

Is our approach to rainfall-runoff modelling future climate ready?

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Abstract: Projecting rainfall–runoff responses under future climate change is central to anticipating water security and ecosystem impacts, yet significant shortcomings limit the reliability of current water resource modelling approaches. Most rainfall–runoff assessments focus narrowly on precipitation and temperature as primary drivers, overlooking secondary influences such as vegetation dynamics, soil structure, groundwater–surface water interactions, and landscape change. These processes can substantially alter the partitioning of rainfall into runoff, but are seldom incorporated due to the coarse resolution and biases of downscaled climate model inputs and the structural limitations of hydrologic models themselves. As a result, critical factors including evapotranspiration feedbacks, CO₂-induced vegetation changes, atmospheric stilling, or soil degradation are poorly represented in most modelling studies.

A further constraint arises from the dominance of lumped conceptual models in climate impact assessments. While these models are attractive for their simplicity, parsimony, and calibration efficiency, their static parameterisations are poorly suited to representing dynamic biophysical processes that evolve under climate forcing. Even process-based models that include soil water balance or vegetation modules are rarely validated under novel climatic regimes, raising concerns about their transferability to futures characterised by non-stationarity, tipping points, and abrupt hydrologic shifts. The assumption that model parameters and relationships derived under historical conditions remain valid in altered climates is particularly problematic, as it risks masking emergent behaviours such as step changes in runoff yield, nonlinear vegetation–soil feedbacks, or shifts in groundwater connectivity. These behaviours may be either synergistic or antagonistic when combined, but this is rarely explored through sensitivity testing, model structural adjustments or even simply defining bounds over which these behaviours may occur.

Current practice in rainfall-runoff modelling risks underestimating the range of plausible hydrologic futures and constrains our ability to distinguish between climate-driven change and internal model artefacts. Addressing these shortcomings requires methodological advances: explicit representation of evapotranspiration and vegetation–soil feedbacks, dynamic parameterisation strategies, frameworks for evaluating model structure and robustness across climates, and workflows that embrace uncertainty rather than treating it as residual noise.

Without these developments, current rainfall–runoff modelling practices risk mischaracterising both the magnitude and direction of hydrologic change under climate forcing. Improved integration of process understanding, model diagnostics, and uncertainty analysis will be essential to ensure that hydrologic modelling contributes effectively to climate adaptation planning and water resource management.

Keywords: *Rainfall-runoff, hydrologic modelling, climate change*