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Green roofs effects on the urban water cycle components

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Abstract

Green roofs are emerging as an increasingly popular Sustainable Urban Drainage Systems (SUDS) technique for urban stormwater management. Indeed, they allow a significant reduction of peak flows and runoff volumes collected by drainage system, with consequent reduction of flooding events and pollution masses discharges by CSO. To estimate the imperviousness of a green roof and to evaluate its hydrological impact within an urban watershed, a bucket model was developed to simulate a rainfall-runoff relationship for a single green roof. The objective is modeling hydrological fluxes in relation to climate forcing, basic technology components and geometric characteristics of green roof systems.

Keywords: Green roofs, storm water, runoff, urban hydrology, modelling;

1. Introduction

In the last decades the importance of storm water management in urban areas has increased considerably, due to both urbanization extension and to a greater concern for environment pollution. Urbanization leads to an increase in impervious surfaces – rooftops, driveways, roads, car parking, and footpaths – which are connected with hydraulically efficient pipes to receiving waters. The natural roughness and filtering action of vegetation, and the infiltration and storage capacity of the underlying soils, is replaced by compacted soils and hydraulically-smooth impervious surfaces at the expense of hydrologic functions such as interception by plants, depression storage, infiltration, soil water storage and flow retardation due to surface roughness. This creates a greater volume of excess water which runs off more quickly for a given rainfall event.

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Traditional storm water control practices, based on the "all to the sewer" attitude, rely on conveyance to route storm water runoff from urban impervious surfaces towards the nearby natural water bodies. On the contrary, green roofs are designed to capture, temporarily retain and infiltrate storm water, promote evapotranspiration and harvest water at the source, encouraging in general evaporation, evapotranspiration and the re-use of storm water. Such technique can provide an opportunity to reduce and attenuate storm runoff at source; in this way, many studies suggest that green roofs can reduce storm water runoff in comparison to conventional roofs with volume retention scores in the order of 40–80% of the total rainfall volume. From literature's data it is also evident that a decrease of 60–80% in runoff peak rates is to be expected from a green roof (Köhler et al., 2001; Hutchinson et al., 2003; Liu, 2003; Moran et al., 2004; Bengtsson et al., 2005; VanWoert et al., 2005; Berghage et al., 2009).

However, the dynamic stormwater response of a green roof to precipitation events is highly variable and related to a particular set of climate conditions and changes with green roof design.

In recent years, due to their particular efficiency in restoring a balance in hydrological cycle quite equal to quite pre-urbanization condition, the impact of green roof implementation in urban watersheds has become a hot research topic. The effect of green roofs has been studied by various methods and several studies, based usually on water-balance models that treat green roofs as simple reservoirs with restricted outlets, examined their hydrologic response. Cater and Jackson (2006), for example, used the Soil Conservation Service (SCS) Curve Number (CN) method as the infiltration and runoff model to test green roof impact at multiple spatial scales. Hilten et al. (2008) conducted a study on the effectiveness of green roofs to mitigate stormwater runoff by using HYDRUS-1D. Hollander (2007) used a modified Green-Ampt method and a physical model to research the effect of green roof implementations; Palla et al. (2009) used the SWMS_2D model, based on Richards' law and the Van Genuchten–Mualem functions to simulate the variably saturated flow within the green roof system; She and Pang (2010) constructed a physics-based model to simulate rain water movement with green roof medium; Sherrard et al. (2012) built a simple bucket model for a single green roof and extrapolated it to an urban scale to test its stormwater reduction effects

The average reduction in stormwater runoff would appear to provide an indication of the impervious contribution of a green roof; when green roofs are implemented into an urban system, they represent a third type of surface area which behaves as pervious before saturation and impervious after saturation. To estimate the imperviousness of a green roof and, as consequence, to evaluate its hydrological impact within a urban watershed, a simple bucket model was developed to simulate the water fluxes in soil layers and to generate a rainfall-runoff relationship for a single green roof. The model is based on the physical processes that affect the green roof stormwater response: during a storm event the key hydrological mechanisms operating within the green roof are the interception of rainfall by the plant layer, evapotranspiration, infiltration and storage in the substrate, and reservoir storage in the drainage layer. This model could only provide a tool for understanding how the implementation of green roofs can affect urban catchment under different conditions; indeed, the objective is modeling hydrological fluxes (interception, evapotranspiration, soil water fluxes in the surface and hypodermic components) in relation to climate forcing, basic technology components and geometric characteristics of green roof systems (thickness of the soil layers and materials, vegetation typology and density). To simplify model parameterization in this study we adopted a simplified bucket model that is conceptually similar to the TOPMODEL soil water accounting scheme (Beven and Kirkby, 1979).

2. Model description

2.1. Green roof design influence on soil-water fluxes

The hydrologic processes in a green roof consist of evapotranspiration, infiltration, and runoff generation. It is critical to quantify each part of the hydrologic budget to determine the efficiency of a green roof at reducing peak runoff rates and volumes. A hydrologic budget balances the inputs and outputs of water in the system with the change in volume of stored water. The hydrologic balance provides the governing equation for determining how much rainfall might be captured by a green roof at any given time.