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Geophysical Imaging For Contaminated Site Characterization

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Geophysical Imaging For Contaminated Site Characterization

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ABSTRACT

The analysis and management of groundwater flow problems often involve the prediction of fluid flow and/or contaminant migration patterns. These phenomena, however, are strongly influenced by the heterogeneity of the hydrogeological properties of the soil. The purpose of this project is to derive joint geophysical-hydrogeological procedures for the characterization of subsurface flow parameters. The first part of this study presents a formal stochastic approach for the integration of surface seismic data and well data into the identification of the spatial arrangement– location, geometry, and interconnectedness– of lithofacies. Towards this goal, the lithology of the subsurface is represented through a random indicator function whose spatial structure is identified from seismic reflection data and well logs. Seismic interval velocities and measures of their uncertainties are computed from normal moveout corrections to the seismic reflection data. Calibration curves constructed from the well logs transform these velocity estimates into a lithology indicator prior probability field. From the well data and the prior probability field, the indicator covariance function and its associated confidence limits are computed. Neighboring lithology logs and the indicator covariance function are then combined to update the indicator probability field. To illustrate the applicability of the proposed characterization procedure, a semi-synthetic case study– based on the Fremont study area near the city of Fremont, California– is performed.

In the second part of this study, a Bayesian method is developed to estimate the spatial distribution of the permeability. In addition to sparsely sampled permeability and pressure data, the proposed approach incorporates densely sampled seismic velocity data along with semi-empirical relationships between seismic velocity, permeability and pressure. A hydrological inversion is first performed, based solely on the permeability and pressure data. In light of the available seismic data, the velocity-permeability-pressure relationships are then used to update, in a Bayesian sense, the image of the permeability field. To demonstrate the usefulness of this approach, synthetic case studies are performed. For further validation, the proposed methodology is applied to real data collected at Kesterson Reservoir, California. These studies demonstrate that by joining seismic data and hydrological data into a common inverse procedure, improved permeability images can be reproduced.

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PROBLEM AND RESEARCH OBJECTIVES

In the analysis of groundwater systems, numerical models are often used to simulate the response of aquifers subject to various excitations and/or initial and boundary conditions. To obtain solutions, the spatial distributions of permeability (and other hydrogeological parameters) must be adequately described over the entire flow domain. In reality, field permeabilities exhibit large spatial variability over several orders of magnitude with complex patterns of spatial connectivity. Consequently, the ability to accurately describe such highly heterogeneous properties becomes strongly dependent on the availability of a large number of field measurements, adequately distributed over the entire flow domain. Measuring permeability directly over the entire flow domain and to the resolution needed by numerical modeling is not feasible. To compensate for the lack of densely sampled hydrogeological data, other types of data, such as geophysical data, must be incorporated into the identification problem.

The main objective of this project is to develop a stochastic geophysical-hydrological inverse procedure for the estimation of subsurface flow parameters. Instead of relying solely on hydrological data, the method also incorporates densely sampled seismic velocity data. The immediate benefit of this approach lies in the substantial increase in the amount of data used in the inversion scheme.

The specific goals of this study are the following:

1. Develop a formal stochastic approach for the integration of surface seismic data and well data into the identification of the spatial arrangement– location, geometry, and interconnectedness– of lithofacies and their mean hydrogeological properties

2. Develop a Bayesian updating algorithm for the estimation of the spatial distribution of the permeability field from permeability, pore pressure and seismic velocity data

3. Apply the proposed methodology to real data collected at Kesterson Reservoir, California.

METHODOLOGY

Heterogeneity of natural geologic formations strongly influences groundwater flow and contaminant movement patterns. The main purpose of this study is to develop joint geophysical-hydrogeological procedures for the characterization of subsurface flow parameters. The first part of this study presents a formal stochastic approach for the characterization of lithofacies and the delineation of aquifer/aquitard boundaries using surface seismic reflection data and well data. The goal is to compute a probabilistic distribution of the lithology indicator function that is constrained by both types of data. The proposed procedure consists of the following steps:

1. From normal moveout corrections and small perturbation analysis, the spatial distribution of the interval seismic velocities is computed. The uncertainties of these distributions are shown to increase with depth and are highest at locations close to facies boundaries.

2. Calibration curves derived from well data are used to transform these velocity distributions into an indicator prior probability field.

3. The prior probability field and the lithology logs are then combined to compute a minimum-variance weighted average of the indicator covariance function and its corresponding confidence limits.

4. An updated probability field is finally computed by conditioning the prior probability to neighboring lithology logs.

Once the spatial arrangement of individual lithofacies is determined, the second objective is to characterize the spatial heterogeneity of the local permeability field within each lithofacies. For this purpose, high resolution seismic velocity data are used to compute the spatial distribution of the permeability field using locally derived physical models between hydraulic soil properties and seismic soil properties. The method consists of the following two main steps:

1. From the permeability and pressure data, a hydrological inversion is initially performed.

2. In light of the available seismic data, the velocity-permeability-pressure relationships are used to update, in a Bayesian sense, the image of the permeability field. The proposed procedure accounts for uncertainty in the seismic velocity data and the seismic velocity permeability pressure relationship.

PRINCIPAL FINDINGS

For demonstration, the proposed methodology is applied to real data collected at Kesterson Reservoir, California. The available data consist of densely sampled seismic velocity data derived from a cross-well tomography and a limited number of laboratory permeability measurements. The data indicate a negative correlation between seismic velocity and permeability. Furthermore, the seismic velocity permeability relationship exhibits high sensitivity to small variations in seismic velocity. Under such conditions, the successful use of seismic velocity data for hydrological purposes is dependent on the availability of accurate seismic velocity estimates. Nontheless, the statistical properties of the seismic velocity data were successfully related to their log-permeability counterparts. Furthermore, additional conditioning on seismic velocity data was shown again to produce improved log-permeability estimates.

PUBLICATIONS AND PROFESSIONAL PRESENTATIONS

Copty, N., Y. Rubin, and G. Mavko. 1993. Geophysical-hydrological identification of field permeabilities through Bayesian updating, *Water Resources Research 29(8)*. 2813-2825.

Copty, N., and Y. Rubin. 1993. A Bayesian Approach for the Identification of Lithological Variations in Multi-phase Heterogeneous Media Using Geophysical and Hydrogeological Data. Presented at American Geophysical Union, Fall Meeting, San Fransisco. December 4-9.

Copty, N., and Y. Rubin. 1994. A stochastic approach to the Characterization of lithofacies from surface seismic and well data. *Water Resources Research.* Submitted.

M.S. THESIS

Leigh, S. 1993 Geostatistical site characterization: Stripa Mine Stokholm, Sweden. M.E. Report, Department of Civil Engineering, University of California, Berkeley, California.

PH.D. DISSERTATION

Copty, N. 1994 Stochastic Characterization of Subsurface Flow Parameters Using Geophysical and Hydrological Data, Ph. D. Dissertation, Department of Civil Engineering, University of California, Berkeley, California.