Modelling surface and shallow groundwater interactions in an ungauged subtropical coastal catchment using the SWAT model, Elimbah Creek, Southeast Queensland, Australia

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Abstract

The study presented here applies the highly parameterised semi-distributed U.S. Department of Agriculture Soil and Water Assessment Tool (SWAT) to an Australian subtropical catchment for the first time, to our knowledge. SWAT has been applied to numerous catchments worldwide and is considered to be a useful tool that is under ongoing development with contributions coming from different research groups in different parts of the world. In a preliminary run the SWAT model application for the Elimbah Creek catchment has estimated water yield for the catchment and has quantified the different sources. For the modelling period of April 1999 to September 2009 the results show that the main sources of water in Elimbah Creek are total surface runoff and lateral flow (65%). Base-flow contributes 36% to the total runoff. On a seasonal basis modelling results show a shift in the source of water contributing to Elimbah Creek from surface runoff and lateral flow during intense summer storms to base-flow conditions during dry months. Further calibration and validation of these results will confirm that SWAT provides an alternative to Australian water balance models.

Key Words

Water balance modelling, SWAT model, subtropical catchment, stream flow, hydrology, Australia.

Introduction

In Australia, the computation of the water balance has been widely applied to numerous catchments, to: (1) determine the water yield on a daily or monthly time step, (2) model the effects and severity of storm events, and (3) allocate and manage agricultural water resources. The majority of the water balance model codes used in Australia have been developed in Australia and for most of the models, all input data, calculations and outputs are in unit of length per time step, e.g. mm/day, thus representing one-dimensional models (Boughton 2005). This factor requires lumped data input and results in spatially uniform water balances with no distinction between different types of land use, soil, geological, and geomorphological features. The U.S. Department of Agriculture water balance model Soil and Water Assessment Tool (Arnold *et al.* 1998) has been widely used internationally. SWAT has been successfully applied to numerous catchments and climate zones on most continents; however, to our knowledge there are few studies reported in the international literature, which apply SWAT to an Australian catchment. Furthermore, most of the Australian water balance models are primarily applied to the Australian continent (Boughton 2005), which may impede the comparison of Australian catchment modelling with international studies. SWAT simulates a catchment water balance based on the interaction between different physical and climatic parameters; it also considers soil water and shallow groundwater, and may be applied to ungauged catchments. It is a semi-distributed model processing data on a continuous time-step that simulates water and nutrient transport (nitrogen and phosphorus) through a catchment and considers different land uses.

In this case study, we apply the Soil and Water Assessment Tool to a small, ungauged agricultural catchment in subtropical southeast Queensland, Australia to test its potential to simulate model runoff in local subtropical catchments, where no stream flow data is available. Only limited work has been reported for such applications in Australia and most of the Australian model codes did not successfully model runoff in ungauged catchments (Boughton, 2009). This study is part of a larger research project and in this paper we will present only preliminary findings and model outputs without calibration and sensitivity analysis.

Methods

Study Area

The Elimbah Creek catchment is located 80 km north of Brisbane, in southeast Queensland (**Figure 3**). Elimbah Creek and its two tributaries (Six Mile Creek and Beerburrum Creek) drain an area of 142 km^2 and

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

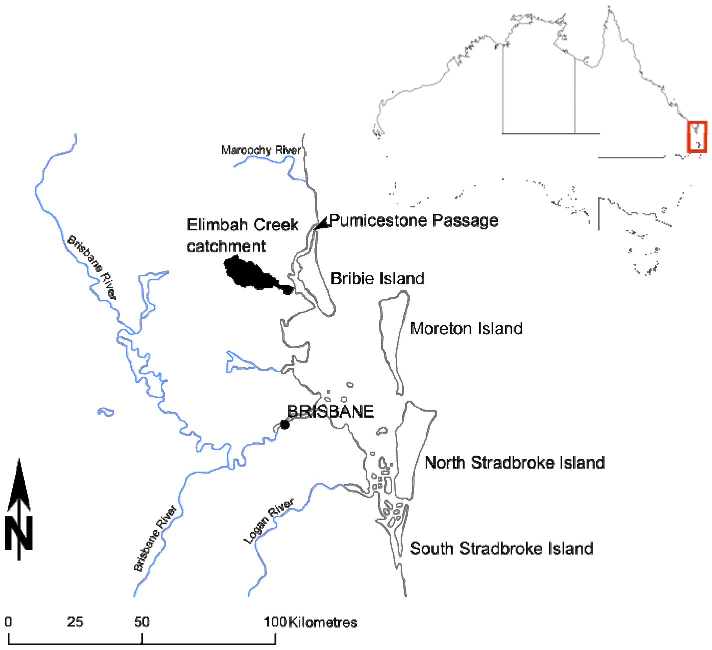

Figure 3. Location of the Elimbah Creek catchment.

form part of the Pumicestone catchment that discharges into Pumicestone Passage. Elimbah Creek is tidal in its lower section, which is common for these coastal catchments with low-gradient coastal plains. These are peri-urban areas with changing land use and the local Moreton Bay Regional Council is expecting almost a doubling in population from the current 139,000 to 235,000 in 2026 (personal communication MBRC, 2008). There are two small rural townships central to the area, Elimbah and Beerburrum, but new residential growth is occurring along waterways and the coastline.

The climate is subtropical, with typically hot, wet summers and cool, drier winters. Thunderstorms and heavy rainfall events are common during the wet season and are often associated with tropical cyclones. The mean minimum–maximum temperature range is 15–26˚C. The average annual rainfall is 1450 mm, with the highest average monthly rainfall usually occurring in February (209 mm) and the lowest in September (44 mm), reflecting typical subtropical seasonal variations (recorded period 1958 - 2009). Ground elevations in the study area range from sea level to 5 m above sea level (ASL) along the estuarine sections, and topography in the remainder of the catchment is characterised by an undulating landscape with elevations of up to 50 m ASL. However, outcrops of Landsborough Sandstone bedrock and the volcanic plugs of the Glasshouse Mountains in the upper part of the catchment may reach elevations of 320 m ASL.

Yellow earths and yellow and sandy yellow duplex soils of varying depth cap the central part of the catchment, where plantation forestry and agricultural practices are most common. These earthy soils are highly porous. The dominant soils in the southeast of the study area are bleached sands. They are moderately deep to very deep and have uniform coarse-textured profiles. Detailed information on soil properties of the area is given by Stace *et al.* (1972).

Plantation forestry is by far the most dominant land use in the Elimbah Creek catchment and covers about 45% of the total area. Plantation forestry is concentrated around the north to northwestern part mainly in the Beerburrum subcatchment. Agriculture accounts for 14% with mainly pineapple and some strawberry farms in Six Mile Creek subcatchment; also turf production occurs in the southwest of this subcatchment. Even with this agricultural activity, there is no official information on fertiliser application for the study area (personal communication with MBRC 2009). Animal husbandry covers around 12% of the study area, and a current trend is increasing development of poultry farms especially in the South Eastern part of the catchment. Residential areas, water, and natural vegetation and national parks cover the remainder of the catchment with 4%, 3% and 22%, respectively.

SWAT principles

For this case study, the SWAT2005 model code was used. The Soil and Water Assessment Tool is a semi-distributed, continuous time, highly parameterised hydrological water balance model (Arnold *et al.* 1998). The model was developed to calculate runoff, sediment, and nitrogen (N) and phosphorus (P) transformations and losses at catchment scale by incorporating the large-scale spatial variability of soil, land use, management practices, and climate. SWAT divides a catchment into subcatchments based on a digital elevation model (DEM) and a user-defined threshold. Each subcatchment may consist of at least one to several hydrologic response units (HRUs). An HRU refers to the total area in a subcatchment with a particular land use, management and soil type. The water balance, sediment, nutrient, and pesticides transformations and losses for each HRU are determined individually, which is different to the Australian model codes. The data is then routed to the associated subcatchment reach and further to the catchment outlet through the channel network. The hydrological processes in SWAT are based on the water balance equation in the soil profile and include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation. Groundwater is partitioned into a shallow unconfined aquifer, which interacts with the channel system and a deep confined aquifer. Except where pumping occurs, the deeper bedrock aquifer is not connected with the surface hydrological system.

SWAT set-up

Watershed discretisation and data input were performed in ArcMAP (ESRI, 2008) using the ArcSWAT interface (Winchell *et al.* 2007). As Elimbah Creek is tidal in its lower section, the catchment outlet was set further inland to avoid tidal influences. Spatial data input comprised a 25m DEM, land use and soil distribution (Queensland Department of Environment and Resource Management 2007). The overlay of land use and soil resulted into 82 HRUs. Climate data, such as daily precipitation, minimum and maximum temperature, windspeed and solar radiation was obtained from the Beerburrum station (Australian Bureau of Meteorology 2009) for the period April 1999 to September 2009. In this study, seven new soil types were incorporated into the model, as SWAT provides detailed soil information based on American soils, only. Soil properties, such as saturated hydraulic conductivity, field capacity, and available water content are based on soil descriptions from Stace *et al.* (1972). Settings for land use were taken from the default SWAT classifications. **Table 2** presents major SWAT parameters, which were calculated based on described input data, and method used.

Table 2. Major SWAT parameters, which have to be modelled during SWAT run, and methods used.

Parameter	Method
Surface runoff	USDA (1972)
Potential evapotranspiration	Hargreaves *et al.* (1985)
Actual evapotranspiration	Ritchie (1972)
Relative humidity	Sharpley and Williams (1990)
Sediment yield	Modified Universal Soil Loss Equation, Williams (1975)

Results

The Soil and Water Assessment Tool calculated the water balance for Elimbah Creek catchment for the period April 1999 to September 2009. **Figure 4**-A shows the monthly estimated runoff at the outlet of the catchment, which drains an area of 115 km^2. Runoff correlates well with actual rainfall with a coefficient of determination (R^2) of 0.8 (**Figure 4**-B).

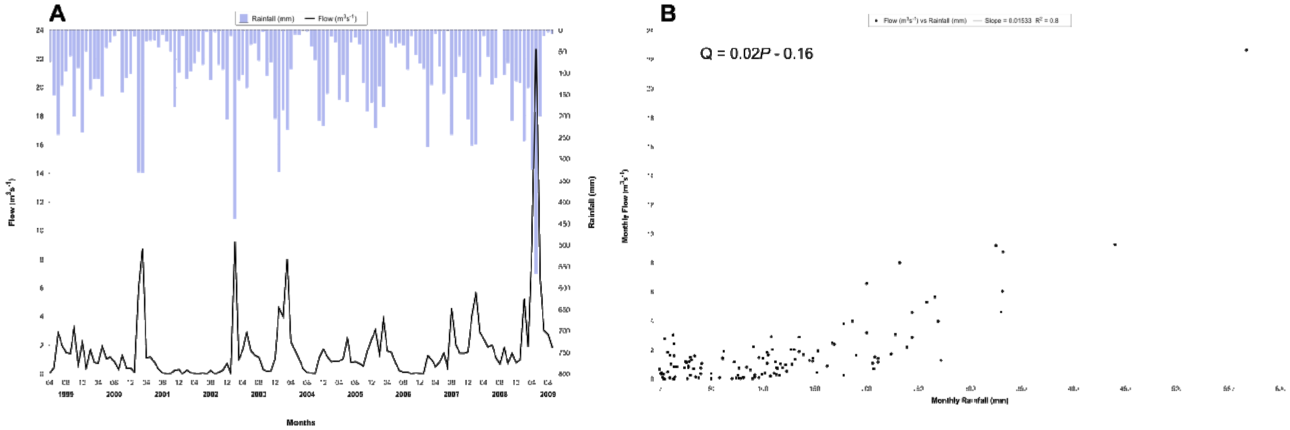

Figure 4. Data for Elimbah Creek catchment outlet, showing, (A) predicted flow (line) and actual precipitation (bars), and (B) corresponding scattergram (B) with *R*^{2}.

For the modelling period, total surface runoff and lateral flow are contributing 65% to the water in Elimbah Creek. Only 36% of the water in the creek is contributed to total base-flow. Around 68% of the rainfall occurring in the catchment is lost through evapotranspiration. The seasonal pattern of the contribution of different water sources show that during the wetter months (January-June) most of the water in Elimbah Creek originates from surface runoff due to high intensity rainfalls. However, during the dry months (July-September) base-flow is the main source of water. Lateral flow contribution is negligible due to the undulating character of the landscape, with no significant steep hill slopes.

Conclusion

In this case study, we applied the Soil and Water Assessment Tool to an ungauged subtropical Australian catchment, which has never been attempted, to our knowledge. As this study is part of a larger research project, only preliminary results are presented here. They show that, with some modifications to its database, SWAT was able to provide a plausible estimation of the water yield in the catchment and to identify the different sources contributing to the total flow. In a similar study in Tunisia, Bouraoui *et al.* (2005) applied SWAT to an agricultural sub-humid catchment to link surface runoff and base-flow to total water yield. The calibrated model showed that SWAT predicted base-flow conditions during dry months and surface runoff into the drainage system during intense summer storms. Further calibration and validation of the Elimbah Creek model is required to confirm that SWAT is indeed a useful tool in catchment hydrological modelling in Australia. Furthermore, the ability to estimate nitrogen, phosphorus and sediment loadings under different management practices in small ungauged catchments makes SWAT a valuable instrument that should be further tested in Australia.

Acknowledgements

This study is funded by (1) Forestry Plantations Queensland, (2) School of NRS, Queensland University of Technology (QUT), (3) Institute for Sustainable Resources, QUT and (4) Moreton Bay Regional Council, Queensland. In addition we acknowledge the assistance of John Ridler, Department of Environment and Water Management, Queensland Government. The authors would also like to thank Jing Yang, EAWAG Switzerland, and Zhulu Lin, NDSU USA for their computational support to SWAT.

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