ANALYTICAL GROUNDWATER MECHANICS

Groundwater mechanics is the study of fluid flow in porous media. Focusing on applications and case studies, this book explains the basic principles of groundwater flow using mathematical expressions to describe a wide range of different aquifer configurations. Emphasis is placed throughout on the importance of developing simplified models that can be solved analytically to provide insight into complex groundwater flow scenarios and to allow better interpretation of the full numerical solution.

Focusing first on identifying the important features of a problem, the book explains how to translate practical questions into mathematical form and discusses the interpretation of the results. Illustrated with numerous real-world examples and graphical results, this is an ideal textbook for advanced undergraduate and graduate courses in earth science, geological engineering, and environmental engineering, as well as a useful reference for researchers and professionals.

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Preface

The subject matter covered in this text is the mathematical description of fluid flow through porous media. Some parts of this book have been taken from Strack [1989], but much of the material is newly written. The two primary objectives are as follows. The first is to instruct the reader in approximating groundwater flow problems in such a manner that they can be solved analytically. The analytic solution will help us to gain insight, prior to constructing a complete solution to the problem using some numerical method if a more elaborate model is required.

The second objective is to explain how to simplify a practical problem so that it is analytically tractable. It requires considerable skill and understanding to approximate an actual flow problem by a simpler one that can be solved analytically, yet provide insight into the essence of the original problem. Even if the problem cannot be handled adequately by simple means, and recourse to a numerical solution is necessary, the determination and interpretation of relatively crude approximate solutions often provides crucial insight. The understanding thus gained can be used with advantage in selecting and setting up a numerical model that may ultimately be used to solve the problem. Modern computational environments exist that are suitable for implementing analytical solutions with relative ease, and are capable of displaying the results in a variety of manners, often in graphical form. The availability of such environments greatly enhances the use of analytic solutions as compared with in the past.

In view of the primary two objectives, emphasis is placed on a detailed coverage of methods for solving a variety of problems, rather than on providing a catalogue of existing solutions. Application of complex variable methods greatly simplifies the method of solution of many groundwater flow problems. Although complex variable methods carry with them a certain level of intimidation for many, once understood, complex variables make major simplification possible, as compared with real variables. We introduce in this text complex variables using Wirtinger calculus (Wirtinger [1927]), which extends the use of complex variables to general

two-dimensional problems. The implementation of complex variables in the majority of modern computational engines makes their use for obtaining analytic solutions attractive, especially in view of the primary objectives of this text.

The subject matter is organized in ten chapters. Each chapter covers one main topic. Chapter 1 is concerned with the basic concepts and the derivation of the governing equations. Chapter 2 deals with steady flow in a single aquifer. Steady shallow interface flow is the topic of Chapter 3, and two-dimensional flow in the vertical plane is covered in Chapter 4. Steady flow in leaky aquifers is covered in Chapter 5 and three-dimensional flow in Chapter 6. Transient flow is discussed in Chapter 7. A substantial part of the text, Chapter 8, is devoted to the use of complex variables for solving a variety of practical problems. It will become apparent to the reader that using complex variables instead of real ones leads to significant simplification, visible not only in the mathematical treatment, but also in the implementation in simple computer codes. An additional advantage of the use of complex variables is that for many of the problems flow nets can be easily produced, giving a graphical illustration of the flow patterns. The reader who completed the exercises will have produced a simple but flexible computer model capable of modeling features such as rivers, wells, lakes of various shapes, areas of recharge, and inhomogeneities in the hydraulic conductivity. Fluid particle paths and contaminant transport are covered in Chapter 9. An overview of numerical methods for solving groundwater flow problems is presented in Chapter 10; the reader is introduced to the basics of both finite difference and finite element methods. Applications as well as exercises are included in Chapter 2 through 10. There are two appendixes.

Many groundwater flow problems, in particular problems of regional aquifer flow, are not solved exactly in this text; approximate governing equations are derived for a variety of aquifer configurations. The mathematical formulations for these configurations are unified by the use of discharge potentials, expressed differently for each type of flow that corresponds to a particular aquifer configuration. The mathematical formulations thus become similar, and solutions and techniques are often transferable from one type of flow to another. An additional, but related, simplification of major practical interest is the application of the concept of vertically integrated flow, which results in accurate predictions of flow rates, while approximating the hydraulic heads.

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The text could not have been created without the help of the author's wife, Andrine D. Strack, who unwaveringly lent her support to the author in his efforts. She created figures and identified, through multiple readings of the text, many places where the explanations lacked in clarity.

Work on this text proceeded over the past 10 years. The text was used in the classroom as it grew to completion. Many of the students attending the classes identified errors and inconsistencies, and the author is grateful for their comments.