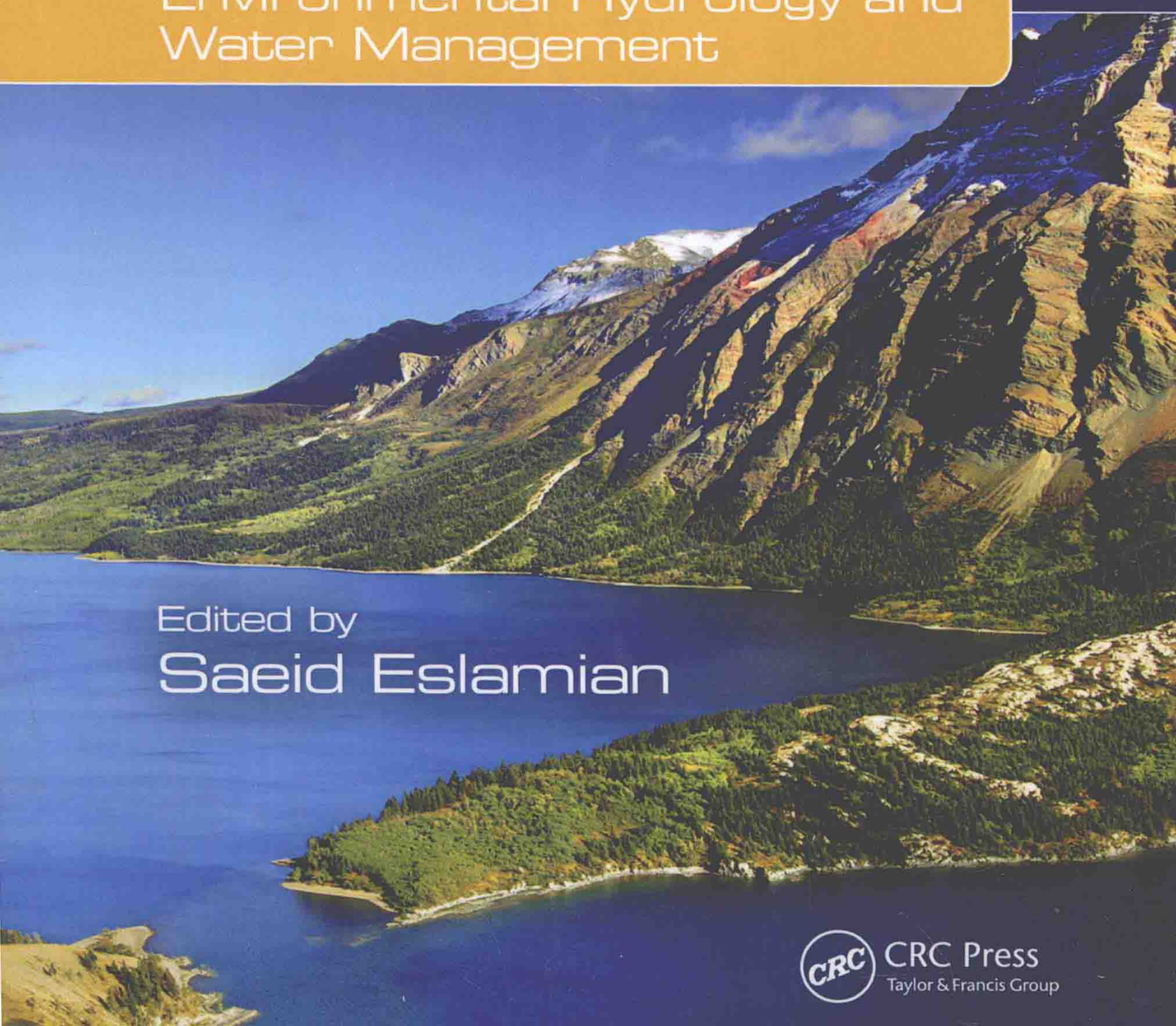
Handbook of Engineering Hydrology

Environmental Hydrology and Water Management



Edited by
Saeid Eslamian

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Preface

Hydrological and ecological connectivity is a matter of high concern. All terrestrial and coastal ecosystems are connected with water, which includes groundwater, and there is a growing understanding that "single ecosystems" (mountain forest, hill forest, mangrove forest, freshwater swamp, peat swamp, tidal mudflat, and coral reef) that are actually the result of an artificial perception and classification can, in the long term, only be managed by a holistic vision at the watershed level. It is essential to investigate ecosystem management at the watershed level, particularly in a changing climate.

In general, there are two important approaches:

1. Adaption to hydrological events such as climate change, drought, and flood
2. Qualitative and quantitative conservation of water, thereby optimizing water consumption

The *Handbook of Engineering Hydrology* aims to fill the two-decade gap since the publication of David Maidment's *Handbook of Hydrology* in 1993 by including updated material on hydrology science and engineering. It provides an extensive coverage of hydrological engineering, science, and technology and includes novel topics that were developed in the last two decades. This handbook is not a replacement for Maidment's work, but as mentioned, it focuses on innovation and provides updated information in the field of hydrology. Therefore, it could be considered as a complementary text to Maidment's work, providing practical guidelines to the reader. Further, this book covers different aspects of hydrology using a new approach, whereas Maidment's work dealt principally with classical components of hydrologic cycle, particularly surface and groundwater and the associated physical and chemical pollution.

The key benefits of the book are as follows: (a) it introduces various aspects of hydrological engineering, science, and technology for students pursuing different levels of studies; (b) it is an efficient tool helping practitioners to design water projects optimally; (c) it serves as a guide for policy makers to make appropriate decisions on the subject; (d) it is a robust reference book for researchers, both in universities and in research institutes; and (e) it provides up-to-date information in the field.

Engineers from disciplines such as civil engineering, environmental engineering, geological engineering, agricultural engineering, water resources engineering, natural resources, applied geography, environmental health and sanitation, etc., will find this handbook useful.

Further, courses such as engineering hydrology, groundwater hydrology, rangeland hydrology, arid zone hydrology, surface water hydrology, applied hydrology, general hydrology, water resources engineering, water resources management, water resources development, water resources systems and planning, multipurpose uses of water resources, environmental engineering, flood design, hydrometeorology, evapotranspiration, water quality, etc., can also use this handbook as part of their curriculum.

This set consists of 87 chapters divided into three books, with each book comprising 29 chapters. This handbook consists of three books as follows:

1. Book I: Fundamentals and Applications
2. Book II: Modeling, Climate Change, and Variability
3. Book III: Environmental Hydrology and Water Management

This book focuses on environmental hydrology and water management. The chapters can be categorized as follows:

- *Groundwater management:* Anthropocenic Aquifer: A New Thinking, Artificial Recharge Experiences in Semiarid Areas, Groundwater Vulnerability, and Hydrofracturing and Environmental Problems.
- *Purification, sanitation, and quality modeling:* Disinfection of Water and Nanotechnology, Environmental Engineering for Water and Sanitation Systems, Environmental Nanotechnology, Modeling of Wetland Systems, Nonpoint Source and Water Quality Modeling, Water Pollution Control Using Low-Cost Natural Wastes, and Water Supply and Public Health and Safety.
- *Surface water management:* Environmental Flows, River Managed System for Flood Defense, Stormwater Modeling and Management, Stormwater Modeling and Sustainable Management in Highly Urbanized Areas, Tourism and River Environmental Hydrology, and Transboundary River Basin Management.
- *Wastewater and sediment management:* Historical Development of Wastewater Management, Sediment Pollution, and Sustainable Wastewater Treatment.
- *Water law:* Water Governance, Water Scarcity, and Water Security: Concept, Measurement, and Operationalization.
- *Water resources management:* Formation of Ecological Risk on Plain Reservoirs, Modification in Hydrological Cycle, Sustainable Development in Integrated Water Resources Management, Transboundary Water Resource Management, Updating the Hydrological Knowledge: A Case Study, and Water Resources Assessment in a River using AVSWAT Model.

About 200 authors from various departments and across more than 30 countries worldwide have contributed to this book, which includes authors from the United States comprising about one-third of the total number. The countries that the authors belong to have diverse climate and have encountered issues related to climate change and water deficit. The authors themselves cover a wide age group and are experts in their fields. This book could only be realized due to the participation of universities, institutions, industries, private companies, research centers, governmental commissions, and academies.

I thank several scientists for their encouragement in compiling this book: Prof. Richard McCuen from the University of Maryland, Prof. Majid Hassanizadeh from Utrecht University, Prof. Soroush Sorooshian from the University of California at Irvine, Profs. Jose Salas and Pierre Julien from Colorado State University, Prof. Colin Green from Middlesex University, Prof. Larry W. Mays from Arizona State University, Prof. Reza Khanbilvardi from the City College of New York, Prof. Maciej Zalewski from the University of Łodz′-Poland, and Prof. Philip B. Bedient from Rice University.

In addition, Research Professor Emeritus Richard H. French from Las Vegas Desert Research Institute, who has authored the book *Open Channel Hydraulics* (McGraw-Hill, 1985), has encouraged me a lot. I quote his kind words to end this preface:

> My initial reaction to your book is simply WOW!
>
> Your authors are all well known and respected and the list of subjects very comprehensive. It will be a wonderful book. Congratulations on this achievement.

Saeid Eslamian
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Editor

Saeid Eslamian is an associate professor of hydrology at Isfahan University of Technology, Iran, where he heads the Hydrology Research Group at the Department of Water Engineering. His research focuses mainly on statistical and environmental hydrology and climate change. In particular, he specializes in modeling and prediction of natural hazards including floods, droughts, storms, wind frequency, and groundwater drawdowns, as well as pollution in arid and semiarid zones, particularly in urban areas.

Prof. Eslamian was born in Isfahan, a large city located in the center of Iran. He received his BS in water engineering from Isfahan University of Technology in 1986. Later, he was offered a scholarship for a master's degree at Tarbiat Modares University, Tehran. He completed his studies in hydrology and water resources in 1989. In 1991, he was awarded a grant for pursuing his PhD in civil engineering at the University of New South Wales, Sydney, Australia. His supervisor was Professor David H. Pilgrim, who encouraged him to conduct research on regional flood frequency analysis using a new region of influence approach. Soon after his graduation in 1995, Eslamian returned to Iran and worked as an assistant professor at Isfahan University of Technology (IUT). In 2001, he was promoted to associate professor.

Eslamian was a visiting professor at Princeton University, Princeton, New Jersey, in 2006 and at the University of ETH Zurich, Switzerland in 2008. During this period, he developed multivariate L-moments for low flow and soil–moisture interaction.

Eslamian has contributed to more than 300 publications in books, research journals, and technical reports or papers in conferences. He is the founder and chief editor of the *International Journal of Hydrology Science and Technology* and the *Journal of Flood Engineering*. He also serves as an editorial board member and reviewer of about 30 Web of Science (ISI) journals. Recently, he has been appointed as the chief editor for a three-set book series Handbook of Engineering Hydrology by Taylor & Francis Group (CRC Press).

Prof. Eslamian has prepared course material on fluid mechanics, hydraulics, small dams, hydraulic structures, surface runoff hydrology, engineering hydrology, groundwater hydrology, water resource management, water resource planning and economics, meteorology, and climatology at the undergraduate level and material on evapotranspiration and water consumption, open channel hydraulics, water resources engineering, multipurpose operation of water resources, urban hydrology, advanced hydrology, arid zones hydrology, rangeland hydrology, groundwater management, water resources development, and hydrometeorology at the graduate level.

He has presented courses on transportation, Energy and Agriculture Ministry; and different university departments in governmental and private sectors: civil engineering, irrigation engineering, water engineering, soil sciences, natural resources, applied geography, and environmental health and sanitation.

Eslamian has undertaken national and international grants on "Studying the impact of global warming on the Kingdom of Jordan using GIS," "Study of the impact of different risk levels of climate change on Zayandehroud River Basin's climatic variables," "Feasibility of reclaimed water reuse for industrial uses in Isfahan Oil Refining Company," "Microclimate zoning of Isfahan city and investigation of microclimate effect on air temperature, relative humidity and reference crop evapotranspiration," "Feasibility of using constructed wetland for urban wastewater," "Multivariate linear moments for low flow analysis of the rivers in the north-eastern USA," and "Assessment of potential contaminant of landfill on Isfahan water resources." He has received two ASCE and EWRI awards from the United States in 2009 and 2010, respectively, as well as an outstanding researcher award from Iran in 2013. Persian being his native language, Prof. Eslamian is also fluent in English and is professionally familiar with French and Arabic.

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Anthropocenic Aquifer: New Thinking

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Frederik Stefanus Botha has a PhD from the University of Free State. He is a water resource specialist, with a PhD in groundwater and MSc in engineering geology, with 15 years of experience in the government and private sector in both South Africa and Australia. He was involved in a number of water resource assessment and planning studies and recently his focus has shifted to mine water management and planning. He works both at strategic and implementation levels. His most recent work (2012) included the optimization of water use at Vanggatfontein for Kenton Energy. The result is that the mine can now operate with lower levels of raw water input thereby setting new production records. He is also directly involved in the platinum sector.

PREFACE

With South Africa transitioning to a situation in which future economic growth and development is likely to be constrained by the fact that almost all of the national water resources have already been allocated to various users, the issue of alternative management paradigms becomes relevant. Given that South Africa has a mining-based national economy, the role of the mining sector in the development of possible future solutions to the constraints of fundamental water scarcity is starting to be explored. Traditionally, the hydraulic foundation of the national economy has been based on the capture of streamflow in large dams, so an alternative resource utilization paradigm based on the management of evaporative losses is becoming relevant. One possible approach is to store water in aquifers rather than dams, with the obvious advantage being the significant reduction in evaporative losses. Taking this logic one step further, this chapter explores the notion of using mining methods to deliberately engineer an aquifer as a component of a planned mine closure strategy. This provides benefits to society, mostly in the form of improved water yields arising from a significant reduction in evaporative losses. However, it also provides potential benefits to mining, most notably in the reduction of post-closure liabilities. It is therefore argued that the use of a reengineered mine void as an anthropocenic aquifer can change the business case for mining while also yielding other benefits to society in water-constrained countries.

1.1 Introduction

There is converging opinion among scientists that we are now living in a new geological epoch known as the Anthropocene [56,57]. This recognizes the impact that human beings have on processes that create the earth, raising the question of how we can continue to do this in a responsible manner. This chapter makes the case for an engineered aquifer (anthropocenic aquifer) as an element of responsible mine engineering in water-constrained areas that are ecologically and culturally sensitive.

1.2 Understanding the Anthropocene

The earth has evolved over geological timescales, each with clearly discernible characteristics, often associated with the stratigraphy of specific sedimentary rock sequences [23]. Transitions between epochs need to present clearly discernible signals that are omnipresent in all rocks of a given sequence globally, and approved by the International Commission on Stratigraphy, in order to be officially recognized. An example of such a transition is the so-called K-T boundary, which refers to the transition between the Cretaceous (abbreviated as "K") and Tertiary (abbreviated as "T") period, dated back to 65.5 (±0.3) million years before present [28]. This coincides with the end of the Mesozoic and the start of the Cenozoic Era, which occurred when a number of meteorites struck the earth [31], one known to be at Chicxulub on the Yucatan Peninsula [24,35]. The significance lies in the fact that the K-T boundary is rich in iridium, a rare radioactive element closely associated with meteorites [29], found in this specific geological stratum at levels many times stronger than background values [2]. The transition from the Cretaceous to the Tertiary period is thus identified by a strong iridium signal that is clearly discernible and totally unique.

The Holocene–Anthropocene transition on the other hand is a recent event. While there is not yet total consensus on the exact date of this, there is growing consensus on the existence of the Anthropocene [56,57], with some scientists now advocating 1945–1950 as the actual date of transition [27], citing the existence of elevated levels of radionuclide and heavy metals in recent sediment samples taken from major river systems, all showing a discernible spike at that specific date. In this context, it is the elevated levels of radionuclide and heavy metals in river sediments (rocks of the future) that provide the peculiar signal in much the same way as iridium levels do in the K-T boundary. Significantly it is the existence of elevated levels of both radionuclide and heavy metals that characterize the South African aquatic ecosystems' draining areas of mining activities, suggesting that the Anthropocene signature is strong in that country, but more specifically along the Witwatersrand Mining Basin [10–12,51,54,55]. The most probable transition date (1945–1950) is associated with the advent of deep-level gold mining in the Far Western Basin, closely associated with high volumes of uraniferous tailings [26] and peak gold production [20].

It is therefore suggested in this chapter that the Holocene–Anthropocene transition in South Africa occurred around 1945–1950 when elevated levels of radionuclide and heavy metals started to report to the various wetland systems draining the continental watershed divide between the Orange and Limpopo River Basins. This watershed divide coincides with the Witwatersrand Mining Basin, which is characterized by varying strata of gold-bearing reef that is overlain to a large extent by one of the largest karst aquifer systems in the world [8,25,40,53]. The unintended consequence of mining is thus associated with heavy metal and radionuclide accumulations that can become impediments to the developmental potential of the country if left unmanaged [17]. This demands new thinking for responsible mining in South Africa, specifically with respect to the attenuation of pollution plumes.

1.3 South African Hydrology

South Africa has a mining-based national economy that is also water constrained [47]. The annual average precipitation is a paltry 497 mm/year with a high gradient from east to west [4]. The National Water Resource Strategy (NWRS), the official strategic planning document on which all government allocations are based, indicated that by the year 2000, South Africa had already allocated approximately 98% of its total national water resource at a high assurance of supply level [32]. Consistent with the concept of aridity, the evaporative demand to the atmosphere is very high, often exceeding the precipitation levels two- to threefold.

Furthermore, many of the 19 water management areas (WMAs) are overallocated, with some by as much as 120%. The most stressed of these WMAs also coincide with the hydrological boundaries of the Limpopo River Basin, which is shared by four countries—Botswana, South Africa, Zimbabwe, and Mozambique—to the extent that the basin is now closed with demand exceeding supply [46]. One of the major drivers of future development will continue to be mining, with significant mineral resources in the water-constrained areas. The most notable of these are platinum group minerals associated with the Bushveld Igneous Complex (BIC) in the North West Province and coal in Mpumalanga and Limpopo Provinces, all of which are located in different portions of the Limpopo River Basin. This raises the issue of the future role that mining can play, not only in creating the foundation for economic development in the short-term, but also by improving water security at local level that will benefit society during the post-closure phase of mining.

Two latent aspects need to be highlighted in order to substantiate the case being argued:

- The conversion ratio of mean annual precipitation (MAP) to mean annual runoff (MAR)
- The ramifications arising from what is known as the hydraulic density of population

The MAP–MAR conversion ratio gives an indication of the rate at which rainfall and other precipitation is converted into water in a river that can be used as the hydraulic foundation to economic development. In this regard, the MAP–MAR conversion at continental level in Africa is a paltry 20%, compared to that of Asia and North America (45%), South America (43%), and Europe, Australia, and Oceania (35%) [18,48]. This means that Africa as a continent is the least endowed with water when reflected as the natural capacity to convert MAP to MAR, to the extent that the continent is referred to as being "hostage to hydrology" [19]. This arises from the fact that economic performance of many African countries is closely correlated to rainfall. Conceptually, this suggests that the existence of hydraulic infrastructure decouples economic development from fundamental environmental drivers such as rainfall.