KEVIN M. HISCOCK | VICTOR F. BENSE

HYDROGEOLOGY

PRINCIPLES AND PRACTICE

Second Edition

free companion website

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

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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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likely in the form of chemically and/or physically bound water and/or hydroxyl radicals since water ice is not stable near the equator. (Reproduced from Los Alamos National Laboratory. © Copyright 2011 Los Alamos National Security, LLC. All rights reserved.)

Plate 1.5 NASA Landsat-7 satellite image of the Ouargla Oasis, Algeria on 20 December, 2000. In this false-colour image, red indicates vegetation (the brighter the red, the more dominant the vegetation). Pale pink and orange tones show the desert landscape of sand and rock outcrops. The satellite image shows date palms surrounding the urban area of Ouargla and Chott Aïn el Beïda in the southwest, a saline depression that has traditionally collected irrigation runoff, as well as the proliferation of irrigated land to the north and east of Ouargla in the vicinity of Chott Oum el Raneb. The width of the image shown is approximately 40 km. (Reproduced from http://earthobservatory.nasa.gov/IOTD. NASA images created by Jesse Allen and Rob Simmon, using Landsat data provided by the United States Geological Survey. Caption by Michon Scott.)

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ESRI. All rights reserved.)

Plate 2.1 Aerial view of artesian springs and spring mounds west of Lake Eyre South (137°E, 29°S) in the Great Artesian Basin in northern South Australia (see Box 2.10) showing the flowing artesian Beresford Spring (A in foreground), the large, 45 m high Beresford Hill with an extinct spring vent (C), the flowing artesian Warburton Spring (E), and the flat topped hill (F) capped by spring carbonate deposits (tufa) overlying Bulldog Shale. The diameter of the upper part of the circular Beresford Hill, above the rim, is about 400 m. Luminescence ages of 13.9 ± 1 ka were determined for samples from the carbonate mound of the actively flowing Beresford Spring (B) and of 128 ± 33 ka from the northwest side of the dry extinct Beresford Hill spring carbonate mound deposits (D). (Prescott and Habermehl 2008. Reproduced with permission from Taylor & Francis.)

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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 the formation of sedimentary basins 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 Chapter 3 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 research experience. The case studies illustrate international examples ranging from transboundary aquifers and submarine groundwater discharge to the over-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 to determine aquifer 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 in hydrology and hydrogeology within the context of 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

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Symbols and abbreviations

Multiples and submultiples

Symbol	Name	Equivalent
T	tera	10^{12}
G	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
d	deci	10^{-1}
c	centi	10^{-2}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	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)	
B	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*b*	fracture aperture	m
C	shape factor for determining k_i	
C	specific moisture capacity of a soil	(m of water)$^{-1}$
C, *c*	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}
E*h*	redox potential	V
e	void ratio	
e-	electron	
eq	chemical equivalent (see Box 4.1)	eq L^{-1}
F	Faraday constant (9.65 × 10^4 C mol^{-1})	

F	Darcy–Weisbach friction factor	
f_c	infiltration capacity	cm h^{-1}
f_t	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	
H	depth (head) of water measured at a flow gauging structure	m
H	enthalpy	kJ mol^{-1}
h	hydraulic head	m
I	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)	
K	equilibrium constant	mol^n L^{-n}
K (hydraulics)	hydraulic conductivity	m s^{-1}
K (temperature)	kelvin	
K_d	partition or distribution coefficient	mL g^{-1}
K_f	fracture hydraulic conductivity	m s^{-1}
K_H	Henry's law constant	Pa m^3 mol^{-1}
K_{oc}	organic carbon-water partition coefficient	
K_{ow}	octanol-water partition coefficient	
K_s	selectivity coefficient	
K_{sp}	solubility product	mol^n L^{-n}
	intrinsic permeability	m^2

k_i		
L	litre (volume)	
LNAPL	light, non-aqueous phase liquid	
l	length	m
MNA	monitored natural attenuation	
m	mass	kg
mol	amount of substance (see Box 4.1)	
n	an integer	
n	roughness coefficient (Manning's n)	
n	porosity	
n_e	effective porosity	
P	Peclet number	
P	precipitation amount	mm
P	pressure	Pa (or N m^{-2})
P	partial pressure	atm or Pa
P_A, P_o	atmospheric pressure	atm or Pa
Pa	pascal (pressure)	
P_W	porewater pressure	Pa or m of water
PAH	polycyclic aromatic hydrocarbon	
PDB	Pee Dee Belemnite	
PE	potential evapotranspiration	mm
p	$-\log_{10}$	
ppm	parts per million	
Q	discharge	m^3 s^{-1}
Q_f	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	