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Impact of green roofs on stormwater quality in a South Australian urban environment

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HIGHLIGHTS

- This study uses robust statistical methods to investigate the water quality in runoff from the green roofs.
- The performance of the extensive green roofs was generally better than the performance of intensive systems in terms of pollutant removal.
- Green roof runoff water can be reused for urban landscape irrigation and for non-potable purposes such as toilet flushing

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ABSTRACT

Green roofs are an increasingly important component of water sensitive urban design systems and can potentially improve the quality of urban runoff. However, there is evidence that they can occasionally act as a source rather than a sink for pollutants. In this study, the water quality of the outflow from both intensive and extensive green roof systems were studied in the city of Adelaide, South Australia over a period of nine months. The aim was to examine the effects of different green roof configurations on stormwater quality and to compare this with runoff from aluminium and asphalt roofs as control surfaces. The contaminant concentrations in runoff from both intensive and extensive green roofs generally decreased during the study period. A comparison between the two types of green roof showed that except for some events for EC, TDS and chloride, the values of the parameters such as pH, turbidity, nitrate, phosphate and potassium in intensive green roof outflows were higher than in the outflows from the extensive green roofs. These concentrations were compared to local, state, national and international water quality guidelines in order to investigate the potential for outflow runoff from green roofs to be reused for potable and non-potable purposes. The study found that green roof outflow can provide an alternative water source for non-potable purposes such as urban landscape irrigation and toilet flushing.

1. Introduction

Australia is one of the most urbanized countries in the world and 85% of its inhabitants live in towns or cities (Skinner, 2006). The growth of urbanisation in Australia has led to changes of green spaces with the construction of large impervious areas such as roofs, car parks, roads, highways and paving (Berndtsson, 2010). These have led to changes in the urban hydrologic cycle. In particular, increases in runoff volume and peak flow have occurred together with reductions in times of concentration. As a response, relatively new stormwater management strategies such as Low Impact Development (LID) (Voyde et al., 2010), Sustainable Urban Drainage Systems (SUDS) (Palla et al., 2010; Stovin, 2010), Low Impact Urban Design and Development (LIUDD) (Van Roon, 2005) and Water Sensitive Urban Design (WSUD) (Kazemi et al., 2011; Beecham and Chowdhury, 2012) have been developed in various countries. Adelaide is the capital city of the driest state in Australia and it currently faces three major challenges, namely urbanisation growth, water scarcity and climate change. These threats put more stress on the urban water cycle and lead to increased metropolitan temperatures through urban heat island effects. Introducing green infrastructure through WSUD is one of the possible solutions to reduce the harmful impacts of urbanisation while providing additional amenity and water quality benefits for communities and the environment (Beecham, 2003; Beecham et al., 2012). In particular, green roofs have become more widely used in recent years (Emilsson et al., 2006). A green roof is an engineering multi-layered structure with a vegetated upper surface. Green roofs are normally categorized as either extensive (depth = 100 mm to 250 mm) or intensive (depth ≥ 300 mm) (FLL, 2002; Berndtsson, 2010). While much attention has focused on the hydrology of green roofs, few researchers have studied the impact on water quality of outflows from green roof systems (Berndtsson et al., 2009) and consequently there is insufficient reliable scientific data. In

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particular, in Europe green roof water quality studies have been conducted in cool climate countries (Steusloff, 1998; Köhler et al., 2002; Berndtsson et al., 2006; Emilsson et al., 2006; Teemusk and Mander, 2007; Berndtsson et al., 2009; Berndtsson, 2010). Water quality and quantity issues associated with green roofs have also been investigated by other researchers (Monterusso et al., 2004; Hathaway et al., 2008; Bliss et al., 2009; Van Seters et al., 2009; Alsup et al., 2010; Carpenter and Kaluvakolanu, 2011; Gregorie and Clausen, 2011). Moreover, there have been studies in high rainfall areas in Asia, especially in Singapore and Japan (Berndtsson et al., 2009; Vijayaraghavana et al., 2012). Most of the above studies have used different methods of collecting and presenting data and it is still uncertain whether green roofs act as a source or sink of pollutants (Teemusk and Mander, 2007; Carpenter and Kaluvakolanu, 2011; Fassman and Simcock, 2013). Green roof technologies in Australia are still very much in their infancy and there are several barriers to their widespread adoption (Williams et al., 2010). Berndtsson (2010) concluded that the factors that are effective for improving the water quality of green roof outflows include the type of growing media or substrate (composition of soil), the depth of the growing media, the type of vegetation, the local rainfall patterns, and the physicochemical properties of pollutants. The purpose of this paper is to investigate a range of these factors on green roof outflows in the hot and dry climate of South Australia. Moreover, this paper describes the results of a research project investigating the water quality effects of two different types of green roofs, namely intensive (shallow bed) and extensive (deep bed) roofs. The study site contained full scale intensive and extensive green roofs located on top of a 22 storey high-rise building in the Adelaide central business district (CBD). In particular, this study examined the effects of substrate type and depth on stormwater quality.

2. Material and methods

2.1. Adelaide climate

Adelaide has a hot Mediterranean climate based on the Köppen–Geiger climate classification. This generally means it has mild, wet winters and hot, dry summers. Adelaide is the driest of the five Australian state capital cities receiving approximately 550 mm per year on average. Rainfall is generally infrequent, light and unreliable throughout summer and the average precipitation in January and February is approximately 20 mm. In winter, rainfall is much more reliable with June being the wettest month of the year, with approximately 80 mm of rainfall. In summer, the maximum average temperature is 29 °C but there is considerable variation in temperature and Adelaide can usually expect around a week every year when the day time temperature is 40 °C or above (Sturman and Tapper, 2006).

2.2. Experimental setup

The four full-scale green roofs, which were located on the roof top of a 22 storey building in the Adelaide CBD, were monitored from September 2011 until June 2012. The design of the green roofs was based on a free drainage system in order to allow quick drainage of excess water from the systems after each rainfall event. Horizontally laid half-round pipes, 50 mm in diameter and 700 mm in length and blocked at each end of the pipes, were buried in the soil media to collect drainage water for analysis. Holes were drilled at both ends and a hose was attached to facilitate water collection. The four green roof beds were each 14.4 m^2 in area. Two were intensive (I) green roof beds and two were extensive (E) green roof beds. One intensive bed and one extensive bed contained media type-A, which consisted of crushed brick, scoria, coir fibre and composted organics while the other intensive and extensive beds both contained media type-B, which comprised scoria, composted pine bark and hydro-cell flakes (hydrocell®). The four roofs were therefore denoted AI, AE, BI and BE. Four species of plants were used, namely *Carpobrotus rossii*, *Lomandra longifolia Tanika*, *Dianella caerula Breeze* and *Myoporum parvifofium*. After planting, 1 kg of Osmocote fertilizer was applied to each bed over a fifteen week period. For five rainfall events, water samples from the surface of an existing asphalt roof (AS) and an existing aluminium (AL) roof on the same building were also collected as controls to compare the effects on water quality of green and conventional roof systems. Table 1 shows the chemical constituents of the applied Osmocote fertilizer as provided by manufacturer, while Table 2 shows details of the five sampling events.

2.3. Water quality test procedures and methods

In this study, to have replications for water samples for each bed in order to conduct robust statistical analysis, samples were collected in each event from two sample points in each green roof bed. The first sample was collected 90 min after the commencement of rainfall and the second sample was collected 30 min later. This sampling protocol was adopted to minimise the influence of the first flush phenomenon. In addition, two stormwater samples were also collected from each of the aluminium and asphalt control roofs. Therefore, from the four green roof beds and two control roofs a total of 12 stormwater samples were taken during each event. This resulted in 60 water samples that were refrigerated until testing for parameters including pH, Turbidity, Electrical Conductivity (EC), TDS, Nitrate (NO_3^-), Phosphate (PO_4^{3-}), Potassium (K^+) and Chloride (Cl^-). Samples were also sent to a NATA registered laboratory for testing of heavy metals. Water quality parameters assessed, testing methods, and their relative analytical method detection limits (MDL) are summarized in Table 3.

3. Statistical analysis

Statistical analyses were applied using the SPSS software package version 21. For comparing differences between samples taken at the same time, one-way Analysis of Variance (one-way ANOVA) was employed. Firstly, the data was examined for normality and homogeneity of variance using a Kolmogorov–Smirnov test. Whenever ANOVA showed a significant difference among the means, a post hoc analysis was used to investigate where the differences were located. To examine whether temporal changes in stormwater quality occurred over the study period, a two-way Repeated Measures ANOVA (two-way RM-ANOVA) was employed. This test examined the main effects of time and roof type and their interaction (time × roof type) over the study period. Finally, to validate the two-way RM-ANOVA, Mauchly's sphericity test was applied and if the assumption of sphericity was violated, a Greenhouse–Geisser correction was used. Post Hoc Least Significant Difference and Multiple Comparison tests were again used to find out where the differences

Table 1
Constituents of Osmocote fertilizer as provided by manufacturer.

Elements	Percentage (%)	Trace elements	Content (mg/kg)
Nitrogen (N)	17.90%	Boron (B)	42.00
As ammonium nitrogen	1.70%	Copper (Cu)	106.00
As nitrate nitrogen	1.50%	Iron (Fe)	27882.00
As urea nitrogen	14.70%	Manganese (Mn)	124.00
Phosphorus (P) soluble in neutral ammonium citrate and water	0.80%	Molybdenum (Mo)	40.00
Water soluble	0.60%	Zinc (Zn)	35.00
Potassium (K) as sulphate	7.30%	Cadmium (Cd)	0.70
Sulphur (S) as elemental and sulphate	9.90%	Lead (Pb)	4.00
Magnesium (Mg)	0.24%	Mercury (Hg)	Below detectable levels
Wetting agent, non-toxic	2.80%	–	–
Resin coating based on vegetable oils	3.2%	–	–