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Efficient representation of the hydrological state in Stochastic Dynamic Programming: transition probabilities considering persistence in future inflows scenarios

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A current trend in stochastic dynamic programming applications in water resources systems involves consideration of several hydrologic state variables.

We present a scenario-based approach that allows avoiding inclusion of all the hydrologic state variables in the state vector, which alleviates the computational burden incurred when discretizing the state space. We consider just one hydrologic variable, namely an identifier of the current scenario out of a previously defined ensemble. Specifically, our approach considers transition probabilities between current and future scenarios at each stage, unlike classical SDP approaches where the transitions are set between current scenarios and next-stage states.

This approach is particularly useful when dealing with many random inflows whose dynamics is represented using higher-order Markovian models which results in an exponential growth of the number of possible states.

The calculation of transition probabilities between scenarios is based on Bayesian theory and requires an analytical expression of the underlying stochastic process associated to the inflows, which we calibrate statistically. Scenarios can be obtained either from a model or sampled from the historical record.

We identify a case where the calculation of transition probabilities is tractable: when the Markovian model is linear and the stochastic component at each stage is additive and independent. These conditions are met when considering the wide family of autoregressive and moving average models, broadly utilized in hydrology for the generation of synthetic series.

The proposed approach is implemented within a Stochastic Dual Dynamic Programming (SDDP) model, commonly used for multi-reservoir systems. As a base case, we consider transitions between scenarios to be equally likely. This implicitly assumes independent inflows between consecutive stages (i.e. hydrologic process with no persistence).

As a case study, we identify optimal operation policies (in the expected-value sense) for La Paloma irrigation system in Chile, which consists of three reservoirs, with target releases decided at the beginning of two seasons in the year: winter and summer.

In our formulation, we consider three operational objectives: (i) maximize the average yield, (ii) minimize deficits from target releases, and (iii) minimize spillages. Pareto front solutions are then obtained using different combinations of weights on the objective function.

The results of the optimization show that some policies achieve improvements up to 18% in releases when compared to the base case. Also, for almost every policy, summer spillages decrease while winter ones tend to increase to a lesser extent, which means they are distributed more evenly through the year. Additional analysis show improvements up to 20% in releases and reduced spillages in both seasons when comparing with the current operation of La Paloma system.