Interaction between Theory and Practice in Civil Engineering and Construction
Edited by Komurlu, R., Gurgun, A. P., Singh, A., and Yazdani, S.
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ISBN: 978-0-9960437-2-4

THE POTENTIAL FOR GREEN ROOFS IN SUSTAINABLE URBAN DRAINAGE SYSTEMS

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Urban environments tend to lack the capacity to absorb water from precipitation. This is due to vegetated surfaces being replaced by impermeable ones, such as concrete, bitumen or similar. As a result problems can occur, where a period of heavy rainfall coincides with sudden increases in surface water runoff. This in turn can lead to a city's sewerage system becoming overloaded. Sustainable Urban Drainage Systems (SUDS), are recognized worldwide as a successful manner by which to mitigate this phenomenon. One of the principal components of SUDS are permeable areas in an urban setting, which have the ability to absorb and retain rainfall that would otherwise flow as surface runoff. To date there has been little research into what the effect of a massive increase in green roofs would have for cities in Ecuador. As a developing country, it is not uncommon for cities' sewerage systems to suffer collapse when faced with sudden rainfall peak loads. It is suggested in this paper, that instead of looking to implement costly sewerage expansion programs, it would be more cost effective to implement city scale green roof systems. The paper sets out to quantify the theoretical effect of such an initiative.

Keywords: Permeable surfaces, Sewerage, Stormwater, Runoff, Urban planning.

1 INTRODUCTION

The Metropolitan District of Quito (DMQ) has a total surface area of 423,000 ha, where the city itself makes up 19,014 ha (EPMAPS 2011). The main rivers of the city are Machángara, Monjas and Pita (EPMAPS 2011). As an additional point of interest, Quito overlies more than 33 gorges, the majority of which have over time been filled in and built over (EPMAPS 2011). According to the Public Metropolitan Company of Potable Water and Sanitation (EPMAPS) of Quito (2011), the sewerage discharge rates to the main rivers of the city are:

- Manchángara river = 3.48 m^3/s.
- Monjas river = 0.64 m^3/s.
- San Pedro river = 0.69 m^3/s.

In addition to the daily sewerage discharges from the city however, rainwater runoff also plays an important role in determining the urban wastewater distribution system capacity. As the urban area of Quito expands, like any city the amount of permeable ground of that previously unoccupied area, is replaced by hard surfaces that lead to increased surface runoff (Berndtsson 2009). This is turn causes a sharp increase in the flow rate that is needed to be absorbed by the city's sewerage system. One manner in which this can be mitigated is through the separation of rainwater and black water systems. However, in Quito this is not the case and the two flows are combined into one sewerage distribution system (EPMAPS 2011). In this paper it is argued that to better manage Quito's urban drainage systems, three types of intervention are possible:

(1) Increasing the capacity of the sewerage system.

(2) Increasing permeable (green) spaces at the ground level of the city.

(3) Increasing permeable (green) spaces at the level of the roofs of the city.

As a starting point, an annual peak rainfall in the wet season is taken into account. According to the 2014 Annual Meteorological Report of the National Institute of Meteorology and Hydrology (INAMHI 2011), the peak rainfall in Quito over 24 hours was 39.9 mm. This is equivalent to 39.9 l/m^2 in a 24-hour period.

2 INCREASING THE CAPACITY OF THE SEWERAGE SYSTEM

To begin with, an estimate can be made of the surface runoff by a) taking into account the total hard surfaces of the DMQ, and b) adopting an appropriate surface runoff coefficient. In terms of hard surfaces, 10% of the total urban area of Quito is made up of green spaces (Rivadeneira 2014.). This leaves 90% hard surfaces, which for the purposes of the present exercise it is assumed is made up primarily of concrete, paving, asphalt, tarmac, roof tiles and bitumen materials. Table 1 shows the surface runoff coefficients for these material types.

Table 1. Surface runoff coefficients for typical materials in a city's hard surfaces (Pande and Telang 2014).

Material	Surface runoff coefficient
Concrete	0.6-0.8
Paving	0.5-0.6
PVC geomembrane	0.85-0.9
Roof tiles	0.8-0.9
Corrugated metal	0.7-0.9

For this study an average value for the surface runoff coefficient of 0.7 is adopted. Then, if Quito's urban area is 19,014 ha (EPMAPS 2011) and 90% of this can be said to be hard surfaces (Rivadeneira 2014.), it can be deduced that the total surface runoff area is 17,112.6 ha. From this area the peak rainfall over 24 hours is 39.9 l/m^2, with an average surface runoff coefficient of 0.7. As such, the total peak load on the sewerage system is given by: 17,112.6 (ha) * 10,000 (m^2/ha) * 39.9 (l/m2/24hr) * 0.7 = 4,779,549,180 litres over 24 hours, or 55.32 m3 per second average over 24 hours. This is nearly 12 times greater than the total discharges of Quito's residual waters into the Machángara, Monjas and San Pedro rivers combined. It can therefore be concluded that rainwater runoff peak loads, are key in determining whether to increase the capacity of Quito's wastewater discharge systems. This was indeed the case in the Integrated Masterplan for Water and Sewerage for the DMQ, issued by the Metropolitan Public Company of Water and Sanitation (EPMAPS) in 2011. Amongst the suggestions, it was put forward to increase the number of drains to collect surface runoff flows, in addition to improving and increasing the infrastructure links of these drains to the main water network. The estimated cost of works for the Integrated Masterplan came to 161 292,262.25 USD (EPMAPS 2011). It can be said therefore, that increasing the capacity of the city sewerage infrastructure to accommodate peak rainwater runoff flows implies great costs. Additionally, the construction works are likely to be intrusive and over a lengthy time scale.

3 PERMEABLE (GREEN) SPACES AT THE GROUND LEVEL OF THE CITY

Given the lack of SUDS in Ecuador an international case study has been looked into, which has been selected as it was felt to represents an application of SUDS that could potentially be applied to Quito.

3.1 Vibrant Syracuse Spaces and Bioretention Area

The objective of the project was to transform an unused space into a parking lot for the company Gear Factory Inc, but in a manner whereby permeability of the ground was maintained (Mahoney 2011). This was achieved through a mix of using urban vegetation and permeable paving. The areas of vegetation have levels of rainwater filtration in the region of 95% (Berghage *et al.* 2009), and the permeable paving of 84% (Hernández and Martínez 2014). In the state of New York precipitation levels reach 107 mm per month (CustomWeather 2015). By implementing the strategies outlined above practically all of the otherwise 99.51 m^3 of rainwater runoff, from what would have been 930 m^2 of impermeable parking space, was avoided (Mahoney 2011).

4 PERMEABLE (GREEN) SPACES AT THE LEVEL OF THE ROOFS OF THE CITY

In Ecuador it is rare to see a green roof. Nevertheless, there are a number of examples can be drawn on. In this section two case studies of green roofs in Quito are presented. The first is the Ministry of the Environment building in Quito. The third is a private apartment building located in the North of Quito, called vivAlto. In order to understand these green roofs, the basics of green roof design needs to be outlined. A green roof can either be extensive, with a thin substrate and small plants, or intensive, with a thick substrate, large plants and significant subsequent loads on the building structure (Newton *et al.* 2007). For this paper, simple extensive green roofs are considered, where the aim would be that they are applied en-masse without too many complications being incurred on the building structure Two case studies are considered, both to be found in Quito, Ecuador: i) The Ministry of the Environment (MAE) building in Quito, and ii) the Vivalto apartment building. Regarding the MAE building, it was found out from the user of the building conducting the site visit, that the vertical garden was installed as a retrofit to the building (Ministry Technician 2015). A point of interest is that accessible green space was added to the building, without having to sacrifice any floor space of the building itself. Added to this, the garden furniture was made from recycled materials such as tyres, which proved to be not only comfortable, but also resistant to the elements over time. With relation to the Vivalto building, this was built by a private construction firm in Quito. The firm representative highlighted two point of interest in the application of a green roof (Soria, F., Personal Communication, Oct 12, 2015). First it was pointed out how great care needed to be taken over the waterproofing layer, where they had found there to be complications due to water infiltration into the building below. Second, it was pointed out how the green roofs were appreciated by the building residents, where despite being a high-rise, there were nevertheless green areas that children could play in. The roof is shown in Figure 1 (a) and (b).

(a) (b)

Figure 1. a) Green roof at the Ministry of the Environment building in Quito; b) one of the green roofs at the vivAlto building.

5 THE POTENTIAL FOR GREEN ROOFS IN SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS) IN QUITO

It was estimated in Section 2 of this paper, that the total urban surface runoff from Quito was 55.32 m^3/sec over a 24 hour period average. This was with the city having 10% green spaces and 90% hard surfaces. In addition, Quito has a total of 763,719 households (INEC 2010). These are then divided into the following typologies:

- House: 57% (435.320)
- Apartment: 29% (221.478)
- Room: 8% (61.097)
- Temporary housing: 6% (45.824)

The Quito Municipality (DMQ 2011) classifies the surface area the household occupies as:

- Small household ≤ 65 m^2
- Large household = between 65 and 120 m^2 (average = 92.5 m^2)
- Extra large household > 120 m^2 (taken for this study as = 120 m^2

By putting together the house typologies with appropriate surface area, the values shown in Table 2 can be calculated:

Table 2. Estimated roof surface areas for Quito.

Household Type	Total No. Households	Surface Area Classification (m^2)	Total Estimated Roof space (m^2)
Rooms and temporary housing	106,921	65	6,949,865
Apartment	221,478	92.5	20,486,715
House	435,320	120	52,238,400
Total			79,674,980

Overall, it can therefore be estimated that Quito's roof area amounts to approximately 7,967.5 ha. In order to assess the theoretical impact of green roofs in

SUDS for Quito, it is put forward that *all* the roofs have a green roof installed. This would amount to 43% of the 19 014 ha of the city's surface area.

In Section 4, the surface runoff coefficient from green roofs was given as ≤ 0.2. However, it also needs to be taken into account that in the event of peak precipitation loads, the capacity of a green roof to retain water will decrease as the substrate becomes saturated. This can especially be the case in winter periods (Berghage *et al.* 2009). According to Moran *et al.*, (2005, cited in Newton, Gedge, Earlyn & Wilson, 2007), in a peak rainfall of 36 mm/h, a 75 mm thick green roof in North Carolina had a peak flow reduction of 87% (surface runoff coefficient of 0.13). Over a six month testing period however, the average retention was 63% (average surface runoff coefficient of 0.37). Nevertheless, the weather of Quito is distinct to North Carolina, where a typical day in the rainy season consists of a morning with clear skies and sunshine, followed by an afternoon of heavy precipitation and a clear night. Given this, it seems reasonable to assume that the surface runoff coefficient from green roofs will be higher for peak rainfall loads that 0.2, but lower that the average in North Carolina of 0.37. For this paper an average has been taken between the peak flow reduction and average retention of Moran *et al.* (2005, cited in Newton, Gedge, Early & Wilson, 2007), giving a surface runoff coefficient of *0.25*. Let it be assumed that the peak rainfall is 39.9 ltr/m^2/24hr (INAMHI 2011), where instead of but 10% of the 19,014 ha of the city as green space, an additional 43% of the cityscape are green roofs with a surface runoff coefficient of 0.25 (given the period of heavy rainfall). The total peak load on the sewerage system would be given by:

Hard surfaces: (17,112.6 – 7,967.5) (ha) * 10,000 (m^2/ha) * 39.9 (l/m^2/24hr) * 0.7 = *2,554,226,430 litres over 24 hours*, or 29*.56 m^3 per second average over 24 hours*

Green roofs: 7,967.5 (ha) * 10,000 (m^2/ha) * 39.9 (l/m^2/24hr) * 0.25 = *794,758,125 litres over 24 hours*, or 9*.20 m^3 per second average over 24 hours*

Thus giving a total of *38.76 m^3 per second average over 24 hours*. Compared to the original surface runoff to the sewerage system of 53.32 m^3 this represents a reduction of 30%, which could be said to mitigate the need for the expansions proposed by EPMAPS in Section 2.

6 CONCLUSIONS

This paper set out to examine the effect of the widespread application of green roofs in Quito, Ecuador, as a possible alternative to costly sewerage expansion works. Wastewater discharges were studied, and it was shown that peak rainfall runoff was key in justifying expansion works. National case studies of green roof applications were looked into. International case studies of permeable surfaces were also studied. Overall, it was found that in theory should all of the roof space of Quito be harnessed as green roofs, there would be a 30% reduction in peak flows to the sewerage systems. This is likely to have a positive impact in mitigating the needs for costly sewerage expansion works. Additionally, there would be further room to implement permeable surfaces at the ground level of the city.

7 RECOMMENDATIONS FOR FURTHER RESEARCH

The following points are highlighted as of interest for further research. First, further study into the amount of reduction in surface runoff that would be necessary to completely abandon plans for sewerage expansion, coupled with research into possible locations of permeable spaces at the ground level of Quito. Second, study into building typologies and their structures, in order to assess whether green roofs are feasible, in conjunction with social research into the acceptability of green roofs and a study of financial mechanisms to promote their application en-masse.

Acknowledgements

Special thanks needs to be made to Marlon Rios, a student of Architecture at the Pontificia Universidad of Ecuador. His background research in quantifying the total roof space of houses in Quito was invaluable in the development of this paper. In addition, the site visits for the case studies would not have been possible without the support and collaboration of Francisco Soria, Director of the Corprancagua construction company, as well as the Subsecretary of Environmental Quality of the Ministry of the Environment of Ecuador.

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