HYDROVISIONS

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Nanomaterials: New Emerging Contaminants and Their Potential Impact to Water Resources

BY WILLIAM E. MOTZER

This article was edited for length. The fully referenced version with an additional table is available at www.grac.org.

Introduction

Manufactured nanomaterials (MNMs) are a relatively new class of elemental metals, chemical compounds, and engineered materials with particle sizes in the nanometer (nm) range (1×10^{-9} m to 100×10^{-9} m). In comparison, a human hair is 80,000 nm in diameter, a red blood cell is about 7,000 nm wide, DNA is about 2 to 12 nm in width, and a water molecule is approximately 0.3 nm across. This "nanoworld" now includes several different substance classes, including:

1. Carbon-based materials and structures such as C_{60} fullerene, which can be formed into carbon nanotubes.
2. Metal-based substances such as nanogold, nanosilver, and nanometal oxides such as titanium oxide. These also include quantum dots, which are packed semiconductor crystals whose optical properties can change with size; they also have the ability to absorb light and re-emit it in different colors depending on the nanocrystal's size.
3. Dendrimers are polymers constructed from branched units. A dendrimer's surface has numerous chain ends that can be designed to perform specific

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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.

DNAPL Source Zone Characterization and Remediation 2: Meeting the Challenge

BY BETTINA LONGINO, WITH CONTRIBUTIONS FROM JENNIFER NYMAN, YASH NYZNYK, DENNIS MASLONKOWSKI, AND SARAH RAKER

On November 14 and 15, 2007, GRA presented the 19th symposium in its popular and successful *Series on Groundwater Contaminants*, a follow-on offering of the very well-received 2005 ***DNAPL Source Zone Characterization and Remediation Symposium.*** "***DNAPL 2***" drew over 150 attendees to Long Beach from across California, North America, and abroad. Over the course of the two-day symposium, researchers and practitioners from academia, consulting, industry, and regulatory agencies discussed state-of-the-art technologies and techniques being applied to conceptualize, characterize, remediate, manage, and evaluate success at DNAPL source zone sites. Attendees heard presentations on topics including innovative DNAPL source zone characterization and remediation technologies, advances in remediation strategies for complex sites, remedy selection and performance, and long-term site considerations, including evaluating the sustainability of our remediation efforts. In addition to 34 oral and poster presentations, the symposium hosted 21 exhibitors, providing attendees with access to a wide variety

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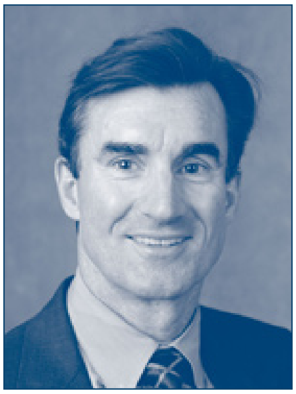

President's Message

BY JAMES STRANDBERG

Transitions — New Faces and Roles on GRA's Board

With the beginning of 2008, GRA's Officers and Directors have undergone a few changes as Officers have completed two-year terms, a seasoned Director "retired" and a new Director joined the Board. Tom Mohr, of the Santa Clara Valley Water District, transitioned from GRA's President to Past President. At the November meeting, the Board of Directors elected several new Officers: I will serve as the new President, Bill Pipes of Geomatrix as Vice President, and Roy Herndon of the Orange County Water District as Secretary. David Von Aspern of the Sacramento County Environmental Management Department was re-elected as Treasurer. By vote of the organization's membership, several Directors were re-elected to three-year terms. Thomas Harter, a professor and Cooperative Extension Specialist in the Department of Land, Air, and Water Resources at UC Davis, was voted in as a new Director. He leads the UCCE Groundwater Hydrology Program, and was the 2007 recipient of GRA's Kevin J. Neese Award. Congratulations Thomas!

As GRA's President for 2006 and 2007, Tom served GRA with distinction. He was, and is, a tireless and passionate advocate of GRA. He seemingly participated on every committee and benefited the organization in numerous ways through his leadership, technical knowledge, and financial acumen. As reported in the Fall 2007 HydroVisions, Tom appropriately received an award at GRA's annual meeting, which reads: "In Appreciation of Your Outstanding and Dedicated Services as President." As Past President, Tom will continue to bring great ideas and energy to GRA.

I am honored to serve as GRA's 9th President. I originally joined GRA at its inception in 1992 and served as the Founding President of the San Francisco Bay Chapter through 1993. I have served as a Director for the past four years, completing two-year terms as the organization's Secretary and Vice President. I have co-chaired the Education Committee with Susan, and for the past two years co-chaired the Events Committee with Eric Reichard. I have learned a great deal about GRA during this time and enthusiastically look forward to my term as President. By way of a brief introduction, I am a California Certified Hydrogeologist with nearly 25 years of experience. During my day job, I am a Vice President and Program Manager for Malcolm Pirnie, a privately held consulting firm with a 100-year dedication to serving clients in the water, wastewater, and environmental markets. I am the Location Manager for the Emeryville office. Thus far in my short career (no retirement in sight with four young kids ranging from a high school freshman to eight-year-old twin boys!), I have worked on a variety of projects, mostly in California, focused on contaminants in groundwater, soil, sediment, and soil gas. Intermittently, and increasingly, my project work has focused on drinking water and water supply.

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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.

GRA's 2008 Emerging Contaminants Symposium

Later this year, GRA will hold a two-day symposium in the San Jose, CA area, on emerging contaminants in groundwater. Emerging chemical contaminants present numerous technical and institutional challenges to society and to environmental and public health professionals. Increasingly sensitive analytical techniques have detected the presence of previously unregulated chemicals in actual or potential sources of drinking water. Many of these chemicals remain unregulated, but the number of regulated contaminants will continue to grow slowly over the next several decades. This event will profile the latest developments in detection, risk assessment, remediation and regulation of emerging contaminants in groundwater. Experts from academia, regulatory agencies, consulting, industry, and the legal arena will participate in moderated speaker sessions and poster sessions. Symposium sessions will cover a variety of chemicals, including the following:

- Manufactured nanomaterials (MNMs)
- Pesticides/herbicides (e.g., 1,2,3-TCP)
- Gasoline additives (e.g., MTBE, TBA)
- Pharmaceuticals, including antibiotics
- Phthalates
- Personal care products (e.g., polycyclic musks)
- Disinfection byproducts (e.g., NDMA)
- Industrial additives (e.g., 1,4-dioxane, 1,2,3-TCP)
- Persistent organic compounds (e.g., PBDEs)
- Fluorinated compounds (e.g., PFOS)

The planning committee for the symposium is currently being assembled. If you are interested in being involved, please contact Jennifer Nyman, committee co-chair, at jnyman@pirnie.com.

Upcoming Events

Call for Abstracts

Groundwater Resources Association 17th Annual Conference & Meeting "GROUNDWATER: Challenges to Meeting Our Future Needs"

SEPTEMBER 24-26, 2008
COSTA MESA, CA
HTTP://WWW.GRAC.ORG/ANNUAL.HTML

"The Nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value." –Theodore Roosevelt, 1910

The Groundwater Resources Association of California (GRA) invites you to join us for our 17th Annual Conference and Meeting "*GROUNDWATER: Challenges to Meeting Our Future Needs.*"

GRA has partnered with stakeholders from all segments of the profession and industry to develop an annual conference that covers technical, regulatory, legal, and policy issues affecting groundwater and facilitates networking and the exchange of the latest research and information. Conference speakers will be featured in a plenary assembly and also in concurrent sessions that include the following issues and topics:

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Save the Date

"CLIMATE CHANGE AND GROUNDWATER"
AUGUST 12-13, 2008, SACRAMENTO, CA

On August 12 and 13, 2008, GRA will convene its first conference on evaluating the impacts of climate change on groundwater resources management. The conference, which will take place in Sacramento, will be organized along three primary tracks: 1) technical aspects of the effects of climate change on groundwater availability, recharge, timing and water supply and demand; 2) legal and policy issues; and 3) what is a groundwater manager/agency to do? Climate change already is being touched upon in CEQA studies and will likely be necessary as a component of the next round of Urban Water Supply Plans and/or groundwater management studies. This conference will bring together a combination of invited experts and abstract-solicited speakers to talk about the newest developments and strategies for dealing with the technical, legal and political ramifications of climate change associated with management of groundwater resources. This conference will provide critical information for groundwater professionals, water agency technical staff and managers, water and planning attorneys, significant groundwater users, agricultural interests and City, County and State agencies. Look for the call for abstracts in early March, 2008.

Upcoming Events

Vadose Zone Hydrology, Contamination, and Modeling

JUNE 9 – 11, 2008
UNIVERSITY OF CALIFORNIA,
LOS ANGELES (UCLA)

CO-SPONSORED BY THE UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION GROUNDWATER HYDROLOGY PROGRAM

Course Description

The objective of the course is to introduce participants to principles of vadose zone flow and transport, including gas and multiphase transport phenomena (VOCs), to discuss field characterization and monitoring techniques appropriate for model data collection, to introduce common modeling techniques and their limitations, and to provide hands-on experience with several commonly used one- and multi-dimensional computer models for vadose flow, transport, and multiphase flow. The shortcourse is designed for scientific and technical staff working with consulting firms and regulatory agencies that are involved in the design, review, and implementation of point source and nonpoint source contamination studies, recharge projects, and site assessment and remediation of vadose zone contaminants (e.g., soil vapor extraction, steam venting). Participants should be familiar with PC Windows and are assumed to have some college training in groundwater hydrology, engineering, or soil and water science. Experience with computer modeling, however, is not a prerequisite. The course will be taught by Thomas Harter, Ph.D., (Univ. of California, Davis), Jan Hopmans, Ph.D., (Univ. of California, Davis), Jirka Simunek, Ph.D. (Univ. of California, Riverside), Toby O'Geen (University of California, Davis), and Kent Udell, Ph.D. (Univ. of Utah). The course will be held at UCLA. Early enrollment is encouraged as space is very limited. For more information, contact Mary Megarry, Groundwater Resources Association of California, 916-446-3626.

Course Topics

- principles and concepts of vadose zone flow and transport
- VOC transport and multiphase flow in the vadose zone
- hydraulic characterization of the vadose zone
- vadose zone monitoring
- numerical methods in vadose zone modeling
- overview of modeling software
- hands-on software training
- case-studies and illustration of water /solute/VOC/multiphase flow in the vadose zone

Principles of Groundwater Flow & Transport Modeling

MARCH 18-20, 2008
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

CO-SPONSORED BY THE UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION GROUNDWATER HYDROLOGY PROGRAM

LIMITED SPACE AVAILABLE -- REMEMBER TO REGISTER!

This course introduces the conceptual principles and practical aspects of groundwater modeling in an intuitive yet comprehensive manner. The course objective is to demystify the use of groundwater models by providing solid understanding of the principles, methods, assumptions, and limitations of groundwater models, as well as hands-on experience with the planning, preparation, execution, presentation, and review of a modeling project. At the end of the course, participants should be able to understand and actively engage in planning, supervision, and/or review of groundwater modeling projects.

Course Topics (partial list)

- principles and concepts of groundwater modeling
- data collection and preparation
- model grid design
- boundary conditions
- modeling multiple aquifer systems
- sensitivity analysis, model calibration and verification
- contaminant transport modeling
- capture zone analysis

Course instructors include Graham E. Fogg, Ph.D., Thomas Harter, Ph.D., and Peter Schwartzman, M.S. The course will be held at UCLA. For more information, contact Mary Megarry at GRA, mmegarry@nossaman.com or 916-446-3626, and visit GRA's Web site at www.grac.org.

Wells and Words

Technical Corner

BY DAVID W. ABBOTT, P.G., C.HG.
TODD ENGINEERS

Data download and public domain statistics: Buyer beware!

Inaccurate conclusions can result from data collection and data analysis using data downloaded from the internet and applying statistics with popular and public domain software. Below is a brief discussion of both occurrences.

Downloading Data

Two sets of monthly rainfall data downloaded from the California Department of Water Resources (CDWR) web site have numerical and typographical errors. Data were tabulated for the Santa Rosa (SRO) gage (1905 to 2007) and Healdsburg (HEA) gage (1966 to 2007). In fairness to the electronic format, CDWR provides a disclaimer: "provisional data, subject to change." Comparison of these data to paper copies of the *Climatological Data Annual Summary* published by the National Oceanic and Atmospheric Administration (NOAA) indicates that 9.5% of the values for SRO provided by CDWR are in error; 17.5% of the values for HEA are in error. These are significant errors that merit attention and warn that electronic data, particularly historical data, may contain errors. Assuming that NOAA data are correct and have been properly reviewed for quality assurance and quality control (QA/QC), then errors found in the electronic data are transcription errors caused by inaccurate keying, mis-identification of characters with scanning and character readers, or computer-related data conversions.

Rainfall data (1930 and 2007) were also downloaded from NOAA-COOP for SRO. The rate of transcription error for these data were lower (1.8% error); but persistent little errors still occur in the database. Initial reviews of the errors for each database show no systematic or logical patterns. However, multiple rainfall stations may have been combined in the electronic data sets and the 1981 to 1983 timeframe is consistently missing data. Transfer of data from older computer code to newer code, character recognition scanning, and keyed-in data may not be 100% accurate. The most time-consuming and tedious part of the transcription process is QA/QC, which requires significant man-hours. A quick method to gauge the accuracy is to review each annual rainfall total from both paper and electronic forms. If the total rainfall for each set is the same, then assume that the monthly data are accurate; if the sets are different, then assess the monthly differences. Beware of electronically handled data and check against paper records.

Statistics from public domain software

Electronic and computer-generated errors using statistical tools from publicly available or popular software such as Microsoft Excel have limitations (see www.practicalstats.com)[1]. Figure 1 shows a plot of 840 data points (specific capacity [SC]; depth) for fractured rock aquifers. The Excel-generated trendline shows two segments (lower solid curve). The actual trend, computed by using the given power trendline equation and substituting values of X and solving for Y, is a curvilinear line (dashed line). Clearly, the computer-generated trendline is in error. Beware of software generated statistics and trendlines.

Interpretation of Figure 1

Incidentally, Figure 1 uses the same two data sets (combined) that were discussed in the winter 2007 *HydroVisions* article. However, the data are presented using SC rather than the hydraulic conductivity. Figure 1 shows a positive

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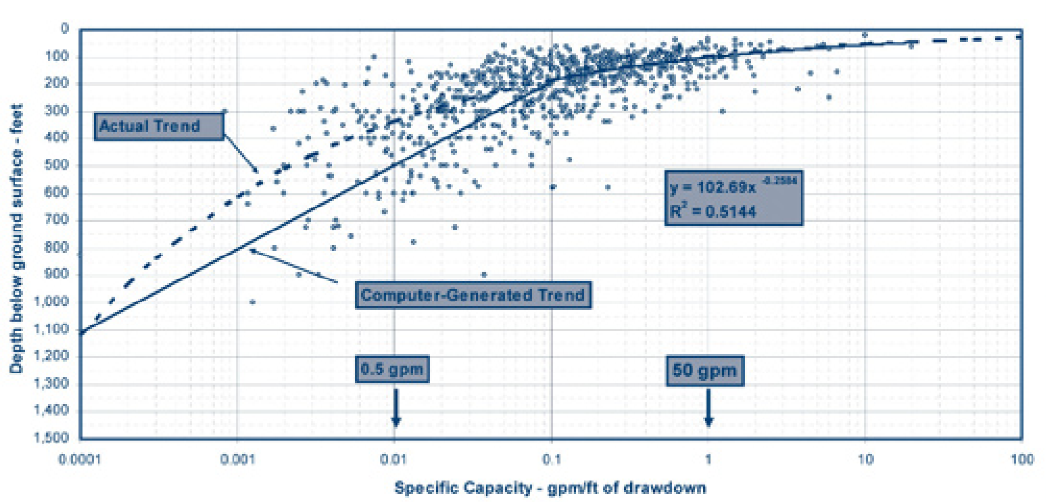
Figure 1: Specific Capacity (SC) Distribution with Depth (N = 840)



The Federal Corner

BY JOHN UNGVARSKY

Federal Legislative/Regulatory Corner

A Call to Action

The Ground Water Protection Council's Report to the Nation: *A Call to Action* discusses a variety of issues of concern and actions to take regarding the nation's groundwater. This report was developed under an EPA cooperative agreement. For more information, go to: http://www.gwpc.org/calltoaction/.

Watersheds, Groundwater and Drinking Water

The University of California's Division of Agriculture and Natural Resources just published *Watersheds, Groundwater and Drinking Water – A Practical Guide*. The book, partially funded by an EPA grant and edited by Thomas Harter and Larry Rollins, will help readers to better understand and assess water supplies and to define and protect water sources. The book is available at: http://anrcatalog.ucdavis.edu/Items/3497.aspx.

Technologies for Arsenic Removal

The Arsenic Removal Technology Demonstration Program was initiated in 2002 by EPA's National Risk Management Research Laboratory to provide cost-effective technologies, training, and technical assistance for small water systems. The first round of the demonstration program matched 12 small utilities with the best-fit arsenic removal technologies to gather performance and cost data. Rounds 2 and 2a identified 38 additional sites, bringing the total to 50 systems to be installed and operating by summer of 2008. For more information, go to: http://www.epa.gov/nrmrl/wswrd/dw/arsenic/tech/index.html.

UIC Website Updated

EPA has revised its Underground Injection Control (UIC) program web site. It includes basic information on wells regulated under the UIC program; videos, posters and other publications showing how the wells are constructed and managed; and compliance assistance. The site also has background on carbon sequestration. For more, go to: http://www.epa.gov/safewater/uic.

Water Efficiency Leader

Santa Clara Valley Water District (SCVWD) was recently recognized by EPA as one of six winners of the 2007 National Water Efficiency Leader awards for their efforts in reducing, reusing and recycling water. Winners were chosen by a panel of national water experts on the basis of three criteria: leadership, innovation and water saved. SCVWD has helped the San Jose area reduce water demand by 55,000 acre-feet, or 12 percent of demand, through conservation and water recycling.

Subsidence in the Coachella Valley

A new study by the U.S. Geological Survey confirms Coachella Valley Water District concerns that land subsidence is occurring because of overdraft in areas of substantial groundwater use throughout the Coachella Valley. For more information, see: http://ca.water.usgs.gov/news/release071217.html.

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 and NV. For information on any of the above topics, please contact John at 415-972-3963 or ungvarsky.john@epa.gov.

CGA Celebrates 60th Anniversary

The California Groundwater Association will celebrate its 60th Anniversary in 2008. The year's big event will be the CGA Convention and Trade Show at John Ascuaga's Nugget in Sparks, Nevada. We're planning a trade show, multiple seminars and workshops with a mix of networking and fun activities. This will be one of CGA's earliest shows; the dates are October 30 – November 1. We hope to see some GRA members in attendance – it's a chance for us to work together to promote groundwater protection and wise use. You'll find a bit more info at CGA's website, www.groundh2o.org.

CGA's Mission And 2008 Goals

CGA's Board of Directors recently reaffirmed the organization's mission and goals for 2008. Our Mission is:

Caring for California's groundwater resources

Giving high quality service to members and the public

Acting in the best interest of the groundwater industry

CGA's 2008 Goals are shown below (if questions, please call the CGA office at 707-578-4408):

- Celebrate CGA's 60th Anniversary
- Initiate a new membership recruitment program – "It Starts With Me!"
- Implement a grassroots legislative program
- Resolve government competition issue
- Expand CGA Leadership training opportunities
- Expand Branch and member participation

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Alliance Corner

GRA Requests Nominations for the 2008 "Lifetime Achievement" and "Kevin Neese Awards"

The purpose of the GRA Awards Program is to recognize noteworthy projects and unique individual contributions related to the understanding, protection and management of groundwater. The objectives of the annual Awards Program are:

1. To provide recognition to individuals who have demonstrated leadership and continuous dedication in the field of groundwater;
2. To provide recognition for unique contributions to the field of groundwater in 2007-2008.

All nominations for the Lifetime Achievement and Kevin Neese Awards must be received by Stephanie Hastings at admin@grac.org no later than Friday, June 13, 2008.

Nominations should be completed using the nomination forms available on the GRA's website at http://www.grac.org/awards.asp. Nominations should: not exceed one page, identify the award for which the nomination is made, and include justification for the award based on the criteria listed.

The GRA Awards will be presented to the recipients selected by the GRA's Board of Directors during GRA's Annual Meeting in Costa Mesa, September 24-26, 2008.

Awards

Lifetime Achievement: presented to individuals for their exemplary contributions to the groundwater industry, and contributions that have been in the spirit of GRA's mission and organization objectives. Individuals that receive the Lifetime Achievement Award have dedicated their lives to the groundwater industry and have been pioneers in their field of expertise.

Previous Lifetime Achievement Award recipients include:

2007 - Dr. Herman Bouwer
2006 - Glenn Brown
2005 - Dr. Luna P. Leopold
2004 - Dr. John Bredehoeft
2003 - Rita Schmidt Sudman
2002 - Tom Dibblee
2001 - Carl Hauge
2000 - Joseph H. Birman
1999 - David Keith Todd
1998 - Eugene E. Luhdorff, Jr.

Kevin J. Neese: recognizes significant accomplishment by a person or entity within the most recent 12-month period that fosters the understanding, development, protection or management of groundwater.

Previous Kevin J. Neese Award recipients include:

2007 – University of California Cooperative Extension (UCCE) Groundwater Hydrology Program in recognition of its efforts to engage scientists, regulators, farm advisors, dairy industry representative, and dairy farmers to better understand the effects of dairy operations on water quality.

2006 – Senator Sheila Kuehl for her work to improve the production and availability of information about the

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Chemist's Corner

Let's Get Small – Nanochemistry

BY BART SIMMONS

As the hype of nanotechnology is replaced with the reality of product development, the environmental impacts and benefits of nanotechnology will become clearer. Nanoscale objects, typically defined as those having a characteristic dimension <100 nm, of course include many substances with well-understood chemistry. For comparison, ATP synthetase, a key metabolic enzyme, is about 10 nm in diameter. However, the ability to design and manufacture on a nanoscale has produced materials with novel mechanical and chemical properties.

Some nanomaterials have been present, undiscovered, throughout human history. Fullerenes, named for the architect and futurist Buckminster Fuller, were discovered in soot, suggesting an ancient presence in the earth's environment. The discovery of Fullerenes opened a new and exciting area of research into this new class of aromatic compounds. The nanotechnology movement, moreover, has created a variety of substituted nanotubes and other nanosubstances with novel chemical properties. A 2007 EPA white paper (http://www.epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf) classified nanoparticles as: 1) Carbon-based materials, like Fullerenes, 2) metal-based materials, including zerovalent iron, titanium dioxide ($TiO2$), zinc selenide, ($ZnSe$), and silicon dioxide ($SiO2$), 3) Dendrimers, polymers built from branched monomers, and 4) Composites of nanoparticles with bulk materials.

The chemical variety of nanomaterials provides unique opportunities to tailor materials to obtain desired physical and chemical properties. For example, although the fullerenes have low water solubility, the modification of them by hydroxylation will produce nanoparticles with significant water solubility. In addition, like naturally occurring colloids, nanoparticles could provide an avenue for rapid and long-range transport of waste in underground water.

Concern for the environmental impacts of nanomaterials is focused on the innate toxicity of the materials, the potential for biological uptake, and the large surface area of nanomaterials. The toxicity and potential ecological effects of nanomaterials are being actively investigated. At the cellular level, the uptake of nanomaterials, specifically, the ability to cross biological membranes, is a critical area of research. Fullerenes and other nanoparticles are toxic to bacteria in some cell assays, and can cause oxidative stress, but are also antimutagenic in some assays, providing an interesting toxicological paradox. The studies to date have been primarily in vitro, and may not translate to environmental conditions.

Nanoparticles have the potential for long-range transport in water, but particles that are readily transported and attach to mineral surfaces may be less mobile in groundwater aquifers. Because groundwater tends to have relatively high ionic strength and significant concentration of metal salts, nanoparticles as a rule may be deposited easily. Many nanoparticles may aggregate to form larger colloids with mitigated toxicity and mobility.

Of course, nanomaterials also provide new tools for remediation. For example, zero-valent iron and gold nanoparticles coated with palladium have successfully reduced TCE contamination without the formation of vinyl chloride as a reaction product. Nanoparticles have also removed chlorinated pesticides from water which were not removed by conventional filters. The surface chemistry of nanoparticles affects their subsurface transport, and it may be possible to design particles with specific transport distances.

Nanotechnology is providing a complex challenge in risk assessment for nanomaterials, but also providing new, customizable tools for environmental remediation. The trick may be to ensure the right match of nanochemistry to site-specific conditions.

Bart Simmons can be reached at bartonps@aol.com.

Organizational Corner

2008 Directors Election Results

The election for GRA's 2008 Board of Directors is officially completed. Board incumbents Tom Johnson, Tom Mohr, Tim Parker and Eric Reichard were re-elected. Thomas Harter was elected as a new member of the Board. All Directors elected in 2008 will serve three-year terms ending in 2010.

GRA extends its sincere appreciation and best wishes to Susan Garcia as she retired from the GRA Board of Directors at the end of 2007.

Renew Your Membership Online – It's Quick and Easy

If you haven't already, it's time to renew your GRA membership for 2008. 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 kblatt@ihappi.com. 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.

With nearly 1,400 members at the end of 2007, the goal of having 1,600 members by the end of 2008 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 for only $100.

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

2008 Contributors to GRA — Thank You

FOUNDER *($1,000 and up)*
Brownstein Hyatt Farber Schreck

PATRON *($500-$999)*
DrawingBoard Studios

CORPORATE *($250-$499)*
David Abbott
Geomatrix
Luhdorff & Scalmanini Consulting Engineers
Malcolm Pirnie

CHARTER SPONSOR *($100-$249)*
Stanley Feenstra
John McAssey
Iris Priestaf

SPONSOR *($25-$99)*
ARCADIS Geraghty & Miller, Inc.
Craig Altare
Richard Amano
Charlene Ayers
Thomas Ballard
Pollyanna Barnich
Kate Burger
Steve Campbell
Bob Cleary
Jim Crowley
Daniel B. Stephens & Associates, Inc.
Jessica Donovan
Robert Dougherty
Earth Tech
EMAX Laboratories
Larry Ernst
Alicia Falk
John Farr
Fred Flint
Avram Frankel
Alvin Franks
Laura Frost
John Gallinatti
Martha Guzman Aceves
Davis Harnish
Pat Havard
Iris Environmental
Sachiko Itagaki
Ted Johnson
Bob Joyce
John Karachewski
Carol Kendall
Christy Swindling Kennedy
Arthur Kidman
Taras Kruk
Brian Lewis
LFR, Inc.
Tara MacHarg
Gerald Marasovich
Sally McCraven
Peter Mesard
Jean Moran
Alec Naugle
Aaron O'Brien
William O'Brien
Susan Panttaja
John Peterson
Peter Quinlan
John Reay
Eric Reichard
Roscoe Moss Manufacturing Company
Robert Sawyer
Heather Shannon
Mel Simons
James Specht
Robert Stettler
Eric Strahan
Francis Thie
Ed Wallick
Welenco, Inc
Brandon Whitehead
Gus Yates
Anthony Zampiello
William Zavora

SUPPORTER
James Malot
Gabriel Sabadell
Frank Yeamans

GRA Welcomes the Following New Members

NOVEMBER 13, 2007 THROUGH FEBRUARY 5, 2008

Alarcon, Tania	LFR, Inc.
Altare, Craig	MWH
Barber, Simon	Burns & McDonnell
Barnich, Pollyanna	Raney Geotechnical, Inc.
Behrens, Anna	Iris Environmental
Behzadi, Harry	Accutest Laboratories
Bittner, Mark	Locus Technologies
Bratton, Patrick	Burns & McDonnell
Brodie, Dana	LFR, Inc.
Bui, Thomas	ENSR Corporation
Casas, Felipe	Self-Help Enterprises
Clarke, Joyce	Analytical Environmental Services
Connelly, Pete	City of Vacaville
Cooley, Jeff	Vironex
Cooper, Eliot	Valley County Water District
Dickinson, Brian	Daniel B. Stephens & Associates, Inc.
Dodge, John	Trihydro Corp.
Edeburn, Paris	Fugro West, Inc.
Emery, Karen	Secor International Inc.
Falk, Alicia	Malcolm Pirnie, Inc.
Fleming, Ryan	Weiss Associates
Fogwell, Tom	Stoel Rives, LLP
Foster, Melissa	Santa Clara Valley Water District
Fostersmith, Ellen	CSUN California State University Northridge
Garcia, Colleen	
Gerritzen, Gina	Malcolm Pirnie, Inc.
Glover, Kent	ARCADIS
Goltz, Ian	Brown & Caldwell
Gomez, Paola	AEI Consultants
Gonzales, James	LFR, Inc.
Greene, Sarah	Central Coast Water Quality Preservation, Inc.
Hansen, Christopher	Earth Tech
Harkare, Shrikant	ENSR Corporation
Harris, Abigail	TEC Accutite
Heron, Gorm	Terratherm
Hinds, Jean	Turlock Irrigation District
Jensen, Dianna	City of Davis Public Works
Kaasa, Barrett	West Yost Associates, Inc.
Kelty, Thomas	California State University, Long Beach
King, Nathan	SFBRWQB
Klitzke, Tiffany	Geomatrix Consultants, Inc.
Knoche, Chris	Brown & Caldwell
Lapuyade, Larry	LFR, Inc.
Lawrence, Rebecca	Iris Environmental
Lecina, Kristina	Black & Veatch
Lim, Kayleigh	LFR, Inc.
Lovell, Randy	Instrumentation Northwest
MacHarg, Tara	Earth Tech
Manning, Jason	LFR, Inc.
McGlochlin, Linda	Parsons
McManus, Terence	Kleinfelder
Mehta, Khyati	ENSR Corporation
Messerotes, Gary	Burns & McDonnell
Namvar, Reza	WRIME, Inc.
Narayanan, Ram	Water Assets Management, LLC
Nugent, Melissa	MACTEC
Otterstetter, Heather	ARCADIS
Pacetti, John	EMAX Laboratories, Inc.
Pang, Caspar	Fitgerald Abbott & Beardsley, LLP
Pasquinelli, Sara	LFR, Inc.
Paz, Lucas	Geomatrix Consultants, Inc.
Plett, James	H2O Engineering, Inc.
Reindl, Brittany	LFR, Inc.
Robinson, Charles	ProHydro
Rogers, Alicia	Brown & Caldwell
Rosenberg, Phil	Central Coast Water Quality Preservation, Inc.
Schmidt, Kirk	
Schroeter, Angela	Central Coast Region – RWQCB
Singhal, Alka	ARCADIS, Inc.
Smith, Jennifer	Geomatrix Consultants, Inc.
Smith, Lee	Stoel Rives, LLP
Snyder, Jessi	Self-Help Engerprises
Steely, Lauren	Columbia Technologies
Stone, Linda	Central Coast Region – RWQCB
Turner, Allison	ARCADIS
Verdeyen, Meagan	ENVIRON
Vossler, David	Winzler & Kelly Consulting Engineers
Walchuk, Nick	ENVIRON
Warner, Dave	Self-Help Enterprises
Webb, Mathew	Geomatrix Consultants, Inc.
Wilson, Bill	Valley County Water District
Wong Hodges, Laurie	DOWNEY | BRAND
Xiong, Zhong	Geomatrix Consultants, Inc.
Zoba, Joseph	Yucaipa Valley Water District

chemical functions. Also, dendrimers generally are hollow spheres into which other molecules or atoms can be placed. This makes them useful for drug delivery.

4. Bio-inorganic composites, such as titanium with attached DNA strands. These can be used to treat disease.

Several classes of MNMs are now globally manufactured in hundred to thousands of metric tons per year. These include MNMs for structural applications (ceramics, catalysts, films and coatings, and composite metals), skin care products (metal oxides), information and communication technologies (nanoelectronic and optoelectronic materials, organic light emitters, and nanophosphors), biotechnology (drug delivery, diagnostic markers, and biosensors) and environmental technologies (nanofiltration and membranes).

Characteristics

The unique size of MNMs means that, in some ways, they will behave as new chemical substances. Two main factors distinguish MNM properties from ordinary materials:

1. They have relatively large surface areas when compared to the same mass of material produced in larger form. For example, a 1.0 cm cube has a surface area of 6 cm^2. This same cube separated into 1.0 mm cubes now has a surface area of 60 cm^2; but if further divided into 1.0 nm cubes, the total surface area becomes 60 x 10^6 cm^2. This may cause the substance to become more chemically reactive; substances that were inert in large-scale form can become reactive in nanoscale form. Size reduction may also affect the material's strength.
2. Quantum effects can begin dominating MNMs, particularly at the lower end of the scale, affecting their optical, electrical and magnetic behavior.

Nanoparticles also can quickly change into larger particles by agglomeration processes.

Occurrence in the Environment

Naturally occurring (geogenic) nanomagnetite exists in some bacteria, which use this mineral to sense the Earth's magnetic field. Primary geogenic nanoparticles also occur as aerosols from ocean spray (salts and sulfates), volcanic emissions (sulfate aerosols), forest fires (soot and elemental carbon, and polycyclic aromatic hydrocarbons or PAHs).

Primary anthropogenic nanoparticles are similar in composition to geogenic nanoparticles, ranging from less than PM_1 (≤1,000 nm) to ultrafine particles (UFP) (≤100 nm). Sulfate, hydrogensulfate, and nitrate nanoparticles are emitted to the atmosphere from industrial sources and power plants, and nanocarbons are emitted from internal combustion (primarily diesel) engines. Major MNM sources with potential impacts to air, soil, surface water and groundwater are from industrial production, including amorphous silica, carbon blacks and fullerenes, and titanium and zinc oxides.

Both geogenic and anthropogenic secondary nanoparticles may be formed in the atmosphere from gas-to-particle conversions such as oxidation. Secondary nanoparticles may also "grow" by coagulation and agglomeration to micrometer sizes. Table 1 contains a summary of primary nanoparticles produced by anthropogenic and geogenic sources and uses.

Detection and Analysis

Current chemical ("conventional") contaminants require an understanding of their physical properties (molecular mass, boiling and melting points, vapor and water density, water solubility, and volatility from water including Henry's constant, etc.), chemical characteristics (chemical formula, octanol water partition coefficient or K_{OW}, soil/water partition coefficient or K_{OC}, adsorption coefficient, etc.), and toxicity to determine transport, fate, and ecological and human health risk. Over the past three decades analytical methodologies for determining such parameters have been carefully developed and perfected using instruments such as atomic absorption spectroscopy (AAS), gas chromatography – mass spectrometry (GC-MS), inductively-coupled mass spectrometry (ICP-MS), etc., and also using parameter estimation methods.

An entire analytical industry of commercial environmental and University laboratories has evolved to conduct conventional contaminant analysis with many hundreds of thousands and even multi-million dollar investments in instrumentation. The detection and analysis of MNM will require an understanding of additional parameters and considerable investment by these laboratories in "newer" analytical equipment. Examples of some of the parameters required to characterize MNMs include:

1. *Surface area analysis* can be done using an epiphaniometer, whereby particles are exposed to radiation, passed through capillaries, and collected onto a filter for radiation level analysis. The detected radiation level is proportional to the surface area. Other methods include the Braunauer, Emmet, and Teller (BET) Method, which measures the amount of gas absorbed onto surface areas.
2. *Surface effects* in which properties like dispersibility, conductivity, catalytic behavior, and optical properties are determined because these will vary with different particle surface properties.
3. *Particle size distribution* by dynamic light scattering (DLS) or photon correlation spectroscopy (PCS). Nanoparticle sizes from <5 nm to 1,000 nm are analyzed in liquids.
4. *Zeta potential* is the function of a nanoparticle's surface charge; therefore, it is related to electrostatic repulsion. It gives no data on the nanoparticle's chemical composition, but is important for determining nanoparticle dispersion. Zeta potential can be measured by experiment.

Instrumentation that may be required for MNM analysis includes:

Continued on page 12

1. *Secondary ion mass spectroscopy (SIMS)*, which is a destructive method allowing analysis of 1 to 3 nm layers. The analysis provides elemental composition only.
2. *Atomic force microscopy (AFM)* can be applied in air or liquid media and utilizes the van der Waals forces between the microscopic tip of the AFM and the nanoparticle. Particle size and morphology are determined.
3. *Scanning electron microscopy (SEM)* and *transmission electron microscopy (TEM)*, including energy dispersive X-ray analysis (EDX), wavelength dispersive X-ray analysis (WDX), and electron energy loss spectroscopy (EELS) are used for determining nanoparticle size, morphology, and chemical composition.

Toxicity

The toxic effects to animal and human health by some MNMs are just now being investigated. For most MNMs, no toxicity data are available. Most current toxicological studies are for the hazards of inhaled nanoparticles produced by industry for several decades in amounts now exceeding many metric tons per year. These bulk-produced nanoparticles include colloidal silica, titanium dioxide, and various iron oxides. Toxicity data indicate that these substances, once considered as nuisance dusts, can, upon prolonged exposure to rats, cause inflammation and lung cancer. Acute effects in humans also come from combustion nanoparticles.

In the case of potential MNM toxicity from ingested water, C_{60} fullerene water suspensions have been observed as antibacterial agents, antioxidants, and protein stabilizers, whereas metallofullerenes were observed to accumulate in rat liv-

TABLE 1 – **Various Sources of Primary Geogenic and Anthropogenic Nanoparticles**

Nanoparticle Source	*Examples*	*Application/Main Use(s)*
Geogenic:		
Oceanic-derived aerosols	Sea salt (largely halite or NaCl)	Environmental exposure
	Sulfates and nitrates	
Volcanic aerosols	Sulfates (including H_2SO_4) and nitrates	
Forest fire aerosols	Carbon black (soot), PAHs	
Anthropogenic:		
Combustion aerosols	Diesel exhaust	Environmental exposure
	Fly ash	
Bulk synthetics	Amorphous silica (SiO_2)	Paints and fillers, dispersants and flowing agents, toothpaste, tires
	Carbon blacks	Pigments, tires (rubber), toners, inks
	Carbon fullerenes (C_{60})	Medical applications
	Carbon nanotubes	Composite fillers, electronics
	Ceria (cerium oxides)	Catalysts in cars, polishing
	Titanium dioxide (TiO_2) as Titania, anatase, rutile)	Cosmetics, pigments, paints UV-absorber, catalyst
	Zinc oxide (ZnO_2)	Polymer filters, UV-absorber
Engineered (MNM)	*Organic:*	
	Liposomes	Drug delivery
	Polycyanoacrylates	
	Polyethene	Implants
	Inorganic:	
	Gold, dendrimers	Drug delivery
	Quantum dots (cadmium, selenium, indium, gallium, and zinc composites)	Medical imaging
	Zeolites, silver	Antibacterial agents

References: modified from Borm (2004); Lucas and Akimoto (2007); Mädler (2007).

ers. Inorganic MNMs such as amorphous silicon dioxide (SiO_2) cause pulmonary inflammation in rats, and anatase (TiO_2) acts as an antibacterial agent also causing rodent pulmonary inflammation. Because many MNMs are smaller than cellular membrane pores, they may have considerable direct impact on animal tissues and DNA. The toxicity of harmful and even relatively nontoxic metals may also be increased upon sorption onto nanoparticles. Leaching of these metals into a cell may occur once such a metal-nanoparticle has penetrated the cell wall.

Transport and Fate

Very little is currently known about MNM's dispersal (transport and fate) in the environment and their impacts, particularly to soil, surface water, and groundwater. Also unknown is individual MNM transformation and degradation products and potential associated toxic impacts. MNM release sources are similar to conventional chemical contaminant release sources, including discharge and leakage from production and storage facilities (e.g. laboratories and factories), transportation (railcars, trucks, and ships, etc.), and applications and disposal of consumer products as waste (landfills and wastewater treatment plants). Environmental transport of some MNMs will result in transformation and diffusion by sunlight, water, and atmospheric oxygen, and dilution from precipitation, surface water runoff and groundwater. Some MNMs will agglomerate into larger particles; these agglomerates may have the potential for blocking porous materials, including wastewater treatment filters and even aquifer materials.

Many MNMs have greater environmental mobility than "ordinary" materials, perhaps resulting in greater exposure potentials because they could be dispersed over much larger distances. An interesting phenomenon is illustrated in multiwalled carbon nanotubes having 1.6 nm inner diameters. Measured velocities of water flowing through these nanotubes exceeded by more than three orders of magnitude those calculated by hydrodynamic models (Joseph and Aluru, 2008). Would pollutants entering or leaching from such nanotubes result in their moving faster than groundwater advection rates? As MNMs become more prevalent in commercial products, their adverse effect from manufacturing practices and possible improper disposal may become more widespread. For example, some MNMs have the potential for easily penetrating sand and commercial filters (>2 µm) used in both wastewater and potable-water treatment systems, and they also may easily penetrate natural porous and permeable media in aquifers and even aquitards (Wiesner and others, 2006).

Regulation

The processing, use and reuse, recycling, transport, and disposal for most MNMs are not currently regulated. However, many current federal regulatory programs probably will be expanded to cover MNMs, including: (1) Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); (2) Occupational Health and Safety Act; (3) Resources Conservation and Recovery Act (RCRA); and (4) the Toxic Substances Control Act (TSCA), the Comprehensive Environmental Response and Liability Act (CERCLA – also known as Superfund), and the Clean Water Act (CWA). Undoubtedly, these will provide some of the legal basis for the future regulation of MNM waste and discharge to the environment. However, many regulatory programs, particularly those on the state level, will have to be amended for MNMs. One example, reported by the U.S. EPA, is for silver ion generating washing machines. These are covered by FIFRA, because the nanosilver generated by such machines is considered a pesticide because it is released into laundry for the purpose of destroying microbial pests.

Remediation

Very little has been written concerning remediation of possible MNM environmental contamination. This is because we have not completely determined MNM toxicity and risks, do not have the required regulations governing proper disposal and cleanup of MNM wastes, and have not identified or characterized significant contaminant sites. Possible remediation for some MNM might include methods that would force agglomeration, precipitation, and adsorption onto some type of media.

Conclusions

MNMs and their potential impact to the environment and water resources are becoming a concern to regulatory agencies such as the U.S. EPA, and California EPA (DTSC). Concern is also growing among water treatment facilities and water districts about the potential of MNMs to affect the quality of both surface and underground drinking-water sources. Regulators, research scientists and engineers in academia and industry need to expand our knowledge of the characteristics, environmental effects, and potential toxicity of MNMs. In the next decade, consulting scientists, hydrogeologists, engineers, and analytical chemists (all of whom do the bulk of contaminant investigations) will be challenged to expand their knowledge of MNMs to protect our water resources.

William E. Motzer, Ph.D., PG, is a Senior Geochemist with Todd Engineers in Alameda, California. He may be reached for comment at bmotzer@toddengineers.com.

of professionals demonstrating technologies and expertise in the field of DNAPL source zone characterization and remediation. Symposium co-sponsors included Geomatrix Consultants, GeoSyntec Consultants, Malcolm Pirnie, RSI Drilling, and TerraTherm.

DNAPLs, or dense nonaqueous phase liquids, such as chlorinated solvents, PCB oils, coal tars, and creosote, are commonly encountered as groundwater contaminants throughout industrial areas of North America as a result of their use in industrial operations such as dry cleaning, metal degreasing, manufactured gas production, and wood preservation operations. Because DNAPLs are denser than water, they are able to migrate beneath the water table and will continue to move downward in unconsolidated or fractured media until either accumulating above a low permeability zone or becoming immobilized as residual along the migration pathway. This residual and accumulated DNAPL in the subsurface is typically termed the "source zone." Drinking water MCLs are generally orders of magnitude lower than DNAPL aqueous solubilities; as such, dissolved plumes associated with DNAPL source zones can cause pervasive and persistent contamination of drinking water aquifers. In 2005, the National Research Council estimated as many as 25,000 subsurface contaminant plumes attributable to DNAPL sources may exist nationwide.

Effectively and efficiently addressing DNAPL source zones involves difficult technical issues with respect to characterization and remediation; policy challenges with respect to performance metrics and exit strategies; and – indivisible from it all – significant life cycle costs. Participation in and feedback from the inaugural GRA *DNAPL Symposium* in December 2005 underscored the interest among groundwater researchers, consultants, and regulators in techniques and technologies for characterization, removal, and more effective management of DNAPL source zones. This follow-on Symposium continued the important dialogue between researchers, practitioners, and policy makers -- with a sense of optimism. In 2005, the discussion focused primarily on *facing the challenge*; in 2007, the discussion focused on efforts and success in *meeting* it!

Symposium Summary

The symposium opened with a **State of the Practice** keynote by ***Dr. Michael Kavanaugh*** of Malcolm Pirnie, which set the stage for the sessions to follow by reminding the audience of the evolution of the DNAPL remediation challenge from the early "denial" stage to use of diagnostic and decision-making tools that address performance metrics, and the regulatory and social demands that comprise today's framework. Looking to the future, Dr. Kavanaugh characterized the DNAPL challenge as a unique societal problem in which demands for complete restoration will continue to be at odds with technical limitations, and for which professionals must understand the importance of credible, independent communication of risk to all stakeholders.

Session 1: DNAPL Source Zone Characterization

The session recognizing the importance of source zone characterization to effective choice and implementation of remediation techniques, long term monitoring and management decisions, and efficient site cleanup and closure was kicked off by two invited speakers, ***Dr. Jason Gerhard*** of The University of Western Ontario and ***Seth Pitkin*** of Stone Environmental. Dr. Gerhard presented an overview of the *Evolution of Our Understanding of DNAPL Source Zones*, including migration, dissolution, and source zone architecture. He concluded that substantial progress has been made in understanding and modeling DNAPL source zones, but that complexity at real field sites remains a challenge presenting myriad avenues for further work. Mr. Pitkin's presentation, aptly titled *The DNAPL is in the Details*, focused on dynamic investigation strategies able to provide scale-appropriate source zone information in real time, including collaborative use of tools such as geophysics, passive soil gas, and direct-push techniques. He emphasized that understanding source area architecture and dissolved-phase plume core anatomy on a vertical scale of centimeters and horizontal scale of meters is essential for successful remediation.

Peter Bennett of Geomatrix Consultants, Inc. continued the discussion of innovative approaches to DNAPL characterization using case studies from three DNAPL release sites at which membrane interface probe (MIP) profiles and soil conductivity probe data were used to assess subsurface distribution of VOCs. Data collection using these high-resolution characterization techniques resulted in improved individual site conceptual models that were crucial to the development of efficient and cost-effective approaches to remediation at each site.

The third invited speaker in the session, ***Dr. Gary Wealthall*** of the British Geological Survey, discussed *Quantifying Uncertainty in DNAPL Source Zone Mass Estimates*. The presentation described management and communication of data uncertainty in the context of the UK Source Area BioREmediation (SABRE) study site. The multi-faceted SABRE study is incorporating a quantitative analysis of the impact of heterogeneity on estimating DNAPL mass by comparing a low density site characterization data set, representative of a "typical" site investigation, with a high density site characterization data set, representative of a research-level site investigation, to quantify the effects of data minimization on DNAPL mass uncertainty.

Dr. Walter Illman of the University of Iowa/University of Waterloo returned the discussion to characterization tools by introducing the audience to a new characterization approach that uses hydraulic and partitioning tracer tomography (HT/PTT) technology to achieve detailed imaging of the spatial distribution of DNAPL residual in the source zone. This approach has been demonstrated in modeling and experimental studies as a robust technology that can provide accurate characterization of subsurface heterogeneity in comparison to traditional geostatistical approaches, with less invasive sampling.

Dr. Mark Kram of the U.S. Navy described the use of the high-resolution piezocone (HRP) for determination of important hydrogeologic parameters, including hydraulic head, gradient, conductivity, effective porosity, and seepage velocity. This information was coupled with contaminant concentration data to develop a high-resolution, three-dimensional understanding of contaminant flux and groundwater flow, which is essential for proper remedial design, risk determination, and evaluation of remediation effectiveness. Dr. Kram compared the HRP approach to conventional methods for characterizing contaminant distribution, such as long- and short-screened wells; the data indicated savings both in terms of overall cost and time for field implementation.

Keynote: Sustainable Remediation

The evening keynote session stepped attendees back to a much broader remediation perspective with a joint presentation on *Sustainability and DNAPL Remediation Choices* by ***Paul Hadley*** of the California DTSC's Green Remediation Team and ***Dr. David Ellis*** of DuPont and the Sustainable Remediation Forum (SURF). Their presentation focused on understanding and incorporating sustainability into remediation decisions, and the changing thinking that comes from considering sustainability.

The DTSC's Green Remediation team is an initiative to promote the use of green technologies – those that are least disruptive to the environment, generate less waste, are recyclable, and emit fewer pollutants and greenhouse gases – in site remediation. Mr. Hadley presented examples of green technologies, such as energy efficient remediation systems, alternative energy sources to power remediation systems, and heavy equipment using bio-diesel and discussed the varying degrees of life cycle assessments that can be incorporated into our standard comparisons of remedial technologies.

SURF was established in 2006 as an open group of regulators, industry, academics, and public advocates whose mission is to establish a framework that incorporates sustainable concepts throughout the remedial action process, that provides long-term protection of human health and the environment, and that can achieve public and regulatory acceptance. Dr. Ellis discussed a number of measures to evaluate sustainability, including quantification of resource and energy use and emissions of global warming compounds such as carbon dioxide. He articulated a number of remediation sustainability challenges, including building sustainability into regulatory regimes, balancing efforts between source and plume cleanups, developing sustainability methods useful for big and small sites, and mitigation of the impact of non-degradation policies

Continued on page 16

DNAPL Source Zone Characterization and Remediation 2: Meeting the Challenge – Continued from Page 15

on groundwater remediation. He left attendees with the lesson – or challenge – that we not simply trade one set of contaminants for another as we choose and implement remediation efforts.

Session 2: DNAPL Site Remediation

Presentations during Day 2 of the Symposium focused on remediation technologies and metrics. Invited speaker ***Dr. David Major*** of Geosyntec introduced a DNAPL Technology Evaluation Screening Tool (DNAPL TEST) being developed under the Environmental Security Technology Certification Program (ESTCP) and discussed its development path to date. The tool allows users to evaluate specific remediation technologies based on their performance at similar sites using numerical simulation and case study results for a variety of environmental conditions. A Beta version of the tool is scheduled for release in the near future.

Session 2 continued with presentations on specific remediation technologies applied to DNAPL sites. ***Catherine Miceli*** of VeruTEK discussed a modification to traditional *in situ* chemical oxidation (ISCO) technology by adding surfactants designed to solubilize immiscible phase liquids (S-ISCO®). The patent-pending formula of biodegradable, food-grade cosolvents and surfactants was effective at removing coal tar in a recent field trial. A case study demonstrating hydraulic displacement of DNAPL was presented by ***Danielle Ondic*** of Hargis + Associates. The pilot test involved simultaneous pumping of groundwater and DNAPL from extraction wells at varying extraction rates to evaluate the relationship between hydraulic gradient and DNAPL recovery. Over 450 gallons of DNAPL were recovered during the test and groundwater was re-injected after solid filtration.

The final set of presentations in the session focused on *in situ* thermal treatment technologies for DNAPL site remediation. Invited speaker ***Dr. Gorm Heron*** of TerraTherm discussed *Mobilization of DNAPL During Subsurface Heating*, addressing the common question: What happens to DNAPL (pooled and residual) as it is heated? TerraTherm personnel are participating in a SERDP-funded research project examining this question through 2-D and 3-D controlled-release experiments and accompanying numerical models. Dr. Heron concluded that subsurface heating can mobilize DNAPL, but that appropriate design can prevent spreading and unwanted mobilization.

Greg Smith of Thermal Remediation Services discussed recovery and destruction mechanisms that contribute to the success of electrical resistance heating (ERH) in DNAPL remediation applications, including hydrolysis, biodegradation, and gas bubble flotation. ERH has been applied at over 75 sites to date, including sites contaminated with chlorinated and coal tar DNAPLs.

Dr. David Cacciatore of Shaw Environmental & Infrastructure presented a case study where ERH was implemented for DNAPL source removal within the cores of three separate plumes at the former Alameda Naval Air Station. The primary contaminants of concern in each case were trichloroethane, dichloroethene, and dichloroethane. In two areas, driven sheet-pile electrode members were used to create hexagonal heating cells, and vapor extraction wells were installed within and around the plume for VOC vapor recovery; in the third area, combined electrode/vapor recovery wells were installed using a hollow stem auger. Average groundwater concentrations in the two areas at which ERH is complete were reduced from 54,000 micrograms per liter (µg/L) to less than 100 µg/L and from over 400,000 µg/L to less than 1,400 µg/L, respectively.

Session 3: Complex Sites

This session addressed sites that present some of our biggest remediation challenges, including those impacted by viscous DNAPLs such as coal tars, those underlain by fractured rock, and those where DNAPL has migrated to significant depths. To start the session, invited speaker ***Dr. Andrew Coleman*** of the Electric Power Research Institute (EPRI) presented a *Best Practices Manual for Managing and Investigating Coal Tar DNAPL in Bedrock*. The manual is being published by EPRI in collaboration with its members and Queen's University as a tool for manufactured gas plant (MGP) site managers faced with characterizing bedrock aquifers impacted by MGP DNAPLs such as coal tar. Dr. Coleman presented a tiered framework for characterizing fracture flow and DNAPL migration potential in impacted bedrock aquifers.

Next, ***John LaChance*** of TerraTherm discussed the *Use of Thermal Conduction Heating for the Remediation of DNAPL in Fractured Bedrock*. He presented a case study where TCH was applied to remove TCE DNAPL and the sorbed, dissolved, and vapor phases from a source zone that extended 90 feet below ground surface. The upper 75 feet of the treated zone, which consisted of saprolite and weathered bedrock, was the primary target of the remedial effort. However, in order to minimize the threat of downward mobilization of DNAPL into the fractured gneiss, the heated/treatment interval extended 15 feet into the underlying fractured gneiss to create a "hot floor" within the upper portion of the competent bedrock. Data from this work was presented showing the thorough and rapid heat-up of the bedrock by TCH.

Dr. Mary DeFlaun of Geosyntec Consultants presented a *Pilot-Scale Demonstration of Bioaugmentation for TCE DNAPL Remediation in Fractured Rock*. The retention of bacteria in fractured bedrock can be a challenge for bioaugmentation, especially when dealing with DNAPL in bedrock. In this demonstration, DNAPL in fractured bedrock was treated with a combination of KB-1® bacteria and a hydrophobic emulsified oil substrate intended to act as an electron donor and help retain bacteria at the surface of the fractures. Monitoring results suggest that the oil/bacteria coating on the fractures is preventing diffusion of TCE from the sandstone/shale bedrock into groundwater by degrading TCE at the rock/water interface.

Dr. Rula Deeb of Malcolm Pirnie described a fractured shale site where sodium permanganate was used to reduce the mass flux of PCE and its daughter products leaving the site. In advance of the remedy selection, detailed site characterization was performed, including installation and sampling of four multilevel monitoring systems, fracture network characterization via borehole geophysical and hydrophysical logging and inter-borehole flow testing, rock coring, VOC sub-sampling, and rock matrix characterization. Detailed rock core sampling showed high PCE concentrations adjacent to many fractures where contaminant mass, originally present as DNAPL, was now present as dissolved and sorbed mass in the rock matrix. Dr. Deeb discussed selection of performance metrics for, and lessons learned to date from, the full-scale ISCO application at this complex site.

Session 4: Long Term Site Considerations

The final session addressed long-term considerations for DNAPL sites. ***Dr. Suresh Rao*** of Purdue University began the session with an overview titled *Site Remediation Design and Performance Assessment Based on Contaminant Mass Discharge*. Dr. Rao presented several DNAPL case studies in which mass discharge measurements and modeling provided information about whether to target remediation efforts on source mass, the downgradient plume, or both. Dr. Rao also presented the results of mass discharge measurements using three methods: the Integral Pumping Test, the Passive Flux Meter™ and the Transect Method (which uses average groundwater fluxes and contaminant concentrations). Mass discharge estimates using the three methods were in agreement.

Next, ***Dr. Eric Suchomel*** of Geosyntec Consultants presented his graduate research work assessing the impacts on contaminant mass discharge of partial PCE DNAPL mass removal using surfactant flushing. Using 2-D aquifer cell experiments, he observed 70 to 90 percent reductions in effluent PCE concentrations and mass flux following surfactant treatment. Dr. Suchomel concluded that the relationship between mass removal and mass discharge depended on the initial DNAPL ganglia-to-pool ratio.

The final presentation of the session, by ***Scott Warner*** of Geomatrix Consultants, returned to *The Connection Between DNAPL Remediation and Sustainability*. Mr. Warner emphasized the importance of clarifying DNAPL remediation objectives early in the process, and using focused site characterization to develop remedial technologies and approaches specific and optimal to each site. He noted that sustainable remediation approaches for DNAPL sites must balance economy, technology, resource protection, and resource use, but optimistically concluded that sustainable and effective solutions *do* exist.

This final discussion of metrics for success in the selection and implementation of DNAPL remediation strategies provided a fitting summation for the two-day symposium, reminding us all of the ongoing challenges facing DNAPL practitioners and of the importance of maintaining an open and constructive dialogue among stakeholders.

A binder with copies of speakers' slides and a list of references on various aspects of DNAPLs may be requested via www.grac.org or GRA's main offices, (916) 446-3626.

***Dr. Bettina Longino** is a Senior Consultant with Geomatrix Consultants, Inc., based in Ontario, Canada. She was a co-chair of both the GRA DNAPL 1 and 2 Symposia and has an extensive background in subsurface fate and transport of DNAPL and dissolved-phase constituents.*

- ***Groundwater Challenges:*** water quantity and quality issues, national groundwater availability, emerging contaminants, water issues in the west, sustainable groundwater management strategies, climate change
- ***Surface Water/Groundwater Interactions:*** conjunctive management, ecosystem considerations, groundwater banking and transfers, groundwater quality influenced by natural and artificial recharge, surface water/groundwater modeling
- ***Groundwater Storage:*** challenges/benefits and reducing risks/uncertainties, enhancing water supply availability
- ***Watershed Water Quality Management:*** salt balance methods, salinity management, water and agricultural-chemical transport
- ***Delta Issues:*** shift in pressure to groundwater basins; ecologic issues; legislation
- ***Collegiate Groundwater Colloquium:*** GRA seeks to increase participation by university and college faculty and students in its programming. This new Colloquium will provide an opportunity for students to showcase their research and its application to groundwater challenges in California or elsewhere in the world. Please e-mail Jean Moran, GRA Education Committee Chair, at moran10@llnl.gov for more information.
- ***Recycled Water for Recharge:*** evolution of recycled water regulations, monitoring wastewater constituents through Soil Aquifer Treatment and Direct Injection (e.g., pharmaceuticals, PCPs, TOC, BDOC, other indicators and surrogates) assessing potential risk to receptors, etc.
- ***Coastal Groundwater Supply and Quality Issues:*** seawater intrusion; coastal groundwater discharge; brine water discharge estuarine environments; assessing supplies and optimizing groundwater management approaches in coastal environments
- ***Groundwater Protection and Remediation Success Stories:*** examples of groundwater cleanup success stories, wellhead treatment, desalination, contaminant containment and removal technologies
- ***Demonstrating Groundwater Supply Sufficiency and/or Reliability:*** deciphering SB 610/221/UWMPs/IRWMPs
- ***Emerging Technologies on the Horizon***

Luncheon Keynote: On September 25, Robert Glennon, Morris K. Udall Professor of Law & Public Policy at the University of Arizona and author of the book "Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters" (Island Press, 2002), will provide a compelling talk titled "Tales of Bottled Water and French Fries: The Environmental Consequences of Groundwater Pumping." You'll hear a striking collection of stories that bring home the actual and potential consequences of our growing national thirst.

Field Trip: An optional field trip on September 24 includes a tour of the world's largest indirect potable reuse facility, Orange County Water District's new Groundwater Replenishment System, as well as OCWD's artificial recharge facilities in Anaheim.

Short Course: The one-day course, *Introduction to Practical Statistics*, is being offered on September 24 and instructed by Dennis Helsel, Ph.D. Dr. Helsel is the lead author of the popular textbook "Statistical Methods in Water Resources" (USGS, 2002) and of "Nondetects And Data Analysis" (Wiley, 2005) as well as many technical articles.

The short course will emphasize basic principles of data analysis, including when to transform data and why, how to handle outliers, what hypothesis tests are good for, and how to build a good regression equation. Advantages of newer nonparametric and permutation tests for scientific applications will be highlighted. Common pitfalls of traditional methods will be discussed. Attending this course will clear up misconceptions, point to further resources, and get you heading in the right direction.

Call for Abstracts Deadline May 1, 2008: Abstracts are invited for oral or poster presentations relevant to the session topics highlighted above. The Call for Abstracts, and samples of Oral and Poster Abstract formats are located at http://www.grac.org/abstracts.html.

Cooperating Organizations: California Groundwater Association, International Association of Hydrogeologists, Water Education Foundation, Sustainability of semi-Arid Hydrology and Riparian Areas

Sponsors and Exhibitors: GRA is pleased to invite participants to sponsor Conference functions or to exhibit at the Conference, including during the President's Reception. Please contact Mary

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Remediation Technology Symposium

MAY 14-15, 2008 – 8:30-5:30
BYRON SHER AUDITORIUM, 1001 I STREET, SACRAMENTO, CA
PROPOSED OPTIONAL FIELD DAY MAY 16TH, LOCATION TBA – 9:00-3:00

Sponsored by: Department of Toxic Substances Control, Cal/EPA
Co-Sponsored by: United States Environmental Protection Agency
In Cooperation with: Groundwater Resources Association of California

***Symposium Description:** The California Department of Toxic Substances Control (DTSC) invites you to the Remediation Technology Symposium – 2008.*

This multi-day symposium will present current technology used in site characterization and remediation. The target audience is DTSC cleanup staff, other state and local agency staff, cleanup consultants, interested Brownfields developers, and community members impacted by contaminated sites.

This symposium is free and open to the public. It will be offered live in Sacramento and by webcast. It will be available later on DTSC's webpage and on DVD. Registration is required for on-site attendance, and space is limited to 250 persons. Webcast attendees are encouraged to register as well to receive notification of future symposia and information updates. May 16, 2008 is proposed as a day of field demonstration of equipment and technologies. It will not be webcast and will be limited to the first 200 persons that register.

Check the DTSC's Web page: www.dtsc.ca.gov and search for Remediation Technology Symposium on the home page for updates to the agenda, details on the registration, and information about the webcast.

If you have a special accommodation or language need, please contact DTSC by e-mail at RemSymp@dtsc.ca.gov at least 30 days before the symposium.

Symposium Presenters and Topics:

- Murray Einarson, Geomatrix Consultants - Site Characterization and Monitoring in the New Millennium
- Brad Call, Army Corps of Engineers, Sacramento - The Triad Approach for Investigation and Remediation
- Eliott Cooper, Vironex - Membrane Interface Probe (MIP) for Remedial Design Data
- Randy St. Germain, Dakota Technologies - New Generation Optical Sensors for Characterizing NAPL Source Zones
- Michael Kavanaugh, Malcolm Pirnie, Inc. - Decision Making for Source Remediation
- Paul Johnson, Arizona State University - Air Technologies for Subsurface Remediation
- Lisa Alvarez-Cohen, University of California, Berkeley - In Situ Bioremediation: An Overview and Recent Research
- Doug Mackay, University of California, Davis - Natural and Enhanced Remedial Strategies
- Kent Sorenson, CDM - In Situ Bioremediation for Source Remediation of Volatile Organic Compounds

Continued on page 21

President's Message – Continued from Page 2

Consistent with our mission, dedication to resource management that protects and improves groundwater through education and technical leadership, GRA has become a leading source of technical education to a wide range of stakeholders on all aspects of groundwater in California. Our Events Committee, presently co-chaired by Eric Reichard of the USGS and Ted Johnson of the Water Replenishment District of Southern California, and supported by numerous energetic event chairs and committee members, has held successful symposiums and workshops. As a vibrant organization, our value to our members stems from our Directors, Committee Chairs, and individual event chairs and committees. I strongly encourage all of you to engage in future events by identifying topics of interest, serving as the champion, or joining a committee to help make every event a huge success. I learned some time ago that participating in, rather than simply being a member of, a professional organization like GRA will enhance your own professional development and provide that rewarding feeling that you gave something to your profession. For those of you in supervisory positions, I strongly encourage you to motivate and guide your staff to volunteer their time and energy and experience the professional and personal benefits. To learn more about GRA, please regularly visit our website (*www.grac.org*). I wish you all a successful 2008.

Wells and Words – Continued from Page 5

correlation using a power trendline of the form y = Cx^{-m} between the estimated SC and the depth of the well below ground surface. The median value for the data set is 0.108 gallons per minute per foot of drawdown (gpm/ft of dd). The median SC corresponds to a reliable and long-term well yield of about 5.4 gpm utilizing 50 feet of drawdown (50 feet x 0.108 gpm/ft of dd).

The median SC for wells exceeding 300 feet is 0.018 gpm/ft of dd (0.9 gpm), while those drilled below 600 feet have a lower median SC of 0.004 gpm/ft of dd (0.2 gpm). This data set shows that 151 wells (18%) with depths >300 feet and nine wells (1%) with depths >600 feet have a SC >0.01 gpm/ft of dd or estimated yield of >0.5 gpm. This analysis ignores wells that were deemed "dry" by the contractors.

In summary, wells drilled deeper than 300 feet in fractured rock aquifers will yield insignificant amounts of additional groundwater. Reliable and realistic increased well yields in fractured rock aquifers at depths greater than 600 feet typically range from <1 to 2 gpm. Well yields >25 gpm in fractured rock aquifers are the exception rather than the rule.

1. On September 24, 2008 Dennis R. Helsel, Ph.D. (currently with the USGS, contributor to this website, and coauthor (with R.M. Hirsch) of **Statistical Methods in Water Resources**) will be presenting *Introduction to Statistical Methods in Water Resources* in association with the 2008 GRA Annual Meeting in Costa Mesa, California. GRA is pleased that Dr. Helsel can offer this follow-up course to *Applied Environmental Statistics* offered by GRA in May 1994.

Call for Abstracts – Continued from Page 18

Megarry at mmegarry@nossaman.com or 916-446-3626 for more information; for Sponsorship & Exhibitor Opportunities see http://www.grac.org/se.pdf

Please reserve the Conference dates and join us to hear the latest scientific, management, legal, and policy advances for sustaining our groundwater resources. For more information, contact Kathy Snelson at (916) 446-3626 or executive_director@grac.org.

CGA Celebrates 60th Anniversary

– Continued from Page 7

- Further relationships with other water organizations

National Groundwater Awareness Week

Every week should be groundwater awareness week as we talk to clients and friends about the valuable water resource beneath them. But just in case you want a bit more emphasis, tell them that March 9-15 is National Groundwater Awareness Week in 2008. You can find a wide variety of activities at the NGWA websites – www.ngwa.org, www.groundwateradventurers.org and at www.wellowner.org. CGA participates on NGWA's Public Awareness Committee which developed a PR Tool Kit you may find useful.

After doing some March activities, why not plan some more activities during Water Awareness Month in California in May. Check out the California Water Awareness Campaign's web site at www.wateraware.org for info. on educational materials about groundwater and other public awareness projects. This year, the CWAC is planning a new "Nice Save" campaign that will focus on thanking folks for conserving water. In a year with lots of discussion on water issues, getting notice of groundwater's value to all Californians would be a good thing to do!

CGA & GRA Members To Head To Washington DC

CGA and GRA members will again participate in the NGWA Fly-In in Washington DC in late February. Past efforts have paid benefits for groundwater industry members, including funding for household wells, support for groundwater sustainability programs, training for well inspectors, and tax credits. This year's Fly-In, scheduled for February 25-26, will again focus on geothermal tax credits (we're seeing more GSHP emphasis in CA), LUST funding, groundwater investigations and the SECURE water act. There will also be an info. session on emerging air quality issues which may have a significant impact on the CA groundwater industry. CGA is working with other groups on the current and pending CARB regulations.

Mike Mortensson, CGA Executive Director

GRA Requests Nominations for the 2008 "Lifetime Achievement" and "Kevin Neese Awards"

— Continued from Page 7

state of our groundwater resources, with which reasonable and sensible groundwater management may be developed

2004 – California Department of Water Resources for publication in 2003 of its updated Bulletin 118: "California's Groundwater"

2002 – Glenn County Water Advisory Committee for formulating a significant groundwater management ordinance that was adopted by the Glenn County Board of Supervisors

2001 – American River Basin Cooperating Agencies and Sacramento Groundwater Authority Partnership for fostering the understanding and development of a cooperative approach to regional planning, protection and management of groundwater

2000 – Board of Directors of the Chino Basin Watermaster for delivering a remarkable OBMP that created a consensus-based approach for making water supplies in the Chino Basin more reliable and cost effective

1999 – Governor Gray Davis for his work and leadership in addressing MTBE

Remediation Technology Symposium

— Continued from Page 19

- Evan Cox, Geosyntec Consultants - Combined Remedies for Chlorinated Solvent and Perchlorate Sites
- Wilson Clayton, Aquifer Solutions - In Situ Chemical Oxidation
- Mike Basel, Haley & Aldrich - Thermal Treatment

Please monitor the DTSC web site for the final agenda and speaker biographies.

Save the Date

"APPLICATIONS OF OPTIMIZATION TECHNIQUES TO GROUNDWATER PROJECTS"

SACRAMENTO, CALIFORNIA

OCTOBER 15 - 16, 2008

This day-and-a-half symposium will focus on the uses of operations research (optimization) techniques in addressing groundwater projects. The purposes of the conference are to: Provide the background information necessary for attendees to understand the mechanics of, and unique benefits derived from, performing optimization analyses, and Demonstrate a range of successful optimization applications so attendees will be able to recognize when the application of optimization techniques could be beneficial to their projects.

The conference will consist of 1) an optional afternoon class that presents the basics of groundwater optimization techniques and 2) a one-day, single-track set of presentations that may include:

Remediation:
- Plume Capture
- Concentration Management
- Seawater Intrusion Management and Mitigation

Water Resources:
- Wellfield Management
- Conjunctive Use Planning
- Water Supply Sufficiency and Reliability Analysis
- Groundwater Management for Quantity and Quality
- Integrated Regional Water Resources Management Planning

Economics:
- Conjunctive Use Management
- Water Banking
- Water Transfer Valuation

Litigation:
- Damage Assessment
- Adjudication
- Groundwater Pumping v. Water Rights and Other Third Party Effects

Please contact Rob Gailey with questions or comments (415-407-8407, rob@rmgailey.com).

Prospects for Managed Underground Storage of Recoverable Water

BY WILLIAM S. LOGAN AND ANNE JURKOWSKI

Growing demands for water in many parts of the nation are fueling the search for new approaches to sustainable water management, including how best to store water. Society has historically relied on dams and reservoirs, but problems such as high evaporation rates and a lack of suitable land for dam construction are driving interest in the prospect of storing water underground. Managed underground storage should be considered a valuable tool in a water manager's portfolio, although it poses its own unique challenges that need to be addressed through research and regulatory measures.

People are moving to Las Vegas at a rate of several thousand per week, a phenomenon also observed in California, Arizona, and elsewhere. Today, when these newcomers turn on the taps in their new homes, water comes out—one day, it might not. Periodic droughts, changing land use, rising temperatures, overallocation of rivers, overdrafting of aquifers (underground water reserves), water quality changes, and environmental problems, combined with rapidly increasing populations, have heightened awareness of the pressing need to find sustainable, long-term water management solutions. Water problems are not confined to the western U.S.; eastern states are also feeling the crunch. There is little doubt that the future will bring increasing stresses on water supplies across the nation—as well as increasing burdens on water managers to keep meeting demands.

A reclaimed water recharge well in Phoenix, AZ. SOURCE: Andy Terrey, City of Phoenix.

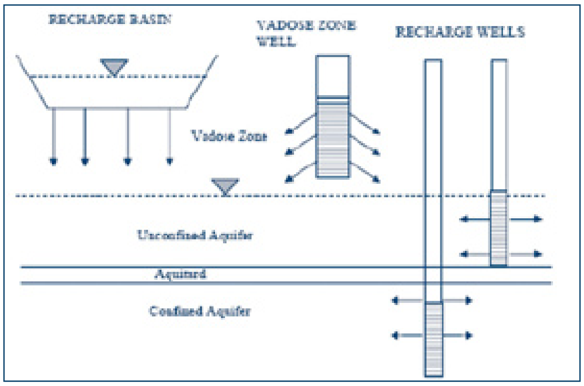
Several strategies have been proposed to address the need for sustainable water solutions by reducing water use, increasing water supplies, and reusing treated wastewater. In addition to such strategies, however, there will likely always be a need for temporarily storing water during times of abundance for later release during times of need. Historically, dams and reservoirs have been used for this purpose. But a number of factors—including high evaporation rates, environmental costs, and the decreasing availability of land for dam construction—have increasingly made building additional dams impractical. These factors have led to an increased interest in prospects for storing water underground as part of a long-term water management approach.

The National Research Council convened a committee to evaluate past experiences with managed underground storage of recoverable water and to identify the research priorities for development of future underground storage projects. This report, resulting from the committee's activities, assesses the factors affecting the performance of such projects and recommends ways to implement and regulate managed underground storage systems.

What is Managed Underground Storage?

The concept of "managed underground storage of recoverable water," here shortened to managed underground storage, encompasses a number of approaches that purposefully add water into (recharge) an aquifer system for later recovery and use. In general, managed underground storage involves the following elements:

1. ***Water is captured from a source.*** These sources can include surface water, groundwater, treated effluent, and stormwater.
2. ***Water is recharged into an aquifer.*** Aquifers are recharged through use of recharge basins, vadose zone wells (wells above the water table), or direct recharge wells (see figure).
3. ***Water is stored.*** The water is stored in a wide spectrum of confined and unconfined aquifer types, from unconsolidated sands and gravels to limestones and fractured volcanic rocks.
4. ***Water is recovered for use.*** Recovery is typically achieved through extraction wells or dual-purpose recharge and recovery wells, but occasionally is achieved via natural discharge of the water to surface-water bodies.
5. ***Water is used.*** Recovered water is used for drinking water, irrigation, industrial cooling, and other purposes.



Methods for aquifer recharge.

Evaluation of Managed Underground Storage: Future Prospects

Some simple forms of managed underground storage have been used for millennia; the most recent developments were implemented about four decades ago. Adequate experience exists, therefore, for evaluating the overall success rate of managed underground storage systems and for identifying the challenges faced by these systems.

The report concludes that managed underground storage has a generally successful track record in a variety of environments. Given the growing magnitude and complexity of the nation's water management challenges, managed underground storage should be seriously considered as one means to satisfy the demand for water and cope with water scarcity.

Challenges and Research Needs

There is no simple solution to the nation's growing water problems. Although managed underground storage is generally successful in achieving its goals, it also poses its own set of challenges, which need to be addressed through careful planning and research. These challenges include generally high costs to design, construct, and monitor underground storage systems; loss of some percentage of the water; chemical reactions with aquifer materials; ownership issues; and environmental impacts.

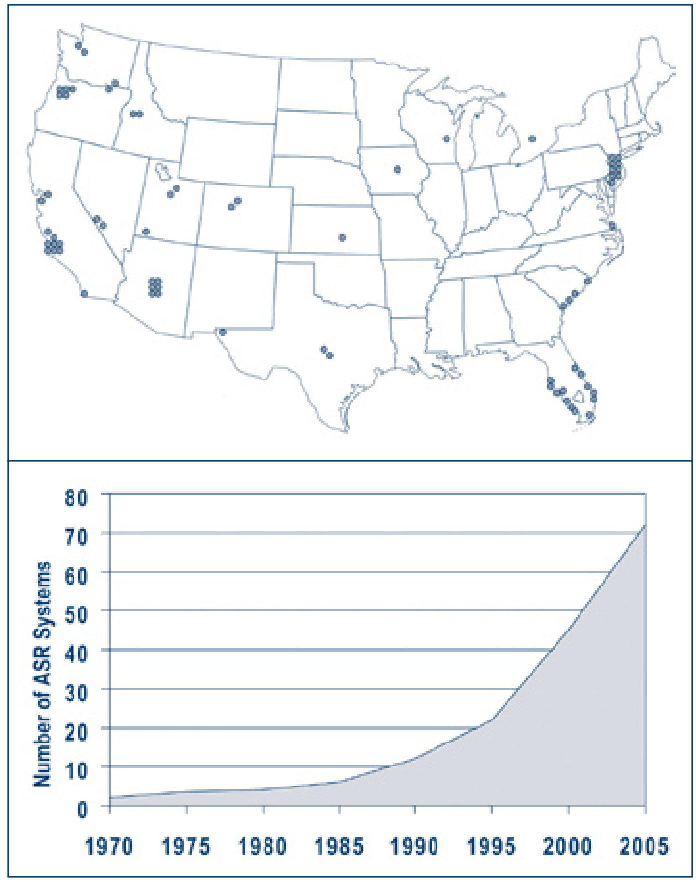
The development of a managed underground storage system from project conception to a mature, well functioning system is a complex, multistage operation requiring interdisciplinary knowledge of many aspects of science, technology, and institutional issues. Water managers should consider these projects in a watershed and regionally-based context and as part of an overall water management strategy. Professionals from many fields, including chemists, geologists, hydrologists, microbiologists, engineers, economists, planners, and other social scientists should be involved in analysis of the options in managed underground storage projects. The report recommends that water agencies create an independent advisory panel at an early stage to provide objective, third-party guidance regarding design, operation, maintenance, and monitoring strategies for these projects.

Some of the primary challenges to be considered at all stages of a managed underground storage system are described below.

Hydrogeological Issues

A first step in planning a managed underground storage project is identifying favorable locations. Some types of aquifers have hydrogeologic characteristics that are better suited for managed underground storage than others; aquifers with several different kinds of pore space such as fractured sandstone appear to present the greatest difficulties. The report recommends that water managers considering underground storage incorporate 3-D capable geographic information systems to map and analyze major aquifers as part of comprehensive, regional planning efforts.

Also in the planning process, monitoring and modeling should be used to predict likely effects—positive or negative—of managed underground storage systems on the surrounding physical system at various scales. Managed underground storage systems can have long-term impacts on both native groundwater and surface water. Appropriate measures can, and should, be taken in the design and implementation of these systems to minimize negative effects.



Distribution of aquifer storage and recovery systems, 2005 and growth of aquifer storage and recovery systems in the U.S., 1968-2005. Adapted from David Pyne, copyright 2005.

To enhance the ability to predict and assess the success and effects of a managed underground storage system, the report recommends further research on various aspects of the hydrologic feasibility of managed underground storage projects, the impacts of these projects on surface water, and the hydrogeologic properties of underground aquifers.

Water Quality Issues

Preserving water quality is of utmost importance in any water management system. Managed underground water storage has both positive and negative effects on water quality. In some cases, recharging aquifers may improve the source water quality, because the subsurface has the ability to naturally decrease many chemical constituents and pathogens through physical, chemical, and biological processes. Recharging water can also displace saline groundwater and locally improve the quality of the groundwater. However, storing water underground can also increase the risk of contamination, depending on factors such as the source water used for recharge, the chemicals used to treat the water prior to storage, and the geochemistry of the aquifer matrix and mixed water.

Continued on page 24

The type of source water used for recharge influences the quality of the native groundwater. Urban stormwater, for example, is highly variable in quality; for this reason, caution is needed in determining whether stormwater is of acceptable quality for recharge. Additional research should be conducted to evaluate the chemical and microbial constituents in urban stormwater and their behavior during infiltration and subsurface storage. In general, there is a need for better understanding of the potential contaminants in the various sources of recharge water.

Pathogen removal or disinfection is often required prior to storing water underground. If primary disinfection is achieved via chlorination, disinfection by-products (DBPs) such as trihalomethanes and haloacetic acids may be formed. These have been observed to persist in some managed underground systems. To minimize the formation of DBPs, alternatives to chlorination, such as ultraviolet light, ozone, or membrane filtration, should be considered. However, chlorine is generally considered the most cost effective agent for control of biofouling in recharge wells; hence, it may not be possible to entirely eliminate the use of chlorine in these systems.

Successful managed underground storage requires thorough chemical and microbiological monitoring. A proactive monitoring plan is needed in order to respond to emerging contaminants and to increase knowledge about potential risks. There is a need for a better understanding of the potential removal processes for chemical and microbial contaminants in different types of aquifer systems. Research on new surrogates or indicators for chemical and microbial contaminants will help document the performance and reliability of managed underground storage systems.

Economic and Policy Considerations

Planning and implementing managed underground storage projects raises new questions for states, counties, and water authorities. This new approach has its own set of economic impacts and will likely require adjustments to traditional water rights allocation schemes.

Economic Aspects

Managed underground storage has numerous economic benefits, but it also entails costs. An economic analysis of a project should capture its multiple benefits and costs. These projects invariably entail the achievement of multiple objectives; for this reason, the report emphasizes that third party impacts, such as the environmental consequences, should be included in the overall economic analysis of a project. Failure to account for all benefits and costs, including ones that may not be reflected in market prices for water, can lead to underinvestment in groundwater recharge, overconsumption of water supplies, or both.

Water resource development has historically been characterized by substantial federal and state subsidies; as water shortages intensify, the political pressure for investment in new technologies will increase. In order to ensure that there is optimal investment in managed underground storage and other technologies, subsidies should only be provided when there are values that cannot be fully reflected in the price of recovered waters—for example, an environmental benefit that accrues to the public at large.

Regulatory Frameworks

Regulatory frameworks play a key role in ensuring the safety, reliability, and quality of water storage systems. There is, however, inconsistency in the federal regulatory requirements for managed underground storage. Federal Underground Injection Control regulation, for example, only addresses projects that recharge or dispose of water directly to the subsurface through recharge wells, while projects that infiltrate water through recharge basins are regulated by state standards that may vary by state. Also, there are incompatibilities between the Clean Water Act and the Safe Drinking Water Act that impact managed underground storage systems. For example, some jurisdictions try to control surface water contamination problems by diverting polluted water from above ground to groundwater systems. This approach may undermine managed underground storage programs by putting contaminants underground without appropriate controls.

Federal and state regulatory programs should be examined with respect to the need for continued federal involvement in regulation, the need for a federal baseline for regulation, and the risks presented by inadequate state regulation. The report recommends that a model state code be drafted to assist states in developing regulatory programs for managed underground storage systems. At a minimum, states should help in defining property rights for water before, during, and after it is stored underground.

Science-based criteria should be developed to help determine adequate subsurface residence time or travel distance of recharged water before withdrawal for later use. These criteria should take into account site variables such as aquifer type, geochemical conditions, and source water quality, and need to be adequate for both pathogens and chemical contaminants. Finally, they should consider the time needed to detect and respond to any water-quality problems that may arise.

States should review their water laws and regulations and create a regulatory structure specifically tailored for the unique characteristics of managed underground storage projects. Moreover, state laws and regulations should provide regulatory agencies with discretion to weigh the overall benefits of managed underground storage while resolutely protecting groundwater quality. For any managed underground storage project—including storage of potable water, stormwater, and recycled water—it is important to understand how water quality differences between native groundwater and the stored water will be viewed by regulators.

In addition to water quality factors, a broader consideration of benefits, costs, and risks would provide a more desirable regulatory approach. Therefore, weighing water quality considerations together with water supply concerns, conservation, and public health and safety needs is essential.

William S.Logan is Senior Program Officer, Water Science and Technology Board, National Research Council of the National Academies; Anne Jurkowski is Communications Officer, Division on Earth & Life Studies, National Research Council of the National Academies.

Committee on Sustainable Underground Storage of Recoverable Water: Edward J. Bouwer *(Chair)*, Johns Hopkins University; **Richelle M. Allen-King**, State University of New York at Buffalo; **Jonathan D. Arthur**, Florida Geological Survey; **William A. Blomquist**, Indiana University Purdue University; **James Crook**, Independent Consultant; **Denise D. Fort**, University of New Mexico; **Peter Fox**, Arizona State University; **Jorge I. Restrepo**, Florida Atlantic University; **Joan B. Rose**, Michigan State University; **Zhuping Sheng**, Texas A&M; **Catherine J. Shrier**, Golder Associates; **Henry J. Vaux, Jr.**, University of California at Berkeley; **Michael Wehner**, Orange County Water District; **William S. Logan** *(Study Director)* and **Ellen A. De Guzman** *(Research Associate)*, National Research Council.

The National Academies – through its National Research Council – conducts a unique public service by working outside the framework of government to ensure independent expert advice on matters of science, technology, and medicine. This report brief was prepared by the National Research Council based on the committee's report. For more information or copies, contact the Water Science and Technology Board at (202) 334-3422 or visit http://nationalacademies.org/wstb. Copies of *Prospects for Managed Underground Storage of Recoverable Water* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu. Support for this study was provided by the American Water Works Association Research Foundation, WateReuse Foundation, U.S. Geological Survey, The CALFED Bay-Delta Program and the California Department of Water Resources Conjunctive Water Management Branch, Water Replenishment District of Southern California, City of Phoenix, Inland Empire Utilities Agency, Sanitation Districts of Los Angeles County, Chino Basin Watermaster, and the NRC President's Committee of the National Academies.

Sacramento Branch Highlights

BY JOHN W. AYRES, BRANCH SECRETARY, AND STEVE LOFHOLM, BRANCH VICE PRESIDENT

The October meeting featured Bob Niblack, DWR, who presented the Sacramento Valley Water Management Program. The SVWMP proposes to operate 23 conjunctive use projects in coordination with California's major water supply projects. The resulting coordinated water management operation is focused on maintaining water quality in the Delta, which requires fresh water inflow to mitigate the effects of saline water encroachment. DWR, USBR, water users in the Sacramento Valley, and export water users south of the Delta, developed an agreement that was accepted by the SWRCB. The Sacramento Valley parties will provide their share of water to meet Delta water quality standards by substituting groundwater for diversions, thereby providing up to 174,400 acre-feet of "project capacity" in certain water year types.

In November, Senior Engr. Geologist Chris Bonds of DWR described some fascinating findings from a deep exploratory test hole drilled in June 2004 adjacent to the Yuba River east of Marysville. The test hole penetrated the Riverbank, Laguna, Mehrten, Neroly, Upper Princeton Valley Fill, Ione, and Capay Formations, and yielded 140 fair to excellently preserved fossil specimens from 760 to 810 feet bgs. Fossils recovered include gastropods, scaphopods, bivalves, corals, and one shark tooth. These fossils have yielded new information on the fauna, age, and depositional environment of the Capay Formation, indicating that it was deposited between 46 and 50 million years ago, and (locally) was deposited on a tropical shallow-marine shelf environment. After the presentation, Mr. Bonds provided mounted fossil specimens and a microscope for our viewing pleasure.

The December holiday meeting was co-hosted with AEG at Sudwerk in Davis. About 100 attendees saw a sobering presentation by Dr. Raymond Seed, entitled "*New Orleans Levee Performance in Hurricane Katrina: Lessons for California's Levee Situation*." Dr. Seed is a Professor of Civil and Env. Engineering at UC Berkley and led a NSF-sponsored independent levee investigation team that completed a forensic analysis of the levee failures resulting from Hurricane Katrina. Their findings showed that although most of the levee failures in the central New Orleans area were thought to be the result of overtopping, many key failures were related to poor foundation soils underlying the levees. The investigation team made recommendations to improve the performance of the levees and provided insights and recommendations for mitigating potentially serious deficiencies in the temporary/emergency repairs at a number of breached sections. Dr. Seed discussed the precarious situation in northern CA, where most levees are constructed of natural materials dredged from rivers and are structurally unsound, which could lead to devastation exceeding that observed in New Orleans.

Southern California Branch Highlights

BY PAUL PARMENTIER, BRANCH SECRETARY

September 2007 Meeting: Field Demonstration of Investigation Methods

On September 12, the Southern CA Branch held its bi-monthly meeting in the field. With support from Cal State Fullerton, about 30 GRA participants toured several "stations" where investigation methods were presented. Demonstrating their services and products were: Calscience Laboratories, Beacon Environmental (passive soil gas and indoor air), Fugro (CPT and ROST fluorescence testing), Locus Technologies (Environmental Database and Passive Diffusion Bags and Snap Sampler), Environmental Support Technologies-EST (active soil gas surveys), and Cal State Fullerton who, with Orange County Water District, demonstrated the tools used to check water levels and sample the WestBay multi-port well at the University.

The vendors provided pizzas and soft drinks served tail-gate style (Thank you!). Participants were then led into a quick tour of each station for a 5-minute overview. On completion of the tour, participants returned to stations of their choice for further discussion. The field format was well received, and provided for informative, one-on-one discussions; GRA So Cal is considering for 2008 a similar "field trip" focusing on remediation technologies.

November 14, 2007: Sustainability consideration during selection of site cleanup options.

In conjunction with the DNAPL II conference in Long Beach, the Southern Branch held a dinner meeting during which Paul Hadley (CA DTSC) and David Ellis (DuPont) described their efforts in promoting the consideration of sustainability parameters during the process of remedial method selection. The speakers astutely pointed to the apparent shift in the current degree of acceptance of sustainability concepts compared to the introduction of Monitored Natural Attenuation in the 1990s. The speakers presented case studies that incorporated evaluations of overall environmental impact. The DTSC Green Remediation Team and the Sustainable Remediation Forum (SURF) were also introduced. The talks were followed by lively audience discussions about the topic of sustainability in the groundwater remediation industry.

Pending changes in Branch officers for 2008 were announced including Emily Vavricka (AQUI-VER), who will assume the position of President, and Peter Murphy (Kennedy/Jenks Consultant), who will become the Treasurer. Paul Parmentier (Locus Technologies) and Toby More (Chief Hydrogeologist for Golden State Water) will be Technical Advisors. Candidates for Vice President and Secretary Positions are currently being finalized.

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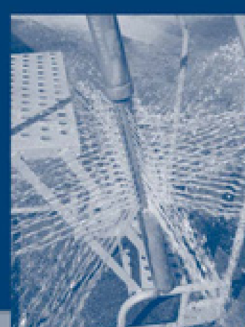
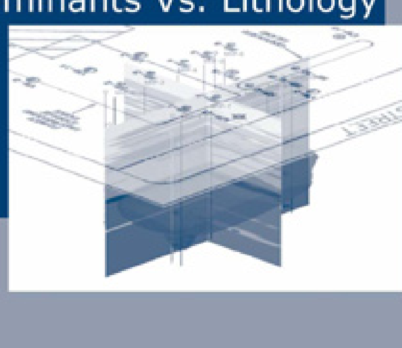



Contaminants Vs. Lithology



Membrane Interface Probe

Todd Hanna
Southern California
Santa Ana

800-VIRONEX

John McAssey
Northern California
Pacheco

Dates & Details

GRA Meetings and Key Dates

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

GRA Legislative Symposium & Lobby Day	**March 12, 2008** Sacramento, CA
GRA Course *Groundwater Modeling*	**March 18-20, 2008** Los Angeles, CA
GRA Board Meeting	**April 5, 2008** Sacramento, CA
GRA Course *Vadose Zone Modeling*	**June 9-11, 2008** Los Angeles, CA
GRA Course *Climate Change*	**August 12-13, 2008** Sacramento, CA
GRA Course *Groundwater Modeling*	**September 22-24, 2008** Redwood City, CA
GRA 17th Annual Meeting & Conference	**September 24-26, 2008** Costa Mesa, CA
GRA Symposium *Applications of Optimization Techniques*	**October 15-16, 2008** Sacramento, CA
GRA Symposium *Emerging Contaminants*	**November 2008** No. CA

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