Stochastic Multiobjective Management of Groundwater Supply Systems

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Abstract. A typical management problem associated with the development of groundwater resources involves the design of pumping schemes the maximize benefits while meeting a series of economical, technical and environmental constraints. Groundwater flow models combined with optimization algorithms are used to tackle this management problem, which is usually solved deterministically, that is, assuming perfect knowledge of the subsurface system. However, it is widely recognized that, due to scarcity of information on hydrogeological settings, parameter distributions, boundary and initial conditions, stochastic modeling approaches are often more appropriate. In general, since the implementation of a pumping strategy assessed based on uncertain hydrogeological parameters leads to a decision involving the risk of not meeting the design constraints, operations may be designed trough a multi-objective optimization framework that considers the tradeoffs between the benefit and the reliability of the groundwater supply system.

In this work, an innovative stochastic multiobjective framework for optimizing the design and the management groundwater supply systems in the presence of parameter uncertainty is advanced. The objective is the determination of pumping strategies that minimize the total cost of the water supply system, while meeting a prescribed demand and minimize the probability of violating limitations imposed on aquifer drawdown. The fundamental components of the framework are: a three-dimensional finite element saturated flow model to calculate the aquifer response to pumping; a stochastic simulator of multivariate random processes to generate spatial distributions of the uncertain aquifer parameters, e.g. hydraulic conductivity; a niched Pareto genetic algorithm (NPGA) for the solution of unconstrained multi-objective optimization problems.

A rigorous solution to this multiobjective optimization problem would require the NPGA to be combined with a stochastic groundwater flow model, used to calculate the management objectives as a function of any given pumping scheme. Because of the overwhelming computational effort involved, a "response surface" model must be introduced to estimate the objective functions. The response surface model used here stems from the development of matrices that relate the pumping rates for a number of potential well locations to the drawdown at the same locations. These "response matrices" are calculated from a series stochastic flow simulations using unit pumping rates at each candidate well. In the case of confined aquifers subject to most common boundary conditions, there exists a linear relationship between pumping rates and drawdown. In these instances, the response surface model obtained with this approach represents an exact solution.

In the investigated problem, two approaches are analyzed for addressing the tradeoff cost vs. reliability: in one case the reliability is estimated in terms of the probability of drawdown violation; in another, the reliability is assessed from the average intensity of drawdown violation. The analysis of the two approaches indicates that averaging violations can account not only for their frequency, as the probability of failure does, but also for the intensity with which they occur. Ultimately, the average drawdown violation method allows for considering less restrictive pumping policies.

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