BOOK REVIEWS

Vadose Zone Science and Technology Solutions. Edited by BRIAN B. LOONEY and RONALD W. FALTA. Batelle Press, 505 King Avenue, Columbus, Ohio 43201-2693. 2000. Hardbound, 2 volumes, 1540 p. ISBN 1-57477-085-3.

The preparation and the writing of this 1500+ two-volume publication on vadose zone principles and applications, together with an accompanying CD of case studies, was sponsored by the U.S. Department of Energy (DOE) in close collaboration with other U.S. Agencies such as EPA, USGS, DOD, and USDA, and scientists at universities and with industries. This comprehensive compilation of current state-of-the-art principles and technology applications was the result of three separate national workshops, with participation of about 50 scientists, having basic and applied backgrounds in a variety of disciplines that collectively comprised a representative cross section of the vadose zone scientific community, including graduate students in science and engineering, professionals, research scientists, and managers. Although the book agrees that much progress has been made in applying basic principles to remedy pollutant fate and transport in the vadose zone environment, it is argued that many issues still remain unresolved and that a concerted effort is required by funding agencies, vadose zone managers and regulators, and the scientific community. The premise of the book is to provide an understanding of vadose zone concepts to a broad audience so as to convince policy makers to continue their sustained support of long-term multi-disciplinary research. This is accomplished by identifying and describing the most significant challenges and knowledge gaps in vadose zone research, using a technical format that may be understood by all stakeholders in the general environmental arena. To achieve this goal, the authors have chosen not to pursue an in-depth review of all scientific details of vadose zone science.

The extensive description of vadose zone science is especially important when realizing that enhanced understanding of the vadose zone is essential for the improved control and management of pollutants in the subsurface, with the ultimate aim to minimize the risks of contamination of groundwater. The books point out that, as compared with groundwater, the vadose zone has not been studied as extensively as a comprehensive science, but rather by a multiple array of separate disciplines, resulting in a wide knowledge gap of underlying principles and delaying effective application of remediation and long-term stewardship technologies. Because of vadose zone complexities, integration of all earth and environmental sciences, including management and policy, is highly relevant. The two books serve to convince the environmental community that existing knowledge and technologies are not adequate to satisfactorily characterize, monitor, manage, remedy, and/or predict the fate and transport of pollutants in the vadose zone. Case studies such as at those conducted at Hanford and Yucca Mountain and many other sites are presented to highlight the common lack of scientific understanding and inadequate technologies. The major shortcomings are identified in the final chapter.

The first chapter defines vadose zone science, its importance, fundamental processes, and the current state-of-the-art, particularly its significance and its controlling role for environmental cleanup, by including high-visibility case studies to document knowledge gaps and future directions. In the second chapter the reader is introduced to a list of principles of effective vadose zone management, to mainly help policy makers overcome technical difficulties, scientific knowledge gaps, and regulatory barriers. One of the guiding principles is the development of a roadmap that formalizes long-term objectives and goals, while considering current limitations of knowledge, data uncertainty, risk analysis, and resources availability. Chapters 3 and 4 comprising some 450 pages, summarize technologies and applications of current and future developments of vadose characterization and monitoring methods, including chemical and biological monitoring. Case studies demonstrate applications of techniques at contaminated sites, such as at INEEL, Yucca Mountain, Hanford, the Savannah River Site, and other DOE facilities. Developments in vadose zone modeling, described in Chapter 5, include sections on data needs and model calibration. The concluding section of this chapter on recommended future research directions points out the need to improve data quantity and quality and to reduce model uncertainty. The importance of geochemical and microbiological processes on contaminant mobility and fate is emphasized in Chapter 6. This chapter concludes that future work must focus on the incorporation of biological and geochemical processes in vadose zone transport models, their control by spatial and temporal variations of hydrological processes, and their upscaling from the laboratory to the field scale. Chapters 7 and 8 review principles and operation of various remediation technologies, and their performances with organic and anorganic chemicals in the vadose zone, respectively. Organic remediation includes contaminant recovery and bioremediation, as well as other attenuation techniques such as reactive barriers and phytoremediation. Key gaps in current capabilities of these technologies are caused by soil and geologic heterogeneities, and a lack of pilot-scale field tests of remedial technologies. In situ remediation of inorganic contaminants (heavy metals, radionuclides, nitrate) include removal, stabilization, and natural attenuation by physical, electrochemical, and biological methods. Principles and performances of various barriers and containment methods are presented in Chapter 9.

The final chapter, "Future Science and Technology Focus," was written by the editors and reviewed by all lead authors of the book. It therefore gives a collective view of the research needs of vadose zone science. I have generalized these in the following three priorities. First, the text concludes that an interdisciplinary approach is needed, including participation by theoreticians and practitioners, across a wide spectrum of disciplines, including soil science, hydrology, geology, engineering, mathematics, social sciences, policy, and management. Such an approach is evident when considering the complexity of the pollutant problem that begs for applying all possible techniques available. In addition, pollutant fate is controlled by physical, chemical, and biological processes that are historically studied in separate disciplines, rather than by the proposed collective effort. Also, the chapter makes a clear case that the transition of application of basic theory to real world applications is greatly enhanced by combining expertise early on, thereby providing more ideal conditions for validation and testing new characterization, monitoring, and remediation technologies.

Second, the vadose zone community must apply theory, measurements, and technology applications to a range of spatial scales, and develop spatial scaling procedures. Much research, both theoretical and applied, and specifically chemistry and biology, should move from the lab bench early on to investigate its validity under real soil conditions. Specifically, it is recommended to prioritize detailed and integrated medium-scale field experiments (at the meter scale), preferentially conducted at existing contaminated sites.

Third, it is recommended to prioritize the development of a standard toolbox of enhanced characterization and monitoring techniques and technologies that can incorporate soil heterogeneity. Especially needed are instrumental and mathematical techniques that improve data quality and better address uncertainty of fate and transport in the vadose zone. Moreover, it is stressed that such tools may be scale-specific and that different characterization and data collection techniques may be needed at different spatial scales, and for different purposes. Within this general priority area, the need for improved coupled (physics, hydrology, chemistry–biology) numerical modeling techniques was highlighted, stimulated by the proposed interdisciplinary research approach.

In summary, the two-volume text provides an enormous inspiration for the vadose zone research community by presenting many opportunities for vadose zone research. In addition to highlighting many specific research areas in a wide spectrum of disciplines, reading this vadose zone text will also stimulate scientists, students, stakeholders, and policy and decision makers to take a general integrated approach so as to provide a consensus among all that vadose zone problems are complex and require a collective vadose zone research effort. As such, the books may serve as a reference that can be used by policy and decision makers to justify their commitment to vadose zone research. In addition, the book provides an excellent overview of vadose zone concepts and measurement techniques, with a broad suite of example applications.

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Conceptual Models of Flow and Transport in the Fractured Vadose Zone. Panel of Conceptual Models of Flow and Transport in the Fractured Vadose Zone, National Committee for Rock Mechanics, Board on Earth Sciences Resources and National Research Council. National Academy Press, 2101 Constitution Avenue, Washington, DC 20055. 2001. Soft cover, 392 p. $69.00. ISBN 0-309-07302-2

Conceptual Models of Flow and Transport in the Fractured Vadose Zone is a thought-provoking collection of invited presentations originally delivered during a two-day workshop, convened by the National Research Council in March 1999, by a renowned group of water research specialists.

The book consists of the Panel's report, followed by 10 technical papers by scientific experts. The book covers an array of vadose zone research and includes an exhaustive survey of schematics, graphs, and photos. It is a thorough academic contribution. As noted in the preface of the book, the presentations not only describe the current state of conceptual models for flow and transport in the fractured vadose zone, but also provide guidance for government regulatory agencies and contribute knowledge and experience of related disciplines.

The book is arranged in 11 chapters. The first is the Panel's report, which consists of an overview of the general problem and modeling concepts, developing, and testing. Chapter two by Flint and coauthors is a summary of the hydrology assessment framework for the high-level radioactive nuclear repository at the Yucca Mountain site in Nevada. The authors describe the evolution of theoretical and experimental approaches to assess water flow in the highly heterogeneous, deep, unsaturated zone. The chapter provides descriptive references of the different conceptual models proposed by several investigators in the last 15 years. Particularly noteworthy is how the authors describe the evolution of the modeling concepts resulting from the need to address the expanding body of experimental evidence showing unexpectedly large transport rates, not predicted by the existing models. Chapter three by Jardine and coauthors addresses the problem of fractured weathered shales in a low-level radioactive waste repositories at the Oak Ridge Laboratory in Oak Ridge, Tennessee. The authors focus primarily on experimental techniques at different scales (laboratory, pedon, and field scale) to quantify physical nonequilibrium and to differentiate between matrix and fracture flow. The chapter provides an overview for readers interested in experimental methods, but gives little detail about actual modeling concepts, relying instead on references.

In Chapter 4, Berkowitz and co-authors discuss certain assumptions and theoretical treatments of phenomena related to flow and chemical transport in fractured media. The authors address, for example, non-Gaussian chemical distribution of the plume and an alternative approach to describe it, such as the continuous time random walk framework. The authors also stress the importance of using three-dimensional models for fracture flow quantification due to the strong three-dimensional nature of the flow patterns. This stimulating critical analysis emphasizes the necessity of developing new conceptual frameworks.

The use of different conceptual models depending on the scale of investigation of the system remains a problematic issue in hydrological science. In Chapter five, Hendrickx and Flury address this, and classify preferential flow based on the scale of its occurrence. Liquid flow in porous media can be described by different concepts, mathematical formalisms, and parameters, depending on the scale of investigation. The authors discuss evidence showing that preferential flow occurs at pore, field, and aerial or large scales, and they discuss modeling approaches for each of these scales. The chapter offers valuable material and references for readers interested in the "scaling problem" and its consequences for flow and transport. In similar fashion, Chapter 11 by Bodvarsson and coauthors addresses the application of "up-scaling" concepts for the parameterization of hydraulic properties of fractured media at the Yucca Mountain site. Bodvarsson and co-authors conclude that "up-scaling" methods conventionally used in homogeneous media cannot be used for fractured rocks because fractures may affect matric permeability on a larger scale.

A flow model for agricultural soils is described in Chapter 6 by Jarvis and Larsson. MACRO, a model for macropore flow, is currently under development for pesticide regulation in the European Union. The model solves the Richards' equation and the convection–dispersion equation, and it divides the flow domain into micro and macropores, with different hydraulic properties. Alternative concepts to describe water flow trough fractures are proposed by Dragila and Wheatcraft in Chapter 7 and by Doe in Chapter 8, where film flow and flow of discrete drops are noted as potentially significant factors in determining liquid transport in fractured media.

Chapter 9 by Phillips is mostly a summary of the use and limitations of different environmental tracers as tools for transport studies, where application to soils and rocks is considered and discussed. In Chapter 10, Neuman and co-authors presented a collection of results from experiments conducted at the Apache Leap Research site in Arizona, as well as conceptual models applied to the compelling study. The authors adroitly present the challenges of characterizing the hydrology of the site, such as potentials and limitations of using gaseous tracers rather than liquid, suspended or dissolved tracers. They also provide a numerical inverse interpretation of the results, and a thorough discussion of the results.

Overall, the book is a valuable collection of high-quality review papers that address pressing environmental water resource problems such as groundwater contamination from nuclear waste repositories, agricultural systems, and other sources. The book offers a diversity of approaches and ideas for addressing this problem, but the fragmented nature of our current knowledge about flow and transport in the fractured vadose zone is also apparent here. The authors recognize that there are still many unanswered questions, and they appropriately stress the need for additional research. A significant contribution has been provided in this collection of papers, however, and those interested or involved in vadose zone research will find it a stimulating, rewarding read.

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Flow and Transport Through Unsaturated Fractured Rock—Second Edition. Edited by DANIEL D. EVANS, THOMAS J. NICHOLSON, and TODD C. RASMUSSEN. Geophysical Monograph 42. American Geophysical Union, 2000 Florida Avenue, N.W., Washington, DC 20009. 2001. 196 p. $38.50 (AGU Member) $55.00 (Nonmember). ISBN 0-87590-983-3.

The subject of fluid flow in fractured rock has long been of considerable interest in the oil and gas industry for purposes of enhancing oil recovery and exploitation of geothermal reservoirs. Research in this area has gradually broadened to more comprehensive environmental problems involving flow and transport processes into and through fractured rock formations. More recently, a substantial research effort, known as the Yucca Mountain Project (YMP), has greatly promoted the development of a more systematic approach toward acquiring a better understanding and quantitative description of nonisothermal multi-phase flow and transport processes in variably saturated fractured rocks. Sponsored primarily by the U.S. Department of Energy over the last two decades, the YMP aims to obtain a detailed characterization of Yucca Mountain as a potential site for geologic isolation of high-level radioactive waste.

Major challenges of the Yucca Mountain Project are the presence of a multitude of strongly coupled nonlinear thermal, hydrological, chemical, and mechanical processes; the extremely complex geologic setting of Yucca Mountain; and the need to obtain reliable predictions of system performance over tens of thousands of years in the future. This broad agenda has brought together integrated research efforts across disciplinary boundaries to address the problem of safe disposal of nuclear waste in unsaturated fractured rock. Considerable progress in research over the years has now made the topic of flow and transport through unsaturated fractured rock a much more mature scientific discipline.

Originated by concerns and research needs relevant to high-level nuclear waste disposal in unsaturated fractured rock, the first edition of this book collected 22 full-length papers from a special symposium held during the American Geophysical Union (AGU) meetings in San Francisco in December 1986. That volume, published by AGU in 1987, covered a broad spectrum of the then state of knowledge within the area of “Flow and Transport through Unsaturated Fractured Rock”. The current second edition, revised and published in 2001, includes five papers selected from the first edition, plus nine new contributions that reflect important recent developments in the unsaturated rock research arena. Of the five papers selected from the first edition, only one paper (i.e., “Flow and Transport Through Unsaturated Fractured Rock: An Overview”) was succinctly updated with many recent references. The other four papers remain unchanged.

While many of the papers collected in the first edition still provide important concepts and fundamental processes of the physical system, I would have preferred to see only papers from the first edition that had been updated and revised. I did not quite understand the rationale for including papers that were not changed. As such, one obvious shortcoming of the second edition is the inclusion of a review paper that was written for the first edition more than a decade ago. Updating that review paper would certainly have been a worthwhile endeavor.

The 14 papers of the revised second edition are interdisciplinary in flavor. Topics covered include review material, laboratory and field studies, modeling and simulations, and discussions of basic concepts and critical physical processes of the system. These topics lean heavily toward the physical side of the spectrum, with little or no discussion of equally important chemical processes. Highlighting new insights and recent advances in hydrogeochemistry would have made the text much more appealing to a wide range of readers. The book could have benefitted also from some rearrangement of the different papers; this and adding subheadings in the table of contents section would have provided readers with a much easier to use reference work.

While by itself maybe a relatively minor point, the text also contains a few irritating typographic and factual errors. Among those, one concerns the References section of the otherwise very interesting paper “Multiscale Investigations of Liquid Flow in a Fractured Basalt Vadose Zone” by Faybishenko and colleagues. The paper of Su et al. cited in that paper was stated to be submitted to *Water Resources Research* in 1998. That paper actually appeared in Vol. 35(4):1019–1037, 1999. In addition, two very relevant publications referenced by Illman et al. were not listed in their own paper “Type-curve Analysis of Single- and Cross-Hole Tests” in this volume. Those two papers dealing with single-hole and cross-hole tests were published in *Ground Water* Vol. 38(6):899–911, 2000, and *Water Resources Research* Vol. 37(3):583–603, 2001, respectively.

In general, however, I very much liked the book, which should provide a very useful resource for advanced students and experts in the field of hydrogeology. The text may be especially appealing to scientists and researchers, and even regulators, already working in the fractured rock area who desire a survey of current accomplishments and future directions. Postgraduate students and postdoctoral researchers should find this volume equally stimulating and informative.

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Soil Science Simplified, Fourth Edition. MILO I. HARPSTEAD, THOMAS J. SAUER, and WILLIAM F. BENNETT. Illustrated by MARY C. BRATZ. Iowa State University Press, 2121 South State Avenue, Ames, Iowa 50014. 2001. Hardback, 225 p. $44.95. ISBN 0-8138-2942-9.

The first edition of this book was published in 1980. The second edition was published eight years later and the third edition was recently published in 1997. Soil physicist Thomas J. Sauer replaced Francis D. Hole as the second author starting with the third edition. Soil fertility and management were expanded in the second edition. Primarily, soil water, soil temperature, and soil engineering were revised in the third edition. Despite only four years between the third and fourth editions, the fourth edition is an extensive revision.

This book is easily accessible to both high school and beginning post-high school students. It will also benefit professionals outside of soil science who desire an easily accessible introduction to the basic principles of soil science. Soil scientists will find it a handy compendium of soil science concepts. Although a few concepts are too simplified, most are technically accurate. An annotated "References for Further Study" at the end of each chapter would greatly enhance the utility of this book.

Soil Science Simplified is profusely illustrated with line-art drawings by Mary C. Bratz. Her illustrations add greatly to the appeal of this book. The illustrations immediately grab one's attention and help one retain key concepts of soil science. In this edition, important terms are now set off in bold, and italics are used for added emphasis. Along with Bratz's illustrations, this makes skimming the book more rewarding.

There are 13 chapters in this edition. They appear as: The Soil Around Us, Soil Formation, Soil Physical Properties, Soil Biology, Soil Colloids and Chemistry, Soil Water, Soil Temperature and Heat Flow, Soil Fertility and Plant Nutrition, Soil Management, Soil Conservation, Soil Classification, Soil Surveys, and Soil Engineering. In the very brief first chapter a working definition of soil is given and some of the uses of soil are introduced. The stated aim of this book "is to explain the basic principles of soil science in a practical way." Surprisingly, the connection between the treatment of soil and sustainable civilizations is not immediately made. (One has to wait until the soil conservation chapter.) Books such as *Soil Science Simplified* that address a broad audience are uniquely positioned to help foster the concept of a sustainable land ethic. As soil scientists, we should do everything we can to help develop this concept and educate those involved in land use.

The authors appropriately begin their explanation of soil science with the geology behind soil formation. The essential features of soil formation are concisely and accurately established. Because of their permanence and the difficulty in controlling them, soil physical properties are next introduced as those soil properties that should receive the greatest attention during land-use planning. Soil texture and structure, porosity and density, consistence, and color are condensed to the essentials.

Soil biology is introduced in Chapter 4. Here the reader is given a simplified account of the known roles played by microorganisms in the soil ecosystem. These microorganisms are said to provide important carbon sequestration and nitrogen cycling services. Interest in this branch of ecology has greatly increased during the last few years, and there is still so much we do not know. In this book, numerous management practices that may help sequester carbon are listed, but I did not get an appreciation of what we do not know. I was left wondering why the authors state "the net effect of increased atmospheric CO_2 is not known, but it has been suggested that reduction of CO_2 in the atmosphere would be 'environmentally friendly.'" Practically all climate change scientists agree that CO_2 levels in the atmosphere have dramatically increased since the beginning of the industrial era and that these higher levels of CO_2 are responsible for increases in global temperature during this time. The debate is over the rate of future change.

The next chapter on soil colloids and chemistry includes more details on the clay fraction previously introduced. It is natural to combine colloids with soil chemistry since much of soil chemistry is governed by the ion exchange complex on clay-sized particles. Concise information in this chapter makes understanding of this difficult aspect of soil science easier. Soil chemistry concepts discussed involve clay structure, ion exchange, pH, base saturation, buffering capacity, acid and alkaline soils, and soil aggregation. The last three editions of this book state that 0.1 μm is commonly given as the upper limit to colloid diameter when it is really 1 μm. The important electrical double-layer is not adequately explained, but this is a minor issue for a book of this kind. (Again, an annotated "References for Further Study" would help.)

Soil physical properties involving water, temperature, and heat flow comprise the next two chapters. This edition has more description of energy budgets and an expanded irrigation section. There are elementary explanations of the hydrologic cycle, water budgets, plant water use, heat transfer processes, the factors affecting soil temperature, management of soil temperature, and the combined effects of water and temperature on soil bodies.

The soil fertility and plant nutrition chapter combines many of the previous concepts and relates them to plant requirements. Plant growth nutrients and techniques to gather soil samples for nutrient analysis are appropriately summarized. Precision farming is introduced as a means to more efficiently utilize fertilizers. There are very short sections on composting and organic farming methods. The authors do not address the long-term sustainability of conventional fertilizer use. They state, "Enough food could not be provided for the world's population if the plant nutrients for food crops were to be supplied solely from organic sources." Methane, a nonrenewable fossil fuel, is used in the Bosch-Haber process: $4N_2 + 3CH_4 + 6H_2O \rightarrow 8NH_3 + 3CO_3$. Note that Fig. 8.9 illustrating this process in the book is missing the steam input.

The importance of soil physical condition in maintaining a healthy soil is again reiterated in the soil management chapter. Tillage practices are discussed at some length. This chapter also includes sections on the management of organic matter, soil pH, saline and sodic soils, and plant nutrients. An important but short section relates soil health to crop production practices appropriately adapted to local conditions. Logically, the soil conservation chapter follows next. Factors of soil erosion are explained as are techniques to minimize agriculturally induced erosion of a precious resource—soil. Curiously, the soil loss equation is not mentioned.

Reorganization of soil classification is particularly notable in this edition. The main features of the USDA 12-order, 1998 revision of soil taxonomy have been nicely condensed to 24 pages. Diagnostic epipedons and subsurface horizons are succinctly defined and made easily accessible to the lay reader. The 12 soil orders are summarized with just the right amount of detail for easy recall. The following chapter on soil surveys is similarly written.

The final chapter on soil engineering now includes a brief introduction to the soil classification schemes developed by engineers. Chapter sections discuss the relation of soils to dams, levees, roads, buildings, ponds, canals, recreational areas, and other structures. Important sections on reclamation and remediation of waste and disturbed lands are also included.

In summary, this book is a concise introduction to soil science. It strikes just the right balance of content, illustrations, and detail for students and professionals who desire a fast, accurate introduction to soil science. Soil scientists will find this book a handy compendium of soil science not readily summarized elsewhere in compact form. This book is only available in hardback; a more affordable paperback edition would help get this book into the hands of younger students for whom the sustainable use of soil is vitally important.

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Spatial Patterns in Catchment Hydrology: Observations and Modelling. Edited by R. GRAYSON and G. BLÖSCHL. Cambridge University Press, Cambridge, UK. Hardback, 404 p. $95.00. ISBN 0-521-63316-8.

The struggle to develop better models of hydrologic processes has been a continuing area of intense research for the last several decades. One promising avenue of watershed hydrologic research lies at the intersection of new measurement technology (e.g., remote sensing, TDR and eddy-flux towers) and spatially distributed models of catchment hydrology. In this book, with the assistance of other leaders in the effort to unify field measurement and spatial models, Grayson and Blöschl introduce the naive user to the concepts of how to observe and model spatial patterns at the catchment scale. The book does an admiral job covering the concepts involved in spatial measurement, analysis, modeling, and model evaluation. The book makes a strong intellectual case for using measurements of spatial patterns to improve our understanding of catchment hydrologic processes and to develop better tests for spatial models. The authors succeed in making the case for this approach and produce a book that serves as a suitable summing of work to date and ideas for the future. The book itself is divided into three main sections: the fundamentals of spatial patterns in catchment hydrology, case studies of the joint use of measurement and models of spatial patterns, and the implications of spatial patterns information on models and understanding of catchment hydrologic processes.

The first chapter, "Spatial Processes, Organisation and Patterns" by Grayson and Blöschl, introduces the prevalence of pattern in hydrology. This chapter also makes the point that simple geostatistics alone are not enough for understanding spatial pattern. The second chapter, "Spatial Observations and Interpolation" by Blöschl and Grayson, covers the concepts of spacing, extent, and support (the scale triplet) and covers how the importance of the scale triplet has implications for the information that can be extracted from field measurement. The chapter also covers the concept of interpolation using a variety of methods and discusses how surrogate data (e.g., topography) can be used to improve interpolation. The third chapter, "Spatial Modelling of Catchment Dynamics" by Grayson and Blöschl, discusses the elements of spatial modeling: why one would use spatial models, links between spatial models and process understanding, spatial model structure, spatial discretization, element size, ways to represent subelement variability, and the level of complexity warranted in a model. In the fourth chapter, "Patterns and Organisation in Precipitation" by Foufoula-Georgiou and Vuruputur, the current state of knowledge on precipitation dynamics and spatial organization is discussed. Both downscaling and upscaling approaches are covered as well as the underlying mathematical and physical understanding that underpin these approaches. The fifth chapter, "Patterns and Organisation in Evaporation" by Hipps and Kustas, covers the basics of evapotranspiration (ET) estimates from measurement, and how these link up at different scales, to models of ET and how real world variability can be represented in ET estimates and in land surface models of ET.

The second section of the book is a series of cutting-edge case studies on spatial patterns in catchment hydrology. "Runoff, Precipitation, and Soil Moisture at Walnut Gulch" by Houser and others investigates the use of spatial rainfall measurements, remotely sensed soil moisture, land surface models and data assimilation techniques to improve models and predictions of runoff in semiarid environments, specifically the Walnut Gulch watershed in Arizona. "Spatial Snow Cover Processes at Kuhtai and Reynolds Creek" by Tarboton and others covers the processes controlling snow distribution and melt, as well as how to use remote sensing data and energy budget models to estimate snow water equivalence at watersheds in Idaho and the Austrian Alps. "Variable Source Areas, Soil Moisture and Active Microwave Observations at Zwalmbeek and Coet-Dan" by Troch and others covers the use of synthetic aperture radar (SAR), field surveys, and elevation data to investigate variable source area dynamics at field sites in Belgium and in Brittany, France. "Soil Moisture and Runoff Processes at Tarawarra" by Western and Grayson shows how combining detailed field observations and a robust spatial model can be used to improve model falsification of catchment hydrologic models at a research watershed in Australia. "Storm Runoff Generation at La Cuenca" by Vertessy and others successfully shows how very simple technologies (surface runoff detectors) can be used to improve our understanding of spatial processes and includes use of these measurements to test a spatial model for a catchment at the headwaters of the Amazon in Peru. "Shallow Groundwater Response at Minifelt" by Lamb and others covers how fine resolution spatial observations of groundwater elevation can be used to test spatial models and how these measurements can be used in combination with uncertainty methods to develop stochastic predictions of groundwater elevation at the whole catchment scale for this field site in the south of Norway. "Groundwater–Vadose Zone Interactions at Trochu" by Salvucci and others covers how the detailed understanding of groundwater recharge and evapotranspiration processes can be improved using spatial observations of groundwater elevation, surface halt measurements, and topography for this legendary field site in Alberta, Canada.

The final section of the book investigates the overall implications of the case studies. "Towards a Formal Approach to Calibration and Validation of Models Using Spatial Data" by Refsgaard advocates for better use of computational models in hydrology and for better evaluation of model performance, in part using a case study of the Karup catchment in Denmark. This chapter should be required reading for anyone wishing to use a distributed catchment model in a robust manner. In the final chapter, "Summary of Pattern Comparison and Concluding Remarks", Grayson and Blöschl argue that progress cannot be made in understanding catchment hydrologic processes without coordinated work on new observational methods that are tightly coupled to spatially distributed models.

This final point shows the cumulative importance of this book. While technology obviously brought catchment hydrologic modeling to where it is, technology is not a panacea for solving the remaining scientific questions. While technology obviously has a role, even simple observation techniques like surface runoff detectors (La Cuenca) or surface salt observations (Trochu) can have great utility if used properly in testing hydrologic models. While there are possibly other ways for us to improve forecasts of the fluxes and state variables of water across the landscape, this book makes a strong case for an empirical approach to catchment hydrology (developing and using spatial observation for the falsification of spatial models) to parallel hydrology's strong theoretical tradition. The book is suitable for a wide range of individuals interested in hydrology, from senior undergraduates to experts in spatially distributed hydrologic modeling.

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Soils in Our Environment, Ninth Edition. RAYMOND W. MILLER and DUANE T. GARDINER. Prentice Hall, Upper Saddle River, NJ 07458. 2001. Cloth bound with CD-ROM, 642 p. $100.00. ISBN 0-13-020036-0.

Introductory soil science is taught to a large number of students at the freshman and sophomore levels. Several textbooks are available for introductory soil science courses. Among these texts, the Miller and Gardiner book belongs in an intermediate category in terms of content and breadth: it is more comprehensive than books like Plaster's *Soil Science and Management* (E.J. Plaster, 1997, Delmar Publishers, Albany, NY), but less comprehensive than the classic *The Nature and Properties of Soils* by Brady and Weil (N.C. Brady and R.R. Weil, 2002, 13th ed., Prentice Hall, Upper Saddle River, NJ). In its contents and comprehensiveness, it is similar to the Singer and Munns text, *Soils, An Introduction* (M.J. Singer and D.N. Munns, 2002, 5th ed., Prentice Hall, Upper Saddle River, NJ).

Like many other introductory soil science books, Miller and Gardiner start with the topic of soil formation. The next four chapters cover soil physical, chemical, and biological properties, followed by soil taxonomy and two chapters on acidity and salinity. Three chapters are then devoted to soil fertility. The remainder of the book covers more applied topics, including tillage systems, soil erosion, water resources and irrigation, wetlands and drainage, pollution, and soil surveys. The book ends with a chapter on greenhouse soils and soilless cultures.

That the books starts out with soil formation may be helpful for students to put soil science in perspective, but I have experienced that it is difficult for students to understand soil formation without basic knowledge of physical, chemical, and biological properties and characteristics of soils. As an instructor, I therefore postpone this chapter until after I have discussed soil physics, chemistry, and biology. The chapters on soil physics and chemistry are rather short and not as comprehensive as in Singer and Munns (2002). The chapters on soil biology and particularly on soil fertility are excellent and, in my opinion, the best part of the book. The chapters on tillage systems, soil erosion, water resources, wetlands, and pollution are . very useful. Although somewhat superficial, they provide a picture of the applied side of soil science, including some regulatory and legal aspects of soils.

Each chapter starts out with a preview highlighting the most important features of the chapter. This is very helpful and keeps the reader focused on the main points of the chapter. The text is illustrated with plenty of photographs and figures, making the book attractive and interesting to read. Special topics are emphasized and highlighted in "Details", and example calculations illustrate the quantitative use of the theory presented. At the end of each chapter, useful information for further study is given, often in the form of web links; however, references to more specialized literature for in-depth study are missing. The book comes with a CD-ROM, which contains a summary of the chapters as well as interactive study questions for students.

The Miller and Gardiner text is a valuable textbook for a university-level introductory soil science course and serves at the same time as a reference book for soil and non-soil scientists seeking a brief introduction into topics of soil science. The strength of the book lies in the parts on soil organisms, soil taxonomy, soil fertility, and the integration of the individual disciplines of soil science. Less emphasis is given to soil physics and chemistry.

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Water Use in Crop Production. Edited by M.B. KIRKHAM. Food Products Press, 10 Alice Street, Binghamton, NY 13904-1580. Hard cover, $89.95. ISBN: 1560220686. Soft cover, $49.95, ISBN: 1560220694.

Co-published as *Journal of Crop Production*, Vol. 2, No. 2, 1999, this book comprises 16 chapters on the state of research on water use in crop production. The first three chapters are reviews of water conservation principles and practices, crop water use response to carbon dioxide and temperature, and crop response to water shortage. Other chapters are concerned with particular crops including citrus, cotton, olive, rice, safflower, sorghum, sunflower, turfgrass, and wheat. The chapters are uneven in kind and quality. Some are reviews, while others report specific experiments. But the best chapters, including the chapter detailing effects on water use of carbon dioxide and temperature increases, the review chapter on olive water use, and the chapter on risk assessment for irrigated cropping, are by themselves worth the asking price.

The first chapter, on water conservation, focuses on practices in subhumid, semiarid, and arid climates for dryland or irrigated agriculture, mostly relevant to practices in the United States despite the chapter's subtitle, "A Global Perspective". Although many references are cited, there is no analytical basis given for the discussions on principles of water conservation, practices, and water use efficiency. There is also relatively little discussion of the effects of conservation practices on yield and profit—the emphasis being on effects on soil water storage. Otherwise, the chapter is a good general discussion of water conservation practices for both dryland and irrigated crops.

The second chapter provides an excellent review of the possible effects of global climate change on crop water use and yield. It begins with general discussion of past and present carbon dioxide changes in the atmosphere; the relationships between crop transpiration, yield, and atmospheric humidity; plant photosynthetic mechanisms and growth responses to elevated carbon dioxide; and transpiration and water use efficiency responses to carbon dioxide changes. Later, the focus is on the thermal kinetic window, where it is shown that photosynthetic rates of C_4 plants are generally larger and peak at higher temperatures than those for C_3 plants, but that C_3 plants are more responsive to the elevated carbon dioxide concentrations that are predicted by global climate models to be coincident with higher temperatures. Up to this point, the discussion rests on results of field and greenhouse studies. The interaction of temperature and carbon dioxide effects on plant growth and water consumption is then discussed, supplementing experimental results with the results of several models. The chapter builds to a more complex discussion of climate change predictions generated by five general circulation models (CGM) for doubled carbon dioxide concentrations. Results of the CGM models have been used as input to crop growth models under various scenarios, with the discussion mostly on results for the United States and maize, soybean, and wheat crops. Results generally point to increased water consumption, but this varies by model. Water use efficiency may increase or decrease depending on the scenario and crop. The chapter ends with a discussion of adaptations that may be needed, including shifting of cropping to more northern areas where rainfall is expected to increase (or decrease less) and temperatures will be more moderate, shifting from rainfed to irrigated production systems in the eastern United States, reducing irrigation on the Great Plains, and building more storage reservoirs to capture runoff in the winter when precipitation is predicted to remain greater than evapotranspiration on the landscape. With its many references and an approach that builds logically from the more fundamental and experimental to the more complex and predictive approaches, this chapter alone is worth the price of the book.

The chapter on crop responses to water shortages deals mostly with leaf area index, transpiration, and yield responses. The presentation here is dated and several symbols in the equations are undefined. Thirteen of the 31 references are to works authored or coauthored by the chapter's author, leading to a discussion that lacks generality and that ignores important work in the area, such as that by Musick and others in the U.S. Southern High Plains. For example, the experimental results discussed lead to the conclusion that reduction in leaf area is the primary cause of reduction in yield. As pointed out in several of the other chapters, there are other causes of yield reduction, including reduction of photosynthetic efficiency due to high leaf temperatures, reduced fertilization due to dry silk in maize crops, and reduced translocation of photosynthates to yield members.

The fourth chapter is out of place in this book. Even though it provides an interesting look at the effects on soil properties of irrigating with saline water, it does not discuss crop water use. It reports results from five locations in the Buenos Aires Province of Argentina that were center-pivot sprinkler–irrigated with waters varying in electrical conductivity from 1.1 to 4.0 dS m^{-1} and in sodium absorption ratio from 15.5 to 29.1. Irrigation in the area was supplemental only, and rainfall was sufficient to leach the soils and prevent accumulation of salt in the soil, but infiltration rate was decreased.

Water use by the olive tree is thoroughly reviewed in the excellent chapter of the same name. The chapter describes the species, its habitat, and growth cycles. Drought tolerance is discussed from the point of view of root distribution and activity, root anatomy and growth, root signaling, and hydraulic characteristics of the wood. It is further discussed based on leaf and canopy characteristics, leaf water relations, and transpiration and water use efficiency. Recovery after drought and leaf aging are discussed. Crop responses to irrigation are described, followed by a discussion of several methods of measuring or estimating water use, including the soil water balance, the evaporation pan, methods based on micrometeorological measurements, and sap flow measurements. The chapter ends with discussion of deficit irrigation strategies, irrigation with low quality water, and orchard management. The high water use efficiency of olive is described, along with strategies for increasing total water use efficiency through irrigation scheduling. The entire discourse builds logically and is extensively referenced. Although specific to olive, the chapter is interesting reading to anyone working on crop water use because it brings an integrated view of plant physiological, soil physical, and micrometeorological processes to bear. The chapter's organization would provide a useful guide to anyone wishing to write about the water use of a particular crop.

A short chapter describes the effects of canopy position, leaf age, and vapor pressure deficit on stomatal conductance and water use of citrus in Florida. Measured stomatal conductance is related to measured water use from potted trees using a Penman-Monteith model modified to group leaves as shaded or unshaded. The Penman-Monteith approach provided good results for the 2-year-old potted trees and was scaled up to provide water use estimates for 15-year-old orchard trees.

A 9-year study of irrigation with saline drainage waters is reported in two chapters, one on cotton and the other on safflower. Six salinity levels ranging from 400 to 9 000 ppm total dissolved salts were created by mixing drainage water with canal water. Over the long term, irrigation with salinities $>$3 000 ppm caused cotton yield reduction, probably due to poor stand establishment, but not quality reduction. Crop growth data are discussed, but water use is not presented. Irrigation scheduling and total irrigation amount are not presented, nor are any soil water content measurements. Although tile drains were installed, no drainage flow measurements are presented. Safflower was grown every third year, with one preplant irrigation with canal water and no subsequent irrigation. While safflower oil content and quality were not affected, yield was severely affected by the residual effects of irrigating cotton with saline waters. For both crops, levels of K^+, Na^+, C_a^{2+}, Cl^-, and NO_3^- in leaves are presented. In another, short, chapter on cotton, a single-year study of yield under three irrigation levels (two deficit) of brackish (EC $\approx$ 3.8 dS m^{-1}) water is presented. Cumulative irrigation amounts are presented but crop water use values are not, as no soil water measurements were made. Results mirrored those of the longer-term study in that cotton yield and quality were not affected by water stress, although plant growth was strongly affected.

The chapter on water use in rice production thoroughly reviews how water is used in different systems of rice production and discusses strategies for increasing water productivity both in terms of yield per unit of irrigation water diverted and per unit of water evapotranspired by the crop. Almost all of the work referenced occurred in eastern and southeastern Asia or the Indian subcontinent, thus omitting discussion of practices in Egypt and the United States. Water balance components are examined both for the period of land preparation before planting and during crop growth, and the impacts of different management practices and irrigation system delivery abilities are discussed. Rice yield per unit evapotranspiration is similar to that of wheat, another C_3 crop, and approximately one-third to one-half that of maize. Although this constrains the potential for increasing water use efficiency, several options are available to improve productivity, including changing the crop schedule to more effectively use rainfall, using newer indica and tropical japonica varieties that have larger water use efficiencies due to yield increases or increases in transpiration efficiency, and improving nutrient status and weed management. The author points out that many of the possible practices have negative impacts on labor needs, fertilizer use efficiency, weed management (e.g., dry seeding), or capital cost.

Two short chapters focus on greenhouse studies of sorghum water use. Sorghum transpiration efficiency (TE) increased with water limitation and was significantly different among genotypes in a study in which biomass harvest occurred near anthesis. The study involved 17 genotypes under both well-watered and water-limited conditions. Transpiration efficiency was negatively correlated with transpiration per unit leaf area. Several measurements were made in an effort to discover selection indices for TE. Leaf carbon concentration and ash content were significantly correlated with TE. Hypotheses explaining genetic variation in TE are presented. Hydraulic resistances of sorghum and sunflower are compared in another short chapter. Hydraulic resistance of sorghum was constant for both well-watered and water-stressed sorghum (a C_4 plant), but increased with water stress for sunflower (a C_3 plant), finally becoming close to the resistance for sorghum.

A two-year field study of sunflower response to irrigation water quantity, salinity, and timing found that responses were different in a loess soil and a clay soil with a high water table. In both soils, higher yields were obtained with the same amount of water when irrigations were smaller but covered the entire irrigation season rather than larger irrigations applied for only part of the season. Yield declined with total water applied more quickly in the clay soil, which difference was attributed to a more shallow root system in the clay.

Turfgrass evapotranspiration (water use) is reviewed concisely but effectively in a short chapter of the same name. It is pointed out that there are wide differences in water use among species and cultivars, but that cool-season grasses tend to use more water than warm-season species, and that C_3 grasses use more water than C_4 grasses. The wide-ranging and well-referenced discussion includes factors such as root and shoot characteristics, growth habit, plant density, stomatal characteristics (which have surprisingly inconsistent influence), leaf rolling, and rooting depth and density. The effect of microclimate on water use is discussed, with interesting sections on the effects of wind speed and soil temperature. The effects of mowing height and fertilization are also delineated. The great variability in water use described may give pause to those considering the use of cool season grasses as standards for reference evapotranspiration in schemes for crop water use estimation.

The report of an experiment over three years of the effect of micro-basins on wheat yield and water use is disappointing due to the lack of explanation of the methods used.

The final chapter is a departure into risk assessment for irrigated crops in a maritime climate with erratic rainfall. Although specific to the Auckland province of New Zealand, the approach is general enough to be useful elsewhere and provides insight into the risk associated with allocation of water rights to irrigators. The assessment is based on a one-dimensional computer model of the soil water balance using a 30-year daily weather record and, in the example given, soil properties for the predominant soil of the region. In general, the maximum plant-available water for each crop and soil must be known, as well as the percentage of plant-available water that the crop can use before yields decline. For each crop, cumulative probability distributions are created for precipitation, drainage, crop water use, and irrigation amounts. This allows the selection, for any level of probability, of the amount of irrigation water that must be allocated to avoid a decline in crop production. Crops considered include green leafy vegetables, pasture, onion, potato, and squash. The chapter is a fitting end to the book, as it integrates knowledge of crop water use into the larger consideration of water allocation within a watershed where agricultural, environmental, industrial, and municipal interests compete for water.

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