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Estimating the economic opportunity cost of water use with river basin simulators in a computationally efficient way

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The marginal opportunity cost of water refers to benefits forgone by not allocating an additional unit of water to its most economically productive use at a specific location in a river basin at a specific moment in time. Estimating the opportunity cost of water is an important contribution to water management as it can be used for better water allocation or better system operation, and can suggest where future water infrastructure could be most beneficial.

Opportunity costs can be estimated using 'shadow values' provided by hydro-economic optimization models. Yet, such models' use of optimization means the models had difficulty accurately representing the impact of operating rules and regulatory and institutional mechanisms on actual water allocation. In this work we use more widely available river basin simulation models to estimate opportunity costs. This has been done before by adding in the model a small quantity of water at the place and time where the opportunity cost should be computed, then running a simulation and comparing the difference in system benefits. The added system benefits per unit of water added to the system then provide an approximation of the opportunity cost. This approximation can then be used to design efficient pricing policies that provide incentives for users to reduce their water consumption. Yet, this method requires one simulation run per node and per time step, which is demanding computationally for large-scale systems and short time steps (e.g., a day or a week). Besides, opportunity cost estimates are supposed to reflect the most productive use of an additional unit of water, yet the simulation rules do not necessarily use water that way.

In this work, we propose an alternative approach, which computes the opportunity cost through a double backward induction, first recursively from outlet to headwaters within the river network at each time step, then recursively backwards in time. Both backward inductions only require linear operations, and the resulting algorithm tracks the maximal benefit that can be obtained by having an additional unit of water at any node in the network and at any date in time. Results 1) can be obtained from the results of a rule-based simulation using a single post-processing run, and 2) are exactly the (gross) benefit forgone by not allocating an additional unit of water to its most productive use. The proposed method is applied to London's water resource system to track the value of storage in the city's water supply reservoirs on the Thames River throughout a weekly 85-year simulation. Results, obtained in 0.4 seconds on a single processor, reflect the environmental cost of water shortage. This fast computation allows visualizing the seasonal variations of the opportunity cost depending on reservoir levels, demonstrating the potential of this approach for exploring water values and its variations using simulation models with multiple runs (e.g. of stochastically generated plausible future river inflows).