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anisotropie

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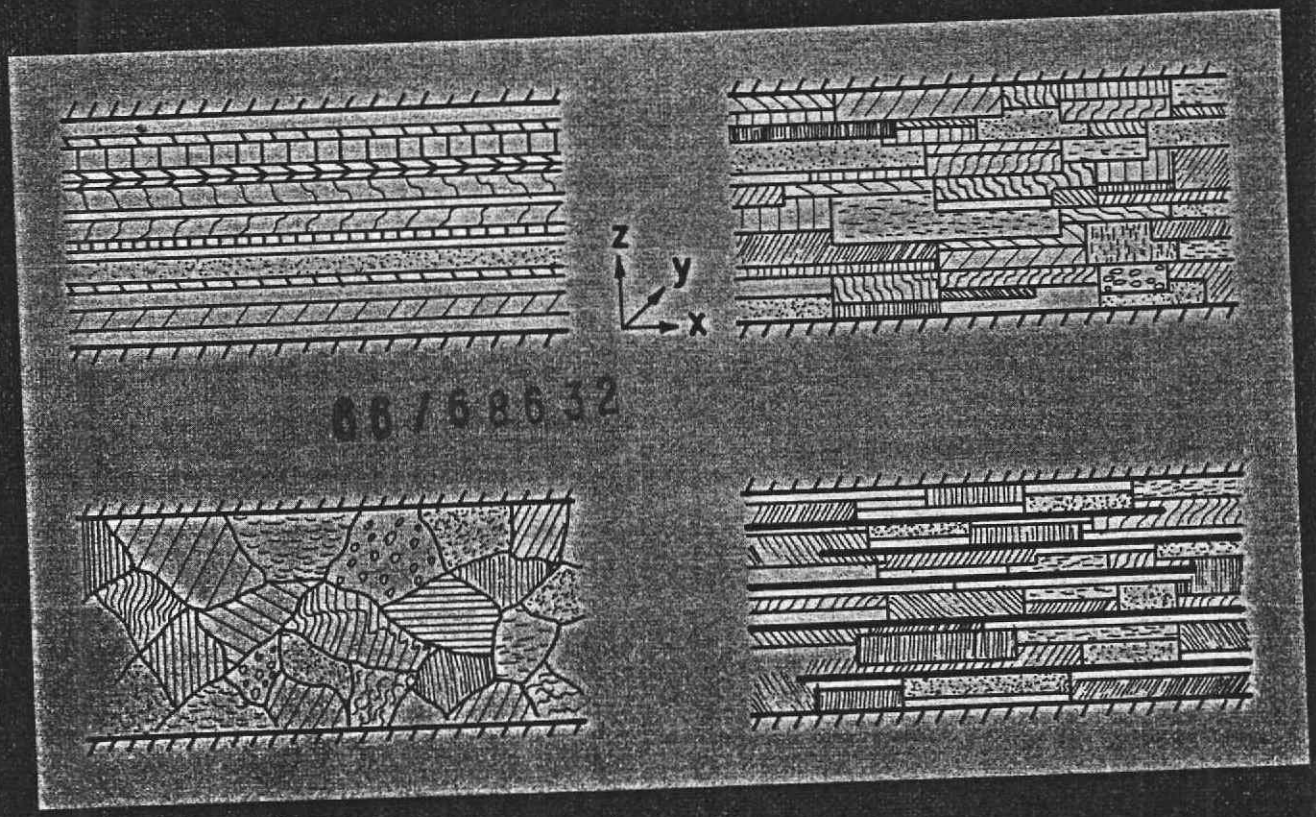
Flow and Transport in Porous Formations



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Flow and Transport in Porous Formations

This comprehensive study of water flow and solute transport in porous media summarizes recent developments of stochastic modelling of subsurface flow and transport at different scales. One of the main topics is the analysis of the effects heterogeneous natural formations exert upon water flow and contaminant transport. This text is suited for graduate courses, ideally supplemented by exercises at the end of most chapters. Researchers and engineers will find the conceptual foundations and the mathematical tools needed in order to model water flow and contaminant transport in aquifers.

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PREFACE

In the mid-seventies, a new area of research has emerged in subsurface hydrology, namely stochastic modeling of flow and transport. This development has been motivated by the recognition of the ubiquitous presence of heterogeneities in natural formations and of their effect upon transport and flow, on the one hand, and by the vast expansion of computational capability provided by electronic machines, on the other. Apart from this, one of the areas in which spatial variability of formation properties plays a cardinal role is of contaminant transport, a subject of growing interest and concern.

I have been quite fortunate to be engaged in research in this area from its inception and to witness the rapid growth of the community and of the literature on spatial variability and its impact upon subsurface hydrology. In view of this increasing interest, I decided a few years ago that it would be useful to present the subject in a systematic and comprehensive manner in order to help those who wish to engage themselves in research or application of this new field. I viewed as my primary task to analyze the large scale heterogeneity of aquifers and its effect, presuming that the reader already possesses a background in traditional hydrology. This is achieved in Parts 3, 4 and 5 of the text which incorporate the pertinent material. The term "porous formations" in the title aludes indeed to the primary preoccupation of the book with phenomena taking place in the natural environment rather than in the laboratory. However, the writing of the book has been delayed considerably for a few reasons. First, the field being in active and permanent development, I had to investigate new topics in order to fill a few gaps. The results of this activity can be found in the articles I published in this period and which are referred to in the book. Second, as I mentioned before, I regarded this book as a continuation of previously acquired knowledge from existing texts on flow through porous media. Most of these texts, however, introduce the basic concepts (Darcy's law, hydrodynamic dispersion) in a deterministic context. Thus, the reader may be left with the impression that treatment of heterogeneity in a stochastic frame is appropriate for large scales only. However, it is well known that the macroscopic laws governing flow through porous media can be derived with the aid of probability concepts also, and in my view this has definite advantages. Presenting a unified theory, based on the same basic concepts, covering flow at all scales, from the pore to the regional one, constitutes a temptation which is hard to resist by any theorist, and I am no exception. As a result, I spent a considerable time in writing Part 2, which covers classical subjects, but under a somewhat different angle. The results of this prolonged effort is a self-contained text,

which may be used by those interested in becoming acquainted with the theory of groundwater fl and transport. Nevertheless, the readers with the adequate background can approach directly Parts 4 and 5. Part 1, a recapitulation of a few probability concepts needed in this book, is meant to sa the labor of reading extensive treatises, which cover much more material. However, it is not a su stitute to a previously acquired background in basic statistics and probability theory.

It is emphasized that this is a treatise which presents the *theory* of flow and transport. It concentrates on deriving in a systematic and rational manner the basic equations governing variou processes, and constitutes the starting point to various applications. Nevertheless, this is a tex written for hydrologists and engineers, the ultimate goal being to apply the concepts to real life probelms. For this reason I tried to emphasize at the beginning of each new part or chapter the experimental or field findings which justify the theoretical approach. Furthermore, to facilitate the understanding of the theoretical concepts and of the accompanying equations, many examples of solutions are presented and discussed. Since their role is mainly illustrative, these solutions are either analytical or based on some rational approximations. Besides the main purpose of helping to grasp the theoretical developments, they may also serve as a benchmark for numerical solutions or ad-hoc approximations. The book does not address the growing and important field of numerical methods and of development of codes to solve complex problems. This subject deserves a separate treatment and is indeed covered by a few texts. In the same vein, the book does not attempt to treat the various practical techniques of solving field problems in order to give immediate answers to pressing questions. It provides only the theoretical background to approach the complex problems posed by real life. Finally, neither experimental techniques, laboratory or field, nor management of water resources, are subjects within the scope of this book.

The field of flow in porous media has expanded vastly in the last few years in relation to its various applications in hydrology, soil physics, reservoir engineering, chemical engineering, etc. This book treats only a limited sector of the discipline, namely saturated flow of water and transport of inert solutes. Some aspects of unsaturated flow, of transport of reactive solutes, of heat transfer and of immiscible flow are touched, but the reader is advised to approach other specialized texts for comprehensive treatments of these subjects.

Although I view the book primarily as a scientific monograph, I hope that it will also serve as an advanced text book for graduate students. For this purpose a few exercises are given at the end of most sections. These are not trivial, of the "number plugging" type exercises, but an extension of the theoretical part, and their solution requires a thorough understanding of the material.

Last not least, this book is not intended to be a compendium or a systematic literature review, but it represents a personal outlook thereby reflecting my own interests and preferences. As such it is definitely biased towards my own previous work and to the others that I considered particularly relevant. I am quite sure that by mistake or neglect some important contributions have been omitted and my apology is due to the authors who have been unintentionally overlooked. It is my belief that

science is the product of a collective effort and my contribution rests on the shoulders of my predecessors and colleagues. Thus, this book expresses, directly or indirectly, the achievements of the community to which I am deeply indebted.