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Optimizing basin-scale coupled water quantity and water quality man-agement with stochastic dynamic programming

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Few studies address water quality in hydro-economic models, which often focus primarily on optimal allocation of water quantities. Water quality and water quantity are closely coupled, and optimal management with focus solely on either quantity or quality may cause large costs in terms of the oth-er component. In this study, we couple water quality and water quantity in a joint hydro-economic catchment-scale optimization problem. Stochastic dynamic programming (SDP) is used to minimize the basin-wide total costs arising from water allocation, water curtailment and water treatment.

The simple water quality module can handle conservative pollutants, first order depletion and non-linear reactions. For demonstration purposes, we model pollutant releases as biochemical oxygen demand (BOD) and use the Streeter-Phelps equation for oxygen deficit to compute the resulting min-imum dissolved oxygen concentrations. Inelastic water demands, fixed water allocation curtailment costs and fixed wastewater treatment costs (before and after use) are estimated for the water users (agriculture, industry and domestic). If the BOD concentration exceeds a given user pollution thresh-old, the user will need to pay for pre-treatment of the water before use. Similarly, treatment of the return flow can reduce the BOD load to the river. A traditional SDP approach is used to solve one-step-ahead sub-problems for all combinations of discrete reservoir storage, Markov Chain inflow clas-ses and monthly time steps. Pollution concentration nodes are introduced for each user group and untreated return flow from the users contribute to increased BOD concentrations in the river. The pollutant concentrations in each node depend on multiple decision variables (allocation and wastewater treatment) rendering the objective function non-linear. Therefore, the pollution concen-tration decisions are outsourced to a genetic algorithm, which calls a linear program to determine the remainder of the decision variables. This hybrid formulation keeps the optimization problem computationally feasible and represents a flexible and customizable method.

The method has been applied to the Ziya River basin, an economic hotspot located on the North China Plain in Northern China. The basin is subject to severe water scarcity, and the rivers are heavily polluted with wastewater and nutrients from diffuse sources. The coupled hydro-economic optimiza-tion model can be used to assess costs of meeting additional constraints such as minimum water qual-ity or to economically prioritize investments in waste water treatment facilities based on economic criteria.