Environmental Pollution 184 (2014) 33–43

Contents lists available at ScienceDirect

Environmental Pollution

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

Metal and nutrient dynamics 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

ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form
20 August 2013
Accepted 23 August 2013

Keywords:
Green roofs
Lead
Urban runoff
Water pollution

ABSTRACT

Runoff and rainfall quality was compared between an aged intensive green roof and an adjacent conventional roof surface. Nutrient concentrations in the runoff were generally below Environmental Quality Standard (EQS) values and the green roof exhibited NO_3^- retention. Cu, Pb and Zn concentrations were in excess of EQS values for the protection of surface water. Green roof runoff was also significantly higher in Fe and Pb than on the bare roof and in rainfall. Input–output fluxes revealed the green roof to be a potential source of Pb. High concentrations of Pb within the green roof soil and bare roof dusts provide a potential source of Pb in runoff. The origin of the Pb is likely from historic urban atmospheric deposition. Aged green roofs may therefore act as a source of legacy metal pollution. This needs to be considered when constructing green roofs with the aim of improving pollution remediation.

1. Introduction

One of the problems of growing urbanisation is the potential for high pollutant loads in urban storm runoff (Rocher et al., 2004). Urban runoff can have significant adverse ecological effects in receiving water bodies. Heavy metals in particular have been found to be highly persistent and toxic to aquatic flora and fauna at low environmental concentrations (Pizzol et al., 2011). Nutrients can also be a problem when urban surface waters discharge to water bodies that are already nutrient-rich, resulting in eutrophication (Ellis and Mitchell, 2006). The poor water quality of urban runoff results from the accumulation of particulate matter and dissolution of environmentally harmful substances as it is conveyed over the impervious roofs and roads in the urban watershed (Lye, 2009). On rooftops these substances include: heavy metals leached from roof surface materials (Rocher et al., 2004); dry and wet deposited air pollutants such as SO_2 and NO_x (Fowler et al., 2007); airborne dusts from vehicle use, industry, construction (Robertson et al., 2003; Göbel et al., 2007); and salts from road de-icing (Lundmark and Olofsson, 2007). The distribution and concentration of pollutants in runoff is related to the nature of the surfaces (Mendez et al., 2011), as well as local patterns of wet and dry atmospheric deposition (Forster, 1999). This Urban Diffuse Pollution (UDP) can be difficult to identify, measure, and control, but there is nonetheless a need to control UDP sources in order to preserve water resources from the pressures of urbanisation and climate change (DEFRA, 2011). One way to control UDP is to employ catchment based measures such as Sustainable Urban Drainage Systems (SUDS). These are preferable because they involve the multiple agencies identified in the process of UDP generation (DEFRA, 2012). They also place a greater emphasis on improving the quality of the water resource by sequestering pollutants where possible (CIRIA, 2007). SUDS technologies that improve the hydrological function of rooftops, such as green roofs, have the potential to be a great benefit for alleviating the problem of UDP, because roofs can account for 50% of the urban impervious area in the UK (Dunnett and Kingsbury, 2004).

The ability of green roofs to reduce the volume of stormwater runoff has been frequently reported (Getter et al., 2007; Stovin et al., 2012) with runoff retentions of between 50% and 100% (Rowe, 2011). Green roofs are also efficient at capturing air pollution such as NO_x, SO_2, ozone (Currie and Bass, 2008), and PM_{10} (Speak et al., 2012) and it is generally expected that the pollutants would be retained in the vegetated roof or consumed in reactions (Berndtsson et al., 2009). However, there is the possibility that air pollution that has been captured by vegetation will eventually leach into the roof runoff, thus trading air pollution for water pollution (Rowe, 2011) unless runoff is treated.

Studies have revealed green roofs to be both sources of water contaminants, as well as sinks. Berndtsson et al. (2006) found extensive sedum-moss roofs to be a source of pollutants such as Cd, Cr, Cu, Fe, K, Mn, Pb, Zn, NO_3^- and PO_4^{3-} when compared to a non-vegetated roof. However, it was concluded that the overall runoff

* Corresponding author.
E-mail addresses: andrew.speak@postgrad.manchester.ac.uk, andyspeak33@gmail.com (A.F. Speak).

0269-7491/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envpol.2013.08.017

quality can be considered good in relation to water quality standards. Mendez et al. (2011) found elevated As and high Pb in the first flush of an extensive green roof. The green roof substrate itself can be a source of metals, as was found in a study with different commercial soil assemblages based on either clay and peat mixtures or inorganic volcanic material and compost. Significant quantities of Fe and Al were leached from some substrate types and considerable quantities of Cu from another (Vijayaraghavan et al., 2012). Most studies, however, find no substantial release of heavy metals from green roofs. A comparison of a Swedish extensive roof with an intensive roof in Japan found neither roof to be a great source of metals (Berndtsson et al., 2009). One of the first studies to investigate green roof runoff quality found percentage retention of contaminant influx to be 95% for Pb and 88% for Cd (Köhler et al., 2002). Metal concentrations found in green roof runoff are generally similar to those in precipitation, and consequently, when the reduced quantity of runoff by green roofs is taken into consideration, the net effect is of a reduced metal flux (Berndtsson, 2010). Concentrations of heavy metals in runoff coming from different urban surfaces, including tiles, concrete and copper roofs, revealed green roofs to have the lowest amount of metals, except for Zn (Göbel et al., 2007). Green roofs also generally act to mitigate mild acid rain by raising the pH from between to 5 to 6 in rainfall to between 7 and 8 (Berndtsson, 2010).

The most common impact on green roof runoff quality comes from N and P. High nutrients have been frequently found in green roof runoff (Vijayaraghavan et al., 2012; Gregoire and Clausen, 2011; Teemusk and Mander, 2007; Monterusso et al., 2004) with the N and P amounts being directly related to organic matter content (Moran et al., 2003). Additionally, the use of artificial fertilisers on green roofs is a major source of nutrients. Emilsson et al. (2007) demonstrated how conventional fertilisers cause high nutrient concentrations in the runoff, and this was influenced by not only the vegetation system type, but by the age of the vegetation mat. Old mats reduced the risk of nutrient leaching, potentially due to temporary storage in the substrate and enhanced uptake by the well-established vegetation. Consequently, reduced application of fertilisers is often suggested by authors to reduce the nutrient concentrations in green roof runoff (Emilsson et al., 2007; Teemusk and Mander, 2011). Dissolved Organic Carbon (DOC) has also been found to be high in green roof runoff due to the presence of organic material (Mentens et al., 2006; Berndtsson et al., 2009). This can be an issue because the discolouration can be problematic in situations where runoff is collected for re-use (Berghage et al., 2007), and concentrations of DOC over 8 mg l^{-1} can produce disinfection by-products which may then require post-disinfection treatment under US legislation (Mendez et al., 2011).

There are a number of factors which can influence the green roof runoff quality such as the volume of rainfall, local pollution sources, plant selection, and substrate composition (Rowe, 2011). NO_3^- concentrations were found to be higher in runoff from a sedum roof in comparison to herbaceous perennials, and in runoff from shallower substrates (Monterusso et al., 2004). The age of the green roof can have an effect on whether the roof behaves as a source or a sink of contaminants. Köhler et al. (2002) found retention of PO_4^{3-} increased from 26% in the first year to 80% in the fourth year of monitoring of an extensive green roof. Similarly Berndtsson et al. (2006) stated that PO_4^{3-} release was not a problem on mature roofs. The age of the roof can affect the hydrological conductivity (Getter et al., 2007) and also the contaminant retention due to uptake by the well established vegetation. Conversely one might also expect saturation of contaminants. For instance, shallow soils can quickly become sites of significant N leaching as a result of high atmospheric inputs and limited retention capacity (Dise and Wright, 1995).

Green roofs are a relatively new technology in the UK, thus studies on aged green roofs are scarce. A benefit of such a study would be to reveal how older green roofs influence runoff water quality and consequently to see if both contemporary and historic loadings of metals in an urban environment significantly impact on this quality. Although many green roofs are now being established in relatively clean environments, this is not the case everywhere. Installation of green roofs in polluted areas as part of an air quality management strategy needs to be guided by an awareness of the issue of legacy pollutants so that suitable recommendations can be issued. There is evidence of legacy inputs affecting water quality in other environments, such as N input to forest ecosystems from chronic atmospheric N deposition exceeding assimilation capacity and resulting in enhanced export of dissolved inorganic N in runoff (Dise et al., 1998). Soils contaminated by historical metal mining or past atmospheric metal deposition can also influence surface water quality (Rothwell et al., 2008; Mayes et al., 2010). Extensive roofs, by definition, have substrates less than 150 mm and there are engineering limits to how deep the soil layer of intensive roofs can be due to the load bearing capacity of buildings. These shallow substrates, positioned within urban environments, have the potential to become saturated with dry and wet deposited pollutants over time. Fine fractions of Road Deposited Sediment (RDS) can also be carried on winds ultimately settling on rooftops, and RDS can frequently be highly contaminated with heavy metals such as Pb (Taylor and Robertson, 2009). The main sources of Pb in urban centres historically are from leaded petrol use in vehicles and industries handling materials that bear Pb (Del Rio-Salas et al., 2012). While the use of leaded petrol in UK has been phased out since 1985, Pb can persist in soils due to its long residence time (Tijhuis et al., 2002). Studies in Manchester have found high Pb levels in RDS several years after the phase-out of leaded petrol, especially in the finer fractions (Robertson and Taylor, 2007). Thus urban soils in Manchester, and possibly old inner city green roofs, are likely to contain elevated Pb, as well as other metals associated with urban anthropogenic inputs, such as Cu, Mn and Zn (Robertson et al., 2003).

There is an ongoing need for quantitative assessments of the impacts of green roofs on water quality, especially if their potential as SUDS is to be promoted. The objective of the current study is to compare the quality of runoff from an aged intensive green roof with that from an adjacent bare roof. The age of the roof, at 43 years, will be a most interesting factor of the study by revealing what impacts age may have on the runoff quality. This will allow the future performance of green roofs to be better estimated.

2. Methodology

2.1. Site description

Manchester is a large city in north-west England with a population of 498,000 (MCC, 2010).

A green roof within the University of Manchester campus, on the Precinct building, was chosen for the study. 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 (which has been dated to 1970 on the original blueprints), and has an average depth of 170 mm. The roof is not within rain shadows of any adjacent taller buildings. Fig. 1 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