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Stormwater quality improvement potential of an urbanised catchment using water sensitive retrofits into public parks

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ABSTRACT

Urban stormwater management is undergoing a transition from centralised hydrologically efficient systems to collections of dispersed, multi-functional elements. In response to a better understanding of impervious surface areas, the adoption of water sensitive urban design is promising for new large urban developments. However, spatial and economic constraints prohibit its adoption in established urban areas. We explore the potential for improvement to stormwater quality if 10% of existing parks in an established urban catchment are reserved for stormwater filtration. Spatially explicit hydrologic modelling is used to model the effects of parks in an existing urban catchment in South Australia as networks of bioretention devices. The allocation of 10% of parks that cover less than 16% of the landscape for bioretention devices may result in a 62% reduction (7.8 tonnes per year) of nitrogen from stormwater. The sources and destinations of stormwater pollutants are mapped to explore the strength and weaknesses of park size and distribution within each sub-catchment. Large parks situated lower in the catchment along the main trunk, and distributed smaller parks higher along the secondary stormwater network are shown to be effectively located. The potential for increasing the utilitarian value of many public parks by demonstrating the capacity for significantly improving urban stormwater quality is illustrated in this exploratory model. Opportunities for targeted improvements to stormwater quality are examined in the discussion.

Introduction

The management of urban stormwater is undergoing a transition from engineered systems for hydrologically efficient disposal to a philosophy that integrates a range of distributed, multi-functional elements. The traditional approach to stormwater is to treat it as a nuisance and risk by disposing of it via hidden infrastructure with little regard for receiving waterways. As urban populations grow and intensify, more adaptive and less environmentally intrusive approaches are coming to the fore.

Traditional urban stormwater management addresses 'nuisance' runoff in response to its increased frequency and volume and to mitigate against flood events, both of which are consequences of increased impervious surface area (Arnold and Gibbons, 1996; van Roon, 2007). As the engineering criteria for flood mitigation exceed the requirements of the lower flow events, stormwater drainage networks are designed to accommodate rain events of 2–10 years annual recurrence interval (ARI) in the minor network and up to 100 year ARI in the major network (ASCE & WEF, 1992). Failure of the systems to address these less probable events leads to considerable social and economic losses (Jha et al., 2012). However, the strategy of extremely efficient hydrologic routing leads to degraded water quality, morphology and biodiversity in urban streams and coastlines (Booth and Jackson, 1997; Wang et al., 2001; Hatt et al., 2004; Ladson et al., 2005). The extent of degradation has been strongly tied to the amount of impervious surface area (ISA) in the catchment, leading to the increased rate, frequency and velocity of surface runoff, pollutant and sediment loads and temperature (Alley and Veenhuis, 1983; Arnold and Gibbons, 1996; Booth and Jackson, 1997; Mitchell, 2004; Roy and Shuster, 2009; Schueler et al., 2009).

The vast majority of rainfall occurs in events of less than 3 month ARI (Walsh et al., 2009). Under pre-development conditions similar events would lead to little or no runoff, depending on antecedent conditions (Holmann-Dodds et al., 2003). The hydrologic 'smoothness' of ISA results in runoff during minor rainfall events (<2 year ARI) that would otherwise have been retained on natural surfaces for evaporation and infiltration. ISA is therefore a primary input for all urban surface hydrology modelling (Elliott and Trowsdale, 2007).

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Recognition of the unsustainability of traditional approaches to urban stormwater management has grown over the last 30 years. The financial cost of maintaining and upgrading drainage networks to accommodate increased ISA resulting from urban consolidation is proving to be untenable (Mays, 2001). The shift in perception of stormwater as a waste and nuisance to being a resource is a result of the increased demand and decreasing availability of water, as well as growing environmental awareness (Mitchell, 2006; van Roon, 2007). Depending on the jurisdiction, the practical application of integrated urban watershed management comes under various banners including Best Management Practices, Low Impact Design and Water Sensitive Urban Design (WSUD) to name a few. WSUD is used herein as it is most commonly used in Australia, where this study was undertaken.

The practice of WSUD involves decentralising stormwater management design by shifting the focus from hidden infrastructure to distributed and holistic approaches that include both structural and non-structural measures (Ellis and Marsalek, 1996; Roy et al., 2008a,b). The ultimate aim is to emulate predevelopment flow regimes using distributed treatment measures, policy initiatives and increased public awareness. Structural implementation ranges in scale from small source control measures designed to filter and retard runoff from small rain events, to larger catchment scale devices for flood mitigation and semi-potable water recycling. Smaller measures include rainwater tanks, permeable paving and vegetated swales (US EPA, 2000). Larger infrastructure includes detention and retention ponds and constructed wetlands that attenuate the peak flow and time to concentration and are suitable for flood mitigation, pollutant removal and water recycling (Mitchell et al., 2007). WSUD devices are generally visible and integrated into spaces that are accessible to the general public such as parks and median strips. The facilities are usually vegetated and are designed to be accessible for some level of recreational use, aesthetically pleasing (Carlsson et al., 2003), increase public awareness of stormwater management (Lloyd, 2004) and provide habitat for urban wildlife (Garde et al., 2004; Kazemi et al., 2009).

Initiatives encouraging the uptake of WSUD range from mandated stormwater quality and/or quantity targets to market based instruments such as nutrient removal offset schemes (van der Heijden, 2000; Roy et al., 2008a,b). Regulations typically only pertain to large new developments (Wong, 2006), while smaller redevelopments are rarely required to comply. Large scale developments are rare for established urban catchments, but ad hoc increases to ISA from subdivisions (Stone, 2004) and the increased paving of gardens (Verbeeck et al., 2011) gradually but significantly add to the deleterious impacts of impervious surfaces. Encouraging the adoption of WSUD measures into existing dwellings is necessary to holistically address stormwater quality issues (Fletcher et al., 2011). But any instrument proposed for existing dwellings would most likely be voluntary, resulting in fragmented and gradual progress (Stone, 2004). Moreover, in spite of successes in mitigating the effects of private properties, the impacts of public ISA, namely roads and car parks, would remain unaddressed. Though roads are a relatively small component of urban ISA, they disproportionately contribute approximately 50% of heavy metals (Ellis et al., 1987) and up to 30% to catchment pollutant loads (Barry et al., 2004).

The costs associated with WSUD implementation on new developments are lower than retrofits to an established urban context (Weber, 2008). Although the total space required for WSUD measures can be greater than traditional stormwater treatment, the space requirements for the traditional end of line approach in and established catchment can be prohibitive. The distributed WSUD approach can adapt to the space constraints of a developed catchment (Freni et al., 2010), and be as cost-effective as traditional solutions (Coombes et al., 2000; Montalto et al., 2007; Gilroy and McCuen, 2009; Zhou et al., 2013). However, the perceptions of low demand for WSUD and higher costs lead to resistance to its adaptation (Bowman and Thompson, 2009).

The pressures of competing urban land uses and maintenance costs pose considerable threats to the preservation of open public spaces and have stimulated research into their returns. A substantial body of research has built an understanding of the value urban parks and the urban forest contribute to real estate value (Palmquist, 1982; Price, 2003; Hatton MacDonald et al., 2010; Bae, 2011), quality of life (Burgess et al., 1988; Chiesura, 2004; Florgård and Forsberg, 2006; Mäkinen and Tyrväinen, 2008) and to biotic (Niemelä, 1999; Alberti et al., 2003; Zhang and Wang, 2006; Campbell, 2011) and abiotic processes (McPherson and Simpson, 2004; Wong and Yu, 2005; Nowak et al., 2006; Mitchell et al., 2008). The already considerable value of parks may be augmented by including the additional functionality of sustainable stormwater management.

It is the aim of this paper to investigate the potential role existing parks may play in improving urban stormwater quality in an established urban catchment. Public parks as public land are an often overlooked candidate to begin addressing stormwater sustainability issues in an established urban catchment. This study explores the potential of retrofitting WSUD measures into existing parks across an urbanised catchment. A spatially explicit hydrologic model is employed to consider the nitrogen removal potential of a network of land already reserved for the public good in Adelaide, capital city of South Australia.

Study context

Study area

The 37.7 km^2 study area within the Brownhill–Keswick catchment (Fig. 1) is a sub-catchment of the Patawalonga River and is the site for a greater multidisciplinary study on the social, economic and environmental benefits of urban public parks within the urban section of the catchment. The entire 64 km^2 Brownhill–Keswick catchment spans land ranging in use from conservation reserves and agriculture to highly urbanised residential and light industry. The eastern, upper reaches of the catchment are zoned as the Hills Face Zone, consisting of predominantly rural and protected reserves with minimal residential development. Immediately to the east of the Hills Face Zone lies the urbanised study area. The section of the catchment within the Central Business District (CBD) of Adelaide has been omitted to limit the study to a suburban focus.

The study area is inhabited by approximately 67,000 residents. The predominantly residential catchment is mixed with some light industry and commercial land zonings. There are 124 parks greater than 100 m^2 in the study area, totalling approximately 6.4 km^2 (640 ha). There is a wide variety of parks that can be classified into small pocket parks, medium sized family parks, sporting reserves and conservation parks (Raja Segaran et al., 2009). The parks on the northern boundary of the study area are the southern Adelaide Park Lands that surround the Adelaide CBD. The western edge of the study area intersects with the Adelaide International Airport.

Adoption of water sensitive urban design in Australia

The uptake of WSUD in Australia has occurred at the intersection of drought, water restriction legislation, the ageing of post World War II stormwater infrastructure, an increasing urban population and environmental consciousness. The Queensland and Victorian state governments have introduced recent legislation that reflects an embrace of the principles of WSUD. Southeast Queensland is in the process of implementing legislation requiring that