Application of machine learning techniques to support decision making under uncertainty in water resource management

Contact: Aodhín McBride
a.mcbride@hrwallingford.com
www.hrwallingford.com

McBride, A., Counsell, C., Malde, S. and Simm,J.

Summary

A range of approaches demonstrating the potential for innovative methods to interpret and present complex modelling results.

Background

Water is considered to be one of the main ways people will experience climate change, whether through increasing drought frequency and severity causing more people to experience water stress, or rising sea levels resulting in coastal flooding during storms and high tides. Climate change, coupled with the long term challenge of population growth and urbanisation, and their associated uncertainties, mean that water resources managers are increasingly seeking innovative methods to balance the competing demands being placed on the water environment.

Planners and policy makers need to understand the scale, urgency, location, and likelihood of effects when dealing with pressures on water supply and flooding. Extensive simulation modelling of complex systems are typically required to provide such information. To apply advanced decision making methods and risk based planning methods, modelling and analytical efficiencies are needed. As a result, machine learning approaches, whereby statistical techniques allow applications to become more accurate in predicting outcomes without being explicitly programmed, are being adopted.

We outline a toolset of approaches to complement computationally more expensive process models, and support the rapid simulation times required for applying these methods. Due to the flexible structure of the tools, and the generic approaches used, these techniques can readily be applied to a wide range of settings. User-friendly tools and dashboards are being used to explore and communicate the outputs and facilitate effective decision making, involving all stakeholders.

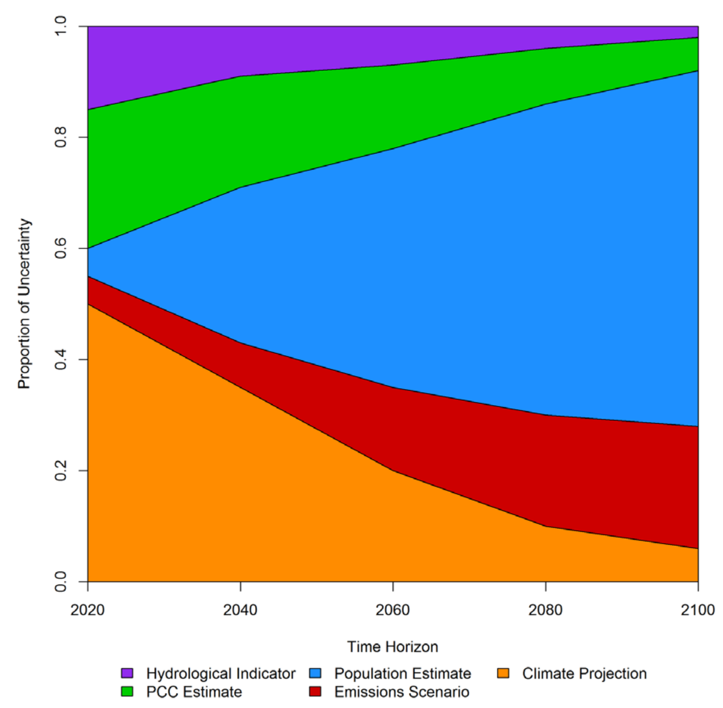
Applications

National scale assessment of water availability

Water availability emulator tool

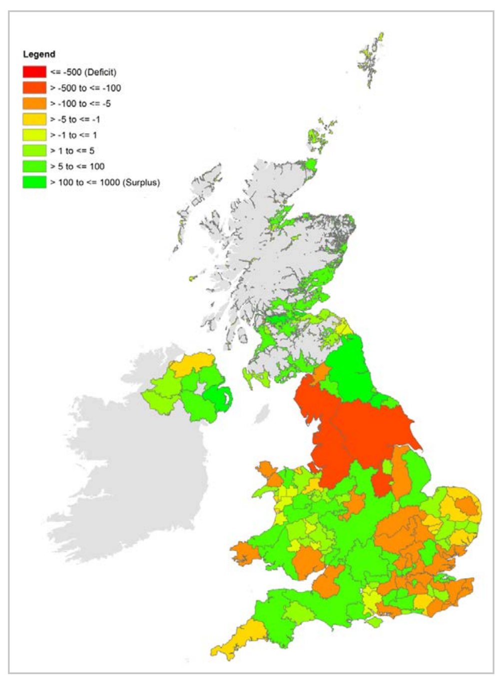
The contributing factors influencing the current levels of risk in water supply planning were evaluated, and then projected across the UK according to a range of plausible and coherent climate, population, adaptation and environmental protection scenarios to 2100. A statistical emulator, conditioned on outputs from detailed local scale supply system modelling, was developed to enable available resources across the UK, to be rapidly estimated whilst reflecting local hydrological, infrastructure and licence constraints.

Combined with demand side projections the results informed government [1] as to the scale of the potential challenges in the future to maintain adequate supplies for society and industry alongside protecting the environment. The spatially distributed approach also highlighted how the magnitude and relative contribution from the different pressures varies geographically and the uncertainty associated with such estimates.



Development of uncertainty with time

[1] UK Climate Change Risk Assessment 2017 Evidence Report - Committee on Climate Change.



Supply demand balance for high emissions climate projection, high population projection and with adaptation actions in excess of current objectives

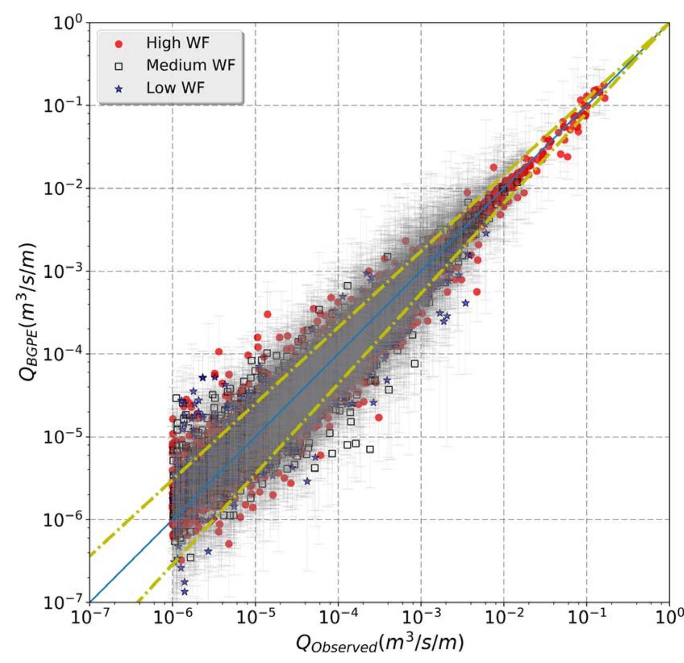
Assess the performance of coastal structures

Mean wave overtopping discharge using Gaussian Process Emulators (GPE)

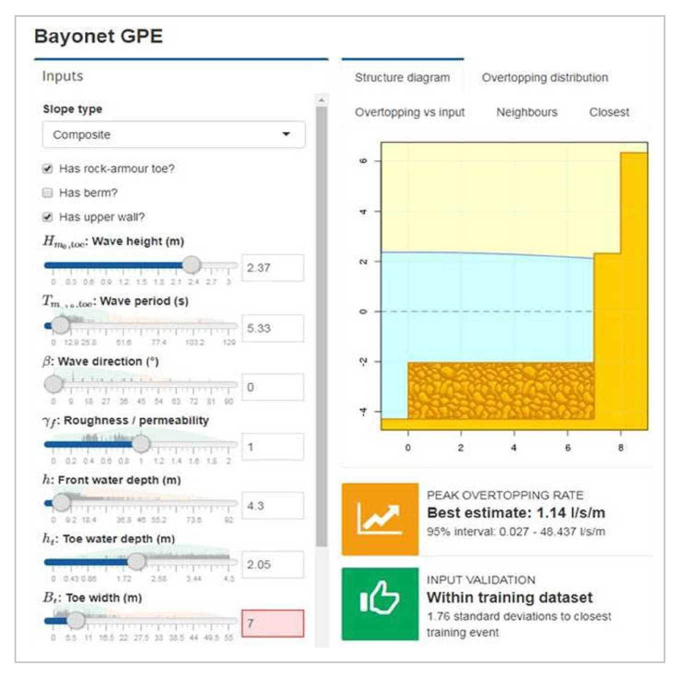
Reduction of overtopping risk is a key requirement for the design, management and adaptation of coastal structures, particularly as existing coastal infrastructure is assessed for future conditions. Economic damage, injuries, and loss of life due to the hazardous nature of wave overtopping are becoming increasing likely as we start to feel the impacts of climate change.

Practical empirical methods for calculating wave overtopping rates of structures have been applied for many years for coastal engineering design and flood risk analysis purposes. These methods are well known to contain significant sources of uncertainty. There are limitations with regard to the extent of quantitative uncertainty information that has been available to date. The GPE model addresses this by implementing a comprehensive method that takes account of a wider range of uncertainties, while improving the robustness of the mean predictions [4].

[4] Pullen et al., 2018, JMAEN 2017:31.



GPE performance figure including uncertainty



Bayonet GPE interactive dashboard

Regional scale assessment of groundwater yield

Groundwater level simulation using Multiple Linear Regression (MLR)

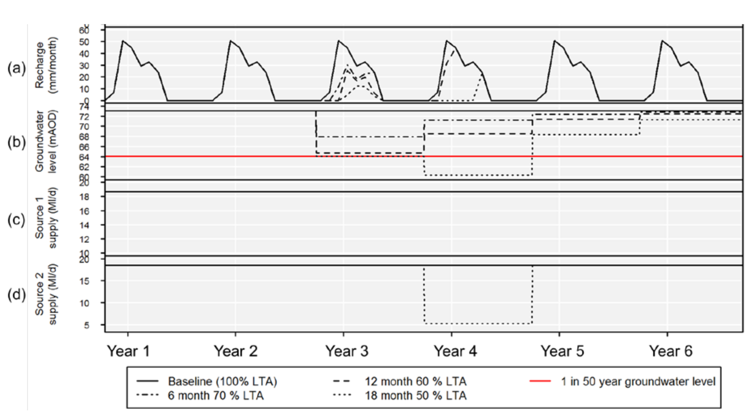
Groundwater processes are complex and physically based models can require long run times which prohibit their applicability for advanced decision making methods. Statistical groundwater models enable groundwater resources to be represented at a high level [2]. These models allow for a distinction to be drawn between dry or wet years compared with average years, and identify particular droughts of interest.

Statistical models were trained using antecedent recharge rates and groundwater level data.Meteorological droughts of specified intensity and duration were run through the model, and a reduction in groundwater levels from average conditions correlated to a reduction in groundwater yield using an empirical relationship based on observation and pumping test data [3].

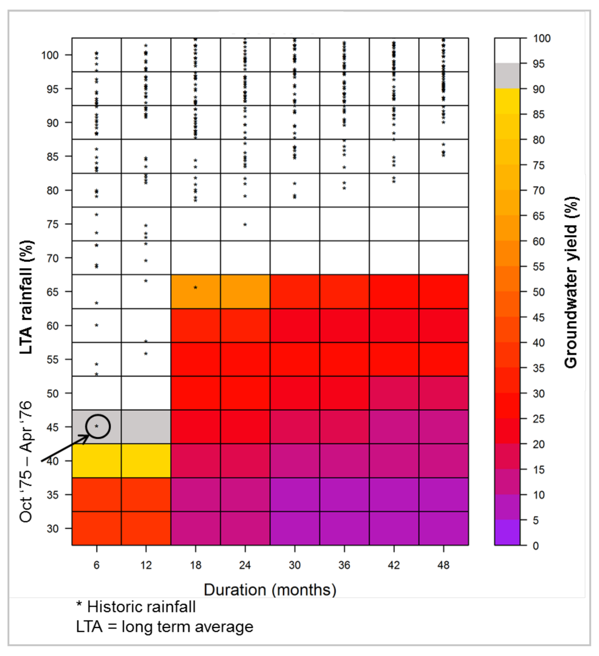
The models were systematically tested to a range of droughts, and results presented on a drought response surface. However, though the results require informed interpretation, the approach enables water resources planners to identify groundwater sources sensitive to drought, and assess the sensitivity of groundwater supply to infrastructure constraints.

[2] Bloomfield et al., 2003, WEJ 17:86.

[3] UKWIR, 2014, Handbook of source yield methodologies.



Stages of groundwater resources modelling for baseline and drought scenarios (a) Recharge time series (b) groundwater levels (c, d) resultant groundwater supply



Groundwater drought response surface with historic rainfall data

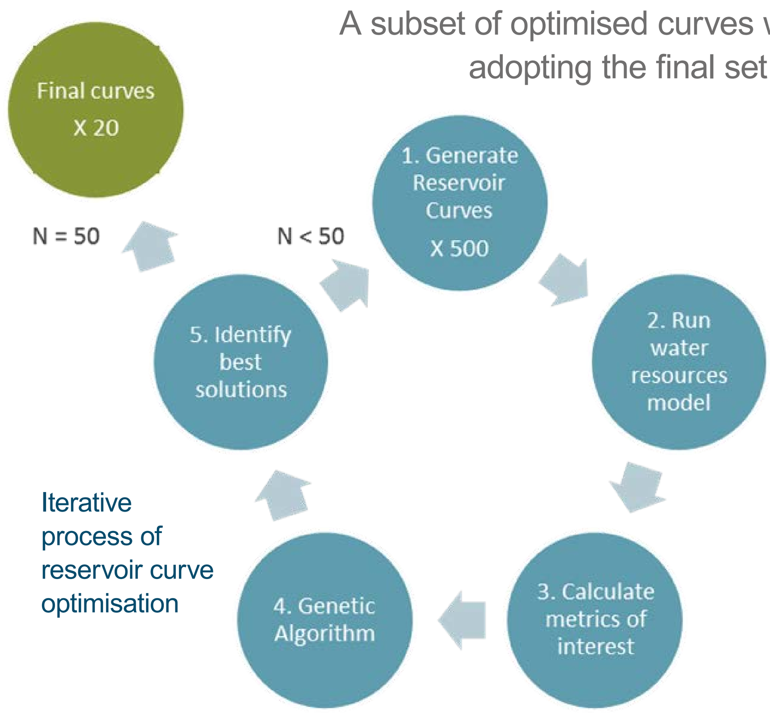
Optimise the management of reservoirs

Reservoir operation curve optimisation using a Multi-Objective Optimisation Algorithm (NSGA-II)

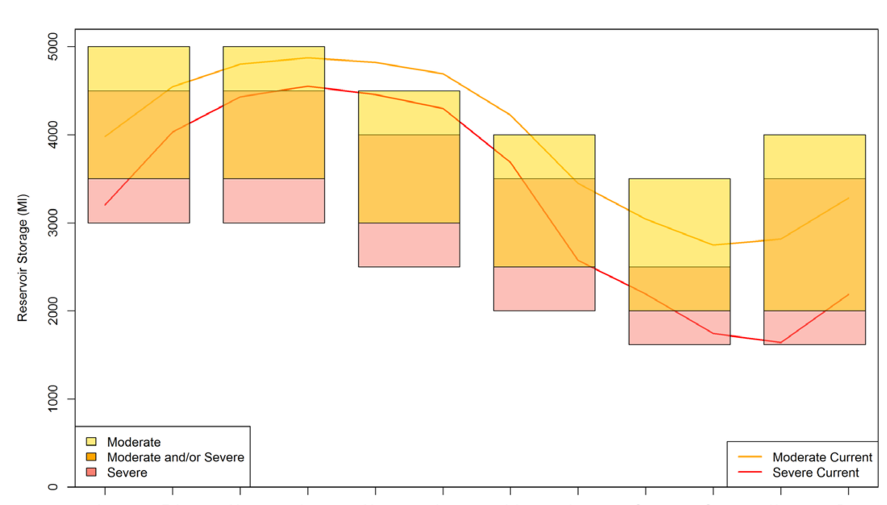
For water supply systems where both groundwater and reservoir sources are managed in combination, a holistic understanding of the system is required to minimise physical, environmental, and economic impacts. Reservoir operation curves are commonly used by water supply managers in the UK to guide the use of water restriction on customers.

A rapid simulation model was developed which balanced available sources with demand. An optimisation process was used to identify new operation curves which considered normal operational priorities, resilience to droughts beyond the historic record, the frequency and duration of water use restrictions, and the use of resources associated with potential environmental impacts.

A subset of optimised curves were reviewed collaboratively with water supply managers before adopting the final set of curves for use.



Iterative process of reservoir curve optimisation



Reservoir control curves