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Climate and land-use change impacts on flow and non-flow drivers of ecological outcomes

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Abstract: Freshwater ecosystems are experiencing significant declines under a range of uncertain factors that threaten their sustainability. While the importance of the flow regime in supporting ecological health is well established and efforts to restore river ecosystems through environmental flows are growing worldwide, ecological outcomes also depend on non-flow drivers such as water quality and sediment loads. Climate change and land-use and land-cover change stand out as the most significant threats to ecological health worldwide, each influencing both flow and non-flow variables. Although there is a range of literature examining these stressors separately, their combined effects on a wide range of flow attributes (variability, magnitude, frequency, duration, timing) and non-flow variables (water quality, nutrients, sediment yield and transport, pesticide transport, etc.) across different ecological objectives, including biodiversity and ecosystem function, have not been studied simultaneously. This gap highlights the need for more comprehensive approaches that capture the complexity of interactions shaping freshwater ecosystem dynamics.

When climate change and land-use change occur together, they can synergistically contribute to the degradation of ecological health. Understanding the most important sources of uncertainty and examining their effects on ecological outcomes will help target future modelling and monitoring efforts to both (i) reduce uncertainty and (ii) manage resources despite the uncertainty. To this end, we explore whether land-use and land-cover change, climate change, or their combined effects have the most significant impact on both flow and non-flow variables of ecological objectives. The relative role of climate and land-use on ecological outcomes will be systematically examined using an integrated model that links climate and land-use drivers to ecological outcomes. Our case study focuses on the Goulburn River in Victoria, Australia, a vital component of the Murray–Darling Basin that is managed to meet diverse objectives, including providing irrigation water for agriculture, supplying drinking water to small regional towns, and supporting ecological outcomes through an environmental water entitlement.

A key component of the methodology is the development of a hydrological and water quality model that simulates the basin's flow and non-flow variables under the impacts of climate change, land-use, and land management practices. We use the SWAT (Soil and Water Assessment Tool) model, a semi-distributed and physically based watershed-scale hydrological model, to simulate hydrological outputs and key water-quality outputs such as nutrient levels, dissolved oxygen, and sediment yield. This is coupled with a water resource model that simulates regulated river management including environmental flows. Both flow and non-flow variables are then combined in conditional probability network-based ecological models, which estimate outcomes in 12 ecological endpoints in the Goulburn River basin related to key environmental objectives. Ecological responses to climate-change and land-use change scenarios are then evaluated using sensitivity analysis to assess the importance of different factors. This reveals how shifts in climate and land-use collectively influence the basin's ecological condition.

Identifying the most important stressors of freshwater ecosystems is essential for credible future scenario development and risk assessment by improving scenario design, prioritise monitoring of the most influential variables, and broadening the scope of contingent actions to include landscape measures and adjustments to regulated flows. This approach thereby strengthens evidence-based environmental water management under changing conditions.

Keywords: *freshwater ecosystems, climate change, land-use and land-cover change, environmental flows, water quality, SWAT model*

