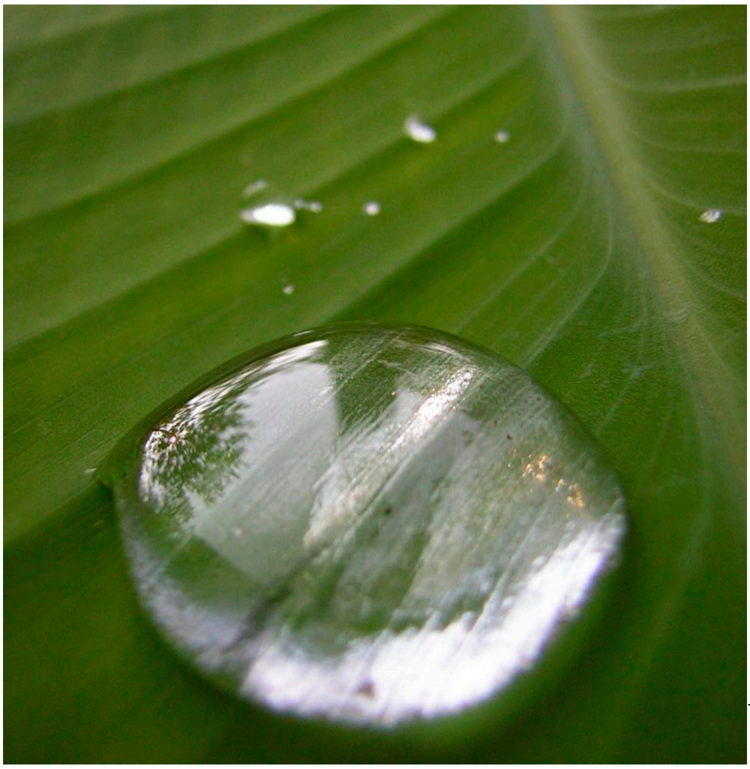
Predictive uncertainty in water resource assessments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A freshly concluded WRC project hopes to take the question mark out of water resource decision-making. Article by Prof Denis Hughes.

The statement that 'there are three kinds of lies: lies, damned lies and statistics' has been attributed to the 19th century British Prime Minister, Benjamin Disraeli (1804-1881) to convey suspicion about the use of statistical models to support arguments in the face of little data. There is little doubt that examples of the unscrupulous use of predictive models (whether statistical or other types of models) can be found throughout the history of science, however, we have also come to rely on models to organise and manage or lives.

Nowhere is this truer than with the sciences that involve natural environmental systems (including hydrology) which are complex and difficult to measure. While most hydrologists and water resource engineers would get (justifiably?) upset if their outputs were considered little better than clever statistics (and therefore no better than lies according to Disraeli), they would all be willing to admit that the outputs of their models contain uncertainties.

Uncertainty is a common feature in all walks of life – health is uncertain, wealth is uncertain, politics are uncertain, the weather is uncertain. Sometimes the uncertainty is explicitly stated, as with weather forecasts that suggest 'a 30% chance of rain', while in other situations the uncertainty has become big business (how many people regularly bet on horse races?).

Unfortunately, while there has been a long history of practical use of hydrology and water resources estimation models in South Africa, the issues associated with uncertainty have been largely neglected. In a very readable scientific journal article, Pappenberger and Beven (2006) provide some very insightful observations about why uncertainty has been neglected as well as some good justifications for why it should not be neglected in the future.

Uncertainty in the results that are generated by hydrology and water resources assessment models are derived from several sources. Firstly, the models themselves are imperfect representations of the real world and even complex models contain spatial and temporal generalisations. Secondly, the 'parameters' that are used to establish a model for a specific drainage basin or catchment are either based on the model user's knowledge and understanding of that area, or on a comparison (using model 'calibration' methods) with some limited observations of stream flow, reservoir water levels or borehole water levels. The latter may all be subject to measurement or interpretation errors. Thirdly, the models are typically driven by observed records of climate inputs (precipitation, temperature, evaporation etc) which may contain errors and may not adequately reflect the real climate inputs because of the limited number of observation stations.

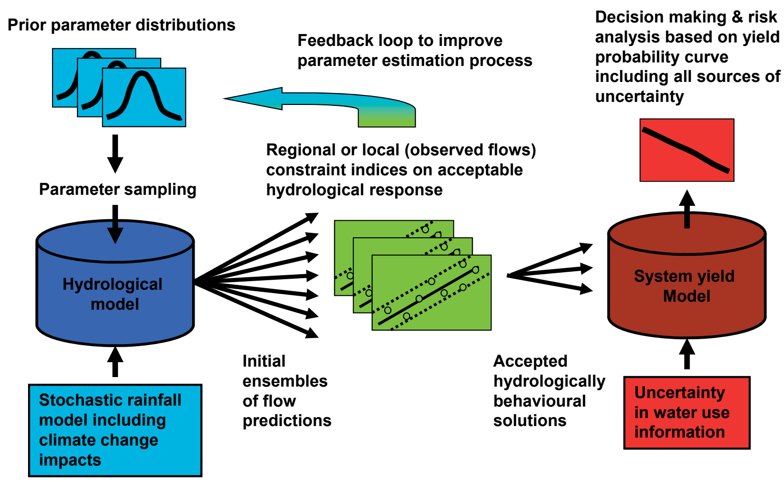
This source of uncertainty is very relevant to mountainous areas where there are large spatial variations in real rainfall and typically few rain gauges. It is also unfortunate that the density of our climate and hydrological observation networks have been shrinking in recent years and therefore the uncertainty in climate inputs to models will be greater in the future unless this trend is reversed.

Even where we have good data records there is uncertainty about whether these can be considered to represent the most extreme conditions that we can expect, even in the near future and even under static climate conditions (i.e. without the possible impacts of global warming). A final source of uncertainty lies in our imperfect knowledge of how much of the natural water resource is already being utilised. There are some situations where some or all of this information is available and can be considered accurate (low uncertainty), but there are many other situations where the degree of uncertainty is very high and yet we cannot wait to make decisions until all of other uncertainties have been reduced (if ever).

In recognition of the importance of these issues, the Water Research Commission funded a three-year project on incorporating uncertainty in water resources simulation and assessment tools in South Africa. The work was undertaken by the Institute for Water Research at Rhodes University, the School of Bioresources Engineering and Environmental Hydrology at the University of KwaZulu-Natal and IWR Water Resources. The project was designed to identify the main sources of uncertainty, establish a framework and associated modelling tools for uncertainty assessments, suggest ways of reducing uncertainty and investigate the links between uncertainty and decision-making risk in water resources planning and management.

The project was also expected to make some recommendations with regard to the future incorporation of uncertainty analyses in the standard water resources assessment methods used in practice within South Africa. The project was supported by funding from the National Research Foundation under the Key International Science Cooperation (KISC) programme which enabled Dr Thorsten Wagener from Pennsylvania State University to participate and attend the project workshops.

A framework for including uncertainty and risk analysis in water resources assessments.



One of the outcomes of the project, which has just been concluded, include new parameter estimation routines for the widely used Pitman rainfall-runoff model that include uncertainty and the generation of ensembles rather than a single sequence of stream flows. The project highlighted the need for improved understanding of the interactions between surface and groundwater and how these processes are integrated with models.

The combined use has been recommended of regional and local (based on observed stream flow data) indices of hydrological catchment response that can be used to constrain the ensemble outputs for further use in water resources assessments to those that can be considered hydrologically 'behavioural' (i.e. realistic). This approach allows for a better integration of the methods used for hydrological simulation across gauged and ungauged catchments. The use of a stochastic rainfall model to integrate climate and model parameter uncertainty was also assessed and compared with the more traditional use of stream flow stochastic generation within a water resources yield model.

The main conclusion of the project is that incorporating uncertainty in practical water resources assessments is necessary and can be achieved without any drastic changes being required to current methodologies. The potential advantages are improved objectivity in hydrological modelling, the identification of interventions that could reduce uncertainty (such as improved monitoring) and more realistic assessments of risk during the process of water resources decision-making.

There remain some questions about how to implement the proposed methods in practice, including the necessary changes to existing software tools, training in the concepts of uncertainty and the interpretation of uncertain predictions from a risk perspective. However, these issues will be addressed in the next phase of the project together with some more research orientated questions that remain unresolved. ❑

An example of yield analysis under uncertainty and an illustration of the links between uncertainty and decision-making risk.