Stochastic watershed models for generating streamflow ensembles

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Deterministic watershed models (DWM) are used in nearly all hydrologic planning, design, and management activities, yet they cannot generate streamflow ensembles needed for long term hydrologic risk management (HRM) nor can they properly reproduce extreme design quantiles obtained from commonly accepted statistical methods. The stochastic component of DWMs which is often ignored in practice, leads to systematic bias in extreme events. Since traditional stochastic streamflow models used in HRM struggle to account for anthropogenic change, there is a need to convert DWMs into stochastic watershed models (SWM) to generate ensembles for use in HRM and also to employ those ensembles to obtain design quantiles which are an improvement over biased estimates obtained from a DWM. A DWM can be converted to a SWM using a post processing (pp) approach to add error to the DWM predictions. Many pp methods advanced in the area of flood forecasting are also useful in long term HRM and for correcting extreme event biases. Selecting a suitable watershed model error model for pp is challenging due to nonnormality, skewness, heteroscedasticity, autocorrelation and heavy tails. We employ a parsimonious pp method based on an autoregressive (AR) model of the logarithm of the ratio of the observations and simulations, which leads to AR model residuals which are approximately symmetric, homoscedastic, and independent. We document the value of pp for improving flood and low flow frequency analysis and we reintroduce the concepts of verification and validation of stochastic streamflow ensembles to ensure that the SWM can reproduce both statistics it was and was not designed to reproduce, respectively. These concepts are illustrated on a Massachusetts basin, and at 1225 other sites across the U.S., using the deterministic USGS Precipitation Runoff Modeling System.