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Original Research Article

Water cycle modelling of peri-urban hydroecological systems: a case study of the South Creek catchment, Australia

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ABSTRACT

Modelling offers a time efficient and cost-effective approach to integrate and analyse different components of complex peri-urban hydroecological systems. This paper evaluates and applies a catchment water balance model (Peri-Urban SimHyd) developed to simulate the complete water cycle of the South Creek catchment, a complex peri-urban catchment in Western Sydney (Australia). Peri-Urban SimHyd combined the modelling of daily rainfall-runoff from both impervious and pervious surfaces with the modelling of monthly reticulated potable water supply, wastewater flows, and surface and groundwater extractions, to simulate the monthly water balance of the catchment. The model was successful (the Nash-Sutcliffe efficiency >0.68) in simulating the monthly total wastewater discharges and streamflows in the South Creek and its main tributary, the Eastern Creek, over a period of 15 years (1992–2006). The model performance was found to be suitable for simulating macro water balance and catchment yield but not for low streamflow hydrographs. Further, the model demonstrated its applicability in assessing the impacts of water cycle management strategies, i.e. '*replacement flows*' and '*water smart farms*' scenarios, on monthly and annual streamflows in the South Creek catchment. In general, Peri-Urban SimHyd has a generic structure and can be employed to assess impacts of various 'what if' scenarios on water cycle and streamflows in other peri-urban hydroecological systems.

1. Introduction

Increasing urbanisation, changing landscape, growing competition and conflict among different water users and controls are putting enormous pressures on hydroecological systems, particularly in peri-urban areas, 'the rural areas surrounding cities'. As in many peri-urban areas, the regional authorities in Western Sydney, Australia are faced with revisiting their water use and management strategies to address increasing water demands, limited water supply, the impact of urban development on streamflows and water quality, and calls for a legitimate share of environmental flows to protect the health of Hawkesbury-Nepean River system (DECC, 2010). This, however, requires a comprehensive understanding and quantification of different water cycle components of complex peri-urban hydroecological systems. Various planned water management activities also require an evaluation of their impact on the water cycle and streamflows in the catchment.

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In this context, researchers have been devoting significant effort in observing and quantifying processes and factors affecting water flow and its management in different hydroecological systems. Integrating the accumulated hydrological knowledge and advancements in computation tools are providing new opportunities to develop hydrological models to assist with analysis and decision making for productive and sustainable water management strategies. Indeed, hydrologic modelling offers a time efficient and cost-effective approach to estimate, integrate and analyse different water cycle components, and to evaluate the impacts of 'what if' scenarios on the water cycle and streamflows in a catchment (Xu and Singh, 1998; Brun and Band, 2000; Mitchell et al., 2001; Singh and Woolhiser, 2002; Chiew et al., 2002a,b; Boughton, 2005; Siriwardena et al., 2006; Kumar et al., 2013).

In a review, Boughton (2005) reported 14 different catchment water balance models developed in Australia, primarily used to simulate water balances of either rural (Chiew et al., 2002a) or urban catchments (Mitchell et al., 2001). The peri-urban water cycle, however, differs significantly from the rural water cycle due to the impact of a larger proportion of urban 'impervious' surfaces, reticulated potable water supply, and wastewater discharge. When compared to urban catchments, peri-urban catchments generally have larger proportions of rural 'pervious' surfaces and higher surface water and/or groundwater extractions for primary production activities. These components of the water cycle have a strong bearing on streamflows in peri-urban catchments such as the South Creek catchment in Western Sydney (Singh et al., 2009a), and thus need to be accounted for in modelling the water cycle of peri-urban catchments.

We developed a catchment water balance model, Peri-Urban SimHyd, to simulate the complete surface water cycle of the South Creek catchment, a typical peri-urban catchment in Western Sydney, Australia. Peri-Urban SimHyd was developed under the umbrella of the Cooperative Research Centre (CRC) for Irrigation Futures' System Harmonisation research program in Western Sydney (Singh et al., 2009a, 2009b). The main objectives of this study were (i) to adapt a selected catchment water balance model for rural landscapes to the conditions of peri-urban landscapes; (ii) to evaluate the developed model Peri-Urban SimHyd to simulate complete water cycle of the South Creek catchment; (iii) to further apply the model to assess the impacts of specific planned water cycle management strategies on the streamflows in the South Creek catchment; and (iv) to examine the model's capabilities, limitations and potential enhancements as a tool for integrated water balance analysis of complex peri-urban hydroecological systems.

2. Modelling the water cycle of the South Creek catchment

The South Creek catchment covers an area of around 625 km^2 in the gently undulating plains and low hills of Western Sydney, New South Wales, Australia (Fig. 1). It is a typical example of a peri-urban catchment with urban development over nearly 20% of the land area and peri-urban agriculture activities, such as market gardens, cut flowers, greenhouse, nursery, orchard, turf farming, and pasture, over nearly 50% of the land area (EPA, 2001). Water cycle in the South Creek catchment is complex including rainfall-runoff from both urban 'impervious' and rural 'pervious' areas, reticulated potable water supply from dams (e.g. Warragamba Dam) outside of the catchment (Fig. 1), wastewater discharges, and surface water and groundwater extractions for irrigation of recreational spaces (parks and golf courses) and peri-urban agriculture activities (Singh et al., 2009a). South Creek has a major influence on flow and water quality of the Hawkesbury River downstream of the township of Windsor (Fig. 1).

2.1. Peri-Urban SimHyd and its input parameters

The catchment water balance model, SIMple HYDrology (SIMHYD) for rural landscapes (Chiew et al., 2002a) was adapted for peri-urban landscapes and is called Peri-Urban SimHyd (Singh et al., 2009b, 2009c). In particular, the Peri-Urban SimHyd model includes modifications needed to account for stormwater flow from urban 'impervious' surfaces, potable water supply, wastewater discharges, and surface water and groundwater extractions to provide a comprehensive water balance representation of a peri-urban catchment (Fig. 2). In Peri-Urban SimHyd, the rainfall-runoff (from infiltration excess, saturation excess and baseflow) and evapotranspiration components over both the impervious and pervious surface are modelled at the daily time-step, which are then aggregated to combine with the modelling of monthly water use and wastewater discharges to simulate the monthly water balance of a peri-urban catchment. The concepts, methods and algorithms used in the development of Peri-Urban SimHyd are described in greater detail in Singh et al. (2009b). The following sections provide a brief introduction to the model, its components (Fig. 2) and input parameters (Table 1), and describe the simulation of the water cycle of the South Creek catchment (Fig. 1).

2.1.1. Simulation control parameters

Peri-Urban SimHyd requires control parameters to specify the simulation period and different components of the peri-urban water cycle that are to be included in the simulation process. The period for simulation of the South Creek catchment's water balance was specified from January 1990 to December 2006 of which the first 24 months were used for warming-up the model. The warm-up period was used to remove the effects of the initial conditions on the model's surface water, soil moisture and groundwater storage levels (Fig. 2). This yielded a 15-year period (1992–2006) to simulate and analyse a spatial and temporal surface water balance of the South Creek catchment.

The South Creek catchment was divided into five sub-catchments, referred to as SCC_A, SCC_B, SCC_C, SCC_D and SCC_E hereafter (Fig. 1). These sub-catchments were delineated by processing a 250 m × 250 m digital elevation model and the location of the selected stream gauges as