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Research article

Potential of combined Water Sensitive Urban Design systems for salinity treatment in urban environments

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ABSTRACT

Water sensitive urban design and similar concepts often recommend a 'treatment train' is employed to improve stormwater quality. In this study, the capability of a combined permeable pavement and bioretention basin was examined with a view to developing a permeable pavement reservoir that can supplement the irrigation needs of a bioretention system in semi-arid climates. Salinity was a key study parameter due to published data on salinity in permeable pavement storage, and the potential to harvest water contaminated with de-icing salts. To conduct experiments, roofwater was collected from a roof in Adelaide, South Australia. Water was amended with NaCl to produce a control runoff (no added salt), a medium (500 mg/l) and a high (1500 mg/l) salinity runoff. Water was then run through the pavement into the storage reservoir and used to irrigate the bioretention system. Samples were collected from the roof, the pavement reservoir and the bioretention system outflow to determine whether significant water quality impacts occurred. Results show that while salinity levels increased significantly as water passed through the pavement and through the bioretention system, the increase was beneficial for irrigation purposes as it was from Ca and Mg ions thus reducing the sodium absorption ratio to levels considered 'good' for irrigation in accordance with several guidelines. Permeable paving increased pH of water and this effect was prominent when the initial salt concentration increased. The study shows that permeable pavements with underlying storage can be used to provide supplementary irrigation for bioretention systems, but high initial salt concentrations may present constraints on beneficial use of stormwater.

1. Introduction

There is a wide body of literature that has identified the negative impacts of urbanization on landscapes, people and aquatic ecosystems (Fletcher et al., 2013). In response, engineers have developed sustainable strategies, or stormwater best management practices (BMPs) for managing urban stormwater. Stormwater BMPs are implemented as part of a broader philosophy termed Water Sensitive Urban Design (WSUD) in Australia, New Zealand and the United Kingdom, or low impact development (LID) and integrated urban water management in other regions (Fletcher et al., 2015). Stormwater BMPs typically target water volume reduction, water quality treatment and/or harvesting and reuse. Good design integrates stormwater BMPs and other urban landscape elements (Kazemi et al., 2009a,b, 2011).

Examples of stormwater BMPs include wetlands, ponds, bioretention systems, permeable pavements and green roofs (Melbourne Water, 2005; Kazemi and Mohorko, 2017). Permeable pavement structures aim to reduce runoff quantity and improve water quality by allowing infiltration of urban stormwater through serviceable, hard standing surfaces to underlying reservoirs. There are several studies that investigate the effect of permeable pavements on runoff quality including reductions in stormwater sediment (Hatt et al., 2007), nutrients (Bean et al., 2007) and hydrocarbons (Newman et al., 2002). Following infiltration and treatment, collected water can be allowed to leave a pavement reservoir via a pipe, infiltrated to surrounding soil or stored for reuse (Myers et al., 2009, 2011). If water is stored, it can potentially be reused for irrigation of urban green spaces, including vegetated

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stormwater BMPs such as bioretention systems (Kazemi et al., 2013). Previous research has looked at the use of stormwater stored under permeable pavements for reuse via irrigation. Myers et al. (2011) and Kazemi and Hill (2015) each used laboratory models to explore the effect of different basecourse aggregate materials on stormwater stored under permeable pavements for irrigation reuse, but there is no published information on the quality of stormwater stored under a full-scale permeable pavement with repeated stormwater loading. This is despite the known impacts of salinity on soil and the overall biodiversity of terrestrial and aquatic ecosystems (Amores et al., 2013; Nielsen et al., 2003).

Bioretention systems are vegetated stormwater BMPs that collect stormwater at the surface and allow it to temporarily pond until it is filtered by gravity through soil media. Following storage and filtration, water can infiltrate to surrounding soil or be collected at the base for disposal downstream. Bioretention systems provide multiple benefits to surrounding streetscapes (Kzemi, 2010) including the retention or detention of urban runoff water, improvement in water quality and enhanced urban biodiversity compared to conventional landscapes (Melbourne Water, 2005; Kazemi et al., 2013). Bioretention systems have been shown to increase the urban aesthetic and increase land values in urban environments (Kazemi et al., 2009a,b, 2011). Several studies have reported the water quality treatment effects of bioretention systems and their broader environmental benefits. For example, reports on the treatment of sediment, heavy metals (Trowsdale and Simcock, 2011) and nutrients (Bratieres et al., 2008) are widespread.

Stormwater BMPs such as permeable pavements with underlying storage and bioretention systems can therefore increase the overall sustainability of urban environments. In this study, we propose that there is strong potential for these two streetscape technologies to act in a treatment train. The importance of adopting a treatment train approach for the removal of pollutants in runoff has been emphasized in literature (Wong et al., 2006). Although less explored in research, the use of permeable pavements with underlying storage reservoirs adjacent to bioretention systems has been implemented in the streetscape design of some Australian cities (Kazemi, 2010). Due to the presence of vegetation, bioretention system performance and appearance can be impaired by long dry spells, particularly in semi-arid environments. Harvesting runoff via a nearby permeable pavement offers an opportunity for irrigation during dry spells. However, the potential water quality and quantity constraints when these two engineered ecological systems are used together has not yet been explored.

This study was undertaken with a strong focus on salinity for irrigation purposes. Sources of salinity in urban environments include collection of runoff contaminated with de-icing salts in cold climates, extended periods of exposure to some permeable pavement basecourse media (Myers et al., 2009, 2011; Kazemi and Hill, 2015) or natural salinity in areas where saline groundwater is or has been used for supplementary irrigation. As such, the primary objective of this research was to examine the effect of harvesting surface runoff with a ranging salinity using a permeable pavement to supplement the water demand of a bioretention system of equal plan area. The results of this study can help practitioners in semi-arid environments to understand how water quality characteristics change in the permeable pavement storage/bioretention basin BMP treatment train.

2. Materials and methods

2.1. Study area

The study area was a small catchment which included a sloped galvanized aluminium roof (projected area = 39 m^2), contributing runoff to a 3 × 5 m permeable pavement with underlying reservoir and an adjacent bioretention basin of the same plan area. The size of the permeable pavement was equal to the size of a standard car space designed in accordance with Australian and New Zealand Standards (AS/NZS 2890.1). At the site, stormwater is normally harvested from the roof and distributed to the permeable pavement surface where it infiltrates into the pavement basecourse. Stored water is used to irrigate the bioretention system via a solar-powered submersible pump and a drip irrigation setup following which the water infiltrated through the bioretenton system and into surrounding soil. A schematic of the system is shown in Fig. 1.

The permeable pavement layers were designed based on typical permeable pavement construction and consisted of (from the surface) 80 mm concrete pavers, a 20 mm layer of quartzite aggregate and a geotextile overlying a 0.7 m deep reservoir lined with 1 mm polyethylene and filled with dolomite aggregate of 20 mm nominal size. The adjacent bioretention basin was constructed according to guidelines developed by the Facility for Advancing Water Biofiltration (2009). It consisted of (from the top) a 70 mm mulch layer overlying a 500 mm filter medium and a 300 mm drainage layer. The mulch layer protected the growing medium from sun, wind, erosion and excessive evapotranspiration and provided organic matter for healthy plant growth. The filter medium was an engineered soil with a loamy sand texture. It provided the main growing medium for vegetation and had a saturated hydraulic conductivity of 180 mm/h, producing a maximum drainage flow of 0.75 l/s for the bioretention system. The drainage layer was placed to ensure free drainage occurs underneath the filter medium and allow storage until water infiltrates to surrounding soil.

2.2. Experiment and water quality analysis

The experiment was undertaken by applying runoff of varying salinity to the pavement surface and measuring the impact of the permeable pavement and the bioretention system on water quality. To conduct the experiment, the arrangement in Fig. 1 was interrupted to control the salinity during the runoff phase. To do this, roof runoff was collected into a rainwater tank. Using this water, solutions with three different salt concentrations were produced and randomly applied to the permeable pavement surface. A control stormwater was applied which was unaltered after collection. There were also two salt spiked stormwaters - a medium salt solution (spiked to reach 500 mg/l NaCl) and a high salt solution (spiked to reach 1500 mg/l NaCl). Salt spiked solutions were produced by diluting NaCl salt in the harvested stormwater until the target salinity was reached. Each stormwater type was then passed onto the permeable pavement surface, and infiltrated by gravity through to the underlying permeable pavement reservoir. The water was then pumped onto the surface of the bioretention basin via an irrigation system in accordance with Fig. 1. Each source water was applied to the pavement surface on four separate occasions, producing a total of 12 irrigation events in this study. The salt concentration levels were selected to simulate salt levels leached from longer term storage with aggregates in the permeable

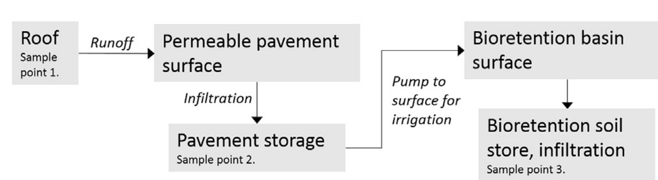

Fig. 1. A schematic view of the systems used in this study.