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Optimal reservoir operation policies using novel nested algorithms

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Historically, the two most widely practiced methods for optimal reservoir operation have been dynamic programming (DP) and stochastic dynamic programming (SDP). These two methods suffer from the so called “dual curse” which prevents them to be used in reasonably complex water systems. The first one is the “curse of dimensionality” that denotes an exponential growth of the computational complexity with the state – decision space dimension. The second one is the “curse of modelling” that requires an explicit model of each component of the water system to anticipate the effect of each system’s transition.

We address the problem of optimal reservoir operation concerning multiple objectives that are related to 1) reservoir releases to satisfy several downstream users competing for water with dynamically varying demands, 2) deviations from the target minimum and maximum reservoir water levels and 3) hydropower production that is a combination of the reservoir water level and the reservoir releases.

Addressing such a problem with classical methods (DP and SDP) requires a reasonably high level of discretization of the reservoir storage volume, which in combination with the required releases discretization for meeting the demands of downstream users leads to computationally expensive formulations and causes the curse of dimensionality.

We present a novel approach, named “nested” that is implemented in DP, SDP and reinforcement learning (RL) and correspondingly three new algorithms are developed named nested DP (nDP), nested SDP (nSDP) and nested RL (nRL). The nested algorithms are composed from two algorithms: 1) DP, SDP or RL and 2) nested optimization algorithm. Depending on the way we formulate the objective function related to deficits in the allocation problem in the nested optimization, two methods are implemented: 1) Simplex for linear allocation problems, and 2) quadratic Knapsack method in the case of nonlinear problems. The novel idea is to include the nested optimization algorithm into the state transition that lowers the starting problem dimension and alleviates the curse of dimensionality. The algorithms can solve multi-objective optimization problems, without significantly increasing the complexity and the computational expenses. The algorithms can handle dense and irregular variable discretization, and are coded in Java as prototype applications.

The three algorithms were tested at the multipurpose reservoir Knezevo of the Zletovica hydro-system located in the Republic of Macedonia, with eight objectives, including urban water supply, agriculture, ensuring ecological flow, and generation of hydropower. Because the Zletovica hydro-system is relatively complex, the novel algorithms were pushed to their limits, demonstrating their capabilities and limitations. The nSDP and nRL derived/learned the optimal reservoir policy using 45 (1951-1995) years historical data. The nSDP and nRL optimal reservoir policy was tested on 10 (1995-2005) years historical data, and compared with nDP optimal reservoir operation in the same period. The nested algorithms and optimal reservoir operation results are analysed and explained.