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Future climate and land uses effects on flow and nutrient loads of a Mediterranean catchment in South Australia

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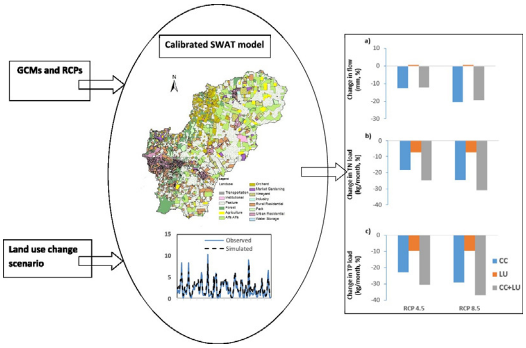
HIGHLIGHTS

- Temperature increases and average precipitation decreases under future climate.
- SWAT was applied to assess the effects of climate and land use change scenario.
- Stream flow and water quality were significantly altered by future climate change.
- Flow decline and nutrient enrichment were indicated for some summer months.

GRAPHICAL ABSTRACT



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ABSTRACT

Mediterranean catchments experience already high seasonal variability alternating between dry and wet periods, and are more vulnerable to future climate and land use changes. Quantification of catchment response under future changes is particularly crucial for better water resources management. This study assessed the combined effects of future climate and land use changes on water yield, total nitrogen (TN) and total phosphorus (TP) loads of the Mediterranean Onkaparinga catchment in South Australia by means of the eco-hydrological model SWAT. Six different global climate models (GCMs) under two representative concentration pathways (RCPs) and a hypothetical land use change were used for future simulations. The climate models suggested a high degree of uncertainty, varying seasonally, in both flow and nutrient loads; however, a decreasing trend was observed. Average monthly TN and TP load decreased up to −55% and −56% respectively and were found to be dependent on flow magnitude. The annual and seasonal water yield and nutrient loads may only slightly be affected by envisaged land uses, but significantly altered by intermediate and high emission scenarios, predominantly during the spring season. The combined scenarios indicated the possibility of declining flow in future but nutrient enrichment in summer months, originating mainly from the land use scenario, that may elevate the risk of algal blooms in downstream drinking water reservoir. Hence, careful planning of future water resources in a Mediterranean catchment requires the assessment of combined effects of multiple climate models and land use scenarios on both water quantity and quality.

1. Introduction

Projected changes of future climate are likely to affect the availability of global water resources in many ways. According to IPCC (2007, 2014),

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extreme meteorological and hydrological events can be expected in future resulting in more frequent droughts, storms and floods posing more uncertainty and risk on river catchments worldwide. Water limited catchments in Mediterranean climate regions experience already high seasonal variability alternating between dry and wet periods, and are particularly vulnerable to global climate change (Giorgi and Lionello, 2008; Piras et al., 2014). Climate projections for Mediterranean catchments in Southeast Australia suggest a decrease in runoff of up to 25% (Chiew and McMahon, 2002) with serious consequences for catchment management (Chiew et al., 2011; Charles and FU, 2015; Hope et al., 2015). Furthermore, future changes in land uses driven by socio-economic and environment variability are likely to occur. They can lead to changes in water availability and nutrient loadings in many different ways. Hence long term assessments of water quality and quantity are required as prerequisite for sustainable water resources management, especially in the context of future climate and land use change.

Previous studies on effects of climate and land use changes worldwide focused mainly on water availability, and only a few studies have addressed responses of nutrients to future changes (Dunn et al., 2012; Mehdi et al., 2015). There is growing evidence that surface water quality is directly affected by several climate related mechanisms (Aldous et al., 2011; Sahoo and Schladow, 2008). Molina-Navarro et al. (2014) found that decreasing runoff magnitudes diminished nitrogen export but increased total phosphorus (TP) loads in a Spanish catchment. Another study conducted in the River Kennet in UK (Wilby et al., 2006) indicated that increased temperature and climate variability may increase nitrate and ammonium concentrations. Moreover, episodic nitrogen peaks due to the “wash up” of accumulated soil nitrogen are likely as soon as the drought breaks. A study of two severe drought periods in the river Meuse, Belgium by van Vliet and Zwolsman (2008) showed, that water quality had been degraded by algal blooms favoured by changed water temperatures and nutrient concentrations. Schneider and Hook (2010) reported that surface water warmed at an average rate of 0.045 ± 0.011 °C year^{-1} by increasing air temperatures during the period of 1985–2009.

Similarly, studies conducted in several river basins of Scotland by Dunn et al. (2012) concluded that land use changes increased nitrate pollution. Another study on Prince Edward Island, Canada by De Jong et al. (2008) suggested an increase of nitrogen leaching by up to 30%. El-Khoury et al. (2015) argued that changed land uses may have a greater impact on nitrogen and phosphorus than climate change, and are crucial for determining adaptation strategies. Since these studies demonstrated that climate and land use changes differently affect nutrient release in catchments, the relative impact of these simultaneously occurring changes is of an interest to know.

Models such as the widely used process-based eco-hydrological model SWAT (Arnold et al., 1998) are generally used for investigating potential impacts of climate and land use changes on catchments. This study applies the SWAT model for the Onkaparinga catchment that has previously been developed by Shrestha et al. (2016) to carry out scenario analyses on flow, total nitrogen and total phosphorus loads affected by future climate and land uses. It combines data from six global climate models (GCM) for intermediate and high emission cases with likely land use changes simulated over a period of 25 years from 2046 to 2070, a time horizon that is relevant for planning restoration and adaptation strategies. It also analyses the uncertainty in predicted flow and nutrient loads caused by the choice of GCM and emission scenarios.

2. Materials and methods

2.1. Study area

The study was carried out within the Onkaparinga catchment situated 60 km east of Adelaide by modelling an area of 317 km^2 upstream of the Houlgraves gauging station (Fig. 1a). The elevation of this area ranges from 10 to 700 m and annual rainfall varies between 522 mm at the coast and 1088 mm in upland areas.

The Onkaparinga catchment is mostly dominated by pasture areas; however, intensive horticulture and viticulture are located in some of the western part of the catchment (Fig. 1b). The western part has hill slopes with clayey to sandy subsoils and has permeable sandstones suitable for orchard and vineyard. While, the eastern part consists of less permeable siltstone with lower slopes and flats that is clayey in texture (Zulfic et al., 2002).

2.2. Model set-up

The process-based semi-distributed catchment model SWAT was used, which can assess the effects of different management practises on water, sediment and nutrient transport in catchments (Arnold et al., 1998). A 30 m Digital Elevation model (DEM) was obtained from Shuttle Radar Topography Mission (SRTM). A 2003 land use and soil map of 2005 were sourced from Department of Water, Soil and Natural Resources of South Australia. Meteorological data were obtained from SILO (Scientific Information for Land Owners, 2015) patched dataset.

This study used the SWAT Onkaparinga catchment model developed by Shrestha et al. (2016) for simulation of monthly flow, TN and TP loadings. It was demonstrated that the multi-site calibration outperformed the single-site calibration in simulating nutrient loadings and hence this multi-site calibrated model was selected for this climate change effect study. However, it was observed that the organic N loading was not reproduced reasonably and the model was further calibrated which improved both organic N and TN loads. Performance during calibration (2000–2009) and validation (2010 − 2013) period for this improved model is provided in Table 1 and figure in Supplements. To understand the impacts of climate change on natural characteristic of the catchment only, the contribution of River Murray derived water was omitted from the calibrated Onkaparinga model. This model then was used for running climate change scenarios.

2.3. Future climate data and model simulation

Climate projection datasets for different regions of South Australia were produced by Task 3 of the Goyder Institute of Water Research Project (GIWR, 2015) and is available on SA Climate Ready portal at https://data.environment.sa.gov.au/Climate/SA-Climate-Ready. This projection used statistical downscaling techniques called Nonhomogenous Hidden Markov Model (NHMM) to simulate daily rainfall from global climate models (GCMS) from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). These rainfalls were calibrated at multiple stations in different regions of South Australia. The GCM grid-scale output of non-rainfall variables were downscaled by using a weather generator conditional on the weather states and rainfall simulated by NHMM (Charles and Fu, 2015). Fifteen Coupled Model Intercomparison Project phase 5 (CMIP5) were chosen for the downscaling project for South Australia which were further studied to identify the six ‘best’ GCMS as provided in Table 2. Future emission scenarios representing two representative concentration pathways (RCP) from the IPCC AR5 were used to represent possible future greenhouse gas concentrations whereby RCP 4.5 and RCP 8.5 represents increases in radiative forcing in 2100 relative to preindustrial levels of 4.5 and 8.5 W/m^2 respectively or simply to put intermediate and high emission scenarios respectively.

Each of the downscaled GCMs produced 100 stochastic replicates (realisations) of future projected climate data until 2100 for rainfall and non-rainfall variables. However, only one realisation for each of the six climate models was used. The realisation that corresponds to the median of projected total precipitation amount for the period between 2006 and 2100 was selected for model simulation.

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