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Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?

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Abstract

During the last two decades, a large amount of research has been published in German on the reduction of rainwater runoff for different types of roof greening. This paper analyzes the original measurements reported in 18 publications. Rainfall–runoff relationships for an annual and seasonal time scale were obtained from the analysis of the available 628 data records. The derived empirical models allowed us to assess the surface runoff from various types of roofs, when roof characteristics and the annual or seasonal precipitation are given. The annual rainfall–runoff relationship for green roofs is strongly determined by the depth of the substrate layer. The retention of rainwater on green roofs is lower in winter than in summer. The application of the derived annual relationship for the region of Brussels showed that extensive roof greening on just 10% of the buildings would already results in a runoff reduction of 2.7% for the region and of 54% for the individual buildings. Green roofs can therefore be a useful tool for reducing urban rainfall runoff. Yet in order to provide a greater effect on overall runoff they should be accompanied by other means of runoff reduction and/or water retention.

Keywords: Green roof; Roof greening; Water retention; Urban hydrology; Runoff; Germany; Models; Vegetative roofs; Ecoroof

1. Introduction

In developed countries, the level of urbanization is still rising and expected to reach 83% in 2030 (United Nations, 2002; Antrop, 2004). Cropland, grassland and forests are displaced by the impervious surfaces of streets, driveways and buildings greatly intensifying storm water runoff, diminishing groundwater recharge and enhancing stream channel and river erosion (cf. Stone, 2004). This ongoing urbanization involves an unsustainable use of natural systems and creates numerous problems both within and outside cities. One of the major environmental problems of urbanization is that the urban hydrological system has to cope with a highly fluctuating amount of surface runoff water which may become extremely high during periods of rainfall and remains low during the rest of the time (cf. White, 2002). Climate change may further increase these fluctuations. In particular, the flood risk will

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further increase (e.g. Environment Agency, 2002; Villarreal et al., 2004). Tools for reducing the high runoff during rainfall and to increase retention include storage reservoirs and ponds where water can be temporary stored (Ferguson, 1998; White, 2002) and green areas where water can infiltrate and evaporate. However, this means a redesign of the urban hydrological system so that it again plays a more active and positive role in the natural hydrological cycle. The creation of more green areas is also an answer to the recent calls for a more ecological and greener urbanization (cf. Onmura et al., 2001; White, 2002; Van Herzele and Wiedemann, 2003; Dunnett and Kingsbury, 2004). Unfortunately, the high amount of impervious surfaces (Blume, 1998; Ferguson, 1998) and the high land prices make the creation of green areas in urban regions very expensive if not impossible. Given the huge amount of unused roof area (about 40–50% of the impermeable surfaces in urban areas (cf. Dunnett and Kingsbury, 2004)), green roofs – also known as rooftop gardens or vegetative roofs or even ecoroofs – may be an interesting alternative. Thanks to their water storing capacity, green roofs may significantly reduce the runoff peak of the most rainfall events. The reduction consists in: (i) delaying the initial time of runoff due to the absorption of water in the green roof system; (ii) reducing the total runoff by retaining part of the rainfall; (iii) distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in the pores of the substrate. Fig. 1 illustrates the reduction in peak runoff from a green roof, as observed in Belgium during a rainstorm. Green roofs may also have an impact on the heat island effect of urban areas through increasing evapotranspiration of water (Ernst and Weigerding, 1985; Von Stülpnagel et al., 1990; Bass et al., 2002) and may reduce the energy cost for cooling and/or heating of buildings (Takakura et al., 2000; Niachou et al., 2001). The heat island effect, which results in higher air temperatures and lower air humidity compared to that in the surrounding areas, is considered to reduce the living quality in the cities (Niachou et al., 2001).

In some highly urbanized societies like Japan, Singapore, Germany and Belgium the advantages of green roofs have already resulted in incentives from the government to encourage or even impose the use of green roofs (see Osmundson, 1999; Wong et al., 2003; Dunnett and Kingsbury, 2004).

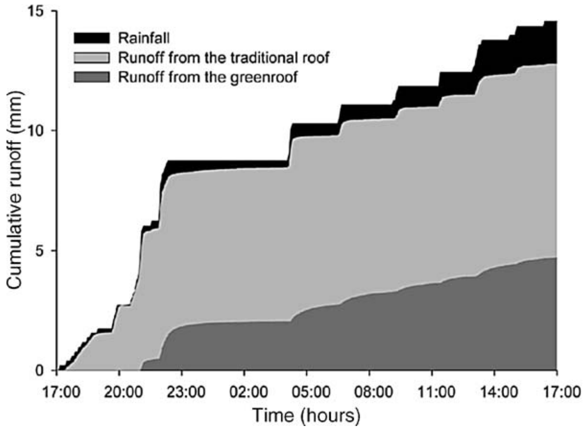

Fig. 1. Typical cumulative runoff from a non-greened roof and an extensive green roof as observed in Leuven (Belgium) during the 24 h period of a 14.6 mm rain shower (April 2003, 5 p.m.–5 p.m. on the next day). Both roofs had a slope of 20°.

Green roofs basically consist of a vegetation layer, a substrate layer (where water is retained and in which the vegetation is anchored) and a drainage layer (to evacuate excess water) (see, e.g. Mentens et al., 2003). Based on the depth of the substrate layer two main types of green roof are usually distinguished in Europe (Krupka, 1992; Kolb and Schwarz, 1999):

- Extensive green roofs with a substrate layer with a maximum depth of about 150 mm. *Sedum* species usually make up the major part of the vegetation. This type may also be installed on sloped surfaces. The slope angle can be as high as 45°.
- Intensive green roofs with a substrate layer with a depth of more than 150 mm. Grasses, perennial herbs and shrubs make up the main constituents of the vegetation. Intensive green roofs are typically installed on roofs with a slope of less than 10° and, depending on design and access, they may be used as roof gardens.

Since the first mentioning of the water retaining capacity of green roofs in the German literature in 1985 (Ernst and Weigerding, 1985), several European scientists have studied the relationship between precipitation, roof properties and runoff. The studied time period and roof characteristics vary widely in the consulted literature. In the last couple of years, two papers (Kolb, 1998; Mann, 2000) summarized part of the existing literature. However, the authors did not re-analyze the