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Optimizing water resources allocation in the Haihe River basin under groundwater sustainability constraints

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Economic development has increased the pressure on China's natural resources for decades, and water management is a current challenge. One of the regions experiencing severe environmental consequences of economic development is the Haihe River basin. Declines in groundwater storage and deterioration of surface water quality have been the reality of past decades. Hydroeconomic models can serve as decision support tools for identifying optimal water resource management strategies. This study applies a multi-objective, multi-temporal deterministic hydroeconomic optimization approach to quantify the economic trade-offs when reducing groundwater abstraction to sustainable levels in the Haihe River basin. A complex basin representation, with ∼140.000 decision variables, is formulated where each decision variable represents a flow-path from a water source to a sink. Available water sources are runoff generated by the sub-basins upstream the nine major surface water reservoirs, the inter-basin transfers from Yellow River and South to North Water Transfer Project (SNWTP) and the natural groundwater recharge to the three main groundwater aquifers. Water demands, i.e. sinks, are aggregated for each model sub-basin in categories of the major agricultural users, domestic, industrial and ecological water demands. Each demand is associated with a curtailment cost. Abstraction of groundwater is associated with a pumping cost. Groundwater overdraft is constrained in each model scenario, ranging from unlimited overdraft in the plain area groundwater aquifer to sustainable abstractions over an eight year period. The model identifies the sub-basins with the highest increase in average water resources shadow prices, indicating where in Haihe River basin water resources will be most valuable under limited groundwater overdraft. Inter-basin transfers are found to play a key role in limiting groundwater overdraft in Haihe River basin. Temporally, the shadow prices of water sources reveal when and which users are curtailed if water resources are managed in the most optimal way. Adding water quality constraints to the water management problem changes the resulting optimal allocation patterns. The costs of supplying sufficiently clean water is considered by adding cleaning costs to meet user- specific quality requirements, in accordance with the Chinese water quality standards. The economic trade-offs and optimal management in a joint water quality and quantity optimization can be found. Further scenario analysis addresses water infrastructure investments such as the impacts of cleaning surface water reservoirs and constructing new parallel channels carrying clean water sources.