Climate Change Adaptation Research Grants Program
- Settlements and Infrastructure Projects

Project title:
Robust optimization of urban drought security for an uncertain climate.

Principal investigators: Professor George Kuczera
Lead organisation: University of Newcastle

Objectives:
The project will deliver:
1. A methodology for identifying different drought contingency plans that trade-off expected triple-bottom line performance against robustness in the face of uncertain future climate change;
2. A case study for the Lower Hunter urban water supply system which has been identified as vulnerable to “running out of water”.
3. System-independent software which implements the methodology and is capable of application to any urban water system.

Project design and methods:
This project will focus on developing a robust and optimal drought contingency plan and evaluating its interaction with long-term infrastructure and demand management decisions. The project plan is built around an exemplar case study that will involve developing a range of ‘climate change impacted’ runoff scenarios, building a simulation model of the water supply system using WATHNET, linking it with a multi-criterion optimization search engine and then critically evaluating the strengths and weaknesses of the proposed approach. The Lower Hunter system has been chosen for the case study. The Lower Hunter faces a particularly difficult drought security outlook. Unlike other major Australian urban systems, the Lower Hunter system harvests water from high yielding catchments and thus has relied on comparatively small annual carryover storage. As a result, it is particularly vulnerable to severe drought because there is insufficient storage to provide adequate lead-time to respond with appropriate contingencies. This has prompted Hunter Water Corporation (HWC) to develop a new yield methodology that explicitly incorporates drought security as well as the traditional level of service criteria. Currently HWC is actively investigating options to secure its system.

The project will develop a WATHNET model of the Hunter Water system and use the latest climate change scenarios available to HWC. Published climate change factors for more pessimistic scenarios such as A1Fi will also be utilised to generate a large set of scenarios reflecting uncertainty in future emissions and choice of GCM. These data will be input to HWC’s calibrated rainfall-runoff models to provide ‘climate change impacted’ monthly runoff data corresponding to each of the scenarios. To capture the climate variability and extreme drought implicitly embedded in each of these climate scenarios, a stochastic model (part of WATHNET) will be calibrated to each of the constructed climate change impacted’ monthly runoff data sets and then used to simulate 1000 replicates of 50-year synthetic streamflow time series that (a) incorporate anthropogenic climate change impacts and (b) sample droughts far more severe than experienced during the historic record. To make the optimization manageable a protocol will be developed to rank these scenarios according to impact and to guide the selection of a reduced set spanning worst to best scenarios. A critical part of the case study involves defining objectives and decision variables to be optimized. This will be negotiated with HWC (with advice from Sydney Catchment Authority) but it is expected that the objectives will include the following:
a) minimize present worth cost of major infrastructure investment, operating costs and the (economic) costs of implementing drought contingency plans;
b) minimize environmental impacts to surface and subsurface water systems; and
c) minimize disruptions to the community by minimizing the chance of triggering the drought contingency plan

To evaluate these objectives, multi-replicate simulations over a long planning horizon of 50 years, will be used. This represents a departure from the traditional simulation approach that uses a very long single replicate. This approach is necessary because it is not known when, in the future, a drought contingency plan will be triggered and whether the triggering of a such a plan will result in permanent changes to the system (eg, a desalination plant may be built in response to the threat of a severe drought; once built, it may be used as alternative source of water altering the risk profile of the system).

It is HWC policy (and indeed a stated goal of the Water Services Association of Australia) that the community should never “run out of water”. This does not mean that the community should not face restrictions on water use during severe drought but rather that the community should not be exposed to the risk of catastrophic shortages of water. Accordingly, the optimization will be steered away from any unplanned shortfall in water supply by imposing the constraint that no feasible solution can have unplanned shortfalls. Without this constraint the optimization would trade-off unplanned shortfalls against the other objectives.

A major innovation in this project is the joint consideration of the drought contingency plan and long-term infrastructure and demand management planning. In the pursuit of robust optimal solutions joint consideration is essential because the triggers for the drought contingency plan are controlled by the operating rules and infrastructure investments in the system. As a result, the decisions that have to explored in the optimization include:

1) Operating decisions: For example, defining rules that control reservoir drawdown, the timing and amount of pumping, source switching and so on;
2) Infrastructure investment decisions: For example, do we build new dams (where and how big), install rainwater tanks (how many), build desalination plants or recycle wastewater (what size and when do we use);
3) Drought contingency decisions: For example, when do we trigger interventions, what type and how severe should the intervention be. Interventions include rapid response actions (such as imposition of restrictions and, in more extreme cases, temporary closure of supply) and infrastructure-based actions seeking to provide emergency sources of water (such as desalination).

This is a complex decision space. Multi-criterion optimization is well suited to identifying the best solutions of the decision space where trade-offs and negotiations are required.
There are three major practical challenges with multi-criterion optimization:

1) It is computationally time-consuming requiring requires tens of thousands of simulations. Two strategies have been developed: the first employs parallel computing (part of the budget involves the addition of a server with 12 core processes to increase the capacity of the present parallel cluster); and the second involves smarter simulation using a technique developed by the Kuczera’s group called critical period compression (this will need further refinement during the project). Another strategy using machine learning algorithms to approximate the objective function surface is currently under investigation.
2) Our experience with multi-criterion optimization is that it involves considerable iteration in problem formulation. This primarily arises in new applications (such as this one) where there are no precedents. As solutions are obtained, it is expected that decision makers will reformulate criteria and decision variables many times over as their understanding and insight develops. This task represents a major part of the project effort.
3) Visualization of multi-criterion results, in our experience, is challenging and problem-specific. We expect to develop custom software to assist in the visualization and understanding of results.