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Can conceptual rainfall-runoff models capture multi-annual storage dynamics?

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Abstract: Conceptual rainfall-runoff models are widely used in hydrology, but many perform poorly under prolonged droughts or changing climate conditions. One of the reasons is that they focus on seasonal or shorter streamflow responses and neglect multiannual dynamics (Fowler et al., 2020). For example, during the Millennium Drought in southeastern Australia, many groundwater bores in Victoria showed a clear year-to-year decline, but the simulated water storage in models applied during this period reflected only seasonal fluctuations. The multi-year water deficit is not well represented in those models; in other words, they tend to wipe "clean the memory of past events" (Fowler et al., 2020).

To address this gap, we investigate whether specific structural components enable models to reproduce multi-annual storage dynamics. We hypothesise that three elements are required: (1) a store responsible for long-term behaviour, (2) disconnection of that store from direct streamflow generation, and (3) a water loss mechanism from that store (e.g. evapotranspiration or groundwater export) that allows gradual depletion.

We systematically tested this hypothesis using 46 daily models from the Modular Assessment of Rainfall-Runoff Models Toolbox (MARRMoT). Each model was applied in three Australian headwater catchments that experienced multi-annual declines in storage during the "Millennium" Drought (1997–2010). We also included a synthetic drought scenario designed to evaluate delayed streamflow recovery after an idealised multi-year drought. Of the 46 models, nine contained all three hypothesised components. These models were far more successful: 5 of the 9 passed both tests, compared to only 1 of the 37 models without the hypothesised full structure. However, model structure alone did not guarantee success, as restrictive process formulations or calibration settings sometimes prevented slow-storage behaviour from emerging in models with the hypothesised full structure.

These results highlight the need to better represent key processes to avoid underestimating climate impacts on streamflow. They point toward next steps for adapting conceptual models in applications where hydrological memory and long-term drought response are important.

REFERENCES

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