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Preface

Studies on Water Movement and Solute Transport in Arid Regions

Low precipitation rates and high evapotransporation rates commonly result in low rates of water movement and thick vadose zones in arid regions. Arid regions have been considered as favorable sites for storage of nuclear wastes and other contaminants. Understanding groundwater recharge, water movement and solute transport in these regions is crucial for the rational management of water resources, preservation of subsurface water quality, optimization of irrigation and drainage efficiency, safe and economic extraction of subsurface mineral and energy resources, subsurface storage of energy and waste, and perhaps prediction of global climate change. In the last several decades, important studies have been conducted in this area and much progress has been made. However, owing to the complexity of the media, such as the complex fracture system and large heterogeneity of the various hydraulic properties, and limited available field data, groundwater recharge, flow and solute transport in the complex subsurface environments have not been fully understood. To meet the demands of accurate prediction of flow and transport processes for various environmental projects, development of more efficient and accurate measurement methods and more appropriate modeling approaches is imperative. A systematic summary of the current study results and existing problems in this area will guide scientists in new research directions.

This special issue brings together selected papers from the 2000 meeting of the Geological Society of America (GSA), session T91, “Studies on Water Movement and Solute Transport in Arid Regions”, convened by Z. Yu and Bill X. Hu. These papers collected cover various aspects of subsurface water-related issues in arid regions, which include field measurement and modeling of groundwater recharge processes, stochastic and numerical modeling of subsurface flow and solute transport. The research on water and solute transport in complex subsurface environments is growing rapidly at present. Various measurement methods and modeling approaches have been developed in the last two decades. The selected papers reflect the cutting-edge results of the research and also look to what might be expected in the near future. The main results of these papers are summarized below.

The water flow and solute transport in the vadose zone are commonly controlled by the rapid preferential flow along fractures and bedding planes. The preferential flow may result in accelerated contaminant transport to depth and/or sequestration into relatively immobile regions. Mayes and others used soil cores collected from various field sites in the United States to conduct column experiments to investigate the influence of physical nonequilibrium, coupled preferential flow and matrix diffusion on nonreactive/reactive solute transport processes. Their study focused on the influence of soil structure and moisture saturation on the generation of preferential flow. The study results will help us identify the importance of preferential flow, matrix diffusion, and the formation of immobile water on solute transport processes.

Because of very low water fluxes, on the order of a few millimeters or less, physical techniques have limitations in arid areas. The numerical model has been proved to be a useful tool to evaluate flow processes and to analyze interactions and feedback mechanisms among various controlling variables. Dong and others used a soil hydrologic model to simulate soil water movement through unsaturated zone at the Nevada Test Site. A parameterization scheme with dual processes of matrix and macropore is included in the model to derive effective hydraulic conductivity. The integral-balance model based on

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water flux at different degrees of water saturation was used to calculate the macropore conductivity. The effects of soil texture, vegetation, and macropore on soil water content were evaluated. The simulated results provide information on the potential groundwater recharge and understanding of the flow mechanisms in the vadose zone.

It is complex to simulate water flow in the heterogeneous vadose zone with Richards' equation because of the nonlinearity of the equation and the uncertainty of hydraulic properties. The general method of linearizing hydraulic conductivity around the ensemble mean pressure head would produce significant errors. Tartakovsky and others used an approach to avoid such a linearization by making the soil parameter a random variable and deriving the moment equations for pressure head. The results provide theoretical insights and information on how to predict the unsaturated flow in heterogeneous soils with spatially distributed uncertain hydraulic parameters.

Groundwater recharge is always an important issue for groundwater resource and contamination. Manning and Solomon used noble gases as tracers to determine the relative importance of recharge to inter-mountain basin-fill aquifers in Utah from the mountain block and streams. The method provides an approach to identify the major recharge area for a specific aquifer, which will help protect water resources.

Stochastic study of groundwater flow and solute transport has been a very active research area over the last three decades. However, most of the studies are limited to theoretical development. In Wu and others' study, a nonstationary stochastic transport theory was applied to study the solute transport in the saturated zone below the Yucca Mountain Project area, where the complex subsurface environments are beyond the scope of stationary transport theories. Their study may lead to a new research area, application of stochastic method to predict solute transport, especially for uncertainty prediction, which will greatly help the design of contaminant remediation in many environmental projects in the United States.

Another area of active research is flow and transport in fractured media, especially since this type of medium has been considered for contaminant disposal. Huang and others applied a particle tracking method and Monte Carlo simulation approach to study solute transport in a fractured porous medium with dual-porosity structure. In their study, the hydraulic conductivity in the fracture domain and mass diffusion rate are both assumed to be spatial random variables, and their influences on flow and transport are investigated. The study results are also compared with the analytical results obtained through the perturbation method, showing consistency with each other.

In Hassan and Mohamed's study, particle-tracking methods are developed to study solute transport in single-continuum and dual continua porous media. The developed methods are then compared with two standard software programs, SUTRA and MT3D. Their study results indicate that in using an analytical solution as a standard, the newly developed methods will provide more accurate results than the two software programs, which suffer from numerical dispersion. These study results provide a more accurate and efficient tool for solute transport prediction.

We hope that the papers presented in this special issue will be of interest and help to readers and will provide some research directions in the area of water flow and solute transport in arid regions.

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