

# Substrate Soil Moisture Impact on Green Roof Performance for an Experimental Site in Tomblaine, France

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**Abstract.** During the last decades, urbanization completely changed the layout of the cities, increasing the imperviousness and reducing infiltration, evapotranspiration and groundwater recharge. The direct consequence of this is the enhancement of floods in urban context. It is widely known that Nature Based Solutions such as Green Roofs may represent a successful solution in supporting traditional drainage systems in the management of an ever-increasing stormwater runoff.

To the purpose, an improved knowledge of the hydrological behavior of such infrastructures and the relation between their retention capacity and climate or design variable is essential to enhance their effectiveness.

Starting from the analysis of 56 rainfall-runoff events, this paper aims at assessing the behavior of a 98 $m^2$ experimental green roof, located in Tomblaine (Northern-Eastern France), with specific reference to the relation between runoff retention capacity, soil moisture content prior to the triggering rainfall event and the rainfall event properties. For the specific case study, the ANOVA analysis pointed out that soil moisture content appeared to be the best predictor of retention capacity both under moderate and severe rainfall. However, a weak correlation between the two variables was detected with a maximum 0,67 coefficient reached by a single regression of the low retention group.

**Keywords:** Green roofs · Soil moisture content · Retention capacity

## 1 Introduction

Land use changes and soil sealing gradually transformed the hydrological cycle and increased urban flooding risk [1]. In this context, Nature Based Solutions appear fundamental strategies for a sustainable management of stormwater runoff at the city scale [2–4]. Among them, green roofs (GRs) are valuable solutions that allows an optimal retrofitting of traditional roofing, reducing stormwater runoff and bringing numerous additional benefits for both nature and humans [5–7].

Specifically referring to the role of GRs in the mitigation of urban flooding, these infrastructures seem to be effective in the reduction of runoff peak flow and volumes [5].

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Nevertheless, according to literature, both climate and design variables seem to affect the GRs behaviour. For example, higher substrate depths and spread or light rains are undoubtedly the best conditions for their efficiency [8, 9], as well as the right choice of vegetation [10].

However, the retention performance of a GR can vary on a large extent and this is mainly due to the interplay of technological features and geographical contexts of each infrastructure [11, 12]. Researchers worldwide discuss about the existence of a relationship between retention capacity of GRs and some specific hydrological variables, such as the initial soil moisture content or the antecedent dry period to an event but so far, contrasting results came out [13, 14].

In the current paper, the performance of an experimental green roof of 98 $m^2$ located in Tomblaine, Northern France, was investigate through an event scale analysis that involved 56 rainfall-runoff events occurred during the period July 2014 – December 2015. The study aimed at providing additional explanation on the hydrological behaviour of the GRs in a geographical context characterized by a temperate climate and at improving the prediction of the retention capacity using design and climate-related variables.

## 2 Materials and Methods

### 2.1 Case Study

The in situ experimental GR, set up in July 2011, is located in Tomblaine (Fig. 1a), northeast of France (48° 40′ 48” N, 6° 13′ 9”E, 202 m a.s.l.). The infrastructure is placed above a 6-m high building with a traditional flat roof [15]. Even if the overall area occupied by the GR is of about 600 $m^2$, this study analysed only a part of it, characterized by a 98 $m^2$ area (Fig. 1b) independent from the rest of the roof.

The GR only includes two layers: a vegetation and a substrate layer. The vegetation, as often occurs for these systems, is composed by different kind of sedum (Sedum album, Sedum reflexumlarix, Sedum reflexum germanium, Sedum sexangulare and Sedum floriferum). It does not exceed the 15-cm height, including 5 cm of roots. The substrate, ranging between a 7.5 to a 9.5-cm depth, is made by pozzolana (80%) and organic fraction (20%) (Fig. 1c). The pozzolana, widely used for its physical-hydraulic properties (low bulk density, mechanical resistance and high storage) is made by particles ranging from 3 to 6 mm, for 80% of the composition, and from 7 to 15 mm for the remaining 20%. The organic fraction is instead composed of peat dust and maritime pine bark in equal shares.

The runoff overflows from the top of the roof and is collected in gutters and conveyed through a pipe in a tipping bucket system, closed in a metal box and fixed to an outside wall, in order to measure it (Fig. 1d, just one of the three systems in the picture refers to the investigated roof).

### 2.2 Case Study Climate and Hydrological Data Characterization

The city of Tomblaine is characterized by a temperate climate. It comes under Cfb class according to the Köppen-Geiger climate classification that include temperate-climate

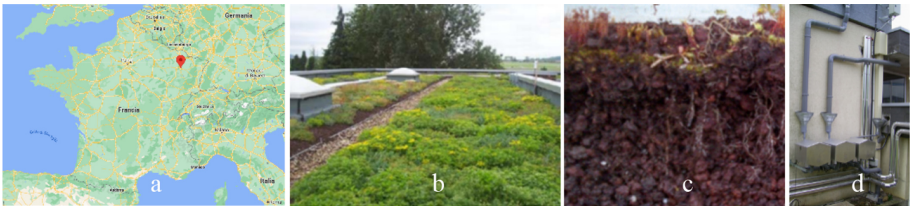



**Fig. 1.** a. Localization of Tomblaine, the city where the installation is placed; b. in situ experimental green roof; c. detail of the growing media (pozzolana and organic fraction); d. runoff measurement system (just one of the three systems refers to the roof analyzed).

areas with wet summers, temperature of the hottest month below 22 °C and at least four month with temperatures higher than 10 °C. The average temperature in Tomblaine is 10.6 °C while the annual rainfall amount is around 897 mm (Fig. 2).

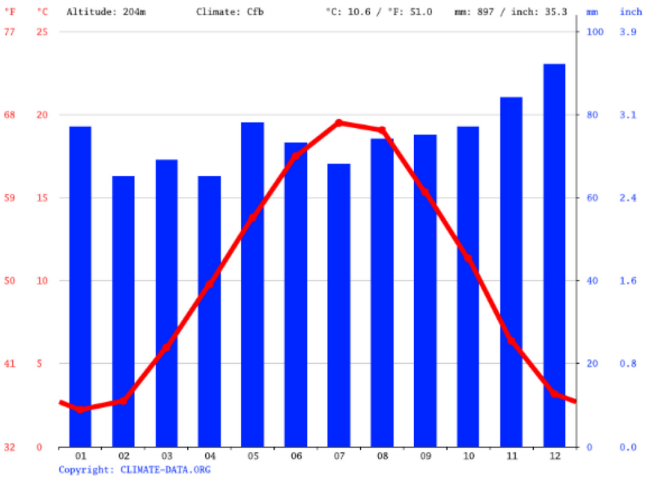



**Fig. 2.** Tomblaine mean monthly temperature and rainfall. Picture from https://en.climate-data.org/

From July 2014 to December 2015, rainfall, runoff and soil moisture content (SWC) values were continuously measured and collected (Fig. 3). During the monitoring period (almost one year and half) the total rainfall amount was 875.1 mm while the total runoff registered was 256.3 mm, defining a long-run retention capacity of 71%. Soil moisture content reached the maximum value, 45.93%, in January while the lowest value, 6.89%, in June; the mean was 35.87%. Provided the high frequency of rainfall occurrences and the absence of a drainage system to remove subsurface water stored into the GR substrate, the soil moisture temporal profile is characterized by long period of stationarity with no significant changes in soil moisture values. Soil water content depletion typically occurs during the summer period, but it quickly recovers after precipitation events.

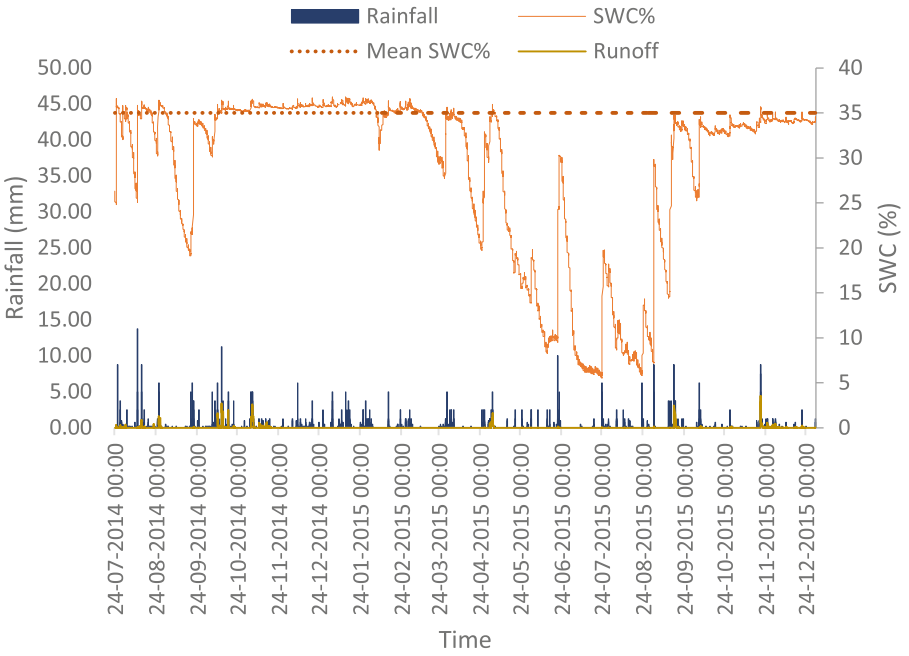



**Fig. 3.** Rainfall, runoff and SWC monitoring over time.

### 2.3 Retention Capacity of the Experimental GR

The current analysis concerned 56 rainfall-runoff events extracted from the mentioned database. Rainfall characteristics (duration and cumulate), mean substrate soil water content registered before the occurrence of the rainfall event and cumulate runoff were assessed. For each observed event, the hydrological performance in term of retention capacity (RC) was computed as follows:

$$1-C* = RC \tag{1}$$

Where C* is the discharge coefficient, computed as the ratio between the cumulative observed runoff depth and the cumulative observed rainfall depth at the event scale.

## 3 Results and Discussions

Soil moisture content of the selected rainfall-runoff events varies from a minimum of 7.28% to a maximum of 44.59% with a mean value of 30.46%. Probably due to the building technology of the experimental roof assessed, few values of soil water content below 20% were registered and only during the summer season. Much more frequent are SWC major than 35%. Rainfall also varies a lot both in terms of cumulate (ranging from 0.20 to 60.20) and duration (ranging from 1 to 77 h). Retention Capacity shows a great variability, ranging from 1 to 100%, with a mean value of 76% representative of a good overall performance of the experimental roof.

**Table. 1** Minimum, maximum and average values for pre-event soil water content (SWC), cumulate rainfall (rain) and rainfall duration (duration).

| | Min | Max | Average |
|---|---|---|---|
| SWC (%) | 7.28 | 44.85 | 30.46 |
| Rain (mm) | 0.20 | 60.20 | 10.08 |
| Duration (hr) | 1.00 | 77.00 | 15.64 |

Longobardi and co-workers [14] demonstrated how SWC prior to a triggering rainfall event can be used to identify different hydrological behavior that a single GR can exhibit depending on SWC thresholds. With the objective to assess how the soil moisture content prior to the occurrence of the rain could affect the hydrological behavior of the presented case study, the relationship between the retention capacity and soil moisture content was investigated for each of the rainfall-runoff events. Looking at Fig. 4 it is possible to observe, for the specific case study, that for SWC percentage below 35% the GR is able to store and retain the entire rainfall amount. Hence, in those conditions, the runoff is zero and subsequently the RC is 100%.

When SWC approaches values larger than 35%, RC largely varies from a minimum value of about 1% to maximum of about 100% apparently with no relationship with SWC values.

Especially for what concerns events characterized by SWC > 35%, a distinction can be made with reference to the RC values. Two distinct groups can be highlighted, laying respectively above (high retention group) and below (low retention group) a RC threshold of about 50% (Fig. 4).

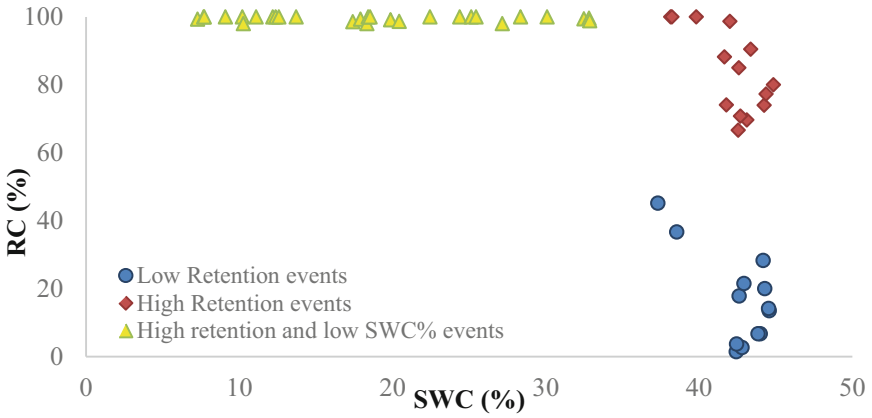



**Fig. 4.** Relation between retention capacity and soil moisture content: identification of groups.

For each group, events SWC, cumulate rainfall, duration and RC were represented as a box plot (Fig. 5). Differences between the two groups are mostly detected in terms of rainfall cumulate and duration. The high retention group of events (RC > 50%, SWC

> 35%), are mostly characterized by rainfall cumulate and duration below the mean value (10 mm and 16 h respectively in Table 1); the group of low retention events (RC never exceeding 50%, SWC > 35%), are characterized by rainfall cumulate and duration above the mean value. A larger variability in terms of cumulate rainfall and duration, compared to the high retention group, is a distinctive characteristic of the low retention group.

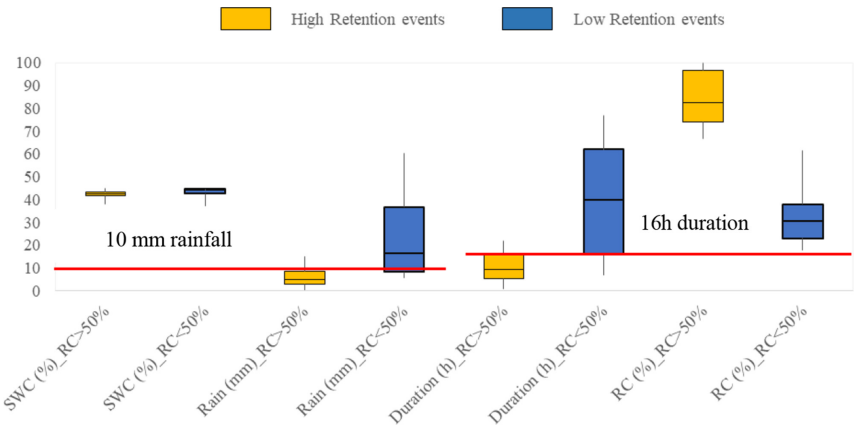



**Fig. 5.** Boxplots representing the characteristic of the events with RC > 50% (orange) and RC < 50% (blue) (Color figure online).

In order to identify an empirical data-based model for RC prediction, the relationship between RC and initial soil water content SWC, cumulate rainfall and rainfall duration, was investigated in a multiple regression framework. The one-way analysis of variance (ANOVA) is a common technique that can be used to compare means of two or more independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different [16]. The ANOVA analysis results are illustrated in the following, for $\alpha = 5\%$. Both in the case of high retention (Table 2) and low retention (Table 3) group, SWC appears as the only significant variable (p-value $< \alpha$). The correlation coefficients equal 0,44 and 0,49 respectively for the high and low retention groups, providing an indication for a weak correlation. Also the case of a single regression of RC against SWC was considered. This led to an improvement in the correlation coefficient, especially for the low retention group for which it increased up to 0,67.

**Table. 2** ANOVA analysis for the high retention events group. ANOVA refers to a multiple regression model of RC versus SWC, cumulate rain and rain duration ($\alpha = 0{,}05$).

| | Coefficients | Standard error | Stat t | p-value |
|---|---|---|---|---|
| SWC | −4,21 | 1,60 | −2,63 | 0,03 |
| Rain | −0,06 | 0,22 | −0,29 | 0,78 |
| Duration | −0,03 | 0,15 | −0,17 | 0,87 |

**Table. 3** ANOVA analysis for the low retention events group. ANOVA refers to a multiple regression model of RC versus SWC, cumulate rain and rain duration ($\alpha = 0{,}05$).

| | Coefficients | Standard error | Stat t | p-value |
|---|---|---|---|---|
| SWC | −4,04 | 1,42 | −2,85 | 0,02 |
| Rain | −0,10 | 0,72 | −0,15 | 0,89 |
| Duration | −0,26 | 0,40 | −0,64 | 0,54 |

## 4 Conclusions

In this paper, the relationship between the retention capacity of an experimental GR located in Tomblaine (France) and the initial (to the triggering rainfall event) substrate soil moisture content SWC was investigated. The results showed that the GR hydrological response is mainly driven by SWC. An SWC threshold of about 35% was found to delimit (SWC $< 35\%$) events for which, regardless for the rainfall properties, no runoff occurred. If SWC $> 35\%$, it was possible to distinguish between low and high retention events. The first occurred for rainfall cumulate and duration well above the relevant average values.

In contrast to other studies, the rainfall cumulate and duration seemed not to affect the performance of this specific experimental roof in terms of retention. In an ANOVA analysis, SWC appeared the only significant variable to predict RC, but the correlation coefficients was rather weak. The results reported in this research are likely related to the specific building technology adopted for the construction which does not see a drainage layer. Further research supported by a conceptual model framework is foreseen to achive a better prediction of the retention properties.

## References

1. Mobilia, M., Longobardi, A.: Using SAR satellite imagery for potential green roof retrofitting for flood mitigation in urban environment. In: GISTAM (Accepted)
2. Bell, S.: Urban water sustainability. Constructing Infrastructure for Cities and Nature. Routledge, London and New York (2018)

3. Brears, R.C.: Blue and green cities: the role of blue-green infrastructure in managing urban water resources. Macmillan Publishers Ltd, London (2018)
4. Sartor, J., Mobilia, M., Longobardi, A.: Results and findings from 15 years of sustainable urban storm water management. Int. J. Safety Security Eng. **8**(4), 505–514 (2018)
5. D'Ambrosio, R., Longobardi, A., Mobilia, M., Sassone, P.: Sustainable strategies for flood risk management in urban areas. Enhancing city resilience with Green Roofs. UPLanD – J. Urban Plann Landscape Environ. Des. **5**(2), 87–98 (2021)
6. Ercolani, G., Chiardia, E.A., Gandolfi, C., Castelli, F., Masseroni, D.: Evaluating performances of green roofs for stormwater runoff mitigation in a high flood risk urban catchment. J. Hydrol. **566**, 830–845 (2018)
7. Mobilia, M., Longobardi, A.: Smart stormwater management in urban areas by roofs greening. In: International Conference on Computational Science and Its Applications. Springer, Cham, pp. 455–463 (2017)
8. Carbone, M., Nigro, G., Garofalo, G., Piro, P.: Experimental testing for evaluating the influence of substrate thickness on the sub-surface runoff of a Green Roof. Appl. Mech. Mater. **737**, 705–709 (2015)
9. Soulis, K.X., Ntoulas, N., Nektarios, P.A., Kargas, G.: Runoff reduction from extensive green roofs having different substrate depth and plant cover. Ecol. Eng. **102**, 80–89 (2017)
10. Cristiano, E., Urru, S., Farris, S., Ruggiu, D., Deidda, R., Viola, F.: Analysis of potential benefits on flood mitigation of a CAM green roof in Mediterranean urban areas. Build. Environ. **183**, 107179 (2020)
11. Nawaz, R., McDonald, A., Postoyko, S.: Hydrological performance of a full-scale extensive green roof located in a temperate climate. Ecol. Eng. **82**, 66–80 (2015)
12. Mobilia, M., D'Ambrosio, R., Longobardi, A.: Climate, soil moisture and drainage layer properties impact on green roofs in a Mediterranean environment, frontiers in water-energy-nexus—nature-based solutions. Adv. Technol. Best Pract. Environ. Sustain. 169–171 (2019)
13. Chenot, J., Gaget, E., Moinardeau, C., Jaunatre, R., Buisson, E., Dutoit, T.: Substrate composition and depth affect soil moisture behavior and plant-soil relationship on Mediterranean extensive green roofs. Water **9**(11), 817 (2017)
14. Longobardi, A., D'Ambrosio, R., Mobilia, M.: Predicting stormwater retention capacity of green roofs: an experimental study of the roles of climate, substrate soil moisture, and drainage layer properties. Sustainability **11**(24), 6956 (2019)
15. Bouzouidja, R., Rousseau, G., Galzin, V., Claverie, R., Lacroix, D., Séré, G.: Green roof ageing or Isolatic Technosol's pedogenesis? J. Soils Sediments **18**(2), 418–425 (2016). https://doi.org/10.1007/s11368-016-1513-3
16. Lepore, E., Aguilera Benito, P., Piña Ramírez, C., Viccione, G.: Indoors ventilation in times of confinement by SARS-CoV-2 epidemic: a comparative approach between Spain and Italy. Sustain. Cities Soc. **72**, 103051 (2021)