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Evolution of nutrient export under urban development in areas affected by shallow watertable

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HIGHLIGHTS

- ► Urbanisation significantly influences catchment water balance and water quality.
- ► Flat sandy catchments and shallow watertable promote nutrient accumulation in groundwater.
- ► Urbanisation results in the 'flushing' of legacy solutes towards the surface water network.
- ► New urban landscape nutrient additions fully control water quality 4–5 years after development completion.

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ABSTRACT

Surface water quality in catchments undergoing urbanisation may be affected by the release of pre-existing (or legacy) solutes, such as nutrients, as well as new sources associated with urban land use. This paper examines both for a number of urbanisation scenarios and adopting the modelling capability developed for the analysis of urbanisation effects on catchment water balance. The flat relief of the study catchment and its sandy soils, in combination with a Mediterranean-type climate, lead to large rates of diffuse gross recharge and diffuse (evaporative) discharge with low overall runoff from the catchment (<1 mm per unit area). Under these conditions solutes stored in shallow groundwater have long residence times (longer than 100 years). Urbanisation of such a catchment leads to significant changes in water regime, leading to a reduction in groundwater residence time and 'flushing' of legacy solutes towards the surface water network. Concurrently, urban development introduces new sources of solutes. It was found that the modelled concentrations of legacy solutes in the urban drains are greater than the water quality standards in the region; though, legacy solute concentrations reduce by 50% within the first 2–3 years and become less than 5% within 10 years for all urban scenarios. The full effect of new urban landscape on water quality was estimated to be longer than 5 years. Urban density and groundwater abstraction for irrigation of public open space and domestic garden have an effect on the surface water quality, as they influence the rate of legacy solute replacement and accumulation of the solute associated with the new urban forms. It was shown that water quality control measures in new urban developments should be directed to legacy nutrients during the first 2–3 years but measures reducing nutrient leachate from soil, such as soil amendments, should be considered for long-term solutions.

1. Introduction

Land cover changes associated with urbanisation affect catchment water balance due to the introduction of impervious surfaces, the removal of deep rooted vegetation and the alteration of drainage systems (Brett et al., 2005; Lerner, 2002; Rose and Peters, 2001; Schoonover et al., 2006). New urban landscapes may also cause changes in water quality due to the alteration of solute transport pathways, shorter water residence times compared with non-urban conditions, and the introduction of new contamination sources (Collin and Melloul, 2003; Dietz and Clausen, 2008; Wang et al., 2005). In turn, changes in the water regime and water quality, as a result of urbanisation, may have an adverse effect on the receiving-water environment. However, reported studies mainly addressed changes in water quality introduced by new urban landscapes (Roy et al., 2008), while the effect of pre-development pools of nutrients or contaminants is not widely reported (Lewis et al., 2006; Walsh et al., 2005).

The effect of urbanisation on water quality is a concern in Perth, the capital city of Western Australia, as it is considered to be one of the key environmental threats to the health of the Swan–Canning Estuary, situated in the centre of the Perth Metropolitan area and has high ecological, cultural recreational and spiritual values (Fig. 1).

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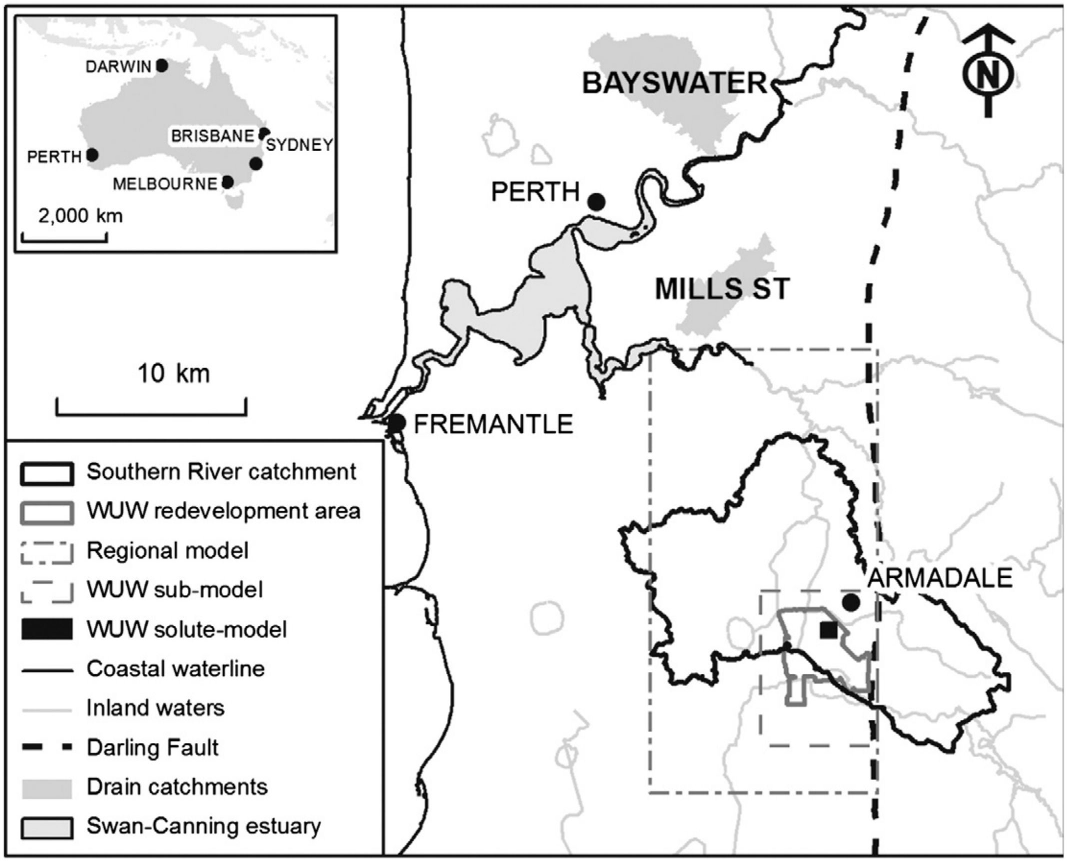

Fig. 1. Location of modelled urban area within Wungong Urban Water (WUW) redevelopment area and the catchments of the urban drains, selected for a comparison with the modelling results.

Urbanisation in many areas of the Swan Coastal Plain (SCP) is challenged by a shallow groundwater table (often within 2–3 m of the surface), hosted by a highly transmissive sandy aquifer. Nutrients are of major concern as urban drains currently contribute 180 tonnes of nitrogen (N) and 16 tonnes of phosphorus (P) to the estuary annually (Swan River Trust, 2009).

Where N is concerned, the dissolved organic nitrogen (DON) fraction dominates N export from undisturbed or minimally disturbed catchments (Lewis, 2002; Perakis and Hedin, 2002). The N speciation in surface waters may also be influenced by the abundance of wetlands (Pellerin et al., 2004) which are common in many SCP catchments (Hill et al., 1996). Human activities affect catchment N balance as a result of fossil fuel combustion, application of inorganic fertilisers, increased use of N-fixing crops and pastures, and wastewater disposal (Galloway et al., 1995; Vitousek et al., 1997; Walsh et al., 2005). This is mostly associated with an increase in dissolved inorganic N (DIN) in the environment, contributing to the eutrophication of river and estuarine systems globally. DIN export increases with urbanisation when compared with forested catchments (6.7 and 0.52 kg-N/ha respectively) but it is still lower than observed in many agricultural catchments (16 kg-N/ha, Groffman et al., 2004). This increase in N export from urban landscape was attributed to the lower water residence times due to changes in the water balance (Wollheim et al., 2005). In addition to DIN, the higher bioavailability of DON derived from human activities when compared to natural DON is increasingly recognised (Pellerin et al., 2006; Petrone et al., 2009, 2011; Wiegner et al., 2006).

Phosphorous is also a major concern for environmental agencies responsible for the health of the Swan River (Swan River Trust, 2009). The highly leached sands in the unsaturated zone of the SCP have a very low phosphorous retention index (PRI) (He et al., 1998; Qiu and McComb, 2004). Thus phosphorus applied to the surface with fertilisers (Sharma et al., 1996) or through decomposition of vegetation (Qiu et al., 2002) is readily transported to the watertable with rainfall. In sandy catchments on the SCP soluble reactive phosphorus has been shown to be an important component of phosphorus export on par with particulate phosphorus (Peters and Donohue, 2001; Petrone, 2010) and inundation by groundwater linked to enhanced phosphorus export (Summers et al., 1999; Donn et al., 2012).

Low nutrient-retention capacity of the sandy soil in the SCP region and nutrient leaching to the shallow groundwater table have led to an enrichment of the shallow groundwater with nutrients. As urbanisation significantly influences water balance in the local groundwater system (Barron et al., 2012), this is likely to have an effect on solute concentration and transport in and from the shallow aquifer. Consideration of the resulting legacy nutrients' mobilisation and their effect on the receiving water quality is largely unknown, and as such is not included in principles set for post-development monitoring guidelines by local water authorities or is taken into account when water quality control measures are designed for new urban developments.

This paper aims to investigate the fate of legacy nutrients stored in shallow groundwater as well as nutrients sourced from a new urban land use, utilising a conceptual modelling approach. One of the main objectives of this study was to provide an insight into the relative importance and possible duration of legacy nutrient impact to post-development surface water quality under various urban development scenarios and water management options, while considering the effect of the new nutrient sources associated with urbanisation. The analysis was based on groundwater and conservative solute transport models, and where possible, compared with data from similar urban catchments, as urban development had not commenced in the studied catchment. The research outcomes presented here are