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Stochastic management of pump-and-treat strategies using surrogate functions

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Abstract

Typical pump-and-treat (PAT) optimization problems involve design of pumping schemes, while minimizing cost and meeting a set of constraints. Due to scarcity of information about the hydrogeological system, stochastic modeling approaches can be used to assess tradeoffs between optimality and reliability. Using a stochastic approach, the constrained, single-objective problem may be turned into a multiobjective problem by substituting constraint inequalities with an additional objective function (OF) that accounts for the reliability of the PAT process. In this work, two approaches are analyzed: in one case, the additional OF consists of the probability of failure of a given remediation policy; in another, the OF additional is represented by the recourse, namely the penalty cost induced by the violation of constraints. In order to overcome the overwhelming computational cost required by stochastic simulation, surrogate forms of the OFs are introduced. In the test case under investigation, such functions are estimated by a kriging interpolation of the OF over a series of data points obtained from stochastic simulations of flow and transport, and calibrated against stochastic optimization solutions. The analysis of the two approaches for addressing the tradeoff of cost vs. reliability indicates that recourse accounts not only for the frequency of constraint violations, as the probability of failure does, but also for the intensity with which these occur. Ultimately, the recourse method allows considering less restrictive policies, although these may be highly sensitive to the choice of penalty functions.

Keywords: PAT remediation; Stochastic multiobjective optimization; Surrogate functions

1. Introduction

The remediation of dissolved chemicals from shallow aquifers is often tackled with pump-and-treat (PAT) techniques. Typical PAT management problems involve selection of decision variables (DVs), such as the number, location, and flow rate schedule of pumping wells, along with an appropriate treatment method, in order to minimize the cost of the remedial action. For a given treatment technique, contaminant flow and transport (FT) models combined with optimization models are used to find optimal designs while considering management objectives and constraints. Possible approaches to groundwater remediation management are extensively covered in recent review papers by Freeze and Gorelick [12] and Mayer et al. [26].

Subsurface problems are usually solved deterministically, that is, assuming perfect knowledge of the subsurface system. However, it is widely recognized that, due to scarcity of information about the hydrogeological setting, stochastic models are more appropriate. The most well-suited approach for dealing with uncertainty would be in principle stochastic simulation, also referred to as Monte Carlo method. With this method, a large number of realizations of the stochastic parameters is generated and the management problem is solved by optimizing the expected value of the PAT cost over this series of events, while meeting the specified constraints in every realization.

Because of the large number of realizations required, the major limitation of the method is represented by its heavy,

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