

## GREEN ROOFS RUNOFF COEFFICIENT: DIFFERENT TIME-SCALE APPROACHES TO ESTIMATE ITS VALUE

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### Abstract

The high impermeabilization in densely populated areas brings numerous problems concerning stormwater management, mainly when intense precipitation events occur. This is frequent in the beginning of the winter/rainy season in the Mediterranean region, namely in Portugal. Implementation of nature-based solutions in general, and green roofs in particular, can minimize the damages caused by such events in urban areas. The reduction of stormwater runoff in Green Roofs (GR), can be estimated with the runoff coefficient, a parameter that assesses their hydraulic performance and contributes to the design of the drainage systems downstream. Due to their natural characteristics, GR have variable performance throughout the year and so models used to determine runoff coefficients should reproduce this behaviour as realistically as possible, adjusted to each season and climate region. In this study, monthly runoff coefficient determination, using experimental data, was assessed through the use of a previous developed model. Runoff coefficient was also determined using different time periods (monthly, weekly and per rain-events) to assess the most adequate approach, considering the practical uses of this coefficient. The monthly determination approach resulted in lower runoff coefficient values, than the weekly or per rain-event determination. However, when applied to a long-term performance analysis, this study showed no significant differences when using the monthly, weekly or per rain-event runoff. Furthermore, the results revealed the need to improve the model for extensive Green Roofs determination, taking into consideration other variables besides temperature and precipitation (e.g. early-stage moisture conditions of the GR matrix). The assessment of different time scales for runoff coefficient determination is a major contribution for GR future performance assessment, and a fundamental decision support tool.

## 1. INTRODUCTION

Fast urbanization over the last decades and the consequent increase of impervious surfaces (through the urbanization of natural soils), brought negative environmental impacts to the urban environment. These changes disrupt the urban hydrological cycle (reducing the ability to intercept, store and naturally infiltrate stormwater runoff) leading to a higher risk of urban flooding exacerbated by climate change [1], with catastrophic consequences in terms of casualties and economic losses [2]. Urban Green Infrastructure (GI) can be used to reduce the amount of stormwater runoff entering traditional drainage systems, through the natural retention and absorption capabilities of vegetation and soils [1] by promoting the infiltration of rainwater to groundwater recharge. Besides, they are often a cheaper, more robust and sustainable solution when compared to traditional gray solutions [3]. Green Roofs (GR) are a relevant example of GI, implemented worldwide as one of the best solutions to manage urban stormwater (through rainwater retention and, the delay and decrease of peak volume) which can greatly alleviate the pressure over urban drainage systems [4]. Hydraulic efficiency of GR has been studied in the last years, being the configuration of the GR system one of the key factors of its performance (substrate depth). However, few studies have focused on the hydrological performance of GR under Mediterranean climate, which is characterized by dry summers and mild wet winters, leading to a seasonal effect on its runoff coefficient (dimensionless parameter that represents the reduction of stormwater runoff), and

therefore must be adjusted to each season and climate region. A proper runoff coefficient determination, as realistic as possible, is thus fundamental to correctly assess GR performance especially in the Mediterranean region, as well as to adequately size the drainage networks downstream. Monteiro et al. [5] developed a model for runoff coefficient prediction for extensive GR in a Mediterranean climate, showing that there are in fact significant variations throughout the year (is seasonally strongly dependent), showing that the use of annual average runoff coefficients in sizing the tanks and other components of rainwater drainage and harvesting system is not feasible. Furthermore, a monthly water balance and consequently a monthly runoff coefficient determination also do not reflect the precipitation intensity variation that occurs in such period, where several days without precipitation or, instead, intense precipitation events may occur. So, in an attempt to clarify the implications of runoff coefficient determination using distinct time periods, this study aimed to determine, the runoff coefficient using a simulation approach, and different time sequences (a month, a week and per rain-event) to conclude which one is the most adequate to size GR systems outflows and their drainage networks, and to determine their long-term performance.

## 2. MATERIALS AND METHODS

### 2.1. GREEN ROOF EXPERIMENTAL PILOT SYSTEM

An extensive GR pilot system of 0.4 m<sup>2</sup>, was implemented on a rooftop in an urban Mediterranean area, at Escola Superior de Biotecnologia – Universidade Católica Portuguesa, Porto, Portugal, under real environmental conditions (Figure 1) and monitored over a whole year with different rainfall conditions.

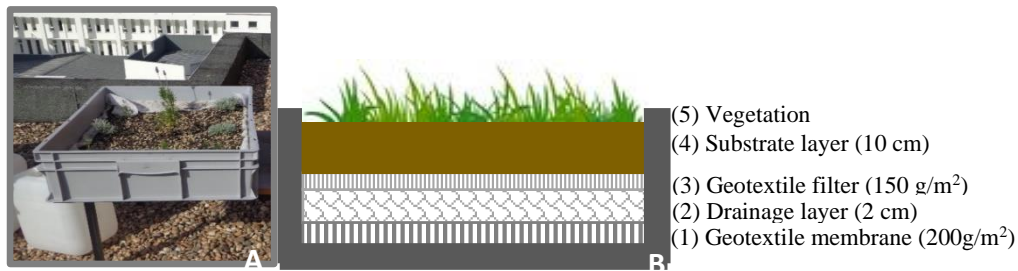


Figure 1 – Green roof experimental set up (A) and layers scheme (B).

### 2.2. RUNOFF COEFFICIENT DETERMINATION – SIMULATION USING DIFFERENT TIME-SCALE APPROACHES

Given the importance of runoff coefficient for GR design, a simulation study was accomplished using different estimated runoff coefficients, to assess how a 200 m<sup>2</sup> GR with the same characteristics of the pilot one, would perform considering each runoff coefficient (monthly, weekly and per-rain event).

## 3. RESULTS AND DISCUSSION

The difference between the annual water inflow into the GR (precipitation and irrigation) and the annual water outflow (water that runoffs downstream the system), divided by the annual inflow, corresponds to the rainwater retention rate. The real value was determined by making a balance at the end of the experience with the pilot GR, considering the total amount of water that entered the pilot GR and the total amount that left through the drainage pipes, and extrapolating to the 200 m<sup>2</sup> area of the simulated one. Table 1 presents the results for runoff coefficient and retention performance for the simulated 200 m<sup>2</sup> GR.

Table 1 – Runoff Performance results of the simulated GR (1-y monitoring).

	Precipitation (m <sup>3</sup> )	Irrigation * (m <sup>3</sup> )	Runoff (m <sup>3</sup> )	Retention (%)
C monthly (simulation)			24.0	90.2
C weekly (simulation)	217.9	26.6	24.9	89.8
C rain event (simulation)			24.8	89.9
Real obtained value (annual)			25.4	89.6

\* The irrigation volume has been estimated based on the irrigation of the present experimental studies, extrapolating for a 200 m<sup>2</sup> area.

Results show a similar outcome for runoff coefficient when using monthly, weekly or per independent rain event because the large study period embraces the variations of the results. In other words, the sum of the shorter water balances meets the result of the monthly average ones. This indicates that the use of monthly values for runoff coefficient, although not suitable for sizing drainage systems, might be used to estimate their long-term performance. The runoff coefficient achieved values are in accordance with the ones presented in previous studies determined for single rainfall events in extensive GR. Schärer et al. [6] presented runoff coefficients ranging from 2.3%–41% in extensive GR's located in four Norway cities, colder than Porto region, which explains higher runoff values. Gong et al. [7] registered in Beijing a runoff retention rate between 12.1%-100% for five types of extensive GR. Also in China, Liu et al. [4] studied different models of extensive GR and observed a runoff retention for these GR ranging between 17.6%–42.1% with an average value of 33.2% under low rainfall intensities, and an average runoff retention of 23.0% (ranged from 6.7%–37.1%) under high rainfall intensities. Artificial experimentation studies can also overestimate the benefits because the test rigs are 100% green coverage, whereas, in real scenario, GR often have quite high proportions of conventional roof surface at the periphery, and/or to provide access for maintenance, or eventually not fully covered by vegetation. Investigating a well-established, real GR which is subject to local weather patterns, will reveal GR characteristics that can be sensibly applied to the real world [5].

#### 4. CONCLUSION

Runoff coefficient determination in new installed GR systems is fundamental to assess their hydrological performance and to size the drainage networks downstream. Determination of runoff coefficients must rely on feasible models that reproduce their retention behaviour as realistically as possible, taking into consideration other variables from local climate characteristics (e.g. air humidity, solar radiation, antecedent dry weather period) and GR system composition (e.g. substrate mixture and vegetation type and retention capacity). When applied to a long-term performance analysis, there were no significant differences when using the monthly, weekly or per independent rain event runoff, resulting in a variation of only 0.9 m<sup>3</sup> of annual runoff. This indicates that the use of monthly values for runoff coefficient, although not suitable for sizing drainage systems, might be used to estimate their long-term performance. Future developments of this study should consider the assembling of a more versatile model to estimate the runoff coefficient of extensive GR placed at the Mediterranean region, and then assess its implementation on a real large-scale GR. Given the sustainability of GR over their full life cycle, policies are needed that encourage their use through regulation or financial incentives (such as water or property fee reduction).

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#### References

- [1] Liu, W.; Feng, Q.; Deo, C.R.; Yao, L.; Wei, W. 2020. "Experimental Study on the Rainfall-Runoff Responses of Typical Urban Surfaces and Two Green Infrastructures Using Scale-Based Models". *Environmental Management* 66, 683-693.
- [2] Cristiano, E.; Farris, S.; Deidda, R.; Viola, F. 2021. "Comparison of blue-green solutions for urban flood mitigation: A multi-city large-scale analysis". *PLoS ONE* 16, e0246429.
- [3] EEA. 2020. "What is green infrastructure and why is it important?" S.l.: European Environment Agency.
- [4] Liu, W.; Fen, Q.; Chen, W.; Wei, W.; Deo, R.C. 2019. "The influence of structural factors on stormwater runoff retention of extensive green roofs: new evidence from scale-based models and real experiments". *Journal of Hydrology* 569, 230-238.
- [5] Monteiro, C.M.; Calheiros, C.S.C.; Pimentel-Rodrigues, C.; Silva-Afonso, A.; Castro, P.M.L. 2016. "Contributions to the design of rainwater harvesting systems in buildings with green roofs in a Mediterranean climate". *Water Science and Technology* 73, 1842-1847.
- [6] Schärer, L.A.; Busklein, J.O.; Sivertsen, E.; Muthanna, T.M. 2020. "Limitations in using runoff coefficients for green and gray roof design". *Hydrology Research* 51, 339-350.
- [7] Gong, Y.; Yin, D.; Li, J.; Zhang, X.; Wang, W.; Fang, X.; Shi, H.; Wang, Q. 2019. "Performance assessment of extensive green roof runoff flow and quality control capacity based on pilot experiments". *Science of the Total Environment* 687, 505-515.