Hydrologic performance of an extensive green roof under different climate conditions

Performance hydrologique d’une toiture végétalisée extensive sous différentes conditions climatiques

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RÉSUMÉ

Les toitures végétalisées (TV) représentent une solution durable pour atténuer le ruissellement pluvial dans l’environnement urbain. Sur la base de l'hypothèse que la capacité de rétention d'eau dépend principalement des conditions météorologiques et que chaque événement de pluie influence différemment la réponse d'une TV en termes de débit, cette étude analyse l'influence des paramètres hydrologiques sur l'efficacité d’une TV expérimentale, installée à l'Université de Calabre (Unical), à Cosenza dans le sud de l'Italie.
Dans la première phase d'étude, le modèle conceptuel "Sigma Drain" (SD), préalablement calé et validé, a été utilisé pour évaluer le ruissellement de la TV, avec les données de pluie enregistrées en deux régions climatiques différentes : Cosenza (Italie) et Lyon (France). Le coefficient de ruissellement, et donc la rétention, pour chaque événement pluvieux a été calculé avec les valeurs obtenues par SD : les deux scénarios ont retenu en moyenne 60 % des volumes précipités.
Dans la deuxième phase, les données de pluie de Cosenza ont été utilisées pour une analyse de régression linéaire multiple; la validation de l'équation a été effectuée en utilisant les pluies de Lyon. Les premiers résultats confirment que la TV installée à Unical, en climat méditerranéen, est également efficace hydrologiquement sous un autre régime climatique tel que celui tempéré de la ville de Lyon.

ABSTRACT

In urban environment, green roofs (GRs) represent a sustainable solution to mitigate stormwater runoff. Based on the assumption that water retention capacity mainly depends on weather conditions and that each rainfall event will differently affect the response in terms of outflow from a GR, this study analyzes the influence of the hydrologic parameters on the efficiency for a specific experimental GR, installed at University of Calabria (Unical), Cosenza in south Italy.
In the first phase of the study, using a Conceptual Model “Sigma Drain” (SD), previously calibrated and validated, the runoff from the GR was evaluated using two rainfall datasets, recorded in two different climatic zones: Cosenza (Italy) and Lyon (France). Based on the values obtained from SD, it was possible to obtain the subsurface runoff coefficient and consequently, the retention for each rainfall event. By comparing the results, both scenarios showed similar behaviors: estimating an average retention capacity of about 60% for both data sets.
In the second phase, using rainfall data collected at Unical, a multiple linear regression analysis was evaluated; the validation procedure made for the equation was performed by using the rainfall data of Lyon. First results show how the GR, installed at Unical, under Mediterranean climate condition, is also hydrologically efficient in another climate condition as the Temperate of the city of Lyon.

KEYWORDS

Green roof, Rainfall-Runoff, Regression Analysis, Retention, Stormwater management

1 INTRODUCTION

The use of LIDs (Low Impact Developments) as storm water management techniques has assumed increased importance in recent years (Sitzenfrei et al., 2013). Despite the benefits are large and well known, the transition to sustainable urban drainage systems is very slow (Piro et al., 2012). The lack of adequate modeling and analysis tools for is a limiting factor in the diffusion of such systems (Elliott & Trowsdale, 2007).

Green roofs represent one of the most diffused LIDs, but due to their morphological complexity, green roof's analysis requires specific modeling techniques that take into account the complex physical phenomena involved. Storm water management performance of a green roof may differ in various climatic regions due to the specific precipitation climatology, building practices and GR materials.

This study will analyze the influence of the hydrologic parameters on the hydraulic efficiency for a specific experimental GR, installed at University of Calabria (Unical), Cosenza. In the first phase of the study, using a Conceptual Model "Sigma Drain" (SD), previously calibrated and validated (Principato et al., 2016), the runoff from the GR was evaluated using rainfall data recorded in two different climatic zones: Cosenza (Italy) and Lyon (France). In the second phase, using rainfall data collected at Unical, a multiple linear regression analysis was evaluated; the validation procedure made for the equation was performed by using the rainfall data of Lyon.

2 METHODOLOGY

2.1 Experimental Site and Data Analysis

The study was performed on the experimental site at the Cube 46/C of University of Calabria (Unical), Italy. The test site, situated on a fifth-floor terrace of a campus's building, is located in a Mediterranean climate region, characterized by a hot-dry summers and cool-wet winters a strongly seasonal rainfall with an annual average of 1000 mm. High temperatures during the summer average 27°C (Carbone et al. 2015). The GR consists of four compartments, each one with an equal area of around 50 m^2 and a slope of 1%, which vary in their stratigraphy, composition elements and the presence, or not, of vegetation species. Precipitation data, consisting of rainfall depth recorded with minute frequency, were collected from two different sites: Green Roof of Unical (Italy) and GR of the Lyon Congress Center (France), located respectively in Mediterranean and Temperate climate conditions. In order to analyze the influence of hydrologic parameters on the efficiency of the green roof, under different climate conditions, it was needed to define each rainfall event in the data sets with time resolution of 1 minute.

For both sites, despite having both rain gauge a resolution of 0.2 mm, only events with rainfall depth greater than 2 mm were selected, based on the assumption that rainfall events less than 2 mm are unlike to produce runoff from a conventional roof (Voyde et al., 2010; Stovin et al., 2012). In this study, individual events were defined as being separated by continuous dry periods of at least two hours; rainfall events separated by less than 2 hours were merged and considered as single event. From this assumptions, a number of rainfall events were selected from each datasets. In specific, under these conditions, a total of 70 and 50 rainfall events, recorded respectively at Unical and Lyon site, were identified and then used in the analysis. Since the experimental site is installed in an area with a Mediterranean climate, characterized by precipitations which mostly result distributed in the autumn and winter season, the data collected in the period between September and April were considered.

2.2 The *SIGMA DRAIN* Conceptual Model

The *SIGMA DRAIN* conceptual model (Principato et al., 2016), is a new tool developed to simulate the hydraulic response of the extensive green roof installed at the University of Calabria, realized using the calculation engine of EPA-SWMM (Storm Water Management Model) software (Rossman, 2010) for the simulation of the hydrological and hydraulic phenomena, while being completely independent of the user interface. The *SIGMA DRAIN* model idealizes the green roof as a system consisting of three individual components in series, each of them corresponding to the main technological modules of the GR. The *surface layer*, exposed to the atmosphere and covered by vegetation, is conceptualized as sub-catchment; it is defined by the real size of the vegetated roof surface (area and % slope), and is characterized by a specific permeability of the soil dependent on fraction of vegetation coverage. The following *soil* and *drainage layers* are schematized through two reservoir elements, which describe respectively the percolation in the substrate and the transport through the drainage layer. A mass balance equation is applied to each block, taking into account the specific physical phenomena that occur in each module and the flow is instead regulated by the Richard's equation.

2.3 Multi-linear Regression Analysis

In this study, the Multiple Linear Regression Analysis was used in order to:

- statistically define the most influencing hydrological factors on the hydraulic efficiency of the experimental green roof located at University of Calabria;
- get regression equations that an engineer could use for a preliminary study on the performance of the green roof, without the implementation of the conceptual model.

The Multiple Linear Regression Analysis is used to assess the association between two or more independent variables and a single continuous dependent variable. The multiple linear regression equation is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon \qquad \text{Eq. 1}$$

where Y is the predicted or expected value of the dependent variable, X_1 through X_p are p distinct independent or predictor variables, β_0 is the value of Y when all of the independent variables (X_1 through Xp) are equal to zero, β_1 through β_P are the estimated regression coefficients, and ε is the residual term which translates the inability of the model to accurately reproduce the observed reality. In this study the independent variables are the hydrological parameters, such as precipitation depth, rainfall duration and rainfall intensity, while the dependent variable is the runoff depth and the retention capacity.

In order to evaluate the significance of each regression coefficient a *t*-test was used. A *p-value* of 0.05 was considered in this study. To define how close the data are to the fitted regression line, the R^2 coefficient is used.

This analysis is carried out by firstly defining the runoff depth at event scale, by using 1-minute rainfall data as input data in the SIGMA DRAIN conceptual model. The rainfall data set from Unical (Italy), and the model runoff, are used to obtain the multi-regression relationships, which were, then, validated with the data set from Lyon, France.

3 RESULTS AND DISCUSSION

A multiple linear regression analysis, using the rainfall data collected from the experimental site at University of Calabria, was evaluated. The results of the multiple linear regression analysis are summarized in Table 1, where the t-statistics (significant at p = 0.05) are presented in the same order as the parameters in the equation.

Table 1 - Multiple Linear Regression Analysis for rainfall data collected at University of Calabria

Regression equation		R^2	***T-statistic***
RD = - 4.10 + 0.71PD	*(EQ. 1)*	*0.9*	*24.7*
lnVR%= - 4.92 - 0.18 lnPD – 0.02d	*(EQ. 2)*	*0.7*	*-4.7, - 4.0*
VR= 1.13 - 0.03d – 0.03i	*(EQ. 3)*	*0.7*	*-10.9, -4.2*

The first relationship (Eq. 1) correlates the runoff depth (RD) with the rainfall depth (PD) and presents a R^2 equal to 0.9. The second equation (Eq. 2) was defined by considering how the Retention capacity (%) could be express as a function of rainfall depth (PD) and rainfall duration (d). Although this relationship exhibits a R^2 equal to 0.7, the *t-statistic* of both parameters were characterized by a low significance level. In the regression equation (Eq. 3), the retention capacity (VR) was obtained by using the rainfall duration (*d*) and intensity (*i*), with an R^2 equal to 0.7. In agreement with Stovin et al. (2012), the antecedent dry weather period (ADWP) was not found to be a good predictor of retention. The multi-regression relationships, reported in Table 1, are validated by using the rainfall data recorded at Congress Center in Lyon. In the validation process, the SIGMA DRAIN model was used as a reference to verify the soundness of the data obtained from the statistical relationship. One of the result obtained for Eq. 1, is compared with those obtained from the SIGMA DRAIN model - loaded with the 1-minute rainfall data as well - are shown in the Figure below (Fig. 1).

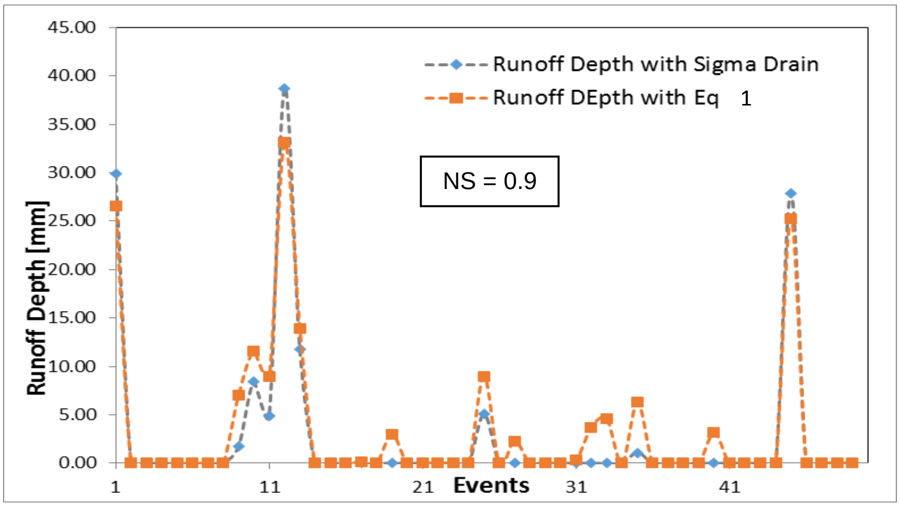

Figure 1 – Runoff Depth predicted by the Eq. 28 and modelled with SIGMA DRAIN model, with Lyon dataset.

The runoff obtained from the regression relationship (Eq. 1), for the entire data set is similar to the runoff provided through SIGMA DRAIN model, corresponding to a NS value equal to 0.9. In particular is possible to notice how the runoff depth obtained by the Eq. 1, generally overestimates the SIGMA DRAIN values, except for events with a rainfall depth higher than 40 mm.

4 CONCLUSION

In this study, the model SIGMA DRAIN was loaded with datasets collected in two different sites (Unical, in Italy and Lyon, in France), in order to analyze the influence of the hydrologic parameters on the green roof efficiency. A similar behavior for both scenarios (Unical and Lyon) is evident by comparing the results provided by SIGMA DRAIN in terms of runoff: the two sites area follow the same trend, suggesting that this GR package, developed at University of Calabria, under Mediterranean climate conditions, has a good hydraulic performance also in a different climate, as the Temperate one, in which the Lyon data were recorded.

Furthermore, to statistically determine the significance of the hydrological parameters on the performance of the GR, the multiple linear regression analysis was applied. The investigation revealed that the most influencing parameters on the retention capacity of the green roof are the rainfall depth, the duration and intensity, according to which, the substrate moisture condition changes. The relationships founded and validated with Lyon dataset, can be used to preliminarily predict the runoff depth and the retention capacity, for a given rainfall event, when more advanced model are not available.

Acknowledgments
The study was developed and co-funded from the Italian National Operative Project (PON) - Research and Competitiveness for the convergence regions 2007/2013: PON01_02543 "*Integrated and Sustainable Management service of water-energy cycle in urban drainage systems*".

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