https://doi.org/10.71573/c8hx1e85



# Modelling green roof hydrologic performances for past and future climate in eight cities around the world

*J.-L. Bertrand-Krajewski*[*1] https://orcid.org/0000-0003-3204-8861, *S. Barbera*[1], *G. Duval*[1], *L. Angelini-Sobrinha*[1,2] https://orcid.org/0000-0002-1626-5420, *V. Pons*[3,4] https://orcid.org/0000-0001-8574-5674, *J. Bonneau*[1] https://orcid.org/0000-0003-1161-1993, & *J.-C. Grimard*[5]

[1] *INSA Lyon, DEEP, UR7429, F-69621 Villeurbanne cedex, France*

[2] *School of Engineering, Federal University of Grande Dourados, Dourados/MS, Brazil*

[3] *University of Science and Technology (NTNU), N-7491 Trondheim, Norway*

[4] *Dept. of Civil, Environmental, and Natural Resources Engr., Luleå Univ. of Technology, S-97187 Luleå, Sweden*

[5] *Le Prieuré, F-41160 Moisy, France*

**Corresponding and presenting author email: jean-luc.bertrand-krajewski@insa-lyon.fr*

## Abstract

The Olympluie project investigates the modelled hydrological performance of green roofs under varying climatic conditions in eight cities in the world, through long-term simulations (13–29 years) for both historical and future climate data. It also examines performance metrics (e.g. evapotranspiration efficiency) for different green roof designs (varying substrate depths, underlying storage capacities, etc.). Simulations revealed that green roof performance varies significantly with geography, while the analysis of future climate scenarios (2071–2099) for the city of Lyon, France, projected a moderate drop in green roof performance. However, the variability across 12 future climate rainfall timeseries was substantial. These results highlight the necessity of site-specific designs to optimize green roof efficiency under both current and future conditions and confirms the potential of green roofs to mitigate urban runoff. However, in a context of climate change, uncertainty surrounding future rainfall patterns is high and must be accounted for in future design.

## Highlights

- Green roofs perform very differently in various cities in the world: local design is necessary.
- Future time series show a significant influence of climate change on green roof performance.
- Accounting for uncertainty in future weather time series is necessary to in design.

## Introduction

Event and long-term hydrological performance indicators of green roofs (retention, evapotranspiration, peak flow attenuation, outflow, etc.) depend on numerous factors. For a given green roof with a particular design (e.g. substrate depth, underlying storage capacity, controlled outflow, etc.), its performance is expected to vary according to its geographical location and to the prevailing meteorological conditions. For a given location, the performance varies for current climate (annual variability) and will evolve in the future due to climate change. Based on long-term simulations (13 to 29 years), the Olympluie project aims to evaluate and compare the performance of an advanced green roof with different designs for eight cities around the world, and, for some of these locations, to estimate how the performance will change by using future time series based on the IPCC RCP 8.5 scenario. In this abstract, due to length restrictions, only some examples of the results obtained can be presented.

# Material and methods

## Green roofs

The advanced green roof simulated in this work (Figure 1, left) includes i) a substrate depth ranging from 60 to 240 mm, ii) a separation plate with cells filled with clay pellets, and iii) an additional underlying storage layer below the separation plate with a storage capacity ranging from 52 to 150 mm (or L/m$^2$). The green roof is vegetated with sedums and equipped with outflow controllers. It is manufactured by the French company Le Prieuré and is installed on the roofs of the Paris 2024 Olympic Games Athletes' Village (hence the project French name "Olympluie", i.e. Olympic rain).

## Green roof model and specifications

The Gepeto model (Figure 1, right) developed by INSA Lyon in partnership with Le Prieuré is used for the simulations. It was previously tested and calibrated with experimental data (Bournique *et al.*, 2019; Principato *et al.*, 2015). The green roof standard key specifications are the following ones: substrate depth = 80 mm with a storage capacity = 52 mm, separation plate cells storage capacity = 4 mm, underlying storage capacity = 52 mm, controlled outflow = 10 L/s/ha, threshold depth in the underlying storage to initiate the outflow control = 9.83 mm (only storage below this value), and two outflow controllers per roof.

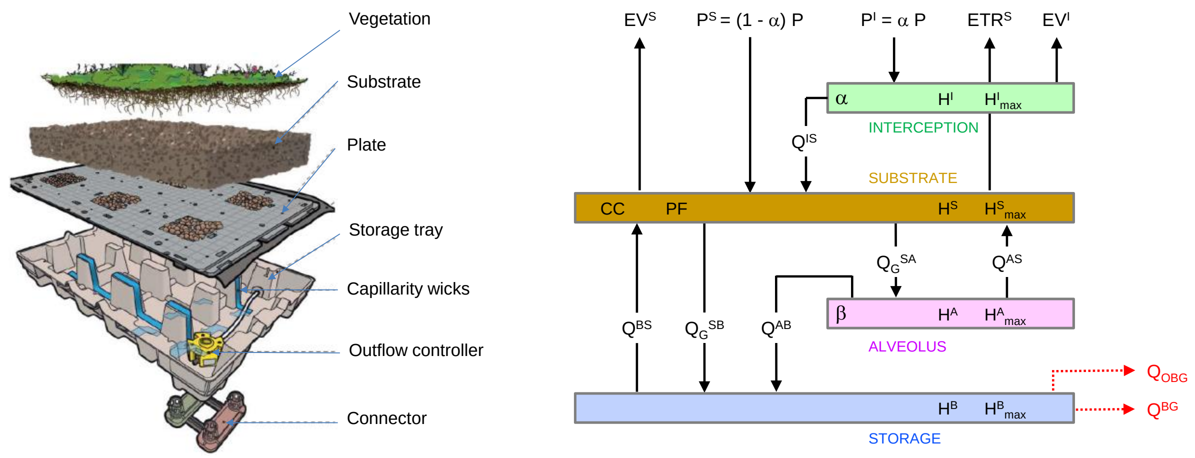


**Figure 1.** Structure of i) the OASIS advanced green roof (left) and ii) the Gepeto model (right).

## Historical and future time series

Rainfall intensity, and potential evapotranspiration (PET) or air temperature data were collected for eight cities (Table 1) around the world, with time steps from 1 minute to 1 hour (resp. 1 day). When PET data were not available, PET was estimated from the measured or calculated average daily temperature by means of the Oudin formula. Rainfall intensity (*I*, mm/h) and PET (*PET*, mm/h) time series have been processed (detection of data gaps, outliers, etc.) and prepared for simulations, with simulation time steps ranging from 6 to 15 minutes (Table 1). IPCC RCP 8.5 regional climate projections data at daily resolution for future precipitation and temperature are available and easily accessible for some cities. Combined with historical time series, these data have been used to create up to 12 future time series for the period 2071-2099 by means of statistical downscaling with the MRC (multiplicative random cascade) approach (details in Pons *et al.*, 2022).

## Simulation scenarios

Simulations are carried out with both historical and future time series listed in Table 1. In the first phase of work presented in this abstract, three design specifications varied: i) the thickness of the substrate *D*, with seven values = 60, 80 (default value), 100, 120, 160, 200, and 240 mm, ii) the underlying storage capacity *H*, with five values = 52 (default value), 75, 100, 125, and 150 mm, and iii) the presence and size of outflow controllers (*r* = 0: no outflow controller, *r* = 1 to 4 for four different types of controllers with r = 2 the standard one).

**Table 1.** Cities, time series (precipitation and potential evapotranspiration) and time steps used for simulations.

| City, Country (abbreviation) | Historical time series | Future time series | Simulation time step |
|---|---|---|---|
| Lyon, France (LY) | 2000-2019 | 2071-2099 (12 series) | 6 minutes |
| Melbourne, Australia (ME) | 2000-2019 | in progress- | 6 minutes |
| Seoul, South Korea (SE) | 2000-2019 | in progress- | 6 minutes |
| Montreal, Canada (MO) | 2005-2021 | 2071-2099 (3 series) | 6 minutes |
| Los Angeles, USA (LA) | 2000-2019 | in progress- | 15 minutes |
| Dourados, Brazil (DO) | 2009-2021 | in progress- | 15 minutes |
| Cape Town, South Africa (CT) | 2000-2019 | in progress- | 15 minutes |
| Trondheim, Norway (TR) | 2000-2019 | 2071-2099 (3 series) | 6 minutes |

# Results and discussion

## Global evapotranspiration efficiency

Evapotranspiration efficiency (EE) is defined as the percentage of water that is evapotranspirated by the green roof compared to the amount of rain for a given duration. A 60% EE means that 60% of the rain falling on the green roof during the simulation period are evapotranspirated. Reciprocally, 40% of the rainfall volume are i) discharged by the green roof either as controlled outflow or as overflow in case the green roof maximum total storage capacity (substrate + cells + underlying storage) is reached, and ii) stored in the substrate, in the cells, and in the underlying storage at the end of the simulation period. For example, in Lyon, the global simulated EE for the historical period 2000-2019 for a standard green roof (*D* = 80 mm, *H* = 52 mm, *r* = 2) is 66.7%.

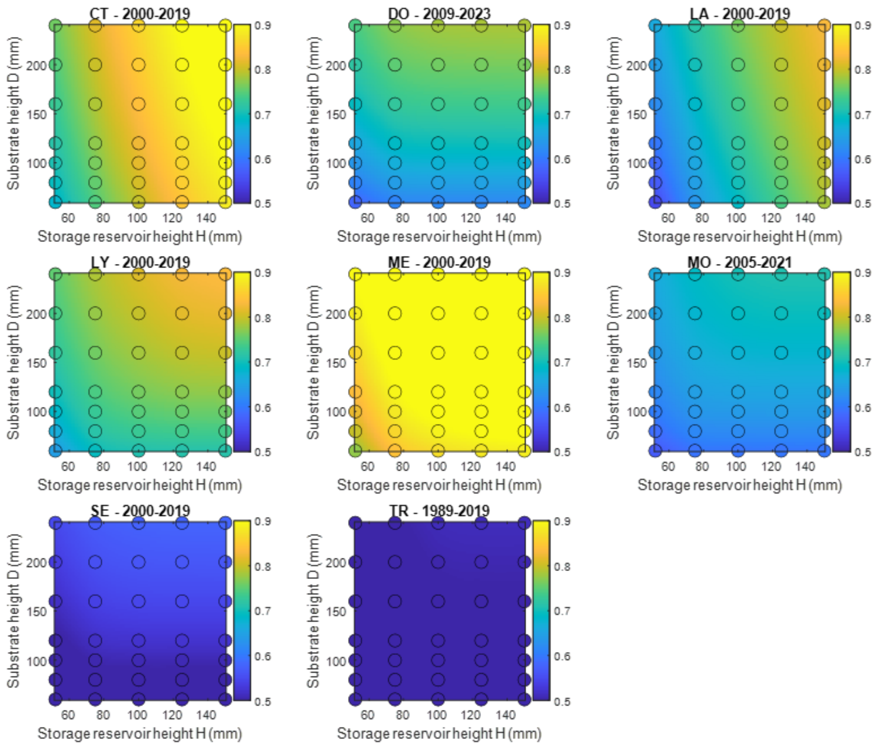


**Figure 2.** Global EE in the eight cities for historical time series, for all tested substrate heights *D* and storage reservoir heights *H*, with outflow controller *r* = 2. Each circle on the graphs represents a simulated case.

Figure 2 shows how EE varies very significantly for historical times series in eight cities: the best performances are obtained for Melbourne and Cap Town, and the two lowest ones for Seoul and Trondheim, due to their climatic specific conditions. Further analysis of EE at annual and seasonal scales (not shown in this abstract) show also a very high variability.

**Climate change and evapotranspiration efficiency**

Figure 3 shows the global EE for 12 future time series obtained from 12 different IPCC models of climate change the period 2071-2099, compared to the EE for the historical period, for 3 green roof settings. The EE varies significantly for the 12 future time series, but the global trend shows a moderate decrease of the green roof performance in the future compared to the historical period.

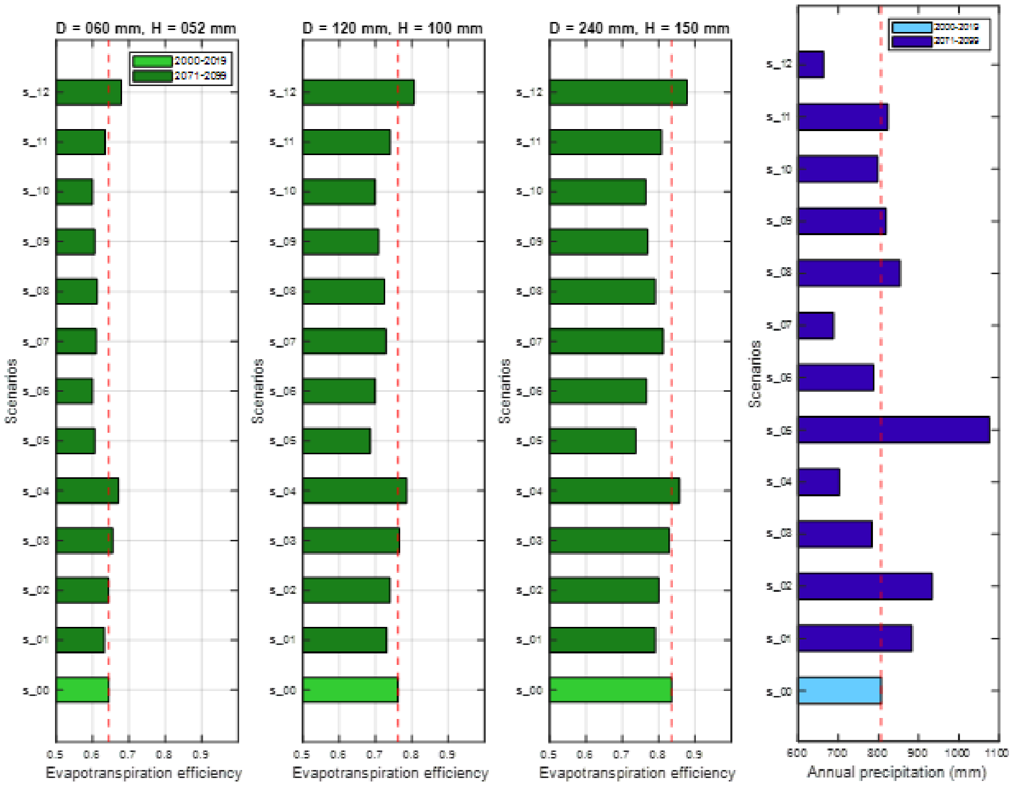


**Figure 3**. Global EE and mean annual precipitation in Lyon for 12 future time series for the period 2071-2099, compared to the EE for the historical period (light bottom bar of each graph).

# Conclusions

The Olympluie project simulates a high number of various green roof design scenarios for 8 cities in the world, with both historical and future climate time series. Performance indicators are evaluated for a detailed comparison of scenarios, allowing to adapt the green roof design to each geographical and climatic context, in particular climate change. The full paper will present, analyse and discuss all simulation results for all cities, at inter-annual, annual, seasonal and event scales. It will show how to adapt the green roof design to various climatic contexts for given performance specifications.

# Acknowledgments

Work done within the Graduate School H2O'Lyon (ANR-17-EURE-0018) and Université de Lyon (UdL), as part of the programme "Investissements d'Avenir" by Agence Nationale de la Recherche (ANR). Thanks to all colleagues in Melbourne, Seoul, Montreal, Los Angeles, Dourados, Cape Town and Trondheim for sharing or sourcing data in their cities.

# References

Bournique R., Bassan V., Arias L., Grimard J.-C. & Bertrand-Krajewski J.-L. (2019). Modélisation hydrologique d'une solution de toiture bleue – verte de gestion des eaux pluviales. *Proceeding of Novatech 2019*, Lyon, France, 01-05 July, 4 p.

Pons V., Benestad R., Sivertsen E., Muthanna T. M. & Bertrand-Krajewski J.-L. (2022). Forecasting green roof detention performance by temporal downscaling of precipitation time-series projections. *Hydrol. Earth Syst. Sci.*, 26(11), 2855–2874. doi: 10.5194/hess-26-2855-2022.

Principato F., Piro P., Grimard J.-C. & Bertrand-Krajewski J.-L. (2015). Test of a vegetated roof hydrological model with two experimental data sets. *Proceeding of 10th UDM - International Conference on Urban Drainage Modelling*, Mont Sainte Anne, Quebec, Canada, 20-23 September.