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Using Atmospheric Tracers to Reduce Uncertainty in Groundwater Recharge Areas and Quality Trends in Transient Flow Systems

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Abstract

A Monte Carlo-based approach to assess uncertainty in recharge areas shows that incorporation of atmospheric tracer observations (in this case, tritium concentration) and prior information on model parameters leads to more precise predictions of recharge areas. Although the addition of atmospheric tracer observations and prior information produced similar changes in the extent of predicted recharge areas, prior information had the effect of increasing probabilities within the recharge area to a greater extent than atmospheric tracer observations.

For gradient-based parameter estimation methods, where a simulation model is run repeatedly to populate a Jacobian (sensitivity) matrix, there exists a need for rapid simulation methods of known accuracy that can decrease execution time, and thus make the model more useful without sacrificing accuracy. We have employed convolution-based methods that can be executed rapidly for any desired input function once the residence-time distribution is known. This distribution can be calculated efficiently using particle tracking. Particle tracking can also be used to simulate recharge areas, but in many cases these recharge areas are highly uncertain because parameters such as hydraulic conductivity and recharge rates have errors associated with them. We have developed Python scripts to run Monte Carlo simulations with Latin hypercube sampling where model parameters such as hydraulic conductivity and recharge are randomly varied for a large number of model simulations, and the probability of a particle being in the contributing area of a well is calculated based on the results of multiple simulations. We also developed a convolution-based particle tracking algorithm for transient flow fields, which is better able to capture multimodal breakthrough caused by changes in pumping at the well.

Finally, we applied these numerical tools to an existing groundwater-flow model of Salt Lake Valley, Utah. The model was adapted for use with convolution-based advective particle tracking to explain broad spatial trends in dissolved solids. Our model supports the hypothesis that water produced from wells is increasingly younger with higher proportions of surface sources as pumping changes in the basin over time. Calibration to tritium concentrations was used to estimate effective porosity and improve correlation between source area changes, age changes, and measured dissolved solids trends. Uncertainty in the model is due in part to spatial and temporal variations in tracer inputs, estimated tracer transport parameters, and in pumping stresses at sampling points. For tracers such as tritium, the presence of two-limbed input curves can be problematic because a single concentration can be associated with multiple disparate travel times. We also applied the model and effective porosity was adjusted until simulated tritium concentrations match concentrations in samples from wells. Two calibration approaches are used: a complex highly parameterized porosity field and a simple parsimonious model of porosity distribution. Of the models tested, the complex model (with tritium concentrations and tritium/helium apparent ages) performs best, even though tritium breakthrough curves simulated by complex and simple models are very generally similar.

Bio

Ross Bagtzoglou is Professor and Department Head of Civil and Environmental Engineering at the University of Connecticut, where he teaches Water Resources and Environmental Engineering courses and specializes in numerical modeling of environmental and hydrologic processes. He holds a Diploma in Civil Engineering from the Aristotle University of Thessaloniki-Greece (1985), a MS in Hydrology and Water Resources Engineering from the Florida Institute of Technology (1987), and a PhD in Water Resources and Environmental Engineering from the University of California at Irvine (1990). He is a licensed civil engineer in Greece. As a graduate student he has been the recipient of Fulbright and NATO scholarships. Before joining academia he has held research and development positions first as a post-doctoral associate (1990-91) at the University of California under funding from the US Department of Energy (US DOE), and then as a research engineer (1991-1993) and senior research engineer (1993-96) at the Southwest Research Institute under funding from the US Nuclear Regulatory Commission (US NRC). He served as Assistant Professor of Water Resources and Geo-Environmental Engineering at Columbia University (1997-2002), joined UConn as an Associate Professor in 2002, served as Director of Environmental Engineering (2005-2009), and became Department Head in 2009. Professor Bagtzoglou currently serves as Associate Editor for the journal Stochastic Environmental Research and Risk Assessment (2006–) and is member of the editorial board for the journal of Environmental Forensics (2003–). Professor Bagtzoglou has a record of over 160 technical publications including 80 papers in archival journals, book chapters, and monographs. He has delivered more than 100 presentations all over the world and has taught as visiting professor in Ethiopia, France, and Greece. He has received over $12M in research funding as PI, co-PI, or Senior Personnel. He is an elected Member of the Connecticut Academy of Science & Engineering (2009) and New York Academy of Sciences (1999). He is an elected Fellow of the American Society of Civil Engineers (2012), the Institution of Civil Engineers (2012), and the American Water Resources Association (2014).

Ross Bagtzoglou, PhD

Professor and Head, Department of Civil & Environmental Engineering

UNIVERSITY OF CONNECTICUT

Education

- **PhD, Water Resources & Environmental Engineering, *UNIVERSITY OF CALIFORNIA - IRVINE***
- **MS, Hydrology & Water Resources Engineering, *FLORIDA INSTITUTE OF TECHNOLOGY***
- **Dipl., Civil Engineering, *ARISTOTLE UNIVERSITY OF THESSALONIKI-GREECE***

Research Interests

- **Hydrologic modeling**
- **Reconstruction of past hydrological events**
- **Chaotic advection & enhanced mixing**
- **Estuarine & river water quality management**

Selected Service and Awards

- **Asst. Prof., Columbia University (1997-2002)**
- **Assoc. Prof., Full Prof., Head, UConn (2002-)**
- **Assoc. Editor, *Stochastic Environmental Research and Risk Assessment***
- **Ed. Board, *Environmental Forensics***
- **Elected Member, CASE, NYAS**
- **Elected Fellow, ASCE, ICE, AWRA**