# Can and should water companies use stochastic methods to inform water resources investment decisions?

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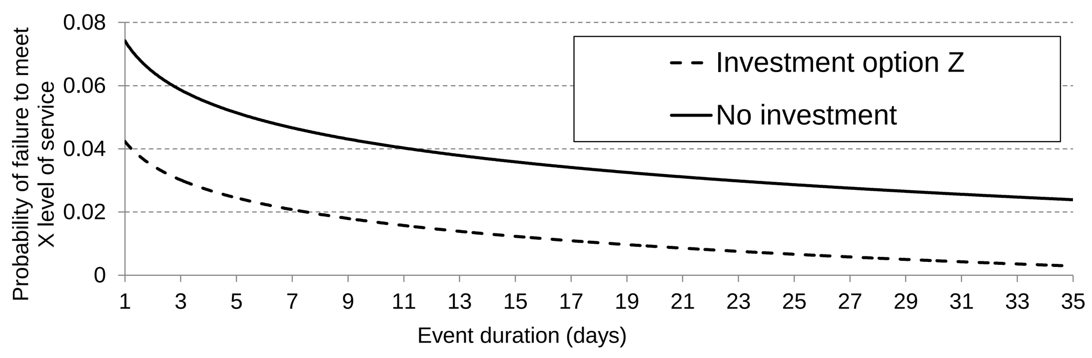
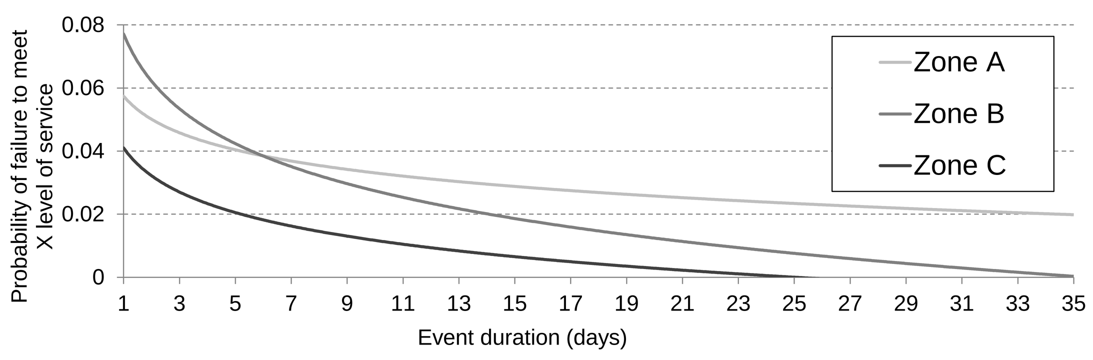
## Study A – The 'Ennerdale problem'

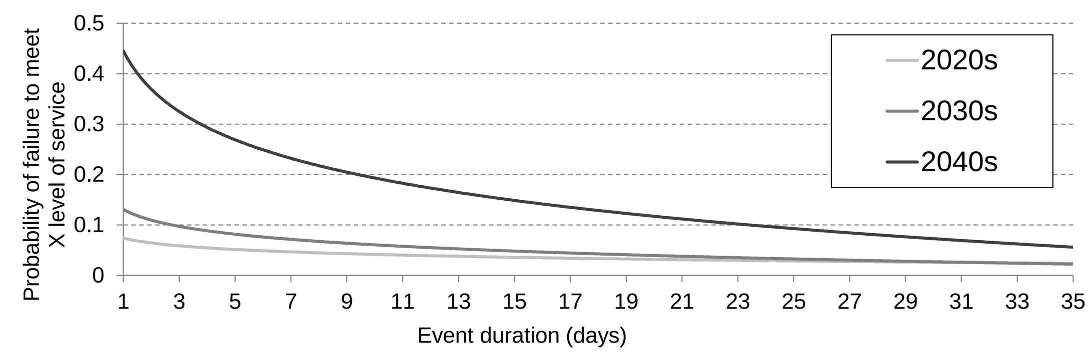
Background: United Utilities must understand the viability of Ennerdale Water as a supply source under new requirements to increase compensation releases to protect the local aquatic environment.

Method: Stochastic analysis of the Ennerdale system (as a stylised single-reservoir problem) using Aquator™ batched from external code. 100 UKCP09 model variants were selected from 10,000 using Latin Hypercube Sampling. The selected variants were used to produce (using the Weather Generator) hundred-year daily precipitation and evaporation time series for the 2030s time slice. These were converted to flows using a simple rainfall runoff transform and routed through the system model. A Monte-Carlo simulation procedure incorporated demand uncertainty.

Output: The risk curves below illustrate three beneficial applications of this approach: first, an understanding of the reduction in risk achieved by a given investment; second, an unbiased comparison of risk across different zones; and, lastly, picture of changing risk through time.




Three key findings:

- Detailed inspection of the conventional planning methodology revealed significant biases (namely 'emergency provision') that a stochastic approach might address
- The above method is practically feasible on small resource zones, but would be difficult to scale up to larger, more complex systems
- Further method development would be required to demonstrate how this approach could fit with economic options appraisal and regulatory process

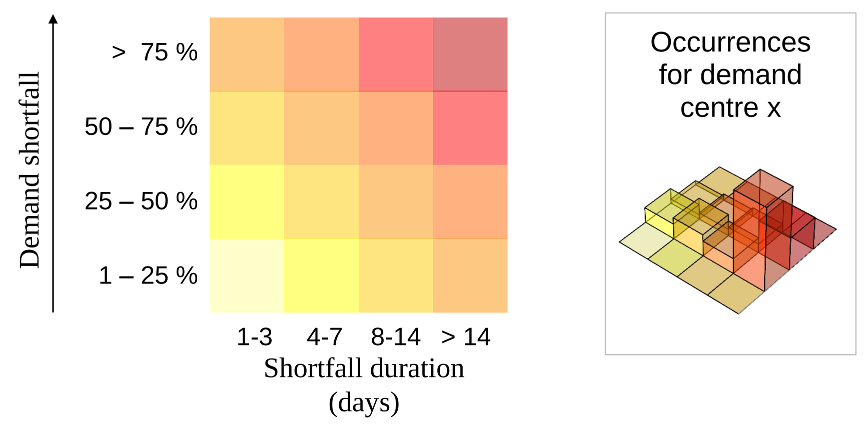
Turner, S., Blackwell, R., Smith, M. and Jeffrey, P (under review) Risk-based water resources planning in England and Wales: Challenges in execution and implementation, *Urban Water Journal*.

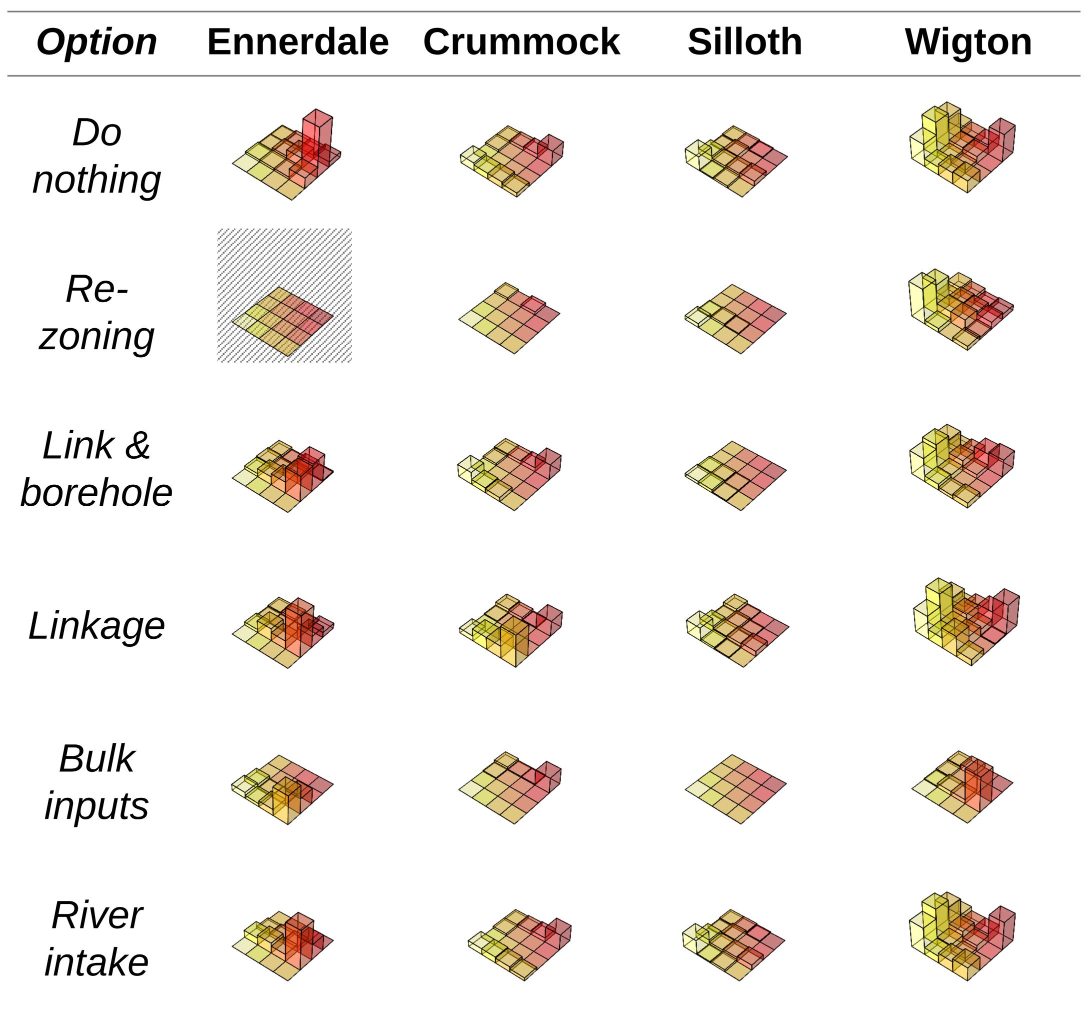
## Study B – The influence of stochastic methods on investment options appraisal

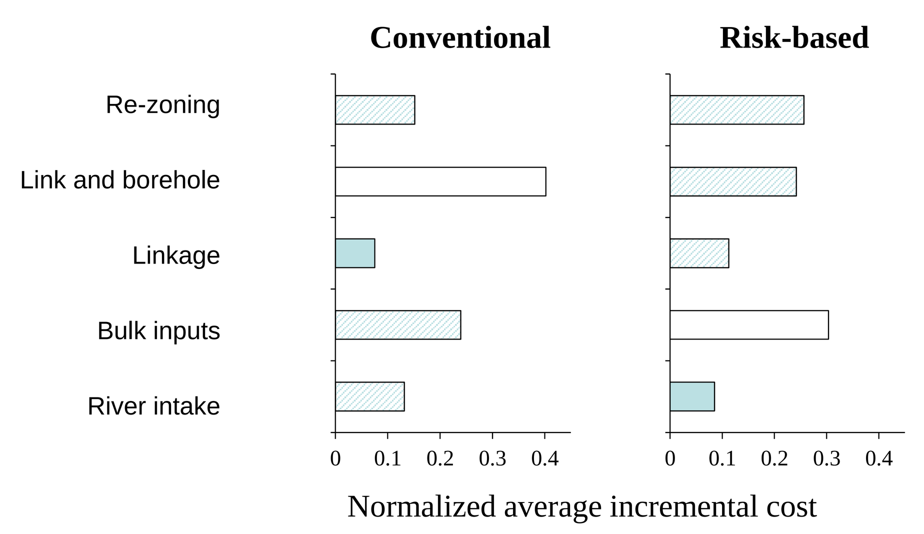
Background: This study builds on 'Study A' to ask how the analysis would impact planning decisions in a more complex interconnected system.

Method: Stochastic simulations of the West Cumbria Resource Zone under a discrete set of interventions. The risk surfaces shown below were derived from 2750 single-year scenarios incorporating uncertainties associated with stream flow variability, climate change (using the 11-member HadRM3 ensemble), demands and asset constraints.

Outputs:




Three key findings:

- Stochastic stress-testing of this weakly interlinked system revealed previously unrecognised risks
- This improved understanding of risk would endorse significantly different system design
- Cost-benefit appraisal that aims to justify investment should be avoided in this context

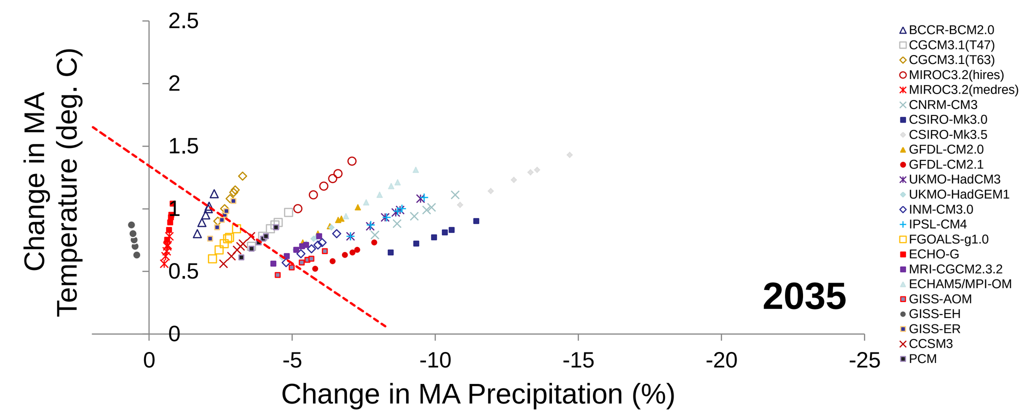
Turner, S. and Jeffrey, P. (2013) Risk-based water resources planning: Challenges for reaching rational decisions based on quantitative frameworks, *Proceedings of the 8th International conference of the European Water Resources Association*.

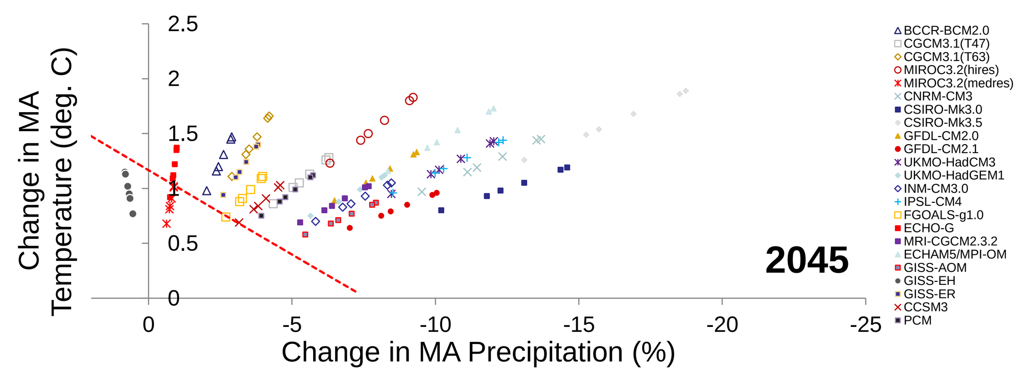
## Study C – 'Decision-scaling' applied to the Melbourne bulk supply system

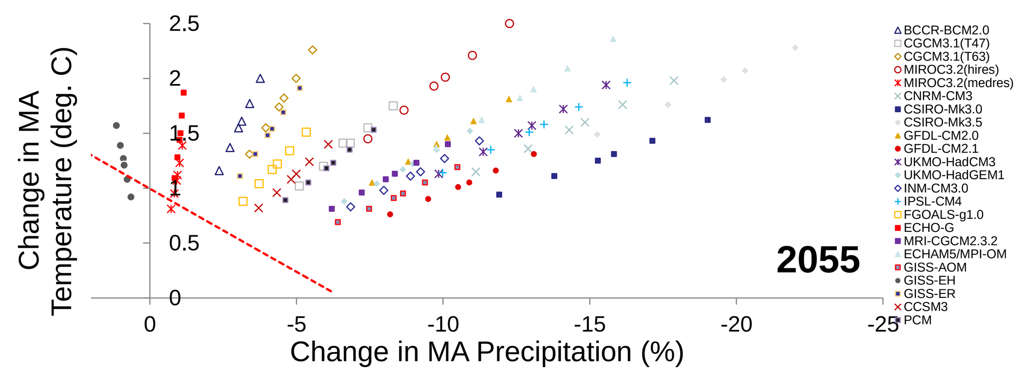
Background: Melbourne Water is seeking new methods for understanding the uncertainties in their supply/demand assessments. This study applied the 'decision-scaling' methodology first proposed in Brown *et al.* (2012). The method reverses the contemporary risk-based planning procedure by beginning with an attempt to understand a system threshold in terms of broad climate statistics.

Method: 1000 hundred-year stochastic replicates were generated using a multi-site auto-regressive model. Each replicate was routed through a bulk supply model, built using eWater Source and commanded externally using a script in *R*. System yield - constrained using reliability and severity criteria - was computed for each replicate and compared to underlying inflow statistics (annual and seasonal means, skew, standard deviation and serial correlation at lag1). Stepwise regression was used to reveal an acceptable relation ($R^2$ = 0.74) between mean annual flow in a major catchment (encompassing four of the largest reservoirs in the system) and a demand-yield threshold. A multiple log linear regression was applied to understand the climate statistics linked to that threshold and derive a climate response function that demarks the climate conditions that would prompt system augmentation (red dotted line in the diagrams below). GCM output was then plotted against this function to understand climate change uncertainty.

Outputs:




Three key findings:

- The methodology can be successfully applied to more complex zones than previously established
- The method produces similar quality results to top-down stochastic assessment, but with far less computational effort
- Applicability in the UK context would be case-dependent

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