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Climate Variability

Project 5.2: National Data Bank of Stochastic Climate and Streamflow Models

Project Leader: Prof Tom McMahon (The University of Melbourne)

Background

The considerable variation of rainfall and runoff from year to year is part of the natural variability in the climate system. The management of land and water resources involves designing and operating to cope with this variability. The management challenges in Australia are compounded by Australian streamflow (and to a lesser extent climate) that is much more variable than elsewhere in the world.

The mission of the CRC for Catchment Hydrology is to deliver to resource managers the capability to assess the hydrologic impact of land-use and water management decisions at whole-of-catchment scale. Climate is a key driver in models developed by the CRC and other groups. The goal of the Climate Variability Program is to improve our ability to quantify climate variability by developing tools that can be used with hydrological and ecological models to quantify uncertainty in environmental systems associated with climate variability.

There are two research areas in the Climate Variability Program. The aim of the first research area is to improve models for forecasting rainfall and streamflow for various lead times. The aim of the second research area is to develop and test stochastic climate data generation models.

Project objective

The objective of this project was to develop and test stochastic models for generating annual, monthly and daily rainfall (and climate and streamflow) at a site.

What is stochastic climate data? In short, stochastic data are random numbers that are modified so that they have the same characteristics (in terms of mean, variance, skew, short and long term persistencies, etc) as the historical climate data from which they are based. Each stochastic climate replicate (time series sequence) is different and has different characteristics compared to the historical data but the average of each characteristic from all the stochastic replicates is the same as the historical data.

Why do we need stochastic climate data? Using historical climate data as inputs into hydrological models provides results that are based on only one realisation of the past climate. Stochastic climate data provide alternative realisations that are equally likely to occur (can be of a different length to the historical data). Stochastic climate data can therefore be used as inputs into hydrological models to quantify uncertainty in land and water resources and environmental systems associated with climate variability (expressed as probabilistic outcomes of model simulations - see Figure 1).

COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

Published June 2004

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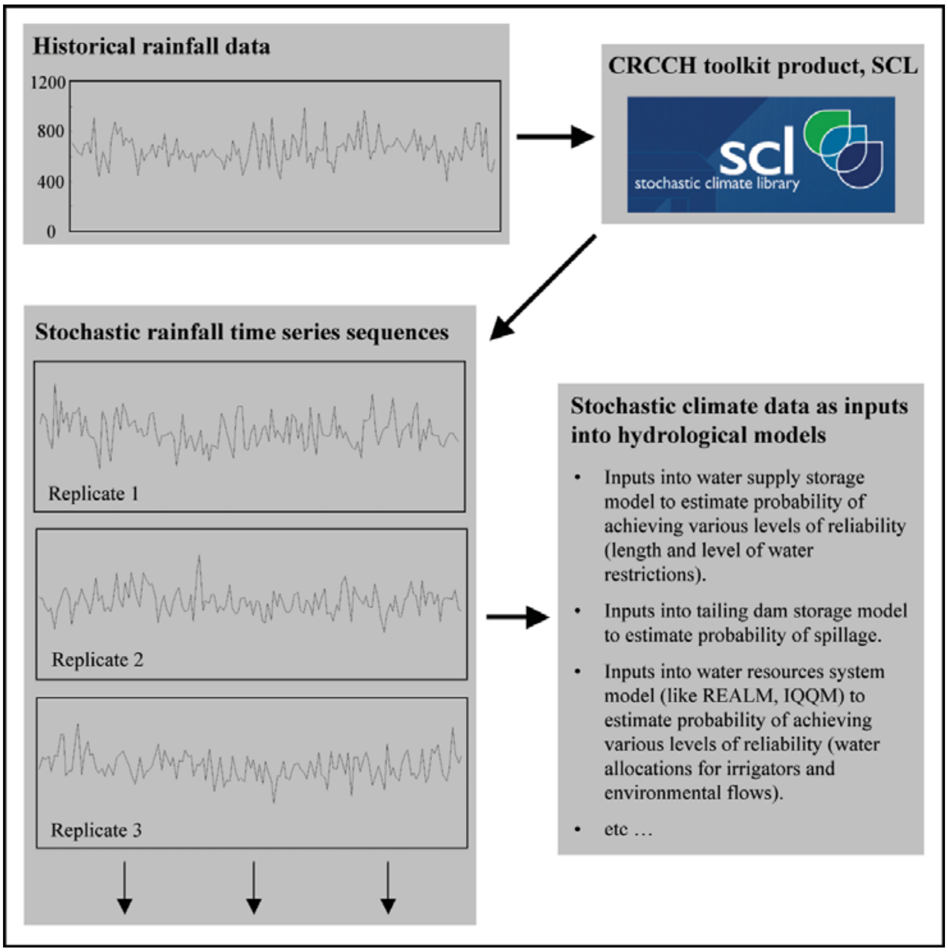

Figure 1: Using stochastic climate data as inputs into hydrological models to quantify uncertainty in hydrological systems associated with climate variability

Model Development and Testing

This project, in collaboration with researchers from University of Newcastle and University of New South Wales, has developed and tested stochastic models for generating rainfall and climate data (correlated rainfall and other climate data) at a site at annual, monthly and daily time steps. A summary of the model development and testing is given below:

- A comprehensive review of the literature on stochastic climate models was completed early in the project. The review was published as a CRC for Catchment Hydrology Technical Report 00/16 and summarised in an invited paper in the European Hydrology and Earth System Science journal.
- Three stochastic models of annual rainfall [AR1 (Lag One Autoregressive), AR1pu (AR1 with parameter uncertainty) and HSM (Hidden State Markov)] were developed/modified and tested using data from 44 locations across Australia. The results indicated that AR1pu and HSM performed satisfactorily and equally well, whilst AR1 could not reproduce the low rainfall sums of 2- and 3-year durations at some locations.
- Two stochastic models of monthly rainfall [MFM (Modified Method of Fragments) and NMM (Nonparametric Monthly Model)] were tested using data from 10 locations across Australia. Both models performed satisfactorily, but NMM was considered to be marginally better because with NMM, there is no need to define water years and there are no repetitive patterns of monthly rainfall.

- Two stochastic models of daily rainfall TPMb (Transition Probability Matrix with Boughton correction) and DMM (Simplified Daily Monthly Mixed Model)] were tested using data from 21 locations. Both models performed satisfactorily. The main advantage of TPMb over DMM is that is preserves the mean daily rainfall on different types of wet days, while DMM does not. The DMM preserves the correlation between monthly rainfalls better than TPMb.
- A comparison of runoff simulated with a calibrated daily rainfall-runoff model (SIMHYD) using daily rainfall generated by TPMb and DMM was carried out at eight Australian catchments. The results indicated that there was little difference between the modelled daily runoff characteristics using stochastic rainfall generated by the two models.
- Models for generating climate data (correlated rainfall and other climate data) were developed/modified and tested using data from ten locations. The annual climate was generated using MVM (Multivariate AR1), the monthly climate was generated using MFM (Modified Method of Fragments) and the daily climate was generated using DMA (Multivariate AR1 conditioned on rainfall state and nested in monthly and annual models). The results indicated that the daily, monthly and annual stochastic climate models (rainfall, evaporation and maximum temperature) could reproduce the statistics of the historical data at the ten sites satisfactorily.

The model testing indicated that in general, from a hydrological modelling perspective, the differences between the better stochastic models are marginal.

Further information:

Results from the model development and testing have been presented in local and international meetings, as well as published in seven CRC for Catchment Hydrology technical reports and five CRC working documents. The references to these reports on model development and testing and detailed descriptions of the models can be found in the CRC Technical Report 03/16; Stochastic Models for Generating Annual, Monthly and Daily Rainfall and Climate Data at a Site by Ratnasingham Srikanthan and Francis Chiew (2003). The report can be downloaded as an Adobe .pdf file from www.catchment.crc.org.au/publications.

Stochastic Climate Library (SCL)

The appropriate stochastic climate models developed and tested as part of this project are now part of the SCL (Stochastic Climate Library) software, a product that is available through the Catchment Modelling Toolkit web site at www.toolkit.net.au/scl

SCL is a library of stochastic climate models, designed for hydrologists, environmental scientists and modellers to facilitate the generation of stochastic climate data. SCL is easy to use and is based on relatively robust stochastic data generation models. SCL requires a continuous time series as input data. SCL provides outputs of the stochastically generated climate data, compares the means and percentiles of various statistics of the generated data with those of the historical data, and provides an overall assessment of the quality of the stochastically generated data.

Figure 2 shows the types of stochastic data that can be generated using existing models in SCL, and other types of stochastic models that will be added to future versions of SCL (2003-2006). Current research efforts are concentrating on developing and testing multi-site (spatial) daily rainfall models and single-site sub-daily rainfall models, as well as improving some of the models that are currently in SCL.

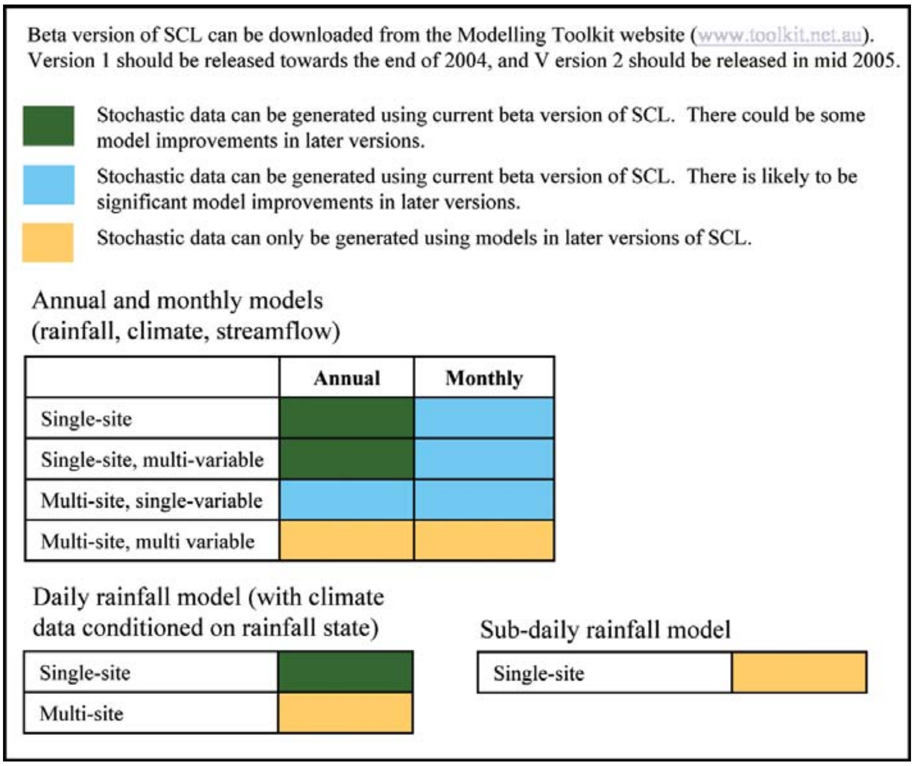

Figure 2: Stochastic climate models in SCL (Stochastic Climate Library)

Space-Time Stochastic Design Rainfall

The Climate Variability Program has also developed a space-time rainfall model called MOTIVATE, which generates stochastic sequences (10 minutes or less) of spatial rainfall (down to 1 km) i.e. the equivalent of radar rainfall measurements) for a given mean areal rainfall and storm duration. MOTIVATE is based on a multiplicative cascade concept, where rainfall is characterised by variability over a wide range of scales and the temporal evolution of a feature in a rain field is dependent on scale.

MOTIVATE is particularly useful for providing stochastic realisations of design storms. Melbourne Water and Sydney Water recently used 1 in 5 year stochastic space-time rainfall generated by MOTIVATE as inputs into their models to assess their sewerage network design.

The MOTIVATE software allows for the generation of stochastic space-time rainfall using default parameters (for Melbourne, Sydney, Darwin and Brisbane), as well as automatic calibration against radar rainfall data.

Acknowledgements

Project 5.2 Researchers:

Francis Chiew, Tom McMahon, Lionel Siriwardena, Sri Srikanthan, Senlin Zhou

Other Researchers and Project 5.2 Reviewers:

Tom Chapman, George Kuczera, Rory Nathan, Geoff Pegram, Alan Seed, Ashish Sharma, Mark Thyer