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Optimal Groundwater Management using Discrete, Stochastic Optimization – Methodology and Application to the North-West Sahara Aquifer System

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Traditional, gradient-based optimization techniques in groundwater management problems overly restrict the allowed complexity of the optimization problem. The development of recent multi-objective evolutionary optimization algorithms and their capability of successfully handling complex simulation-optimization models motivated the development of a multi-objective groundwater management tool. Under the assumption of given time-varying demand at specified locations, this tool is capable to identify a set of Pareto-optimal location-allocation strategies. This set is particularly useful in problems where conflicting management goals are present and no single optimal solution exists. Such is for example the case in the utilization of a common property resource. The set provides a base for negotiation with the ability of a quantification of tradeoffs.

In our approach, groundwater provision costs for each demand location determine the multi-objective goal function. From a given set of pumping locations and for each demand location, conveyance networks are defined by which the pumped water is transported. Costs then are composed of installation and nonlinear running costs that incur due to the pumping and the conveyance of groundwater. Furthermore, a heuristics that relocates boreholes once a drawdown or gradient constraint at a certain location is no longer fulfilled is presented. The heuristics also ensures that already installed boreholes can be activated again after a certain head recovery. Mutation and variation operators are operating on pumping location and pumping time series.

Consequently, the simulation-optimization model is applied to The North-West Sahara Aquifer System (NWSAS), one of the largest groundwater systems of the world. It

consists of two main aquifers, the Terminal Complex and the underlying Intercalary Continental, and covers in total an area of more than 106 km^2. Present day recharge is limited in quantity and only of local relevance. The bulk of the water pumped from the system is utilized for the irrigation of approximately 14'000 km^2 of agricultural land in Algeria, Tunisia and Libya. The present situation can be characterized as fossil groundwater mining, the total abstraction being 80 – 100 m^3/s.

Two different location-allocation strategies in the context of the NWSAS are ranked against a non-cooperative Status Quo-strategy. The Perpetuation-strategy is one where the decision-makers cooperate on freely distributing demand over existing infrastructure, irrespective of national borders. The Imaginary future-strategy is one where existing water provision infrastructure is refuted and optimal location-allocation patterns are sought from scratch.

Model results show that the latter strategies cause excessive costs compared to the former two. Furthermore, average per unit water provision prices in the year 2050 up to one order of magnitude smaller for the Perpetuation-strategy compared with the Status Quo-strategy. Therefore, it appears to be individually rational for the Northern African decision-makers to implement optimal Perpetuation strategies. They are characterized by intelligent scheduling, i.e. intermitting pumping stress between boreholes and aquifers, upon the existing and required future infrastructure. Over the optimization time horizon of 50 years, demand can be covered without the large-scale renewal of groundwater provision infrastructure. Due to the threat of salination in the great salt lakes region of the central NWSAS basin, transboundary cooperation between Algeria and Tunisia would be beneficiary. Due to the size of the resource however, large volume transboundary water transfers do not result from optimization and each country has enough options to cover its demand under cost-minimizing behavior on its own territory during the next 50 years.