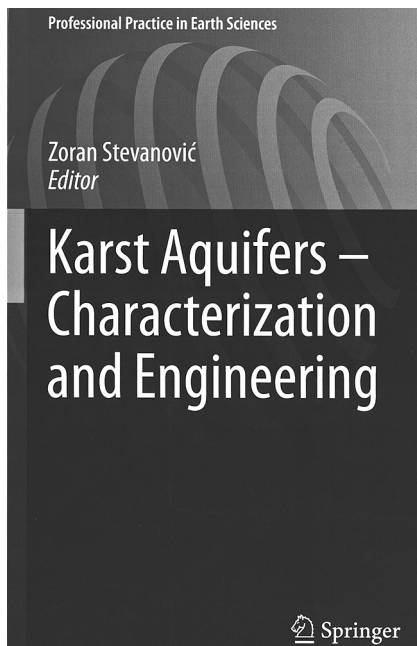


Book reviews

Karst aquifers – characterisation and engineering, by Zoran Stevanović (Ed.), 2015. Springer International Publishing, Switzerland. 692 pages. Hardback: price \$219.99, ISBN 978-3-319-12849-8; paperback: price \$199.99, ISBN 978-3-319-35422-4.



The scientific literature on karst hydrogeology has acquired a new valuable contribution, published by Springer within the framework of the Professional Practice in Earth Sciences Series. The tome was edited by Prof. Zoran Stevanović, a well-known karstologist with great international reputation. The team of authors comprised experienced researchers with an extensive scientific output in the field of karst hydrogeology, as well as young researchers, generally their students. In the introduction, Prof. LaMoreaux writes that the book helps to understand the complex issue of karstic environments better, and thus can facilitate decisions in the management of karst aquifers. This appears to be the principal goal of all authors of this tome which covers a wide range of problems linked to karst hydrogeology. Numerous high-quality illustrations, photographs and well-described case studies lend the book the character of an excellent textbook useful for those involved in geology and especially in karstic problems.

The present book is divided into three parts: I. 'Characterisation of karst aquifers', II. 'Engineering

aspects of control and protection of karst aquifers' and III. 'Regulating and protecting karst aquifers – case studies'.

The first part presents a historical overview of karst research (LaMoreaux and Stevanović). The history from the period of the Bible up to the present day is described, with emphasis on the history of karst investigations. A special space is dedicated to its founding fathers, namely H. Darcy (hydrogeology) and J. Cvijić (karstology). This is without doubt an interesting topic showing the development of scientific ideas in hydrogeology and especially in karst hydrogeology.

In general, karst aquifers are the most complex hydrogeological environments and their physical and mathematical description is very difficult in view of their extreme heterogeneity and anisotropy of hydraulic parameters.

Perhaps there is a lack of information about two fundamental theories of flow in karst that developed simultaneously from the start of the twentieth century. A. Grund (in his 1903 paper) suggested that karst environments were a continuum that took part in the flow of groundwater. This view was applied to the study of flow patterns in carbonate rocks (Motyka, 1998; Zuber & Motyka, 1998). On the other hand, Martel (1921) developed the ideas of Cvijić (1918) about flow in 'underground rivers' in karst systems. This approach considers a system of a hierarchical net of groundwater flow in karst aquifers, later suggested by A. Mangin. Unfortunately, 'the Vienna school', represented by Grund, remained in the periphery of karst hydrogeology, now dominated by 'the Paris school' of Cvijić and Martel.

The second part, presented by Z. Stevanović, covers a large spectrum of issues in karst environments. There is the interesting topic of caves as shelters for humans and animals, general processes of carbonate and evaporate dissolution, regional distribution of karst phenomena and its classification on the basis of geological criteria (geosynclines, carbonate platforms, hypogenic and evaporate karsts) and climatic criteria (tropical karst, glacial karst).

However, it is questionable if geological and climatic criteria can be grouped. Also, it is unclear if glacial karst (thermokarst) belongs here, because its origin is linked to melting ice and not to the chemical dissolution of rocks. However, the community of karstologists have accepted the term “glacial karst”, but perhaps a more convenient term should be found for karstic forms in glaciers similar to those in carbonates and evaporates. On page 26, it should of course have been “halite (NaCl)” rather than “halite (HCl)”.

Next is an important chapter by Z. Stevanović on the characterisation of karst aquifers; this is a good introduction to the complexity of karst environment for readers. In the introductory part, the author presents a philosophical question regarding the possibility of characterisation of karst aquifers and simultaneously supplies the answer by using his deep knowledge of such environments. We share his opinion about necessary humility in such characterisation. As stated earlier, this is an extremely heterogeneous and anisotropic environment. Also, considering the size of some karstic structures and the possibility of entering caves by humans, there is an important role for the scale of investigation. Here the classification of karst reservoirs by White (1969) would be useful.

There is a very interesting part about karst aquifers and their geometry. However, some statements presented here may be questioned, e.g., that karstification is the total conversion of primary into secondary porosity. When primary porosity is considered syngenetic porosity, bedding planes also fall into this category. In our opinion, the classification of Choquette & Pray (1970) is more convenient in this respect, because it is based on geometry, rather than genesis. It would have been useful to consider here the results of the conference entitled, ‘Evolution of karst: from prekarst to cessation’ held at Postojna in 2002 and published in *Acta Carsologica* (2002). In those proceedings, there is a detailed discussion of flow in karst, including recharge, discharge and water quality in karstic reservoirs.

In the chapter on methods applied in karst hydrogeology, N. Goldscheider presents their principles and applications in karst aquifers. He pays attention to the large heterogeneity of such hydrogeological environment where, in addition to common methods, e.g., geological, geophysical hydrogeological, hydraulic, hydrogeochemical and isotopic, other methods specific for karst are applied, e.g., tracer tests.

The second part of the book is dedicated to water reserves in karst aquifers. It guides the readers from the general characteristics of surface and ground waters to methods of evaluation of karst aquifer

recharge, vulnerability to contamination, types of karst flow modelling and tapping of karst groundwater. The chapter by O. Bonacci, a world-famous karstologist, on surface and ground waters in karst is clear, concise and comprehensive. It is based on the assumption that boundaries of karst aquifers have to be clearly defined. Very impressive conceptual models demonstrate the complexities of mutual relationships between surface and ground waters in karst.

Z. Stevanović dedicates the next chapter to water balance and calculation of groundwater reserves in karst. He presents water balance equations and methods of measurement or estimation of their parameters. One of them is the total error (E) of calculation as a sum of partial errors of each parameter in water balance, a concept which is not used in hydrogeological practice in Poland. General methods of water reserve calculations and case studies follow.

P. Malík, expert in this field, discusses in a detailed way discharge regimes of karstic aquifers. First of all, discharge regimes are defined. Special attention is paid to karst springs and an analysis of their temporal changes in discharge applying mathematical models. Classification of springs is presented on the basis of their hydrographs. Here we would have appreciated spectral analysis of springs by A. Mangin, which is different from standard forms of spring hydrograph descriptions. There are several case studies which, in an excellent way, demonstrate the theoretical principles presented.

The vulnerability of the karst environment is discussed by A.I. Marion and B. Andreo. They present several methods of vulnerability evaluation, taking into account the specific properties of karst environment and including several examples of their applications. It seems that the large number of possible methods for the evaluation of vulnerability complicates the choice of a method for any particular karst aquifer. It would be interesting to compare these methods in a single selected aquifer.

Physical modelling of karst environment by S. Milanović is based on 3-D numerical modelling, in which equations of water flow and chemistry are incorporated. Regional geological and hydrogeological factors are also taken into account. This is an interesting tool for studying and understanding of karst flow including prognosis. However, cave systems accessible to man in the vadose zone and at the boundary between the vadose and phreatic zones should also be considered in the modelling. This portion of the book is complemented by ‘Mathematical modeling of karst aquifers’ (A. Mikszewski and N. Kresić). There is no doubt that mathematical treatment of water flow in karstic environment is a real challenge. It is necessary to consider not

only the extreme heterogeneity, but also different types of flow (laminar and turbulent) in different karst zones. There also is scale effect, e.g., Kiraly (1975). The authors present the results of numerical modelling using several codes and results that are promising, but these are early days for difficult field of karst hydrogeology.

Next is a chapter in which Z. Stevanović describes various methods of tapping karst waters. He begins with karst springs, inclusive of Ancient Greece and Rome, and next discusses factors which should be considered when deciding about exploitation of a karst spring. Drilling of wells follows with the description of necessary steps to guarantee a satisfactory yield of a well (definition of water need, location of well, project, drilling technique, well design, well development, well testing and optimisation of exploitation).

S. Milanović and L. Vasić present the principal rules of monitoring of karst waters, location of monitoring points, type of monitoring (quantity, quality), sampling intervals and type of sampling equipment. There are numerous examples of monitoring in various karst regions.

Problems of engineering activities in karst are outlined by P. Milanović. In the introduction, he presents typical constructions such as dams, reservoirs, tunnels and man-made caverns. The last-named type is not explained clearly, but it seems that the author means mining works. This well-illustrated chapter presents case studies, including breaking of dams, in a very didactic way.

In the third part of this book, the regulation and protection of karst aquifers is presented in a selection of case studies. In the introductory chapter, Z. Stevanović defines three groups of problems in karst aquifers: 1. watering – effective utilisation of karstic water resources for the supply of drinking water and other purposes, 2. dewatering – mitigation of karst inflow in mining, urban areas and construction works, and 3. protecting – prevention of pollution and remediation of karst water quality. In the next step he describes and defines general scientific problems and provides examples of conceptual models for some engineering objects and engineering works in karst. This chapter is closed by general recommendations on how to exploit karst waters safely, without any negative ecological impact. This, of course, is a true challenge.

Next is a comprehensive chapter on karst groundwater availability and sustainable development by F. Fiorillo, V. Ristić Vakajanc, I. Jemcov, S. Milanović and Z. Stevanović, with a wide range of issues. The authors present a different approach to problems described in previous chapters of the

tome, e.g., the analysis of spring hydrographs. In this case there is an introduction to the stochastic approach that differs from the deterministic approach presented by P. Malik. It would have been better to have presented both approaches side by side because they are complementary. In this chapter there are several relatively complex methods of statistical analysis of spring hydrographs. Particular attention is paid to the protection of springs in dry period and during earthquakes. The link between both events is unclear and they would perhaps have deserved separate treatment.

The chapter dedicated to speleology and cave diving is very impressive, with excellent illustrations and photographs. The objective of this part of book is the exploration of accessible cave systems supporting decisions about tapping of karst waters. The author, S. Milanović, is aware of the fact that caves accessible to exploration are only a fraction of the system where groundwater in karst is transmitted and stored. We have noted a small terminological error on p. 477, instead of “specific yield” it should have been “specific capacity”. Z. Stevanović discusses briefly engineering regulations of karst waters in dry periods. He lists two principal groups of regulations: regulation in discharge zone and intervention in the wider catchment area. There is also a discussion of the triad *solution-impact-cost* of regulation in selected examples.

An extensive chapter, written by a group of authors, deals with the prevention of leakage and mixing of karst waters. In an introduction, S. Milanović presents the necessary studies needed for decisions regarding to locations of dams. There are well-illustrated and well-described case studies that are of great interest to readers. It is a pity that the numerous works of Adolfo Eraso Romero, who studied geological foundation and grouting of the base of dams at the end of the last century, are not mentioned here. Problems linked to mining activities in karst are described by V. Dragišić, who emphasises problems of inflow prediction into mining works caused by the extreme heterogeneity of karst environment and also changes of karst water quality caused by mining exploitation. He briefly outlines hydrogeological types of ore deposits in karst environments and presents case studies of groundwater inrush into mining workings and dewatering of ore deposits in karst aquifers. Finally, he only touches the complex problem of deterioration of karst water quality caused by mining exploitation.

Remote sensing applied to the mapping of karst is discussed by M.M. Radulović. He presents applications of remote sensing and GIS in the evaluation of fault density and karst mapping. The examples

presented are highly didactic. The final topic discussed by the author is sustainable tapping and the use of fresh karstic waters and their vulnerability to intrusions of salt and brackish water.

The final, comprehensive part of the book, written by a group of authors, is dedicated to hazards in karst regions and management of karst water quality. Following a brief introduction, M. Parise focuses on the peculiarity of karst using examples to discuss typical hazards in karst, such as sinkholes, mass movements and floods and, in the next step, he introduces their mitigation. N. Ravbar presents advanced strategies in managing and sustaining karst water quality, starting with the concept of vulnerability and contamination risk assessment and illustrating case studies of methods applied in karst.

V. Zivanović deals with the difficult issue of delineation of karst groundwater sanitary protection zones (SPZ). This is an ambitious issue from the viewpoint of the large volume of literature on mass transport and contamination in heterogeneous media with fracture-karstic permeability, where various mathematical models are applied. The author emphasises the geological point of view; we considered this to be a good approach. He applies the widely accepted method of isochrones and presents its applications in several European countries. He also presents, albeit briefly, the vulnerability and combined approach and applications of modelling using the program MODFLOP CFP. The next logical step is remediation of groundwater in karst by A. Mikszewski and N. Kresić. In their introduction they present schematic figures with popular and typical remediation methods and then discuss their pros and cons. The section on *in-situ* chemical oxidation (ISCO) and bioremediation seems to have been written in a technical language that is not very comprehensible to a hydrogeologist. The last part is dedicated to pump-and-treat remediation.

J. Mádl-Szőnyi presents a short, yet interesting overview of genesis and exploitation of thermal waters in deep carbonate systems. There is again an outline of problems and types of karst waters and an important discussion of thermal water genesis and impact of their pumping. Figure 17.34 is impressive in showing a flow of waters with different temperatures in a deep carbonate structure. The author stresses the importance of deep carbonate systems for the formation of CO₂, because CO₂-driven dissolution of carbonates increases transmissivity and, consequently, efficiency of thermal water capture. In this valuable overview, there are practical examples with illustrations and, finally, there is a short introduction of drilling methods in deep karst formations.

The final portion of the book by N. Kukurić is dedicated to transboundary aquifers (TBA) in karst. The author discusses political and practical problems connected to karst reservoirs shared by several countries that frequently have different laws and water policies. He presents a brief outline of transboundary aquifers across the world, but the map is not of good quality. Next he presents methodological issues and documents relating to TBA and prepared by various international organisations and gives examples of international treaties about TBA. Special attention is dedicated to the Dinaric karst region (DIKTAS).

The present tome is a very valuable contribution to the hydrogeology of karst regions. It can be used by both research and practising hydrogeologists and students. It is written in such a way that is accessible to all people who are interested in speleology and water in karstic structures. We believe that Jim LaMoreaux and Zoran Stevanović could stimulate work on a sequel that is dedicated to the properties of carbonate rocks, interpretations of pumping tests and hydrogeological problems in mining and mass transport in carbonate rocks, including vadose zones.

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