



Comparing Constant and Gaussian Rainfall Patterns in Experimental Setups [†]

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[†] Presented at the 6th International Conference on Efficient Water Systems (EWaS6), Thessaloniki, Greece, 11–14 May 2026.

Abstract

This study investigates the accuracy of the constant-intensity rainfall approach in laboratory experiments with artificial rains by replacing the conventional application with a time-varying profile modelled by a Gaussian curve. The aim is to assess how a non-uniform rainfall pattern affects the hydrological responses of green roofs and whether it offers a more realistic representation of natural precipitation. The methodology includes developing a Gaussian-shaped intensity and conducting comparative tests with an equivalent constant-intensity set. The results showed that constant-intensity rainfall can represent the hydraulic response of green roofs, providing a simpler, more practical setup and still accurate.

Keywords: rainfall assessment; experimental investigation; green roof; hydraulics; stormwater management

1. Introduction

The rapid growth of urban centres has had a major impact on biodiversity, ecological systems and human well-being, causing global repercussions [1,2]. And although urban growth often involves modifying ecosystems, one very promising solution has been to adapt cities to the natural environment around them [3].

Therefore, the future viability of cities depends on reintegrating nature into urban planning [4,5]. However, even with projects to increase green areas to mitigate the impacts caused by increased urbanisation, the urbanisation process has led to a decrease in green areas in most cities around the world [6].

The main issue is that this increase in climate change leads to an increase in extreme rainfall events and their intensity [7]. And with the loss of these green areas comes a loss of infiltration areas, which hinders stormwater management, as a greater volume of water ends up being discharged into the city's drainage system [8].

In this context, the use of nature-based solutions (NbS) represents a promising solution because it generates not only ecological but also social and financial benefits [9]. Among these NbS, rooftops are a challenging solution because they utilise spaces that are normally overlooked and give them a new purpose. Several studies are based on these structures [10,11]. To conduct these studies, a constant representation is typically used, where the average of a real case is chosen. The problem is that although this is a more practical representation for artificial rainfall setups, real rainfall presents many variables



Academic Editor: Vasilis Kanakoudis,
Evangelos Keramaris, Francesco
De Paola, Habib Muhammetoglu
and Theodora Papamitsou

Published: 1 July 2026

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such as peak rainfall value, time of greatest intensity, and variation from peak to average precipitation [12]. Therefore, it is important to ascertain whether this simplification can generate the hydraulic response of real cases.

This study aims to analyse whether this simplification is a trustworthy representation. To do this, two sets of experiments were performed. One set entailed a Gaussian curve to realistically represent a rainfall event, and another one with a constant inflow, both resulting in the same average inflow. The tests were conducted on a green roof model with artificial rainfall. This makes it possible to generate the desired inflow and measure the hydraulic response of the green roof through volumetric and temporal values of runoff and subsurface outflow.

2. Materials and Methods

The experiments were carried out in the Department of Civil, Building and Environmental Engineering (DICEA) of the University of Napoli Federico II at Naples, Italy ($40^{\circ}49' \text{ N}$, $14^{\circ}11' \text{ E}$) under Mediterranean climate. For the experiments, two rainfall patterns were chosen to be tested on an extensive green roof. The first pattern followed a constant intensity of 45 mm/h, and the second followed a Gaussian equation that also resulted in rainfall of 45 mm/h, corresponding to violent rainfall occurrences [13].

2.1. Experimental Setup

The model consists of a main structure with a length and width equal to 2 m and a height of 63 cm, with a 10 cm substrate and grass inside (Figure 1). The structure is open at the top with a framework for generating artificial rainfall through an irrigation system with inflow control to generate rainfall with the desired intensity.



Figure 1. Green roof model.

To evaluate the soil responses of the green roof, volumetric containers with an accuracy of 0.05 litres were used for measuring the outflow rate. Recordings were taken at a 2 min interval. A rate that is enough to capture the variations in the outflow between the constant and Gaussian inflow patterns and sufficiently sensitive to measure flow variations without them being affected by measurement noise. By monitoring outflow values over time, it is possible to understand the water infiltration and retention process and thus evaluate the structure's response to both rainfall models.

2.2. Rainfall Profiles

For the experiments, the irrigation system was used to generate two artificial rainfall patterns. In the first case, a Gaussian equation was used to model rainfall (Equation (1)). For comparison, a second case of constant intensity was used to verify the approximation's ability to represent a real case in a more practical way.

$$f(x) = a \exp\left(-\frac{(x-b)^2}{2c^2}\right) \quad (1)$$

where a is the maximum value of the curve (75.87 mm/h) and is the central point of the curve, x is the time variable, b is the position of the centre of the curve (15 min), and c is the standard variation (12 mm/h). The value c depends on the distribution, whether the curve is sharper or wider. The selected value results in a wide storm, chosen because it represents a sudden case and guarantees precise inflow (<20 mm/h) due to facility limitations.

Figure 2 represents the plot of Equation 1 for a rainfall duration of 30 min. As the values of the equation would be the central ones, an additional 1.5 min was considered to match the last timestep. In addition, the equation still generates some additional values to generate a more realistic rainfall stop. Despite this, these values were not considered for the average rainfall period, as they represented less than 10% of the rainfall volume. Thus, the peak is slightly shifted towards the beginning of the event, which more accurately represents real rainfall.

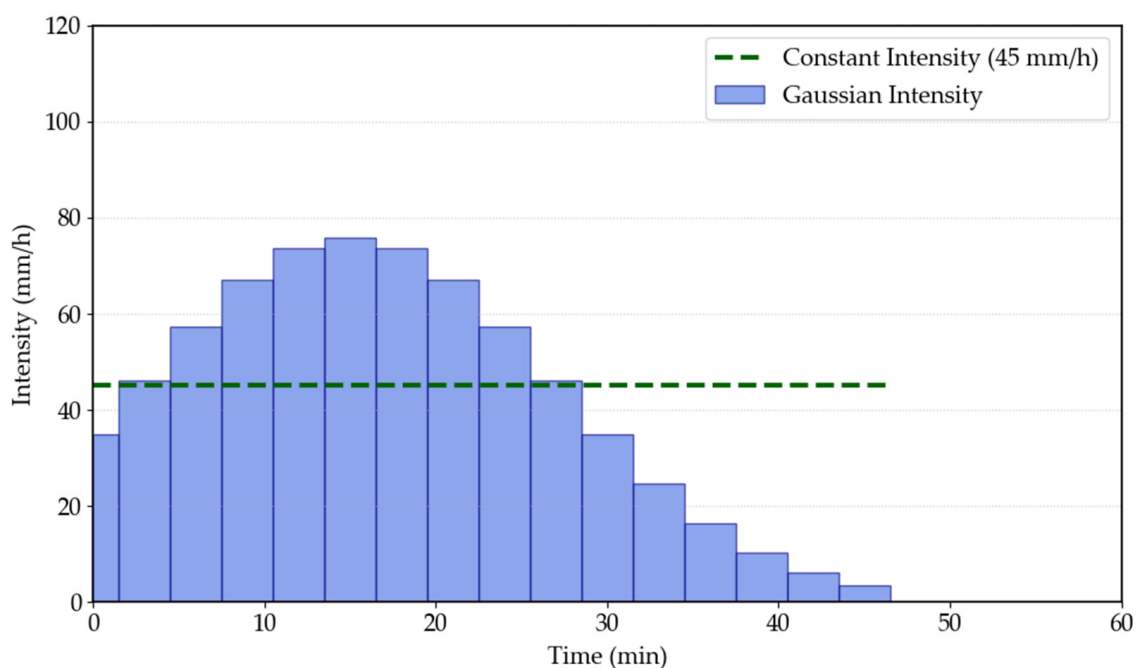


Figure 2. Gaussian and constant inflow.

3. Results

Figure 3 shows the hydrological response of the green roof for the case with a Gaussian curve and for a constant inflow, both with an average value of 45 mm/h, which is classified as violent rain. Figure 3a represents the unit value per minute and green roof area for both cases, and Figure 3b represents the accumulated value per area for both cases. All outflow was generated by water that infiltrated the soil, as there was no runoff.

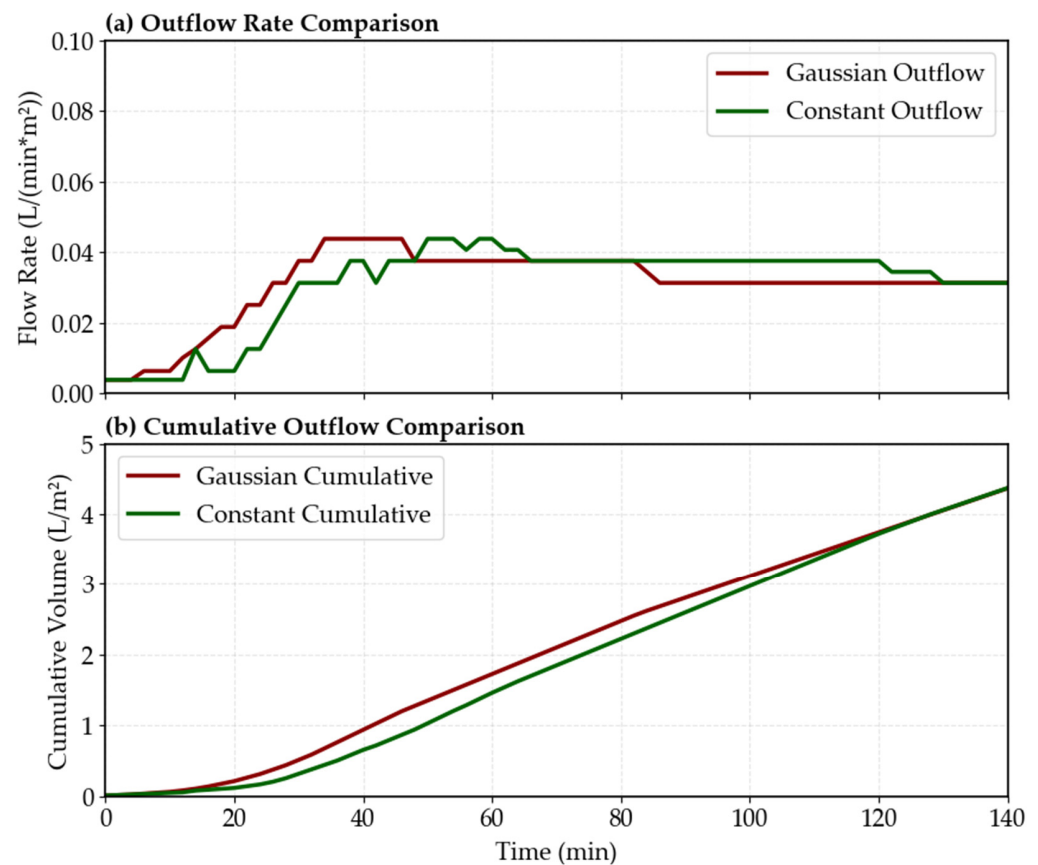


Figure 3. Hydrological responses of the green roof: (a) unitary outflow of the model; (b) cumulative outflow of the model.

In Figure 3a, the outflow from the constant rain case showed slower growth, reaching the peak of $0.0875 \text{ L}/(\text{min} \times \text{m}^2)$ at the end of the rain event. Followed by a decrease to $0.0625 \text{ L}/(\text{min} \times \text{m}^2)$, which remained constant for 56 min, 22% minutes longer than the duration of the rainfall. Meanwhile, in the case with the Gaussian distribution, there was a more gradual increase in outflow, with the same peak value of $0.0875 \text{ L}/(\text{min} \times \text{m}^2)$ that occurred in the last 1/4 of the event. Notably, the Gaussian curve showed an earlier peak with the same duration and intensity as the constant case. In addition, the constant case showed a more gradual decrease in outflow, but subsequently equalled that of the constant case, and both remained stable.

Figure 3b shows that both cases maintained a very similar accumulated value throughout the first 1/3 of the rain event. Despite the greater increase in the Gaussian curve, the more gradual decrease in outflow in the constant case generated an approximately equal cumulative value of $3.75 \text{ L}/\text{m}^2$ after 2 h from the start of the event, approximately the duration of the rain plus 160%. This value, despite increasing, remains the same for both cases after the end of the measurement due to the gradual decrease and minimal variation at the end of the primary drainage phase.

4. Discussion and Conclusions

The Gaussian curve showed an earlier peak runoff due to the higher maximum rainfall intensity of this model during the first 1/2 of the event; however, the ability to absorb and retain soil water generates the same total outflow shortly after the event. Despite specific differences, the soil showed a very similar hydraulic response in the long run for both cases.

Thus, the Gaussian curve does not offer a robust advantage in long-term analyses. However, its uneven distribution shows a significant difference in analyses during rainfall and in the period immediately following it. Therefore, in long-term analyses, constant intensity is more advantageous because it is easier to implement and yields very similar results, especially over larger time scales.

When taking this into account, it is also important to think about the scale of the experiment and apply it to real-world scenarios. The experiment ran on a 4 m square surface (2 m by 2 m). A surface area this size is big enough to avoid the edge effects that come with smaller micro-scale testing, but it mainly looks at vertical infiltration and first-flush drainage behaviour. Despite this area being of considerable value, in a full commercial setup, it is common to have much bigger areas. While the comparative retention capacity between the two different rainfall patterns is valid, the actual timing of the outflow peaks might be a little far from real-world scenarios, since larger areas are less subject to effects such as soil cracking caused by roots or the dry–wet soil cycles in localised zones.

In terms of general behaviour, the results presented were consistent with other studies. Where there was retention of a large part of the rain, gradual growth of outflow, and no generation of runoff for this intensity and duration of rainfall [10,11]. So, neither of the two models is outside what is considered realistic, but they are being analysed in the search for a model more faithful to real rainfall. However, for a fully comprehensive analysis, it is necessary to analyse other precipitation patterns. Another possible study would be the evaluation of non-symmetrical patterns, such as front-loaded storms and back-loaded storms, or cases of two increases interspersed by a drop in intensity. These other curves can define the inflow in a more subtle way, generating hydraulic responses that are more consistent with reality. This is because they more closely resemble the erratic nature of real rainfall, in which factors such as the moment of peak precipitation determine its essential characteristics.

Despite this, there are still some variables to be considered for possible future studies. One would be the analysis with different substrate depths, since the experiment was carried out only with an extensive green roof. However, it is worth noting that greater soil depths should generate more similar results between the two curves, since it has been shown that water retention absorption capacity generates uniform outflow, and greater depth generates greater water storage capacity due to its larger volume. Another would be different rainfall intensities; however, lower intensity would not represent such a critical case for stormwater management, and higher intensities would already be very extreme and rarer cases.

Author Contributions: Conceptualization, F.R.d.C. and F.P. (Francesco Pugliese); methodology, F.R.d.C. and F.P. (Francesco Pugliese); validation, F.R.d.C. and F.P. (Francesco Pugliese); formal analysis, F.R.d.C.; investigation, F.R.d.C. and F.P. (Francesco Pugliese); resources, F.P. (Francesco Pugliese), L.D. and F.P. (Francesco Polverino); data curation, F.R.d.C.; writing—original draft preparation, F.R.d.C.; writing—review and editing, F.P. (Francesco Pugliese) and L.D.; visualisation, F.R.d.C.; supervision, F.P. (Francesco Pugliese), L.D. and F.P. (Francesco Polverino); project administration, F.P. (Francesco Pugliese) and L.D.; funding acquisition, F.P. (Francesco Pugliese) and F.P. (Francesco Polverino). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study is available on request from the corresponding author. The data is not publicly available currently to ensure the proper interpretation of the experimental parameters and raw sensor outputs.

Conflicts of Interest: The authors declare no conflicts of interest.

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