Assessment of the green roof retention capacity: the role of the evapotranspiration

Evaluation de la capacité de rétention des toitures végétalisées : le rôle de l'évapotranspiration

A. Palla, I. Gnecco, J.J. Sansalone

Department of Civil, Chemical and Environmental Engineering, University of Genova, Italy (anna.palla@unige.it; ilaria.gnecco@unige.it)
Engineering School of Sustainable Infrastructure and Environment, University of Florida, United States (jsansal@ufl.edu)

RÉSUMÉ

L'évapotranspiration (ET) est une clé de voûte qui affecte la performance hydrologique des infrastructures vertes puisque le processus ET est le processus hydrologique responsable de la restauration de la capacité de rétention d'eau des infrastructures vertes. Compte tenu de la nécessité d'estimer efficacement l'impact des infrastructures vertes sur la réponse hydrologique à l'échelle du bassin versant urbain, une attention particulière a récemment été accordée à l'estimation de l'ET réelle dans les simulations continues. Dans ce cadre, l'objectif principal de ce document est d'évaluer le rôle de la ET actuelle dans la restauration de la capacité de rétention d'eau des toits verts dans le climat méditerranéen. En particulier, l'analyse s'appuie sur 19 mois de surveillance continue de la teneur en eau du sol du site expérimental de toiture végétalisée, situé à Gênes (IT). L'étude illustre un modèle de bilan hydrique et une procédure simple d'estimation des facteurs de correction basée sur l'analyse des périodes de temps sec surveillées; les résultats confirment la pertinence du modèle proposé pour décrire les pertes d'humidité pendant la période sèche, mais le facteur de correction spécifique (K_s) est nécessaire pour mesurer correctement les taux réels d'évapotranspiration.

ABSTRACT

Evapotranspiration (ET) is a keystone that affects the hydrological performance of green infrastructures since ET is the hydrological process responsible for the restoring of water holding capacity of green infrastructures. Taking into account the needs to effectively estimate the impact of green infrastructures on the hydrological response at the urban catchment scale, particular attention has recently been given on the estimation of the actual ET in continuous simulations. In this framework, the main objective of this paper is to assess the role of the actual ET in restoring the water holding capacity of green roofs in the Mediterranean climate. In particular, the analysis is supported by 19 months continuous monitoring of the soil water content of the green roof experimental site, located in Genoa (IT). The study illustrates a water balance model and a simple procedure to estimate correction factors based on the analysis of monitored dry weather periods; results confirm the suitability of the proposed model in describing the moisture losses in the dry period however the specific correction factor (K_s) is needed to properly measure the actual evapotranspiration rates.

KEYWORDS

(crop coefficient; evapotranspiration; green roofs; water balance equation; water-holding capacity)

1 INTRODUCTION

Taking into account the need to effectively estimate the impact of green roof on storm water management, particular attention has recently been given on the evapotranspiration (ET) process that is responsible for the restoring of green roof water-holding capacity (e.g. Stovin et al., 2013).

Recently methodological approaches are proposed to properly account for the actual ET in continuous simulations (e.g. Palla et al., 2018) while experimental study are addressed in order to properly account the role of the local climate, vegetation and specific conditions in enhancing the water-holding capacity.

In this framework, the main objective of this paper is to assess the role of the evapotranspiration in restoring the water holding capacity of green roofs. The study is supported by 19 months continuous monitoring of the soil water content of the green roof experimental site, located in Genoa (IT).

2 METHODOLOGY

2.1 The experimental site

Aiming at the assessment of the role of green roofs on the storm water management, since 2008 the University of Genova has carried on a monitoring programme on the green roof experimental site (Palla et al., 2009). The site is a flat roof covered with grass-herbaceous plants; the instrumented portion has a catchment area equal to 170 m^2. The stratigraphy consists of a protection layer (geotextile-300 gr/m^2), a drainage layer (realized by lapillus for a depth of 20 cm), a filter layer (geotextile -100 gr/m^2) and a growing medium with mixed soil (lapillus, pumice, zeolite and 200 l/m^3 of peat) for a depth of 20 cm.

The site is equipped with a meteorological station (for rain data, air temperature and humidity, global incoming solar radiation and air pressure); with a hydraulic device for continuous subsurface-outflow monitoring. The experimental site is a modern technological system fully equipped with sensors for on-site meteorological, hygrometric and flow rate measurements. In particular, the site is equipped with a meteorological station (for rain data, air temperature and humidity, global incoming solar radiation and air pressure), with a hydraulic device for continuous subsurface-outflow monitoring and with a set of TDR (Time Domain Reflectometry) probes for the soil water content measurement. Based on the rooftop stratigraphy 4 TDR probes have been installed horizontally along each vertical profile according to the following scheme: 2 in the growing layer and 2 in the drainage layer.

The soil water content data, available at 1 min resolution, are obtained by using the Topp equation (Topp et al., 1980) as discussed in Palla et al. (2009).

2.2 The monitoring period

Provided data continuity and reliability, the monitoring period selected for this study ranges from September 2008 to April 2010. In this 19 months of continuous monitoring 22 dry weather periods have been selected for study purpose. The selected dry weather period ranges from 5 to 18 days and are well distributed all over the solar year.

2.3 The modelling of the evapotranspiration losses

The daily water balance equation was used to simulate the soil water content behaviour during dry periods. Given the present focus on dry weather periods, precipitation is neglected and, if the soil water content is below the field capacity, it is assumed that the moisture loss is solely due to the evapotranspiration (ET). Otherwise the runoff (R) contribution is also evaluated. ET is calculated using the basic form of the Soil Moisture Extraction Function (SMEF) model (Zhao et al., 2013) that estimates actual ET under conditions of restricted moisture availability. The actual ET rate (expressed as a proportion of PET) at the end of the dry period is calculated as the ratio between the soil water content (S)and the maximum water holding capacity (S_{max}) corresponding to the field capacity condition.

$$R_t = \begin{cases} 0 \quad , & S_{t-1} - ET_t \le S_{Max} \\ S_{t-1} - S_{Max} - ET_t \, , & S_{t-1} - ET_t > S_{Max} \end{cases}$$

$$S_t = \begin{cases} S_{t-1} - ET_t \, , & S_{t-1} - ET_t \le S_{Max} \\ S_{Max} \, , & S_{t-1} - ET_t > S_{Max} \end{cases}$$

PET refers to the expected ET rate associated with a reference crop under well-watered conditions. In this study the energy balance-aerodynamic FAO-56 Penman Monteith equation is used to estimate the PET value.

The daily water balance equation is used to determine green roof system factors (K_s) specific for the monitored experimental site. This coefficient takes into consideration the specificity of green roof substrates and the difference between the tested sedum vegetation and the reference grass crop in the PET models used (Berretta et al., 2014).

3 RESULTS

Figure 1 illustrates the comparison between the daily evapotranspiration (ET) rates observed and simulated (blue dots) for the selected dry weather period. Subsequently the simulated values are corrected by multiplying for the green roof system factor (K_s) (red dots in Figure 1). The green roof system factor (K_s) is calculated by minimizing the root mean square error and it results equal to 0.77.

Results plotted in Figure 1 confirm the suitability of the proposed model in describing the moisture losses in the dry period furthermore the specific correction factor (K_s) is useful to properly measure the actual evapotranspiration rates for the investigated system.

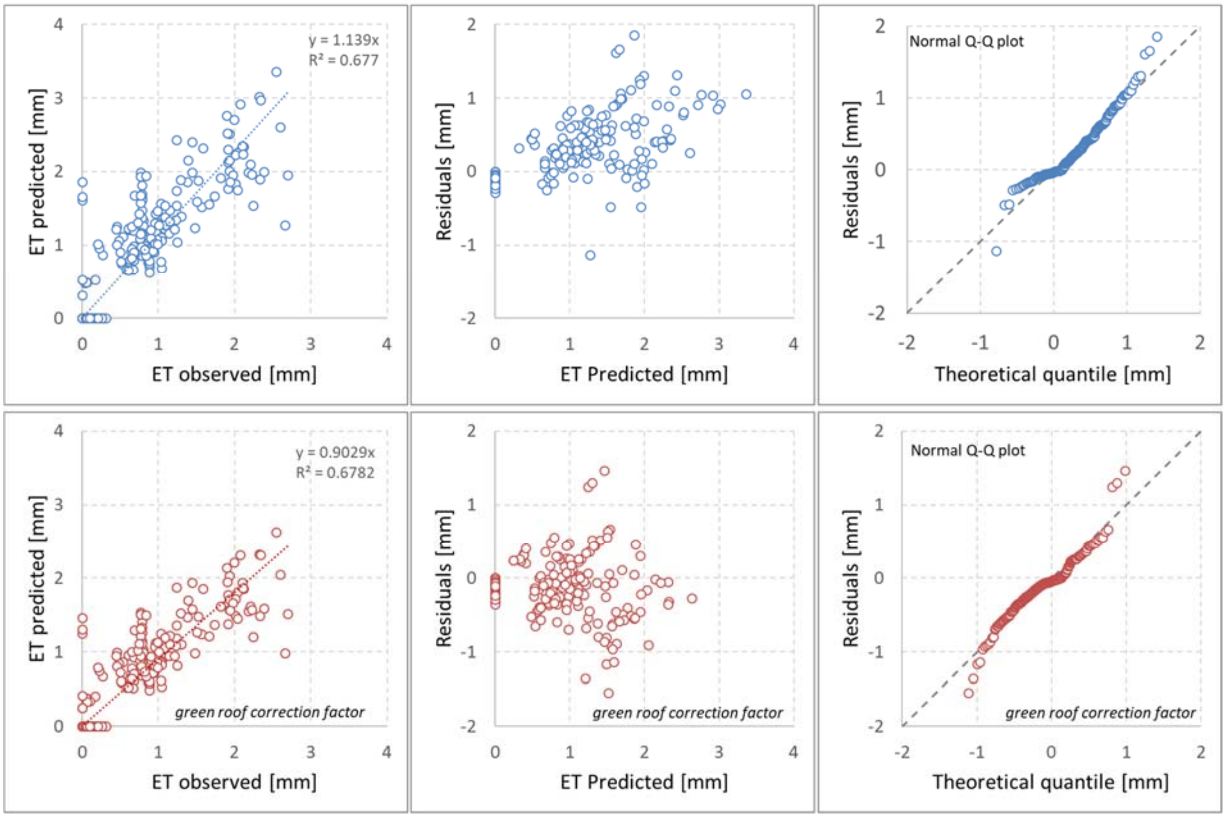

Figure 1: Predicted Vs. observed daily evapotranspiration (ET) rates for the selected dry weather period. The blue and red dots refer to the model calculation without and with the green roof system factor (K_s), respectively.

4 CONCLUSIONS

The study illustrates a water balance model and a simple procedure to estimate correction factors based on the analysis of monitored dry weather periods. The calculation of correction factors accounting for specific system characteristics linked to the water stress and vegetation conditions is needed to improve the accuracy of green roof water-balance model in predicting the green roof water-holding capacity. Long-term estimates of correction factor values along with observations for different plant species could be used for defining empiric equations of a generalizable correction factor value.

LIST OF REFERENCES

Berretta, C., Poë, S. and Stovin, V. (2014). *Moisture content behaviour in extensive green roofs during dry periods: The influence of vegetation and substrate characteristics*. J. Hydrol., 511, 374–386.

Palla, A., Gnecco, I. and La Barbera, P. (2018)*. Assessing the Hydrologic Performance of a Green Roof Retrofitting Scenario for a Small Urban Catchment*. Water, 10(8), 1052.

Palla, A., Gnecco, I. and Lanza, L.G. (2009). *Unsaturated 2D modelling of subsurface water flow in the coarse-grained porous matrix of a green roof.* J. Hydrol., 379(1-2), 193-204.

Topp, G.C., Davis, J.L. and Annan, A.P. (1980). *Electromagnetic determination of soil water content: measurement in coaxial transmission lines.* Water Resour. Res., 16(3), 574-582.

Stovin, V., Poë, S. and Berretta, C. (2013). *A modelling study of long term green roof retention performance.* J. Environ. Manag., 131, 206–215.