also added.

Vegetation included the following: *Sedum acre, Sedum album, Sedum kamtschaticum ellacombianum, Sedum pulchellum, Sedum reflexum, Sedum spurium* 'Coccineum' and 'Summer Glory' (Getter et. al., 2007).

Study 1 tested three types of roofs, each .67 x 2.44m with 2.5 cm of growing media. Roofs were randomly planted with vegetation, no vegetation, and 2 cm gravel ballast. Tipping buckets recorded runoff, air temp, humidity, wind speed, and photosynthetic radiation.

Study 2 utilized 12 vegetated green roof platforms. Three beds had a 2% slope with 2.5 cm of media. Three beds had a 2% slope with 4 cm of media. Three beds had a 6.5% slope with 4 cm of media. Three beds had a 6.5% slope with 6 cm of media (Getter et. al., 2007). (See Figure 10)

Results concluded vegetated roof systems reduce stormwater runoff and extend its duration beyond the time of the rain event. Vegetated roofs retained 60.6% of rainfall, media-only roofs retained 50.4% of rainfall, and gravel ballasts retained 27.2% of rainfall over the 14 month period. Data was collected from August 28th, 2002 to October 31st, 2003 (Getter et. al., 2007).

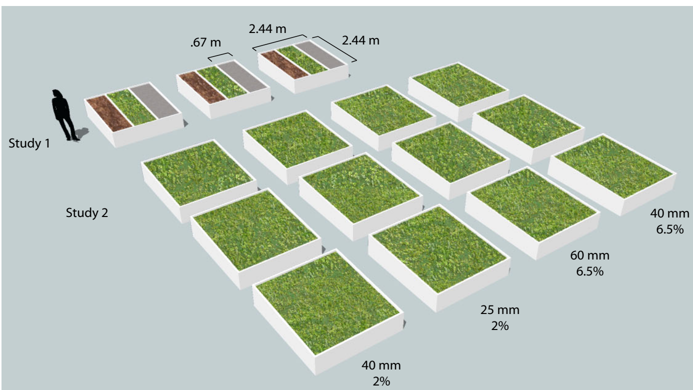

Figure 10. Diagram of experiment performed in Lancing, MI

Water retention for individual storm events varied. During medium storm events, media-only roofs and vegetated roofs performed similarly; therefore, researchers concluded media and water retention fabric were the main factors in retaining stormwater. Vegetation was important in preventing erosion and mitigating heat island effect. The depth of the medium influenced growth, drought stress, and drought tolerance of the vegetation (Getter et. al., 2007).

Study 2 discovered that slope and media depth both have an effect on stormwater runoff retention. The greatest retention, 87%, was documented in the roof with a 2% slope and 4 cm of soil. During medium and light rain events, this roof had the greatest retention while there was no difference between roofs during heavy rain events. Increasing media depth only increased the water retention in the 2% sloped roof. Scientists speculated that deeper media provides a greater delay in runoff due to its water holding capacity (Getter et. al., 2007).

REVIEWING THE RESEARCH

After reviewing the work of these four research stations, conclusions can be drawn that seasonal weather patterns and various storms types are major factors impacting stormwater retention. The studies specifically found that yearly weather patterns, heaviness of the rainfall, and frequency of rainfall were the main factors in governing stormwater retention.

As the world faces climate change, weather patterns will be even more difficult to determine. If landscape architects want to design green roofs to maximize stormwater retention, there are certain qualities of green roof design that can modified to make them more efficient. Media depth and composition as well as vegetation and slope can all contribute to a green roof's capacity for water retention. The following recommendations have been devised for extensive green roofs in order to improve their capacity for water retention:

- Thicker media is more desirable in retaining water and 75 to 100 mm of media is most optimal depending on weather patterns
- In choosing the composition of green roof media, carrying capacity of materials should be the deciding factor. If media contains materials that have a greater carrying capacity, the green roof will retain more stormwater (Berghage et. al., 2007).
- Water retention fabric serves as an additional water retention device (Getter et. al., 2007)
- To improve water quality, green roofs should minimize the amount of organic content in the growing media. By reducing organic content, there is a reduction of phosphorous and potassium in stormwater runoff.
- Where possible a minimal slope (optimal 2%) is most effective for stormwater retention(Getter et. al. 2007).
- Vegetation can be used as a significant contributor in recharging the water-holding capacity of the media within the first 5 days after a rainstorm. Therefore, it is highly advantageous to plant vegetation, succulent plants in particular (Berghage et. al., 2007).

- *Sedum album, Sedum acre*, and *Sedum spurium* are excellent plant choices as they retain water very well and are adapted to dry climatic and soil conditions. They are able to survive in extreme conditions because they store water in their leaves, stems, and roots (Dimmitt, 2006). Their adaptability to dry conditions, thin soil depths, and limited organic material requirements makes them favourable as green roof plants.

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