Assessing Nonpoint Source Pollution in the Vadose Zone

Sustainable agriculture is viewed as the only viable means of meeting the food demands of the world's projected population of 11 billion by the year 2050. Sustainable agriculture is predicated on a delicate balance of maximizing crop productivity and maintaining economic stability while minimizing the use of finite natural resources and avoiding the detrimental environmental impacts of associated nonpoint source (NPS) pollutants. NPS pollutants include pesticides, fertilizers, trace elements, salts, sediments, etc., and are known to be carcinogenic, mutagenic, or teratogenic. NPS pollutants threaten sustainable agriculture and are recognized as the single greatest threat to surface and subsurface drinking water resources.

Against this backdrop scientists met to address the application of advanced information technologies to NPS pollution in soil at the 1997 Joint AGU-Chapman/SSSA Outreach Conference "Application of GIS, Remote Sensing, Geostatistics, and Solute Transport Modeling to the Assessment of Nonpoint Source Pollutants in the Vadose Zone." The objective of the conference was to explore multidisciplinary approaches for assessing NPS pollutants in the unsaturated region from the soil surface to the groundwater table (vadose zone). The conference provided a forum to stimulate interaction between the subdisciplines of spatial statistics, remote sensing, geographic information systems (GIS), and solute transport modeling to enhance the development and evaluation of techniques for the measurement, inventory, and monitoring of NPS pollution in soil and subsurface waters.

The conference answered two questions related to assessing NPS pollution vulnerability with GIS technology: What is currently possible and what is on the horizon? Perhaps the forthcoming greatest technological advance for modeling and assessing NPS pollution in the vadose zone will be the ability to perform regional-scale simulations with a system that integrates GIS, solute transport modeling, pedotransfer functions, neural networks, and remote sensing for estimating and/or measuring transport properties, geostatistics for characterizing variability structures and spatial interpolation, fuzzy set theory for handling vague and imprecise data, spatial and temporal analysis, and uncertainty analysis to allow decision-makers to evaluate the reliability of information.

Conference Agenda

One hundred and two scientists from nine countries participated during the 4-1/2 day conference and presented a total of 8 keynote papers, 22 invited papers, and 51 volunteered papers. The papers covered GPS, GIS, spatial statistics, remote sensing, solute transport modeling, neural networks, transfer functions, fuzzy logic, scale and scaling, and uncertainty analysis as these pertain to assessing NPS pollution in the vadose zone.

A keynote address concerning the role of environmental modeling in the decision-making process kicked off the conference. Even though policy-makers and environmental modelers are converging, the policy-making process is necessarily about politics. Models used in that realm are most likely to be applied as political weapons, not as unbiased tools. The notion that science and technology will mitigate environmental problems on a "truth wins" basis is probably illusionary. Subsequent keynote addresses dealt with the advanced information technologies needed to assess NPS pollutants in the vadose zone, including (1) current and future trends in the development of integrated GIS methodologies and data-capturing technologies; (2) the virtues of an integrated analysis of both vadose zone and groundwater processes to address aquifer vulnerability by applying geomorphological modeling and hydrostratigraphic structure to account for the spatial variability of flow within and below the vadose zone; (3) stochastic modeling of NPS pollutants in the vadose zone at regional scales as being the most viable solute transport approach because extensive spatial variability of water flow and solute transport properties make deterministic modeling unfeasible at this scale, necessitating some form of approximate stochastic approach using a local model representation that extrapolates from limited sample data; (4) the role of spatio-temporal statistical modeling; and (5) general and specific applications of remote sensing and noninvasive techniques.

Perhaps the most controversial, thought-provoking presentation was a keynote paper about scaling spatial predictability by Philippe Baveye which stabbed directly at the heart of distributed parameter modeling, and thereby the use of GIS as a viable approach for assessing NPS pollutants. An analogy was drawn between the present state of knowledge of modeling NPS pollution and the development of thermodynamic gas laws from physical theories of particle dynamics. The analogy caused pause for thought. Despite the inability of Newton's fundamental equations of a particle in motion to predict individual motions of gas particles in a container, an independent line of theory led to the formulation of the thermodynamic gas laws. Thus, despite the inability to predict larger scale behavior from smaller scale conceptual understandings, there are coarser scale, simpler descriptions that allow accurate prediction of the average behavior of the system. Analogously, scientists may be studying NPS pollution at a level of understanding and detail dictated by measurement instruments, such as remote sensing, and information technology tools such as GIS rather than at a level dictated by the appropriate conceptual framework.

Furthermore, the fundamental unit for landscape study is often specified as a catchment or a watershed, or even more arbitrarily by survey or geopolitical boundaries (that is, quarter section lines or water district boundaries), without knowing if these units are meaningful or whether they are the appropriate levels of aggregation for subsurface solute transport. It may be that policy-makers are asking scientists to predict at a level of detail something that is inherently unpredictable. This suggests the need for exploration of the scales, or ranges of scales, at which the dynamics of processes are drastically simplified.

The invited presentations were intended to be more parochial than the keynote presentations by focusing on specific issues concerning the assessment of NPS pollutants in the vadose zone. An integrated Earth science/economics-based approach provided an estimate of the societal value of information for assessing NPS pollution. From a transport modeling perspective, the multiscale effects of mass transfer processes on contaminant transport at a watershed scale were examined and the uncertainties arising when local scale processes are upscaled to a watershed were quantified. The difficulty of validating models for large regions was attributed to the challenging issues of model structure, nonlinearity, complexity, spatial and temporal variability, and scale transition errors that make it difficult to detect errors in model structure and parameterization over large regions.

The single greatest challenge to modeling and assessing NPS pollutants is obtaining sufficient spatial and temporal data. Viable estimation and parameterization approaches include applying artificial neural networks and the group method of data handling or developing pedo-transfer functions (PTFs), and the utilization of similar media scaling and conditional simulations with soft data to parameterize flow and transport models. Remote sensing and noninvasive techniques are crucial for providing direct or indirect surface and subsurface hydrologic measurements. The derivation of soil hydraulic properties in the vadose zone from remote sensing and the spatial delineation of actual and relative evapotranspiration from remote sensing instrumentation and energy balance equations remain as areas of current and future study.

The ability to delineate and quantify spatial variability is a key to applying GIS to model NPS pollutants. Spatial variability can be incorporated into existing soils databases by estimating spatial dependence from existing data, applying robust statistical methods such as bootstrapping, applying remotely sensed data, and taking more samples based on current information. Fuzzy logic and inference techniques derive accurate and detailed soil spatial information, allowing the realistic characterization of the joint spatial distribution of landscape parameters for distributed modeling at the watershed scale. The application of fractals as a primary model for the distribution of soil properties and modeling solute transport in porous media was illustrated with compelling evidence provided for the utility of this approach.

Many of the volunteered papers focused on integrated information technology.

Pollution (cont. on page 220)

MEETINGS

ANNOUNCEMENTS

■ July 5–10, 1998. **Pattern Formation in Earth Sciences.** Henniker, New Hampshire, U.S.A. Sponsor(s): Gordon Research Conference. H. L. Hederson, Dept. of Physics, University of Ottawa, Ottawa, ON, K1N 6N5, CANADA. Tel: +1-613-562-5700 ext. 6770 or 6273. Fax: +1-613-562-5190. E-mail: hhenders@aix1.uottawa.ca. Web Site: http://www.grc.uri.edu/.

Abstract deadline is May 22. The conference goal is to group together geologists, geophysicists, physicists, chemists, physical geographers, and mathematicians to study and discuss the diversity of nonequilibrium patterns in geosystems with a view to understanding the nonlinear processes involved. Topics include patterns in earthquakes, landscapes, crystal growth, geological systems, hydrogeological systems, nonlinear geochemical kinetics, self-organization in geological systems, and bacteriologically-induced patterns.

■ July 20–24, 1998. **20th International Union for Pure and Applied Physics (IUPAP) International Conference on Statistical Physics.** Paris, FRANCE. Sponsors: Commissariat a l'Energie Atomique (CEA), Centre National de la Recherche Scientifique (CNRS), IUPAP, others. (A Gerbil, Conference Secretariat, STATPHYS 20, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France. Fax: +33-1-69-08-81-20. E-mail: statphys@spht.saclay.cea.fr.)

This conference will cover such topics as general results in equilibrium statistical physics, nonequilibrium systems, correlated quantum systems, disordered media, dynamical systems and turbulence, long range interactions, reactive systems, interfaces, heterogeneous and granular materials, soft matter, biologically motivated problems, and applications to economics and other fields.

■ August 4–7, 1998. **Cross Currents in Water Policy.** Hood River, Ore., U.S.A. Sponsor(s): Universities Council on Water Resources (UCOWR). (UCOWR, Executive Director, 4543 Faner Hall, Southern Illinois University at Carbondale, Carbondale, IL 62901-4526. Tel: +1-618-536-7571. Fax: +1-618-453-2671. E-mail: ucowr@uwin.siu.edu. Web Site: http://www.ucowr.siu.edu/ucowr/.)

This conference will explore old water policies and new conceptions of sustainable development. Attention will be given to issues in the Western United States through discussion of the current Western Water Policy Review and examination of river management in the Pacific Northwest. Issues to be discussed include legal and institutional reforms, incentive-based water policies, interdisciplinary perspectives on water management, risk assessment, conflict resolution including interstate issues, management of water quality and ecosystems including hypoxia, river management, water quantity and allocation, and integrating policy and technology.

■ September 10–14, 1998. **Science Editing and Information Management–A Joint Meeting of the Association of Earth Science Editors (AESE)/Council of Biology Editors (CBE)/European Association of Science Editors (EASE).** Washington, D.C., U.S.A. Sponsors: AESE, CBE, EASE, others. (L. Zirkel, c/o AGU, 2000 Florida Avenue, NW, Washington, DC 20009 USA. Tel: +1-202-462-6910, ext. 379. Fax: +1-202-328-0566. E-mail: edinfo98@kosmos.agu.org. Web Site: http://earth.agu.org/ednonnfo98/.)

This integrated meeting will explore how today's economy and technology affect how data are being created and synthesized into published results. Science editors, librarians, researchers, and managers will learn about the challenges and successes of production, management, and the use of scientific information in an increasingly wired world. Technical talks, panel discussions, demonstrations, posters, and workshops will provide a forum for discussing the critical issues and questions facing editors and managers of scientific information. Topics include electronic publishing, ethics, intellectual property, information retrieval, archiving, and preservation, economics of publishing, science communication, and editor education. Field trips are offered in and around the Washington, D.C., area.

Abstracts will continue to be considered by the Program Committee as the sessions are being developed.

■ October 26–29, 1998. **The Geological Society of America 1998 Annual Meeting.** Toronto, CANADA. Sponsor(s): The Geological Society of America (GSA Meetings Department, P.O. Box 9140, Boulder, CO 80301. Tel: +1-303-447-2020. Fax: +1-303-447-0648. E-mail: meetings@geosociety.org. Web Site: http://www.geosociety.org/).

Abstract deadline is July 13. This meeting will focus on the theme "Assembly of a Continent." It will include regional, structural, tectonic, and stratigraphically-related topics. It will also discuss such diverse subjects in anthropology, hydrology, education, geochemistry, Quaternary, environmental studies, petrology, and mineralogy. Thirteen field trips have been proposed covering hydrogeology, the Grenville, stratigraphy, archaeology, and history in the Great Lakes Region.

BOOK REVIEWS

Geomorphology—A Systematic Analysis of Late Cenozoic Landforms, 3rd Edition

Arthur L. Bloom, Prentice-Hall, Upper Saddle River, N.J., xi +482 pp., ISBN 0-13-505496-6, 1998, $90.

Geomorphology is the study of how landscapes form. This deceptively simple description encompasses a branch of geoscience that is teeming with fundamental questions of how landscapes develop similar or different morphologies, and whether their developments can be explained historically or modeled theoretically. Geomorphology also involves the surface processes that inexorably convert rock into sediment. Because the study of either landforms or landsculpting is linked to active processes commonly occurring on human timescales, it might be fair to classify geomorphologists as the existentialists of geology.

The book's opening statement, "Let the fun begin," introduces a very well written compendium of ideas and commentary covering the dynamic field of geomorphology. Presented in 20 chapters, this well-balanced, fact-filled, informative, and interesting volume covers the fundamentals of geomorphology; Cenozoic climate and tectonics; constructional landforms; erosional landforms; glaciation; and coastal geomorphology.

Bloom methodically presents background material and develops an understanding of the science of geomorphology through carefully selected discussions. Sequentially building on earlier concepts, the book moves through the subjects of climatic and tectonic landforms, opting for a separate chapter on volcanic landforms. Each chapter is part essay and part review. The chapters not only review the literature that has added to our understanding of a particular landform or process but also discuss ideas that have turned out to be "wrong."

Discussion of those "wrong" ideas is as important as the valid ones in developing analytical abilities. In other instances, the book highlights competing explanations for a single phenomenon. References at the end of each chapter are valuable departure points for further reading.

Both the breadth and depth of the coverage are truly remarkable for a field that in practice represents many subdisciplines. Despite the fact that the book is intended for students with only basic geology prerequisites, it provides truly insightful, sophisticated, and thoughtful analyses that point out critical elements of a study or topic. Thought provoking discussions appear on nearly every page. The author has a knack for immediately recognizing critical elements of a subject and focusing on them. The chapter on Late Quaternary climatic geomorphology, which reviews climate proxy data and the landforms that have resulted from past climates, is particularly useful, and in some ways, makes this book unique as a modern geomorphology text.

Several weaknesses detract slightly from the book. Although acknowledging the importance of remotely sensed images, and in fact using them throughout the book, Bloom does not explain what the images represent and how they differ from ordinary optical photographs. Typographical errors are encountered as early as in the Table of Contents. Illustrations and photographs are generally black and white and their quality is highly variable. Fourteen color plates are included in the center of the book, but why these particular plates were selected is difficult to ascertain. Equations, where used, are presented in a way that unfortunately inhibits, rather than promotes, a deeper understanding of the topic.

Students who read this book will certainly benefit from an excellent survey of geomorphology provided by one of the field's most engaging writers. For professional geomorphologists, the book represents a wonderful collection of essays constituting an authoritative retrospective of the field.—*Larry Mayer, Geology Department, Miami University, Oxford, Ohio, USA*

Plate Tectonics and Crustal Evolution

K.C. Condie, Butterworth/Heinemann, UK, 282 pp., ISBN 0-7506-3386-7, 1997, $40.86.

Ever since plate tectonics revolutionized Earth science, university courses presenting Earth processes in the framework of plate tectonics have become as plentiful as earthquakes. Consequently, this segment of the textbook market, which includes popular classroom classics such as Keary and Vine's *Global Tectonics*, is heavily contested. Condie's book attempts to secure a portion of the pie by targeting advanced undergraduates, graduate students, and specialists "who want to keep abreast of scientific advances in this field," as stated in the preface.

Condie covers many topics, including the geology, atmosphere, and climate of Earth and planetary evolution. The book's title—*Plate Tectonics* (big and bold) *and Crustal Evolution* (several font sizes smaller)—suggests a thorough and timely review of plate tectonics as the main course on the menu. However, plate tectonics turns out to be merely an appetizer, and copious inaccuracies and omissions will likely leave an undergraduate student in a state of confusion.

Condie had to make careful choices in Chapter 1, titled "Plate Tectonics," to present the book's foundation coherently within a limited space, without detailed discussion. Wegener's theory of continental drift is introduced, long after plate tectonics—which is comparable to introducing Newton's laws after the theory of relativity. Readers who are curious about how plates move will find a short paragraph on cycloid plate motions. No concepts fundamental to plate motions are explained, including instantaneous, stage and finite rotations, and Euler poles. In contrast, discussion of supercontinents is concise and up-to-date. Chapter 2 presents a good overview of the structure and properties of the Earth's crust, but coverage of yield-strength envelopes and their significance is meager.

Given the primary mission of the book, crustal evolution in a plate tectonic framework, it is surprising that Chapter 3, titled "Tectonic Settings," is not organized according to plate boundary type (divergent, convergent, strike-slip), but rather contains a curious mix of subtopics. In a reversal of the sequence of tectonic events, passive margins (jointly with cratons) are discussed before continental rifts. Discussion of passive margins covers less than half a page, and Condie does not mention volcanic margins or fundamental processes such as pure versus simple shear in terms of margin formation. Considering that passive margins are critical in both the plate tectonic cycle and crustal evolution, it would seem that they deserve more space, given the book's title.

Chapter 4 discusses the Earth's mantle and core comprehensively, with two exceptions. Condie omits major recent advances in understanding how the geodynamo works (Glatzmaier and Roberts; Kuang and Bloxham). His discussion of the mantle thermal boundary layer also fails to mention fundamental contributions by Sclater, Parsons, and McKenzie on oceanic depth-age relationships, based on the thermal boundary layer or the plate model. Condie merely states that lithospheric thickness is a function of age, but he does not reveal the nature of this function.

Chapters 5 and 6 (crustal and mantle evolution and the atmosphere; oceans and climate) are the book's highlights. They provide the reader with concise, up-to-date, and well-written accounts of Archean to recent chemical, physical, and biological processes. Condie concludes with a condensed account of comparative planetary evolution, but the book would become more well-rounded if other topics, in particular, the fundamentals of plate tectonics and tectonic settings, were to receive more attention in future editions.

Given that this is the 4th edition of Condie's book, it is surprising to find factual errors such as the statement that "ridge-ridge transforms retain a constant length through time" (page 34) (this would only be true in the absence of spreading asymmetries). The coverage of crustal and mantle evolution is the book's main strength and what sets it apart from its competitors. However, these subjects are not typically required in undergraduate courses, which are often focused on conveying the fundamentals of plate tectonics and resulting Earth processes at the same time.

Further, the book's shortcomings in terms of organization, coverage of basic principles and lack of up-to-date information in some areas makes it less useful for those advanced readers not primarily interested in crustal and mantle evolution. The figures are simple, clear, and instructive about essential points. The book is recommended as a relatively affordable and useful reference for readers interested in its main theme. However, its content could be clarified by renaming it "Crustal Evolution and Plate Tectonics"—emphasizing the former rather than the latter, with Pangean-size font. Then the potential reader would be less confused about what to expect.—*Dietmar Mueller, Department of Geology and Geophysics, University of Sydney, Sydney, Australia*

Pollution (cont. from page 219)

approaches and case studies. A particularly noteworthy and encouraging trend in contrast to earlier published papers of GIS-linked NPS pollution modeling was the significant increase in the application of uncertainty analysis to augment the modeling studies as a source of reliability information. Three important advances in assessing NPS pollution vulnerability that were reported by the volunteered papers included evaluating the worth of supplemental chemical, climatic, and soil data; adopting the Jury transfer function model to regional scales; and extending geostatistical analysis into the time dimension.

Future Directions

Even though tremendous advances have been made in assessing NPS pollution in the vadose zone during the last decade [*Corwin and Loague*, 1996; *Corwin et al.*, 1997], much remains to be done. The direction of future research needs became evident at the conference. The pertinent areas requiring development include (1) instrumentation and methodology for the geospatial establishment of stream-tube boundaries (that is, spatial domains of statistically homogeneous properties of solute transport) and the fuzzy boundaries between stream-tubes; (2) remote sensing and noninvasive techniques for measuring solute transport model parameters at multiple scales in a cost-effective manner; (3) a clearer understanding of the issues of upscaling of spatial data and its aggregation, as well as downscaling and disaggregation; and (4) ultimately, the integration of scientific, economic, and political considerations to make NPS pollution assessments with advanced information technologies a decision-maker's, rather than a purely scientific, tool.

Acknowledgments

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The 1997 Joint AGU Chapman/SSSA Outreach Conference, "Application of GIS, Remote Sensing, Geostatistics, and Solute Transport Modeling to the Assessment of Nonpoint Source Pollutants in the Vadose Zone," was held October 19-24, 1997, in Riverside, California, USA.

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