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A conceptual model for predicting hydraulic behaviour of a green roof

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Abstract

In urban environment green roof represents a sustainable solution for mitigating rainfall-runoff volumes delivered to combined sewer systems. Despite numerous studies have been focusing on long-term monitoring of green roof in urban watersheds, few literature has analysed and built models for predicting the hydraulic efficiency of a green roof.
This study proposes a conceptual model to predict the hydraulic behaviour of a small-scale physical model of a green roof. The model green roof is idealized as a system consisting of three individual components in series. Each component is subjected to different hydrologic and hydraulic processes and therefore, is treated as a separate module. A mass balance equation is applied to each component, taking into account the specific phenomena occurring in each module. The model is loaded by a series of constant rainfall intensities. The physical model testing is also performed.
Results demonstrate the model is accurately able to predict the hydraulic behaviour of the system as compared to measured data. In future research study this model will be applied to long-term basis simulations.

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Keywords: Infiltration; Substrate; Continuous simulation; Drainage layer.

1. Introduction

In urban environment green roof represents a sustainable solution for mitigating rainfall-runoff volumes delivered to combined sewer systems. The on-going urbanization generates the increase of impervious surfaces of buildings, roads and parking lots. This process produces a change in the natural hydrological cycle with the

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consequence of increasing runoff volume over the watershed (Farrell et al., 2013). Higher runoff volume strains urban systems that must operate beyond design capacity and causes the potential for flooding. Urban runoff also threatens the water quality by washing pollutants from roads, parking lots, and rooftops to local waterways.

Among stormwater best management practices (BMPs) have been suggested and implemented in order to reduce the effect of runoff, green roofing may be a sustainable solution, especially where land area is unavailable for other BMPs. Green roof consists of three major components: a vegetative/surface layer, a substrate (soil) and a storage/drainage layer (Teemusk and Mander, 2007; Fioretti et al., 2010; Dietz, 2007; Getter and Rowe, 2009; De Nardo et al., 2003). Green roofs mitigate runoff since the substrate and vegetation absorb precipitation, providing rainfall retention (Speak et al., 2013).

Despite numerous studies have been focusing on monitoring of green roof in urban watersheds. Few literature studies have analysed and built models for predicting the hydraulic efficiency of a green roof in order to evaluate the potential benefits of the system, especially on long-term basis (Palla et al., 2012, Hilten et al., 2008, Spolek, 2008, Teemusk and Mander, 2007).

Modeling the hydraulic behaviour of a green roof is a complex task. Some authors limited their investigation to the evaluation of the peak flow rate delivered from a green roof by applying watershed runoff equations, based on curve number (CN) or rational coefficient. Getter et al. (2007) derived CN varying from 85 to 90 for green roofs with differing slopes. Moran et al. (2005) derived a rational coefficient of 0.5 for 10 different rain events.

Other authors proposed approaches for simulating the hydrologic and hydraulic behaviours of green roofs. Hilten et al. (2008) used HYDRUS-1D model to evaluate the green roof performance based on the prediction of the soil moisture transport. The study demonstrated that rainfall depth significantly impacts the performance of the system, providing complete retention for small events and detention for larger storms. Also Teemusk and Mander (2007) observed 85.7% retention for a 0.21 cm storm whereas for larger storms, green roofs provided little retention. Bengtsson (2010) used the water balance approach to investigate the hydrology of a green roof in Sweden, and demonstrated that annual runoff can be reduced by up to 64% due to evapo-transpiration. Palla et al. (2009) demonstrated the SWMS_2D model, based on Richards' law and the Van Genuchten-Mualem functions was able to accurately predict the infiltration process and water content profiles within green roof system.

This study aims to predict the hydrological and hydraulic behaviours of a green roof by using a conceptual model. In this model a green roof is idealized as a system consisting of three individual components in series. Each component is subjected to different hydrologic and hydraulic processes and therefore, is treated as a separate module. A mass balance equation is applied to each component, taking into account the specific phenomena occurring in each module. The surface layer is represented by the first module where the evapotranspiration/evaporation processes are modelled; the soil/substrate by the second module which predicts the infiltrated volumes. Finally the drainage layer is modelled as a storage and the linear storage equation is used. The model is applied to two micro-test beds with different stratigraphy and loaded with a series of constant intensity rainfall events.

Modelling results are then coupled to measured data collected from an experimental testing on two test beds with different stratigraphies to calibrate the model. Finally the calibrated model is loaded with the rainfall distribution generated from an urbanized watershed for a selected representative year to predict the hydrological and hydraulic behaviour of a green roof on long-term basis.

2. Methodology

2.1. Experimental testing of a test bed

An experimental system is built to perform a series of hydraulic tests. In Figure 1 a schematic of the experimental setup is reported. Two test beds of 50 cm by 50 cm are used. The first test bed is characterized by the following stratigraphy: (1) soil substrate of 8 cm; (2) 'egg box' drainage and storage layer in pe-ad (storage capacity of 8,7 L/m^2). The entire package is 15 cm.