BOOK REVIEW

Enhanced Characterization and Representation of Flow through Karst Aquifers

S. L. Painter, A. Sun, and R. Green, 2007. AwwaRF Report 91139, Denver, Colorado, IWA Publishing (International Water Association), 104 p. ISBN 978-184339979-7, soft-bound, $240.

Karst aquifers are generally considered difficult or sometimes even impossible to characterize or to model mathematically. This is mainly because of their often extreme hydraulic heterogeneity and problems in detecting and characterizing karst conduits. Still, it is important to deal with karst groundwater quantitatively, since it constitutes important water resources and because the aquifer responses are highly variable in space and time. Aquifer-management issues are of prime importance. The very low storage and high hydraulic conductivity of most carbonate aquifers imply that groundwater storage volume might not last throughout lengthy droughts. Appropriate mathematical tools are required to manage groundwater resources properly by controlled pumping, conjunctive-use schemes, artificial recharge, etc. Also, runoff from extreme recharge events can be rapidly transmitted through karst systems and may contribute to flooding. Therefore, I welcome contributions to the methodology of modeling karst groundwater flow and transport. Most publications dealing with mathematical modeling of karst aquifers to date are based on working codes that are not widely available and are difficult to handle. Developing a code similar to the USGS MODFLOW would be a great step toward quantitative analysis of karst groundwater systems. Although not explicitly stated as a primary objective of this book, this was apparently the authors' intention. The book is written in a report style and includes project planning issues rather than just results. The AwwaRF Report Series has recently been retitled the Water Resources Foundation Report Series.

The Introduction (Chapter 1) describes the motivation, objectives, and structure of projects. While it covers the development of tools for flow simulation, the authors also develop a program package for the modeling of complex transport problems.

Chapter 2 is a short review that illustrates the importance of following a variety of pathways in the modeling of karst aquifers. The short description of karst classification includes descriptions of different types of karst aquifers and types of cave origin. The latter is not especially relevant in this context, since many caves (e.g., those developed under vadose conditions) are not necessarily compatible with the modeling. Few important karst aquifers are dominated solely by conduit flow. The authors confirm this in the section "Groundwater Flow Regimes." The relevance of their Figure 2.1 is not well substantiated: it shows a correlation between permeability and the age of the rocks. It demonstrates the large variability of hydraulic conductivity, but provides little information about how to make generalizations from the data. Better examples, or a schematic, would have better demonstrated the dual-flow response of springs and the coupling between matrix storage and conduit flow.

In Chapter 3, the main approaches for simulating flow in conduits are briefly summarized. The authors describe three different modeling approaches: the "smeared conduit" (an equivalent porous medium, single-continuum approach), the "embedded channel" (a hybrid, discrete pipe–continuum approach), and the "dual conductivity" (a dual-continuum approach). This classification follows that presented by earlier authors. Since no new concept is introduced, I suggest that the existing terminology could have been used to avoid confusion. The problem of employing appropriate flow laws, laminar or turbulent, is addressed, as well as the issue of representing flow in unconfined aquifers. Technical aspects such as the drying and rewetting of cells in MODFLOW and the necessity of specifying the vertical position of conduits for unconfined conditions are also addressed. In a numerical experiment, the effect of the flow law employed on the simulated head is demonstrated.

Chapters 4 and 5 demonstrate with numerical experiments the capabilities and limitations of the two modeling approaches "smeared conduit" and "Dual-Conductivity Model" (DCM). At the time of publication in 2007, development of the "embedded conduit" model was not yet complete. The performance of an equivalent porous medium (single continuum, MODFLOW) model is compared with a prototype discrete model, generated with FEFLOW. The first experiment investigates the response in a single conduit following a recharge event; the second features a two-branch conduit, and the third a dendritic conduit pattern. The authors state that the models perform reasonably well except when the total conduit volume becomes large. These kinds of numerical experiments had been conducted already in the 1990s by U. Mohrlok (e.g., Mohrlok and Liedl, 1996; Mohrlok et al., 1997), who compared a prototype complex aquifer response with a dual-continuum approach. The problem with single-continuum models is that they generally honor flow and the water balance but fail to simulate observed transport velocities. This limitation should be clearly stated. The geometry adopted for the modeling experiments should be closer to that actually observed for karst catchments (e.g., conduits generally drain to surface-water bodies). There is uncertainty about the type of boundary condition at the spring. The authors presumably assume fixed-head conditions.

The experiments with the newly developed double-continuum DCM package consist of simple aquiferdrainage experiments for validation, an imposed recharge pulse on the earlier dendritic conduit network, and an individual conduit in an unconfined karst aquifer. Model results are compared with the FEFLOW prototype and a single-continuum approach. DCM matches well the prototype pulses. To simulate natural aquifers more closely, experiment three should be designed so that the conduits can drain directly to the constant-head boundary.

Finally, in Chapter 6, a model of the Barton Springs catchment of the Edwards Aquifer is built with the double-continuum approach, and a 1-year period was simulated with DCM code. Stability and performance characteristics were tested.

Since this report was published in early 2007, and considerable progress may have been achieved since then, my comments may be outdated. Nevertheless I would like to make a few final conclusions. The authors demonstrate that dual-continuum modeling is feasible for simulating karst aquifers. The data requirement is moderate, and the models mimic the typically observed spring responses. It is also important to provide the community with a tool that is readily available to and usable by consultants. In getting this message across, the authors have contributed a great deal. Regarding the report itself, its preparation could have been more professionally oriented, especially given the high price. It could use a proper review of available karst models and their relative benefits and limitations, including the work of European scientists active in this area since the 1970s; a discussion, with illustrations, of the special characteristics of karst systems and why they require specific modeling approaches; a stronger emphasis on guidelines; and integration of the figures with the text. The title is somewhat misleading, since characterization issues are not addressed.

In any case, this work has potential and I look forward to a new edition of the book, which can be expected to include the recent achievements in karst-model development of the author group, as well as other advances, such as the newly developed hybrid model of the USGS (W. B. Shoemaker, CFP-Model).

References

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