

## 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  $^2\text{H}$ ) and  $^{13}\text{C}/^{12}\text{C}$  respectively, and the radioactive isotopes of tritium ( $^3\text{H}$  or T) and carbon ( $^{14}\text{C}$ ).

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  $\text{H}_2^{16}\text{O}$  relative to

$\text{HD}^{16}\text{O}$  and  $\text{H}_2^{18}\text{O}$ , 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  $\delta\text{D}$  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

**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

**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

**Solving Ground Water Problems with Models** ,1987 *Introduction to Quantitative Hydrology* Aly I. El-Kadi,2025-09-16 This textbook serves as an introductory quantitative course on the fundamental elements of the hydraulic

cycle It enhances students understanding by discussing the latest advancements in hydrological science covering both experimental and computational techniques This textbook is self contained requiring no prior knowledge and includes numerous illustrations to clarify scientific concepts Complex mathematical treatments are minimized focusing on clear step by step examples and guides that utilize scientific calculators and spreadsheets Where appropriate chapters include assignments that reinforce the textbook s role in academic settings A virtual laboratory section is also provided featuring experiments and example datasets for student analysis Additionally the text outlines the equipment needed to set up a physical laboratory making it practical for educators to implement Targeted at first year college students this book supports early career exploration in fields such as natural resources earth sciences and civil and environmental engineering Offering this course early allows students to make informed decisions about their academic and career paths before they reach their senior year providing them with ample time to pursue specialized interests

**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

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Rapid, Reproducible, and Robust Environmental Modeling for Decision Support: Worked Examples and Open-Source Software Tools Jeremy White,Michael Fienen,Catherine Moore,Anneli Guthke,2023-10-11

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

Ground Water Models National Research Council,Division on Engineering and Physical Sciences,Commission on Physical Sciences, Mathematics, and Applications,Committee on Ground Water

Modeling Assessment,1990-02-01 The discovery of toxic pollution at Love Canal brought ground water contamination to the forefront of public attention Since then ground water science and modeling have become increasingly important in evaluating contamination setting regulations and resolving liability issues in court A clearly written explanation of ground water processes and modeling Ground Water Models focuses on the practical aspects of model application It examines the role of models in regulation litigation and policy development explains ground water processes and describes specific applications for models presents emerging technologies and offers specific recommendations for better use of ground water science in policy formation Water for World Development: Hydrology and groundwater, climate, energy International Water Resources Association,1988 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 *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 **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 **Inconvenient Hydrology?**,2007 **Hydrology 2000** International Association of Hydrological Sciences. Hydrology 2000 Working Group,1987 *Forensic Hydrology* ,2007 *Advances in Ground-water Hydrology* ,1997 *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 Southwest Hydrology, 2008

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