Groundwater Management in Large River Basins

Milan A. Dimkić
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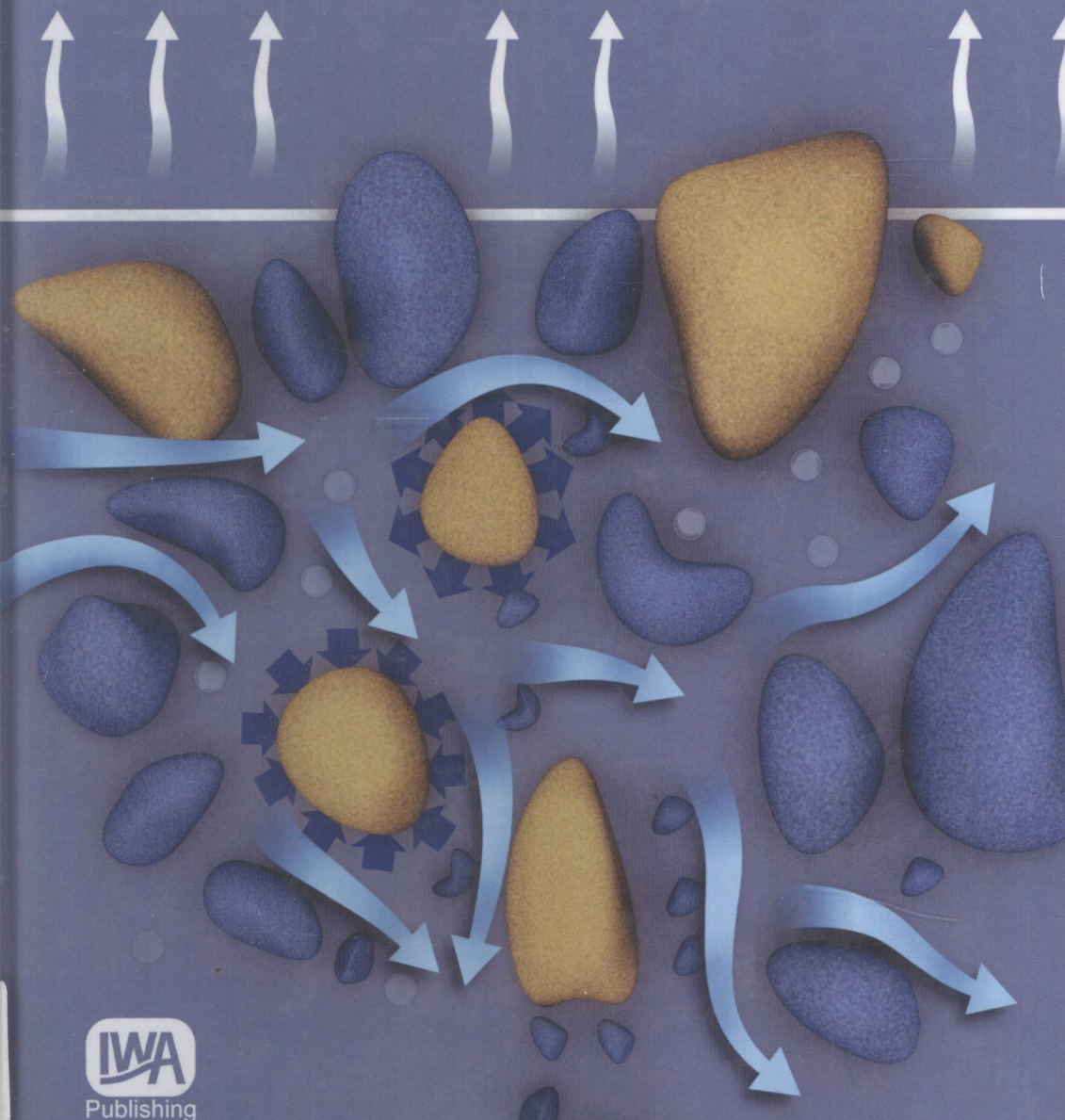
Michael Kavanaugh



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Edited by
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GROUNDWATER MANAGEMENT IN LARGE RIVER BASINS

Preface

Apart from glaciers, groundwater is quantitatively the most significant freshwater resource on the planet Earth. At the same time, it is the most often used and preferred drinking water resource. Groundwater ensures the continuity of streams during dry periods and the survival of numerous wetlands which sustain biodiversity.

Groundwater is part of the natural water cycle, and groundwater management is part of water management. However, groundwater is special in many ways. The velocity of groundwater flow is generally in the order of one meter per day, while that of rivers is in the order of one meter per second. A solute in an aquifer remains exposed for a long time to various physical and biochemical processes that take place in groundwater, the aquifer skeleton, or at the interfaces between different phases (water, skeleton, air).

In view of the flow velocity and the extent of the processes, the nature of groundwater is more local than that of surface water. Still, there are many groundwater bodies which are shared by several countries and whose management of quality and quantity regimes requires a joint effort.

Many books which address groundwater processes and groundwater treatment have been published. However, there is a notable demand for literature which discusses the specifics of groundwater management, particularly groundwater management in large river basins. This is especially true in Europe, where there is a stringent timeframe for the development of River Basin Management Plans, within the scope of implementation of the EU Water Framework Directive.

In June 2007, a regional IWA conference, Groundwater Management in the Danube River Basin and Other Large River Basins, was held in Belgrade. In addition to the International Water Association (IWA), the International Association of Waterworks in the Danube Catchment Area (IAWD), and the International Commission for the Protection of the Danube River (ICPDR), this Conference was sponsored by UNESCO, the Serbian Government, and the Serbian Academy of Sciences and Arts. The Conference was organized by the Jaroslav Černi Institute for the Development of Water Resources and the Belgrade Waterworks and Sewerage Public Utility. One

of the follow-up points agreed to at the conclusion of this successful conference was to write the book you are now holding in your hands and thereby extend the valuable knowledge gained and shared at the conference. Milan A. Dimkić, Heinz-Jürgen Brauch and Michael Kavanaugh were appointed as editors of the book.

This book addresses the socio-economic and organizational framework of groundwater management, as well as the natural processes and methods which we can use to formulate and implement groundwater management objectives.

The book is meant to offer planners additional insight into groundwater management issues. Professors who address groundwater issues will also find it helpful, as will advanced post-graduate and post-doctoral students, and engineers who wish to dwelve deeper into this topic.

We have attempted to write the book so it can be read in its entirety and thus provide a comprehensive insight, but also to allow for each chapter to be read individually, to gain insight into a specific subject matter.

This book is founded on the outcomes of the Belgrade Groundwater Conference; the works and tradition of the "Belgrade School of Groundwater", the Jaroslav Černi Institute, and the TZW Institute from Karlsruhe; and experience gained in the course of remediation of polluted groundwater sites in the USA. The exchange of ideas at meetings with the IAWD Technical Group and the ICPDR Groundwater Task Group has also added to the value of the material.

Contributions from more than twenty authors in a number of different countries have come together to make this book a reality. Several hundred sources have been cited, both old and new.

Working with the three editors, Philippe Quevauviller co-edited Chapter 2 and Milenko Pušić co-edited Chapter 5.

A number of individuals have also lent their hand to the creation of this book through peer reviews and assistance with the preparation of the manuscript. We will begin by acknowledging the work of Miodrag Milovanović (who is also one of the contributing authors), and of Milan Peca Nikolić. Biljana Potkrajac, Brankica Majkić, Mladen Jordanovski, and Viktor Babić, among others, were instrumental in typesetting and checking the text. Special credit for translating parts of the text into English goes to Dubravka Miladinov who, along with Beverly Lynch, also proofread the final version of the book. We would also like to thank all those whom we are unable to mention here, but whose help and contributions are greatly appreciated.

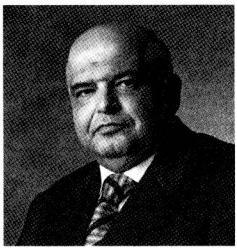
We wish to extend our special gratitude to Hans Sailer, President of the IAWD, and Philip Weller, Executive Secretary of the ICPDR, and Vladimir Taušanović, general manager of Belgrade Waterworks and Sewerage, for their support during the writing and promotion of this book.

For their understanding and patience, as well as their valuable technical assistance, we wish to thank David Burns, Michael Dunn, and their excellent team from the IWA.

Last but not least, we would like to thank the families of the editors and contributors who supported and accepted the intensive efforts which went into the creation of this book.

Milan A. Dimkić, Heinz-Jürgen Brauch and Michael Kavanaugh

Editors



Dr. Milan A. Dimkić was born in 1953 in Belgrade, Serbia. He graduated from the Mathematics Gymnasium and obtained his Bachelors degree in Hydraulic Engineering from the University of Belgrade, Faculty of Civil Engineering, where he also completed his Masters degree and his PhD. His professional and scientific career is closely linked to the Jaroslav Černi Institute for the Development of Water Resources, where he founded and developed the Department of Groundwater Protection. From 1999 to the present, he has held the position of Director General of the Institute.

In his professional career, Dr. Dimkić has encountered countless groundwater protection cases, and dealt with the protection and remediation of heavily-polluted groundwater resources. He has also participated in the design and development of numerous groundwater sources, the planning and development of hydraulic engineering systems, and the development of water management.

Dr. Dimkić has made significant professional and scientific contributions in the areas of:

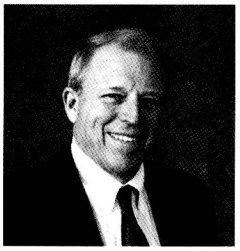
- Groundwater flow in confined aquifers, including compressible soil characteristics;
- Purification processes during groundwater flow;
- Specific technical issues related to groundwater extraction;
- Protection and regeneration of the quality of groundwater resources; and
- Management of water resources.

Dr. Heinz-Jürgen Brauch was born on 23th January 1953. He studied chemistry at Karlsruhe Technical University from 1974-1980. After that he finished his PhD work on "Adsorption of NOM onto activated carbon" in 1984 and got a PhD degree in Chemical Engineering. From 1984-1989 he worked as a scientist at the DVGW-Research Center in Karlsruhe. His special interests are inorganic and organic micropollutants, from their analytical determination to the occurrence in the aquatic environment and their fate during drinking water treatment.

Since 1990 he is the head of the Analytical Department of TZW, the research institute of the German Gas and Water Works. He is involved in national and international research programmes, monitoring activities on surface water and groundwater, water quality management as well as analytical and technical issues.

From 1993 up to now Heinz-Jürgen Brauch is a lecturer at the Technical University of Dresden and is honorary professor since 2005.

He published more than 150 scientific papers and was directly involved in 30 research projects. He is a member of national and international scientific groups.



Dr. Michael C. Kavanaugh is Vice President and the Global Science and Technology Leader for Malcolm Pirnie, Inc. He is a chemical and environmental engineer with over 35 years of consulting experience. Dr. Kavanaugh has been project engineer, project manager, principal-in-charge, technical director or technical reviewer on over 200 projects covering a broad range of environmental issues. He has co-authored over 35 peer reviewed technical publications, edited two books, and has made over 100 presentations to technical audiences, legislative bodies, and public advocacy groups. He has chaired two boards under the National Research Council, the Water Science and Technology Board from 1989 to 1991 and the Board on Radioactive Waste Management from 1998 to 2000. Dr. Kavanaugh has a B.S. and a M.S. in Chemical Engineering from Stanford and UC Berkeley, respectively and a PhD in Civil/Environmental Engineering from UC Berkeley. He was a Peace Corps volunteer in Guatemala from 1964 to 1966. He is a registered professional engineer in California and Michigan and a Board Certified Environmental Engineer by the American Academy of Environmental Engineers. Dr. Kavanaugh is also a Consulting Professor in the Civil and Environmental Engineering Department of Stanford University. He was elected to the National Academy of Engineering in 1998.

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Numbers in the parentheses indicate the chapters of authors' contribution

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Introduction

M. Dimkić, H. J. Brauch, M. C. Kavanaugh (Eds.)

Groundwater is an exceptionally important component of the water system on the planet Earth. It is the dominant source of the supply of drinking water. During dry periods, groundwater is also a major contributor to river flow. Furthermore, groundwater is important for the creation and conservation of wetlands, and also of oases in arid regions. It is a very popular source of public water supply because of the accessibility and self-purification properties of aquifers, but also because of a traditionally positive attitude toward this resource. It is also an archetype which many of us associate with the beauty and power of a mountain spring. Our people, in fact, have a saying that "in order for water to be drinkable, it needs to pass over seven stones".

All over the world, people use groundwater as their main resource for drinking water. However, occasionally the question is raised: Why do we use groundwater so often?

The response to this question is sometimes rather banal: "Groundwater is used when technical and economic assessments indicate that it is more appropriate than any other competing resource".

This leads to a further question: Why do we use groundwater so often, even when the source is distant and the abstraction costly? Part of the answer can be attributed to self-purification processes which take place in groundwater.

These processes result in the stabilization, and in most cases, improvement of groundwater quality.

Tradition is another factor which leads people to demand water from this resource. Professional and scientific practice shows that an intergranular aquifer is often comparable to an extensive physical and biochemical reactor. As such, it contributes to the safety of water supply and to a general improvement of

groundwater quality. Coupled with this is the fact that the aquifer environment is extremely heterogeneous, and processes which take place during groundwater percolation are numerous, as are their effects.

Groundwater resources are managed in an integrated manner, within the scope of the overall natural water cycle and overall human activity. However, the nature of groundwater is such that the approach in addressing problems relating to groundwater resources is somewhat different from that which is applied in addressing surface water problems.

Over time, water management has evolved into a very complex pattern of inter-dependent activities. These activities affect water quality, the water regime, water use, and protection against the adverse effects of water.

Water management involves many areas of human activity and constitutes a very large system. Its proper function largely determines the state of a human community, and is even a pre-condition for its survival.

In many areas, groundwater used to be a virtually inexhaustible source of water supply, and was convenient because it was accessible, and because it continued to deliver a good quality of water. However, increasing rates of abstraction and the broadening scope of human activity have led to increased constraints on water management, including the use and protection of groundwater. Water use and water management can be divided into three stages:

Stage 1: Abundance: Water use and water pollution are low relative to available resources.

Stage 2: Depletion: Water use and water pollution are considerable relative to available resources, leading to a gradual depletion of resources.

Stage 3: Sustainable development: Water management must be implemented in such a way as to conserve good water status and avoid the depletion of resources to future detriment.

Water management within large river basins is both an important and a challenging issue. Throughout the world, major efforts are being made to achieve sustainable development of water systems. However, their success depends on two major factors which largely determine the ability to achieve sustainable management of water resources in various countries and regions: natural abundance of water and economic power.

In an ideal situation, there is an abundance of natural resources and a substantial economic power enjoyed by the society; in such a situation there are no major impediments to establishing sustainable management of water resources.

However, many countries are unable, either because of their low economic power or sparse resources, to implement sustainable management of water (or groundwater) resources at this time. Such countries will have to continue to utilize non-renewable or slowly-renewable groundwater resources for some time, in order to provide drinking or irrigation water.

Climate change on the planet Earth is currently affecting and will increasingly continue to affect the nature of water management. It has been recognized that

climate change has resulted in a re-distribution of atmospheric precipitation with regard to area, intensity and time. Areas which used to be green are now becoming arid. There is a fear at present that such changes, believed to have been brought about by global warming, will intensify.

Water management, therefore, needs to be adaptive. It should take into account the specificities associated with the natural and socio-economic status of individual areas, as well as those associated with potential climate changes, while striving to achieve sustainability.

Compared to surface streams, the velocity of groundwater flow is much lower. Substances dissolved in groundwater are exposed to physical and biochemical processes over long periods of time. Additionally, groundwater quality transformation processes are more local in nature than those of surface streams.

Consequently, issues relating to disturbances and protection of groundwater quality have also more of a local nature than those of surface water. However, over-exploitation is an issue which can affect vast areas and aquifers that extend across two or more countries.

The role of global and regional institutions should be to provide a common denominator for efforts aimed at achieving the highest possible sustainability of groundwater management.

The importance and nature of groundwater resources call for mankind to act at global, regional, and local levels. Groundwater management requires appropriate legislation, infrastructure and socio-economic framework, as well as proper planning and undertaking of engineering measures in the field.

Each of these levels is specific in both hydrologic and economic terms, and appropriate mechanisms must be found at each level in order to ensure either sustainable management of groundwater resources or appropriate management which will lead to sustainability in the future (adaptive management).

At the *global level*, mechanisms need to be established which suit countries and regions which abound in water and are economically powerful, and those which are deficient in both water and economic power. The United Nations should assume an important role – through UNESCO and its other divisions – in the creation of a legal framework for international cooperation based on the principles of sustainability, adaptivity, and solidarity. Global water associations, such as the IWA, should make significant contributions toward this goal by building capacity in these areas, disseminating knowledge, creating links between regions at different levels of development, and so on.

At a *regional level*, the ultimate goal is to establish a legal and institutional framework for such water management. In some regions, especially those which are economically powerful, the establishment of sustainable water management is already under way. For example, European water directives promote water protection and sustainable water management. Many European countries have invested heavily in water protection. A good example is the Danube River Basin, where a number of countries are successfully cooperating within the scope of the International Commission for the Protection of the Danube River (ICPDR).

The European Water Framework Directive, Groundwater Directive, and various other documents set criteria for the management of groundwater resources. Associations of water supply providers (e.g., the IAWD), which operate within the same river basin, also contribute to the setting of unique criteria for sustainable water management. On the other hand, some regions (Saharan countries) are establishing frameworks for the management of water resources which are either slowly-renewable or non-renewable.

At a *local level*, it is important to ensure appropriate legal, social, economic and other mechanisms to achieve the highest possible sustainability of groundwater management. Local measures should include budgeting, monitoring and protection of both groundwater as a resource and of individual groundwater sources of water supply.

Protection of a groundwater resource should include restrictions associated with the protection of groundwater quality (e.g., restricted use of fertilizers). More stringent restrictions should be imposed on groundwater sources of drinking water supply. In both cases (groundwater resources and groundwater sources), the numerous processes which lead to self-purification during percolation of groundwater should also be addressed. Local regulations and the national infrastructure generally define criteria for operator performance and set water tariffs which can support adequate management of groundwater resources.

This book purports to collect and build upon the achievements of the Regional IWA Conference Groundwater Management in the Danube River Basin and Other Large River Basins, which was held in Belgrade in June of 2007. Its goal is to allow the reader to gain insight into the world of groundwater resource management:

- For experts, this book will constitute a review of sorts which might provide some new information or firmer insight into specific topics;
- For planners and decision-makers, this book will provide an opportunity to familiarize themselves in a specific way with the various elements of groundwater planning and management; and
- For advanced students, this book will provide an opportunity to more deeply into groundwater problems.

The first effective chapter (formally Chapter 2) is an attempt to address the entire natural and socio-economic framework of groundwater management in large river basins, as well as in large groundwater basins in general. This chapter includes an overview of the types of groundwater resources and provides insight into the present state and potential effect of climate change on groundwater management. It also addresses the legislative framework relating to groundwater at global, regional and local levels. Additionally, this chapter raises questions regarding the economic and financial system which is necessary for successful management of groundwater resources. It describes achievements in legislation and groundwater management in Europe; the Danube River Basin, in particular, is a good example of water and groundwater management which purports to achieve sustainability. Finally, the chapter contains overviews of groundwater management in several countries.