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Modelling the hydrological impacts of leaky weirs on catchment rehydration using SWAT+ model

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Abstract: Australia's Millennium Drought severely affected many productive landscapes, triggering widespread soil degradation, biodiversity loss, and water scarcity. In response, the Mulloon Research Institute pioneered landscape rehydration initiatives to restore hydrological function and improve drought resilience (Peel et al., 2022). Central to this approach is the use of in-stream structures known as Leaky Weirs, constructed from logs and boulders, designed to slow streamflow, increase infiltration, and support regenerative agriculture. While field evidence suggests positive ecological and hydrological outcomes, the mechanisms by which Leaky Weirs influence catchment-scale water movement remain poorly understood.

This study examines the hydrological impacts of Leaky Weirs in the Mulloon catchment using the Soil and Water Assessment Tool (SWAT+), incorporating the GWFlow module to simulate distributed groundwater–surface water interactions (Bailey et al., 2020). The model was calibrated for 2008–2023, encompassing both wet and dry climatic conditions. More than 20 unique parameters were spatially calibrated across the upper, mid, and lower Mulloon catchment to account for heterogeneity in system behaviour. Leaky Weirs and land management practices were dynamically represented in the model using the SWAT+ decision table feature, reflecting their gradual implementation over time. Simulations evaluated shifts in key hydrological components, including streamflow, surface runoff, lateral flow, percolation, evapotranspiration, and soil moisture, under scenarios with and without Leaky Weirs. Comparative analysis with the standard SWAT+ groundwater module highlights the enhanced capability of GWFlow to represent rehydration processes and groundwater storage dynamics.

Model calibration for daily streamflow in Lower Mulloon produced satisfactory results, with a Kling–Gupta Efficiency (KGE) of 0.72 and a Nash–Sutcliffe Efficiency (NSE) of 0.60, despite the challenging simulation period that included the Millennium Drought and Tinderbox Drought. Preliminary results revealed unexpected flow dynamics: mean high flows increased slightly by 0.11 m^3/s (3.6%), mid flows decreased by 0.02 m^3/s (5.8%), and low flows declined by 0.007 m^3/s (12.5%) following weir implementation. These results contrast with the initial hypothesis that Leaky Weirs would sustain baseflows and attenuate high flows. A possible explanation is that: (i) high flows are minimally buffered due to the small storage capacity of the structures, leading to rapid spill and occasional flow pulses; (ii) mid-range flows are reduced as moderate inflows are captured and lost through infiltration or evapotranspiration; and (iii) low flows are not sustained as stored water is lost to evapotranspiration or deep recharge rather than supporting baseflow. These dynamics will be further evaluated through analysis of additional hydrological components and by comparing the SWAT+ GWFlow representation against the generic groundwater module.

A key limitation of this study is the assumption that the calibrated parameter set with Leaky Weirs is transferable to scenarios without them, due to insufficient observational data prior to weir installation. Nonetheless, the results provide new quantitative insights into the hydrological function of in-stream rehydration structures and contribute to understanding how regenerative practices can be scaled to improve landscape resilience under drought-prone conditions.

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