Science of the Total Environment 461–462 (2013) 28–38

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Rainwater runoff retention on an aged intensive green roof

A.F. Speak [a,*], J.J. Rothwell [a], S.J. Lindley [a], C.L. Smith [b]

[a] Geography, School of Environment and Development, The University of Manchester, Arthur Lewis Building, Oxford Road, Manchester M13 9PL, UK
[b] College of Science and Engineering, University of Leicester, Bennett Building, University Road, Leicester LE1 7RH, UK

HIGHLIGHTS

- Average rainfall runoff retention was 65.7% on an intensive green roof.
- High organic matter content of substrate could contribute to high retention.
- High rainfall events displayed significantly reduced green roof retention.

ARTICLE INFO

Article history:
Received 17 January 2013
Received in revised form 26 April 2013
Accepted 28 April 2013
Available online 24 May 2013

Editor: Simon James Pollard

Keywords:
Green roof
Sustainable urban drainage systems
Rainwater runoff

ABSTRACT

Urban areas are characterised by large proportions of impervious surfaces which increases rainwater runoff and the potential for surface water flooding. Increased precipitation is predicted under current climate change projections, which will put further pressure on urban populations and infrastructure. Roof greening can be used within flood mitigation schemes to restore the urban hydrological balance of cities. Intensive green roofs, with their deeper substrates and higher plant biomass, are able to retain greater quantities of runoff, and there is a need for more studies on this less common type of green roof which also investigate the effect of factors such as age and vegetation composition. Runoff quantities from an aged intensive green roof in Manchester, UK, were analysed for 69 rainfall events, and compared to those on an adjacent paved roof. Average retention was 65.7% on the green roof and 33.6% on the bare roof. A comprehensive soil classification revealed the substrate, a mineral soil, to be in good general condition and also high in organic matter content which can increase the water holding capacity of soils. Large variation in the retention data made the use of predictive regression models unfeasible. This variation arose from complex interactions between Antecedant Dry Weather Period (ADWP), season, monthly weather trends, and rainfall duration, quantity and peak intensity. However, significantly lower retention was seen for high rainfall events, and in autumn, which had above average rainfall. The study period only covers one unusually wet year, so a longer study may uncover relationships to factors which can be applied to intensive roofs elsewhere. Annual rainfall retention for Manchester city centre could be increased by 2.3% by a 10% increase in intensive green roof construction. The results of this study will be of particular interest to practitioners implementing greenspace adaptation in temperate and cool maritime climates.

1. Introduction

In the UK, green roofs are increasingly being recognised for their role as Sustainable Urban Drainage Systems (SUDS) (White and Alarcon, 2009). SUDS are defined as management practices designed to drain surface water in a more sustainable way than conventional systems (CIRIA, 2007). Green roofs reduce the rate and volume of runoff, and are located close to the source, thus helping to improve stormwater management. This, along with other benefits such as air pollution reduction (Speak et al., 2012), local urban cooling (Takebayashi and Moriyama, 2007), and creation of habitats for wildlife (Oberndorfer et al., 2007), means that green roofs are becoming a more prominent factor in local government planning guidelines (MCC, 2009).

Urban areas are characterised by large proportions of their surface area being impervious to rainfall runoff, which can lead to pluvial (surface water) flooding during heavy rainfall events. Recent flood management legislation in the UK has improved the priority given to pluvial flooding, as 2 million people in UK urban areas are at risk of a 1 in 200 year event (Houston et al., 2011). Climate change could lead to an increase in flooding events, because winter precipitation increases of up to 33% are predicted for the UK by the 2080s under a medium emissions scenario, especially in western parts (Murphy et al., 2009). Summer precipitation is expected to decrease, however, rainfall could

* Corresponding author at: School of Environment and Development (Geography), The University of Manchester, Arthur Lewis Building, Oxford Road, Manchester M13 9PL, UK. Tel.: +44 7792025678.
E-mail address: andrew.speak@postgrad.manchester.ac.uk (A.F. Speak).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.04.085

become concentrated into intense downpours, with an increase in the frequency of 20, 30, 50 and 100 year return period events for the north west UK (Sanderson, 2010).

Adaptation techniques that aim to promote infiltration and restore the urban hydrological balance include the creation of green areas such as parks, bunds and swales (CIRIA, 2007). Due to development pressures the extent to which new green spaces can be established in urban areas is generally very limited. Green roofs have the benefit of not requiring upheaval of the existing urban form, and rooftops can constitute up to 50% of the impervious area in densely built-up urban centres (Dunnett and Kingsbury, 2004).

Green roofs consist of three layers – vegetation, substrate and drainage – and two main types exist, defined by the depth of the substrate layer, with extensive roofs being generally less than 150 mm and intensive roofs having deeper soils. The deeper substrates on intensive roofs allow for a greater diversity and biomass of plants in the vegetation layer. The overall runoff reduction process consists of: (i) delaying the initiation of runoff; (ii) reducing the quantity of runoff; and (iii) distributing the runoff over a longer time period via slow release of excess substrate pore water (Mentens et al., 2006). The amount of rainfall that is retained is of interest to urban hydrologists and flood prediction managers.

Research on the hydrological properties of green roofs has revealed a range of average rainwater retention efficiencies. For extensive green roofs these are 45% (DeNardo et al., 2005; Mentens et al., 2006) and 60% (Moran et al., 2003), and cumulative annual retentions of 50% (Stovin et al., 2012) and 60% (VanWoert et al., 2005). Carter and Rasmussen (2006) report downfall dependent retentions of 90% for small storms and 50% for large storms. Substrate depth has a major influence due to the direct relationship between deeper substrates and higher retentions due to the enhanced storage capacity, with retentions of 75% possible on intensive roofs (Mentens et al., 2006).

A number of factors can affect the retention efficiency. The season can have a large effect, with lower rainfall totals and higher evapotranspiration rates in warmer months and therefore shorter retention capacity recharge times between rainfall events. A meta-analysis of seasonal runoff data showed runoff was significantly higher during winter (80% of winter rainfall becoming runoff and 53% in summer) (Mentens et al., 2006). Antecedent Dry Weather Period (ADWP) is another factor related to the inter rain event recharge potential, and Stovin et al. (2012) found low ADWPs often produce low retention, however a high ADWP does not guarantee high retention due to the finite retention capacity of the roof and the influence of weather conditions during the ADWP. The intensity and duration of the rainfall is important,with small showers (<10 mm) being fully absorbed in a study in Texas (Simmons et al., 2008). Stovin et al. (2012) found the mean retention for 21 significant large storms to be 43%, however, the total depth retained was only 29.3% of total rainfall due to lower retention in larger storms.

Slope of green roof (Getter et al., 2007), vegetation composition (Dunnett et al., 2008a) and roof position, vegetation coverage and local climate (Berndtsson, 2010) have all been stated as having an influence on green roof hydrological performance. VanWoert et al. (2005) claim the physical characteristics of the substrate layer are more important than the vegetation, and studies should attempt to investigate the properties of the substrate. Higher organic contents in mineral soils confer higher infiltration rates and holding capacities (Brady and Weil, 2008). The age of the roof can therefore become an important factor as substrate properties change over time due to build up of organic material, and macropore creation by vegetation roots or tunnelling invertebrates, which would increase retention capacity, and soil compaction which would decrease it (Getter et al., 2007). There are few examples, to date, of studies which link the soil characteristics of aged green roofs to retention capacity. This is important, as it allows estimates to be made of the future performance of green roofs as adaptation strategies for the increased flood risks caused by climate change.

The majority of green roof hydrological studies are carried out on artificial extensive green roof test beds (VanWoert et al., 2005; Dunnett et al., 2008a). There is a need therefore for research to focus on real, intensive green roofs to characterise the benefits afforded by investing in deeper substrates and to see how those benefits are maintained in a real world situation, in different seasons, and when subjected to extreme rainfall events. Similarly, as green roofing is a relatively novel technology in the UK, there is a lack of literature on how older green roofs perform, and, therefore, the implications of their use as longer-term adaptation strategies in UK urban areas is not discussed. This study aims to quantify the rainfall retention properties of an aged, intensive green roof in Manchester city centre. A comprehensive monitoring approach will be used to make a comparison between the green roof and an adjacent conventional paved roof surface, which will allow any differences in rainwater retention to be investigated for a number of different rain events.

2. Methodology

2.1. Site description

Manchester is a large city in north-west England with a population of 498,000 (MCC, 2010). The main source of flood risk to the Greater Manchester sub-region is from fluvial flooding (Kazmierczak, 2011), however surface water flooding can become more important in urban areas (DEFRA, 2008). Flooding was found to be the dominant climate impact in the region, over temperature extremes, high winds, fog and drought, with some evidence that flood events have been becoming more frequent over recent decades (Smith and Lawson, 2012). The majority of pluvial flooding events occurred during the summer months, and this may indicate the significance of short duration, heavy rainfalls characteristic of this season, and/or an increase in the impervious nature of the landscape leading to increased surface runoff (Smith and Lawson, 2012). Surface water flooding events have the potential to impact seriously on Manchester's critical and transport infrastructure (Kazmierczak, 2011), which can result in loss of power to homes and services, and large financial costs for cleanup and recovery.

A green roof within the University of Manchester campus, on the Precinct building, was chosen for the study (Fig. 1). The area is classified as open midrise, characterised by a fairly open arrangement of buildings of 3–9 storeys with some trees, typical of an inner city university campus area (Stewart and Oke, 2012). The roof was chosen because it has a conventional roof area (900 m^2), consisting of concrete paving slabs, adjacent to a large (408 m^2) intensive green roof, which is 43 years old, and has an average depth of 170 mm. The roof is not within rain shadows of any adjacent taller buildings. Fig. 2 shows cross sectional representations of the two study roofs. The green roof is of fairly standard construction with the vegetation and substrate layers divided from the 'egg box' design plastic drainage layer by a fibrous membrane. The roof itself is protected by a tough geotextile membrane. The bare roof is a conventional roof surface consisting of concrete paving. The 60 × 60 cm paving slabs sit on top of an insulating polystyrene cushion and a plastic foam membrane that are impermeable to water.

The green roof is of particular interest due to its age, the fact that the roof was not constructed specifically for the study, and due to it having a mineral soil substrate rather than the more usual, prefabricated, light weight aggregate (LWA) based substrate. Green roof studies with an experimental component often use specially constructed extensive green roof test rigs. It can be argued that studies of this type can over or underestimate the benefits of actual green roofs. For example, Stovin et al. (2012) recognised that the small size (3 m^2) of their green roof setup could underestimate the lag and attenuation of their runoff hydrograph. Artificial experimentation studies can also overestimate the benefits because the test rigs are 100% green coverage, whereas in reality green roofs often have quite high proportions of conventional roof surface,