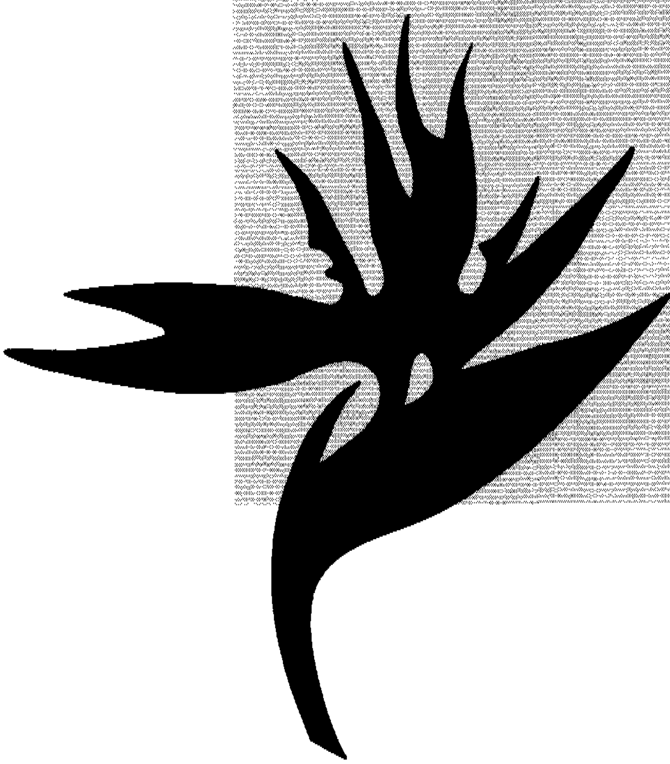
ASSESSMENT OF GROUNDWATER MODELS: 1994



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Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the conference participants and do not necessarily reflect the views of the sponsoring organizations.

The 1994 Pacific Northwest/Oceania Conference
ASSESSMENT OF MODELS FOR GROUNDWATER RESOURCES ANALYSIS AND MANAGEMENT

March 21–23, 1994

Turtle Bay Hilton

O'ahu, Hawai'i

sponsored by

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Water Resources Research Center
and
Department of Geology and Geophysics

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U.S. Environmental Protection Agency

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U.S. Geological Survey

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ASSESSMENT OF GROUNDWATER MODELS: 1994

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Editor

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WATER RESOURCES RESEARCH CENTER
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CONTENTS

INTRODUCTION

Assessment of groundwater models was the focus of the Pacific Northwest/Oceania conference held on March 21–23, 1994, at the Turtle Bay Hilton, Oahu, Hawaii. This conference differed from other modeling meetings by focusing on critical assessment—to what extent models have been adequate to address water, land, and environmental problems and have been able to advance scientific understanding of groundwater systems. These needs have been made acute by the very popular use and sometimes misuse of computational (numerical) models in recent years. Consequently, the crucial issue is, what is needed in the next generation of models in light of the critiques?

With such weighty needs, the conference called for national participation of the highest quality, with a balanced input from the tripartition of model creaters, model users, and natural resource managers.

The National Science Foundation's interests in the subject matter have been deeply rooted for some time, as partially reflected by its Environmental Engineering Program under the direction of Dr. Edward H. Bryan. The program activities transcend research projects on the subsurface system to include conferences. For example, in 1990 the program participated in an in-depth inquiry into groundwater models in the context of scientific and regulatory applications, sponsored by the National Research Council's Water Science and Technology Board; and as recent as October 1992, the program sponsored the second forum on NSF research activities in subsurface systems at Ann Arbor, Michigan. Because of its high interest in the subject matter, NSF decided to share in the costs of the 1994 conference by awarding a grant to the University of Hawaii.

This publication complements other products of the 1994 conference, namely the "Program and Abstracts" produced by the Water Resources Research Center at the University of Hawaii at Manoa and the book titled *Groundwater Models for Resources Analysis and Management* published by Lewis Publishers. The full agenda, together with abstracts of the presentations, is documented in the "Program and Abstracts," which was included among the materials given to the conference participants upon registration. Invited and selected papers presented at the conference appear in the Lewis Publishers book. This publication presents highlights of the conference and summaries of the forum on the next generation of groundwater models, as well as NSF perspectives on groundwater research, a list of the nineteen papers in the Lewis Publishers book, and some information about the conference participants.

It is worth noting that Turtle Bay, the site of the conference, is located in a quiet, secluded rural environment far away from urban centers and distractions. Such a location facilitated greater interaction and communication among participants than could have otherwise been achieved.

Keynote Addresses

A plenary session featuring a keynote speaker was held on the first and second days of the conference. Mary P. Anderson spoke on the science aspects in her talk titled "Groundwater modeling in the 21st century: Where are we going?" John D. Bredehoeft spoke on the management aspects in his talk titled "Modeling complex hydrologic systems for the purpose of management."

Anderson forecast major directions for modelers that include using parameter estimation codes to help with calibration, using improved modeling protocols to improve model reliability, and developing new field techniques to help with geological characterization of heterogeneity and plume characterization. Anderson has been a professor of geology and geophysics at the University of Wisconsin since 1975 and was the 1992 recipient of M. K. Hubbert award for outstanding contributions to groundwater science.

The bottomline of Bredehoeft's presentation on the benefit from regional groundwater management is that if it works, don't fix it. Many existing groundwater developments are currently operated at near-optimal economic efficiency. As a result, one should proceed cautiously in changing current institutions. Bredehoeft has devoted 30 years of public service at the U.S. Geological Survey and pioneered numerical models for groundwater systems.

Sessions

After the plenary session, the conference proceeded with concurrent sessions in which invited and contributed papers were presented. Two choices were provided: one for participants more concerned with application of models for resources management and the other for those more involved with modeling itself. The choices were as follows:

Choice 1

- General application of models
- Pacific model applications
- Geothermal modeling
- Management/liability/economic issues

Choice 2

- New modeling approaches
- Model validation/postaudit

General Application of Models

- *T.-C. J. Yeh, J. Mas–Pas, T. M. Williams, and J. F. McCarthy.* Observation and simulation of three-dimensional chloride and natural organic matter plumes in coastal sandy aquifers, Georgetown site, South Carolina (Invited paper)
- *S. V. Makepeace, W. W. Woessner, and R. Delk.* The use of a groundwater flow model to assess the consequences of mandated tribal instream flow demands on the groundwater system, western Montana: Irrigators, the confederated Salish–Kootenai tribes, and hydrogeologists
- *Y.-C. Tan.* A case study of damage assessment of groundwater resources
- *G. S. Johnson, J. M. Hubbell, C. W. Bishop, and J. G. Lucas.* Simulation of the impacts of ground-water pumping on flows of the Snake River in southeast Idaho

Pacific Model Applications I

- *L. S. Lau and J. F. Mink.* Groundwater modeling in Hawaii: A historical perspective (Invited paper)
- *J. W. Jenson and H. G. Siegrist, Jr.* A first order modeling study of the northern Guam lens aquifer
- *W. R. Souza.* Regional model of a freshwater–saltwater groundwater system
- *H. K. Endo, J. Mink, and M. Tagomori.* Groundwater modeling of subsurface grout curtains in Kona
- *T. E. Johnson and D. K. Kreamer.* Results and limitations of semianalytical modeling of flow and hydrocarbon transport in a coral atoll environment
- *S. J. Winter.* Groundwater development in remote areas of Federated States of Micronesia
- *S. Orr.* Modeling trace organic transport into and within a deep phreatic aquifer in Hawaii
- *S. A. Anderson and L. K. Thallapally.* Measurement and modeling of infiltration in a steep residual soil slope
- *T. Nishikawa, R. T. Hanson, and E. G. Reichard.* Concurrent flow, transport, and optimization modeling for the management of groundwater resources in a coastal basin

Pacific Model Applications II

- *F. L. Peterson and S. B. Gingerich.* Modeling atoll ground water systems (Invited paper)
- *D. J. Ackerman and L. J. Mann.* Extending model usefulness—Eastern Snake River Plain aquifer system, Idaho
- *R. Willis and B. A. Finney.* Groundwater optimization modeling in the Pacific rim

Geothermal Modeling

- *A. J. Menzies.* A review of geothermal reservoir modeling (Invited paper)
- *J. Dexter.* An application of finite element modeling to fluid density-dependent groundwater flow with energy transport for improved hydraulic conductivity estimates
- *S. B. Gingerich.* Numerical simulation of solute and energy transport in the near-surface aquifer of the Kilauea east rift zone, Puna District, island of Hawaii
- *V. Ranganathan.* 3-D simulations of geopressure-induced groundwater expulsion in radial faults around salt domes

Management/Liability/Economic Issues I

- *J. W. Massmann and M. T. Hagley.* A comparison of model and parameter uncertainties in groundwater flow and solute transport predictions (Invited paper)
- *M. G. Piepho.* Groundwater modeling with time-dependent hydraulic/ transport parameters for long time periods
- *W. W. Woessner.* Answered or unanswered questions, what does the regulator get: Assessing flow modeling results

Management/Liability/Economic Issues II

- *T. A. Prickett and W. A. Pettyjohn.* Groundwater modeling and litigation (Invited paper)
- *H. S. Rifai and P. B. Bedient.* A review of biodegradation models: Theories and applications
- *P. Berger.* The use of models (WHPA, VADOFT, VIRALD, CANVAS) to determine vulnerability to virus contamination
- *M. V. Yates.* Evaluation of the draft groundwater disinfection rule "natural disinfection" criteria using field data (Invited paper)

- *M. M. Aral and M. L. Maslia.* Integrating environmental modeling, demographic analysis, and spatial analysis technologies to determine a population's exposure to contaminants

- *D. S. Weber and E. L. Montgomery.* Projections for long-term groundwater yield from the Coconino–Supai aquifer, City of Flagstaff, Lake Mary wellfield area, Coconino County, Arizona

New Modeling Approaches I

- *B. Travis, N. Rosenberg, and W. Soll.* Groundwater modeling: Present capabilities and future directions

- *S.-G. Li and D. McLaughlin.* A new approach for modeling three-dimensional contaminant transport in heterogeneous aquifers

- *M. M. Hamed, P. B. Bedient, and J. P. Conte.* Uncertainty analysis of subsurface transport of reactive solutes using reliability methods

- *S. Orr.* High resolution Monte Carlo simulations of radial flow

- *T. Cheema and R. Islam.* New modeling approach for predicting anisotropic behavior of fractured formations

New Modeling Approaches II

- *A. I. El-Kadi.* On the accuracy of numerical solutions of unsaturated flow

- *R. J. Wagenet and J. L. Hutson.* Consequences of scale-dependency on application of chemical leaching models: A review of approaches (Invited paper)

- *S. Liu, W. B. Mills, R. A. Johns, C. S. Martin, K. J. Wilkinson, L. Pilo, and I. P. Murarka.* Modeling the effect of remediation action on contaminant transport in the vadose zone and groundwater

- *C. Chen, D. M. Thomas, and R. E. Green.* Modeling simulation of gas transport of 1,3-D volatile and radon through unsaturated zone

New Modeling Approaches III

- *M. Y. Corapcioglu.* Modeling multiphase contaminant flow in groundwater aquifers (Invited paper)

- *W. E. Hathhorn.* A statistical discussion of model error in the use of the advection-dispersion equation

- *T.-C. J. Yeh.* An interative co-conditional simulation model for flow and solute transport in variably saturated and heterogeneous porous media

Model Validation/Postaudit

- *L. F. Konikow.* The value of postaudits in ground-water model applications (Invited paper)

- *M. S. Beljin and W.-J. Fang.* Groundwater modeling of the Great Miami aquifer, Ohio: A postaudit study

- *P. K. M. van der Heijde.* Model testing: A functionality analysis, performance evaluation, and applicability assessment protocol (Invited paper)

- *F. Ghassemi, T. H. Chen, A. J. Jakeman, and G. Jacobson.* Two and three dimensional simulation of sea water intrusion: Performances of the SUTRA and HST3D models

- *P. W. Huntoon.* Is it appropriate to apply porous media ground water circulation models to karstic aquifers?

Posters/Demonstrations and Field Trip

Informal exhange was facilitated by posters and demonstrations, as well as a field trip. The former consisted of the following:

- *T. E. Johnson and D. E. James.* Modeling of subsurface dioxin transport in a tropical near-shore marine environment (Poster)
- *D. L. Corwin, P. J. Vaughan, H. Wang, J. D. Rhoades, and D. G. Cone.* A GIS application for predicting areal distributions of solute loading to the groundwater for a non-point source pollutant (Poster)
- *P. K. M. van der Heijde, D. A. Kanzer, and S. S. Paschke.* The development and application of saturated zone numerical ground-water model testing protocols (Poster)
- *S. Liu, W. B. Mills, R. A. Johns, C. S. Martin, K. J. Wilkinson, L. Pilo, and I. P. Murarka.* Demonstration of ROAM, the remedial options assessment model
- *A. I. El-Kadi.* Geographic information system as a modeling shell (Demonstration)
- *S. R. Spengler and S. B. Gingerich.* Incorporation of groundwater transport modeling results into an ecological risk assessment prepared for Kure Atoll, Hawaii (Poster)

During the field trip, participants visited the Halawa shaft and Mililani water treatment plant. The shaft is a facility extracting 14 mgd (0.61 m^3/s) of drinking water by infiltration gallery from the thick freshwater lens in the Pearl Harbor basal aquifer. The entire facility is located underground and is accessed by an inclined shaft. The Mililani plant provides above-ground remediation by granular activated carbon, of the organic contaminated groundwater source in Mililani in the Pearl Harbor aquifer. Both facilities are operated by the Board of Water Supply, City and County of Honolulu.

COMPOSITION OF PARTICIPANTS

Nearly 140 people attended the conference (see participant list in Appendix), including about 53% from the U.S. mainland (28 states from Massachusetts to California and Washington, D.C.) and Guam, 42% from Hawaii, and 4% from foreign countries (chart 1). The attendance by affiliation was a very desirable three-way split: 39% from academic institutions; 37% from consulting firms and industries; and 24% from governmental agencies, public interest groups, and concerned citizens (chart 2). The significance of the conference is reflected in representation by academic institutions that are renowned in groundwater modeling such as Massachusetts Institute of Technology, Stanford University, University of Wisconsin, Rice University, Cornell University, University of Arizona, University of Washington, and University of California at Riverside; major governmental agencies including the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Los Alamos National Laboratory, and U.S. Public Health Service; and numerous (48) consulting firms.

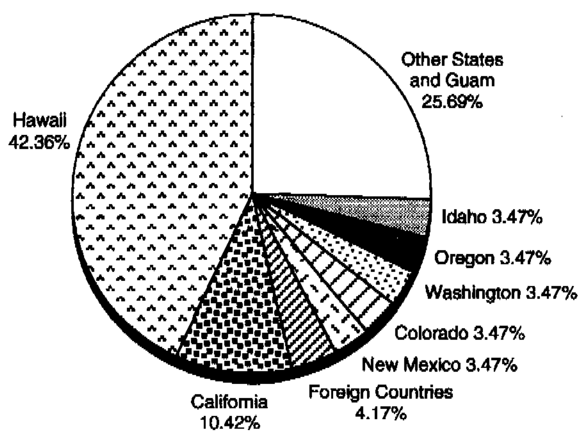

Chart 1. Conference attendance by state and foreign countries

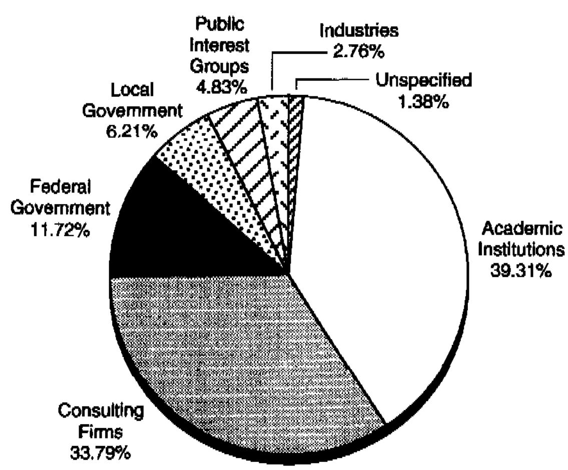

Chart 2. Conference attendance by affiliation

CONFERENCE FORUM:
[illegible] MODELS

An open forum was held on the last day of the conference to identify the weaknesses of models and modeling and to suggest needs for the next generation of models. It was candid and critical, yet creative and constructive. It was convened by Steven M. Gorelick of Stanford University, and panelists of high credential were as follows:

Research

- Lynn W. Gelhar, Lawrence Berkeley Laboratory, Berkeley, California; on leave from Massachusetts Institute of Technology
- Joel W. Massmann, University of Washington, Seattle, Washington
- R.J. Wagenet, Cornell University, Ithaca, New York

Regulation/Decision Making

- Philip Berger, U.S. Enivronmental Protection Agency, Washington, D.C.
- Leonard F. Konikow, U.S. Geological Survey, Reston, Virginia

Model Use

- Thomas A. Prickett, Thomas A. Prickett and Associates, Urbana, Illinois
- Daniel B. Stephens, Daniel B. Stephens and Associates, Albuquerque, New Mexico

Quality Assurance/Quality Control

- Paul K.M. van der Heijde, International Groundwater Modeling Center, Golden, Colorado

The following summaries of discussions held during the forum represent a near consensus among the participants. Complete agreement was evident on many issues related to process simulation, parameter evaluation, and model application.

Research

Groundwater models can be classified, in general, as flow and transport/fate models. Flow models have progressed to reach what can be termed a second-generation status with improved modeling capabilities. In such a class, it is now possible to model three-dimensional flow problems on faster computers. The success is mainly attributed to the validity of the macroscopic viewpoint of flow in porous media. However, success is not as sound regarding modeling fracture or preferential flow where the continuum principle is not valid, such as flow in karstic or volcanic formations. A detailed account of the various hydraulic properties of the medium is not generally possible. Techniques for measuring such properties, as well as conceptual models for heterogeneity analysis, are very much needed. Although research models have addressed uncertainty assessment, an acceptable rigorous approach is not readily available. Another difficulty exists in modeling nonlinear flow problems, such as those related to unsaturated and density-dependent flow. Numerical solutions may require the use of a very fine grid to achieve acceptable accuracy. Efficient solution techniques are essential here to solve large-scale field problems. The third generation of models additionally requires the ability to use visualization and to have interactive and complete control of the modeling process.

Although transport/fate models have advanced in their capabilities, they have not overcome their first-generation status in terms of their limited ability to solve field problems. Difficulties include failure to describe the flow field on the appropriate scale and the absence of accurate conceptualization of the chemical and biological activities involved. The next generation of transport/fate models needs to overcome the major specific problems summarized below.

Field Techniques

Computer technology has out-paced field technology. The lack of appropriate data causes significant barriers in the modeling process. Many parameters of concern cannot be independently estimated, and a type of inverse technique is needed in this regard. The estimated parameters depend thus on the conceptual model used in the inversion process and the scale of measurements. There is a need to develop new field techniques to characterize subsurface properties. The techniques should be able to characterize the heterogeneities involved in the physical, chemical, and biological parameters.

Conceptual Models

Many modeling processes and their interaction are not well understood. Conceptual models having realistically practical data requirements are lacking in such areas as chemical, biological, and multiphase-flow modeling, especially under nonequilibrium conditions. Modeling coupled processes, particularly under complicated field conditions, is an area that requires much attention. There is a need to consider heterogeneity of biological and chemical processes. Such processes have been assumed as spatially invariant, which may not be an accurate conceptualization, due to the interrelation among chemical, biological, and hydrological parameters. The problem of parameter variability needs to be studied on both the small and large scales. Scale-up theories, which will allow better interpretation of field measurements at the correct scale, need to be advanced.

Of immediate need also are efforts to estimate various transport/fate parameters, such as dispersivities, independently of chemical concentration data. Although Fickian transport theory has been proven, through several controlled field experiments, to be adequate in describing the dispersion phenomenon, there is still a need to develop other vehicles for modeling contaminant transport.

Models to quantify uncertainty and risk should be advanced, most appropriately within a stochastic framework that links the modeling process to available data. Finally, interdisciplinary research efforts should be encouraged to include cooperation among the various branches of earth sciences. For example, it is possible to integrate advances in oil engineering, soil physics, and hydrogeology in addressing a certain problem from an environmental perspective.

Computation

Software and hardware computer technology has advanced greatly over the last decade, outgrowing our conceptual and data-collection abilities. Three-dimensional modeling is now possible; yet, because such models are not flexible, more efficient solution techniques are needed. For example, nonlinear flow and transport problems require the use of an extremely fine grid, on the order of a few centimeters, which would make a field-scale problem intractable. The new class of "mega-models," which is promoted as "general," is probably not useful at this stage because of the degree of complexities involved and the need for experienced users.

Applications

Modeling

The availability of models that are too user-friendly can lead to their misuse. New advances in computer software and hardware provide the opportunity for developing a relatively easy modeling process with a user-friendly interface. However, because many models in such systems are too simple and are based on severe assumptions, the user has to be aware of the limitations and restrictions involved. User interaction, intuition, and common sense are important parts of the modeling process and should not be substituted by the machine and its software. Decision or policy models are generally generic with many built-in parameters and are intended for screening purposes. Policies or decisions based on these models should be analyzed carefully and their interpretation based on the assumptions included within a comparative framework. In this and other cases, modeling goals and objectives should be set clearly as early as possible because they constitute an important factor in choosing a model.

It is essential that modelers reveal their subjectivity and personal judgment in the study report. The basic element in any report should be the ability of the modeler to defend his or her effort and justify any modeling decisions. One of these decisions concerns model choice with the appropriate level of complexity. Although complex models are generally more accurate, their use requires extensive data sets and therefore may not be suitable for the problem at hand.

Successful model use requires the availability of experienced model users and good model documentation that adopts acceptable standards. Well-trained modelers should have the knowledge and expertise necessary to reduce any chance of model misuse. Documentation should clearly describe model limitations and restrictions. There is also a need to close the gap between model researchers and users and to improve on the usability of research models. Modeling conferences and workshops that involve the two groups should be held regularly. Many research models are not suitable for use mainly because of their extensive data requirements, the absence of documentation, and their experimental, unfinished status.

Model Validation

A clear and consistent modeling vocabulary needs to be used. The use of many fitting parameters that cannot be independently defined has deemed model validation a useless concept. A need exists to fully examine this issue and to standardize techniques to gain confidence in the predictive capability of models. It should be realized that general modeling standards can be useful although they may not be appropriate for all conditions. Standards cannot and should not substitute for a modeler's justification for a specific model use and for specific results interpretation. Although postaudits deal with site-specific problems, they can be useful. Such studies are concerned with assessing model predictions based on actual outcomes and therefore can enhance the understanding of processes involved and add to the modeler's practical experience.

A book containing 19 invited and selected papers presented at the conference, including the paper on the next generation of models, was published by Lewis Publishers (2000 Corporate Blvd., N.W., Boca Raton, Florida 33431-9868). The manuscripts were submitted to the publisher in June 1994, and the book, *Groundwater Models for Resources Analysis and Management*, was released in April 1995. The cost for the 432-page book is U.S. $69.95/outside U.S. $84.00.

The list of papers, by section, is as follows.

Groundwater Models for Resources Analysis and Management

Edited by Aly I. El-Kadi
University of Hawaii at Manoa

Section 1. General Model Assessment

- A comparison of model and parameter uncertainties in groundwater flow and solute transport predictions

  J. W. Massmann and M. T. Hagley

- A statistical discussion of model error in the use of the advection-dispersion equation

  W. E. Hathhorn

- Model testing: A functionality analysis, performance evaluation and applicability assessment protocol

  P. K. M. van der Heijde

- The value of postaudits in groundwater model applications

  L. F. Konikow

- Groundwater modeling in the 21st century

  M. P. Anderson

- Needs for the next generation of models

Section 2. On Models as Management Tools

- If it works, don't fix it: Benefits from regional groundwater management

  J. D. Bredehoeft, E. G. Reichard, and S. M. Gorelick

- Uncertainty analysis of subsurface transport of reactive solute using reliability methods

  M. M. Hamed, J. P. Conte, and P. B. Bedient

- Groundwater modeling and litigation

  T. A. Prickett and W. A. Pettyjohn

Section 3. On Unsaturated/ Multiphase Flow and Transport Modeling

- On the numerical solutions of one-dimensional flow in the unsaturated zone

  A. I. El-Kadi

- Consequences of scale-dependency on application of chemical leaching models: A review of approaches

  R. J. Wagenet and J. L. Hutson

- Stochastic modeling of water flow and solute transport in the vadose zone

  T.-C. J. Yeh

- Modeling multiphase contaminant flow in groundwater aquifers

  M. Y. Corapcioglu, K. K. R. Kambham, and R. Lingam

Section 4. On Island Modeling

- Groundwater modeling in Hawaii: A historical perspective

  L. S. Lau and J. F. Mink

- Modeling atoll groundwater systems

  F. L. Peterson and S. B. Gingerich

Section 5. On Biodegradation/Virus Transport Modeling

- A review of biodegradation models: Theory and applications

  H. S. Rifai and P. B. Bedient

- Evaluation of groundwater disinfection rule "natural disinfection" criteria using field data

  M. V. Yates

Section 6. On Fracture Flow Modeling

- A new modeling approach for predicting flow in fractured formations

  T. J. Chema and M. R. Islam

- Is it appropriate to apply porous media groundwater circulation models to karst aquifers?

  P. W. Huntoon

An intent of the National Science Foundation grant (BES 94-03359) was to foster research on specific topics such as those recommended at the 1992 Ann Arbor NSF meeting, namely, (1) multiphase flow and transport, (2) microbial processes, and (3) aquifer heterogeneity. These topics, which received major attention at the 1994 conference, are addressed in the Lewis Publishers' book as follows: topic (1) in section 3, topic (2) in section 5, and topic (3) in section 6.

NSF's purposes were explicitly acknowledged at the first-day luncheon. The scheduled luncheon speaker was Dr. Edward Bryan, an NSF representative; unfortunately, he was unable to attend the conference. On his behalf and at his request, the grant principal investigator gave a summary of the NSF Environmental Engineering Program funding and trend in groundwater research, announced that the Ann Arbor report was recently released, thanked the NSF principal investigators, and wished great success for the conference.

The all-important forum held on the third and final day of the conference was promoted by NSF, whose grant enabled two key scientists, who are NSF principal investigators, to be a part of the workshop. The grant also supported two other NSF principal investigators and one other scientist—all of whom made important presentations and interactions with others at the conference.

APPENDIX

List of 1994 Pacific Northwest/Oceania Conference Participants

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