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The need to avoid determinism and weak links in modelling chains when assessing climate impacts

Rory Nathan [a]

[a] *Department of Infrastructure Engineering, University of Melbourne, Parkville, 3010, Australia*
Email: rory.nathan@unimelb.edu.au

Abstract: The dominant paradigm adopted by industry when assessing the impacts of climate change is the "Groundhog Day" approach, whereby deterministic models are forced by historic climate data that has been adjusted to represent projected changes in seasonal or annual climate variables. This approach is conceptually flawed as it assumes the future sequence of wet and dry extremes is a merely a repeat of the past. While the practical implications of this assumption for systems that are stressed by short term (eg daily to monthly) fluctuations are probably benign, it becomes highly problematic when adopted for systems (such as water supply networks) that are vulnerable to multi-year or decadal stresses (Nathan et al, 2019). Some more enlightened agencies strive to use stochastic sequences in lieu of historic, but this creates impractical computational burdens which both confound the interpretation of outcomes and severely limit the exploration of key uncertainties. Interestingly, these problems are not restricted to industry: in an extensive review of international literature John et al (2020) found that 54% of environmental impact studies adopted single (perturbed) climate sequences, and that the vast majority of studies that considered stochastic sequences employed modelling chains that were mismatched in their ability to accommodate the inherent uncertainty in both impacts and responses.

One of the key factors influencing the reliance on such mis-matched deterministic modelling chains is that hydrologists commonly select models on the basis of their personal familiarity, or the legacy of institutional factors, rather than on their fitness of purpose (Addor and Melsen, 2019; Melsen, 2022). For example, in Australia a large amount of effort has been expended on the development and application of daily rainfall-runoff and river system simulation models. While there is no doubt that such models play a crucial role in the management and auditing of our water resources, little or no consideration is given to evaluating their suitability for climate impact studies. Indeed it is the experience of this author that institutional factors commonly constrain any meaningful exploration of alternative modelling strategies, and this severely undermines our ability to explore the salient implications of the major epistemic and aleatory uncertainties inherent to climate impact studies.

The focus of most climate impact studies is on the changing risks to the safety, reliability, and sustainability of water resource systems over various planning horizons. The risks of projected changes can be assessed in a variety of ways (Fowler et al, 2024), but in essence all approaches involve the characterisation of changes in the frequency and intensity selected outcomes. To this end, we need to adopt probabilistic modelling approaches that combine projected climatic variables with the impact pathways of most interest to the stakeholders. Rather than attempt to shoehorn the deterministic models used for traditional management and regulatory purposes into a cumbersome modelling chain, we need to develop bespoke stochastic modelling tools that reproduce the key outcomes of interest with sufficient accuracy. We have good examples of this being done in a manner suited to integrated modelling tasks, for example John et al (2021) demonstrate the efficacy of using coarse rainfall-runoff models, Oldenkamp et al (2023) successfully used stochastic regression models to simulate computationally laborious models of pesticide runoff processes, Moe et al (2024) describe the value of incorporating such modelling elements into integrated assessments using Bayesian Network models, and John et al (2022) used integrated modelling heuristics to explore compound climate interactions on freshwater ecology. It is clear that the major barriers to the adoption of better modelling practices are institutional and cultural, not technical.

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