

Application of isotope hydrology to groundwater problems in engineering geology

P.J. Leggo, C.D. Warren & D. Blakeway

ABSTRACT: Research on the natural variation of the isotopic species of hydrogen and oxygen has led to a firm understanding of the physical processes involved in the isotopic fractionation of these elements in water. Although much use has been made of artificially introduced chemical tracers to investigate flow patterns and characterise the groundwater, this method commonly suffers from bulk dilution and additional problems that limit its applicability to many investigations in engineering geology. Such limitations are avoided in the use of stable isotopic measurements as it is the variability in the isotopic species of the water molecule itself that are used as the characterisation parameters providing a 'fingerprint' for each particular water sample.

In this paper background details of stable isotopic fractionation are summarised and two recent case histories presented to demonstrate its application to groundwater studies, on a small scale, commonly met in many civil engineering situations, namely investigation of possible leakage from a reservoir and identification of the source of water contained within a large landfill. By the seasonal variations in the isotopic values, trends in groundwater isotopic composition can be identified and interpreted within the often limited geological and hydrogeological constraints of the site so as to provide conclusions as to the origin of the groundwaters.

Introduction

In recent years increasing use has been made of the distribution of the various isotopic species occurring naturally in water, particularly where the introduction of chemical tracers suffers from the problem of bulk dilution (Siddle *et al.* 1984), or may be considered unacceptable if the reservoir or groundwater source is for consumer use. Interpretation of isotopic data can provide information on source of water, flow path, velocity, mechanism of recharge, chemical mixing and the age of the water. Isotopes commonly measured in water include the stable isotopes of oxygen, hydrogen and carbon, usually expressed as relative isotopic ratios $^{18}\text{O}/^{16}\text{O}$, D/H (D refers to deuterium or ^2H) and $^{13}\text{C}/^{12}\text{C}$ respectively, and the radioactive isotopes of tritium (^3H or T) and carbon (^{14}C).

Research on the natural variation in the isotopic composition of hydrogen and oxygen has led to an understanding of the isotopic fractionation of water that occurs during the meteoric cycle. In general the isotopic fractionation of hydrogen and oxygen occurs during every phase transformation and the meteoric cycle has been likened to a giant multi-stage distillation column (Epstein & Mayeda 1953). It is well established that fractionation patterns produced by evaporation and condensation of water in the lower atmosphere are preserved in precipitation and their accurate measurement provide parameters which can be used for the characterisation of water. Due to the higher vapour pressure of H_2^{16}O relative to

HD^{16}O and H_2^{18}O , water vapour becomes enriched in the lighter molecule during evaporation and similarly during condensation the liquid phase becomes enriched in the heavy species. In this way repeated evaporation and condensation leads to progressively lighter isotopic values in the vapour phase.

The degree to which any particular rain is isotopically fractionated is a function of many variables but the main controlling influence of air temperature has been known for some years. (Dansgaard 1964). The isotopic composition of rain is also controlled, to various degrees, by such factors as: physiographic relief, latitude, inland distance and rainfall amount, and worldwide studies have shown that seasonal variations in air temperature can be directly correlated to systematic variations in isotopic composition. Thus rainfall at colder temperatures, higher altitudes and latitudes, and greater distance from the ocean will be characterised by isotopically light δD and $\delta^{18}\text{O}$ values (see below for terminology). The dependence of $\delta^{18}\text{O}$ values on altitude has been found to be from -0.13 to -0.3% per hundred metres (Evans, 1982). Such isotopic effects produce variations often orders of magnitude greater than analytical variance and can be used to characterise water from differing environments.

Isotope hydrology

In order to characterise the water so as to provide some clue to its source, one first has to measure the

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HYDROGEOLOGY: PROBLEMS WITH SOLUTIONS NANDIPATI SUBBA RAO, 2016-12-01 Numerical calculations are inevitably required in the field of hydrogeology and play a significant role in dealing with its various aspects. As often as not, students are seen struggling while solving numerical problems based on hydrogeology as they find difficulty in identifying the correct concept behind the problem and the formula that can be applied to it. Also, there is a dearth of books which help the readers in solving numerical problems of varied difficulty level and enable them to have a firm grounding in the subject of hydrogeology. The book *Hydrogeology Problems with Solutions* fills this void in the finest way and, as desired, chiefly focuses on the sequential steps involved in solving the problems based on hydrogeology. It concisely covers the fundamental concepts, advanced principles, and applications of hydrogeological tasks rather than overemphasising the theoretical aspects. The text comprises sixty solved hydrogeological problems which are logically organised into ten chapters including hydrological cycle, morphometric analysis, hydrological properties, groundwater flow, well hydraulics, well design and construction, groundwater management, seawater intrusion, groundwater exploration, and groundwater quality. The practice of pedagogy of hydrogeology in yesteryears was a two-tier approach of theoretical principles with toy problems and in situ case studies for research start-up. This book bridges the gap between routine problem solving and state-of-the-practice for future. The book is primarily intended for the undergraduate and postgraduate students of Earth Sciences, Civil Engineering, Water Resources Engineering, Hydrogeology, and Hydrology. It also serves as an excellent handy reference for all professionals.

KEY FEATURES Key Concept succinctly explores the models, methods, and theoretical concepts related to each problem. Necessary equations and formulae are specified. Appendices and Glossary are included, leaving no scope to refer any other book. Bibliography broadens the scope of the book.

Handbook of Drought and Water Scarcity Saeid Eslamian, Faezeh A. Eslamian, 2017-09-01 This volume includes over 30 chapters written by experts from around the world. It examines numerous management strategies for dealing with drought and scarcity. These strategies include management approaches for different regions such as coastal, urban, rural, and agricultural areas. It offers multiple strategies for monitoring, assessing, and forecasting drought through the use of remote sensing and GIS tools. It also presents drought mitigation management strategies such as groundwater management, rainwater harvesting, conservations practices, and more.

Practical Problems in Groundwater Hydrology E. Scott Bair, Terry D. Lahm, 2006 For courses in Groundwater Hydrogeology or Ocean and Water Resources. This is the first groundwater hydrology book composed entirely of genuine applied problems that cover the range of concepts addressed in most groundwater hydrology courses. Twenty-one exercises help develop students' quantitative skills, require data analysis, and concept exploration, and incorporate current image and graphic technologies to enhance learning.

Applied Groundwater Hydrology Richard Allen Downing, W. B. Wilkinson, 1991 Hydrogeology is a crucial and increasingly topical subject. Groundwater is one of the world's most vital resources, providing a large proportion of the water supplies in many

countries Although naturally of very high quality groundwater is being insidiously polluted by the careless and ignorant actions of man This book reflects the concern of specialists about the deterioration of groundwater quality as a result of waste disposal acid rain drainage and agricultural practices It discusses the feasibility of harnessing geothermal energy and the repercussions of deep disposal of nuclear waste Recent research and practical methodologies used in hydrogeology are described and consideration is given to recent management changes in the water industry and the integration of groundwater development with other water sources This book will be of interest to all who are concerned with the development of groundwater resources and with maintaining their quality

Subsurface Hydrology David W. Hyndman, 2007-01-09 Published by the American Geophysical Union as part of the Geophysical Monograph Series Volume 171 Groundwater is a critical resource and the Principal source of drinking water for over 1.5 billion people In 2001 the National Research Council cited as a grand challenge our need to understand the processes that control water movement in the subsurface This volume faces that challenge in terms of data integration between complex multi scale hydrologic processes and their links to other physical chemical and biological processes at multiple scales Subsurface Hydrology Data Integration for Properties and Processes presents the current state of the science in four aspects Approaches to hydrologic data integration Data integration for characterization of hydrologic properties Data integration for understanding hydrologic processes Meta analysis of current interpretations Scientists and researchers in the field the laboratory and the classroom will find this work an important resource in advancing our understanding of subsurface water movement

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Water for World Development: Hydrology and groundwater, climate, energy International Water Resources Association, 1988 [Solving Ground Water Problems with Models](#), 1987

Eurokarst 2018, Besançon Catherine Bertrand, Sophie Denimal, Marc Steinmann, Philippe Renard, 2019-04-09 This book presents selected papers from the EuroKarst 2018 conference which highlighted the latest advances in the field of Karst Hydrogeology and Carbonate Reservoirs The event attracted more than 180 participants From among their contributions the papers were selected and subsequently reviewed by the scientific committee to ensure the highest possible quality

[Applications in Physics, Part B](#) Vasily E. Tarasov, 2019-02-19 This multi volume handbook is the most up to date and comprehensive reference work in the field of fractional calculus and its numerous applications This fifth volume collects authoritative chapters covering several applications of fractional calculus in physics including electrodynamics statistical physics and physical kinetics and quantum theory

Southwest Hydrology, 2008 **The Protection and Conservation**

of Water Resources Hadrian F. Cook, 2017-06-26 This book is about water in Britain and in the world It is about water resources their conservation protection of water quality for human consumption and aquatic ecosystems Since the publication of the first edition in 1998 major political and regulatory changes have taken place this book provides a clear and comprehensive update of conservation and water resource management issues in the UK over the past two decades and in an expansion of its original UK perspective now includes examples of global best practice The UK's 2003 adoption of the EU Water Framework Directive has had enormous implications for the conservation and management of our water resources In 2016 with the UK's decision to leave the EU the governance scene is entering upon an unpredictable future regarding its major water resource policies The Protection and Conservation of Water Resources Second edition provides a clear and comprehensive update of conservation and water resource management issues Chapter 1 deals with sustainability and water policy outlines the issues and challenges and asks what is integrated water management Chapter 2 reviews water availability and sufficiency in Britain while Chapter 3 explores the dynamic between institutions and legislative framework Chapter 4 introduces the catchment approach and chapters 5 and 6 explore the issues of sustaining bulk supply and the imperatives of climate change Chapter 7 looks at the contemporary background to water quality issues and Chapter 8 provides case studies of catchment problems both urban and rural Chapter 9 describes solutions in land use change including technical fixes and their sustainability Chapter 10 is concerned with emerging governance arrangements and Chapter 11 takes a global view looking at successful examples around the world to find positive lessons from Europe north America and Australia

Hydrogeological Regimes and Their Subsurface Thermal Effects Alan E. Beck, Grant Garven, Lajos Stegena, 1989

Published by the American Geophysical Union as part of the Geophysical Monograph Series Volume 47 There are a number of reasons for organizing a symposium One is to bring specialists together to discuss a specific problem in which they all have expertise and encourage the participants to talk openly about their current work which in all likelihood is not going to be in publishable form for some time Another reason might be that a problem has been identified by one group of experts which needs the input from a previously loosely allied group before real progress can be made The International Union of Geodesy and Geophysics Symposium U S Hydrogeological Regimes and Their Subsurface Thermal Effects organised for the August 1987 General Assembly in Vancouver was a symposium of the latter type

Sojourns in Probability Theory and Statistical Physics - II Vladas Sidoravicius, 2019-10-17 Charles M. Newman has been a leader in Probability Theory and Statistical Physics for nearly half a century This three volume set is a celebration of the far reaching scientific impact of his work It consists of articles by Chuck's collaborators and colleagues across a number of the fields to which he has made contributions of fundamental significance This publication was conceived during a conference in 2016 at NYU Shanghai that coincided with Chuck's 70th birthday The sub titles of the three volumes are I Spin Glasses and Statistical Mechanics II Brownian Web and Percolation III Interacting Particle Systems and Random Walks The articles in these volumes which cover

a wide spectrum of topics will be especially useful for graduate students and researchers who seek initiation and inspiration in Probability Theory and Statistical Physics *Computational Methods in Subsurface Hydrology* G. Gambolati,1990
Advances in Ground-water Hydrology ,1997 *Water* Unesco,World Water Assessment Programme (United Nations),2006 This illustrated report sets out a global review of the state of the world s freshwater resources based on the collective work of 24 United Nations agencies following on from the conclusions of the first UN World Water Development Report *Water for People Water for Life* published in 2003 ISBN 9231038818 This second edition discusses progress towards the water related targets of the UN Millennium Development Goals and examines a range of key issues including population growth and increasing urbanisation changing ecosystems food production health industry and energy as well as risk management valuing and paying for water and increasing knowledge and capacity It contains 16 case studies which consider key challenges in water resource management and makes a number of recommendations to guide future action and encourage sustainable use productivity and management of our increasingly scarce freshwater resources **Groundwater** Mary P. Anderson,2008 **Handbook of Applied Hydrology, Second Edition** Vijay P. Singh,2016-03-07 Fully Updated Hydrology Principles Methods and Applications Thoroughly revised for the first time in 50 years this industry standard resource features chapter contributions from a who s who of international hydrology experts Compiled by a colleague of the late Dr Chow Chow s *Handbook of Applied Hydrology Second Edition* covers scientific and engineering fundamentals and presents all new methods processes and technologies Complete details are provided for the full range of ecosystems and models Advanced chapters look to the future of hydrology including climate change impacts extraterrestrial water social hydrology and water security Chow s *Handbook of Applied Hydrology Second Edition* covers *The Fundamentals of Hydrology Data Collection and Processing Hydrology Methods Hydrologic Processes and Modeling Sediment and Pollutant Transport Hydrometeorologic and Hydrologic Extremes Systems Hydrology Hydrology of Large River and Lake Basins Applications and Design The Future of Hydrology* **Selected Water Resources Abstracts** ,1989

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