GROUND-WATER ENGINEERING

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About the Author

Dr. Abdel-Aziz Ismail Kashef is a geotechnical and groundwater engineering consultant. He was professor of civil engineering and head of the Earth Science Division at the American University of Beirut from 1956 through 1960. From 1962 to 1980, he was professor of civil engineering at North Carolina State University. He practiced engineering full time for 10 years and has worked as a consultant for 27 years in the United States and five other countries.

Dr. Kashef's degrees include a B.S. in irrigation engineering, an M.S. in structures, and a Ph.D. in soils from Purdue University. He was associated with the United Nations and also served as consultant for the High Aswan Dam of Egypt. From 1970 to 1972 he was editor of the *Water Resources Bulletin* of the American Water Resources Association and is a fellow both of that organization and of the American Society of Civil Engineers.

PREFACE

Over the years of my professional life as an engineer, I have had the privilege of changing my specialization from that of a practicing professional engineer (irrigation, structures, and foundation engineering) to that of a teacher at various universities in the United States and the Middle East. From 1962 to 1980, I taught two graduate courses on groundwater at North Carolina State University. Perhaps because of this diversified career, I have observed two distinct groups of people whose approach to groundwater is quite different and between whom a gap exists: those who confine themselves to theory, and those who believe only in practice. In addition, the two main groups of people who deal with groundwater, engineers and geologists, have in the past been interested in different aspects of groundwater. The engineer's interest has been in seepage through and around dams, in dewatering of foundation sites, and in municipal groundwater supplies. Engineering geologists and geologists have been more concerned with the overall management of groundwater, particularly water-well production. However, this latter group has recently become aware of the importance of some aspects of geotechnical engineering, such as leakage, land subsidence, and seepage through dams, which is analogous to some conditions of saltwater intrusion. The intent of this book is to present the basic premises of groundwater flow and related subjects, with the hope of providing engineers and geologists with a text that combines both theory and practical solutions to groundwater problems in a single source that can be used by all.

Groundwater sciences have grown rapidly in the last 30 to 40 years. Formal courses in groundwater are presently taught in many universities. During the last decade, much attention has been focused on the use of numerical approaches, such as the finite-difference method, the finite-element method, the method of characteristics, and boundary integrals. By using these methods, one is able to solve complex equations on groundwater flow and the movement of contaminants if the natural and boundary conditions are known. These methods, however, have not proved to be totally effective for dealing with, for example, water-pollution problems. There are several specialized books and publications on numerical analysis, so that this and other topics, such as well drilling, water pollution, unsaturated flow, modeling techniques, and geophysical methods, have been excluded from this book. However, the correlations between these fields are explained and supplemented with selected references.

The main purpose of the book is to present the field of groundwater with a minimal amount of mathematics in a simple and clear manner, emphasizing the techniques of quantitative evaluations of groundwater flow, seepage through and around dams, water wells, saltwater intrusion, and groundwater management. The book can be used by students and professionals with little or no previous experience in this field and should be useful to those working in the fields of numerical analysis and modeling as a refresher course in basic fundamentals. The main features of the book are (1) simple presentation of complex topics, (2) avoidance of burdensome mathematical details that may disrupt the sequence of presentation, (3) emphasis on basic principles and the limitations of both theoretical and practical aspects, (4) introduction of reliable simple formulas that have been checked against more rigorous solutions, and (5) solved examples wherever it is felt that the material in the text needs further explanation. It is my hope that this book can be used by graduate and undergraduate students in geology, agriculture, and engineering, as well as by planners, environmentalists, water-resources managers, geologists, and professional engineers, such as geotechnical, sanitary, hydraulic, irrigation, agricultural, and construction engineers.

The book is divided into nine chapters. The first two chapters are devoted to a review of the basic fundamentals of groundwater occurrence and the properties of flow media. A discussion of groundwater quality is also included in these chapters. Chapter 3 explains the fundamentals of groundwater flow. The history of groundwater engineering is discussed in Chapter 4. Recent advances in groundwater engineering and a listing of sources of pertinent data and literature references are also included in Chapter 4. Two-dimensional flow systems are explained in Chapter 5, with emphasis on flow nets, seepage through earth dams (including new, simple approaches), and hydraulic design of solid dams or weirs. Chapter 6 discusses the various means of determining the hydrologic parameters of aquifers (other than by well pumping, which is presented in detail in Chapter 8). The environmental effects on these parameters as well as their inclusion in the hydrodynamic equations are also explained in Chapter 6. The main elements of groundwater management are briefly discussed in Chapter 7, supplemented by a relatively long list of references. Water-well hydraulics is discussed in detail in Chapter 8. The available techniques used in water wells are explained, and new techniques are introduced for overpumped artesian wells and gravity wells. Chapter 8 also includes a special section on land subsidence due to well pumping. Chapter 9 is devoted to an analysis of saltwater intrusion. Special attention is given to some recently introduced approaches: a modified version of the Ghyben-Herzberg curve, disturbance of the natural interface due to discharge wells, and a design method of controlling saltwater intrusion using recharge wells. All chapters (except Chapter 4) are followed by problems and discussion questions.

I am deeply grateful to the reviewers of the manuscript and to Mrs. Candace C. Morse for typing the manuscript and for her patience.

Finally, I would like to dedicate this book to the late Mrs. Awatef Sidky Kashef, who despite serious illness helped and encouraged me and to whom I am most grateful.

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CONTENTS

CHAPTER 1

PROPERTIES OF ROCKS AND SOILS

The physical and mineralogic properties of the media through which groundwater percolates affect the quality of groundwater and its circulation. These properties can be better understood by studying the geologic origin of these media and how they were formed. The main types and properties of the media through which groundwater flows are briefly summarized in this chapter. These media include rocks and soils that originate from rocks known sometimes as regolith or unconsolidated rocks.

1.1 Rock Formations

Rocks were and are still being formed continuously (Legget, 1962) as a result of various natural processes, such as the cooling of molten rocks in the form of a hot liquid (magma) that percolates from considerable depths below the earth's surface, the precipitation of inorganic materials in water, the deposition of shells of various organisms, the condensation of gas containing mineral particles, the disintegration of other rocks due to various causes and the subsequent accumulation of the resulting minerals to form new types of rocks, and the action of intense heat and/or pressure on previously existing rocks. Rocks may be classified on the basis of their origin as *igneous, sedimentary,* or *metamorphic*. Each of these types has a characteristic general form, texture, structure, and mineral composition (U.S. Bureau of Public Roads, 1960; Legget, 1962; U.S. Bureau of Reclamation, 1977). Some of the main types of rocks are described in the following list:

Granite (igneous). The color of granite varies from pale gray to deep red. It is primarily composed of feldspar (about 60 percent), quartz (about 30 percent), mica, and possibly hornblend. The granitic structure is usually massive. Joints in a massive granitic formation divide it into large blocks. However, closely spaced joints give a sheet appearance.

Volcanic rocks (igneous). These may be hard or interbedded with loose permeable volcanic materials such as tuff, ashes, or sand. Basalt (traprock) is an example of a volcanic rock. Its color varies from dark gray to black, and it is characterized by the absence of quartz, the predominance of plagioclase, and the presence of considerable amounts of pyroxene and some olivine. In general, basalts are composed of fine-grained minerals. Columnar jointing (almost hexagonal) is one of the well-recognized features of basaltic structures. Weathered basalts become rusty in color.

Sandstone (sedimentary). Sandstones have fine- to coarse-grained texture and are usually massive, although they may also be cross-bedded. Quartzite resembles limestone yet is harder and contains almost equal amounts of feldspar and quartz. Practically, sandstones may be looked on as cemented sand. Graywacke is a dark-gray to black sandstone cemented by silica or clay. Graywacke also may contain flakes of slate and shale.

Limestone (sedimentary). This has a fine to coarse texture, and its color may be white, yellow, brown, gray, or a combination of these. Limestone is primarily calcium carbonate, and in the absence of fissures and solution channels, it is impervious; otherwise it is porous and has a loose texture. Marls and chalks are other forms of limestone.

Shales (sedimentary). These are laminated rocks, mostly dark in color. Shales consist of clay-size particles and sometimes small percentages of sand or silt-size particles. The structural strength of shale varies from extremely soft to very hard, depending on the particle characteristics and the degree of their compaction and cementation.

Conglomorate (sedimentary). The texture of conglomorates varies from very coarse to very fine, depending on the size of the cemented loose material. Usually 10 percent or more of the grains are coarse (larger than the size of sand).

Schist (metamorphic). This is a foliated rock, yet the foliation is not usually visible to the naked eye. Some schists are composed entirely of silica and form massive structures. Generally, the dip of the planes of schistosity is different from the dip of the whole formation.

Slate (metamorphic). This is a platy rock with an extremely fine texture. It is dark in color and susceptible to easy cleavage.

A simplified rock classification is given in Tables 1.1 to 1.3.

TABLE 1.1 Common Igneous Rocks

Color	Light		Intermediate	Dark	
Principal mineral	Quartz Feldspar Other minerals, minor	Feldspar	Feldspar Hornblende	Augite Feldspar	Augite Hornblende Olivine
Texture					
Coarse, irregular, crystalline	Pegmatite	Syenite pegmatite	Diorite pegmatite	Gabbro pegmatite	
Coarse and medium crystalline	Granite	Syenite	Diorite	Gabbro	Periodotite
			Dolerite		
Fine crystalline	Aplite			Diabase	
Aphanitic	Felsite			Basalt	
Glassy	Volcanic glass			Obsidian	
Porous (gas openings)	Pumice		Scoria or vesicular basalt		
Fragmental	Tuff (fine), breccia (coarse), cinders (variable)				

SOURCE: Naval Facilities Engineering Command, *Soil Mechanics*, Design Manual 7.1, Department of the Navy, NAVFAC, Alexandria, Va., 1982.

TABLE 1.2 Common Sedimentary Rocks

Group	Grain size	Composition		Name
Clastic	Mostly coarse grains	Rounded pebbles in medium-grained matrix		Conglomerate
		Angular coarse rock fragments, often quite variable		Breccia
	More than 50% of medium grains	Medium quartz grains	Less than 10% of other minerals	Siliceous sandstone
			Appreciable quantity of clay minerals	Argillaceous sandstone
			Appreciable quantity of calcite	Calcareous sandstone
			Over 25% feldspar	Arkose
			25–50% feldspar and darker minerals	Graywacke
	More than 50% fine grain size	Fine to very fine quartz grains with clay minerals		Siltstone (if laminated, shale)
		Microscopic clay minerals	<10% other minerals	Shale
			Appreciable calcite	Calcareous shale
			Appreciable carbonaceous material	Carbonaceous shale
			Appreciable iron oxide cement	Ferruginous shale

Group	Grain size	Composition	Name
Organic	Variable	Calcite and fossils	Fossiliferous limestone
	Medium to microscopic	Calcite and appreciable dolomite	Dolomite limestone or dolomite
	Variable	Carbonaceous material	Bituminous coal
Chemical	Microscopic	Calcite	Limestone
		Dolomite	Dolomite
		Quartz	Chert, flint, etc.
		Iron compounds with quartz	Iron formation
		Halite	Rock salt
		Gypsum	Rock gypsum

SOURCE: Naval Facilities Engineering Command, *Soil Mechanics*, Design Manual 7.1, Department of the Navy, NAVFAC, Alexandria, Va., 1982.

TABLE 1.3 Common Metamorphic Rocks

Texture	Structure	
	Foliated	Massive
Coarse crystalline	Gneiss	Metaquartzite
Medium crystalline	Schist (sericite, mica, talc, chlorite, etc.)	Marble Quartzite Serpentine Soapstone
Fine to microscopic	Phyllite Slate	Hornfels Anthracite coal

SOURCE: Naval Facilities Engineering Command, *Soil Mechanics*, Design Manual 7.1, Department of the Navy, NAVFAC, Alexandria, Va., 1982.