Book review: Numerical Simulation of Groundwater Flow and Solute Transport, edited by L. Elango

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Abstract

A book review is presented on Numerical Simulation of Groundwater Flow and Solute Transport, edited by L. Elango, published by Allied Publishers Pvt. Ltd. in 2005, 245 pp, Hardback ISBN 81-7764-923-X**.**

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Groundwater is an important component of hydrologic cycle, playing a pivotal role in maintaining human survival and industrial production in the arid and semi-arid regions. With the changing of global climate and increased human activities, groundwater is imposed on more environmental and resource pressures. Groundwater over-exploitation, groundwater pollution, saltwater intrusion, soil salinization and other environmental problems have been reported in many parts of the world, seriously restricting the sustainable development of local economy and the stability of human society. With the awareness of the growing importance of groundwater in everyday life of humans and the aggravation of groundwater pollution, hydrogeologists, environmentalists and government officials have paid much attention to various groundwater related researches. Numerical modeling is a useful tool that has been widely used in various aspects of the groundwater study. During the past several decades, there have been tremendous developments in modeling methodologies and software, which have made a significant contribution to solving existing and emerging problems in science and engineering (Elango, 2005a). However, performing an accurate and efficient numerical modeling is of great challenge to beginners, and there will also be many unpredictable uncertainties during the simulation even to modeling experts. In addition, fast development of science and rapid innovations in modeling theories and methodologies also calls for an efficient monograph or textbook designed for both junior and senior modelers.

Numerical Simulation of Groundwater Flow and Solute Transport edited by L. Elango (published by Allied Publishers Pvt. Ltd. in 2005, 245 pp, Hardback ISBN 81-7764-923-X) originates from the results of the inter-disciplinary and multi-institutional training activities conducted in India (Elango 2005a). This book is a valuable addition to the literatures and a worthwhile asset to hydrogeologists and modelers who are involved in groundwater modeling and groundwater pollution control. It comprises 19 separate papers (chapters) contributed from 20 contributors all of whom are experienced and skilled hydrogeologists and modelers. However, most of these contributors come from India, which could be seen as one of the factors that limit the international popularity of the book. The book covers a wide variety of topics in hydrogeology and numerical modeling, ranging from introduction about the basic theory in hydrogeology and groundwater modeling to case studies of groundwater flow modeling and groundwater contamination modeling in various formations. The entire book can be roughly divided into two parts according to the topic of each chapter: part I including the first 9 chapters relates to theoretical introduction of numerical modeling, while part II that comprises the other 10 chapters describes 10 case studies of groundwater modeling for different purposes. A reference list is included at the end of each chapter except Chapters 3, 7 and 12, which enables readers to find out more on each specific topic by reading. In spite of some drawbacks, the book, in my opinion, will be extremely helpful to groundwater modelers, and therefore I recommend it to the international hydrogeological community.

Prof. L. Elango and C. Sivakumar contribute the first chapter, introducing some of the most basic concepts in hydrogeology including aquifer, aquitard, aquiclude, porosity, specific yield, storativity and transmissivity, isotropy and anisotropy, homogeneity and heterogeneity. This chapter also introduces the Darcy's Law that forms the basis of modern hydrogeology and groundwater modeling. By introducing groundwater flow in steady unidirectional flow, steady radial flow and unsteady radial flow, the authors introduce the derivation of the general groundwater flow equation at the end of the chapter. Although the contents in this chapter are known by all hydrogeologists and hydrogeological students, they are essential to be included at the very beginning of a book as an introductory material, because it allows scholars without a background in hydrogeology to gain a general knowledge of groundwater modeling.

Chapter 2 contributed by A.K. Sinha describes some basic issues regarding groundwater modeling such as model classification, basic information required by a groundwater modeling, and model application. Interestingly, the author states the necessity of modeling studies by asking a question "Why do we need modeling studies?" just after Introduction of the chapter. The author lists some most common misuses and mistakes in groundwater modeling at the end of the main content of this chapter, which I believe is one of the most useful knowledge to modelers in this chapter. Improper conceptualization, inappropriate selection of code for solving the model, improper model application and misinterpretation of model results are four types of common misuses and mistakes associated in groundwater modeling (Sinha, 2005), which will make the modeling nonsense if not resolved properly, and thus, it is necessary to point out these important issues to modelers. In this chapter, the author also introduces four types of boundary conditions: no flow boundary, constant head boundary, constant flux boundary and river boundary. However, the author classifies drain boundary into river boundary category, which in my opinion is inappropriate, because drain boundary and river boundary are actually two different types of boundaries. River boundary can let water into and/or out of the aquifer, while drain boundary can only allow groundwater out of the aquifer. It is necessary to point out the difference to learners.

Chapter 3 provides a theoretical introduction of the finite difference solution that has been widely applied in solving complex partial differential equations in groundwater modeling. This chapter is rather theoretical and mathematical, which may cause confusion to students who do not possess a strong mathematical base. However, this situation could be solved or improved by reading some mathematical textbooks. Water bearing properties of rock formations such as porosity, permeability, compressibility are introduced in detail in Chapter 4 contributed by P.N. Ballukraya. Understanding these properties is necessary for model conceptualization. The Problem-Answer box used in this chapter is extremely good for modelers, which enable readers to obtain a good understanding of how to calculate these properties. Providing a list of typical values of these properties in common lithological units is another merit of this chapter. It provides a general perceptual knowledge of rock properties of different lithological units to readers. Chapter 5 contributed by the same author as Chapter 4 deals with some issues in hard rock hydrogeology. Hydrogeological research and groundwater modeling in hard rocks are more complex that in granular aquifers due to the high degree of spatial variation of properties in hard rocks (Ballukraya, 2005). This chapter can be viewed as a further discussion of Chapter 4 on rock properties. Comparisons of aquifer properties between granular aquifers and hard rock aquifers in this chapter are helpful to readers to understand the differences between the two different types of aquifers.

Input data preparation for groundwater modeling is one of the most time-consuming and difficult work, because for a realistic modeling a great amount of input data are mandatory. The type of data might vary slightly according to the purpose of modeling (Elango, 2005b). Common input information includes aquifer parameters, local geology, hydrogeology, landforms, locations and flow rates of wells, boundaries, initial boundaries, land cover/change, precipitation, sinks and sources, and potential contamination sources, etc. Chapters 6 and 7 discuss the issues relating data collection, data classification and data preparation. Specially, Chapter 6 introduces the use of Remote Sensing (RS) in data collection. By interpreting a remotely sensed image, surface information that governs the subsurface water conditions can be obtained (Sanjeevi, 2005). Various surface information that a remotely sensed image can provide is introduced in this chapter, which is of immense help for readers to understand what RS can do for a groundwater study. This chapter will also promote the popularity of RS in groundwater study worldwide. As a supplement, Chapter 7 provides information on the type of information required for a groundwater modeling. Matters needing attention during data preparation are also mentioned in the chapter. Additionally, the last section of the chapter describes data gaps associated with groundwater modeling. In many cases, data for a realistic modeling are insufficient, which is rather an embarrassed thing. Based on my personal modeling experience, data collection and preparation are the most difficult work for a modeling study. In case you do not have sufficient data for a modeling, you have to pay more time and money on collecting data. In cases where collecting data are impossible, you have to change your modeling objects from time to time based on the available level of data and understanding.

Previous chapters are mainly topics relating to groundwater flow and groundwater flow modeling. As a supplement, Chapter 8 provides a theoretical introduction on solute transport modeling in a fractured rock aquifer. Groundwater modeling in fractured rock aquifer is more difficult and complex than in granular aquifers. These years, groundwater studies in fractured areas have attracted considerable attention from hydrogeologists. It is therefore vital to have one or more chapters discussing the issues associated with groundwater studies in fractured rock aquifers. This chapter provides expressions of solute front velocity, effective solute front dispersivity and macro-dispersion coefficient in fractured rock aquifers, which is of help for hydrogeologists and hydrogeological students.

After interpreting the results, a model documentation report is usually compulsory for any modeling study. Chapter 9 summarizes the steps and procedures that should be followed to prepare a model report. In this chapter, the information that has to be provided in a model report is listed and described in detail. The sections, tables and figures that should be included in the organization of the report are also suggested. In particular, information that should be provided by figures such as North Arrow, Scale Bar and Legend is also mentioned in this chapter. This chapter, in my opinion, reports the most practical and easy-to-follow contents for modelers among all topics of this book.

Chapters 10 to 19 are case studies of groundwater modeling except Chapter 12 that deals with theoretical introduction of solute transport modeling and in my opinion should be included in the first part of the book. Topics of these case studies include groundwater flow modeling (Chapters 10, 11 and 19), solute transport modeling (Chapters 13 to 17) and hydrogeochemical modeling (Chapter 18). Chapter 10 takes waterlogged areas in Hirakud as a case to formulate groundwater development strategies. The most valuable aspects of this chapter are that it provides a comprehensive literature review on optimization and/or simulation approaches for groundwater resources planning, performs a detailed estimation of groundwater balance for models, and establishes five scenarios for conjunctive use of surface water and groundwater. The author stated that a sensitivity analysis was carried out in the study, but did not introduce the results in detail, which could be a weakness of this chapter. The references listed at the very end of the chapter are helpful to readers, but they are all very old (ranging from 1963 to 1996). Chapter 11 analyzed the effects of sub-surface barrier construction on the groundwater flow regime by a finite-difference flow model. This chapter is interesting and helpful to engineering geologists. Groundwater flow modeling in fractured rocks is complex and difficult due to high heterogeneity of fractured formations and high uncertainty in fractured groundwater modeling. Chapter 19 illustrates a groundwater flow simulation in a weathered gneissic formation using stochastic method. Stochastic approach is a relatively advanced theory that allows the uncertainty that affects various properties and parameters to be incorporated in models of subsurface flow and transport (Dagan and Neuman, 2005). More literature reviews, in my opinion, should be performed in this chapter to delivery more information of this theory to readers. Among the five chapters regarding solute transport modeling, Chapters 13, 14, 15 and 17 focus at transport simulation of contaminants from industries in saturated zone, while Chapter 16 discusses contaminant transport in unsaturated zone using HYDRUS-2D. All these chapters are good examples of solute transport modeling, but Chapter 14 reports the results of sensitivity results, which is a merit that other chapters do not possess. Chapter 18 is devoted to mass balance modelling of groundwater, and it is the only chapter in the book discussing hydrogeochemical modeling. The concept and data requirements for mass balance modeling are introduced and an inverse mass balance modeling case is studied in this chapter. In my opinion, geochemical modeling is as important as geophysical modeling, and therefore should be given adequate attention. This book apparently did not do it.

This book covers a wide variety of topics in groundwater modeling. However, as a textbook designed for modelers, the following topics are recommended to be covered and/or improved in future editions:

(1) S**oftware/code for groundwater modeling:** A large number of calculations must be performed for a modeling. Therefore, it is almost impossible without well developed software/codes. There have already been several popular modeling software/codes adopted by many modelers, such as MODFLOW,

MT3DMS, Visual MODFLOW, GMS, FEFLOW, PHREEQC. However, some modelers are not truely understand the merits and weakness of each software/code, which may induce wrong uses of these software/codes. In my opinion, including a chapter introducing the scope of usage, the merits and weaknesses of some most popular modeling software/codes is helpful for readers to select proper software/codes for their modeling studies.

(2) **Boundaries and initial conditions for groundwater modeling:** As stated by Reilly (2001), boundary conditions have an important influence on the extent of the flow domain to be analyzed or simulated. This book mentioned in Chapter 7 that boundary selection is a critical step in model design, it, however, did not make a detailed description of how to define proper boundaries for a model domain. Providing a chapter dealing with this critical issue is important and useful for modelers. Therefore, I recommend inclusion of a topic on boundary conceptualization.

(3) Reactive solute transport: The solute transport modeling described in this book focus mainly on nonreactive solutes. These years, the research on reactive solute transport in porous media is becoming increasingly a hot topic, and reactive solute transport modeling has attracted a great amount of attentions from hydrogeologists and environmentalists. It has become an indispensable part of simulation studies. Therefore, it will be meaningful and helpful to have one or more chapters introducing the advances of reactive solute transport and the important issues associated with reactive solute transport simulation.

(4) Sensitivity analysis in groundwater modeling: Sensitivity analysis is becoming increasingly important in modeling studies. This book, however, does not pay sufficient attention to this topic. A chapter introducing issues relating to uncertainty and sensitivity analysis of groundwater models is needed for readers. Its inclusion in further editions of the book will enrich the contents of the book and improve its readability.

(5) Supplementary materials for readers: It is helpful to provide some supplementary materials to readers, which allow them to find more information on specific topics, enhancing their knowledge on groundwater modeling.

(6) International collaboration of contributors: More international contributors are strongly suggested to be invited to contribute papers to further editions. As mentioned previously, most of the contributors are from India. If more international hydrogeologists or modelers are invited to contribute topics on groundwater simulation, the book will definitely become more international than present. In addition, the depth and breadth of the book will also be enhanced by inviting more international contributors, especially those from Europe, the United States and Canada.

Overall, the book covers may topics on groundwater modeling. I am sure it is quite useful for hydrogeologists, hydrogeological students and modelers. Although there are some issues needing further improvement, the book is recommendable and worthy of reading and referencing for scholars.

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