Preface

Studies of solute fate and transport in the subsurface environment have been playing a significant role in hydrogeology over the past half century. The problem directly relates to the quality of natural water resources, which are essential to all kinds of life, and are a basic element in many sectors of human society. Most migration studies of both natural and anthropogenically derived species have considered the motion of a fluid (groundwater) accompanied by diffusion–dispersion phenomena, physicochemical interactions, as well as microbiological transformations, known to be the dominant factors providing the impact of contaminants upon groundwater supplies.

Over the last decades, essential progress in the migration process description has been achieved due to the development of mathematical background and numerical methods and laboratory and field investigations of particular transport mechanisms and physicochemical interactions. However, in many real situations, the subsurface material heterogeneity and variations in fluid properties, resulting in nonlinear contaminant plume behavior, make the prediction accuracy of the transfer processes too low to satisfy the practical needs. The lack of comprehensive field studies of solute movement is often cited as a major impediment to our understanding of solute transport in such systems.

Therefore, this work is aimed at the development of the basic knowledge of the subsurface solute transfer with a particular emphasis on field data collection and analysis coupled with modeling (analytical and numerical) tool application. The book is based mostly on field materials from author's long-standing, recent, and current experience in the study of groundwater quality related problems. The diversity of these problems is concerned with the variety of geological settings as well as the anthropogenic effects and processes caused by human activity. Some problems encountered in practice looked as challenge-like and, thus, the author was encouraged to search for new solutions and approaches. The relevant theoretical developments are concerned mainly with the formulation and solution of deterministic mass-transport equations for a wide range of engineering issues in groundwater quality assessment and forecasting that can be of some interest for bridging the gaps still existing in our knowledge of contaminant hydrogeology.

The book gives many computation examples and case studies drawn from the conducted field investigations. Those examples show the applicability of the theory and methods for solving various practical problems and making decisions in contaminant hydrology to explain the observed and to forecast the future groundwater quality. The analyzed problems are as follows:

(1) investigation and prediction of groundwater contamination by industrial contaminants and solutions (radionuclides, chloride and nitrate brine) with special focus on the effect of (a) aquifer heterogeneity, anisotropy, and dual porosity, (b) density contrast between industrial waste and groundwater, (c) physicochemical interactions that play a major role in retarding (e.g., adsorption) or enhancing (e.g., interactions between dissolved species and mobile colloids) contaminant transport;
(2) prediction of the effects of pumping on groundwater quality at wellfields: (a) the displacement of stratified initial concentration in artesian and coastal (off-shore) groundwater systems due to water pumping, (b) downward movement of mineral-weathering products in the vadoze zone (above the lowering water table) with water recharge to the producing aquifers;
(3) groundwater dating using stable and radioactive isotopes for prediction and assessment of contamination potential and the time that would be needed to displace contaminants from the groundwater system;
(4) field and laboratory tests' design and analysis, and monitoring data interpretation;
(5) partitioning of surface and subsurface flows using isotope technique;
(6) formation of evaporated salt deposits in closed surface water reservoirs having a hydraulic connection with the surrounding groundwater systems.

Several parts of the book demonstrate the potential for using numerical groundwater flow and transport models in environmental risk assessment of subsurface contamination by dense or light miscible liquid waste. Environmental isotope data were utilized for defining the groundwater systems and modeling data analysis. However, numerical modeling emerged in the book mostly as one of the primary tools used to understand the most important physical and physicochemical processes that occur in groundwater systems, as well as for getting analytical approximations for some coupled problems, which do not necessarily have exact solutions in closed analytical forms or cannot be treated with the classical methods.

One of the most essential topics addressed in the book is the migration and fate of radionuclides. Model development is motivated by field data analysis from a number of radioactively contaminated sites in the Russian Federation: near-surface radioactive waste (RW) disposal sites in northwestern Russia and the Southern Urals, and two deep-well RW injection sites in Western Siberia. These sites are part of huge nuclear industry enterprises licensed to possess radioactive materials and also involved in hazardous-waste operations, which are supervised by RosAtom, the State Nuclear Energy Corporation, Russian Federation.

The total activity of radionuclides that were released (accidentally or intentionally) in aquifers at many sites reaches hundred thousands to hundred millions Ci. Any of the three RW disposal sites out of the four mentioned here (located in Southern Urals and Western Siberia) probably contains more radioactive contamination in the subsurface than any other site in the world. Additionally, detailed information on physical, mechanical, and solute transfer properties of clay formation (which is considered as a host medium for the engineered underground RW repository in the northwestern part of the Russian Federation) is also analyzed.

Those sites play a unique role in the advancement of knowledge of the subsurface behavior and fate of many hazardous radionuclides and can be considered as field-scale laboratories. The book is focused on the modeling and analytical assessments of a range of physical and chemical processes and interactions of concern. Some of the key issues needed to be addressed included:

(1) study of the behavior of a broad spectrum of radionuclides (fission products and actinides) in waste (with low content of dissolved solids and brine) based on long-term (up to 50 years) monitoring data in shallow and deep aquifer systems;
(2) study of the spatial variability of migration properties of aquifer materials and clayey semipervious formations;
(3) assessment of the role of brine-induced advection in redistribution of radioactive components at waste disposal sites;
(4) study of adsorption hysteresis implying isotherm nonsingularity and other non-ideal sorption phenomena, as well as the assessment of their role in natural attenuation of radioactively contaminated sites;
(5) analysis of transient hydrogeochemical-barrier effects, facilitating radionuclide transport, and some other mechanisms responsible for "fast" radionuclide transport in aquifers;
(6) experimental evidence for colloid-facilitated radionuclide (actinide) transport, and mathematical description of the phenomena.

The model developments were accompanied by laboratory studies into natural attenuation, radionuclide adsorption and desorption kinetics and equilibrium (including when colloidal particles are involved). Batch tests were conducted with different radioactive solutions under different temperature and pressure conditions. Anomalous behavior of radionuclides was observed and modeled.

This study can be regarded as the continuation of a series of works started by the author in the 1970s in cooperation with the outstanding Russian scientist, hydrogeologist, V.A. Mironenko, whose contribution to the development of several lines of studies in hydrogeology and hydrogeomechanics is difficult to overestimate. At the same time, this book could not appeared were it not for the all-round support from colleagues – researchers from E.M. Sergeev Institute of Environmental Geology, St. Petersburg Division, RAS, and St. Petersburg State University, who rendered assistance in the preparation of parts of the book. In this connection, the author very much appreciates the help of Leonid Sindalovsky in implementation of many numerical algorithms considered in the book, the contribution of Pavel Konosavsky to the joint studies of adsorption hysteresis and the development of some models of solute transfer in the porous media under disturbed flow conditions. The author also appreciates Igor Tokarev's willingness to share his data on regional isotope study of a groundwater system in the area of RW disposal at Tomsk-7 site.

The study discusses experiments carried out in laboratories of A.N. Frumkin Institute of Physical Chemistry and Electrochemistry, RAS, and A.P. Alexandrov Technical Institute under supervision of Drs. Elena Zakharova, Elena Kaimin, and Elena Pankina. The author expresses his sincere gratitude to these groups for cooperation that have yielded new results.

The author appreciates the cooperation of Aretech Solutions and TIHGSA Enterprises allowing him to learn new hydrogeological aspects related to the formation of groundwater resources and quality in arid regions.

The author also much appreciates the attention to his work and fruitfull discussions with Profs. Vsevolod Shestakov and Sergey Pozdniakov, Moscow State University, and Dr. Andrei Zubkov, the head of the Environmental Protection Division (Siberian Chemical Plant), and many other brilliant experts–hydrogeologists, whose talent and enthusiasm in scientific and production work allows the author to believe in the future of the Russian hydrogeological school.

Many efforts were made by Dr. Chin-Fu Tsang and Prof. Jacob Bear to organize this work in a proper way in order to prepare the book in a format acceptable for the international publishing company, Springer. Discussions and exchange of information, ideas, and opinions with them was a great support to this work.

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Thus, the book, along with theoretical findings, contains field information, which will facilitate the understanding of subsurface solute transport and the development of a methodology for practical application to groundwater hydrology. This book addresses scientists and engineers who are interested in the quantitative approach to studying groundwater migration processes. The book can also be profitably read by students.

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