Modelling the hydrologic response of intermittent catchments to rainfall variability

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Introduction

Intermittent streams have a crucial role in shaping and maintaining ecological functions of seasonally dry ecosystems. However, most studies on runoff generation refer to perennial streams. The effect of land-use change and climate variability on water resources of intermittent catchments might cause increase of intermittency and water shortage.

Modelling the response of intermittent catchments to rainfall is a challenging endeavor that has received little attention. Since streamflow is not continuous over the year, models need to be able to capture discontinuities in the flow regime during a significant period of the year in addition to reproducing its magnitude. Moreover, because of the key role of groundwater in supplying seasonal flow, hydrological models must be able to account for interactions between surface and subsurface flow. Because nonlinearities, heterogeneities and complexities associated with the landscape are not considered in lumped models, these models can be efficiently used only with large simplifying assumptions [1]. Conversely, Integrated Surface-Subsurface Hydrological Models (ISSHMs) are able to simulate the dynamics of the components of the catchment water balance, thereby being more suitable for applications in intermittent catchments.

Aims

The overarching aim of this study is to assess impacts of rainfall variability on runoff generation. This study uses the spatially-distributed model CATHY (CATchment Hydrology) to analyze how, for given annual rainfall depths, the frequency at which daily rainfall is delivered can affect the water balance of an experimental intermittent catchment. After calibrating and validating the model against experimental measurements of streamflow and groundwater levels, the role of rainfall variability in affecting streamflow characteristics, such as magnitude, duration, timing, and frequency, will be explored using different scenarios. In this regard, annual total flow, 1-day maximum flow (magnitude and date), number of no-flow days in wet season, starting and ending day of flow, and number of times the daily hydrograph rose above annual average flow will be used as the metrics to represent effects of each scenario on different streamflow properties.

Study area

Located in southwestern Victoria, almost 300 km west of Melbourne, Gatum Farm is a catchment with an area of 1.61 km^2 that is used as a pasture for cattle and sheep grazing (Figure 1). The catchment is characterized by a Mediterranean climate with hot and dry summers and cool and wet winters. The average annual pan evaporation and average annual rainfall during 1954-2012 were 1400 and 611 mm, respectively. The elevation in the catchment ranges from 235 to 265 m AHD. There are 10 bores in the catchment, with screen length of 2-3 m and water table in the deepest bore can reach approximately a depth of 11 m. A V-notch weir at the outlet is used to measure streamflow at 30 min intervals. The bores have been equipped with a groundwater logger, for measuring water table at a 4-hour time interval. A tipping-bucket rain gauge was also installed at the catchment weir to measure rainfall at 30 min intervals. The data were then aggregated into daily rainfall.

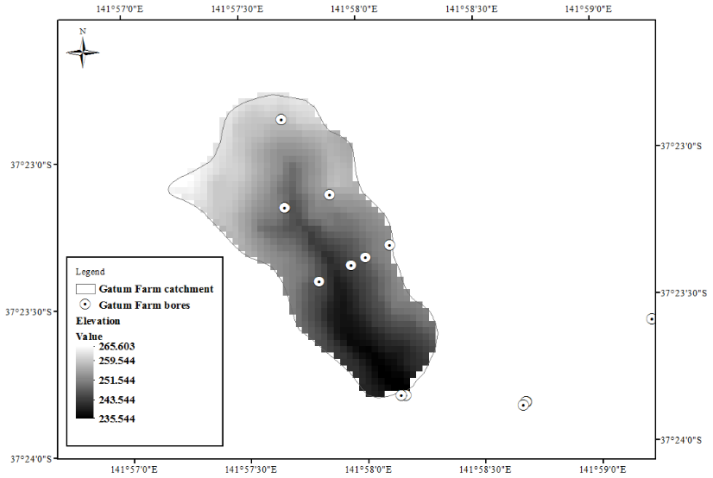

Figure 1: Map of the study area

Methods

CATHY features a three-dimensional solver of the Richards equation for subsurface flow in variably saturated soil coupled with a one-dimensional diffusion wave approximation of the de Saint Venant equations for surface water routing [2]. The main inputs to the model are rainfall and potential evapotranspiration, while output data include distributed variables, such as water table and soil moisture, as well as the main water balance components computed as integral variables, i.e., streamflow, actual evapotranspiration, and storage change.

To assess the role of annual rainfall on the catchment water balance, annual rainfall depth scenarios are generated by maintaining the occurrence of daily rainfall as measured, while multiplying daily rainfall depths to different percentages so that the total annual rainfall will be decreased. This helps quantify the minimum rainfall able to generate streamflow, thus highlighting the role of surface runoff and subsurface water in triggering the beginning of flow conditions. Additionally, scenarios on rainfall patterns with total annual rainfall depth constant will be devised. Long-term series of daily rainfall will be used to calculate statistics of daily rainfall frequency and depths. A probabilistic model of daily rainfall will be used to generate scenarios with the same annual rainfall delivered to the catchment with different frequencies. Daily rainfall events are assumed to occur according to a Poisson process, with daily rainfall having a Gamma or Mixed-exponential distributions. This will show the role of rainfall frequency in generating streamflow; as future climatic projections suggest an increase of large rainfall events with similar annual rainfall, these scenarios will apply to future climatic conditions [3].

Expected results

When rainfall intensity is greater than the soil infiltration capacity (i.e. the main runoff generation mechanism is Hortonian overland flow (HOF)), we expect the scenarios with events having higher intensities to generate more runoff, because the catchment receives rain in a shorter period. However, if the main runoff generation mechanism is not HOF, we expect the scenarios with fewer days of no-rainfall to generate more runoff, because the connectivity of groundwater and surface water will be longer (subsurface saturated flow) and soil will be saturated for a longer time (saturated overland flow).

References

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