Can our conceptual hydrological models really 'get' evapotranspiration? Lessons from testing 15 equations

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Abstract: Accurate estimation of evapotranspiration (ET) is central to the catchment water balance, yet its representation in conceptual hydrological models often receives less scrutiny than streamflow performance. Misrepresentation of AET processes can lead models to simulate long-term water partitioning incorrectly, even when calibration appears successful. Such biases risk being amplified in climate change projections. To address this, we systematically evaluated 15 widely used actual evapotranspiration (AET) formulations, which convert soil moisture and potential evapotranspiration (PET) into AET within conceptual hydrological models, using the MARRMoT modelling toolbox (Trotter et al. 2022). We substituted these equations into three conceptual rainfall-runoff models (GR4J, SimHyd, VIC) and calibrated them using a composite objective function equally weighting streamflow and flux tower AET, scaled to the catchment using a long-term water balance adjustment, across seven Australian catchments. Equations were ranked by objective function performance across models and catchments, and further assessed using evapotranspiration signatures. By assessing equations independent of model structure, we ensure that performance differences reflect the equations themselves rather than model structural artefacts, providing clearer insight into their strengths and weaknesses (Burns et al. 2025).

Only a subset of equations performed consistently well, with one formulation emerging as the most robust. Its strength derives from two features: (i) a parameter limiting AET to remain below PET, even under wet conditions, and (ii) a concave, non-linear dependence on soil moisture, together, better reflecting vegetation function in Australian catchments. Calibrated parameter values confirmed the frequent need for limiting AET below PET and concave soil-moisture responses across catchments. In contrast, poorer-performing equations often assumed linear relationships or allowed AET to equal PET, neglecting known vegetation and transport constraints.

Despite this improvement, limitations remain. Even the most robust equation could not fully resolve systematic mismatches in seasonal timing, with models tending to overestimate AET early in the wet season. This points to missing ecohydrological processes in current conceptual frameworks, such as delayed transpiration onset, vegetation growth constraints, or conservative water use strategies adapted to climate variability. This raises multiple questions about how transferable existing formulations are under global change, as well as whether such dynamics are important in other regions as well.

These findings show that inaccurate AET representation can distort projections, especially under scenarios that depart from the calibrated climate envelope. By showing where and why common equations succeed or fail, this study highlights the need to move beyond linear or empirically convenient relationships toward more process-informed formulations. Our findings suggest that adopting more process informed equations can improve robustness in the short term, but further integration of vegetation dynamics and seasonal ecohydrological feedbacks will be essential to ensure reliable projections under climate change.

More broadly, this study demonstrates the value of systematic, model-structure-independent evaluations of internal flux equations. Such frameworks should become more common practice in conceptual modelling, where fixed but under-examined internal formulations can strongly shape results. By bringing equation-level testing to the forefront, hydrological modelling can move toward more transparent, physically grounded, and reliable projections of catchment behaviour in a changing climate.

Keywords: *Conceptual hydrologic models, actual evapotranspiration*

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