Optimization Approaches for the Management of Groundwater Supply Systems under Parameter Uncertainty

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Abstract. Typical groundwater supply management problems involve the design of pumping schemes that fulfill current water needs while meeting a set of economical constraints and minimizing the impact on the aquifer system. To address this management, problem optimization algorithms are typically combined with groundwater flow models. Due to scarcity of information on the hydrogeological system, stochastic modeling approaches can be used to incorporate parameter uncertainty into groundwater flow models. Since groundwater management under parameter uncertainty is inevitably accompanied by concerns about the risk of violating design constraints, it is necessary to explicitly address the tradeoffs between the expected cost of pumping policies and the probability of not meeting the design constraints.
In this work, a stochastic multi-objective optimization framework is presented and applied to a hypothetical example of a heterogeneous confined aquifer in both steady-state and transient flow conditions. The fundamental components of the framework include: 1) a three-dimensional finite element saturated flow model to simulate the aquifer response to pumping, 2) a stochastic simulator of multivariate random processes to generate scenarios for the uncertain parameters of the model, and 3) evolutionary optimization algorithms to identify optimal pumping policies. Here, two different evolutionary genetic algorithms are implemented and compared: a chance-constraint genetic algorithm (CCGA) and a niched-Pareto genetic algorithm (NPGA). The CCGA evaluates a chance-constrained single objective function that minimizes the expected cost of the pumping system while keeping the probability of drawdown violation under a prescribed level. The NPGA searches an optimal set of non-dominated solutions by minimizing the expected cost and the probability of drawdown violation at the same time.
Due to the intense computational efforts involved in this problem, a "response surface" model is introduced to estimate objective functions. This model provides the exact solution for any possible pumping policy in the case of a confined aquifer subject to homogeneous boundary conditions. The computational efficiency is further improved by parallelization on multi-processor computers of simultaneous evaluations of the management objectives and constraints associated with alternative candidate pumping policies. Through these methods, the optimization/simulation framework is enabled to search optimal designs over large sets of decision variables.

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