# Evaluating the hydrological behavior of a green roof in different hydrometeorological contexts: comparison between Belo Horizonte Metropolitan Region (Brazil) and Ile-de-France

# Évaluation du comportement hydrologique d'une toiture verte dans différents contextes hydrométéorologiques : comparaison entre la région métropolitaine de Belo Horizonte (Brésil) et l'Île-de-France

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## RÉSUMÉ

Cette étude examine la performance hydrologique d'une toiture végétalisée dans des climats contrastés : tropical à Belo Horizonte et tempéré en Île-de-France. Un modèle EPA SWMM, calibré avec des données expérimentales du Brésil, a simulé le comportement de la toiture végétalisée sur des périodes de deux ans pour les deux régions. Les résultats montrent que les toitures végétalisées ont significativement réduit les coefficients de ruissellement et les débits de pointe dans les deux contextes (réduction d'environ 30 %). À Belo Horizonte, caractérisée par de fortes précipitations, le ruissellement a diminué de 26 %, tandis qu'en Île-de-France, avec des précipitations moindres, un effet proportionnellement plus marqué a montré une réduction de 47 %. L'évapotranspiration des toitures végétalisées, élevée dans les deux villes, souligne leur capacité de diminuer les flux à l'exutoire. Cette recherche confirme que les toitures végétalisées offrent des bénéfices hydrologiques robustes dans différents contextes climats, performant notamment mieux dans des conditions de faibles précipitations, performance qui est susceptible de diminuer dans le contexte de changement climatique.

## ABSTRACT

This study investigates the hydrological performance of a green roof in contrasting climates: tropical Belo Horizonte and temperate Île-de-France. An EPA SWMM model, calibrated with experimental data from Brazil, simulated the green roof's behavior over two-year periods for both regions. Results show that green roofs significantly reduced runoff coefficients and peak discharges in both contexts (approx. 30% peak reduction). In high-rainfall Belo Horizonte, runoff decreased by 26%, while in lower-rainfall Île-de-France, a stronger proportional effect yielded a 47% reduction. Markedly higher green roof evapotranspiration in both cities highlights their enhanced water retention capacity. This research confirms green roofs provide robust, consistent hydrological benefits across distinct climates, performing better proportionally in lower-rainfall conditions, performance that is likely to decrease in the context of climate change.

## KEY WORDS

Evapotranspiration, Nature-based solutions, source control, SWMM, urban drainage

# 1 INTRODUCTION

Green roofs provide multiple benefits, such as mitigation of hydrologic cycle changes and thermal comfort, and they are commonly pointed out as a mitigation and adaptation strategy for climate change, which may improve urban resilience (Haowen et al., 2020). However, climate changes influence rain and temperature patterns, which may affect the performance of green roofs on different time scales. Green roof performance in different climates has already been evaluated in articles related to thermal performance (e.g., Bevilacqua, 2021) and rain event scales analyses. Few studies compared the hydrological behavior of green roofs for different climate conditions in an annual water balance scale. The ability of a green roof to retain and release water is intrinsically linked to complex hydrological processes occurring within its layers. Evapotranspiration is a crucial component in its water balance (Getter & Rowe, 2007). Although the hydrological efficiency of green roofs has been extensively studied, the understanding on how climatic and consequent rain and evapotranspiration variations may affect green roofs efficiency still warrants scientific and practical attention. Different precipitation, temperature, and solar radiation regimes imply very distinct hydrological responses for green roof design. In a context which climate changes are influencing hydrological patterns, this work aims to investigate the impact of rain and evapotranspiration on the yearly water balance hydrological behavior of green roofs by comparing two regions with contrasting climates, one in Brazil, in tropical highland climate, and the other in France, in a temperate oceanic climate. In a context in which climate changes are making hydrological patterns more contrasting and extreme, moving the temperate regions towards subtropical climate, these comparisons could visualize the impact of this shift and should give indication for green roof design adaptation.

# 2 METHODS

The methodology of this work consisted of: (1) calibrating a green-roof in the SWMM model based on monitoring data from an existing green roof in Belo Horizonte; and (2) using the model to simulate the hydrological behavior of the monitored green roof considering two different input precipitation and evapotranspiration data series, in order to explore the differences in yearly water balance responses.

## 2.1 Green roof representation and calibration in EPA SWMM

Data from an experimental flat roof with approximately 11 m², located in Belo Horizonte, Brazil, at the Federal University of Minas Gerais Campus, was used to calibrate a green roof model in SWMM. The green roof is composed of an impermeabilization layer, a geocomposite drainage layer MacDrainJ, the substrate of regular garden soil, having thickness of 8 cm and is planted with local exotic species (*Plectrathus ornatos*). A reference apparatus consisting of a conventional impervious roof, also with 11 m² situated beside the green roof, was also monitored and calibrated in SWMM. Runoff from the roofs was measured each 5 minutes at the outlet of the downspout with tipping buckets with a resolution of 0.003 mm from 2020 to 2023. Rainfall was measured at the center of the experimental roof with a tipping buckets rain gauge, with a resolution of 0.02 mm. The model was calibrated for an event (October 2nd, 2021), ranging from subcatchment and green roof parameters detailed on the results section. Another event (November 10th, 2021) was used for model validation.

## 2.2 Climatic conditions of Brazil and France and the data used

The data series used concerned continuous two-year periods issues of stations located in contrasting urban environments: Belo Horizonte, Brazil (2020-2021) and Île-de-France, France (2022-2023). These years were selected due to data availability and because they could represent cumulative rain volumes over the average for both contexts. Belo Horizonte (Brazil) climate is tropical, with an altitude of 900 m, mean annual rainfall 1400 mm and mean annual evapotranspiration 1496,2 mm (INMET, 2022). Two main seasons can be identified: the rainy season from October to Mars and the dry season from April to September. A 10-minute resolution precipitation record series from January 2020 to December 2021 from Belo Horizonte Municipality (Station 17) situated in Pampulha region, close to the experimental green roof, was used for simulating the Brazilian climate conditions in the SWMM model (Figure 1). The mean annual rainfall for this two-year period was 1796 mm and the mean annual evapotranspiration was 1492 mm. Daily average potential evapotranspiration (Penman-Monteith) based on climate monitored data for Belo Horizonte (INMET, 2025) have been incorporated into the SWMM model.

The Île de France region (France) has a temperate climate, with mean annual rainfall of 634.3mm an altitude of 90m and mean annual evapotranspiration 890.5mm (Météo France, 2025). climate data used for modeling of French climate came from the Sense City research facility located at the university campus at Champs sur Marne between January 2022 and December 2023 were used, having a 1-minute time step for rain and daily interval for the potential evapotranspiration estimated by Penman–Monteith equation (FAO).

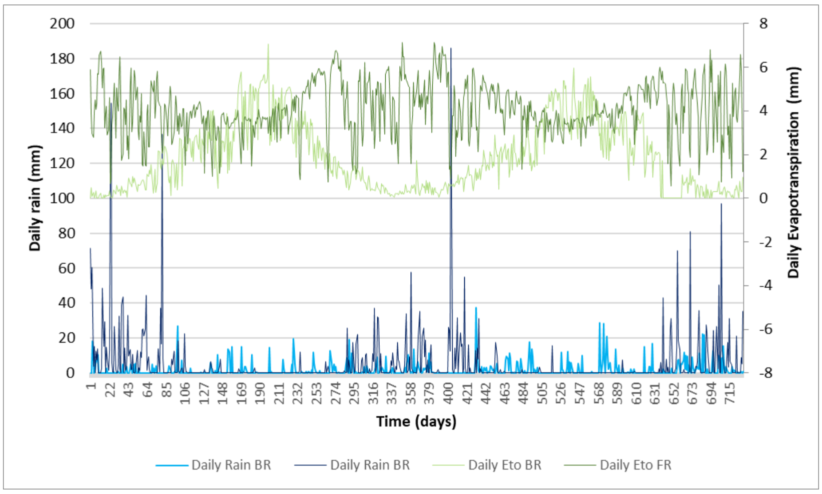
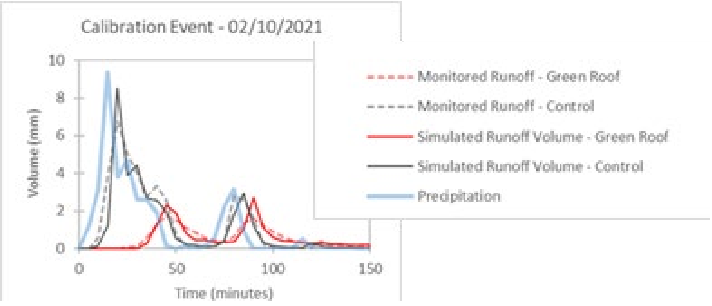


**Figure 1**. Rain and evapotranspiration time-series used in simulations.

# 3 RESULTS AND DISCUSSION

## 3.1 Calibration of green roof model

Hydrograph for the event used in calibration and the goodness-of-fit metrics are summarized in Figure 2. Both the Nash–Sutcliffe efficiency and the runoff volume error yielded good performance in the calibration and validation stages. The calibrated surface-layer parameters were berm height (10 mm), vegetation volume fraction (0.2), surface roughness (0.2), and slope (2%). Soil-layer characteristics included thickness (80 mm), porosity (0.52), field capacity (0.15), wilting point (0.05), hydraulic conductivity (117.4 mm/h), conductivity slope (39.3), and suction head (48.3 mm). For the drainage layer, the calibrated parameters were thickness (10 mm), void fraction (0.9), and roughness (0.05). The calibrated parameters for the subcatchment representing rooftops were width (1.5 m), slope (2%), Manning's roughness coefficient for impervious areas (0.05), and depression storage depth on impervious areas (4 mm).



| | **Calibration** | | **Validation** | |
|---|---|---|---|---|
| | Impervious Roof | Green Roof | Impervious Roof | Green Roof |
| **Nash-Sutcliffe Coefficient** | 0.86 | 0.74 | 0.80 | 0.95 |
| **Peak Runoff Error** | 27% | 57% | 4% | -32% |
| **Runoff Volume Error** | -12% | 1% | -12% | 19% |

**Figure 2**. Calibration hydrograph and synthesis of indexes for calibration and validation

## 3.2 Simulation results comparison

Green roofs substantially reduced runoff in both climatic contexts, but their relative impact differed between Belo Horizonte and Île de France due to contrasts in precipitation volume and evaporative demand (Table 1). In Belo Horizonte, where total rainfall during 2020–2021 was high (3592 mm), the green roof lowered the runoff coefficient from 0.89 to 0.64 and reduced total runoff by 885 mm (28%) compared to the impervious roof. In Île-de-France, despite a much lower total precipitation (1300 mm during 2022–2023), the green roof showed an even stronger proportional effect, reducing the runoff coefficient from 0.81 to 0.46, and reducing runoff by 450 mm (43%). The later data seems to be coherent with the observation of Gromaire et al (2013) for green roofs in Île de France.

Evaporation from green roofs was also markedly higher than from impervious roofs in both cities, reflecting the increased storage and transpiration capacity of the vegetated system. Peak runoff followed the same pattern, with green roofs reducing peak discharge by roughly 40% in both locations. Overall, the results indicate that green roofs deliver consistent hydrological benefits across distinct climates, with particularly strong relative performance in the low-rainfall conditions of Île-de-France. Though if take into perspective the climate change with wetter winters and drier summers and an increase of annual precipitation according to prevision of French Ministry of Environment and Transport (PIDF 2025), this means longer rain events and rain events with higher intensity. To maintain the green roof runoff reduction capacity, the design should also be adapted. The presentation will give deeper insights in this aspect.

**Table 1**. Summary of modeling results

| | **Belo Horizonte, Brazil** | | **Île de France, France** | |
|---|---|---|---|---|
| | Impervious Roof | Green Roof | Impervious Roof | Green Roof |
| **Simulated period** | 2020-2021 | | 2022-2023 | |
| **Total precipitation (mm)** | 3592 | | 1299 | |
| **Total evapotranspiration (mm)** | 470 | 1250 | 282 | 682 |
| **Runoff (mm)** | 3203 | 2318 | 1051 | 600 |
| **Runoff Coefficient** | 0.89 | 0.64 | 0.81 | 0.46 |
| **Peak Runoff (L/s)** | 0.51 | 0.31 | 0.16 | 0.10 |

## 4 CONCLUSIONS

Green roofs substantially reduced runoff coefficients and peak discharges in both Belo Horizonte and Île-de-France, with peak discharge reductions of approximately 40%. Runoff volume was lowered by 26% in Belo Horizonte's high rainfall and 47% in Île-de-France's lower rainfall. Evapotranspiration from green roofs was also markedly higher than from impervious roofs in both cities, indicating consistent hydrological benefits across distinct climates. According to some *in situ* studies (e.g. Stovin, 2010; Speak, 2014) evapotranspiration plays a fundamental role in removing water from the green roof system, directly influencing its subsequent water retention capacity. It was remarkable that in the French context, evapotranspiration was more significant for runoff reduction than in the Brazilian context, once temperature and radiation in Brazil are higher than in France. The presence of more intense events in the Brazilian context in comparison to the Franch one could explain part of these differences. The research focus actually on better transpiration data, uncertainty analysis and climate scenarios to confirm actual hypothesis and get green roofs more resilient in the future.

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