The Feasibility of Installing a Green Roof System to Mitigate Large Water Runoff

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Abstract *— The purpose of this project is to determine if it is economically and physically feasible to install a water management system that will help solve the flooding problem that the educational institution XYZ has been presenting over the years. It was determined that a combination of an extensive green roof system and a rainwater harvesting system could be used for this situation. The weight that would be exerted over the existing roof satisfies the permissible load. The cost was determined to be $41,000. Given this and the actual economic situation of the institution, it was determined that in order to continue with this project, donations or sponsorships would be required.*

Key Terms *— Green roof, rainwater harvesting, stormwater runoff, water management.*

INTRODUCTION

XYZ is a public educational institution located in the west of Puerto Rico. The location of XYZ can be categorized as urban, which means that great amounts of stormwater runoff is generated from heavy rain events. XYZ has long been presenting flooding problems, with major consequences at one of its parking lots. The focus of this project is to find a feasible solution that will reduce the stormwater runoff in the adjacent areas, which will result in minimizing the effects of a flooding event.

Objectives

The objectives of these project are the following:

- Determine the physical feasibility of locating a green roof system in the building adjacent to the parking lot.
- Determine the economic viability of implementing this system.

Methodology

The following methodology was followed to complete the project:

- Determine the impact the impervious surfaces have on this area.
- Determine maximum load.
- Perform an economic analysis.

LITERATURE REVIEW

The growth of population has led to the development of civil infrastructure and many urbanized areas. Urbanized areas consist of areas with high concentration of impervious surfaces. This creates a problem in the event of heavy rainfalls, because the water runoff cannot infiltrate through the soil and absorbed to the underground water bodies, or because there is more water than the amount that the surrounding soil can absorb [1].

According to the Center for Watershed Protection, “stormwater runoff picks up and carries with it many different pollutants that are found on paved surfaces such as sediment, nitrogen, phosphorus, bacteria, oil and grease, trash, pesticides and metals. These pollutants come from a variety of sources, including pet waste, lawn fertilization, cars, construction sites, illegal dumping and spills, and pesticide application” [2]. This can create a water contamination problem and a public health crisis. Stormwater runoff is the major cause of urban flooding. Therefore, it is important to implement measures to manage stormwater that will reduce its adverse effects.

Stormwater management is defined by the Center for Watershed Protection as “the use of specific practices, constructed or natural, to reduce, temporarily detain, slow down and/or remove pollutants from stormwater runoff” [2]. EPA suggests that included among the benefits of effective stormwater runoff management are: "the protection of wetlands and aquatic ecosystems, improved quality of receiving water bodies, conservation of water resources, protection of public health, and flood control" [3]. The optimal option to avoid stormwater runoff is to preserve the natural vegetation undisturbed, which results in a much more cost-effective alternative [2]. Some alternatives used to manage stormwater runoff are green roof systems, infiltration planters, swales, inlets, catch basins, water harvesting, porous pavements, among other methods [4].

Green Roof Systems

A green roof is a green space created by adding layers of growing medium and plants on top of a traditional roofing system to help retain, absorb and filter storm water. Other than reducing the amount of storm water runoff, a green roof can delay the time when the runoff occurs, which results in less flow of water through the sewer systems at the peak flow hour and help moderate the temperature of the building. Other benefits include: acting as a filter, noise reduction, improving air quality, increasing the value of the property and acting as a recreational space or other amenity.

There are different types of green roof systems that can support different types of plants and amenities. Therefore, green roofs are classified into two types: intensive and extensive. Intensive green roof systems have deeper soil profiles to support a diverse variety of vegetation, including shrubs and trees, and recreational spaces like sidewalks, benches, among other. Intensive green roof systems can weight approximately 48 psf [5]. Maintenance in these types of roofs are higher and permanent irrigation and fertilization must be ensured. Extensive green roof systems are mainly intended for the prime benefits of green roofs and are not used for recreational purposes, like the intensive type. This type is characterized by its low depth and requires less maintenance. Extensive green roof systems can weight about 20 psf in average [5].

Green roofs are generally composed of the following layers [6]:

- Roof cover
- Waterproof membrane
- Drainage layer
- Filter layer
- Substrate
- Vegetation

The way a green roof system works is that part of the water that falls on if will be retained and absorbed by the system, say the soil and the plants, and the other part will be drained. The factors that influence the capacity of water retention and runoff in the system depend on:

- Specific characteristics of system such as the amount of layers and thicknesses in the system, type of materials, soil type, selected vegetation, roof geometry and dimensions [6].
- Climatic conditions such as the length of preceding dry period, season, temperature, wind conditions, humidity, intensity and duration of the rainfall event [6].

Rainwater Harvesting

Rainwater harvesting consists of collecting stormwater and storing it for later use. It is considered a small-scale best management practice and it is an economic solution [5].

Analysis

When a green roof system is implemented, a delay in the water runoff is experimented in comparison to a conventional roof. Therefore, a time gap between the peak runoff of a conventional roof and a green roof is created for the same rain event. This occurs because of the amount of water that is retained and absorbed by the green roof system. This is illustrated in Figure 1.

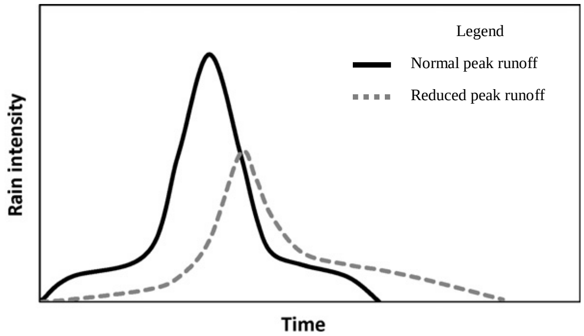

Figure 1
Peak Runoff Reduction

Stormwater Runoff

For this project there are two areas of interest: the area where the flooding occurs (271,477 ft^2) and the area where the green roof and where the rain water harvesting will be installed on (5,985 ft^2). In order to complete the runoff analysis, a second field visit was conducted, in which actual readings were obtained. The amount of rainfall was calculated as follows:

$(325\ cm^3) / (729.7\ cm^2) = 0.4454\ cm$

$0.4454\ cm / 2hr = 0.2227\ cm/hr = 0.2227\times10^{-2}\ m/hr$

The retention was estimated with a 50% of catch as follows:

$[0.2227\times10^{-2} m/hr \times 358.98\ m^2] \times 0.50 =$

$0.3997\ m^3/hr = 399.7\ L/hr = 105.6 gal/hr$

The data and results are summarized in Table 1.

Table 1
Rainwater Retention Estimate for Harvesting System

Time	Recipient	Volume	Rainfall	Retention
2 hrs	729.2 cm^2	325 mL	0.2 cm/hr	105.6 gal/hr

The National Oceanic and Atmospheric Administration (NOAA) is a government agency dedicated to studying and informing about the changes in the environment, including the ocean floors. The Atlas 14 is a tool from NOAA's National Weather Service (NWS) that delivers information about the precipitation frequency estimates in an area. This information is based on physical stations located in different parts of the country. This tool generates a full report that includes historical data and estimates based on the desired frequency, which will vary according to the study being carried-out.

Roof Load Capacity

The weight of a green roof has great variety that depends on the depth, the materials and other components. The important measurement is wet weight because that is when fully saturated fabrics and plants are at their heaviest. The saturated weight (q) of 23 psf taken from the Conservation Technology website [5], was used to perform the roof load capacity analysis.

In order to ensure that the installation of this system is feasible and safe, the deflection of the roof was computed following the Deflection of Concrete Floor Systems for Serviceability paper [5] as a guide. The slab thickness was assumed as a solid, one-way slab with both ends continuous. Based on these assumptions, and a span length (L) of 258 inches, equation (1) was used and the slab resulted in 10 inches.

$$\text{Slab Thickness } (h) = L / 28 \quad (1)$$

The deflection needs to be computed for the roof as is, without load, and also applying the load of the green rooftop system. The maximum permissible computed deflection (Δ_{MAX}) without load was calculated with equation (2) and resulted in 1.43 in.

$$\Delta_{MAX} = L / 180 \quad (2)$$

The deflection after the load is applied was computed with equation (3) and resulted in 0.0056 in. The coefficients used were the aspect ratio (γ) of 2.04, the deflection coefficient (k) of 0.0018 and the modulus of elasticity (E) of 4×10^6 psi.

$$\Delta = k\,(qa^4 / Eh^3) \quad (3)$$

Given that the deflection of the roof does not exceed the maximum permissible deflection, it is feasible to locate the green roof system in the selected roof.

Results

Based on the data collected on the field and on the data obtained from the Atlas 14, it was concluded that the stored water from the rainwater harvesting system could be used for irrigation of plants in dry weather. Figure 2 shows the amount of precipitation based on the amount of time of precipitation and the recurrence interval. For a 2-hour rainfall event, with a yearly recurrence, the precipitation estimate is approximately of 2.5 inches.

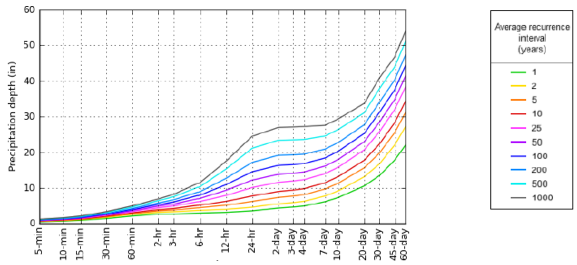

Figure 2
Graphic Precipitation Frequency from NOAA's Atlas14

According to the study carried out by Carpenter and Kaluvakolanu [7], the average water retention in a green roof system is between 45-78%. During the summer months, where most rain events occur, 70% to 80% of the precipitation that falls can be absorbed, whereas during the winter months 25% to 40% of the rainwater can be absorbed.

Proposed Design

The proposed design follows a granular drainage system described in the Conservation Technology website [5]. These types of layouts were designed to maximize the water retention, while minimizing the weight they exert over the roof. The proposed design will consist of an extensive type of rood with a 2 inches of extensive soil mix, such as horticultural pumice or scoria mix, cinder sand, peat moss, among other, 2 inches of granular drainage media, 0.25-inch layer of protection fabric, 0.125-inch layer of separation fabric, such as polypropylene, such as polypropylene, and a total of 4 inches of nominal thickness.

A variety of plants, such as the sedum herb varieties, can be used in this type of green roof system. The selected plant for this project is the sanseviera trifasciata, also known as golden hahnii and colloquially known as "lengua de vaca". The caracteristics of the sanseviera trifasciata is shown in Table 2 and an image is shown in Figure 3.

Table 2
Characteristics of Sansevieria Trifasciata

Typical Height	5 in
Typical Width	5 in
Light Requirement	Full Sunlight
Water Requirement	Dry Tolerant
Soil Requirement	Sandy soil
Maintenance	Low
Irrigation Frequency	Weekly
Growth Speed	Slow

Figure 3
Sansevieria Trifasciata (Golden Hahnii)

The sanseviera trifasciata tend to propagate abundantly, therefore for this design it is recommended to plant them leaving a 2-foot distance between plants. Given this specification, a total of 963 plants will be required.

In addition, a rainwater harvesting system is proposed to catch and store the remaining 50% of stormwater that will not be absorbed by the green rooftop. A 1,000-gallon HDPE tank is being recommended to store the water and use for irrigation purposes.

Cost Analysis

The price of the sanseviera trifasciata plant that would be used in the green roof system varies by size and ranges between $1.00-$2.00 per unit in a local nursery in Cayey called "El Pulguerito".

Taking $1.50 as an average price, the total cost for the plants is of $1,610.62 including taxes.

The cost of the green roof system, including materials and installation, ranges from $6.00/ft^2 to $12.00/ft^2; it all depends on the procedure that is to be used to install it and the green roof type using ASSA Caribbean Inc. of Puerto Rico as contractor. ASSA Caribbean Inc. of Puerto Rico is a local company located in Guaynabo, Puerto Rico that specializes in roof technologies including roof sealing techniques and green roof systems. Taking $9.00/ft^2 as an average price for the green rooftop and having calculated a total area of 3,864.29 ft^2 to cover, the total cost would be of $38,778.15, including taxes. Therefore, the total cost is:

Total Cost = Plants + Green Roof System + Water Tank = $1,610.62 + $38,778.15 + $599.99 = $40,988.76

Conclusion

From the load analysis it was determined that the physical implementation of this system is feasible, since the load it exerts is almost negligible. The total cost to implement a system that would reduce the stormwater runoff was calculated to be approximately $41,000.00 Given the fact that XYZ has a very limited budget, the only way it would be economically feasible to construct would be if it sponsored externally.

If the project is to be constructed, plants would need maintenance. Therefore, a plan can be arranged so that students can work with wage labor or as part of an engineering or agricultural sciences class or investigations.

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