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Evaluating stochastic weather generators for simulating hydrological extremes

Fiona Johnson[a], Ze Jiang[a] and Clare Stephens[b]

[a] *Water Research Centre, School of Civil and Environmental Engineering, University of New South Wales, Sydney, 2052, Australia*
[b] *Hawkesbury Institute for the Environment, Western Sydney University, Richmond, 2753, Australia*
Email: f.johnson@unsw.edu.au

Abstract: Stochastic weather generators (SWGs) have been widely used for some time to simulate meteorological inputs for hydrological and agricultural modelling and water engineering design (Wilks and Wilby, 1999). They are also used for scenario neutral or bottom up approaches to climate change impact assessments (Steinschneider and Brown, 2013). However, their ability to accurately reproduce rainfall variability across multiple time scales remains a critical challenge, particularly when modelling hydrological extremes. This study evaluates three single-site multivariate SWGs—WGEN (Richardson and Wright, 1984), the Stochastic Climate Library (SCL) model (Srikanthan and Chiew, 2003), and ARMA-WGEN (Steinschneider and Brown, 2013) which generated long-term daily rainfall and evapotranspiration data across 153 Australian catchments. These synthetic datasets were used to drive two conceptual rainfall-runoff models: GR4J (Perrin et al., 2003) and AWBM (Boughton, 2004).

We assessed the performance of each SWG using conventional statistical metrics and wavelet power spectrum analysis to capture biases in rainfall variability across time scales ranging from daily to annual. Results show that WGEN variants consistently underestimate rainfall variance and annual maxima, leading to substantial underestimates of extreme flows. In contrast, SCL and ARMA-WGEN better preserve rainfall variability, with SCL showing improved performance in simulating annual maximum flows due to its nested structure that captures multi-scale variability.

Wavelet analysis reveals that all SWGs struggle to reproduce rainfall variability at sub-monthly and annual scales, which are critical for simulating hydrological extremes. These deficiencies propagate through hydrological models, resulting in substantial biases in streamflow simulations—particularly in annual maximum flow statistics. The study highlights the importance of both short-term persistence and long-term variability in rainfall generation for reliable hydrological modelling.

Our findings underscore the need for careful selection and evaluation of SWGs in climate impact assessments and stress testing of water resource systems. Future work should explore the interaction between SWG structures and hydrological model sensitivities, especially under changing climate conditions where extreme events are expected to intensify.

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