Combining Stormwater Infrastructure

Green Roofs and Rain Gardens as Stormwater Mitigation Strategies in Vancouver's West End

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ABSTRACT Green roofs are often cited as an integral part of green infrastructure systems and promoted for their ability to mitigate stormwater runoff from impervious surfaces which can be detrimental to receiving water bodies. That being said, the ecological and financial benefit of stormwater mitigation by green roofs must be weighed against the potential ecological and financial costs of their maintenance.

This paper demonstrates how a cost-benefit analysis can be used by designers and policy makers as a decision making tool in determining the appropriateness of water mitigation strategies such as green roofs and rain gardens for a given site or area. One block of Vancouver's West End is used as a case study to determine the potential annual water mitigation efficacy of green roofs on this block's residential buildings. This benefit is then weighed against the annual water cost of irrigating these same roofs. The same analysis is done for rain gardens, assuming both public and private underutilized green space can be suitably fitted with rain gardens to conclude that green roofs in this area are not a sustainable part of a stormwater mitigation strategy. Rather, we propose at grade mitigation techniques as a more effective design strategy for mitigating stormwater while maintaining lower maintenance requirements.

INTRODUCTION

Stormwater runoff from impervious surfaces and other urban land covers can be detrimental to receiving water bodies. The water that runs off rooftops, parking lots, and streets travels faster than water that collects on pervious surfaces and often carries with it heavy metals, bacteria and other pollutants. The high volumes of runoff in caused by these surfaces can erode stream banks, cause localized flooding and contribute to sewer overflows in which raw sewage is directly discharged into local waters. (Douglas, 104-120).

In Vancouver as well as many other North American cities, the existing sewer systems are ill equipped to manage the increasing rates of stormwater runoff. The sewer systems in place were originally designed to capture and transport stormwater, untreated sewage, and wastewater from toilets and industrial drains to wastewater treatment plants as part of a single-pipe "combined sewer system" (CSS). When rain or melting snow creates large volumes of runoff, the total volume of stormwater and wastewater in the combined sewers exceeds the capacity of the wastewater treatment plant. When the system becomes overloaded, it diverts the mixture of stormwater and sewage releasing it directly into local rivers or coastal waters. These "combined sewer overflows," or CSOs, dump millions of gallons of raw waste and other dangerous pollutants into fishbearing rivers, creeks, lakes, and oceans.

In Vancouver, there are 42 combined sewer outfalls lining the city's coastline. Although most of our sewage goes to treatment plants, raw sewage frequently backs up into the stormwater system dumping 36 billion litres of untreated sewage into the Fraser River and Burrard inlet each year. That's enough to fill B.C. Place stadium more than 28 times. (Buck- Suzuki, 4) In 2001, the Greater Vancouver Regional District committed to a 50 year initiative to separate the most problematic of Vancouver's CSOs. (Metro- Van 2008) However, the Buck Suzuki foundation has judged this to be an insufficient response to the problem. (Buck-Suzuki, 12) The need for upgraded waste infrastructure is not limited to Vancouver of course- a report from the EPA states US communities are facing a total of $106 billion in stormwater management and combined sewer correction upgrades or improvements. (EPA Cleanwater Needs, 10).

GREEN ROOFS AS STORMWATER MITIGATION

Green roofs, along with bioswales, engineered wetlands and stormwater ponds are able to mitigate the deleterious effects of stormwater runoff. Many academic studies have investigated the potential for extensive green roofs to re-establish natural water cycle processes and to operate hydrologic control over stormwater runoff with a derived peak flow attenuation, runoff volume reduction and increase in the time of concentration. (c.f. Bengtsson, Stovin, Kohler et al., Scholtz-Barth, and Roehr) These studies indicate that there are two key variables that determine a green roof 's stormwater mitigation capacity. The first is the composition of the substrate and drainage layers into which the water is infiltrated and stored. This infiltration and holding capacity determines the rate at which water is released into the storm outlets, thereby attenuating peak flow. The second factor is plant type which determines how much water is evapotranspirated back into the atmosphere during dry periods.

Some scholars have posited the idea that green roofs could be used as a city wide low impact development system, and cities seem to be responding to this idea (c.f. Centgraf, Met- ens, Deutsch, Villareal and Roehr). Green roofs are being incorporated as part of a citywide stormwater mitigation strategy in cities such as Portland, Phiadelphia, Syracuse, New York, Washington and Toronto. Although it is home to many of the largest high profile green roof projects, Vancouver has no citywide policy. One might think that neighborhoods like Vancouver's downtown and Westend, where on-grade infiltration sites are limited, would be a good opportunity for a green roof strategy.

Figure 1. Combined Sewer Outfall, Comox Street, Vancouver

GREEN ROOFS IN VANCOUVER'S WEST END

Vancouver's West End is a densely developed urban residential neighborhood made up of cluster housing, most often with large flat bitumen covered roofs, small front lawn areas, and narrow boulevards planted with mature street trees. The density of the neighborhood means that it has a very high gray to green area ratio and green space is limited. Any water infiltration strategy must be able to fit within the strict pre-existing confines of its urban context. Much of the area is reliant on a combined sewer system. These factors collectively point to a need to investigate green roofs as a viable stormwater management solution.

Our test site for this study is a residential block in Vancouver's West End, located between Chilco street, Nelson Street and abutting Stanley park. It was chosen because of it's composition of three mid to large scale residential buildings flanked by asphalt roads and a back lane. Concrete sidewalks, and small green boulevards are typical of the area. The nearly 1ha (9644 m^2) case study area consists of 19% permeable green space and 81% impervious surfaces. Of the impervious surfaces 36% (2,014 m^2) is found to be roofs and 74% (3,802 m^2) is comprised of streets and sidewalks. We used the annual rainfall records of 2006, a typical rainy year, in which there was 1254mm of precipitation to calculate runoff and irrigation requirements for the study area.

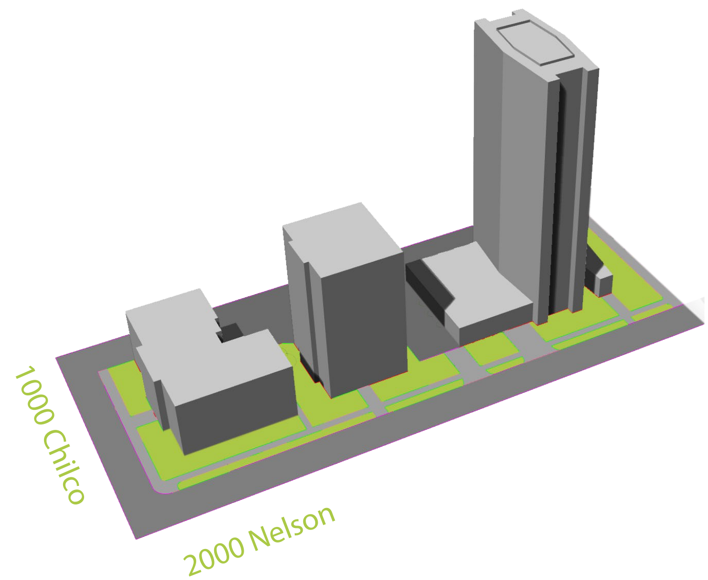
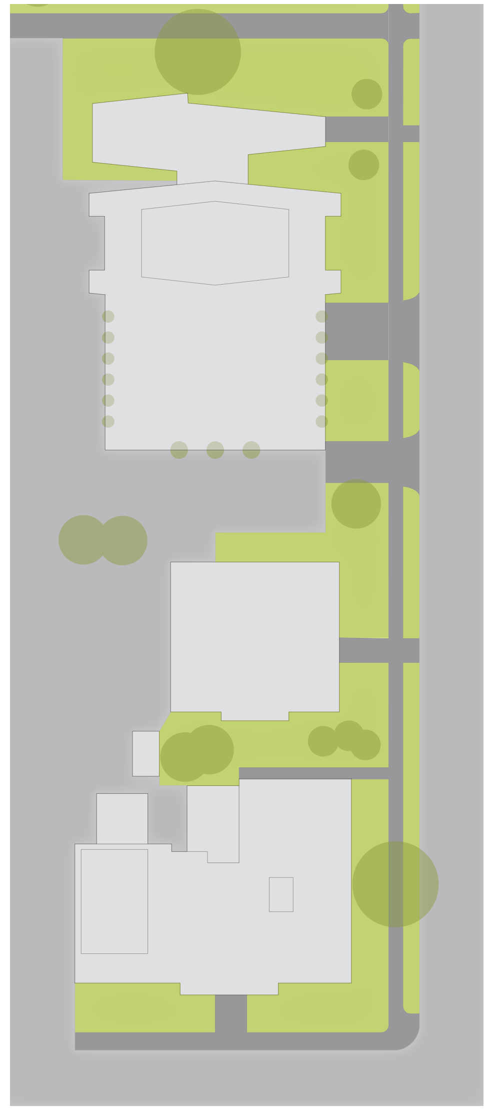


Figure 2. Model of our selected sample block in Vancouver's West End Neighborhood.

Using the US department of agriculture's SCS-CN curve number method for calculating stormwater runoff, we determined that the roof surfaces per hectare in downtown Vancouver would generate a total runoff volume of 2,578 cubic meters per year, approximately the same amount of water that is needed to fill an Olympic size swimming pool.

Next we posited the performance of a hypothetical green roof that was made with a sandy loam substrate of 150 mm depth. This particular substrate composition would have a field capacity (that is, the maximum amount of water that the soil can hold) at 47 mm, a wilting point of 17mm, and a resulting available water amount for plants of 30mm (water available to plants in the space between the sandy loam particles). We posited low water use plants such as sedums for the green roof plantings. We calculated that a green roof with these specifications would reduce the annual runoff from the areas by 215.1mm per annum or, on average, 29%.

The annual precipitation and evapotranspiration rates only tell us half the story, however. If we review the monthly precipitation patterns in Vancouver (Figures 5/6), we can see that the green roof does not perform at a consistent rate of 29%. In fact, evapotranspiration rates during the months with the heaviest rainfalls are significantly lower than in the summer months in which there is little to no precipitation. We can see that during the months of June-September there is in fact a deficit of water. During these warmer months, the plants evapotranspire more water than they receive from rainfall. Using the monthly evapostranspiration rates provided in Roehr and Kong (2010, Figure 2, 41,) we estimate the water needed to irrigate green roofs on this site to be about 1500 cubic meters per annum.



19 % Gray :81% Green

Boulevard: 271.07 m

Lawn: 1669.63 m

Asphalt: 4150.20 m

Pavement: 817.70 m

Roofs: 2735.08 m

Total area: 9643.68

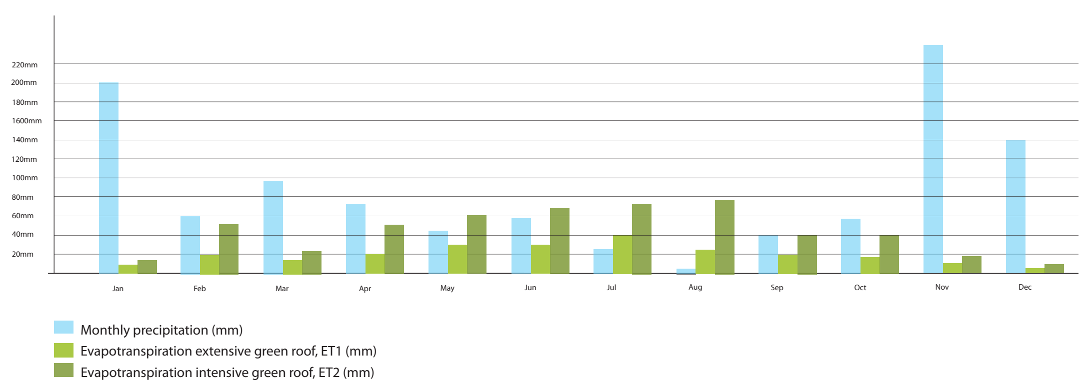


Figure 5 (above). Annual Precipitation and Evapotranspiration chart, Vancouver BC. Adapted from Roehr and Kong (2010), 41.

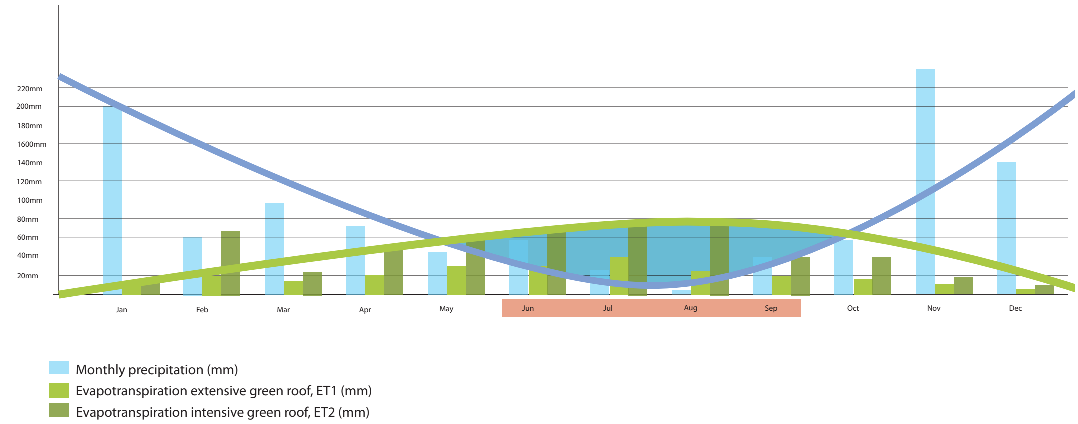


Figure 6. Irrigation required during warmer summer months.

MITIGATING WATER IN THE WEST END

Given these high irrigation requirements for green roofs and their relatively low ability to retain water throughout the rainy season, a number of design guidelines have been developed for the West End:

- Green roofs are not appropriate in this context for stormwater mitigation unless cisterns are provided for irrigation
- Retrofitting cisterns under West End buildings is possible but would be incredibly difficult and costly where space is at a premium.
- Installing rooftop cisterns to collect and store water for summer irrigation is the most feasible and more ecologically sound solution for employing green roofs in the West End. This also ensures not having to pump water to the rooftop.

It is worth noting, however, that cisterns are still difficult to gain legal permission to use in Vancouver, and they can be costly to install on older buildings. This has led to our investigation of raingardens as an at-grade alternative to dealing with issues of stormwater in Vancouver's West End. The second half of this paper will explore how a series of at-grade rain gardens could be integrated into the existing neighborhood green space as a means of comparing their efficiency with that of green roofs.

RAIN GARDENS IN THE WEST END

Rain Gardens are depressed absorbent landscapes that promote infiltration of rainwater back into ground water sources, recharging local aquifers (Greater Van- couver Regional District, 2005: 43).

Furthermore, rain gardens can have a significant ability to capture and remove pollutants from urban stormwater runoff (Atchison, 2006: 4). Unlike green roofs, which primarily promote the attenuation and reduction of stormwater runoff peaks, rain gardens (in adequate soil conditions) can completely remove the need for stormwater to enter municipal wastewater systems, providing a system that more truly represents predevelopment hydrologic cycles.

Within Vancouver, 95% of daily precipitation throughout the year is less then 25.4mm (Environment Canada, 2008). Using the SCS-CN method for a typical 24hr rainfall event 20mm of run off will be produced by impervious surfaces. The resultant total run-off generated from streets and sidewalks in the case study area during a typical 24hr rain event would be 99.36m^3 while potential run-off from roofs would be 54.70m^3, or a total site runoff from impervious surfaces of 154.06m^3.

In order to calculate the potential reduction of stormwater runoff, the design of rain gardens is assumed to have a sandy loam soil with a porosity of 40%, a soil depth of 1,000mm, and a ponding level of 150mm (Greater Vancouver Regional District, 2005: 44). Prior research from Portland has shown that a total area for rain gardens with these specifications needs to be about 5-7% of the impervious drainage area in order to infiltrate 50%- 95% of the total runoff generated annually (Kurtz, 2008). Given that Portland and Vancouver share similar precipitation patterns, this rule was used to test the potential efficiency of rain gardens in Vancouver's West End.

In the case study area using a 7% ratio of the at-grade impervious drainage area for boulevard rain gardens would allow for a total storage capacity of 105.63m^3 of water. Rain gardens that are sized to 7% of the roof areas, divided amongst the three residential towers, would have a total storage capacity of 53.6m^3. This leaves a volume of 1.1m^3 in runoff overflow from the roofs which could easily be handled by the boulevard bioretention facilities. Therefore, the use of boulevard bioretention facilities for the at grade drainage area and rain gardens for roof runoff would effectively allow for the capture of 95% of annual rainfall events. In order to meet the 7% area requirement to capture all stormwater on site, a total of 569m^2 is needed. This equates to 29% of the total available green space within the case study site. (Figure 7)

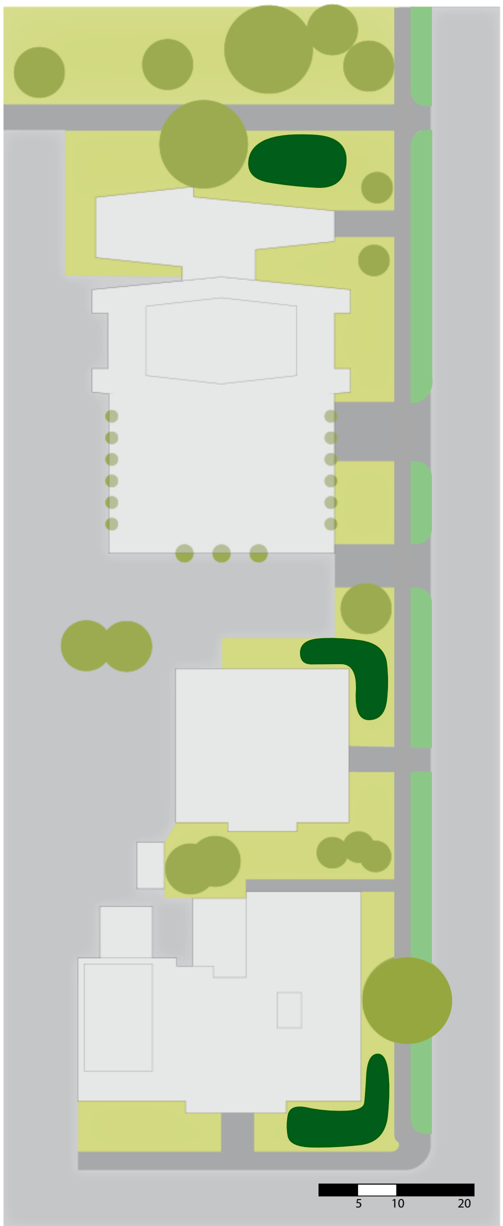


Figure 7. Rain Garden Scenario: Bioretantion Facilities and Rain Gardens.

Roof: **2735.08m2**

Asphalt (roads): **4150.20 m2**

Pavement (sidewalks and walkways): **817.70 m2**

Boulevard Bioretention Facilities: **377.56m2**

Rain Gardens : 191.46m2

MINIMIZING POTABLE WATER USE

Rain gardens not only serve an important function in mitigating stormwater and removing pollutants, they also serve as important landscape features along streets and sidewalks (Greater Vancouver Regional District, 2005: 43). As has been mentioned earlier in the discussion about green roofs, Vancouver's particular climate requires irrigation to keep most garden plant species healthy through the summer months. Particularly, the months of June through October in the Pacific Northwest, resulting in the greatest use of potable water for irrigation (WSU and Partnership: 251). Thus, neither rain gardens nor green roofs meet Vancouver's ideal to recreate predevelopment hydrologic cycles which do not require the use of potable water for irrigation (Greater Vancouver Regional District, 2005: 3).

In order to address irrigation needs, we have looked to 'naturalized' planting schemes that strives to reproduce the vertical stratification and natural canopy cover of a forested area. Previous research has found that to protect against rain garden failure with minimal irrigation, a minimum of three varieties of small tree, three varieties of shrub, and three varieties of ground cover should be used which are adapted to the varying stresses of wet and dry conditions (Department of Environmental Resources, 2007: pg. 82&90). Further Washington State University suggests that in order to create a stratified canopy similar to that of the native forests of the Pacific Northwest, spacing should be at 4.5-6m for trees and 1.2m for shrubs, on center and a 1:1 ratio of structural trees to shrubs is ideal. (WSU and Partnership, 2012; 75-76)

For this study, we elected to use an equal division of high, moderate, and low water use plants in the design scenario in order to create a multilayer canopy which accounts for the varying moisture conditions of rain gardens and establishes an evenly distributed root structure. Using crop coefficients and the commonly accepted rooting depths of groundcovers, shrubs, and trees to calculate the gardens' water needs, we calculated that rain gardens which mitigate roof runoff on our study site in the West End would require 185m^3 of water for irrigation annually.

DESIGNING FOR STORMWATER MITIGATION

In a typical year, rain gardens in the West End will require approximately .97m^3 of water per 1m^2 of area for irrigation each year. By utilizing 100% of the existing typical boulevard green space to establish boulevard bioretention facilities, our study site in the west end could meet 72% of the required area needed to mitigate the runoff generated by streets and sidewalks for 95% of annual rain events. If also using rain gardens as an alternative to green roofs to mitigate stormwater, 29% of the existing greenspace in a typical westend block would be needed to accommodate boulevard bioretention facilities and rain gardens.

Vancouver's specific climatic conditions mean that the greatest rainfall occurs during the lowest evapotranspiration period for vegetation and when soil moisture is consistently at or near field capacity. This means that in the wet months, the performance of green roofs is limited. They perform optimally for stormwater management during the dryest months, but they rely heavily on irrigation throughout these months to maintain healthy plants. As Vancouver's current policy and bylaws prohibit the use of cisterns and other stormwater collection methods, green roofs in Vancouver often rely on vast amounts of potable water.

Upon comparing at-grade stormwater mitigation measures such as rain gardens with green roofs for the purpose of retaining stormwater, it has become very apparent that the performance of rain gardens is far higher than that of green roofs. Typically, rain gardens can capture 95% of annual rainfall in Vancouver, while green roofs typically capture only 29%. In estimating irrigation requirements, rain gardens also ranked superior. Green roofs which would utilize 100% of the roof area on our study site have been found to require 1500m^3 of potable water for irrigation, while rain gardens and boulevard bioretention facilities which utilize 29% of the available green space on our study site require a mere 550m^3 of water for irrigation each year.

Not only do rain gardens promote stormwater attenuation and the reduction of peak flows, they also significantly reduce urban stormwater pollutants and have the ability to infiltrate water back into the ground. However, it should be noted that within this study we were unable to establish the nature of soils or below grade infrastructure. From simple observation of current developments within the West End it is highly probable that what appears to be pervious green space connected to below grade in-situ soils, may actually be a complex network of below grade infrastuctures which would severely inhibit the infiltration capacity of rain gardens. As such, it is suggested that further research is needed into the nature of below grade infrastructure before making further recommendations on the best methods for managing stormwater within Vancouver's West End.

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