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An inverse nested approach to optimize planning and operation of water reservoir systems

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In the water resources management scientific literature and practice, planning (i.e. reservoir sizing) and management (i.e. reservoir operation) are generally considered as two distinct problems to be solved separately. Within the infrastructure design domain, several methods are proposed for designing the reservoir's capacity assuming basic, pre-defined operating policies. To ensure reliable water supply performance, most of these approaches identify over-sized reservoirs. An alternative approach is to explicitly formalize the interdependency between planning and management as a two-stage optimization procedure, nesting an optimal dynamic control problem for designing the optimal control policy into a global static optimization routine, which explores the space of the reservoir's capacity. This approach is, however, computationally intensive as it requires solving an optimal control problem for each candidate reservoir's capacity.

In this work, we contribute an inverse nested approach, which first optimizes a single control policy parametric with respect to the reservoir's capacity and, then, searches the best sizing under its optimal operations as provided by the parametric policy previously designed. The proposed approach relies on a novel algorithm, called Planning Fitted Q-Iteration (pFQI), which extends the batch mode reinforcement learning Fitted Q-Iteration (FQI) algorithm by operating in an enlarged state-action space that includes the planning decision space. This allows determining - in a single learning process - a continuous approximation of the optimal action-value function over the reservoir's capacity domain, i.e. a single control policy that is optimal for all the candidate reservoir's capacities. The method is demonstrated on a numerical problem of dam sizing, where the reservoir must be designed and operated to supply an irrigation water demand while minimizing the dam construction cost. Numerical results suggest that the pFQI algorithm is able to identify Pareto optimal solutions (i.e. reservoir size and associated operations) that dominate the ones calculated via traditional reservoir sizing techniques. Moreover, we also show that pFQI allows halving the computational requirements of a standard nested method at the cost of a 1% reduction in terms of system performance.