KEVIN M. HISCOCK | VICTOR F. BENSE HYDROGGEOLOGY PRINCIPLES AND PRACTICE

Second Edition



WILEY Blackwell

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The Shower

Henry Vaughan 1621–1695

> Waters above! eternal Springs! The dew, that silvers the Doves wings! O welcom, welcom to the sad: Give dry dust drink; drink that makes glad! Many fair Ev'nings, many Flow'rs Sweeten'd with rich and gentle showers Have I enjoy'd, and down have run Many a fine and shining Sun; But never till this happy hour Was blest with such an Evening-shower!

Thalia Rediviva, 1678

Hydrogeology Principles and Practice

(Second Edition)

Kevin M. Hiscock and Victor F. Bense

WILEY Blackwell

This edition first published 2014 © 2005 by Blackwell Science Ltd; 2014 by John Wiley & Sons Ltd

Registered office: John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

111 River Street, Hoboken, NJ 07030-5774, USA

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Library of Congress Cataloging-in-Publication Data

Hiscock, K. M. (Kevin M.)

Hydrogeology : principles and practice / Kevin M. Hiscock and Victor F. Bense. – Second edition.

pages cm

Includes bibliographical references and index.

ISBN 978-0-470-65662-4 (cloth) – ISBN 978-0-470-65663-1 (pbk.) 1. Hydrogeology. I. Bense, V. F. (Victor Franciscus) II. Title.

GB1003.2.H57 2014

551.49-dc23

2013022469

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover caption: Composite image of the River Aille, Fisherstreet in the Doolin Valley, County Clare, Ireland disappearing down sink holes in the Carboniferous limestone forming the river bed.

Cover image: Photos by Kevin M. Hiscock

Cover design by Design Deluxe

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Preface to the second edition

Reflecting on the first edition of this book, written a decade ago, it has become increasingly evident that groundwater will play an essential part in meeting the water resources demands of the 21st century, with groundwater already supplying an estimated 2 billion people worldwide with access to freshwater. Furthermore, the challenge of feeding a projected population of nine billion people by 2030 is likely to require an ever greater demand for water in growing crops, with a large fraction of irrigation water supplied by groundwater. Combined with other global environmental pressures resulting from altered patterns of temperature and precipitation as driven by climate change, adaptation responses to water use and management will become critical if demands for water are to be met. Hence, in order to set the scene for students and practitioners in hydrogeology, the second edition of this book includes new sections on the distribution and exploitation of global groundwater resources and possible approaches to adapting to climate change. A longer term view is also presented in which processes that act over geological timescales, such as formation of sedimentary basins the and crustal deformation during ice ages, are shown to have a profound influence on our understanding of groundwater flow patterns and the distribution of fresh groundwater resources today.

As with the first edition, the main emphasis of this second edition is to present the principles and practice of hydrogeology, without which the appropriate investigation, development and protection of groundwater resources is not feasible. An important addition to the current edition is <u>Chapter 3</u> in which regional characteristics such as topography, compaction and variable fluid density are introduced and explained in terms of geological processes affecting the past, present and future groundwater flow regimes. In support of the new material presented in this chapter and throughout this second edition, and given the positive reception to the case studies published in the first edition, a further 13 boxes are included, as well as a set of colour plates, that are drawn from our teaching and experience. The studies research case illustrate international examples ranging from transboundary aguifers submarine groundwater discharge to the overand pressuring of groundwater in sedimentary basins and, as a special topic, the question of whether there is groundwater on the planet Mars. To help with a more rational presentation, some reorganisation of material has occurred to separate investigation of catchment processes required to understand the role of groundwater as part of a catchment water balance (Chapter 6) from groundwater investigation techniques used determine aquifer to properties (Chapter 7). Also, Appendix 10 now includes a set of answers to the review questions in order to assist the reader consolidate his or her hydrogeological knowledge and understanding.

> Kevin Hiscock & Victor Bense, Norwich July 2013

Preface to the first edition

In embarking on writing this book on the principles and practice of hydrogeology, I have purposely aimed to reflect the development of hydrogeology as a science and its relevance to the environment. As a science, hydrogeology requires an interdisciplinary approach with applications to water resources investigations, pollution studies and environmental management. The skills of hydrogeologists are required as much by scientists and engineers as by planners and decision-makers. Within the current era of integrated river basin management, the chance to combine hydrogeology with wider catchment or watershed issues, including the challenge of adapting to climate change, has never been greater. Hence, to equip students to meet these and future challenges, the purpose of this book is to demonstrate the principles of hydrogeology and illustrate the importance of groundwater as a finite and vulnerable resource. By including fundamental material in physical, chemical. environmental isotope and contaminant hydrogeology together with practical techniques of groundwater investigation, development and protection, the content of this book should appeal to students and practising professionals in hydrogeology and environmental management. Much of the material contained here is informed by my own research interests in hydrogeology and also from teaching undergraduate and postgraduate courses hydrology and hydrogeology within the context of in environmental sciences. This experience is reflected in the choice of case studies, both European and international, used to illustrate the many aspects of hydrogeology and its connection with the natural and human environments.

Kevin Hiscock, Norwich

May 2004

Acknowledgements

No book is produced without the assistance of others and we are no exception in recognizing the input of colleagues, family and friends. Several people have provided help with proof reading sections and in supplying references and additional material. These people are Julian Andrews, Alison Bateman, Ros Boar, Lewis Clark, Sarah Cornell, Kate Dennis, Jerry Fairley, Aidan Foley, Tom Gleeson, Thomas Grischek, Rien Habermehl, Norm Henderson, Mike Leeder, Beth Moon, Rajasooriyar, Peter Ravenscroft, Mike Rivett, Lorraine Wilhelm Struckmeier and John Tellam. An enormous thank you is owed to Phillip Judge and Sheila Davies for their patient and expert preparation of the majority of the figures and Rosie Cullington for typing the many tables contained throughout. The staff and facilities of the Library at the University of East Anglia are appreciated for providing the necessary literature with which to compile this book. If this were not enough, we are indebted to Tim Atkinson, Richard Hey and Alan Kendall for helping form the content of this book through the years spent together teaching and examining undergraduate and postgraduate students in hydrology and hydrogeology in the School of Environmental Sciences at the University of East Anglia. We are also grateful to the editorial team at Wiley-Blackwell for their guidance and support during the publication process. Last but not least, we especially thank Cathy, Laura, Rebecca, Sylvia, Ronja, Kailash and Nico in supporting our endeavours in hydrogeology and for their patience during the long hours spent writing this book.

Symbols and abbreviations

Multiples and submultiples

Symbol	Name	Equivalent
Т	tera	10 ¹²
G	giga	10 ⁹
М	mega	10 ⁶
k	kilo	10 ³
d	deci	10 ⁻¹
с	centi	10 ⁻²
m	milli	10 ⁻³
μ	micro	10 ⁻⁶
n	nano	10 ⁻⁹
р	pico	10-12

Symbols and abbreviations

Symbol	Description	Units
[-]	activity	mol kg ⁻¹
(-)	concentration (see Box 4.1)	mol L ⁻¹ or mg L ⁻¹
A	area	m ²
A	radionuclide activity	
AE	actual evapotranspiration	mm
ASR	artificial storage and recovery	
(aq)	aqueous species	
atm	atmosphere (pressure)	
В	barometric efficiency	

BOD	biological oxygen demand	mg L $^{-1}$
Bq	becquerel (unit of radioactivity; 1 Bq = 1 disintegration per second)	
b	aquifer thickness	m
2 <i>b</i>	fracture aperture	m
С	shape factor for determining k_i	
С	specific moisture capacity of a soil	(m of water) ⁻¹
С, с	concentration	
°C	degrees Celsius (temperature)	
CEC	cation exchange capacity	meq (100 g) ⁻¹
CFC	chlorofluorocarbon	
Ci	curie (older unit of radioactivity; 1 Ci = 3.7×10^{10} disintegrations per second)	
COD	chemical oxygen demand	mg L $^{-1}$
D	hydraulic diffusivity	m ² s ⁻¹
D	hydrodynamic dispersion coefficient	m ² s ⁻¹
D*	molecular diffusion coefficient	m ² s ⁻¹
DIC	dissolved inorganic carbon	mg L $^{-1}$
DNAPL	dense, non-aqueous phase liquid	
DOC	dissolved organic carbon	mg L ^{-1}
d	mean pore diameter	m
$\left(\frac{dh}{dl}\right)$	hydraulic gradient	
E ^O	standard electrode potential	V
EC	electrical conductivity	S cm ⁻¹
Eh	redox potential	V
е	void ratio	
e-	electron	
eq	chemical equivalent (see Box 4.1)	eq L $^{-1}$
F	Faraday constant (9.65 x 10^4 C mol ⁻¹)	

F	Darcy-Weisbach friction factor	
f _C	infiltration capacity	cm h ⁻¹
ft	infiltration rate	cm h ⁻¹
f _{oc}	weight fraction organic carbon content	
G	Gibbs free energy	kJ mol ⁻¹
g	gravitational acceleration	m s ⁻²
g	gram (mass)	
(g)	gas	
Н	depth (head) of water measured at a flow gauging structure	m
Н	enthalpy	kJ mol ⁻¹
h	hydraulic head	m
1	ionic strength	mol L $^{-1}$
i	hydraulic gradient $\left(\frac{dh}{dl}\right)$	
IAEA	International Atomic Energy Agency	
IAP	ion activity product	$mol^n L^{-n}$
J	joule (energy, quantity of heat)	
к	equilibrium constant	mol ⁿ L ⁻ⁿ
K (hydraulics)	hydraulic conductivity	m s ⁻¹
<i>K</i> (temperature)	kelvin	
K _d	partition or distribution coefficient	mL g ⁻¹
K _f	fracture hydraulic conductivity	m s ⁻¹
Кң	Henry's law constant	Pa m ³ mol ⁻¹
K _{OC}	organic carbon-water partition coefficient	
K _{OW}	octanol-water partition coefficient	
Ks	selectivity coefficient	
K _{sp}	solubility product	$mol^n L^{-n}$
	intrinsic permeability	m ²

k _i		
Ľ	litre (volume)	
LNAPL	light, non-aqueous phase liquid	
1	length	m
MNA	monitored natural attenuation	
т	mass	kg
mol	amount of substance (see Box 4.1)	
n	an integer	
n	roughness coefficient (Manning's <i>n</i>)	
n	porosity	
n _e	effective porosity	
Р	Peclet number	
Р	precipitation amount	mm
P	pressure	Pa (or N m ^{—2})
Р	partial pressure	atm or Pa
P _A ' P _O	atmospheric pressure	atm or Pa
Ра	pascal (pressure)	
P _W	porewater pressure	Pa or m of water
PAH	polycyclic aromatic hydrocarbon	
PDB	Pee Dee Belemnite	
PE	potential evapotranspiration	mm
р	-log ₁₀	
ppm	parts per million	
Q	discharge	m ³ s ⁻¹
Qf	fracture flow discharge	m ³ s ⁻¹
q	specific discharge or darcy velocity	m s ⁻¹
R	hydraulic radius	m
R (R _d)	recharge (direct recharge)	mm a ⁻¹
R	universal gas constant (8.314 J mol $^{-1}$ K $^{-1}$)	
RC	root constant	mm
R _d	retardation factor	