Optimizing conjunctive use of surface water and groundwater resources with stochastic dynamic programming

Claus Davidsen (1,2,3), Suxia Liu (2), Xingguo Mo (2), Dan Rosbjerg (1), and Peter Bauer-Gottwein (1)

(1) Technical University of Denmark, Department of Environmental Engineering, DK-2800 Kgs. Lyngby, Denmark, (2) Chinese Academy of Sciences, Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Beijing, 100101, China, (3) Sino-Danish Center for Education and Research (SDC), DK-8000 Aarhus C, Denmark

Optimal management of conjunctive use of surface water and groundwater has been attempted with different algorithms in the literature. In this study, a hydro-economic modelling approach to optimize conjunctive use of scarce surface water and groundwater resources under uncertainty is presented. A stochastic dynamic programming (SDP) approach is used to minimize the basin-wide total costs arising from water allocations and water curtailments. Dynamic allocation problems with inclusion of groundwater resources proved to be more complex to solve with SDP than pure surface water allocation problems due to head-dependent pumping costs. These dynamic pumping costs strongly affect the total costs and can lead to non-convexity of the future cost function.

The water user groups (agriculture, industry, domestic) are characterized by inelastic demands and fixed water allocation and water supply curtailment costs. As in traditional SDP approaches, one step-ahead sub-problems are solved to find the optimal management at any time knowing the inflow scenario and reservoir/aquifer storage levels. These non-linear sub-problems are solved using a genetic algorithm (GA) that minimizes the sum of the immediate and future costs for given surface water reservoir and groundwater aquifer end storages. The immediate cost is found by solving a simple linear allocation sub-problem, and the future costs are assessed by interpolation in the total cost matrix from the following time step. Total costs for all stages, reservoir states, and inflow scenarios are used as future costs to drive a forward moving simulation under uncertain water availability. The use of a GA to solve the sub-problems is computationally more costly than a traditional SDP approach with linearly interpolated future costs. However, in a two-reservoir system the future cost function would have to be represented by a set of planes, and strict convexity in both the surface water and groundwater dimension cannot be maintained. The optimization framework based on the GA is still computationally feasible and represents a clean and customizable method.

The method has been applied to the Ziya River basin, China. The basin is located on the North China Plain and is subject to severe water scarcity, which includes surface water droughts and groundwater over-pumping. The head-dependent groundwater pumping costs will enable assessment of the long-term effects of increased electricity prices on the groundwater pumping. The coupled optimization framework is used to assess realistic alternative development scenarios for the basin. In particular the potential for using electricity pricing policies to reach sustainable groundwater pumping is investigated.