

Long Term Hydrological Performance of a Blue-Green Roof as Urban Nature-Based Solution [†]

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Abstract

Effective water management is a core function of nature-based solutions (NBSs), enabling them to deliver vital ecosystem services and enhance urban resilience. This study examines the hydrological performance of a specific NBS, the Blue-Green Roof (BGR). In contrast to conventional green roofs, the BGR incorporates a subsurface storage layer that retains infiltrated rainfall, thereby sustaining vegetation, boosting evapotranspiration and cooling, and reducing the burden on urban drainage systems. The research evaluates the BGR's hydrological dynamics over the long term, drawing on data collected between May 2021 and May 2025 at a pilot site in Central Italy.

Keywords: blue-green roof; green roof; nature-based solutions; resilience; water management

1. Introduction

Urban areas are increasingly exposed to pressures from population growth, rapid land-use change, and climate extremes, including prolonged droughts and intense rainfall events [1]. These factors heighten the risk of pluvial flooding and intensify urban heat islands, posing challenges to infrastructure, public health, and overall urban livability [2]. The COVID-19 pandemic has further emphasized the importance of accessible green spaces in cities, which provide critical benefits for physical and mental well-being [3].

To address these intertwined challenges, cities are implementing a mix of conventional stormwater measures, such as rainwater harvesting [4], alongside nature-based solutions (NBSs) that enhance urban resilience while delivering multiple co-benefits, including biodiversity support, improved air quality, and local cooling [5]. Among NBSs, green roofs (GRs) are widely adopted for their ability to reduce stormwater runoff, lower building energy demand, and moderate surface temperatures [6].

An evolution of traditional GRs, the multilayer blue-green roof (BGR) combines vegetated layers with engineered subsurface storage to retain, regulate, and potentially reuse rainfall. By integrating the hydrological benefits of water retention with the ecological and thermal advantages of vegetation, BGRs offer enhanced stormwater management, flood mitigation, and cooling capacity in densely built urban areas [7].

Recent implementations in Mediterranean contexts have demonstrated their capacity to adapt to highly variable climatic conditions, including seasonal droughts and episodic



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heavy rainfall [8–10]. Building on these advances, this study assesses a pilot BGR installation in Central Italy, analyzing a four-year dataset (May 2021–May 2025) to evaluate its real-world hydrological performance at the monthly scale, allowing considerations about its contribution to urban resilience.

2. Materials and Methods

The BGR examined in this study is the Polder Roof system (Figure 1) developed by Metropolder (Amsterdam, The Netherlands), and installed at the Tuscia University hydrological experimental site (<https://mechydrolab.unitus.it/pages/?page=homepage>, accessed on 1 April 2026). The Polder Roof is a multilayer technology specifically designed to enhance rooftop water retention and controlled release [11]. The investigated prototype consists of a vegetated layer composed of *Sedum album* and *Sedum acre*, species selected for their high tolerance to arid Mediterranean conditions, underlain by a lightweight engineered soil substrate (70% pumice, 20% peat, 10% sand).



Figure 1. The investigated Polder Roof.

Below the soil, a geotextile filter fabric allows percolation while preventing particle migration into the 8 cm Permavoid storage layer. The structure is sealed by a waterproof membrane that protects the underlying roof. A smart, remotely controlled valve—set at a 7 cm water level for this study—was used to maximize storage capacity and maintain consistent management rules, allowing for a direct comparison with conventional green roofs in terms of stormwater retention and release dynamics under Mediterranean climatic conditions. Outflow was directed into two rain barrels (each one with a volume of 1000 L) equipped with Baro-Diver[®] sensors (Vanessen) for continuous monitoring.

Meteorological forcing was measured at the nearby Tuscia macro-hydrological station [12], which includes four rain gauges, an air thermometer, a pyranometer, and an anemometer. In addition, on-site thermometers and Baro-Diver[®] sensors were used to measure local air temperature and water level variations, ensuring accurate barometric compensation. All variables were logged at a temporal resolution of 5 min. The dataset analyzed in this work spans four years (May 2021–May 2025). The present analysis focuses on the hydrological response of the BGR at the monthly scale, with data processing procedures including time synchronization to CET+1 and filtering to remove barometric noise and spurious fluctuations related to evaporation processes.

3. Results and Conclusions

Figure 2 presents the monthly cumulative rainfall alongside the corresponding runoff from the polder roof over the four-year monitoring period (May 2021–May 2025). The data highlights the polder roof's consistent performance in retaining rainfall and mitigating urban runoff in a densely built environment. Over multiple months, cumulative precipitation varied widely—from as little as 10 mm to over 130 mm—yet runoff was often negligible, with runoff coefficients frequently at 0%. Even during wetter periods, when some runoff was observed, coefficients typically remained below 20%, with only occasional peaks exceeding 50%, such as in December 2021 (69.2%) and December 2022 (56.0%). Such variability in runoff coefficients likely reflects differences in antecedent moisture, rainfall characteristics, and seasonal evapotranspiration. Thus, total rainfall alone does not determine runoff response; the timing and temporal patterns of rainfall are crucial for understanding BGR hydrology.

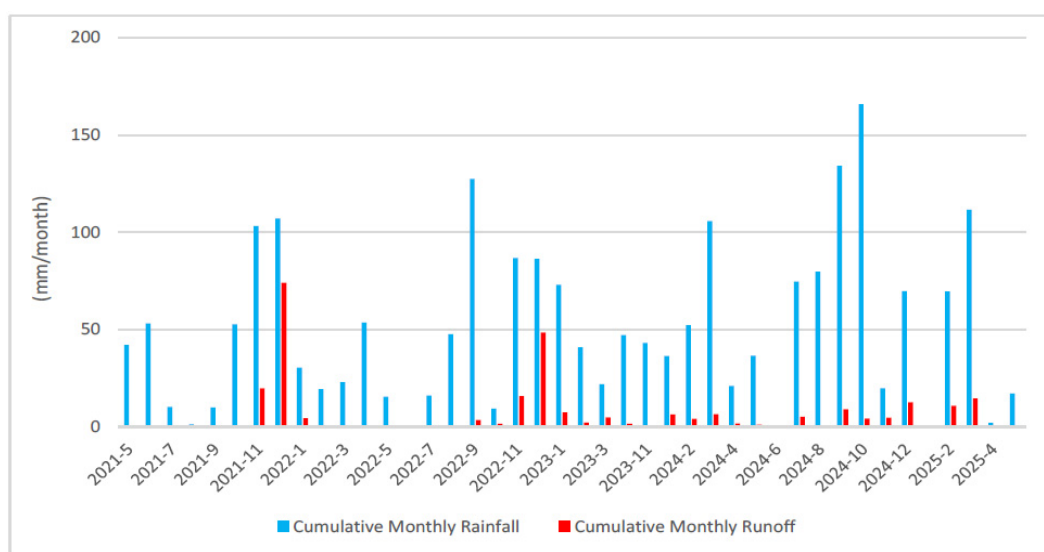


Figure 2. Monthly cumulative rainfall and runoff measured on the Polder Roof.

Previous studies conducted at the event scale have demonstrated that BGR can moderate both the volume and intensity of runoff entering urban drainage systems in Mediterranean climates [9,10]. The results presented here show that the Polder Roof functions as an effective urban water buffer across different years and seasons. This is particularly relevant in urban areas, where impervious surfaces often accelerate runoff and exacerbate drainage challenges. However, large-scale implementation of BGR can be challenging in several urban contexts. Combining them with other NBSs, such as permeable pavements and vegetated swales, could contribute to a more distributed and adaptive approach to stormwater management and a reduction in urban flood risk.

The findings suggest that incorporating polder roofs into urban landscapes represents a viable nature-based strategy for strengthening urban resilience, supporting sustainable stormwater management, mitigating climate-related risks such as flooding and heat, and promoting the multifunctional utilization of rooftop areas.

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