Groundwater Resources Association of California

HYDROVISIONS

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Water Crisis and Uncertainty: Shaping Groundwater's Future

Summary of the 27th Biennial Groundwater Conference and 18th Annual Meeting of GRA

By Steve Phillips, U.S. Geological Survey; Greg Bartow, San Francisco Public Utilities Commission; Chris Frahm, Brownstein Hyatt Farber Schreck; Vicki Kretsinger Grabert, Luhdorff & Scalmanini, Consulting Engineers; Thomas Harter, University of California, Davis; Richard Laton, California State University, Fullerton; Jean Moran, California State University, East Bay; Tim Parker, Parker Groundwater; Sarah Raker, MACTEC Engineering and Consulting, Inc.; James Strandberg, Malcolm Pirnie, Inc.; Laosheng Wu, University of California, Riverside

The 27th Biennial Groundwater Conference and 18th Annual Meeting of GRA was held in the Sacramento Convention Center on October 6-7, 2009. This being the third year of drought compounded with environmental restrictions on water exports from the Delta, the theme of water crisis and uncertainty and how this will shape the future of groundwater in California was quite appropriate.

Special thanks are due to Mary Scruggs of the California Department of Water Resources (DWR) for heading the Organizing Committee, Christine French of the U.C. Center for Water Resources for excellent administrative support, and to the rest of the Organizing Committee and support staff. Thanks also to the conference sponsors, co-sponsors, cooperating organizations and vendors that make such an event possible.

Shocking news arrived during the conference that the University of California Office of the President announced the closure of the Center for Water Resources by December 31, 2009 and hopeful transfer of the Water Resources Archive to a new home by June 2010. The Center for Water Resources began the very successful Biennial Groundwater conference series 54 years ago, and GRA has been a proud partner in the series for the last 18 years. This conference series, however, is but a small token of the contributions the Center has made over the years toward research efforts critical to the improved understanding and management of California's water resources. Please see the article on page 38 to learn more about this issue, the potential loss of the Water Resources Center Archives, and how you can convey your opinion.

Following are summaries of presentations from a diverse group of speakers on a wide range of topics, including an excellent set of student talks in the Collegiate Groundwater Colloquium. The program began with three excellent talks in the Plenary Session followed by a two-track program for the balance of the conference before ending with a popular joint closing session. Presentation files and supporting documents are currently

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The Groundwater Resources Association of California is dedicated to resource management that protects and improves groundwater through education and technical leadership.

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Columns & Corners

HYDROVISIONS is the official publication of the Groundwater Resources Association of California (GRA). GRA's mailing address is 915 L Street, Suite 1000, Sacramento, CA 95814. Any questions or comments concerning this publication should be directed to the newsletter editor at editor@grac.org or faxed to (916) 442-0382.

Changing Times for Water in California and GRA

By James Strandberg

On November 7, 2009, Governor Arnold Schwarzenegger signed a historic five-bill water infrastructure package, which had been passed two days earlier by the Legislature. All should be commended for the marathon bipartisan effort. The package will surely affect the use and management of water across the State. Perhaps the most gratifying part of the package for GRA is Senate Bill 6, Groundwater Monitoring. As many GRA members know, GRA has consistently lobbied for this important policy mandate. The Association's active involvement and support can be traced to 2003 with legislation focusing on the establishment of uniform groundwater data standards. GRA representatives testified at several hearings in support of SB 6. In addition to these significant policy changes, the $11.1 billion bond measure SB7X-2, which contains numerous earmarks for projects throughout the state, will be put before voters on the November 2010 ballot. The bond includes $1 billion for groundwater protection and water quality, and $3 billion for competitively selected surface and groundwater storage projects. GRA's Legislative Committee chair, Tim Parker of Parker Groundwater, and GRA's lobbyists, Chris Frahm and Paul Bauer of Brownstein Hyatt Farber Schreck, deserve recognition and appreciation for their persistent efforts in representing GRA's interests throughout the process. Please see the California Legislative Corner for a full briefing on the content of this historic water package.

On October 6 –7, 2009, GRA held its 18th Annual Meeting in conjunction with the University of California Center for Water Resources 27th Biennial Groundwater Conference in Sacramento. The Conference was a great success with over 200 attendees giving high ratings to the program developed through the hard work of an enthusiastic organizing committee (please read article in this *HydroVisions*). As part of the Awards Luncheon on October 7th, I had the pleasure of bestowing GRA's 2009 President's Awards to a number of individuals who provided significant contributions to the Association during 2009. Those recognized, listed below, contributed at the organizational level or led successful events during 2009.

Communications Committee: Bill Pipes, Chair (AMEC Geomatrix); Steve Phillips, *HydroVisions* Editor (USGS); and Kathy Snelson, Executive Director, led the effort to redesign and create GRA's electronic *HydroVisions,* which debuted with the Spring 2009 edition.

Finance Committee: Sarah Raker, Chair (MACTEC Engineering and Consulting, Inc.); Kathy Snelson; and David von Aspern, Treasurer (Sacramento Co. Environmental Management Department) substantially improved the Association's ability to organize and use event finance data.

Technical Committee: Brian Lewis, Board Liaison (DTSC); Bill Motzer, Co-chair (Todd Engineers); and John McHugh, Co-chair (Santa Clara Valley Water District) led the revitalization of this important committee.

Dr. Eric Reichard and Dr. Brian Wagner, both with the USGS, co-chaired the successful Groundwater Monitoring Conference held in February (see summer 2009 *HydroVisions*).

Michael Steiger, Erler and Kalinowski, Inc.; Dr. Jean Moran, CSU East Bay; and Vicki Kretsinger, Luhdorff and Scalmanini, Consulting Engineers collaborated with the UC Water Resources Center to co-chair the successful Salinity Conference held in March (see summer 2009 *HydroVisions*).

Chris Frahm and Paul Bauer of BHFS, and Tim Parker (Parker Groundwater) organized an outstanding 2009 Legislative Symposium and Lobby Day held in April (see summer 2009 *HydroVisions*). Chris also leads BHFS's effective lobbying services for GRA with strong support from Paul.

Dr. Rula Deeb (Malcolm Pirnie, Inc.) and Dr. David Sedlak, UC Berkeley, collaborated with the International Water Association to lead the highly acclaimed "Assessment and Control of Micropollutants/Hazardous Substances in Water" event held in June (see fall 2009 *HydroVisions*).

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Changing Times for Water in California and GRA – *Continued*

At this time of year, the Board of Directors develops a slate of candidates to fill seats where terms are expiring. The slate will be put forward to the membership for voting. One incumbent Director, Stephanie Hastings of BHFS, has elected to step down after serving two terms. On behalf of the Association, I extend my sincere appreciation to Stephanie for her service and many contributions. Stephanie served as the Bylaws Committee Chair and led the updating of GRA's Bylaws. She also served as the Awards Committee Chair for the past two years. While Stephanie's seasoned perspective and legal acumen will be missed, she has volunteered to continue to serve as GRA's General Counsel and provide pro bono legal services.

At the November 2009 Board meeting, the Board elected new officers for 2010. Please join me in congratulating Bill Pipes as the incoming President; Sarah Raker, Vice President; Ted Johnson of the Water Replenishment District of Southern California, Secretary; and David Von Aspern, continuing as Treasurer. I also wish to express my gratitude to Bill Pipes for his service as Vice President and Roy Herndon of the Orange County Water District as Secretary for the past two years.

In completing my second term as President, I am grateful for the confidence the Board entrusted in me and for the opportunity to serve the Association in this capacity – it has been an honor and a privilege. I would also like to thank the Directors, the Branch officers, and all event chairs and committees for ensuring GRA's success through these very challenging economic times. Through the significant voluntary contributions of these individuals in addition to our staff, Kathy Snelson and Mary Megarry, and the unwavering support of the membership, GRA continues to build a strong legacy and further its position as the leader in championing the protection, management and improvement of groundwater in California through education and technical leadership. In closing, I encourage you to check the website for a list of GRA's committees and 2010 Chairs and Co-chairs. I am sure you will find, as I have, that volunteering to support GRA in achieving and sustaining its mission is a very rewarding experience and a proud contribution during your professional career. Thank you.

GUEST EDITORIAL

The Complex Future of Hydrogeology

By Devin L. Galloway, U.S. Geological Survey

Introduction

Presently, science in general and the natural sciences in particular are in the throes of a shifting social paradigm towards a 'holism' through synthesis and systems approaches to improving understanding. In hydrogeology, this is leading to even more interdisciplinary research and applications, and to even more complexity at the coupling interfaces of the systems. This paper briefly explores the future of hydrogeology within the context of the movement toward interdisciplinary science.

The State of Hydrogeologic Research

In the Information Age, vast amounts of accessible information are accumulating that passes as various forms of knowledge—untested, empirical, heuristic, and absolute. But is this knowledge translating to science? Hydrogeology is challenged by complex issues of heterogeneity, uncertainty and scale, recalcitrant to present levels of knowledge. Some argue that much hydrogeologic research is follow-on, limited-impact, incremental science that fails to contribute significantly to ongoing practices and applications (Schwartz and Ibaraki, 2001; Miller and Gray, 2002). If hydrogeology is founded more on empirical laws than rigorous, fundamental first principles, as some argue, then much fundamental reductionist research is yet to be accomplished (Miller and Gray, 2002). As related research fields grow, there is a growing need to unify knowledge of shared processes through synthesis of the field-specific knowledge bases. Advances in hydrogeologic research are thus induced toward reduction as well as synthesis.

Movement Toward Interdisciplinary Science

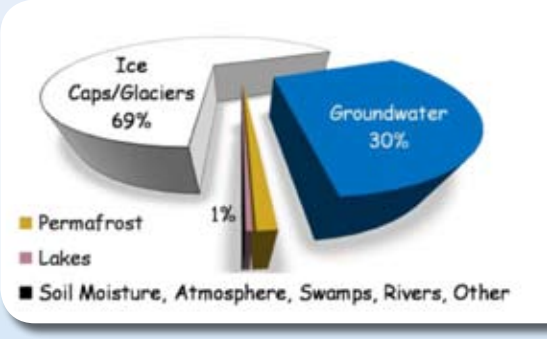
Owing to the focus on "ecosystem" perspectives, the movement toward interdisciplinary science is especially compelling in the natural sciences and hydrogeology in particular. Inherently interdisciplinary, hydrogeologic systems are coupled to other complex systems, often in a nonlinear dynamic. A synthesis of knowledge across and within hierarchies involves folding laws and principles of each level of organization into those at more general, more fundamental levels and is an important part of both the synthesis and reductionist approaches in science (Wilson, 1998).

Future of Research and Applied Hydrogeology

While federal funding for geoscience research since 2003 has been flat (American Geological Institute, 2008) the largest percentage of these research funds has gone to interdisciplinary research. In the private sector, the applied hydrogeology picture is more optimistic: "Scott D. Warner, principal hydrogeologist and a vice president at the environmental consulting firm Amec Geomatrix in Oakland, Calif., said that demand for his firm's services has been strong since the 1980s." (Eilene Zimmerman, New York Times, March 7, 2009). Demand for hydrologists is expected to grow 24 percent from 2006 to 2016, much faster than the average for all occupations (U.S. Bureau of Labor Statistics, 2008). However, despite the comforting forecasts several troubling trends include the waning enrollment in hydrology and water resources programs in colleges and universities since the mid-1990s, the shifting interest away from groundwater hydrology in some of the elite programs, and the aging and pending retirement of career groundwater scientists and engineers (Stephens, 2009).

Toward Synthesis

The focus of the natural sciences is shifting toward holism in order to understand complex systems. The USGS Science Strategy for 2007-2017 (U.S. Geological Survey, 2007) is one example of the shifting focus toward synthesis through ecosystems-based approaches in the natural sciences. The Strategy recognizes that complexities of measuring, analyzing, interpreting, simulating and predicting the status and trends of natural and managed resources require interdisciplinary thinking and action. An integrated science approach to address sustainability is the principal goal. However, the recent focus on systems approaches in the geosciences overlooks many gaps in synthesis at lower hierarchical levels within hydrogeology and between hydrogeology and geology.



Sources of fresh water on Earth—ice caps and glaciers constitute 69% and groundwater constitutes about 30 percent of the total. All other sources compose about 1%.

Sustainability

Alley et al. (1999) define groundwater sustainability as "[…] development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences." Despite major obstacles to sustainability in natural science and technology, cultural (socio-politico-economic)

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The Complex Future of Hydrogeology – *Continued*

factors are critically important and likely will determine whether sustainability is approachable. For now, the focus in hydrogeology is on enabling technology, and exploring the complex linkages between individual dynamic systems in the lithosphere, hydrosphere, biosphere and atmosphere.

The sustainability issues hydrogeology is facing acknowledge that the principal concerns are population growth, ecosystem health, energy, and climate change. Some of these issues are:

a. Groundwater depletion
   i. Quality (water, habit, etc.) restoration/protection
   ii. Saltwater intrusion
   iii. Land subsidence
b. Natural and artificial recharge
c. Groundwater management
d. Inter- and intra-disciplinary coupling of processes
   i. Agricultural practices
   ii. Carbon sequestration
   iii. Geothermal energy
   iv. Radioactive waste disposal
   v. Dependent riparian, littoral and phreatophyte communities
   vi. Exploitation of brackish-water sources
   vii. Biogeochemical transformations
   viii. Crustal dynamics—fluids and tectonic and volcanic processes

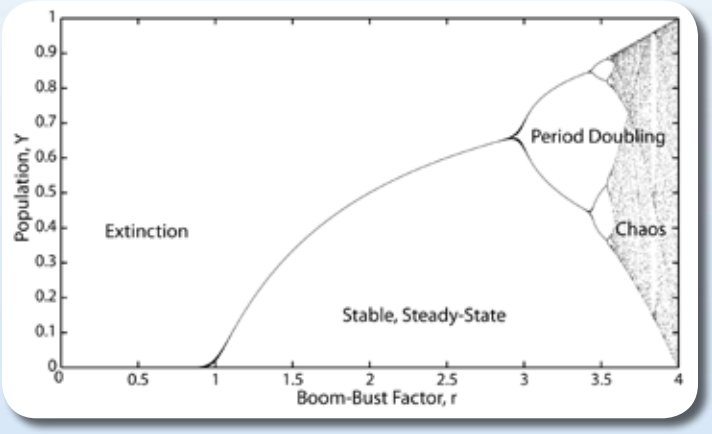
For each issue there is an inherent need to develop analytical and subsurface characterization technologies to support their resolution. For example new simulation capabilities are needed in many topical areas including:

a. 'Fundamental' 1st-principle models
b. Scale
c. Uncertainty
d. Stochastic
e. Numerical simulators
f. Inverse solution methods
g. Management/Optimization
h. Predictability
i. Complex systems

These issues and the need for improved analytical and technical capabilities point to potential future research trends in interdisciplinary processes, quantification-modeling-prediction, and science-and-society. The focus on ecosystems implies more research will be needed in shallow groundwater processes (including groundwater/surface-water interaction, biogeochemistry, and groundwater ecology). Advancements in quantification-modeling-prediction are needed to expand capabilities to simulate subprocesses within the groundwater flow system and to incorporate complexity in dynamically coupled processes. Means to incorporate near-real time data streams into simulations are needed to improve the timeliness, relevance and utility of models, and to provide ready feedback to improve the models. More effective ways to communicate the complexity and uncertainty of analysis tools are needed to reinforce the reliance on data and research to improve these tools, and to support their effective, rational use.

Dynamically Coupled Processes—Complexity Science

Dynamic systems can be classified as 1) deterministic or 2) stochastic. Despite the inherent nonlinearities of hydrogeologic systems, much research and application resorts to linear deterministic approaches. Chaos has been used to define the characteristics of dynamics generated by predominately deterministic processes. Such systems are low-dimensional, dissipative, nonlinear, and sensitive to small variations in initial conditions and control parameters. Deterministic systems are driven by a forcing function described explicitly to simulate the evolution of the system.



Logistics curve bifurcation map. This simple phase-space plot of the logistics curve (May, 1976) used to represent the growth and mortality of biological populations shows that recursive iteration of the population state using the previous state gives rise to periodic instabilities and ultimately aperiodic, nonlinear behavior and chaos as the driving force, r increases. The population is 111tttYrYYwhere r is a boom-bust factor representing a combined rate for reproduction and starvation.

Some hydrological processes that reportedly display chaos include precipitation, runoff, streamflow, groundwater level variations and viscous fingering in porous media. However, there is skepticism whether any hydrologic processes can be chaotic (low-dimensional, deterministic); rather they are thought to be inherently high-dimensional processes with complex dynamics (Koutsoyiannis, 2006). Systems with many dimensions are usually characterized as stochastic systems and modeled using stochastic theory. For pragmatic reasons, dynamically coupled processes within hydrogeology frequently are decoupled, or at best weakly coupled. As hydrogeologists undertake more interdisciplinary science, the coupling of these

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processes extant in groundwater flow systems will acquire larger imperatives for simulating systems behaviors.

The scale dependence of heterogeneous hydrogeologic properties challenges capabilities to scale property value estimates derived from sampling methods that are themselves scale dependent. One promising method that addresses attributes embedded in chaotic systems is fractal-scaling. A fractal is generally "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole," a property called self-similarity (Mandelbrot, 1983). Fractal geometry is the geometry of chaos and self similarity is the underlying theme in fractal geometry (Peitgen et al., 2004).

Toward Reduction

The reductionist approach includes the building blocks of scientific understanding: 1) repeatability, 2) economy (parsimony), 3) mensuration, 4) heuristics, and 5) consilience—the interlocking of causal explanation across science disciplines (Wilson, 1998, p. 53). Two related, important and complex topics challenging hydrogeologic research are heterogeneity and uncertainty. Problems of scale, and deterministic versus stochastic approaches are deeply embedded in each topic.

Heterogeneity

How can flow and especially transport be adequately evaluated given the observational limits and the complex structures and heterogeneous properties of these systems? Two of the promising approaches for simulating heterogeneity in porous-media flow systems include 1) facies modeling through sequence stratigraphy; and 2) genetic, basin-scale sedimentation process modeling. Approaches to sequence stratigraphic modeling include continuous and discontinuous geostatistical methods. Genetic or geologic process models combine fundamental laws of mass transport to simulate spatial distributions, but these approaches have been underutilized in part because of difficulties in conditioning the simulations with observational data (Koltermann and Gorelick, 1996). Three of the promising approaches for fracture flow systems include deterministic and stochastic depictions of 1) fracture networks; 2) nonuniform continua (single, dual or multiple); and 3) their hybrids (see Neuman, 2005).

Uncertainty

Tartakovsky et al. (2008) note that because of the irresolvable heterogeneity, "There remains much work to do because the classic deterministic statement of groundwater theory is incomplete by necessity: It ignores half of the challenge of hydrogeology, which is to represent conductivity and other system parameters in a form that reflects our incomplete knowledge of them. We still lack both theory and practice—and perhaps, the will—to deal realistically with basic observational limits." Generally, two kinds of uncertainty are of concern—those related to structure or model and those related to parameters. Most research is invested in evaluating and reducing parameter uncertainty, and little has been done to assess model and conceptual model uncertainty.

Traditional stochastic (probabilistic) approaches include the Monte Carlo (MC), modified MC and conditioned MC methods, and moment analysis or perturbation methods. Non-probabilistic and 'possibilistic' methods include interval arithmetic, fuzzy set theory, indicator approaches, and fractal-based representations. The indicator geostatistical approaches address categorical applications, as well as provide non-parametric models for continuous variables, because "[...] it is subjective interpretation [...] that makes a good model; the data, by themselves, are rarely enough [...]" (Deutsch and Journel, 1992). One promising indicator-based method incorporates transitional probability as the measure of spatial variability. The transitional probability/Markov approach improves the integration of geologic interpretation of facies architecture into the model development process (Carle and Fogg, 1996; 1997).

The foregoing methods focus on parameter uncertainty, but do not address the underlying uncertainty associated with selecting a conceptual model. Neuman (2003) notes "[…] a single conceptual model is prone to statistical bias and underestimation of uncertainty." Bredehoeft (2005) argues that "Using models for conceptual model synthesis is most appropriate; […] In the end, this may be the most important use of models, more important than future predictions." A comprehensive strategy for using alternative models to render optimum predictions has been proposed by Neuman and Wierenga (2003). A key element of this strategy is Maximum Likelihood Bayesian Model Averaging (MLBMA, Neuman 2003).

Concluding Remarks

O. E. Meinzer, considered by many the *Father of Hydrogeology* (or Geohydrology or Ground-Water Hydrology as he might have preferred), recognized the inherent interdisciplinary nature of hydrogeology as evidenced by his early work in phreatophyte communities and later in microbiology and groundwater [see Narasimhan (2005) and Fryar (2007) for more discussion]. In Meinzer's Presidential address to the Society of Economic Geologists in 1945 (Meinzer, 1946), he appeals to his geologist colleagues to consider water more than a mineral resource: "It has often been said that water is our most valuable mineral. Petroleum geologists probably regard this statement as a gross exaggeration and mining geologists may also be skeptical. The statement is true, of course, in the sense that water is the essential mineral for many domestic, power-development, and manufacturing uses, for the production of all foods and other vegetable and animal commodities, and for the functioning of the human body." Later in the address Meinzer remarked that "Water

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is an interesting mineral for geologic study because its development should be planned for perennial use, in contrast to development of other minerals, which inevitably leads to exhausted mines and oil fields. There has, indeed, been much 'mining' of ground water, especially during the war—that is, development of water supplies by depleting the storage in the aquifers. The major objective of ground-water investigation is, however, much more constructive, namely, to bring about maximum and optimum development of water supplies that will be perennially secure—an objective that is ultimately attainable to a great extent by wise use of the large storage capacities of aquifers. It is a truly vast undertaking that will require the application of specialized knowledge and technique, much of which is yet to be developed. It is an exceedingly important and fascinating undertaking that should contribute much to permanent human welfare." As Fryar (2007) notes: "[…] the most enduring [of Meinzer's] perspectives are those of the societal relevance of hydrogeology, the need to balance practical studies with fundamental research, and the evolution of scientific thought."

One of the greatest challenges in science is the complete description of complex systems. But as Wilson (1998) and others argue, generally there is a need to clarify the susceptible complex systems through more theoretical innovation and practical applications of complexity theory and dynamically coupled nonlinear systems. In hydrogeology, the interdisciplinary nature and history of the discipline coupled with the present-day focus on interdisciplinary science highlights the capability and underscores the need for hydrogeology to lead in addressing these challenges and points to areas of promising future research. If synthesis and integration of discipline-specific knowledge, implicit in the movement toward interdisciplinary science, means minimizing the reductionist approach to refining discipline-specific science then the core of science is threatened. New scientific progress in hydrogeology toward synthesis as well as reduction through recognition of their interactive feedback processes is possible and necessary.

References Cited

Alley, W.M., and Reilly, T.E. and Franke, O.L., 1999, Sustainability of ground-water resources. U.S. Geological Survey Circular 1186, 79 p., http://pubs.usgs.gov/circ/circ1186/, accessed April 1, 2009.

American Geological Institute, 2008, Federal research funding of geosciences. Geoscience Currents, no.14, http://www.agiweb.org/workforce/Currents-014-GeoscienceFederalResearchFunding.pdf, accessed April 1, 2009.

Bredehoeft, J.D., 2005, The conceptualization model problem—surprise. Hydrogeology Journal, v. 13, p. 37–46.

Carle, S.F. and Fogg, G.E., 1996, Transition probability-based indicator geostatistics. Mathematical Geology, v. 28, no. 4, p. 453–477.

———, 1997, Modeling spatial variability with one- and multi-dimensional Markov chains. Mathematical Geology, v. 28, no. 7, p. 891–918.

Deutsch, C.V and Journel, A. G., 1992, GSLIB: Geostatistical software library and user's guide. Oxford, Oxford University Press, 340 p.

Gleick, P.H., 1996, Water resources, in Schneider, S.H. (ed.) Encyclopedia of Climate and Weather. New York, Oxford University Press, v. 2, p.817–823.

Koltermann, C.E. and Gorelick, S.E., 1996, Heterogeneity in sedimentary deposits: A review of structure-imitating, process-imitating, and descriptive approaches. Water Resources Research, v. 32, no. 9, p. 2617–2658.

Koutsoyiannis, Demetris, 2006, On the quest for chaotic attractors in hydrological processes. Hydrological Sciences, v. 51, no. 6, p. 1065–1091.

Mandelbrot, B.B., 1983, The Fractal Geometry of Nature (Updated and augmented). New York, W.H. Freeman and Co., 468 p.

May, R.M., 1976, Simple mathematical models with very complicated dynamics. Nature, v. 261, p. 459–467.

Miller, C.T. and Gray, W.G., Hydrogeological research: Just getting started. Ground Water, v. 40, no. 3, p. 224–231.

Neuman, S.P., 2003, Maximum likelihood Bayesian averaging of alternative conceptual mathematical models. Stochastic Environmental Research and Risk Assessment, v. 17, no. 5, p. 291–305, doi: 10.1007/s00477-003-0151-7.

———, 2005, Trends, prospects and challenges in quantifying flow and transport through fractured rocks. Hydrogeology Journal, v. 13, p. 124–147.

Neuman, S.P. and Wierenga, P.J., 2003, A comprehensive strategy of hydrogeologic modeling and uncertainty analysis for nuclear facilities and sites. NUREG/CR-6805, U.S. Nuclear Regulatory Commission, Washington, D.C., http://www.nrc.gov/readingrm/doc-collections/nuregs/contract/cr6805/, accessed April 1, 2009.

Peitgen, Heinz-Otto, Jürgens, Hartmut and Saupe, Dietmar, 2004, Chaos and fractals: New frontiers of science (2nd ed.). New York, Springer-Verlag, 864 p.

Schwartz, F.W. and Ibaraki, M., 2001, Hydrogeological research: Beginning of the end or end of the beginning? Ground Water, v. 39, no. 4, p. 492–498.

Stephens, D.B., 2009, An imminent human resource crisis in ground water hydrology? Ground Water, v. 42, no. 2, p. 176–183.

Tartakovsky, D.M. and Winter, C.L., 2008, Uncertain future of hydrogeology. Journal of Hydrologic Engineering, DOI: 10.1061/(ASCE)1084-0699(2008)13:1(37), p. 37–39.

U.S. Bureau of Labor Statistics, 2008, Environmental scientists and hydrologists. Occupational Handbook, 2008–09 ed., http://www.bls.gov/oco/ocos050.htm, accessed April 1, 2009.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017. U.S. Geological Survey Circular 1309, 70 p., http://pubs.usgs.gov/circ/2007/1309/, accessed April 1, 2009.

Wilson, E.O., 1998, Consilience: The unity of knowledge. New York, Alfred A. Knopf, 332 p.

Dates & Details

GRA EVENTS & KEY DATES

(Please visit www.grac.org for detailed information, updates, and registration unless noted)

GRA Board Meeting
Feb. 5, 2010 | Sacramento, CA

GRA Shortcourse
Introduction to Groundwater & Watershed Hydrology
Mar. 1 & 2, 2010 | Davis, CA

GRA Symposium on Solvents
Apr. 1, 2010 | No. CA

GRA Annual Legislative Symposium & Lobby Day
April 28, 2010 | Sacramento, CA

GRA Geophysics Course/ Symposium/Field Demo
May 24-26, 2010 | Santa Ana, CA

GRA 19th Annual Conference
Think Outside the Pipe—Exploring Local Water Supplies
Sep. 15-16, 2010 | Burlingame, CA

Introduction to Groundwater and Watershed Hydrology:

Monitoring, Assessment and Protection

MARCH 1-2, 2010
BUEHLER ALUMNI CENTER, UNIVERSITY OF CALIFORNIA, DAVIS

Co-Sponsored by University of California Cooperative Extension Groundwater Hydrology Program

Course Description

Groundwater and watershed monitoring, assessment and protection is an integral part of many water-related programs at the local, state, and federal level designed for sustainable development and protection of water resources in California. Today, through the implementation of programs such as groundwater management plans, source water assessments, conjunctive use agreements, watershed groups, professionals, executives, and employees of diverse background and in a wide variety of private, non-profit, and government responsibilities at the local, state, and federal level are directly or indirectly involved in the management and assessment of groundwater and surface water. Yet, many find themselves lacking the multidisciplinary background, expertise, or means to meet the technical and regulatory challenges related to water and drinking water resources management. The amount of technical information available is often overwhelming.

This short course will review the fundamental principles of groundwater and watershed hydrology, water quality, and water contamination. It will provide an overview of the most common tools for measuring, monitoring, and assessing groundwater and surface water resources. And it will review current local, state, and federal programs dealing with groundwater and watersheds. The course is specifically geared towards an audience that is involved in the management, assessment, and protection of water resources. Course attendees who may have some experience with, but no formal training in hydrology or related engineering or science fields, will benefit from the basic and intuitive, yet comprehensive approach of this course.

Experienced instructors with a broad in-depth knowledge of California groundwater and watershed hydrology will teach the course. Topics include:

- Surface Water Hydrology and Watersheds
- Groundwater Hydrology
- Water Rights and Water Law
- Surface Water Quality
- Groundwater Quality, Sampling, and Monitoring
- Surface Water Contaminants
- Groundwater Contamination
- Defining Watersheds and Groundwater Recharge Areas
- Vulnerability Assessments
- Understanding Potentially Contaminating Activities
- Protecting Water Resources

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Introduction to Groundwater and Watershed Hydrology

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Course Instructors

Randy A. Dahlgren, Ph.D., is a professor of Soil Science and Biogeochemistry in the Department of Land, Air and Water Resources at the University of California, Davis. His research program in biogeochemistry examines the interaction of hydrological, geochemical, and biological processes in regulating surface and ground water chemistry.

Thomas Harter, Ph.D., joined the faculty at the University of California, Davis, in 1995, where he is in charge of the Groundwater Hydrology Cooperative Extension program. His research focuses on characterizing and assessing nonpoint-source pollution of groundwater, on the statistical and hydrodynamic evaluation of groundwater resources where data are limited, on groundwater modeling, and on a better understanding of contaminant transport processes at a wide range of spatial and temporal scales.

Kenneth W. Tate, Ph.D., is the Rangeland Watershed Extension Professor in the Department of Plant Sciences at the University of California, Davis. He has developed and implemented a suite of research projects to address a wide range of contemporary watershed issues across California's 40 million acres of rangeland. His overall focus includes the: 1) quantification of land management impacts on water resources, 2) evaluation of management measures to restore water resources, and 3) development of assessment and monitoring tools to determine management impacts on water resources.

Registration and Additional Information Online registration is available at http://www.grac.org/hydrologyreg. For more information, contact Mary Megarry at GRA, mmegarry@nossaman.com or (916) 446-3626.

Geophysics at the Beach Symposium

in Cooperation with Environmental & Engineering Geophysical Society

MAY 24-26, 2010
DOUBLETREE CLUB HOTEL ORANGE COUNTY AIRPORT AND PENNINSULA PARK, NEWPORT BEACH, CALIFORNIA

CALL FOR ABSTRACTS
Abstract Submission Deadline – December 15, 2009

Groundwater will be relied upon more in the future to meet the increasing demands in a changing climate of hydrology, socio-economic pressures, decreasing surface water availability and rising surface water fees. More reliance on groundwater means an increasing need for better information on subsurface hydrogeology, water quality, and improved predictability of returns on groundwater storage projects.

Geophysics is a discipline that utilizes a suite of high resolution tools that will play an increasing role in clean and contaminant hydrogeologic investigations to obtain high quality and cost effective subsurface information to make better informed management decisions.

Geophysics at the Beach includes the following optional program elements:

- May 24 – Basic and Advanced Borehole Geophysics Short Course
- May 25 – Geophysics at the Beach Symposium
- May 26 – Geophysics at the Beach Field Demonstration in the surf, sand, and grass on the Pacific Ocean

Check the GRA website for abstract submission guidelines (http://www.grac.org/abstractguidlines.asp) and updates such as the program agenda and registration form—http://www.grac.org/geophysics.asp.

Call for Abstracts

Topics for May 25th Symposium

This call for papers is for oral or poster presentation at the May 25th Symposium. This symposium will provide the opportunity to discuss many factors related to state-of-the-art geophysics practices, current research, practical application of geophysics through case studies, and discussions of the value of geophysics information, through one full day of technical sessions. Topics under consideration include the following:

- Geophysics Applications for Alluvial, Fractured Rock, and Carbonate Aquifer Systems
- Geophysics Applications for Water Quality Evaluation
- Geophysics Applications for Groundwater Characterization and Monitoring in Urban/Suburban Environments
- Applications for Monitoring Groundwater Supply, Quality, and Recharge
- Quantitative Incorporation of Geophysics into Hydrogeologic Conceptual Models and Groundwater Simulation Models
- Geophysics Applications for Deep Wastewater Disposal and CO2 Sequestration
- Borehole Geophysics for Groundwater Evaluations
- Understanding the Value of Geophysical Information
- Monitoring Remedial System Performance with Geophysics
- Contamination Characterization with Geophysics
- High Resolution Geophysics for Site Characterization
- Mapping Salt Water Intrusion with Geophysics
- Other Topics Related to Surface and Borehole Geophysics

For additional information, please contact Mary Megarry at mmegarry@nossaman.com or 916-446-3626. GRA welcomes co-sponsors, lunch, and refreshment sponsors.

GRA 19th Annual Conference & Meeting

Think Outside the Pipe: **Exploring and Protecting Local Water Supplies**

SEPTEMBER 15-16, 2010
HYATT REGENCY AT THE SAN FRANCISCO AIRPORT
BURLINGAME, CALIFORNIA

CALL FOR ABSTRACTS
Abstract Submission Deadline – January 31, 2010

This two-day conference will provide the latest scientific, management, legal and policy information regarding sustainable use of our local water resources in urban regions. The conference will cover opportunities and solutions for increasing water use efficiency, integrating local and alternative supplies, reducing and capturing urban run-off, minimizing conveyance and energy costs, issues associated with the protection, enhanced recharge, and expanded use of local groundwater supplies.

Program Focus

Surface water imported through large-scale water delivery projects is a primary drinking water source for many urban regions. However, as climatic and environmental impacts continue to reduce the yield of these surface water systems, local water suppliers and others are facing significant water management challenges. Such challenges include increasing the use of groundwater and other local water sources to meet local demands, protecting and enhancing the quality of the groundwater and other water sources, conjunctively managing surface and groundwater to improve supply reliability, and integrating water management with energy reduction strategies. Additional issues that pose water management challenges include nonpoint source pollution from stormwater, surface water impacts and TMDLs, water use efficiency, overdraft, groundwater salinity, industrial impacts to water supplies, water rights, and water quality and quantity policy conflicts.

Topics for Plenary and Technical Sessions Include

- Stormwater Capture and Reuse - permitting and water rights
- Urban Water Recharge – water quality and permitting
- Brackish water supplies – inland and coastal
- Recycled water – what are the remaining challenges
- Low Impact Developments for water
- Rainfall Rooftop Harvesting
- Graywater Permitting–Black & White, or Still a Lighter Shade of Pale?
- Water Conservation as a New Source
- Water Demand - Using Less and Growing More
- Conjunctive Use and Local Storage Potential – Addressing Related Issues
- Pollution Prevention and Protecting Local Supplies
- Hurdles to Contaminant Site Water Reuse
- Groundwater Policy and Data
- Recycled Water Reuse for Residential Areas
- Emerging Contaminants
- The use of Geographic Information Systems (GIS) to enhance and protect local supplies
- The role of non-traditional local water supply in Integrated Water Supply Plans

Collegiate Groundwater Colloquium

GRA seeks to increase participation by university and college faculty and students in its programming. In pursuit of this goal, GRA launched a new annual meeting module in 2008 called the "Collegiate Groundwater Colloquium." The Collegiate Groundwater Colloquium presents students who are conducting highly relevant research in the general area of the conference theme. The Colloquium and reception provide students with an excellent opportunity to showcase their research and attendees an opportunity to learn from the frontier of groundwater science.

Call for Abstracts

Abstract submittal guidelines are available at http://www.grac.org/abstractguidlines.asp.

Wells and Words

By David W. Abbott, P.G., C.Hg., Todd Engineers

Well behavior and personality – an important observation tied to the plethora of possible permutations of construction methods, well characteristics, and aquifer parameters – or no two wells are the same.

The assessment, appreciation, and competent evaluation of drilling, design, construction, and development of a well is very important for the "correct" interpretation of the hydrogeologic framework, the proper analysis of pumping tests, and the meaningful interpretation of long-term water-level and water-quality data from the well. Each well usually poses unique and complex challenges for installation, design, and testing; wells have a personality, and each behaves differently owing to a variety of combinations of well and aquifer characteristics. A well is not simply a "hole in the ground." Rather, it is an engineered device to remove or inject fluids from or into water-bearing formations. Drilling contractors will often declare: "Each well I have installed is different!" They recognize that every well offers a challenging opportunity to test their skills, including the installation of new wells, and the rehabilitation of existing wells.

Countless combinations of construction methods, well characteristics, and aquifer parameters exist. Well specifications are usually customized to meet the owners' needs and are flexible enough to accommodate construction and design requirements to resolve varied and heterogeneous hydrogeologic environments encountered beneath the ground surface. Each well installation and associated pumping tests are unique experiments conducted under field conditions with unique site characteristics, but the variables involved are governed by general principles and the results from many decades of experience.

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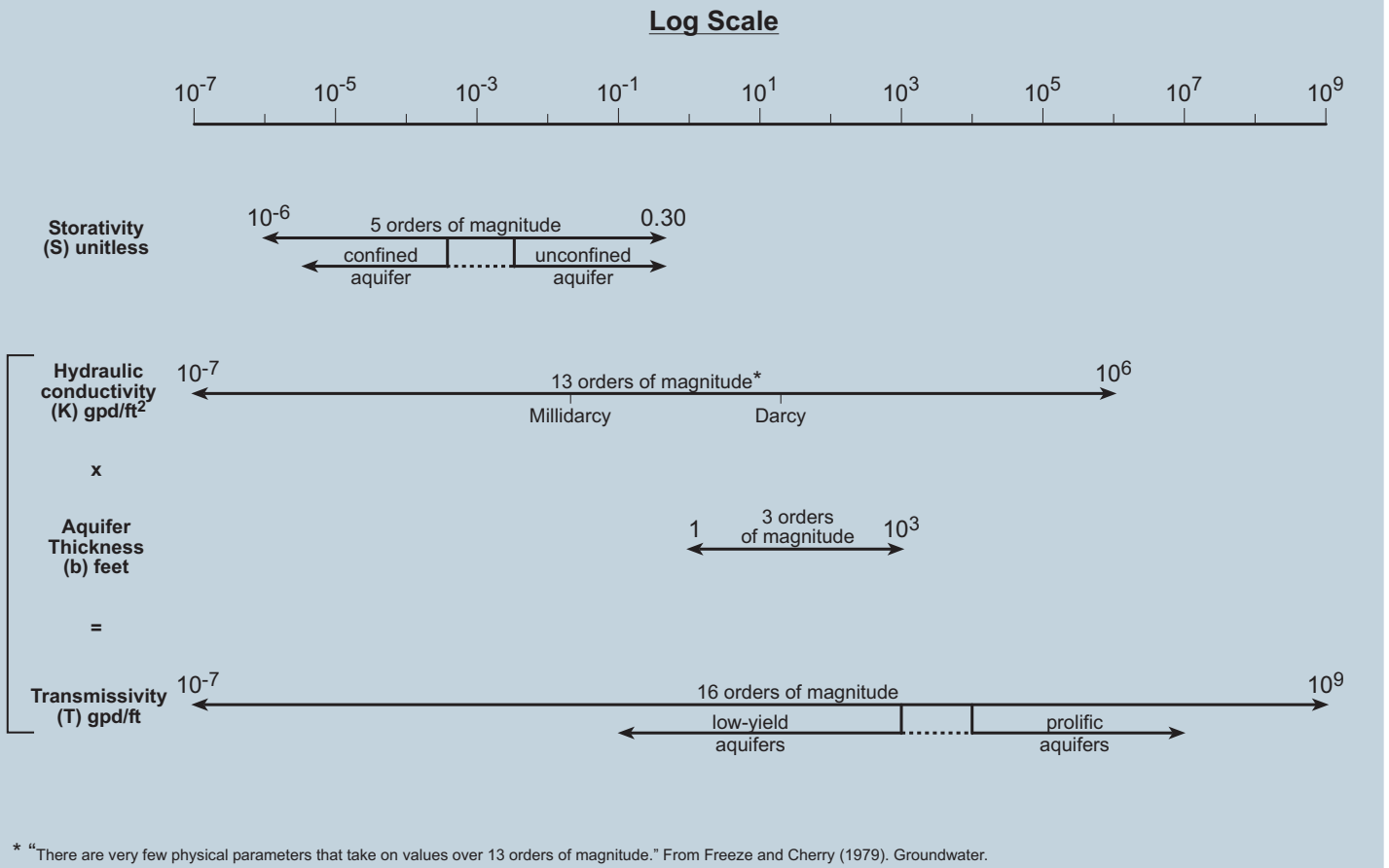
Figure 1. Range of Values for Quantifiable Hydraulic Parameters



* "There are very few physical parameters that take on values over 13 orders of magnitude." From Freeze and Cherry (1979). Groundwater.

TODD ENGINEERS

Wells and Words – *Continued*

Considering the wide range of variables involved and the endless potential combinations of these variables encountered in drilling projects, it is not surprising that each well has a different personality. Some of these variables are quantifiable; for example, transmissivity (T-value) and storativity (S-value). The former has a potential range from 10-7 to 109 gpd/ft while the latter has a range from 10-6 to about 10-1. T- and S-values span about 17 and 6 orders of magnitude, respectively. Figure 1 shows the range of possible aquifer parameters. The T-value is the product of the hydraulic conductivity, or K-value (13 orders of magnitude), and the aquifer thickness (at least 3 orders of magnitude), and is a property of the fluid and aquifer.

For example, a T-value of 40,000 gpd/ft can result from an aquifer that is 5 feet thick with a high K-value of 8,000 gpd/ft2 (clean sand and gravel), or it could be from one that is 500 feet thick with a small K-value of 80 gpd/ft2 (silty sand). The lesson here is that thin high-K aquifers can yield as much or more than thick low-K aquifers.

Some of the other variables in well construction and design include:

1. Drilling methods, drilling fluids and muds, and mud properties;
2. Casing and bit sizes ranging from 2-inches to greater than 42-inches in diameter;
3. Types of screen openings, screen material composition, and slot sizes;
4. Filter pack sizes, particle shapes, composition, and natural filter packs;
5. Vertical hydraulic gradients and water levels; and
6. Well efficiencies.

These variables create a substantial diversity in the design, construction, and performance of each well, leading to a range of individual well personalities. This diversity can be used strategically by the experienced well design engineer to facilitate efficient construction contracts, to take advantage of various well designs, to optimize well yields and efficiencies, and to bring a project to a successful completion.

Installation, design, and hydraulic evaluation of a monitoring, observation, test, or supply well requires considerable amounts of hands-on experience and knowledge of available, efficient, and effective drilling methods and equipment to complete the job. The right tool (drilling rig, fishing tool, casing material, etc.) is dependent on the site-specific conditions.

True, the basic methodology is straightforward: drill the boring, design and construct the well with screen and casing, place filter pack between the casing and borehole, install a cement seal, and conduct well development, which attempts to correct the damage that was done to the walls of the boring during the drilling. The final task is a pumping test to observe discharge and drawdowns from the well and any nearby observation well(s). Books on applied hydrology, such as Groundwater and Wells (Driscoll, 1986), Ground Water Manual (US Department of Interior, 1981), and The Handbook of Ground Water Development (Roscoe Moss, 1990) provide the basic concepts of well drilling, design, construction, development and testing, but each well and aquifer are different. Years of experience are needed to be exposed to a wide range of possible combinations of well construction design, aquifer parameters, and aquifer responses.

Legislative Update

By Tim Parker, GRA Legislative Committee Chairman, Chris Frahm and Paul Bauer, GRA Legislative Advocates

The impact of GRA's legislative program was more evident than ever in 2009 as Governor Schwarzenegger signed into law four policy bills – including SB 6 (Steinberg) relating to groundwater monitoring – and an $11.1 billion water bond. These measures were all passed by the legislature in the early morning hours of November 4, two months after the legislature had adjourned the regular session. The bond package included more than $1 billion specifically for groundwater projects and groundwater monitoring legislation.

At the time the legislature adjourned its regular session on September 11, it was stalled on a number of fundamental water issues including, but not limited to, Delta governance, water rights, groundwater monitoring, water conservation targets and the overall size of the water bond. After about 6 weeks of behind-the-scenes negotiations, the legislature convened in Special Session to consider four bills which were ultimately sent to the Governor's desk, namely SB 1 (Steinberg), Delta governance; SB 2 (Cogdill), an $11.14 billion water bond; SB 6 (Steinberg), groundwater monitoring; SB 7 (Steinberg), water conservation; and SB 8 (Steinberg), illegal diversion enforcement.

GRA's principal objective was to secure groundwater monitoring as part of the final package. As our members are well aware, GRA's previous efforts have resulted in the passage of bills by the legislature, only to have the Governor veto them. During this round of comprehensive negotiations, the legislative leadership held firm on the need to monitor groundwater and used GRA's prior and current support as a basis to keep groundwater monitoring in the forefront and as part of the package. Many times in committee and on the floor legislators argued that groundwater management requires groundwater monitoring. Ultimately, the Governor agreed and for the first time California will be establishing a statewide groundwater monitoring program to gather information about groundwater levels and quality. This is a very significant accomplishment for GRA, and is the result of years of lobbying and educational activities, including the annual GRA Legislative Symposium. We fully expect the legislature to once again turn to GRA for technical expertise as implementation issues arise during development of the program.

In addition to our efforts to secure groundwater monitoring legislation, GRA also worked to support increased funding for groundwater programs, which had ranged in iterations of water bond proposals from a low of $250 million to a high of $500 million. In the final days leading up to the passage of the bill package, GRA worked with the California Groundwater Coalition, big city mayors and others, seeking to secure additional funding of groundwater projects and clean-up. As a result, more than $1 billion was included as a line item for groundwater protection and clean-up. Groundwater also remains eligible in other funding pots, for example as part of the Integrated Regional Water Management Program. The water bond will be before the voters on the November 2010 ballot.

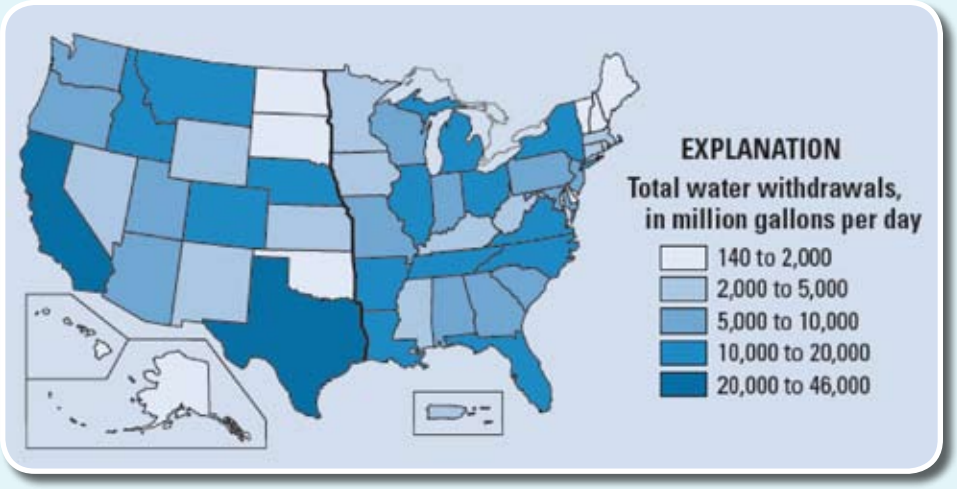
The GRA Board of Directors, Legislative Committee and membership should take great pride in the success of the legislative program in 2009 and in the difference we have made working together to protect and preserve the state's groundwater resources.

The Federal Corner

By John Ungvarsky

Updated Emerging Contaminants Fact Sheets – EPA's Federal Facilities Restoration and Reuse Office has developed fact sheets that address emerging contaminants of particular concern to the federal facility community. These fact sheets include current information on physical and chemical properties; environmental and health impacts; existing regulatory standards and cleanup levels; detection and treatment methods; and additional sources of information. For more information, go to http://clu-in.org/emergingcontaminants/.

Estimated Water Use in the United States in 2005



The United States Geological Survey (USGS) has produced a Fact Sheet summarizing water use in the United States in 2005. About 410,000 million gallons per day (Mgal/d) of water was withdrawn for use in the United States during 2005. About 80 percent was from surface water, and the remaining 20 percent (82,600 Mgal/d) was from groundwater, of which about 96 percent was freshwater. Water withdrawals in four States — California, Texas, Idaho, and Florida — accounted for more than one-fourth of all fresh and saline water withdrawn in the United States in 2005. About 53 percent of the total withdrawals (45,700 Mgal/d) in California were for irrigation, and 28 percent were for thermoelectric power. For additional information, see: http://pubs.usgs.gov/fs/2009/3098/.

Effects of Climate Variability and Change on Groundwater Resources

USGS scientists are working with local, State, Federal, and international partners to understand how the availability and sustainability of groundwater resources in the United States will be affected by climate variability and change. USGS has developed a fact sheet describing climate variability and change, important groundwater resources of the Nation, and how their research is helping to answer critical questions about the effects of climate on groundwater. For more information, go to: http://acwi.gov/sogw/pubs/tr/index.html.

EPA Recognizes Leaders in Water Efficiency

The EPA has named Cobb County Water System (in Georgia), Kohler (faucet and toilet manufacturer), Lowe's (home improvement retailer), James City Service Authority (in Virginia), and Brian Vinchesi (irrigation professional) as each winning this year's WaterSense Partner of the Year Award. They represent the best of WaterSense's four Partner categories and have made great strides in increasing water efficiency and awareness of the WaterSense label across the country. More than 1,000 WaterSense partners helped Americans save 9.3 billion gallons of water in 2008. For more information, go to: http://epa.gov/watersense.

EPA Releases List of Priority Drinking Water Contaminants for Regulatory Consideration

EPA has released its third list of drinking water contaminants that are known or anticipated to occur in public water systems and may require regulation. EPA will continue to evaluate and collect data on the contaminants and determine by 2013 whether or not to propose drinking water regulations for the contaminants. The contaminant candidate list includes 104 chemical contaminants or groups and 12 microbes. For more information, go to: http://www.epa.gov/safewater/ccl.

Pandemic Influenza Fact Sheet for the Water Sector

EPA has published a "Pandemic Influenza Fact Sheet for the Water Sector." Pandemic flu could affect the capability of water system operators to operate and maintain their systems adequately due to increased absenteeism at their systems and material suppliers. In addition to background information on pandemic flu, its potential impacts, and possible interventions, the fact sheet provides references to tools and guidance materials offered by EPA and other organizations. The fact sheet is available at: http://cfpub.epa.gov/safewater/watersecurity/pandemicflu.cfm.

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The Federal Corner – *Continued*

Assessment and Delineation of DNAPL Source Zones

Groundwater contamination from classes of chemicals such as chlorinated solvents, polychlorinated biphenyls (PCBs), creosote, and coal tar is frequently encountered at hazardous waste sites. The contaminants can exist in the subsurface as Dense, Non-Aqueous Phase Liquids (DNAPLs) and have the potential to migrate as a separate liquid phase to significant distances below the water table in both unconsolidated materials and fractured bedrock. This EPA document builds on information from the previous fact sheets to provide a framework for not only assessing the presence of DNAPL, but also for delineating the spatial extent of the DNAPL source zone, a priority at many sites due to the more prevalent use of in-situ remediation technologies. For more information, go to: http://www.epa.gov/ada/download/issue/600r09119.pdf.

John Ungvarsky is an Environmental Scientist at the U.S. Environmental Protection Agency, Region 9. He works in the Water Division's Ground Water Office and oversees source water protection efforts in CA, HI, and NV. For information on any of the above topics, please contact John at 415-972-3963 or ungvarsky.john@epa.gov.

Lies, Damned Lies, and Environmental Statistics

By Bart Simmons

Acceptable sampling and testing protocols have undergone significant changes over the last thirty years, and a critical step in the environmental monitoring process – statistical analysis of the results – has also advanced. Regulations, however, have not kept pace. Some regulations specify that average values should be compared with regulatory limits, without specifying how the averages will be calculated. U.S. EPA has published and maintained guidance on the statistical evaluation of data. For example, QA/G-9S, "Data Quality Assessment; Statistical Methods for Practitioners," and G9-R, "Data Quality Assessment; A Reviewer's Guide" provide guidance for practitioners and data users, respectively. In addition to describing the application of accepted statistical techniques, they attack some of the problems inherent in environmental measurements, as described below.

Non-detects – Environmental test results generally have associated detection limits and/or quantitation limits. The debates about how these are calculated will continue into the indefinite future, but the fact is that some data will be below the reporting limits. Several techniques have been proposed for dealing with this problem, and G9-S provides alternative methods depending on the percentage of non-detects in the data set. Restricted maximum likelihood estimates have been recommended to deal with larger data sets (greater than ten) if non-detects exceed 30%.

Outliers – John Taylor of the National Bureau of Standards (the predecessor to the NIST) said there are three sources of uncertainty in data: random error, systematic error, and blunders. Typically, environmental data sets will have a few results which are different, sometimes wildly so, from the rest of the data. G9-S also provides techniques for identifying outliers, but it echoes the general policy: outliers can be identified statistically, but they should not be removed from the data set unless there are independent reasons, like blunders, to believe that the data should not be included.

Non-normally distributed data – Unlike IQ, height or weight, environmental measurements typically are not normally distributed. One reason is that the lower values are bounded by zero (we do not get results of -50 mg/kg). Another is that contaminants released into the environment tend to follow more of a lognormal than normal distribution. One solution to this problem is the use of nonparametric tests (the Wilcoxon signed-rank test, for example). These tests do not make assumptions about the distribution of the data, and some have almost as much power as parametric tests. Another solution is to transform the data, e.g., with a log-transformation, to produce normally-distributed data. However, neither of these solutions is entirely adequate if one is trying to estimate the upper confidence levels on the mean value.

Other solutions to this problem have been proposed, including the bootstrap and jackknife methods ("The Lognormal Distribution in Environmental Applications, EPA/600/R-97/006", 1997). These methods may not be familiar to most environmental practitioners, but they are easily used with the appropriate algorithms. The bootstrap method involves selecting a random sample of the data set repeatedly for thousands of trials, and using the means to estimate the population mean and upper confidence limits. Thanks to modern computers, these calculations can be done in a snap.

Statistical methods research has provided improved tools for environmental decision-makers. Government guidance and regulations need to keep pace with the science.

Bart can be reached at bartonps@aol.com.

Process and Controls on Rapid Nutrient Removal During Managed Aquifer Recharge

By Calla Schmidt in collaboration with A. Fisher and A. Racz, Earth and Planetary Sciences Dept., University of California, Santa Cruz, CA; M. Los Huertos, Science and Environmental Policy Dept., California State University, Monterey Bay; and B. Lockwood, Pajaro Valley Water Management Agency, Watsonville, CA

Introduction

Managed aquifer recharge (MAR) is used to augment water supplies and limit the adverse impacts of groundwater overdraft. However, as demands on groundwater continue to grow and MAR projects become more common, it is increasingly difficult to secure high-quality water sources for MAR. Instead, resource managers must explore options for using MAR sources such as stormwater runoff, treated wastewater, and supplies influenced by agricultural activity. Many such sources are impaired by elevated nutrient concentrations; thus there is a need to understand the conditions under which the quality of managed recharge can be improved. We are studying processes controlling recharge rates and the impacts of MAR on water quality, with a focus on reducing the nitrate load reaching underlying aquifers.

The central coast region of California (Figure 1) depends heavily on groundwater for agricultural and municipal uses. Overdrafted aquifers are common in this region, resulting in seawater intrusion and other undesirable conditions and processes. To augment the regional freshwater supply and decrease pumping in the coastal zone, the Pajaro Valley Water Management Agency (PVWMA) operates a MAR project as part of a broader effort to improve groundwater conditions in the basin. Surface water is diverted from Harkins Slough during winter (rainy) months when there is sufficient flow in the slough. Diverted water is filtered and pumped into a pond (a modified natural depression) overlying unsaturated eolian and fluvial sand deposits. Recharge water creates a local mound above a clay layer about 30 m below the base of the pond, then is recovered by dedicated wells that encircle the pond for distribution to local growers. As a result of agricultural and other activities in the basin, diverted slough water is often rich in nitrate (historical values as high as 4 mM); similarly high nitrate values have been measured in water from underlying aquifers.

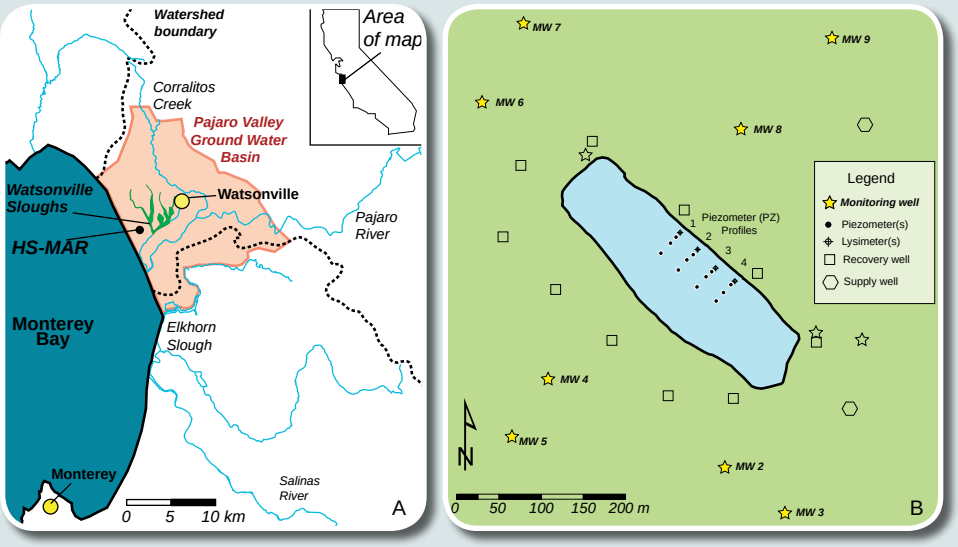

Figure 1. (A) Location of the field area in central coastal Caliornia. The MAR project is located adjacent to Harkins Slough, part of a large wetland system draining southern Santa Cruz county. (B) Site map of Harkins Slough managed aquifer recharge pond, adjacent monitoring wells, and piezometer installations.

Methods

Prior to the Water Year 2008 MAR operational season, we instrumented the Harkins Slough recharge pond to quantify seepage rates and sample infiltrating water beneath the base of the pond. Whole-pond mass balance and infiltration rates were quantified based on a detailed topographic survey of the pond and continuous records of inflows, water level, pond area, precipitation, and evaporation. Nutrients and major ion chemistry were monitored weekly during MAR operation in wells surrounding the recharge pond and in piezometers screened in the shallow subsurface beneath the pond (Figure 1). The stable isotopic composition of nitrate in recharge pond and piezometer water samples was analyzed to investigate whether microbial denitrification (a process which converts nitrate to di-nitrogen gas) could be a mechanism of nitrate removal during recharge. All isotopic data are reported using standard delta notation:

$$\delta\ (‰) = (R_{sample} - R_{standard})/R_{standard} \times 1000$$

where R_{sample} is the ratio of the heavy to light isotope of a sample and $R_{standard}$ is the ratio of the heavy to light isotope of the standard. Nitrogen and oxygen

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Student/Research Corner – *Continued*

isotope ratios are reported relative to atmosphere and Vienna Standard Mean Ocean Water, respectively.

Results and Discussion

MAR totaled 6.0 x 10^6 m^3 (810 ac-ft) in 2008, with diversions occurring from January to May. Diversion was stopped periodically due to variable water quality and slowing percolation rates. The peak recharge rate of 1.5 to 2.0 x 10^4 m^3/day (12 to 16 ac-ft / day) was maintained for nearly 30 days (Figure 2). The greatest pond-wide specific infiltration rate of 1 m/d was achieved within 10 days of filling the pond. Infiltration rates decreased after about 30 days of MAR, eventually becoming nearly stagnant after 50 days.

After delivery of 3 x 10^5 m^3 (about 240 acre-feet), mounding of recharge water became apparent in monitoring wells located 300 to 600 meters from the pond (Figure 2). Prior to filling the recharge pond, head measurements suggest that groundwater in the underlying aquifer flowed mainly to the southwest. The formation of a local mound eventually reversed the head gradients north of the pond. Wells south of the pond showed the greatest response to recharge water, with head increases of 4.5 to 5 meters.

The chemistry of water in the shallow aquifer comprises a mixture of natural recharge from precipitation, MAR water, and irrigation returns from surrounding agricultural fields.

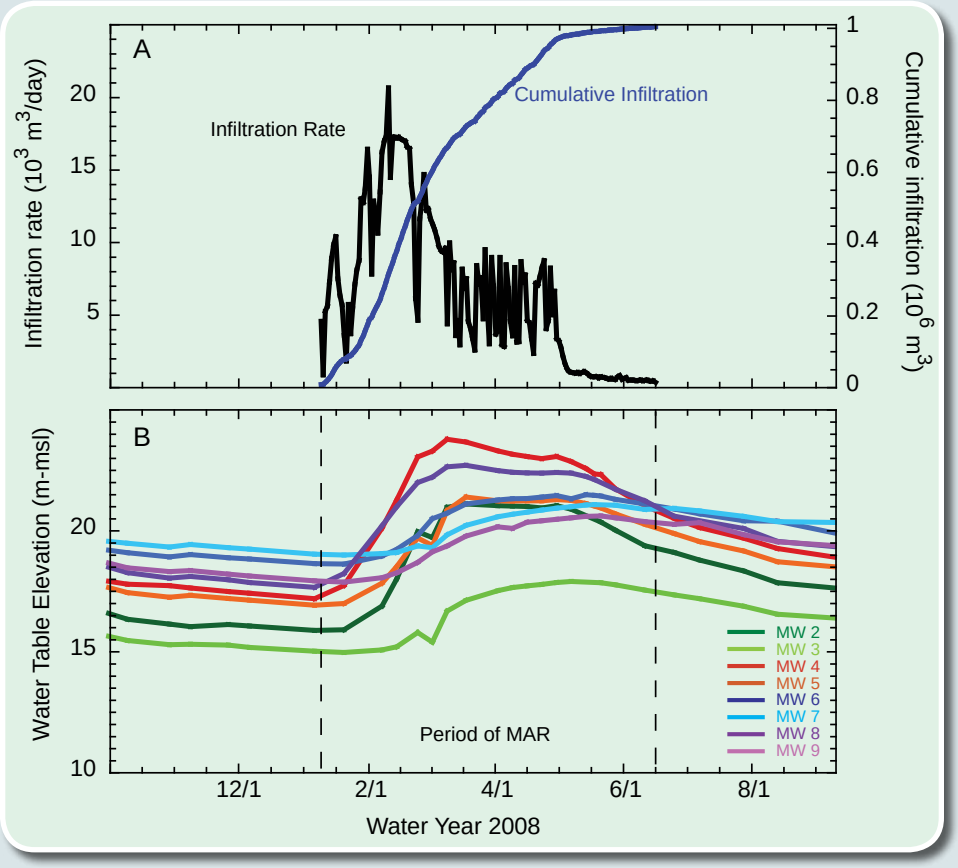

Figure 2. (A) Record of daily infiltration rate and cumulative infiltration from the Harkins Slough recharge pond in the 2008 water year. Daily infiltration rates are based on a pond mass balance calculation derived from measurements of inflows (slough diversions), precipitation, evaporation and storage. (B) Water table elevation in monitoring wells surrounding the recharge pond. The formation of a local groundwater mound is apparent two weeks after the start of MAR.

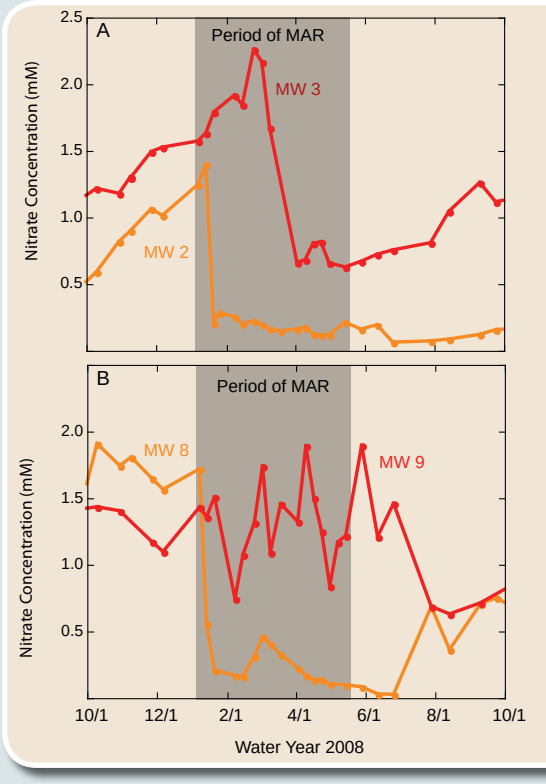

Figure 3. (A) Concentration of nitrate in monitoring wells MW 2 and MW 3 located downgradient from the recharge pone. (B) Concentration of nitrate in MW 8 and MW 9 located upgradient from the pond. While the arrival of MAR water can be seen at MW 2, 3 and 8, MW 9 appears to be minimally impacted by MAR despite being a similar distance away from the pond as MW 3.

Changes in the groundwater chemistry showed the arrival of MAR water within days of filling the pond, much faster than would be predicted based on whole-pond infiltration rates. In 2008, the concentration of nitrate in the underlying aquifer was significantly diluted by the addition of low-nitrate MAR water. The composition of the groundwater observed in downgradient monitoring wells MW 2 and MW 3 showed a greater proportion of recharge water than those north of the pond (MW 8 and MW 9), where the local groundwater mound reversed the flow direction in the aquifer (figure 3). Although the arrival of low-nitrate

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Student/Research Corner – *Continued*

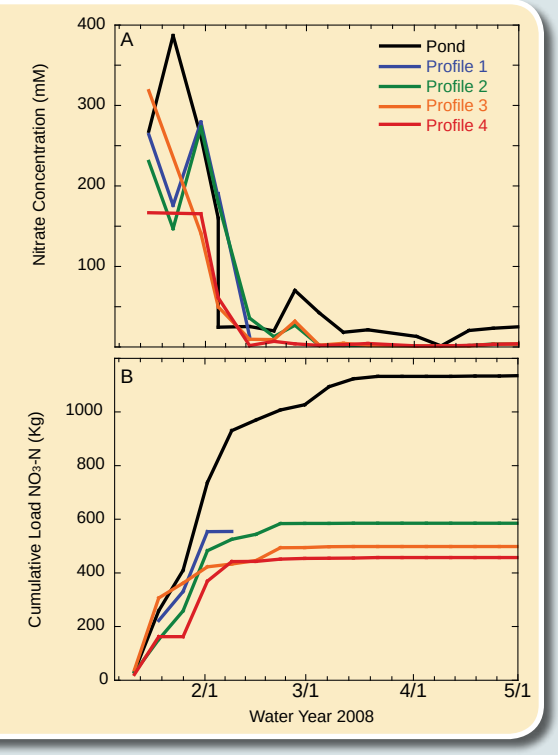

Figure 4. (A) Comparison of the concentration of nitrate in the recharge pond and piezometers screened 0.5 m beneath the pond in instrument profiles 1, 2, 3, 4. (B) Apparent cumulative load of nitrate-nitrogen in the recharge water and piezometers. Load calculations are based on weekly infiltration volumes for the whole pond and weekly measurement of nitrate concentration in a given piezometer profile. This calculation compares potential load reductions if the behavior at that profile is applied to the whole pond infiltration.

MAR water was observed at MW 2 within days of filling the recharge pond, it was several weeks before MAR chemistry was detected at MW 3. To the north of the pond, which is upgradient prior to development of the local mound, the composition of groundwater quickly approached that of the diversion water at the closest well, MW 8, but MAR had minimal influence on the groundwater chemistry observed at MW 9 (Figure 3b). Variations in water level and chemistry around the recharge pond suggest heterogeneous recharge and flow within the perched aquifer.

Nitrate concentrations were lowered in the underlying aquifer during MAR primarily from dilution, but substantial reduction in nitrate concentrations was also observed during shallow infiltration. The concentration of nitrate in diverted slough water was reduced by 10 to 98% during the first meter of infiltration throughout recharge operations in 2008 (Figure 4a). The greatest reductions of concentration occurred at lower nitrate concentrations and slower infiltration rates, but load reductions were significant at higher recharge rates as well, even though removal efficiencies were lower. Observations of nitrate concentrations and recharge rates suggest that the cumulative removal of nitrate after the 40th day of the recharge season was on the order of 600 kg nitrate-N, or more than 50% of the nitrate mass diverted from the slough into the MAR pond (Figure 4b).

Potential mechanisms for the nitrate removal during infiltration include assimilation by plants and microbial denitrification. Microbial denitrification is a process by which nitrate is converted to di-nitrogen gas during the oxidation of organic carbon, generally within a low oxygen environment. Whereas assimilation by plants comprises a temporary sink for nitrate, denitrification represents a true removal of nitrogen from the aquatic environment. Denitrification is well documented in many environments such as rivers and wetlands, but the extent and controls on denitrification during recharge are not well understood (Böhlke et al., 1995).

Stable isotopes of nitrate are useful for identifying denitrification because

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Student/Research Corner – *Continued*

this process is known to enrich the residual nitrate pool in the heavier isotopes of nitrogen and oxygen (higher $\delta^{15}N$ and $\delta^{18}O$ values) in a characteristic ratio of 1:2 (Böttcher et al., 1990). In shallow sediments below the Harkins Slough recharge pond, the ratio of $\delta^{18}O$ to $\delta^{15}N$ in nitrate of infiltrating water was consistently enriched with respect to the nitrate in diversion water. The isotopic enrichment proceeded along a ratio of 1:2 in a plot of $\delta^{18}O$ versus $\delta^{15}N$ in nitrate, suggesting that denitrification is the likely mechanism of removal (Figure 5). Interestingly, diverted slough water had $\delta^{15}N$ and $\delta^{18}O$ values that were relatively high when compared with typical values of fertilizers ($\delta^{15}N$ -5‰ to +10‰) and soil nitrogen ($\delta^{15}N$ +3‰ to +7‰) (Kendall, 2008), suggesting that some denitrification may also have occurred in the slough before diversion to the recharge pond. Denitrification in this system of rapid infiltration does not appear to be limited by the supply of carbon, as organic carbon concentrations in infiltrating water remain high throughout the recharge season. A significant finding of this research is that conditions in the shallow subsurface of the pond can support microbial denitrification, even at infiltration rates as high as 1 m/d, when it might be expected that dissolved oxygen levels would be too high for denitrification to operate efficiently.

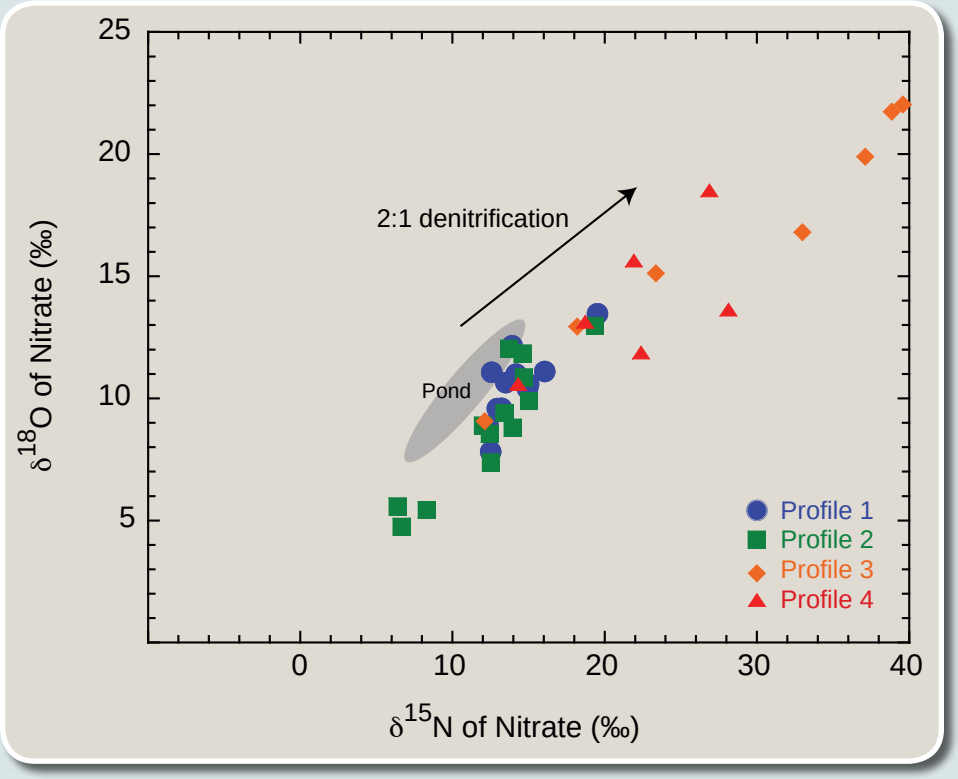

Figure 5. $\delta^{15}N$ and $\delta^{18}O$ of nitrate in water samples collected from the recharge pond and piezometers screened at 0.5 and 1 meter beneadth the pond (Figure 1).

Conclusions

MAR can lead to significant changes in groundwater chemistry. Combined studies of physical and chemical hydrogeology help to resolve water and solute flow paths, reaction, and fate. Groundwater mounding and chemistry below the Harkins Slough MAR pond suggest that recharge, flow, and reactions occur heterogeneously. Nitrate concentrations decrease consistently within the shallow subsurface below the recharge pond, and stable isotopes of nitrate collected from shallow piezometers suggest that denitrification is an important process in nitrate removal from this system. Although there are differences in the extent and rate of nitrate removal across the pond, about 50% of the nitrate load applied in diverted slough water was removed during the first two months of MAR operation. Denitrification appears to be an efficient method of nitrate removal within this MAR system even at high rates of infiltration and initial nitrate concentration.

References

Kendall, C., and McDonnell, J.J., eds., 1998, Isotope Tracers in Catchment Hydrology: Amsterdam, Elsevier Science B.V.

Böhlke, J.K., and Denver, J.M., Combined Use of Groundwater Dating, Chemical, and Isotopic Analyses to Resolve the History and Fate of Nitrate Contamination in Two Agricultural Watersheds, Atlantic Coastal Plain, Maryland: Water Resour. Res., v. 31.

Bottcher, J., Strebel, O., Voerkelius, S., and Schmidt, H.L., 1990, Using isotope fractionation of nitrate nitrogen and nitrate oxygen for evaluation of microbial denitrification in a sandy aquifer: Journal of Hydrology, v. 114, no. 3-4, p. 413-424.

Discovering Historic Water Information

By Paul Atwood, Archivist & Head of Technical Services, Water Resources Center Archives

Historic information is increasing in value in this age of ubiquitous access to electronic information. The assumption that everything worthwhile is online is simply not true. Manuscripts, archives, ephemera, photographs, postcards, scrapbooks, clippings files, maps, architectural records, let alone materials under copyright are just a few examples of consequential information that is widely unavailable via the Web. Those who know how to perform research in both the digital and physical realms quickly identify themselves as experts in their field and crucial to their employers.

Published information tends to be easily discoverable in library catalogs (e.g., Worldcat.org) and increasingly available online. For example, the Internet Archive and the Claremont Colleges have digitized the bulk of the Bulletin series of the California Department of Water Resources (DWR), dating back to 1922 before DWR was officially formed and the series was produced by the Department of Public Works, Division of Engineering and Irrigation. The Bulletin series contains a plethora of important data that, until recently, has only been available in print. The redundancy in these two online collections provides users options for discovery and access tools. Similarly, the Google Books project has digitized millions of titles, but the lion's share of these are not available online and the auto-generated metadata associated with this content is questionable.

On the other hand, gray literature and unpublished information is often only available at unique institutions like the Water Resources Center Archives (WRCA). In addition to creating standardized metadata for inclusion in library catalogs, WRCA staff processes large collections of unique manuscript materials compiled and donated by engineers, attorneys, researchers, government agencies, and NGOs. Collection guides to these materials provide unparalleled organization and access to mass amounts of information, greatly enhancing discovery and, thus, saving researchers time and resources.

Stream gaging in Owens Valley, 1909. J.B. Lippincott Collection

Many materials may be requested for loan or photocopy, while some items are only viewable on-site. WRCA also solicits grant funding to digitize highly desired content, which is then made available online. WRCA staff are available to support research and have access to numerous database – contact us with your query today!

Visit WRCA's website for more information and check out WRCA's delicious bookmarks to view hundreds of useful links. http://www.lib.berkeley.edu/WRCA/, http://delicious.com/wrca

Paul Atwood can be reached at patwood@library.berkeley.edu.

California Groundwater Association Notes

By Mike Mortensson, CGA Executive Director

CGA Convention Expands Educational Opportunities

CGA held its 61st Annual Convention and Trade Show on November 5-7, 2009 at the Silver Legacy Resort Casino and Reno Events Center. This year the educational options were expanded. The ever-popular McEllhiney Lecture has been scheduled for Saturday morning. W. Richard Laton, Ph.D., PG, CPG, of Cal State Fullerton, will present the lecture on "Boring Logs – What's Important and What's Not; A Scientific Perspective." Saturday afternoon sessions will include Drilling Fluids, Air Emission – Fleet Calculators, and The 3R's for CGA Volunteers.

Friday morning sessions included Goulds VFD Analysis, Grundfos VFD Analysis, Safety: How to Organize a Safety Program in your Company, Safety: Lock Out – Tag Out for Water Well Drillers, and Water Treatment (panel discussion).

Thursday, all-day workshops covered Ground Source Heat Pump Installation, and Coliform & Iron Bacteria – THE ANSWERS.

"Tools of the Trade" demonstrations were held on Friday and Saturday on the exhibit hall floor. These half-hour sessions will cover Maps & GPS Usage, Well Blasting, VFD demo, Downhole Cameras, VDECS basics, and Chase'em Back Tools.

CGA Continues Efforts on Unlicensed Drilling

CGA's case against the Semitropic Water Storage District for drilling wells without the required C-57 license, which was dismissed by the Superior Court of Kern County in late 2008, has been appealed. Briefs have been filed but a hearing has not been set. In a separate matter, CGA is working with local health departments, district attorneys and the Contractors State License Board in efforts to halt drilling by unlicensed contractors. It seems that every drought brings in persons wanting to "make a buck" but not following well construction standards. CGA urges any GRA member who may see questionable practices to contact CGA and do a license-check at www.cslb.ca.gov. Everyone in the groundwater industry should be working together to insure proper well construction to avoid groundwater contamination!

Carb Regulations

CGA continues to work with California Air Resources Board (CARB) officials to obtain extensions of compliance times for the multiple regulations affecting the groundwater industry. The portable engine rule eliminates the use of Tier 0 engines as of 1/1/2010. Industry surveys indicate about 30% of the drill rigs in CA use a deck engine (classed as a portable engine); a large majority of these engines are Tier O. The loss of those drill rigs, will make it difficult to meet demands for groundwater, especially during the current drought. CGA is trying to get relief from this rule and the regulations for Off-Road Equipment and On-Road Vehicles. There is concern that the new regulations will result in downsizing of water well contracting firms, thus affecting the availability of groundwater.

For more information on any of these programs/activities, contact CGA at 707-578-4408; Fax: 707-546-4906; or email Mike Mortensson, CGA Executive Director, at wellguy@ groundh2o.org.

GRA Welcomes the Following New Members

August 28, 2009 – November 25, 2009

Aarons, Jerry	Cal EPA, DTSC
Abrol, Sapna	Alpha Environmental
Bardsley, David	WDC Exploration & Wells
Basagaoglu, Hakan	Southwest Research Institute
Baumgras, Lynne	BSK Associates
Berg, Tom	Cal EPA, DTSC
Bickmore, Douglas	On Materials
Campbell, Robert	ETIC Engineering
Carfagno, Matt	Orion Environmental Inc.
Carman, Sarah	Malcolm Pirnie, Inc.
Cramer, Rick	AECOM
Crandall, Timothy	Kleinfelder
Davids, Jeffrey	H2O Tech
Deschenes, Michael	
Didriksen, Erik	GenCorp/Aerojet
Drugan, Sophia	Kleinfelder
Fure, Adrian	AMEC Geomatrix
Goodfriend, Lauren	TechLaw, Inc.
Gribble, Chip	Cal EPA, DTSC
Hoherd, Charlie	Roscoe Moss Manufacturing Company
Hrabe, Orville	WDC Exploration & Wells
Hughes, Eileen	Cal EPA, DTSC
Jones, John Leslie	Developing Water Resources, Inc.
Jones, Linda J.	Developing Water Resources, Inc.
Kelmser, Urmas	Chevron
Lane, John	Lee & Pierce, Inc.
Looney, William	AECOM
Lynch, Chris	PerkinElmer
Mackay, Douglas	University of California, Davis
McArdle, Steve	Cal EPA, DTSC
McCardell, Brad	WDC Exploration & Wells
Montano, Katie	Driscolls
Mork, Ben	Regenesis
Narasimhan, T.N.	University of California at Berkeley
Propes, Juli	Cal EPA, DTSC
Reimer, Anna	West Yost Associates
Reinsma, David	Trinity Source Group, Inc.
Sandberg, Eric	RSI Drilling
Sethi, Dalbir	Lehigh Nanotech LLC
Steinle-Darling, Eva	Erler & Kalinowski, Inc.
Trinidad, Richard	Enviro Nova LLC
Westrich, Ahnna	Camp Dresser and McKee, Inc.
Zepeda, Jacob	TRC

GRA Extends Sincere Appreciation to its Co-Chairs and the Sponsors of the October 2009 27th Biennial Groundwater Conference and 18th Annual GRA Meeting

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Vicki Kretsinger, Luhdorff & Scalmanini Consulting Engineers
Dr. Jean Moran, CA State University, East Bay

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Bob Van Valer

CORPORATE *($250-$499)*
David Abbott
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Martin Feeney
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Tammy Jones
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Larry Ofiaro
Oliver Page
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Eric Reichard
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Tony Ward
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Gus Yates
Anthony Zampiello
William Zavora
Greg Zekoff

SUPPORTER
Angela Carmi
John Farr
Lauren Steely
Frank Yeamans

Renew Your Membership Online – It's Quick and Easy

It's time to renew your GRA membership for 2010. Renew by December 31, 2009 and save $10 as dues rates increase on January 1, 2010! You can renew online via GRA's Web site, www.grac.org, or you can request a hard copy dues renewal invoice from Kevin Blatt at dbadmin@grac.org. To save time and effort, GRA recommends that you renew online as the process is secure and seamless. It will also help GRA to keep related expenses to a minimum.

As GRA approaches 2010 with nearly 1,300 members, the goal of having 1,400 members by the end of 2010 is attainable. To make this happen, please renew your membership and recruit one new member to GRA. Recruiting a new member is a way to introduce your colleagues to a credible, innovative organization that provides many benefits.

Thank you for your interest and continued participation in protecting and improving California's groundwater resources.

GRA 2010 Officers Elected

The GRA Board of Directors elected the following officers for 2010: William Pipes, President; Sarah Raker, Vice President; Ted Johnson, Secretary; and David Von Aspern, Treasurer. Congratulations to all of you for being elected.

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available for most of the speakers at http://www.lib.berkeley.edu/WRCA/WRC/GW27th_program.html.

Plenary Session

Eric Reichard, Director of the U.S. Geological Survey (USGS) California Water Science Center, stated that the many uncertainties facing California's surface-water supply increase the importance of conjunctive management strategies that maximize the benefits provided by groundwater. Collection of new data and application of improved analytic tools will be required to ensure a sound scientific basis for developing such strategies. He provided examples from current USGS studies, including unsaturated zone monitoring, subsidence monitoring, the Central Valley Hydrologic Model, linked watershed-groundwater modeling (GSFLOW), and linked optimization-groundwater modeling (GWM).

Lois Wolk, California State Senator, 5th District, focused her comments on the then-ongoing discussions in the Legislature involving the five-bill water infrastructure program and major water bond. As the Senate representative for areas in the Sacramento-San Joaquin Delta, Ms. Wolk stressed the importance of developing a comprehensive solution that will protect the fragile ecosystem in light of improvements needed to move water through the Delta. She also noted that groundwater resources are critical to resolving Delta issues, but characterization of quality and quantity of groundwater in the Delta region is lacking.

Lester Snow, Director of the California Department of Water Resources (DWR), provided the audience with a comprehensive overview of water resource challenges in California brought on by the three-year drought. He spoke with passion about the significant policy changes needed to enable water managers throughout the state to better manage our groundwater resources. Mr. Snow stressed the need for the reporting of groundwater pumpage, indicating that it can no longer remain private. He stated that groundwater management must occur at the basin and district level. He compared the effort of managing surface water to that of groundwater, noting that the latter is very casual by comparison. Mr. Snow also briefed the audience on the pending legislation under development at the Capital and focused his remarks on Senate Bills that together could provide $5-6 billion for groundwater.

Groundwater Salinity and Nutrient Management

Charlie Kratzer of USGS (currently with DWR) presented "Salinity Inputs to the San Joaquin River from Groundwater." Previous studies estimated groundwater inputs to the lower San Joaquin River (SJR) on the order of 2-3 cfs per river mile, or as much as 15% of summer flow; however, there was a paucity of data on the chemical composition of these inputs. Chemical, hydraulic, and temperature data collected along 114 transects during a recent study of a 60-mile reach from Salt Slough to Vernalis showed, among other things, high variability in groundwater salinity in the streambed. High-salinity zones near Salt and Mud Sloughs (expected) and the Tuolumne and Stanislaus Rivers, with specific conductance values exceeding 6 mS/cm and an upward hydraulic gradient, may be significant contributors to SJR salinity.

Karl Longley, California Water Institute and Chair of the Central Valley Regional Water Quality Control Board, presented his perspective on salinity and nutrient management in the Central Valley. The need for such management to support quality of life and economic vitality is quite clear. A goal for nutrient management is to minimize losses from agricultural lands by focusing on nutrient application efficiency and reduction of runoff and return flow. Salt management requires stakeholder involvement in tracking salts, developing desalting methods, and disposal. Examples of current salt management activities were provided.

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Pamela Creedon, Executive Officer of the Central Valley Regional Water Quality Control Board, presented the CV-SALTS approach to salinity and nutrient management in the Valley. She highlighted key problems, including increasing salinity and nitrates coupled with increasing groundwater demand, no economical means for salt removal and disposal, and an uncoordinated regulatory approach. Ms. Creedon described how CV-SALTS, a stakeholder-driven process, can lead to innovative programs that maximize benefits and provide long-term sustainability. She also gave an overview of the long-term plans of CV-SALTS and encouraged involvement.

Groundwater Quality Sustainability in Urban and Agricultural Settings

Ken Belitz of the USGS discussed the latest findings from the USGS component of the state-funded Groundwater Ambient Monitoring and Assessment (GAMA) program. From 2004 to 2009, groundwater quality has been assessed from samples collected from over 2,000 wells located in priority basins throughout California. Health-based benchmarks, relative concentrations, and "aquifer-scale proportions" provide a context for comparing different constituents and different basins. Inorganic elements are more significant than organic constituents in public supply aquifers. Please see http://www.swrcb.ca.gov/gama/ for more information.

Sally McCraven of Todd Engineers presented an analysis of groundwater sensitivity and vulnerability factors identified in the Santa Clara Valley of northern California. The objective of the study was to help local resource management and planning agencies in understanding the potential impacts of future land use changes on groundwater quality and to help prioritize groundwater monitoring and protection activities. The sensitivity, potentially contaminating activities, and vulnerability were mapped and a web-based GIS tool was developed to easily share the data with key stakeholders.

Dr. Xinyu (Cindy) Li of the Santa Ana Regional Water Quality Control Board presented the rationale for developing and implementing the salt and nitrogen management plan for the Santa Ana Basin. The plan delineated groundwater subbasins into groundwater management zones based on the hydrologic boundaries and management activities that occur in each zone. Using historical data and current ambient water quality, the assimilative capacity of each zone was determined. The plan has been implemented through wasteload allocations to discharges of recycled water to the Santa Ana River and its tributaries. Surface water and groundwater monitoring is being conducted to evaluate and update the plan as needed.

Impacts of Water Reuse/ Recycling on Groundwater

Dr. Laosheng Wu from the University of California-Riverside discussed how to assess the leaching potential of emerging organic contaminants in fields receiving reclaimed wastewater irrigation. One of the concerns of water reuse is the fate of effluent-associated contaminants, such as pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs). Dr. Wu's lab developed a simple and robust analytical method to measure multiple organic compounds simultaneously in soil and water. They assessed representative PPCPs and EDCs in soil and water of three fields that received reclaimed wastewater irrigation. Results show that PPCPs and EDCs were present in runoff at below-LOQ (limits of quantification) to sub-µg/L levels. Although the concentrations were low, the po-

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Water Crisis and Uncertainty: Shaping Groundwater's Future – *Continued*

tential of adverse effects on the aquatic and terrestrial environment cannot be overlooked. Screening models are useful tools for assessing the leaching potential of these compounds.

Elizabeth L. Haven, Assistant Deputy Director for the California State Water Resources Control Board, outlined how to encourage recycled water recharge through statewide policy and streamlined permitting. Groundwater recharge projects using recycled water lessen the impact of persistent drought and strained resources. The State Water Board adopted a Recycled Water Policy earlier this year to promote increased use of recycled water while protecting public health and the environment. The Policy has provisions that affect groundwater recharge reuse projects: (1) streamlined permitting for projects that meet certain criteria; (2) aids complying with the State Water Board's anti-degradation requirements; (3) requires the State Water Board to convene a Constituents of Emerging Concern (CEC) Advisory Panel to answer questions regarding monitoring and testing for CECs; and (4) requires the development and adoption of salt/nutrient management plans for groundwater basins throughout the state (see earlier summary of Pamela Creedon's presentation).

Leah Walker, Chief of the Drinking Water Technical Programs Branch of the California Department of Public Health (CDPH), discussed draft regulations for groundwater recharge with recycled water. She indicated that the CDPH has completed a "semi-final" draft of regulations for groundwater recharge for indirect potable reuse. In August 2008, after a decade of collaborative development, CDPH released the latest version of the draft regulations, and is proceeding towards formal adoption. The regulations are intended to protect aquifers designated as drinking water sources from any harmful effects of a recharge project; they address only indirect potable reuse projects, not direct reuse or surface water augmentation with recycled water. Groundwater recharge projects addressed by these regulations may only use "recycled municipal wastewater" primarily from domestic sewage, not industrial wastewater. The draft regulations and a copy of the presentation can be found at http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Waterrecycling.aspx.

Luncheon Speaker

Chunmiao Zheng, the 2009 GSA Birdsall-Dreiss Lecturer, presented "Will China Run Out of Water?" It was a fascinating look at a vast country with widely varying water availability and significant challenges to overcome. Challenges associated with China's water availability include poor groundwater quality (high nitrates) in many agricultural and urban areas, limited water treatment facilities, land subsidence from overdraft, the need to move water from wetter areas in the south to very dry northern areas, and likely severe environmental consequences of removing water from pristine southern areas.

Optimizing Water Storage: Dams and Subsurface

Stephen Roberts of DWR presented "Optimizing Conjunctive Use Between Surface Water and Groundwater Storage in California." California's water planners are facing complex challenges brought on by drought and federal biological opinions that are reallocating water supplies from the state and federal water projects to Delta restoration efforts. Mr. Roberts discussed initial DWR operations studies done to quantify the effects of 1) the Wanger ruling, 2) drought, and 3) climate change. Results from these studies indicate that new conveyance and new storage provide reliability benefits under most future scenarios; notably, south-of-Delta groundwater storage performs similar to surface storage, with even greater drought-year performance. He also reviewed climate change adaptation strategies, including the suggestion that state, federal and local agencies should develop conjunctive use management plans that integrate floodplain management, groundwater banking and surface storage.

Jim Constantz of USGS discussed analyses of the relative impact of in-reach groundwater pumping versus a large upstream dam on streamflow and stream temperature for humid, semiarid and arid conditions with long dry seasons representing typical conditions where large dams are present. A MODFLOW model with stream/aquifer interaction tools simulated monthly streamflow for 12 watershed scenarios. Results were fed into a stream temperature model assuming the presence of a dam in the upper reach and pumping in the lower reach. Three climates were used and four hypothetical watershed scenarios (natural system, dam only, dam plus groundwater pumping, and groundwater pumping only). Dam removal created significant changes in stream temperature in all cases. Pumping caused stream temperatures to warm slightly in summer and cool slightly in winter owing to reduced alteration in streamflow relative to the dam.

Mary Lou Cotton of Kennedy/Jenks Consultants discussed results from a survey of groundwater banking programs in California commissioned in 2008 on behalf of the Sacramento Groundwater Authority. Seventeen groundwater banking programs were identified in California (11 active and 6 under consideration). The seven targeted for the survey indicate that the most common type of banking program is direct percolation, and the most prevalent goal is to use the local aquifer(s) for storage and/or overdraft correction. Most programs have a monitoring process, assess fees, and have restrictions on deposits or withdrawals. Loss factors associated with evaporation, operational and other losses range from 0-15%. Overall, the survey shows the great degree of success (both operational and political) that these programs have demonstrated.

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Water and Energy: Optimizing Groundwater Pumping

Mike Hightower of Sandia National Laboratories spoke on "Water and Energy: Groundwater Challenges and Issues," which included an overview of current and emerging water availability issues. He emphasized the interdependence of water and energy, particularly the extensive use of water for energy development. Concurrently, water and wastewater pumping, treatment, and distribution consume large quantities of energy. While freshwater availability is becoming limited in many regions, water consumption demands by the energy sector could triple over the next two decades, which could significantly change how freshwater and nontraditional water resources are developed and utilized. He believes that saline groundwater will be used more in the future as it may be less expensive to treat than to transport other less saline water sources.

Robert Gailey, Consulting Hydrogeologist, spoke on "Considering the Consumption of Energy and Other Resources during Pumping at the Well and Wellfield Scales." He provided examples of where optimization techniques were applied at different scales to minimize the consumption of energy and other resources. At the well scale, factors related to energy consumption included wells that would benefit from rehabilitation and wells with a water quality problem that require treatment and/or well modification. At the wellfield scale, he presented an example of contaminant plume containment and cleanup in a sole-source aquifer. A formal groundwater optimization approach was used to design pumping schedules that balance the costs of meeting demand (energy consumption) and cleaning up groundwater (consumption of energy and other costs). Another example considered water quality degradation as a result of wellfield operational decisions.

Collegiate Groundwater Colloquium

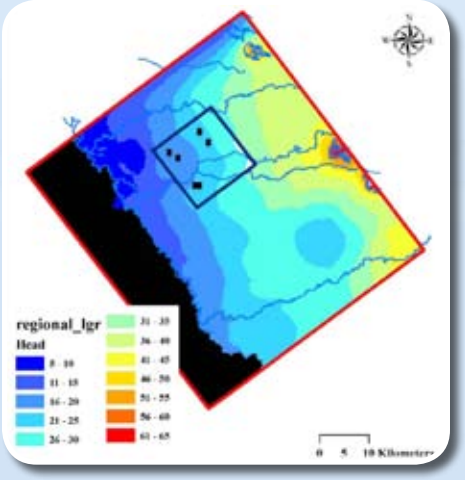
Five students presented their research findings during the second annual Collegiate Groundwater Colloquium. The Collegiate Colloquium offers an opportunity for practicing groundwater professionals to hear about students' recent research, and gives students an opportunity to present their work to an interested audience and to network with practitioners. This year, four graduate students and one undergraduate student from four of California's public universities gave lively presentations on groundwater studies from across California. All five of the presentations included aspects of groundwater/surface-water interaction.

Calla Schmidt, of UC Santa Cruz, advised by Andy Fisher, showed high resolution, detailed results of hydrologic and geochemical conditions associated with infiltration of diverted wetland water at a managed aquifer recharge operation in the Pajaro Valley of central coastal California. Seepage rates were determined data from thermal probes. She showed evidence for very rapid denitrification that results in removal of a large fraction of the nitrate load in this setting. See an expanded discussion of her work in the Student/Research Corner of this issue.

Calla Schmidt collects samples for geochemical analyses at the Managed Aquifer Recharge site in the Pajaro Valley.

Ryan Hines, a graduate student of Thomas Harter's at UC Davis, discussed the results of a Distributed Temperature Survey and subsequent modeling results on a dynamic reach along the Scotts River in the Klamath River Basin of northern California. Decreased baseflow and higher stream temperatures coincide with an increase in groundwater pumping, likely adversely affecting salmon habitat. The temperature survey indicates that groundwater discharge is highly localized, while modeling results point to potential benefits of conjunctive use management.

Hanieh Haeri, who is working with Tim Ginn of UC Davis, presented a unique approach to downscaling a regional groundwater flow model to the local scale. She used a downscaling technique and a USGS groundwater flow model of the Modesto region to examine hydraulics around stormwater infiltration wells in the city of Modesto. Her results suggest that in some cases, the more refined numerical grid is necessary to capture the key characteristics of the flow grid in the vicinity of the infiltration wells.



Hydraulic head is shown for the regional model area, outlined in red, and local model area containing stormwater infiltration wells, outlined in black, used by Hanieh Haeri.

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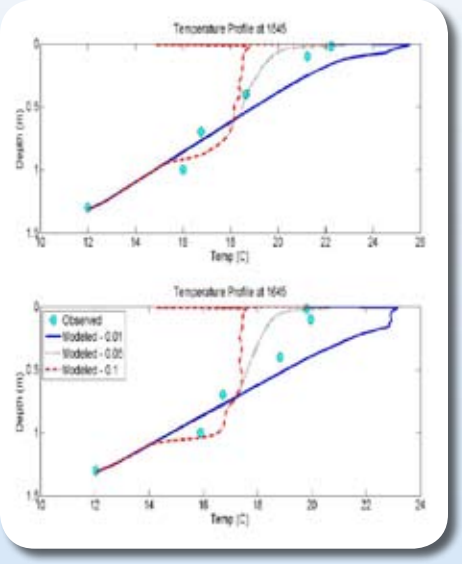
Mandy Plaskett, a senior at CSU Sacramento working under the direction of Dave Evans, presented the results of her senior thesis. Mandy was the recipient of a GRA scholastic support grant from the Sacramento Branch of GRA. She deployed temperature loggers in nested wells along the levee adjacent to the American River on the campus of CSU Sacramento. The results elucidated transport of heat and river water in discrete, highly conductive sand layers.



Results of modeling temperature stratification in a pool for various Richardson numbers, carried out by Ryan Lucas.

Ryan Lucas, who recently completed a Master's degree with Martha Conklin at UC Merced, described interpretation and modeling of temperature and geochemical signals in pools in a montane meadow stream. Temperature dynamics in the pools play an important part in maintaining habitat for macroinvertebrates. Groundwater discharge into the pools is evidenced by stratification in temperature and Radon activity. The stratification was reproduced using two-dimensional fluid dynamical modeling and the Richardson number, which is a useful parameter for predicting pool stratification in low-flow streams with pools.

Impacts of Using Groundwater in a Drought

Tony Morgan of United Water Conservation District presented "Global Warming and the Impacts of Declining Water Levels on Production Wells." He focused on the increased water supply pressures being applied due to both population increases and political decisions. Each of these pressures results in a declining water table which will likely become the norm in the future, causing higher energy costs and lower water quality.

Bob Niblack of DWR presented "2009 Drought Water Bank." Bob described the drought water bank and how it functioned this year. Three types of water transfers were allowed: groundwater substitution, whereby groundwater is used in place of surface-water diversions; reservoir releases; and cropland idling. 322,000 acre-ft of water was transferred in 2009 from upstream of the Delta to downstream users. The questions left for the audience was "are we preparing for 2010?"

Dan McManus of DWR presented "Northern Sacramento Valley Drought-Related Groundwater Impacts." Dan provided an update to the 2009 water year for his area – Northern Sacramento Valley Groundwater Basin. In doing so, it became very evident by the data that precipitation and reservoir storage were lower than average. Consequently, the water index is near critical for the area. Though several counties have experienced minor drawdown in water levels, many are experiencing substantial declines.

Thriving (or Surviving) in Times of Drought: Benefits of Planning

Scott Stine, California State University East Bay, opened the session with his fascinating story and review of California's medieval mega-droughts. He is known perhaps mostly for his discovery and age-dating of old tree stands hidden below the surface of Mono Lake until recent water diversions to LA substantially lowered the lake level. Scott unfolded a story of varied evidence from many more places – from Point Reyes at the Pacific Coast to Walker Lake and Pyramid Lake in the Great Basin – that consistently tell of large mega-droughts from about 900-1100 AD and 1200-1350 AD. In fact, the first half of the 20th century – the period used by engineers as a basis to design our large Western U.S. water projects – was one of the wettest periods in California's climate history of the last two millenia. It is a stark reminder of California climate's variability, even before global warming. Importantly, groundwater appeared to have played a critical role for some plants and animal species to survive these mega-droughts; using pupfish as an example, Scott pointed out that species may have survived over generations in and near springs of Eastern California. It is a concrete, if mostly metaphoric success story from which we may wisely take our cues as we manage an uncertain water future.

Dr. Behrooz Mortazavi of Eastern Municipal Water District (EMWD) described the many sources of water for EMWD: about 45% from the State Water Project, 23% from the Colorado River, 13% from groundwater, 2% from desalination, and 17% through recycling. EMWD has it all: high TDS (brackish) groundwater, low TDS groundwater, expanding urban areas, agriculture and animal farming, large dependence on imported water, a complex array of groundwater basins, local groundwater overdraft, cities, tribal lands, groundwater contamination issues, etc. Through extensive stakeholder participation, negotiation, and education, EMWD has long worked with a diverse group of stakeholders, and has implemented a wide array of groundwater management measures, including extraction and water-quality monitoring, a well abandonment pro-

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Water Crisis and Uncertainty: Shaping Groundwater's Future – *Continued*

gram, recharge projects, tertiary treatment of municipal waste water for in-lieu use as irrigation, and desalination to treat brackish groundwater.

Gary Serrato manages the Fresno Irrigation District (FID), which receives most of its surface water from the Kings River and is part of the Kings River Conservation District, supplemented with water from the San Joaquin River through the Central Valley Project. The district overlies a large groundwater basin, part of the Central Valley aquifer system. FID includes a varied agricultural landscape – citrus and other orchards, vineyards, and cotton and other field crops. For over 40 years, the cities of Fresno and Clovis have received surface water from FID to recharge their (overdrafted) groundwater. Their treated wastewater has also been used to recharge groundwater for many decades. Recharge from irrigation return and recharge basins in the Kings River basin, and groundwater use during drought periods have been intrinsic parts of water operations in FID. An Integrated Regional Water Management Plan and associated documents, including an extensive groundwater modeling study, convey the water management issues and water use history.

Managed (and Unmanaged) Aquifer Recharge

Gary Weissmann of University of New Mexico described glacially-driven stratigraphy along the eastern San Joaquin Valley and its implications for artificial recharge projects. Under depositional environments that existed during glaciated periods in many areas on the east side, features known as incised valley fills (IVFs) were deposited radially along the fluvial/alluvial fans emanating from the Sierra Nevada foothills. These IVFs contain basal gravel units that can be tens of feet thick, as is the case for an IVF deposit identified in the Modesto region. Groundwater flow simulations show that these gravels act as regional conduits for preferential flow, and therefore are potential conduits for transferring artificial recharge on upper fans, where water use is relatively low, to higher-demand areas lower on the fan.

Suzanne Mills of MWH presented a summary of Aquifer Storage and Recovery (ASR) programs and issues in California. ASR, which involves injecting water into aquifers through wells for later extraction, is being practiced in about 16 projects in California using more than 600 wells. It can be a very efficient means for storing water when it is most available for later use during periods of high demand. Saltwater intrusion barriers were the primary injection projects prior to the 1980s, but water supply projects have since increased greatly. Most technical challenges associated with ASR, including clogging of well screens by several mechanisms, have largely been addressed; significant regulatory challenges remain, as waste discharge permits are currently required.

Alan Flint of the USGS presented "Evaluating Future Hydrologic Changes in Western Watersheds: Effects of Climate Change on Water Supply." After laying out existing evidence of rising air temperatures and changes in snowpack and timing of snowmelt, Alan described the use of several simulation models to project climate change and its effects. Global Climate Models predict increasing temperatures; these temperatures are fed into a Basin Characterization Model of the western U.S., which calculates associated changes in snowpack and snowmelt runoff from the upper watersheds. The resulting runoff and temperatures were used to simulate hydrologic conditions through 2100 using the USGS Central Valley Hydrologic Model. Results suggest shifts and overall declines in future water availability coupled with: effects on flooding and sediment transport, changes in plant and animal distribution, and threats to forest health.

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Water Crisis and Uncertainty: Shaping Groundwater's Future – *Continued*

Groundwater Regulation and Permitting in the Southwest

This session focused on groundwater policy and permitting in the Southwest, and prefaced the following session on California groundwater policy. GRA is grateful for the enlightening, stimulating presentations provided by senior representatives from five states including Arizona (**Ken Seasholes**, Senior Policy Analyst, Central Arizona Project); Colorado (**Kevin Rein**, Assistant State Engineer, Colorado Division of Water Rights); Nevada (**Tom Gallagher**, Nevada Water Rights Section Chief); New Mexico (**Jim Brockmann**, Attorney, Stein & Brockmann); and Texas (**Robert Mace**, Deputy Executive Administrator, Water Science & Conservation, Texas Water Development Board). **Tim Parker**, Parker Groundwater, began the session with a brief summary of California's groundwater monitoring, permitting, policy and groundwater rights system.

In five of the six states, groundwater is considered a public resource subject to beneficial and reasonable use, and prior appropriation/senior water rights recognition. Texas is the exception, where groundwater belongs to the overlying landowner and is governed by "rule of capture," which grants landowners the right to capture water beneath their property regardless of associated effects on neighboring wells. Only in Colorado and New Mexico is the connection between surface water and groundwater recognized legally; these waters in the other four states are bifurcated in statute. California uniquely defines "subterranean streams" to differentiate between percolating groundwater and the flow of groundwater confined to a known and defined subsurface channel, which is technically a misnomer because the groundwater flow is not confined by channels, with the possible exception of lava tubes or karst geology.

Groundwater is not permitted in California, but is managed locally via groundwater management plans, special act district authority, county powers and ordinance, and adjudication. Groundwater is permitted in Arizona, Colorado, Nevada and New Mexico, although permitting in Arizona is restricted to six active management areas that cover a small portion of the state but encompass about 85 percent of the population. In Texas, groundwater management areas (GMAs) overlie all aquifers of the state; priority GMAs are designated if there are critical groundwater problems. Within the GMAs, Texas groundwater conservation districts (GCDs) develop groundwater management plans to address local goals, and conduct joint aquifer-scale planning with other GCDs. Colorado is probably the most aggressive regarding groundwater permitting and adjudication, and has the most water resources attorneys and litigation per capita.

Five of the six states have made comprehensive, centralized information on groundwater and wells publicly available; California remains the only state in the US where well logs (for example) are confidential. California has the largest population and gross product of any state, and is the largest user of groundwater, but lags behind the rest of the nation in the collection and reporting of groundwater information and centralized data transparency. The recent passage of Senate Bill No. 6 (Steinberg, Groundwater), may indicate a step towards building the political will to support needed groundwater data collection and documentation efforts.

Groundwater Management: Exploring the Options

Panelists:
Catherine Freeman,
CA Legislative Analyst Office
Scott Slater,
Brownstein Hyatt Farber Schreck
Antonio Rossmann,
Rossmann and Moore

This panel of groundwater law experts was back by popular demand after their appearance earlier this year at GRA's *Legislative Symposium and Lobby Day*. At that time, the legislature was beginning its review of a series of critical water issues which included groundwater monitoring, water rights and state enforcement mechanisms.

As the author of the LAO's March 2009 Report, *Water Rights: Issues and Perspectives*, Ms. Freeman kicked off by updating GRA members on key issues including pending measures for state enforcement of water rights, the need for groundwater monitoring and potential permitting of groundwater rights in California. This led to a spirited debate of these issues specifically, and the possibility of "reallocating" California's water and the Public Trust Doctrine generally. In many areas, our panelists agreed on what the public policy objectives should be if not on the best legislative method for achieving these objectives.

Following the conference, the legislature passed a package of bills which included groundwater monitoring provisions as reported in the Legislative Corner in this edition of *HydroVisions*. Senator Fran Pavley's SB 229, which would have provided a more comprehensive plan for water diversion and use, and included specified civil liability penalties, was not included as part of the final package. This means that our panel lives to debate another day. Mark your calendars now for next year's *Legislative Symposium and Lobby Day*, Wednesday, April 28, 2010 in Sacramento.

Presentation of Groundwater Resources Association of California

2009 Lifetime Achievement Award to Dr. T. N. Narasimhan

Citation by Vicki Kretsinger Graber

Dr. T.N. Narasimhan was presented in October with the Groundwater Resources Association of California's Lifetime Achievement Award. Dr. Narasimhan is an Emeritus Professor in the Dept. of Materials Science and Engineering and the Dept. of Environmental Science, Policy, and Management at the University of California at Berkeley (UCB).

GRA's Lifetime Achievement Award is presented to individuals for their exemplary contributions to the groundwater industry and for contributions that have been in the spirit of GRA's mission and organization objectives, including the management, protection and improvement of groundwater. These individuals are pioneers in their field of expertise.

Dr. T.N. Narasimhan has more than 50 years of experience as a field practitioner, researcher, and professor in groundwater hydrology and water resources. His career has been devoted to the study of water, including its scientific, engineering, cultural, human, and policy aspects. The study of the natural occurrence and movement of water in Earth systems has captured his interests for the past ten years to investigate the evolution of ideas over the past two centuries related to diffusion.

Contributions to Environmental Engineering and Science

In 1956, he received his B.S. in Geology at the University of Madras, India, and began his career as a hydrogeologist in southern India. As a member of the Indian Geological Survey between 1956 and 1969, a significant part of his field experience was in the hydrology of hard-rock terrains and aquifer testing to evaluate water supplies in rural and urban communities.

Dr. Narasimhan

His first published contribution was the development of "An Alternative Method for Computing Aquifer Constants Using the Theis Nonequilibrium Formula" (*Journal of the Indian Geophysical Union*, 1966). His idea was to use "a ratio method as an alternative to the curve matching procedure for solving certain types of problems" (Current Science, 1968) such as "determining characteristics of ideal, leaky, and bounded aquifers" (*International Association Science Hydrology Bull.*, 1967). He was among the first practitioners to apply the Papadopulos-Cooper well bore storage theory to large diameter wells in India. He was also invited to prepare a guest editorial in *Ground Water* (1969) on "Methods of Analysis of Pumping Test Data."

Dr. Mahdi Hantush (famous for his work on aquifer test analysis methods) commended Narasimhan for his early work on well hydraulics and pumping test analysis (Citation by S. P. Neuman in *Geology Bull.*, 1987). Dr. Hantush also provided a letter of recommendation that Narasimhan brought when he came with his family to the United States in 1970 to pursue graduate studies under Paul A. Witherspoon at UCB. He received his M.S. degree in Engineering Science from the UCB Dept. of Civil Engineering 1971. Also in 1971, he participated at the Geological Society of America (GSA) Penrose Conference on "Multiple Aquifer Systems" along with other groundwater notables, including John Bredehoeft, Irwin Remson, M. King Hubbert, Roger Wolfe, Hilton Cooper, and Stavros Papadopulos.

Dr. Narasimhan also studied under Prof. David Keith Todd, Ph.D. for his graduate work at UCB in Engineering Science. Dr. Todd was his advisor for his doctoral dissertation, "A Unified Numerical Model for Saturated-unsaturated Groundwater Flow" (1975). His research focused on the integration of concepts from porous-media theory, soil mechanics, and soil physics to develop mathematical tools and computer codes for the study of transient fluid and soil behavior under saturated and unsaturated conditions in three-dimensional space for complex geological systems. His studies provided a foundation for later works.

From 1976 through 1980, Dr. Narasimhan was a registered Professional Geologist with the state of California. During the early 1980s, he participated in the Yucca Mountain project as a member of the Earth Sciences Division

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Presentation of Groundwater Resources Association of California 2009 Lifetime Achievement Award to Dr. T. N. Narasimhan – *Continued*

Dr. Narasimhan at drilling site in West Bengal, 1958

of the Lawrence-Berkeley National Laboratory (LBNL). The central issue at Yucca Mountain has included the role of groundwater movement through the vadose zone in fractured porous media and its influence on the migration of chemical contaminants. He has also been involved in modeling the water-steam transport phenomena at the Geysers geothermal field in northern California as a manifestation of flow in fractured porous media.

One of his important contributions to groundwater science was the development, with Dr. Karsten Pruess of the LBNL, of a computer modeling concept to investigate the interaction between fluid phases in the porous blocks and factures of rocks subjected to large temperature variations. The concept, based on a unique and powerful four-dimensional grid representation, has helped resolve some important issues relating to "Fluid Reserves and the Production of Superheated Steam from Fractured Vapor-dominated Geothermal Reservoirs" (*Jour. Geophysical Research*, 1982) and led to the development of "A practical method for modeling fluid and heat flow in fractured porous media" (*Soc. Petroleum Engrs*., 1985).

Another very important contribution resulted from his work with Dr. Joseph Wang of the LBNL; this work furthered the understanding of "Hydrologic Mechanisms Governing Fluid Flow in a Partially Saturated Fractured Porous Medium" (*Water Resources Research*, 1985).

In 1986, Dr. Narasimhan received GSA's prestigious Oscar E. Meinzer Award. Dr. Shlomo P. Neuman presented this award and discussed Dr. Narasimhan's historical contributions (*Geology Bull*., 1987).

Promoting Groundwater Awareness

He has contributed substantially to international awareness of the importance of groundwater, having authored more than 110 technical publications and 36 reports, and made contributions to 9 published textbooks in the field of hydrology and water resources.

In 1990, he received a joint appointment in the UCB College of Engineering and the College of Natural Resources to address scientific and engineering aspects of water and its human and policy implications. He considers this a high point in his career as he believes "the future of wise utilization of the world's water is going to greatly depend upon the sciences and the humanities coming together in imaginative ways" (UC Berkeley *Engineering News*, September 19, 2005 Vol. 77, no. 4F).

In 2000, the University of California Water Resources Center Archives began a program that assembles scholars of distinction to provide lectures as part of the *California Colloquium* on *Water*. From its outset, Dr. Narasimhan has been the principal organizer of the series. The lectures are designed to in-

Continued on the following page…

Dr. Narasimhan (left) with distinguished peers at a GSA Penrose Conference, Asilomar, 1971

Presentation of Groundwater Resources Association of California 2009 Lifetime Achievement Award to Dr. T. N. Narasimhan – *Continued*

Dr. Narasimhan receiving GRA Lifetime Achievement Award, Oct. 7, 2009

crease the understanding and appreciation of water resources and contribute to informed decisions about water.

In 2005, he gave a talk at the National Ground Water Association's Ground Water Summit and prepared an insightful paper about the "Groundwater Profession in Transition: Discovery to Adaptation" (*Jour. Geol. Soc. India*, 2005). He notes that following a history of groundwater discovery and exploitation, "the groundwater profession is now on a path of learning to balance exploitation for human benefit with competing environmental and social interests."

Extraordinary Diversity

Throughout his more than 50 years of experience, Dr. Narasimhan has displayed an extraordinary diversity of research, educational, and philosophical pursuits from:

- Developing methods and tools to analyze aquifer test data;
- Researching mechanisms for multiphase flow in fractured rock;
- Exploring social, economic, and policy perspectives relating to water resources issues;
- Analyzing scientific innovations from the 18th century to the present, including how theories about diffusion have evolved over the past two centuries; and
- Conducting comprehensive analyses of Earth systems through applied mathematics.

He is passionate about the major challenges that lie ahead for our technological society to sustain water resources on local and global scales, and remains highly productive. From 2006-2009, he published at least 17 papers on these and other subjects.

In a 2002 Historical Note in the Ground Water Journal, Dr. David Keith Todd wrote, "It is a matter of no small pride for me that men such as Jacob Bear, John Cherry, Allan Freeze, T.N. Narasimhan, and Shlomo Neuman, all students of mine, have gone on to become world [renowned] leaders in the ground water field" (Todd; *Ground Water*, 2002 Vol. 40, No.6).

And that he is!

Dr. T.N. Narasimhan's Acceptance of GRA's Lifetime Achievement Award

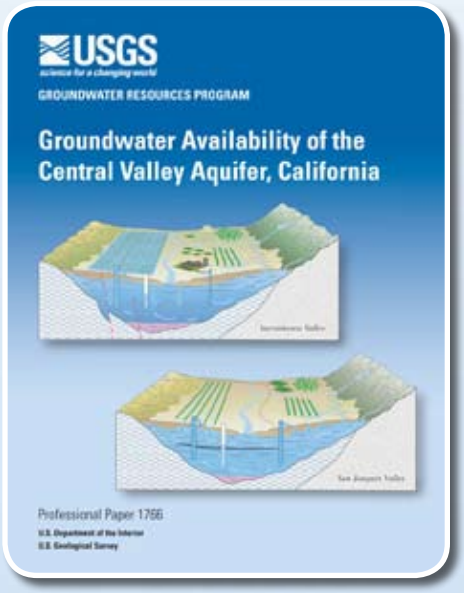
Vijaya, Dr. Narasimhan's wife and a scientist, and also his son, Dr. Ravi Narasimhan, joined Dr. T.N. Narasimhan at the October 7, 2009 luncheon at the 27th Biennial Groundwater Conference and 18th GRA Annual Meeting to honor and congratulate him for his receipt of GRA's Lifetime Achievement Award. Dr. Narasimhan and Vijaya were married in 1962, and she regularly accompanied him on his field work.

Vijaya, 1963, accompanied Dr. Narasimhan during field work

Dr. T.N. Narasimhan accepted the award with great appreciation. His full citation is posted at http://www.grac.org/GW_Profession.pdf and http://www.grac.org/Narasimhan_Acceptance.pdf.

2009 Kevin J. Neese Award Presented to the USGS Water Resources Science Center

GRA President Jim Strandberg presented the 2009 Kevin J. Neese Award to the USGS Water Resources Science Center during the 27th Biennial Groundwater Conference and 18th Annual Meeting of GRA. The award was given for the recently completed report titled "Groundwater Availability of the Central Valley Aquifer," USGS Professional Paper 1766. Claudia Faunt, Editor and Lead Author, accepted the award on behalf of the USGS Water Resources Science Center.



Claudia Faunt, Editor and Lead Author, accepted the award on behalf of the USGS Water Resources Science Center.

The Report culminated a five-year effort by USGS staff to evaluate and document groundwater conditions in the 20,000-square mile Central Valley aquifer. Groundwater production from the Central Valley aquifer represents 20% of the nation's entire groundwater use making it the second most pumped aquifer system in the country. A wide variety of activities, including those listed below, were undertaken to complete the report.

- compiling and evaluating a bibliography of 600 reports and modeling studies
- collecting and compiling data—lithologic, hydrologic, subsidence, water use, land use/crop type, and surface water diversions/deliveries
- compiling and interpreting almost 9,000 well logs
- developing a comprehensive geographic information system (GIS)
- developing a dynamic integrated water supply and demand accounting system at monthly time intervals
- evaluating precipitation and groundwater-surface water interactions
- assessing climatic conditions, including development of three climatic scenarios representing drought, typical and wet conditions
- developing a monthly water budget by region covering 1961 to 2003
- evaluating land subsidence

The Report describes a new crop-based "Farm Process" addition to the USGS MODFLOW modeling suite, which was used to simulate processes occurring on the landscape and estimate groundwater pumping by private irrigation wells. Many of these wells are not metered, or if metered the data are often unavailable; therefore, a thorough and realistic means for estimating this important aspect of Central Valley hydrology was developed as part of this five-year effort.

A key product of the USGS study is a basin-wide numerical flow model, the Central Valley Hydrologic Model (CVHM). CVHM provides an historical look at the water budget from 1961 to 2003, its variability with climate, and long-term trends in groundwater storage and availability. It also provides a valuable forecasting tool for evaluating potential future groundwater conditions. The report and model files are available online at http://pubs.usgs.gov/pp/1766.

The Future of the Water Resources Center Archives is in Jeopardy

By Linda Vida and Paul Atwood, WRCA

The inaugural Hydro-History Corner article about the Water Resources Center Archives (WRCA) was in the Fall 2009 HydroVisions newsletter. Since then events have transpired to put the future of this archives/library and its collections in jeopardy.

CALIFORNIA'S WATER LIBRARY

WATER RESOURCES CENTER ARCHIVES

EST. 1958

WRCA, currently located on the University of California, Berkeley (UCB) campus, is known as California's Water Library and the collections document 150 years of water history in the West. WRCA was established by UCB engineering professors Joe Johnson and Morrough P. O'Brien, who recognized the importance of water in California and the need for documenting the related infrastructure and policies.

In 1956, California Senate Bill 67 was passed giving $100,000 to UC to establish the Water Resources Center (WRC). One of the first acts of WRC was to establish WRCA to support the research of the Center and the University of California, and to serve the people of the State.

In 1958, WRCA began collecting unique technical material pertaining to water in California and the West that other libraries in the UC system did not collect. Today WRCA is recognized as the pre-eminent library of its kind, not only in California, but also nationally and internationally. All of WRCA's materials are easily discoverable to UC students, faculty, staff and the public using UC's online catalogs and the Online Archive of California (OAC). WRCA has more than 200 archival collections donated by early California water engineers and hydrologists and has cataloged 200,000 unique reports published by federal, state and local governments, water and irrigation districts, non-governmental organizations, consulting firms and more. Approximately 65% of the material that WRCA holds is entirely unique.

WRCA has operated on a relatively small budget for 51 years. On October 2, 2009, Dan Dooley, Vice President of the UC Office of the President (UCOP), Division of Agriculture and Natural Resources (ANR), officially announced that WRC will be permanently closed on December 31, 2009. In addition, they announced that ANR will seek a "new academic home for WRCA by June 30, 2010." This announcement, making the future of WRCA uncertain, was unexpected in spite of the severe budget cuts at UCOP and ANR.

ANR's share of the permanent cut this year is $9 million in permanent cuts and $5 million in temporary cuts. By closing WRC, and seeking a new academic home for WRCA, ANR is saving $1.35 million. Some UC and campus programs have been cut 20% in addition to staff furloughs, and other programs have been cut more, but ANR is completely closing WRC and seeks to move WRCA to another UC campus budget. Removing WRCA from ANR will save $230,000 in salaries and operating budget, and an additional $70,000 in benefits. ANR's new strategic vision that was released a few months ago, contains a new water initiative, Water Quality, Quantity, and Security, that apparently has no place for WRC or WRCA. Water management has always been a high priority for California, and WRCA has played a vital role in capturing and making publicly available important material and data. WRCA and its Advisory Board have initiated discussions with ANR about funding for WRCA, but WRCA's future is in doubt.

The best outcome for WRCA would be to remain on the UCB campus in its current space. It would be extremely expensive to move the print collections to another campus. In addition, moving WRCA will make the collection inaccessible for many months at a critical time in California's water history. WRCA's impact, accessibility, and richness would diminish if the collection were split up or assimilated into another library.

ANR has stated that it values the collection, but has made no commitment to WRCA's staff and services. Without dedicated professional staff to maintain and expand the collection, it will become static and will lose relevancy to the water community.

If you are concerned about the future of this valuable resource, please send an email to Dan Dooley, dan.dooley@ucop.edu and Barbara Allen-Diaz, Assistant Vice-President of Programs, barbara.allen-diaz@ucop.edu at ANR with your concerns.

Sacramento

By John W. Ayres,
Branch Secretary

In August, The Sacramento Branch held a meeting featuring Dana Booth, PG, from Sacramento County. Dana gave a presentation on "The Trials and Tribulations of Transferring a Federal Superfund Site to private Ownership," a discussion of the transition at the former McClellan Air Force Base. Negotiations and strategies that have been developed to transfer McClellan Air Force Base from Federal ownership to County and eventually private ownership are in some ways unprecedented. Ownership transfers at the site have a variety of issues including hazardous materials assessment needs and remediation issues, and Dana's work in the McClellan Air Force Base transfers will likely contribute to some operational models that will be used at other Federal facilities throughout the United States.

The Sacramento Branch held a meeting featuring Joel Kiff in September. Joel is the laboratory director at Kiff Analytical, LLC, and specializes in analysis of volatile organic compounds, fuel oxygenates, total petroleum hydrocarbons, and metals. Joel has over 20 years of experience working with analytical methods and has written numerous articles on TPH analysis. His discussion entitled "Diesel at 50 feet? No Way!" was focused on diesel- range hydrocarbons (TPH-D). There are inconsistencies present when samples are analyzed for TPH-D, and it is shown as present even in samples collected at depth, which should not have TPH-D present. Some split samples have returned TPH results differing greatly between labs. Joel presented some experiments performed by Kiff Analytical to determine just why TPH-D is so hard to pin down.

San Joaquin Valley

By Bill Pipes,
President

In 2009, the GRA San Joaquin Valley Branch started an affiliation with the newly formed San Joaquin Valley Chapter of the Association of Environmental & Engineering Geologists (AEG). We have joint meetings and/or on alternate months have Branch/Chapter meetings, and we collaborate on other activities. This arrangement has worked out very well; meeting attendance has increased and there has been a newfound energy in the Branch.

The Branch hosted meetings in March, May, and September. Our speaker for the March meeting was Mr. Nicholas Markevich, PE of Pacific Gas and Electric (PG&E) Power Generation Department's Water Management Section. Mr. Markevich presented an overview of "PG&E's Snowpack Monitoring Program." At the May meeting, we heard from Mr. Dave Orth, General Manager of the Kings River Conservation District, who spoke on the topic of "Sustaining Our Groundwater Resources." We held the September meeting in Bakersfield, where we heard from Ms. Lauren Bauer of the Kern County Water Agency on the topic of "Integrated Regional Water Management Planning (IRWMP) in Kern County."

The most exciting activity this year was joining with AEG on November 4 to co-host an all-day symposium on "Groundwater Withdrawal-Induced Land Subsidence in the San Joaquin Valley: A 2009 Perspective." Though land subsidence associated with aquifer compaction has been a recurring issue in California history, the combination of the recent drought, reduced surface water deliveries, and associated declining groundwater levels from increased pumping has created circumstances where land subsidence is again a threat to our San Joaquin Valley infrastructure and economy. Over 150 people attended the symposium – the largest of its kind to be held in California. The symposium was dedicated to the late Dr. Joseph Fairchild Poland. Dr. Poland's many years of dedication to the study of subsidence and groundwater with the U.S. Geological Survey (USGS), both in California and internationally, served as the foundation for the research discussed during the symposium.

Our Keynote Speaker was Mr. Devin Galloway of the USGS, who authored a popular Circular on the topic. Our lunchtime speaker – all the way from Washington, DC – was Mr. John Tubbs, the Deputy Assistant Secretary for Water and Science for the Department of the Interior. Our speakers and roundtable panelists included recognized experts in land subsidence research and related issues from the USGS, Office of the State Geodetic Advisor (via NOAA), DWR, San Luis Delta Mendota Water Authority, California State University Fresno and the California Water Institute, Westlands Water District, the Fresno County Farm Bureau, and Lawrence Berkeley National Laboratory Earth Sciences Department. Look for more details about this very successful event in the next issue of HydroVisions.

We currently are calling for nominations for new Branch officers to begin in 2010. If you are interested in serving or know someone who would make a good officer, please call or email Bill Pipes at (559) 264-2535, bill.pipes@amec.com.

Please plan to attend our meetings, which are generally held in Fresno on the third Thursday evening of the month (both GRA and AEG). Meeting notices are mailed, emailed, and posted on the GRA website (www.grac.org). If you would like to be on our mailing/emailing list, please contact Cheryl Baldwin at (559) 264-2535 or cheryl.baldwin@amec.com.

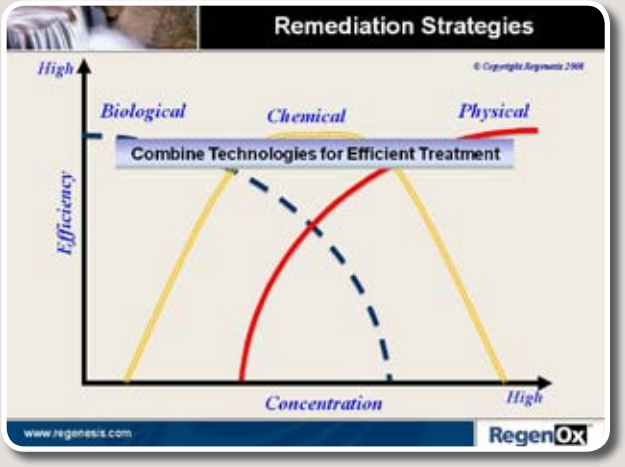
Southern California

By Paul Parmentier,
Technical Advisory Member

In July, in conjunction with the UC Irvine Extension summer class (Groundwater Contamination in Southern California), a field trip was held at the Orange County Water District in Fountain Valley. On Saturday morning July 25th, Tim Sovich, Principal Engineer, presented an overview of groundwater in Orange County. The presentation included a review of the hydrogeology of the area, including the sources of recharge, which are primarily diversions from the Santa Ana River to permeable recharge areas and water infiltration along the seawater barriers along the coast. Mr. Sovich presented an overview of the pumping and recharge activities, graphically demonstrating the summer pumping lowering the groundwater levels in the main aquifer by several tens of feet, followed by water-level recovery during the winter. The talks also included tracer test results that indicate very high groundwater infiltration rates associated with the recharge basins near the Freeways 55/91 intersection in Tustin. After the presentation, the group of about 30 participants was guided through the impressive, award-winning 3-stage water cleanup process (microfiltration, reverse osmosis and UV peroxide).

In October, Paul Parmentier, Southern Branch Technical Advisory member, presented to 50+ Branch members a panel of three experts who discussed remediation methods for groundwater contaminated with chlorinated volatile organic compounds (CVOCs) under the topic "To Thermo, ISCO and/or Bio?"

The first presentation was by Jay Dablow, Senior Partner at ERM, who presented an overview of thermal methods including convective methods (steam-air injection), electromagnetic heating methods (3- and 6-phase heating, RF heating) and In-Situ Thermal Desorption. Jay presented valuable information on applicability of each method to specific lithologies, and to contaminant types. An interesting example of steam injection at Cape Canaveral demonstrated the effectiveness of steam injection.



Gary Cronk of Jag Consulting presented a suite of in-situ chemical oxidation methods (commonly referred to as ISCO), as applicable to chlorinated VOCs. After outlining the design parameters for ISCO applications, particularly sites with high organic oxygen demand (e.g. peat soils), high chemical demands (e.g. brackish water sites) and low permeability sites, Gary introduced the range of oxidants available and described their effectiveness for the suite of CVOCs. The oxidants discussed ranged from longer-lasting liquids (KMnO4), to gases (ozone) to aggressive oxidants with shorter effectiveness that often require injection of multiple compounds for effective oxidation, such as persulfate with NaOH. Gary presented case histories that illustrated the complexities and effectiveness of chemical oxidation.

Scott Wilson, CEO of Regenesis, presented bioremediation methods, emphasizing that a single method is likely to take the remediation from high initial concentrations to the final closure levels, and that remediation planning should include the lifecycle concept of a remediation project's full course. Mr. Wilson presented the documented degradation pathways of most CVOCs, and aerobic and anaerobic enhanced degradation methods using oxygen and hydrogen releasing compounds, emulsified oils... and even beer!

The speakers also agreed that the application of a specific technology at a site is typically not detrimental to a follow-up technology. For example, biologic populations have been shown to rebound very well after thermal or oxidation methods have been applied to a specific site.

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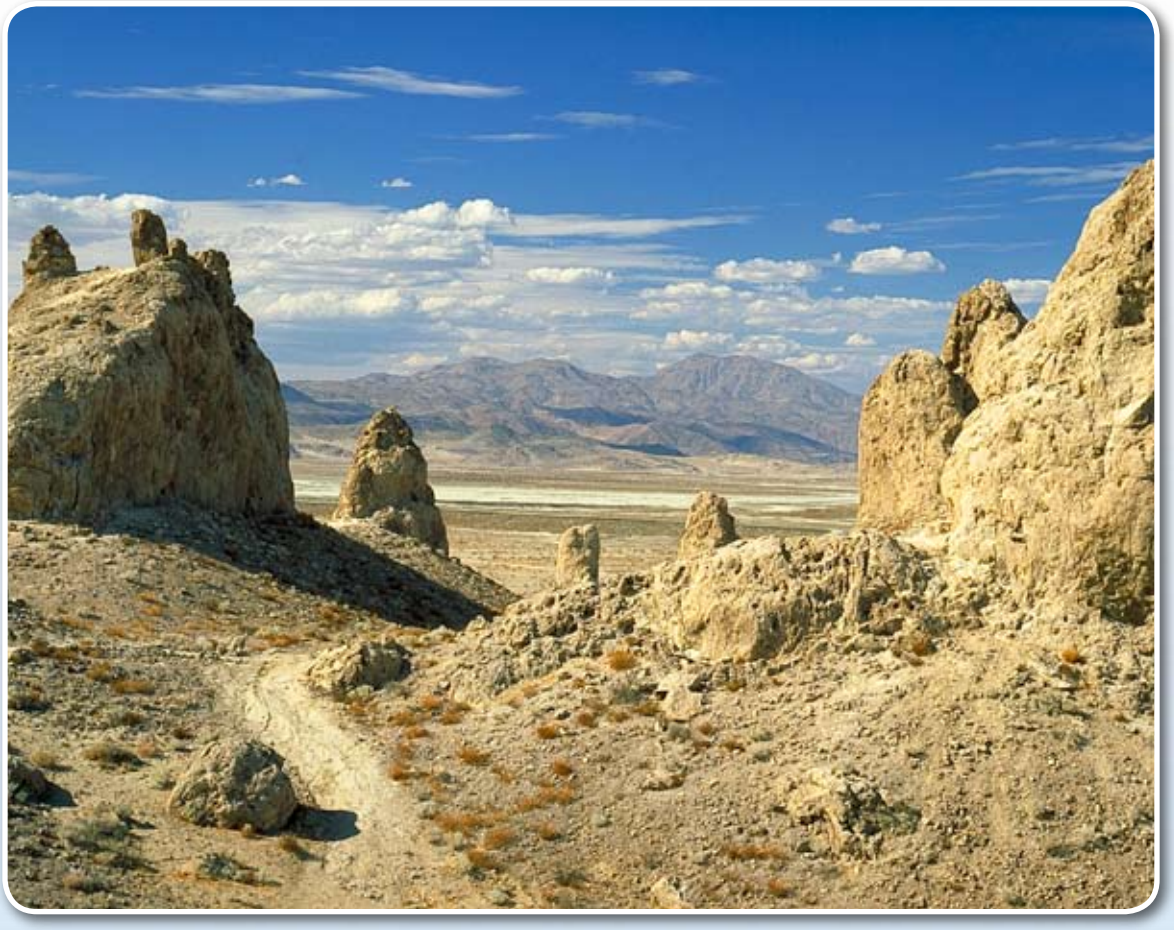

Trona Pinnacles National Natural Landmark, California

The largest concentration of tufa towers, domes, and pinnacles in California, some up to 140 feet high and more than 500 feet in diameter, were deposited along the southwestern edge of Pleistocene Searles Lake. Searles was the third lake, after Owens and China, in a string of five major water bodies nourished by the glacial Owens River, which formerly carried water from the melting snow and ice of the Sierra Nevada to Death Valley. Pleistocene Searles Lake was once about 640 feet deep. The calcite tufa deposits are aligned in a northeasterly direction and developed along a fracture zone where calcium-enriched groundwater springs discharged and mixed with carbonate lake waters. Although several chemical and biochemical processes can lead to the development of tufa deposits, they were formed at Searles Lake primarily by lime-secreting cyanobacteria or blue-green algae. From an economic perspective, the nearby evaporite deposits are mined for potassium salts, borax, boric acid, soda ash, bromine, and lithium carbonate.

Trona Pinnacles National Natural Landmark is accessed via Highway 178 approximately 25 miles southeast of Ridgecrest and 14 miles south of Trona. The pinnacles have appeared as a backdrop in movies, television shows, and print advertisements.

Photograph by John Karachewski, PhD (DTSC).