A framework for transient behavior restriction in WHPA delineation: A dynamic multiobjective approach

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November 13, 2017

In most engineering solutions, Wellhead Protection Areas (WHPAs) are delineated assuming a steady-state environment. However by using this assumption, any change in well catchment outline due to nature's transient behavior or anthropogenic causes such as dynamic pumping rates are neglected.

In order to reduce the influence from such transient drivers, and, thus to make steady-state WHPAs robust against dynamic environments, we propose an engineered pumping management scheme that optimally adapts pumping and injection rates while at the same time considering additional pumping well management issues. We solve our optimization problem using multi-objective optimization (MOO) concepts in order to search for compromise solutions that consider at least three objectives: 1) to minimize groundwater abstraction from outside of a given WHPA, 2) to maximize groundwater supply and 3) to minimize the involved operation costs. For groundwater flow simulation and catchment tracking, an available groundwater model coupled with a Lagrangian particle tracking solution is used.

For purposes of illustrating our multi-objective approach, Figure 1 shows for an arbitrarily chosen time step of the optimization, the set of non-dominated solutions known as Pareto Front, that account for the aforementioned three objectives. For the Costs and Groundwater supply axes, the Pareto solutions are normalized to an interval [0, 1] considering their lowest and highest magnitudes. In the case of the areal demand axis, we use the percentage of actually used catchment area that exceeds the delineated WHPA. Thus, the lowest axis limits at 0%, representative of the prescribed WHPA. For the highest axis limit, we use the maximal that may ever occurs during one year of pumping management. Additionally, we display in blue those solutions that fulfill current groundwater demand while in red those alternatives that represent water shortage. Obviously, those solutions that express sufficient groundwater supply will be the ones that define greater areal demand, and vice versa.

As the optimal solutions evolve over time, the decision maker will have to select from the Pareto front the manage scheme to actually utilize. For example, if there is such a hard constraint to never exceed the current steady-state WHPA, linking together all solutions that represent 0% increment, here displayed in black, would form the decision path to follow. However, this will have a great impact on groundwater supply, as we can see, since it defines the lowest groundwater supply solution. Additionally, we investigate how to select the most appropriate solution among the Pareto alternatives, by means of a subordinated Multi Criteria Decision Analysis that adds further objectives such as a minimally fluctuating pumping regime.

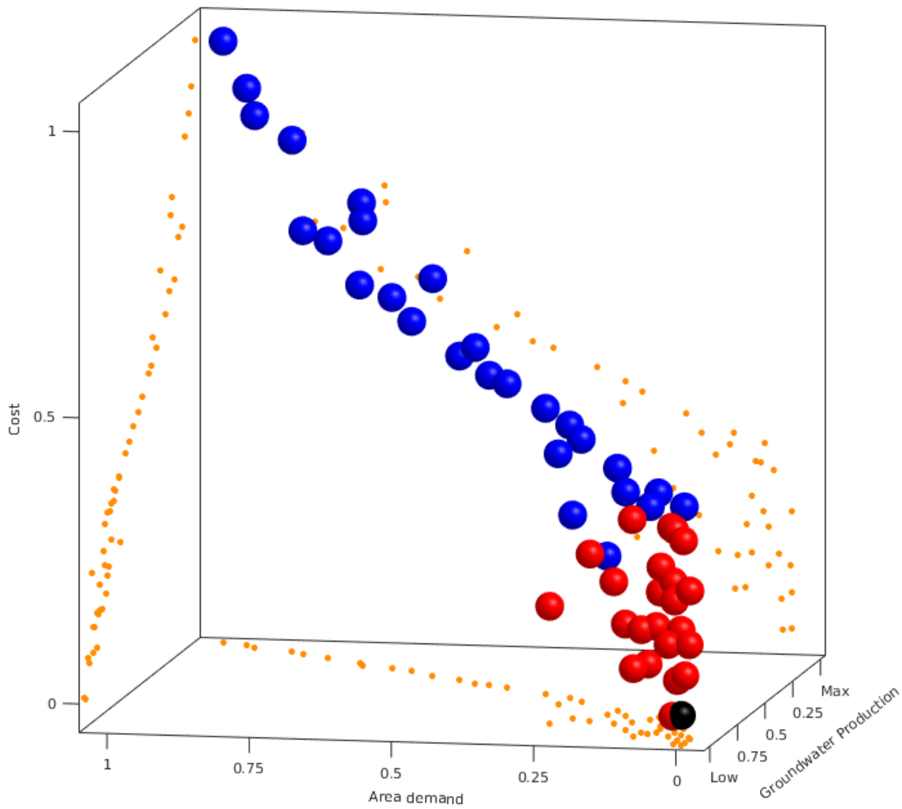

Figure 1: Illustration of multi-objective optimization results from an arbitrarily chosen time step. The blue Pareto solutions describe those alternatives supplying sufficient groundwater while in red those representing groundwater shortage

Finally, we investigate and compare a sub-optimal, though computationally less expensive approach: we implement a so called Robust over-time MOO analysis for pumping injection solutions that remain constant for longer time periods, it provides a less fluctuating WHPA management alternative while skipping many time steps in the optimization.