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Optimal design of pump-and-treat systems under uncertain hydraulic conductivity and plume distribution

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ABSTRACT

In this work, we present a stochastic optimal control framework for assisting the management of the cleanup by pump-and-treat of polluted shallow aquifers. In the problem being investigated, hydraulic conductivity distribution and dissolved contaminant plume location are considered as the uncertain variables. The framework considers the subdivision of the cleanup horizon in a number of stress periods over which the pumping policy implemented until that stage is dynamically adjusted based upon new information that has become available in the previous stages. In particular, by following a geostatistical approach, we study the idea of monitoring the cumulative contaminant mass extracted from the installed recovery wells, and using these measurements to generate conditional realizations of the hydraulic conductivity field. These realizations are thus used to obtain a more accurate evaluation of the initial plume distribution, and modify accordingly the design of the pump-and-treat system for the remainder of the remedial process.

The study indicates that measurements of contaminant mass extracted from pumping wells retain valuable information about the plume location and the spatial heterogeneity characterizing the hydraulic conductivity field. However, such an information may prove quite soft, particularly in the instances where recovery wells are installed in regions where contaminant concentration is low or zero. On the other hand, integrated solute mass measurements may effectively allow for reducing parameter uncertainty and identifying the plume distribution if more recovery wells are available, in particular in the early stages of the cleanup process.

1. Introduction

Pump-and-treat (PAT) techniques are often applied to the remediation of dissolved chemicals from shallow aquifers. A related management problem typically consists of the selection of the pumping policy and the most appropriate treatment method, in order to minimize the cost of remediation while meeting a set of technical, economic and social constraints. Contaminant flow and transport models combined with optimization algorithms are used to tackle the management problem (Freeze and Gorelick, 1999; Mayer et al., 2002). However, the cleanup management of groundwater/contaminant systems is typically carried out in an environment of uncertainties due the limited knowledge of the hydrogeological setting, parameter distributions, and location of dissolved contaminant plumes.

In the past, significant research has been conducted on the problem of identifying groundwater pollution sources and characterizing contaminant plume distributions by integrating field measurements into groundwater stochastic flow and transport models. One of the earliest frameworks for identifying the source and the magnitude of groundwater pollutants was formulated by Gorelick et al. (1983), based upon a least-square minimization of the error between simulated and measured concentration data. Bagtzoglou et al. (1992) proposed a reversed-time particle tracking transport model to locate the most probable source of a sampled contaminant

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