The value of our service equals the sum of our staff.

We are scientists, problem solvers, implementers. People who love what we do. Clear Creek Associates are a group of people whose collective expertise in groundwater-related projects in Arizona is unmatched. We’re dedicated to offering quality-focused, very responsive hydrologic services to clients throughout the Southwest.

We’ve built our reputation on a foundation of strong professional capabilities, finely honed project coordination and communication skills, and extensive statewide experience.

With each addition to our staff over the past six years, the value of our service has grown. You can find out more about our newest staff members, and other matters of interest, at our Web site, www.clearcreekassociates.com.
The New Levelogger Gold represents the next generation of Solinst Levelogger®. Vastly improved over previous versions, the Levelogger Gold is completely designed, developed and manufactured in-house, in the tradition of all Solinst high quality products. Offering higher resolution and high accuracy of 0.05% for a much reduced price, the Levelogger Gold has improved transducer, temperature, and clock accuracies. Altitude, water density, temperature and barometric compensations also add to the major jump in accuracy.

New user-selectable recording schedule, as well as the standard event-based and linear sampling, is just one of the added features of the most friendly software yet. Battery life is 10-Years, even with recordings every minute. Memory is 40,000 readings of pressure and temperature, displayed as temperature compensated level, with an on-board backup of the last 1200 logs. The stainless steel housing protects against lightning and power surges and the golden Zirconium Nitride coating gives extra corrosion resistance.
Chemical disinfection of drinking water—commonly using chlorine, ozone, or chloramines—destroys disease-causing bacteria and viruses and improves the health of populations worldwide. But the process has a downside: residual disinfectants combine with naturally occurring organic matter in water to form disinfection byproducts (DBPs), including several that can be carcinogenic and hundreds of others whose toxicity is unknown.

Water providers must walk a fine line between providing sufficient disinfection and minimizing byproduct formation. Changing the type of disinfectant can reduce the formation of the nine federally regulated DBPs, but it also can increase production of others, some of which could be more toxic than the regulated ones. This issue’s feature articles address DBPs from a variety of angles, from how they are formed and how utilities can treat them to their fate in the subsurface.

Mark your calendars now for Aug. 29-Sept. 1, 2007 so you don’t miss the first-ever Southwest Hydrology symposium, sponsored jointly with the Arizona Hydrological Society. We’re planning a regional discussion about limits to our water resources and how they might be addressed in this era of rapid growth in the Southwest. If you have ideas, please send them to me, and check our website for updated information.

As always, we are grateful to all the contributors to this issue, and encourage you to patronize and thank our advertisers for their support of the magazine.

Betsy Woodhouse, Publisher
The Resource for Semi-Arid Hydrology

A bimonthly trade magazine for hydrologists, water managers, and other professionals working with water issues

We thank the following sponsors for their support:

P.O. Box 210158, Tucson, AZ 85721-0158 • visit our web site: www.swhydro.arizona.edu • 520.626.1805

Tired of Getting Poor Rental Equipment – Problem Solved!

Every Rental comes with the Enviro-Tech

“Quality Guarantee.”

If Requested, Calibration Kit, Video & CD, Tool Kit

Instruction Manual and Rental Agreement

Instrument is Charged & includes Charger

Working Instrument and Certificate of Calibration

All Accessories as needed

Clean Foam Packaging

It Looks Sharp and Professional

Our Quality Guarantee – If we fail to provide any of this, your rental is Free* until we fix it.

*The only condition is you need to notify us immediately.

Phone 1-800-468-8921

Fax 1-925-370-8037
Disinfection Byproducts

Chemical disinfection of drinking water is arguably one of the greatest advances in human health. However, nothing is perfect. The byproducts that form when disinfectants combine with otherwise harmless compounds in water warrant our attention. Although the carcinogenic nature of some disinfection byproducts (DBPs) was first shown in the 1970s, only a few of the hundreds that have been identified are regulated. What are DBPs? How and where do they form, and how do utilities manage them? How do recent stricter compliance standards affect utilities? What is known about other DBPs besides the few that are federally regulated? And what is the fate of DBPs in the subsurface when treated water is used as recharge water to replenish aquifers? This issue’s feature articles help answer such questions.

The ABCs of DBPs
Philip C. Singer
Disinfection of drinking water with chlorination, ozonation, or other chemical methods can cause the formation of DBPs, which have been associated with adverse health effects. What are the factors influencing their formation and how are they being sampled, measured, and regulated to protect human health?

A Utility’s-Eye View of Disinfection Byproducts Compliance
Suzanne Grendahl and Carie Wilson
Scottsdale, Arizona took a multi-phased and proactive approach to achieving compliance with DBP Stage 2 requirements, addressing water storage in the distribution system, developing an extensive monitoring program, creating a water quality model, and identifying capital improvements.

Chemistry and Treatment of Disinfection Byproducts in Drinking Water
Paul Westerhoff
When, where, what kind, and what quantity of disinfection byproducts develop depends on the water quality and type of treatment used. Most treatment plant operators opt to control DBP formation by reducing precursors or using alternative treatments rather than trying to remove them after they form.

A New Generation of Disinfection Byproducts
Using alternative disinfection methods to reduce the formation of regulated disinfection byproducts has produced a new generation of DBPs, of which little is known about their prevalence and characteristics. Summarized from a paper published in Environmental Science and Technology, this article sheds some light on the new priority DBPs.

Experimental Investigation to Limit Trihalomethane Production
J.F. Leising and Eric Dano
Faced with a tripling of total trihalomethane in the water during transit between its Lake Mead treatment facility and its aquifer storage wellhead, the Southern Nevada Water Authority evaluated methods to neutralize free chlorine in delivery system water.

Attenuation of Disinfection Byproducts During ASR Storage
R. David G. Pyne
To store water for long-term needs, large volumes of water are increasingly being artificially recharged to aquifers. Because the recharged water is typically treated, knowing the subsurface fate of DBPs is important. New research is helping determine the subsurface processes that favor DBP attenuation.
Easy-to-use water level equipment, because nature doesn’t make anything easy.

Turn to Hach Environmental to get the total solution for water level monitoring.

Nobody ever claimed measuring water level is a walk in the park. So Hach Environmental offers a complete line of OTT water level monitoring instruments to meet a full range of needs. Our autonomous bubbler and shaft encoder, as well as our radar level and pressure sensors are easy to install, easy to maintain and provide accurate results in unpredictable conditions. Plus, we’re backing you with the superior service and support of Hach Environmental. To learn more about how we can help make your job easier, call your local sales representative or toll-free at 1-800-949-3766 ext. 1 today.
Hualapai Water Quality Standards Program

Hualapai Dept. of Natural Resources and the U.S. Environmental Protection Agency

Recognizing the need to protect and restore the limited waters on its reservation, the Hualapai Tribe of northern Arizona recently enacted a water quality standards program. The program, approved by the U.S. Environmental Protection Agency (EPA) under the Clean Water Act, empowers the tribe to make decisions with federal and state agencies on various actions affecting water quality.

The Hualapai Reservation was established by executive order in 1883; it covers nearly one million acres and 108 miles of the Colorado River in the Grand Canyon, which forms its northern boundary and is the ancestral home of the Hualapai. Approximately 2,000 people live on the reservation, more than 98 percent of whom are tribal members.

Advantages of Standards

Before applying to the EPA for approval to administer a water quality standards program, the Hualapai Department of Natural Resources had to convince tribal members and eventually the Tribal Council to support the endeavor. This effort involved numerous meetings and public discussions to explain the merits of adopting standards. The emphasis from the beginning was to at least maintain and potentially restore the water quality of 49 springs and eight groundwater sources on the reservation. These springs are important for cultural reasons as well as for wildlife and livestock uses. Tribal members were eventually convinced that EPA-approved water quality standards would not inhibit water use activities, but would enhance water quality and benefit farming and ranching practices.

Two factors influenced the Hualapai Tribe’s decision to develop and adopt water quality standards under the Clean Water Act. First, the tribe recognized that having standards would give it a basis to affect water pollution control actions both on and off the reservation. Second, the tribe wanted to protect and restore the relatively unpolluted springs that are important in its water-scarce environment. The reservation also has approximately 21 miles of perennial streams and many ephemeral streams.

EPA approved the Hualapai’s application to administer the water quality standards program on July 22, 2004 and the tribe’s water quality standards on Sept. 17 the same year. These standards were in place under tribal law for several years before EPA approved them under the Clean Water Act. The tribe received strong support from the Arizona Department of Environmental Quality and U.S. Fish and Wildlife Service in its efforts to develop standards.

The Hualapai Department of Natural Resources is responsible for a variety of environmental programs including water quality, nonpoint pollution sources, wetlands, forestry, wildlife and fisheries management, parks, agriculture, air quality, and environmental services. The number of employees fluctuates seasonally between 30 and 50. Maintaining a consistent level of funding to implement environmental programs is an ongoing challenge. The Hualapai currently receive federal funding from the EPA, Bureau of Indian Affairs, Bureau of Reclamation, Fish and Wildlife Service, National Resource Conservation Service, Department of Agriculture, and Geological Survey. In
addition, the tribe also provides funding for Water Resource Program efforts.

**Program Yields Results**

Since adopting water quality standards, the Hualapai Tribe has been an equal partner with federal, state, and local authorities in discussing activities that could affect tribal waters. The tribe has already had success in getting off-reservation livestock grazing practices modified to protect tribal waters. Within the reservation, the water quality standards, coupled with supporting tribal ordinances, provide the tribal government with an enforceable means to modify wildlife management and ranching practices to protect and restore water quality. Some recent modifications include the restoration of riparian wetlands, the addition of fences in grazing areas, and the removal of feral animals from around springs. Even within the relatively short history of applying standards, the quality of spring waters has improved noticeably in terms of clarity, reduced nutrient growth, and reduced odor.

Hualapai water resources personnel recommend that any tribe considering the water quality standards program:

- recognize the empowerment aspects of adopting and applying water quality standards;
- establish reasonable designated uses;
- ensure that adequate legal support is available within the tribe and EPA;
- have the patience to see the process through; and
- develop a strong relationship with EPA personnel.

Contact Alex Cabillo at the Hualapai Dept. of Natural Resources at 928-769-2254 or acabillo@hotmail.com. Visit [www.epa.gov/waterscience/tribes/files/hualapai.pdf](http://www.epa.gov/waterscience/tribes/files/hualapai.pdf) for the original article.

---

The Hualapai Reservation is in northwest Arizona, bounded by the Grand Canyon to the north.
When the Silvery Minnow Turns to Gold

Joseph J. Fluder III – SWCA Environmental Consultants

The Rio Grande silvery minnow (Hybognathus amarus) was listed as an endangered species by the state of New Mexico in 1979 and by the federal government in 1994. Led by the U.S. Fish and Wildlife Service (FWS), numerous federal and state agencies and SWCA Environmental Consultants have contributed to the development and success of silvery minnow rescue and salvage efforts, which have been ongoing since 1998.

These efforts were facilitated by the Biological Opinion updated by FWS in March 2003, which determined that certain actions are necessary and appropriate to minimize the impacts of incidental take (mortality) of the silvery minnow.

Today, the silvery minnow is absent from much of its historical range and is restricted to a reach of river from Angostura Diversion Dam north of Albuquerque downstream to Elephant Butte Reservoir, much of which is susceptible to intermittent flow. The area designated as critical habitat for the silvery minnow extends from Cochiti Dam to Elephant Butte Reservoir, a distance of 150 river miles.

Silvery minnow mortality can occur when the channel dries from drought conditions and intermittent river flow or changes in water operations. The reach between Isleta Diversion Dam and Elephant Butte Reservoir is an area of particular concern, requiring intercession during intermittent conditions to counter potentially substantial silvery minnow mortality. Efforts to rescue and salvage silvery minnows from intermittent sections or isolated areas of the river have reduced the probability of silvery minnow mortality associated with water operations that
would exceed the limit for incidental take, but it is not known whether the rescue program has stabilized the population. Preliminary population data for 2005 indicate a precipitous increase in the number of silvery minnow, although this is most likely a response to hydrology and weather conditions rather than rescue and salvage efforts. Approximately 120 rescue operations were performed in 2005, but this year, because of wet weather and sufficient river flow, crews have only been out approximately 30 times.

**River Eyes Watch**
A cooperative, interagency monitoring team dubbed “River Eyes,” which includes representatives from the New Mexico Interstate Stream Commission and the Bureau of Reclamation, travels the Middle Rio Grande during periods of drought or low streamflow looking for reaches or areas of intermittency during early morning hours. Their reports, as well as USGS stream gauge data and weather conditions, are communicated to FWS leaders who dispatch salvage crews to reaches of the river that may have or are likely to experience intermittency. All-terrain and amphibious vehicles are used to travel efficiently on the riverbed between isolated pools and to transport silvery minnow. The FWS-led crews work on an as-needed basis during periods of intermittency, and are available seven days a week, typically beginning their workdays around five o’clock in the morning.

**Making the Move**
Silvery minnow are collected from isolated pools using seines of varying sizes. Trained field personnel sort the fish, with silvery minnow being placed in five-gallon buckets filled with water. The minnows are later transferred to plastic bags or transport tanks on a hauling vehicle. The plastic bags may be placed in an ice chest for protection after river water, salt (18.9 grams/gallon), and oxygen (less than 6.0 milligrams per liter) are added. Fish densities should not exceed 10 grams of fish per liter of water, equal to around 50 to 75 silvery minnows, depending on whether they are small, such as after a successful spawning season, or large and more mature. During periods of collection, FWS crew leaders also identify silvery minnow that are incidental take resulting from the low water levels. Very few mortalities are associated with the rescue efforts.

The transportation of silvery minnow from collection sites to perennial reaches of the Rio Grande occurs when it is most feasible to transport the fish without causing undue stress to them. Release locations and specific access routes to the river are identified before leaving the collection locations. Upon relocation, the plastic bags containing the transported silvery minnow are placed in the river until water temperatures equalize to help the fish acclimatize before they are released.

Michael D. Hatch of U.S. Fish and Wildlife contributed to this article. Contact Joseph Fluder at jfluder@swca.com.

**Reference**
Cloudy Ruling on Murky Water

In June, the U.S. Supreme Court issued a decision that upheld the Clean Water Act yet maintained the likelihood of further regulatory battles. At issue was the definition of wetlands subject to federal jurisdiction and thus protected by the Clean Water Act.

Four of the nine justices argued to uphold the general definition used by the U.S. Army Corps of Engineers: if any water at all could flow from the area in question to a river or lake, it is a wetland.

Four opposing judges argued for a stricter interpretation in which the wetlands must have a “continuously flowing body of water” within a river or lake, wrote Justice Antonin Scalia, according to the San Francisco Chronicle.

The ninth judge, Anthony Kennedy, said a wetland must have “a significant nexus” to a river or lake for the Clean Water Act to apply, and should be evaluated on a case-by-case basis—a “decidedly murky” view, in the Chronicle’s opinion.

The decision sent four cases involving parcels of land in Michigan that prompted the ruling back to a lower court for interpretation. Had Scalia’s definition prevailed, said the Chronicle, wetlands protection in much of the West would have been undermined, as many so-called wetlands are dry for much of the year. As the ruling stands, the definition remains unclear, leaving open the likelihood of numerous lower court battles over wetlands in the future.


WSWC Issues Water Management Strategies


Water policy and growth: WSWC recommends that states define their water requirements for future growth, develop strategies to present to local decision-makers, and facilitate watershed-scale planning to balance growth and environmental needs for water quantity and quality. When considering water transfers and changes in use, local, tribal, and watershed plans should be taken into account. Also, states should consider the impacts of continued growth that relies on transfers from agriculture and rural areas, and identify alternatives.

Needs and strategies for states to meet future demands: The report cited the need for increased federal and state support and funding for the basic data collection that is necessary for sound decision-making. Agencies should seek more in-kind contributions, more stable funding, and possible user-pay opportunities. Research programs at universities should be encouraged to focus on practical applications of promising new technologies and areas where increased use of technology would improve operational efficiency and cost-effectiveness. WSWC strongly supports the National Integrated Drought Information System (NIDIS) and state-wide drought planning efforts. States should develop and implement strong state water plans built from watershed-scale studies, and work with other states to develop regional basin plans where appropriate.

Water infrastructure needs: WSWC supports continued federal and state revolving funds for the Clean Water Act and Safe Drinking Water Act; more money for U.S. Bureau of Reclamation projects for western water supply needs, particularly in rural areas; more loan guarantee programs for nonfederal project sponsors for rural needs; and renewed support for Army Corps of Engineers projects. Maximal coordination of regional approaches by federal/state groups is recommended. To support the needed infrastructure investment by all levels of government, more outreach and educational programs are also needed.

Resolution of Indian water rights: Pending water rights claims should be settled, and the means to fund them identified.

Preparation for climate change: More funding is required for data collection networks and research for improved climate change prediction/modeling/impact assessment. States must improve planning and coordination with local governments, scientists, policymakers, and water users.

Protection of aquatic species under the Endangered Species Act (ESA): States should establish protocols for implementing the ESA to minimize conflicts between species and other water users. Evaluations of western state water laws could identify possible options for providing water for endangered and threatened species.

The 28-page report is available at www.westgov.org/wswc/publicat.html.

AZ Legislature Approves Earth Fissures Mapping

Last spring, the Arizona Legislature approved HB 2639, requiring that earth fissure maps be made available on request to the public in both printed and electronic formats, and updated on a five-year basis. The bill appropriated $233,000 to the Arizona Geological Survey (AGS) and $81,000 to the State Land Department (SLD) for fiscal year 2006/2007.

Earth fissures are tension cracks at or near the earth’s surface resulting from land subsidence. Subsidence in Arizona is due generally to soil compaction caused by excessive groundwater pumping. Earth fissures are located primarily in the central and southern portions of the state and mainly along or near basin boundaries in basins where depth to water has declined several hundred feet.
In addition, the bill exempts a subdivider, owner, or licensee from liability to any person or governmental entity if notice of the earth fissure map and website is provided in writing or is part of a public report, or if it was not possible to know that the land was subject to earth fissures before the map was posted.

Visit www.azleg.gov.

**AZ County to Monitor Rural Water Use**

The 11,400 domestic water wells in Cochise County in southern Arizona present a challenge to county water managers. Because they pump less than 35 gallons per minute (gpm), they are exempt from metering, so whether they pump on average 1 gpm, 34.9 gpm, or somewhere in between is unknown. The county is hoping to get a better idea of how much water its rural residents actually use through a $100,000 metering program recently funded by the board of supervisors, according to the *San Pedro Valley News-Sun*.

A 2005 water balance developed by the Arizona Department of Water Resources (ADWR) estimated that domestic well users in the area use an average of about 780 gallons per day (about one-half gpm) for an average household of 2.5 people. Water deficits in the county are being projected based on that figure, Carl Robie, Cochise County Board of Supervisors water conservation specialist, told the newspaper, but he warned that the number may not be terribly accurate. Getting it right is important for water managers, especially if the ADWR estimate is low.

The metering program faces a big challenge: for study results to be meaningful, 476 wells must be randomly selected, and their owners will have to agree to cooperate with the program for its two- to three-year duration, Robie told the *News-Sun*. The owners’ identities will be kept anonymous, no restrictions on water use will be required, and the meters and hookups will be free. Owners would simply have to allow officials to enter their property periodically to collect the data. But this is rural Arizona, where government officials are often regarded with suspicion. County officials are hoping that residents will recognize the value of the data and cooperate in the study.


**Arizona Water Atlas Released**

In July, the Arizona Department of Water Resources (ADWR) issued draft versions of the first two volumes of the *Arizona Water Atlas*. The atlas eventually will fill nine volumes; additional volumes will be released for comment in the coming months.

“We view the atlas project as central to our mission of securing Arizona’s water supply,” ADWR Director Herb Guenther said. “It will become a dynamic project, with constant updates as more information is gathered and analyzed.”

The *Arizona Water Atlas* is a compilation of currently available water-related information for the state. Volume 1 is an introductory volume; volumes 2 through 7 cover the six planning areas outside of the state’s Active Management Areas (AMAs), beginning with the Eastern Plateau planning area, which covers roughly the northeast quarter of the state. The five AMAs are considered together and described in Volume 8. Volume 9 is a summary volume for the entire state.

In addition to providing a comprehensive overview of regional water supply and demand conditions, atlas staff are seeking to compile existing information and identify areas that will require further study, provide water supply and demand information to assist rural Arizona planning efforts, identify water resource issues facing rural Arizona communities and help to identify solutions, and initiate a renewed and more systematic effort by ADWR to maintain a rural Arizona database.

The atlas staff are seeking substantive public and professional comment on the

---

**HydroFacts**

- Cubic miles of fresh water in Lake Baikal: **5,660**
- Cubic miles in Lake Superior: **2,900**
- Cubic miles in Lakes Michigan, Huron, Erie, and Ontario combined: **2,539**
- Percent of global fresh water in all six lakes: **39.1**

Although summer’s heat is a fading memory, the urban heat island effect is still a hot topic in major metropolitan areas of the Southwest.

- Average overnight low temperature, Phoenix, July 1948: **75 F**
- Average overnight low temperature, Phoenix, July 2003: **87 F**

- Average cooling degree hours*, Phoenix, 1950s: **95,597**
- Average cooling degree hours, Phoenix, 1990s: **112,551**

- Electricity used for home cooling, Phoenix, 1950s: **7,888 kWh/house/year**
- Electricity used, 1994-2003: **8,873 kWh/house/year**

- Water consumptively used to generate 1 kWh: ~ **0.7 gals.**

---

* A measure of energy needed to cool a structure, calculated hourly as the number of degrees that the outdoor temperature exceeds the desired indoor temperature.
work in progress. An electronic comment form is available on the ADWR website.

ADWR plans to finalize the atlas in early 2007. Printed copies and CD-ROMs will be available when the atlas is complete.

Volumes 1 and 2 are available at www.azwater.gov.

CA Considers Climate Change Impacts on Water Resources

In July, the California Department of Water Resources (DWR) released a technical report looking at changes that may affect California’s water resources in the future. The report, “Progress on Incorporating Climate Change into Management of California’s Water Resources,” is an adjunct to an executive order issued by Gov. Arnold Schwarzenegger in June 2005 that set greenhouse gas reduction goals for California.

Prepared for the governor and the California State Legislature, the report describes the mathematical modeling of four climate change scenarios and the corresponding results. It indicates that climate change could significantly impact California’s water picture in many ways, including: loss of Sierra snow pack and the seasonal water storage it provides; more rain and less snow, impacting both water supply reliability and hydropower generation; more variable precipitation and extreme weather events, such as floods and droughts—the latter resulting in more energy-intensive groundwater pumping; rising sea levels that would increase pressure on Delta levees and compound saltwater intrusion into Delta water supplies and coastal aquifers; higher water temperatures, possibly affecting listed fish species; and changes in annual average State Water Project and Central Valley Project south-of-Delta deliveries.

According to DWR, the climate change report is consistent with the agency’s recently released “California Water Plan Update” that recommends state agencies work with researchers to monitor, predict, and prepare for the effects of global climate change on water systems and the environment.

The climate change report is available at baydeltaoffice.water.ca.gov.

Pipeline Boring Begins for San Diego

Boring began last summer for the 11-mile long, 8½-foot diameter, $273 million San Vicente Pipeline that will connect San Diego with the San Vicente Reservoir in Lakeside, California. The pipeline is part of San Diego County Water Authority’s Emergency Storage Project, a system of reservoirs, interconnected pipelines, and pumping stations designed to make water available to the San Diego region in the event of an interruption in imported water deliveries, such as caused by an earthquake or prolonged drought.

Originally, the agency planned to construct a giant trench from the city to the reservoir, but in 2004 the plans were changed to a pipeline to minimize environmental and traffic impacts, and noise and dust during construction.

The pipeline will be built in a 12-foot-diameter tunnel at a depth ranging from 50 to 600 feet underground and will not pass directly under any homes. Tunneling, rather than cut-and-cover trenching, was chosen to reduce impacts to land surfaces and the surrounding communities. Three tunnel boring machines will be used to excavate the majority of the tunnel. One will excavate rock using a rotating head to break the rock into small pieces. The other two will use a digging arm equipped with a bucket or rotary cutter. Rock and dirt are discharged behind the boring machines and removed from the tunnel by haul trains. The machines can excavate at a rate of 50 to 130 feet a day, depending on rock and soil conditions. Some short sections of the tunnel may contain rocks too hard for the digger shields to mine, and controlled blasting may be needed.

The pipeline is scheduled for completion in 2008.


Power Companies Compete for NV Water

Two power companies hoping to build plants in eastern Nevada are competing for water rights in the Ely, Nevada area, reported the Las Vegas Review Journal. White Pine County officials told the newspaper that they support the construction of both proposed coal-fired plants, one by Sierra Pacific Resources, the holding company for Nevada Power Company, and one by LS Power, but they aren’t certain sufficient water exists for both companies.

LS Power has already obtained from the county a guarantee of 25,000 acre-feet per year in Steptoe Valley; Sierra Pacific Resources applied to the state engineer for rights from the same location, triggering protests by several entities, including the U.S. Bureau of Reclamation, LS Power, and White Pine County, according to the Review Journal. The county commission tried to offer options, such as the two utilities forming a partnership or Sierra or Nevada Power obtaining water from Spring Valley, but the deal had no takers. Both utilities hope to begin operations by 2011 provided the water issues are resolved by next year, said the paper.


Edwards Aquifer Authority Moves to Protect Recharge Zone

Following a “concept memorandum” developed last spring, the board of the Edwards Aquifer Authority in central Texas “unanimously supported the idea of limiting rooftop and asphalt cover to 20 percent on aquifer recharge zone properties,” according to the San Antonio Express-News, but held off drafting actual rules until November.

George Rice, board member and a San Antonio hydrologist, commented to the newspaper, “We punted again,” but expressed hope that eventually the board will stand up to outside pressures influencing its decision.

The memorandum stated that the authority has the power and rights to protect the resources and quality of the Edwards Aquifer. The aquifer is characterized by sinkholes, caves, springs, and extremely high porosity and permeability typical of karst aquifers. As such, any contamination spreads rapidly throughout the system. The memorandum cited several studies showing a decrease in surface water quality as impervious cover increases, particularly when a threshold of 10 to 20 percent impervious cover is reached, and argues that due to the interconnected nature of the Edwards Aquifer, it is likely to experience similar deterioration.

The concept memorandum recommended a 20 percent limit for impervious cover for all new development—across all zoning classes—in the recharge zone within the authority’s boundaries. However, it specifies ways to mitigate the effects of increased cover if a development requires greater than 20 percent impervious cover, such as by implementing permanent stormwater best management practices and purchasing land elsewhere in the same subwatershed to keep vacant.


**Water Sale/Lease Conflict in NM**

A water rights debate is unfolding in the Rio Grande Valley. According to the [Santa Fe] New Mexican, at issue is whether a farmer with senior irrigation water rights in the Middle Rio Grande Conservation District (MRGCD) can sell his rights to the district without being prohibited from irrigating his land with water leased back from the district’s water bank.

According to the July 2 article, the New Mexico Office of the State Engineer considers such practices double-dipping, and if the farmer wants to irrigate again, he must obtain a new permit from that agency. But the conservation district argues that the farmer ought to be able to “lease water that the district has ‘banked’ from people who own water rights but have stopped irrigating,” the article said. It would only be illegal if the farmer began irrigating without leasing the water, according to the district’s attorney, Charles DuMars.

Apparently, it is not uncommon in the district for landowners to sell their rights but continue to irrigate without leasing water. According to the New Mexican, neither the district nor the state engineer’s office has kept good records on which rights have been sold relative to where irrigation is occurring.

DuMars told the newspaper that the primary conflict between the district and the state engineer concerns whether the district can bank water: the district believes it can, while the state engineer says the water right is lost if land is allowed to go fallow and beneficial use of the water no longer occurs. In fact, according to the New Mexican, that policy is enforced elsewhere in the state, and the state engineer is threatening to nullify pre-1907 “water transfers in the district if he finds out the land from which it was moved is irrigated again.”

The MRGCD was created in 1923 to provide flood protection from the Rio Grande and promote urbanization and agriculture in the area, which encompasses the Rio Grande Valley in the central portion of New Mexico, from Cochiti Dam south, through Albuquerque, to the Bosque del Apache National Wildlife Refuge. Today the district contains a mix of small farms, irrigated lands, pastures, and gardens amid urban and suburban landscapes.

According to the New Mexican, the district has the right to irrigate up to approximately 123,000 acres of land, but the volume of water that may be used for irrigation has not been specified, nor has proof of beneficial use been submitted to the state engineer to justify the district’s water entitlement. Some landowners in the district have water rights dating prior to 1907; by state law, pre-1907 rights are senior.


---

**LFR LEVEN•FRICKE**

Today, both municipalities and industry recognize the need for strategic water resource planning to sustain growth and development. LFR Levine-Fricke has experts in water resources and water supply and will help you with your planning needs. We provide the following services:

- Groundwater resource evaluation and basin inventory analysis
- Assured water supply planning and development
- Modeling of groundwater and surface water flow systems
- Litigation support for water rights and resource damage
- Wellhead and aquifer source protection
- Water quality evaluation and treatment (including Arsenic)

**PLEASE VISIT US AT WWW.LFR.COM OR CALL US AT 480.905.9311**
Without doubt, disinfection of drinking water has vastly improved human health. However, while not posing nearly the same health risks as untreated drinking water, disinfection byproducts (DBPs) resulting from common disinfection practices do warrant attention. Certain DBPs have been associated with adverse health effects, notably cancers and reproductive and developmental disorders (see sidebar, opposite page).

Disinfection is the process of chemically inactivating disease-causing microorganisms present in raw water supplies. DBPs are formed by reactions between disinfecting agents and natural organic matter (NOM) and bromide, both of which occur naturally and harmlessly in groundwater and surface water supplies. DBPs are found in all water supplies that are chlorinated, ozonated, or treated with other chemical disinfectants.

Among the thousands of DBPs that can form, the most studied (due to health effects and analytical capabilities) are the halogenated compounds, so named because they contain chlorine, bromine, and less commonly iodine. Among these are the trihalomethanes (THMs) and haloacetic acids (HAAs), which form when chlorine is used as a disinfectant. THMs are formed when individual carbon atoms in NOM are attacked by halogen disinfectants. Small hydrocarbon chains are cleaved from NOM molecules, and the reaction of the halogen species continues until THMs are formed. HAAs are formed in a similar manner. Other halogenated DBPs include bromate, formed when ozone is used to disinfect bromide-containing source waters, and chlorite, formed when chlorine dioxide is used.

What Affects DBP Formation?
DBP formation depends upon the quality of the source water and the types of treatment used. In general, waters with high levels of natural organic carbon concentrations (total organic carbon greater than about 5 milligrams per liter, mg/L, see sidebar, far right) and high bromide concentrations (greater than about 0.10 mg/L) tend to have high
levels of DBPs unless these precursors are removed prior to adding the disinfectant. Other factors influencing their formation are listed below.

**pH:** As pH increases, the overall formation of halogenated organic compounds decreases. Above pH 8, many of the halogenated DBPs hydrolyze, except for THMs.

**Time:** Generally, THM and HAA formation increases as contact time between the disinfectant and NOM-containing water increases. Therefore they continue to form in the water distribution system as long as free chlorine residuals persist. However, some halogenated DBPs, such as haloacetonitriles and haloketones, may form rapidly upon chlorination but then decay in the distribution system due to hydrolysis and continuing reactions with residual chlorine.

**Season:** The rate and extent of DBP formation may be markedly affected by seasonal factors and meteorological conditions. In the warmer summer months, faster reaction kinetics means that more chlorine is consumed, more is required to achieve disinfection, and consequently more DBPs are produced. The composition of organic precursors and bromide concentration may also vary seasonally, for example with increased spring runoff or saltwater intrusion during drier periods.

**NOM characteristics:** The composition of NOM also influences the extent of DBP formation. NOM contains both hydrophobic and hydrophilic organic material arising from the decay of vegetative matter, with hydrophobic material favoring greater DBP formation. The nature and distribution of the organic materials depend on the type of vegetation in the watershed and the species of algae in the water.

**Chlorine:** The rate, extent, and distribution of DBPs are impacted by the chlorine dose and free chlorine residual. Higher doses and residuals favor the formation of HAAs over THMs, the formation of the trihalogenated HAAs over the di- and mono-halogenated HAAs, and the formation of the chlorinated THMs and HAAs over their brominated and mixed bromo-chloro counterparts. THM and HAA formation stops when the free chlorine residual is depleted, although some DBPs continue to be formed to a limited degree as a result of hydrolysis reactions.

**Bromide:** Bromine incorporation into halogenated DBPs increases with higher bromide ion concentrations.

---

**Establishing appropriate regulations was complicated by the fact that alternative disinfectants to chlorine formed disinfection byproducts of their own, also with adverse health effects.**

---

**DBPs: How Bad Are the Risks?**

Studies evaluating the health risks of DBPs, particularly THM4 and HAA5, have been monitored by the U.S. EPA, World Health Organization (WHO), and Lenntech in the Netherlands. Findings from the last decade are summarized here.

**Cancer Risks**

Many studies have evaluated the risks of increased bladder, anal, and intestinal cancer. Meta-analysis of studies indicates that a direct relation between the development of cancer and drinking of chlorinated water is unproven. However, DBP exposure from drinking water has been attributed as the cause of nine percent of human bladder cancers and 15 percent of anal cancers. Moreover, these risks increase after lengthy exposure to chlorinated drinking water. Too little evidence exists to link intestinal cancer to exposure to chlorinated drinking water.

New research (see pages 22-23 and 33) now suggests that emerging DBPs may have greater toxicity than those currently regulated.

**Reproductive and Developmental Effects**

Studies on reproductive and developmental effects have almost exclusively used lab animals. DBP concentrations that have been linked to birth defects and spontaneous abortion (see page 19) are many times larger than those that can cause cancer after lengthy exposure.

Epidemiological studies suggest a connection between exposure to trihalomethanes and spontaneous abortion, birth defects, and growth delay. DBP exposure before and during pregnancy is likely related to low birth weight and growth delay.

**Treatment versus Nontreatment**

A 1993 study by Regli and others compared the risk from known pathogens in untreated drinking water to the risk of getting cancer from DBPs in treated water:

- The risk of death from pathogens is 100 to 1,000 times greater.
- The risk of illness from pathogens is 10,000 to 1 million times greater.


---

**Organic Material: How Much Is A Lot?**

Natural organic matter is a precursor to DBP formation. It is typically measured in water as total organic carbon (TOC) or dissolved organic carbon (DOC). Concentrations of TOC greater than about 5 milligrams per liter (mg/L) are considered relatively high with respect to DBP formation. What are typical concentrations?

- **Colorado River:** 3 to 4 mg/L
- **Central Arizona Project water:** 2.4 to 10 mg/L
- **Stormwater runoff:** 10 to 2,400 mg/L
- **Municipal wastewater:** 10 to 25 mg/L; up to 300 mg/L
- **Tucson-area groundwater:** generally less than 0.2 mg/L
- **AZ municipality drinking water:** average 3.7 mg/L; maximum 8.9 mg/L
- **Las Vegas Wash:** 5 mg/L
- **CA State Water Project (Delta) water:** 3 to 4 mg/L

---


---

**November/December 2006 • Southwest Hydrology • 17**
Scottsdale is a medium-sized Arizona city, having a current population of just over 220,000. The city serves water to customers through 10 points of entry (POE) originating from three sources. Two of these sources are surface water, which makes up 65 percent of the water supply; the balance is derived from groundwater. Chlorine is the source of disinfection for the treatment plants and the distribution system; there are 18 pressure zones. The primary surface water source is Colorado River water delivered via the Central Arizona Project. It serves 65 percent of the residents of Scottsdale, has a finished water total organic carbon (TOC) concentration averaging 2.5 parts per million (ppm), with water temperatures in the distribution system often exceeding 28 degrees Celsius, and in some locations a water age exceeding 14 days. All of these combined factors have presented challenges for the city in controlling disinfection byproducts (DBPs).

Due to the complexity of the water system, compliance with the U.S. Environmental Protection Agency’s Disinfection By-Products Stage 1 Rule (DBP1) required monitoring of 20 locations and use of a system-wide average. Although this average has fallen well below EPA’s maximum contaminant level (MCL) of 80 ppm for the total of four trihalomethanes (THM4), a few locations have exceeded this value. Compliance with haloacetic acid standards (HAA5) has not been an issue.

Scottsdale recognized that compliance with DBP2 would be impossible without implementation of system changes, including additional treatment of surface water sources.

Preparing for Stage 2

With the knowledge that EPA was to promulgate a DBP Stage 2 (DBP2) rule with much stricter criteria, Scottsdale began a multi-phased approach to addressing the problem areas. Initial phases included addressing water storage in the distribution system, developing an extensive monitoring program, creating a water quality model, and identifying capital improvements.

- **Water storage**: With the volume of water being stored (65.1 million gallons in 31 potable storage tanks with capacities of 100,000 gallons or greater), the city worked on optimizing the operation of the tanks to decrease water age. Each tank was studied for set points that would require the tank to empty and turn over faster, but still maintain fire protection.

- **Monitoring program**: Approximately 50 sample stations throughout the distribution system are being monitored monthly to establish a database for numerous parameters, including DBPs.

- **Water quality model**: The city contracted the development of this model, which is being used in combination with the monitoring program to determine water age.

- **Capital improvements**: Multiple projects were identified to address the DBP issue, including installation of granular activated carbon (GAC) at the CAP water treatment plant and improvements to existing reservoirs. GAC was also incorporated into the design of the recently constructed Chaparral Water Treatment Plant.
Initial Distribution System Evaluation (IDSE) monitoring plan by Oct. 1, 2006. The rule outlines four options for fulfilling the IDSE requirements:

- qualify for a very small system waiver;
- meet 40/30 certification requirements (no individual THM4 samples exceed 0.040 milligrams per liter [mg/L] and no individual HAA5 samples exceed 0.030 mg/L);
- conduct a system-specific study using existing monitoring results or a hydraulic model; or
- conduct standard monitoring.

The City of Scottsdale was eligible for only the last option, use of a standard monitoring plan (SMP).

Although an extensive amount of DBP data have been collected over the years, significant changes to the water system have taken place in the past year and will continue through 2006. These changes include the implementation of four satellite groundwater arsenic treatment facilities, commissioning of a 30 million gallon-per-day surface water treatment plant, installation of new reservoirs and booster stations, and disconnection of four groundwater wells. Taking all of these system changes into account, the city determined it would have to follow the SMP requirements of the IDSE. Based on its population, Scottsdale is required by the SMP to monitor 16 additional DBP locations bimonthly for twelve months. These locations must include:

- three near-entry points,
- four sites with average residence times,
- five sites with high THM4, and
- four sites with high HAA5.

City staff have completed selection of the 16 proposed IDSE monitoring locations. Site selection was based on information obtained from the water quality model, a review of historical data, location of the existing Stage 1 sites, and knowledge of the system configuration. The near-entry points were selected as the POEs of the two surface water plants and a POE representing the groundwater wells. The water quality model was run using the current configuration and the assumed future system configuration. A projection of water age was generated (see figure below) and this information was used to select the average residence times for each of the three water sources. Selecting the high THM4 and HAA5 sites was more challenging because many of the potential locations were already Stage 1 sites. The city relied upon extensive historical data collected from a baseline distribution monitoring program and data from the water quality model to determine these locations.

**Lessons Learned Through Compliance**

Through the extensive monitoring for compliance with the DBP1, the City of Scottsdale recognized that compliance with DBP2 would be impossible without implementation of system changes, including additional treatment of surface water sources. Water age, temperature, and TOC concentrations are factors that will prevent multiple sample locations from meeting the LRAA requirement of DBP2. The monitoring that will be performed with the IDSE should provide additional data to further validate this conclusion.

Scottsdale made the significant and costly decision to add GAC as a treatment in both surface water treatment plants. The GAC will lower the TOC concentration, thereby reducing the precursors to DBP formation. Because the Chaparral Water Treatment Plant was being designed at the time of this decision, the additional treatment could be added before construction began. The GAC treatment in this facility is now operational and the benefits should be apparent in future monitoring. Addition of GAC to the CAP treatment plant required a capital project that is still under construction. Completion of this GAC facility is expected in 2007.

The largest complication with performing the IDSE during the required timeframe is the city’s continuing modifications to water treatment and the distribution system. These changes will not be completed before monitoring begins. This may mean that the some of the data will be obsolete and require additional study. We will work closely with the regulatory agencies over the next few years to understand what impact these continuing changes will have on the process to ensure compliance with DBP2 by 2012.

Contact Suzanne Grendahl at sgrendahl@scottsdaleaz.gov.
Disinfection has been used for over a century and has almost eliminated biological waterborne-disease outbreaks in developed countries. However, in the 1970s scientists observed the formation of chlorinated organic materials in drinking water systems using chlorine and recognized their carcinogenic potential. Thus arose a need to balance the health benefits of disinfection to prevent waterborne disease outbreaks against the risk of cancer from long-term (chronic) exposure to disinfection byproducts (DBPs).

Disinfection and Natural Organic Matter
All chemical disinfectants produce organic and/or inorganic DBPs of potential health concern (see table below). All disinfectants oxidize naturally occurring organic and inorganic material in water. Disinfectants react with precursors in drinking water to produce DBPs. The primary precursor is natural organic matter (NOM), which is generally measured as total organic carbon (TOC), and is comprised of roughly 50 percent carbon, 35 percent oxygen, 5 percent hydrogen, 3 percent nitrogen, and lower amounts of phosphorous, sulfur, and trace metals. Bromide is also an important precursor, because bromide is easily oxidized to aqueous bromine (HOBr/OBr⁻), a mild disinfectant that can also react to form bromine-substituted DBPs such as bromoform. Iodide undergoes similar reactions to produce HOI/OI⁻, and iodinated DBPs such as iodoform are also of potential health significance. Reactions between common disinfectants that provide residual disinfection capacity in water distribution systems, such as free chlorine, and precursors such as NOM lead to the formation of DBPs, particularly halogen-substituted organics.

Factors of DBP Formation
Numerous water quality and treatment factors affect DBP formation. The rate and extent of DBP formation are higher as TOC, bromide, temperature, disinfectant dose, and contact time with the disinfectant increase. Several mechanistic and empirical models exist and account for these factors. For example, the following empirical model predicts formation of the four regulated trihalomethanes (THM4):

$$\text{THM4} = 0.0412 \times (\text{TOC})^{1.098} \times (\text{Cl}_2)^{0.152} \times (\text{Br}^-)^{0.068} \times (\text{Temp})^{0.609} \times (\text{pH})^{1.601} \times (\text{Time})^{0.263}$$

THM4 (in micrograms per liter, µg/L) is a function of chlorine dose (Cl₂ in milligrams per liter, mg/L), bromide concentration (Br⁻ in µg/L), water temperature (degrees Celsius), pH, and contact time between the chlorine and water (hours).

The upper chart, next page, illustrates the effects of two key parameters, contact time and seasonal temperature, on THM4 formation. Water treatment plants (WTPs) commonly have 30 to 120 minutes of contact time with chlorine prior to entering the water distribution system (pipes, storage tanks, etc.) whereas contact times range from several hours to days as water is delivered to households, with typical lengths of 1 to 3 days. A significant percentage of the THM4 forms within the WTP (41 percent of THM4 formed within 4 hours in the chart), while the remainder form in the water distribution systems. Seasonal variations in water quality also impact DBP formation. For example, at common summertime temperatures of 25°C (78°F), THM4 concentrations are almost 20121124

Paul Westerhoff – Arizona State University

Disinfectant Efficacy as a disinfectant Provides disinfectant residual in water distribution system? Dominant precursors for DBP formation Dominant DBPs of regulatory concern

<table>
<thead>
<tr>
<th>Disinfectant</th>
<th>Efficacy as a disinfectant</th>
<th>Provides disinfectant residual in water distribution system?</th>
<th>Dominant precursors for DBP formation</th>
<th>Dominant DBPs of regulatory concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone (O₃)</td>
<td>high</td>
<td>no</td>
<td>bromide and TOC</td>
<td>bromate (BrO₃⁻) aldehydes</td>
</tr>
<tr>
<td>Free chlorine (HOCl/OCl⁻)</td>
<td>intermediate</td>
<td>yes</td>
<td>bromide and TOC</td>
<td>trihalomethanes and haloacetic acids</td>
</tr>
<tr>
<td>Monochloramine (NH₂Cl)</td>
<td>intermediate</td>
<td>yes</td>
<td>TOC and organic nitrogen</td>
<td>nitrosamines</td>
</tr>
<tr>
<td>Chlorine dioxide (Cl₂O₃)</td>
<td>intermediate</td>
<td>no</td>
<td>decay of chloroform</td>
<td>chlorite and chlorate</td>
</tr>
<tr>
<td>UV irradiation</td>
<td>high</td>
<td>no</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>
twice those measured at 10 °C for a 24-hour contact time.

The four trihalomethanes regulated by the U.S. EPA are chloroform $(\text{CHCl}_3)$, dichlorobromomethane $(\text{CHCl}_2\text{Br})$, chlorodibromomethane $(\text{CHClBr}_2)$, and bromoform $(\text{CHBr}_3)$. The lower chart at right summarizes the THM4 concentrations leaving a conventional water treatment plant for one water utility in central Arizona over a two-year period, along with the distribution of individual THM species. High THM4 concentrations generally occur in the summer, as expected due to warmer water temperatures. However, during the early winter of 2005, heavy rain and snow led to significant runoff and flooding. As a result, the dissolved organic concentrations increased from less than 3 mg/L in 2004 to greater than 4 mg/L in 2005 due to solubilization of soil organic matter; TOC concentrations exceeded 10 mg/L. As a result, THM4 concentrations were higher due to TOC in the runoff. In addition, the runoff diluted the salts in the surface water sources, which lowered the bromide concentration more than 50 percent. As a consequence of lower bromide levels, the distribution of chlorinated and brominated THMs shifted during the early 2005 runoff period, resulting in greater chloroform production.

**Regulatory Drivers**

Regulatory mandates drive WTP operations and technology changes. Traditionally, THMs, haloacetic acids (HAAs), and many other DBPs were viewed as posing only chronic health risks. As such, THM and HAA compliance depended on meeting regulatory levels based on usually four samples collected throughout the water distribution system on a quarterly basis. All the samples were then averaged on a running annual average to comply with the THM and HAA regulations. This permitted averaging of high summer DBP levels with low winter levels, and locations in the distribution system with shorter (low DBP levels) and longer (high DBP levels) contact times. Recent concerns over possible acute health risks from DBPs (such as spontaneous abortions in women, which refined epidemiology studies are now finding unsubstantiated) and social justice issues have resulted in new THM and HAA regulations that do not permit averaging of concentrations across the entire water distribution system. The standards must be met at each sampling location on a running annual average basis. Updates on the newest DBP regulations can be found at [www.epa.gov/ogwdw/disinfection/stage2/](http://www.epa.gov/ogwdw/disinfection/stage2/).

**Treatment Technologies Evolve**

Over the past 10 to 20 years, DBP regulations have become increasingly stringent. In response, WTP operations and technology selection have evolved. Most WTPs control DBP formation by reducing DBP precursors—removing

---

**Innovative Solutions in Hydrology**

- Vadose Zone Characterization and Modeling
- Groundwater Recharge Investigations
- Water Resources Management
- Mine Reclamation Studies
- Copper and Gold Heap Leach Optimization
- Hydrologic Testing Laboratory
  - Saturated and Unsaturated Flow Properties
  - Calibration of Monitoring Instruments
  - Large Core Testing
  - Custom Testing and Research

**GeoSystems Analysis, Inc.**

2015 N. Forbes Ave, Suite 105, Tucson, Arizona 85745 • Phone: 520-628-9330 • Fax: 520-628-1122

www.gsaanalysis.com

November/December 2006 • Southwest Hydrology • 21
Experimental Investigation

to Limit Trihalomethane Production

J. F. Leising and Eric Dano – Southern Nevada Water Authority

The Southern Nevada Water System (SNWS) operates two facilities that treat water from Lake Mead on the Colorado River and provide over 90 percent of the municipal supply to purveyors within the Las Vegas Valley. One purveyor, the Las Vegas Valley Water District (LVVWD), conducts the nation’s largest deep-well aquifer storage and recovery (ASR) program, which since its inception in 1987 has placed over 330,000 acre-feet of water into the Valley’s primary producing aquifers. Both SNWS and LVVWD routinely monitor water quality parameters including trihalomethanes (THMs).

THMs form through the reaction of dissolved organic matter (DOM) and/or bromide with hypochlorite (“chlorine” or “free chlorine”). For Lake Mead water, the reactions are 90 percent complete within about five days. The principal controls on total THM (THM4) levels include DOM and chlorine concentrations, contact time, pH, and temperature. Ozonation during treatment eliminates some DOM but enough remains that the THM4 concentration triples during the two- to three-day transit time between the treatment facility and the ASR wellhead.

Three Treatments Tested

In November 2005, we performed a bench-scale experiment to test selected chemical treatments that degrade free chlorine in the presence of aquifer lithic material. The experiment was part of a proactive effort to develop field-scale treatment methodologies to limit THM formation in aquifers following ASR injection. Three treatments—sodium thiosulfate, ammonium hydroxide, and hydrogen peroxide—were chosen based on reaction rate, safety, ease of handling, availability, and cost. Hypothesized chemical reactions between hypochlorite and each treatment compound were used to define stoichiometry and estimate the required amount of reagents. In SNWS injectate, these compounds would likely be innocuous. At low concentrations, hydrogen peroxide and sodium thiosulfate both exhibit no toxicity. Some utilities use ammonia to produce chloramines as disinfectants for drinking water. Moreover, reaction with chlorine would eliminate the treatment compounds at time scales comparable to transit time down an injection well. Little or none would enter the aquifers.

The experiment consisted of two components. The first measured the chlorine destruction rate for four stoichiometric proportions of each treatment. The second measured THM4 concentrations in treated and untreated samples after different incubation periods under conditions similar to those encountered by ASR water in the valley’s aquifers.

Sample Collection and Treatment

Initially, a 20-liter bladder was filled, and free chlorine measurements were taken at a sampling tap that had a delivery system hydraulic residence time similar to that of many ASR wells. To prevent hypochlorite photolysis and to maintain temperature, the bladder was placed in an opaque cooler and transported to the SNWS analytical laboratory. A control sample was taken, and 13 1,000-ml bottles were filled from the bladder and placed in a separate cooler. Stoichiometric proportions of 50, 75, 100, and 150 percent of each treatment were then added to individual bottles.

After one minute of agitation, we measured the free chlorine concentration in each bottle, placed some of the water in 60-ml bottles containing lithic fragments, and returned the bottles to the container. The lithic material consisted of drill cuttings (primarily limestone and dolomite) archived from the screened intervals of four ASR wells. Previously, the cuttings had been sieved at 100 mesh, both to emulate the coarser aquifer material that is present around a developed well and to minimize entry of fine particulates to the analytical apparatus. Control samples for each treatment without lithic material were prepared at approximately 100 percent of the concentration required to degrade all free chlorine. At intervals, colorimetric measurements were made of free chlorine in the bottles and in the bladder. The filled bottles were incubated under lightless conditions for periods of 1, 2, 7, 14, 21, and 49 days at 16 degrees Celsius, which approximates the average ASR injection temperature.

Results: Hypochlorite Decay

The upper chart at right illustrates the hypochlorite decay for different stoichiometric proportions of hydrogen peroxide. Irrespective of concentration, the reaction progressed substantially within about four minutes, and was essentially complete after eight to 20 minutes. Comparable reaction rates were obtained with sodium thiosulfate, but ammonia treatments required more than twice as long to achieve...
similar reduction of hypochlorite. At short times, greater stoichiometric proportions of all treatments resulted in greater free chlorine neutralization. At longer times, the distinction among stoichiometric proportions could not be determined because the limit of free chlorine detection had been reached.

For each incubation period, the THM4 concentration in an untreated control blank matched the formation potential for system water, and was thus assumed to represent the maximum THM4 produced in typical ASR water. The center chart plots the ratio of THM4 concentration to THM4 in the control blanks against incubation time for three treated samples with no lithic material and one untreated sample with lithic material. The minimum ratio shown is about 50 percent because THMs were present in the original tap sample.

At approximately one stoichiometric equivalent, both hydrogen peroxide and ammonium hydroxide essentially eliminated THM production in samples containing no lithic material. Similarly, sodium thiosulfate at a calculated 33 percent equivalent inhibited roughly half of the potential THM. This apparent disproportion is because more than one reaction between thiosulfate and hypochlorite is possible. The results indicated that neutralization of free chlorine will prevent THM genesis, which is consistent with published studies and previous SNWS investigations.

**Lithic Fragments Cause Unexpected Results**

Additionally, the lower chart shows that the presence of drill cuttings in an untreated sample prevented THM formation, probably due to lithic chlorine demand. This result was unexpected because no such effect had been observed in ASR wells. The cause of the lithic chlorine demand is unclear, but investigations tentatively indicate an association with the finer-grained fraction of the cuttings. Either bacterial growth during archival storage or residual drilling agents may be responsible.

Another unanticipated result is illustrated in the lower chart. For the hydrogen peroxide treatment, the ratio of THM4 produced relative to its formation potential rapidly stabilized at approximately 50 percent for the control sample without lithic material, but declined even further when lithic fragments were present. This indicates that over time the THM4 concentration continued to decrease below that of the initial sample – more so at higher treatment proportions. Similar though less pronounced effects occurred using ammonium hydroxide and sodium thiosulfate. Presently, the cause of the decline is conjectural and not clearly attributable to THM biodegradation. ASR sample data will be reviewed to determine whether this behavior can be identified at field scale.

**Results Show Promise for ASR**

The bench-scale experiment suggests that hydrogen peroxide and sodium thiosulfate treatments neutralize free chlorine in delivery system water at rates sufficiently rapid to allow their use at ASR injection wells. The degree of neutralization roughly equates to the stoichiometric proportion of treatment used, and similarly limits production of THM. The presence of drill cuttings inhibited THM formation and produced anomalous THM declines in a manner not yet observed in wells. We hope that these results may aid others’ efforts to reduce THM genesis and encourage further experimentation at ASR sites.

The authors wish to thank the SNWS laboratory personnel, especially Stan Van Wagenen, Geoff Haines, and Linda Blish. Contact Joseph Leising at joseph.leising@snwa.com.
Aquifer storage recovery (ASR) is increasingly being utilized by water managers as a cost-effective, viable technology for storing large volumes of water to meet long-term needs. In the Southwest, surface recharge by infiltration through large, shallow basins is the prevalent method, particularly where suitable land is available at relatively low cost. Where basin recharge is technically infeasible or economically not viable, aquifer recharge can be achieved through wells, and indeed, that is the prevailing method nationwide.

Seventy-two ASR wellfields are currently operating in 17 states with more than 300 ASR wells storing fresh water in a wide range of hydrologic and geologic settings, at depths ranging from 30 to 2,700 feet. Recovery capacities range from about 0.5 to 8.0 million gallons per day from individual wells. The largest ASR wellfield is for Las Vegas Valley Water District, with 46 ASR wells. Common to all ASR systems is that they store water in a suitable aquifer through wells when water is available and of suitable quality, and recover water from the same wells when needed.

Because disinfected water is frequently used for ASR, the subsurface fate of disinfection byproducts (DBPs) is of interest. Research (Pyne et al., 1996; Pyne 2005; Dillon et al., 2005; Clinton et al., in press; Fram, 2003) has shown that DBPs attenuate during ASR storage under hydrogeologic conditions common in most of the country, although exceptions occur, particularly in the Southwest. The ASR Well Environment

Most ASR wells store water in deep, anoxic, confined or semi-confined aquifers. Organic carbon and nutrients in the recharge water stimulate microbial activity adjacent to the well, typically within a few tens of feet. As water flows through the pore spaces of the aquifer, the number of pore volume flushes diminishes exponentially with increasing distance from the well; geochemical and microbial gradients likewise decline with distance.

Microbes exist naturally in the aquifer, and depending on the type of water being recharged, they may also be introduced. Some microbes can exist in either anaerobic or aerobic conditions, but prefer aerobic conditions such as those introduced by the oxygenated recharge water. Although the recharge water likely contains chlorine that could kill existing microbes, chlorine reacts relatively quickly with aquifer material and its concentration dissipates a short distance from the well, typically within a few days.

**THMs and HAAs in the Subsurface**

The subsurface fate of five haloacetic acids (HAAs) and four trihalomethanes (THMs), the DBPs currently regulated by the U.S. Environmental Protection Agency, has been most studied. HAAs attenuate very rapidly, typically within a few days, due to aerobic microbial activity that develops near the well. THMs may initially increase for a day or two until the chlorine has fully reacted in the aquifer, but then concentrations attenuate, typically within several weeks, due to anaerobic microbial activity. Brominated THM species attenuate first, followed by chloroform. Both THM and HAA attenuation occur simultaneously where a range of redox conditions occurs in the pore spaces around an ASR well.

The time required for HAA or THM attenuation is usually much shorter than the storage period prior to ASR recovery. The chart below shows THM and HAA concentrations at the ASR well during the first operating cycle for Centennial Water and Sanitation District, Highlands Ranch, Colorado (Pyne et al., 1996). The storage zone is a deep, confined, anoxic artesian aquifer containing fresh water. The recharge water is treated drinking water from the South Platte River, with a dissolved oxygen (DO) content of about 7 milligrams per liter (mg/L) and total organic carbon (TOC) of about 2.5 mg/L. HAAs were eliminated within nine days and THMs were eliminated within nine weeks. These results are reasonably representative of most ASR wells in the United States for which DBP data are available.

**Southwest Aquifer Conditions**

Many of the aquifers in the Southwest are unconfined or semiconfined, or water is recharged into the deep vadose zone, thus ASR storage zones typically contain oxygen. These conditions favor HAA reduction. THM reduction also can occur, however, if the recharge water contains significant concentrations of dissolved...
organic carbon, nitrogen, and phosphorus to stimulate subsurface microbial activity close to the well, depleting the oxygen and causing anaerobic conditions to develop. Recharge water treated to drinking water quality could contain sufficient nutrients in the form of ammonia (a chloramine disinfectant) and phosphorus (an orthophosphate corrosion inhibitor), but some wastewaters have much higher concentrations of these constituents, plus organic carbon. Under these circumstances, THM attenuation could occur, but more slowly than in the anaerobic aquifers, after sufficient time elapses for the chlorine residual to dissipate and a microbial biomass to accumulate around the well. Without a significant concentration of dissolved organic carbon in either the recharge water or the aquifer, or where TOC concentrations are reduced to below 1 mg/L prior to injection, such as occurs in southern California, little microbial activity would be expected. Under such conditions, any chlorine residual would tend to persist and THM concentration would tend to behave as a semi-conservative tracer.

The figure above right shows THM and HAA data for the first operating cycle at a new ASR well in Roseville, California (MWH Americas, 2006). The storage zone is a deep, confined, oxic aquifer, and recharge water is treated drinking water from Folsom Reservoir. THM and HAA reduction occurred slowly during storage, after an initial delay. The 0.46 mg/L chlorine residual in the recharge water persisted underground for several weeks, suggesting the virtual absence of organic matter or microbiota in either the recharge water or the storage zone. Baseline DO in the aquifer was 11 mg/L, and the dissolved organic content of the recharge water averaged 2 mg/L, compared to 1.4 mg/L background concentration in the aquifer. Baseline oxidation-reduction potential in the aquifer was 335 millivolts (mv); it declined steadily during storage, but did not reach a negative value (-78.5 mv) indicative of reducing conditions until after 12 weeks of storage.

Some THM reduction occurred after eight weeks of storage, but more recently, concentrations have leveled off due to the continued presence of chlorine residual and lack of organics. In contrast, HAA reduction began after just two weeks, and was essentially complete after two months.

Chloride concentration is an excellent conservative tracer at this site: the recharge water has a concentration of 4 mg/L compared to ambient groundwater’s concentration of 162 mg/L. After 10 weeks of storage, the recovered water sample had a chloride of 19 mg/L, representing a mix of 90 percent recharged water and 10 percent ambient groundwater. In ASR sites recharging reclaimed water, elevated concentrations of organic carbon and nutrients in the recharge water stimulate subsurface microbial activity very close to the well, thereby reducing THM concentrations.
Urban Effect May Increase Phoenix Precipitation

Results of a study published in the Journal of Arid Environments suggest that the Phoenix area has experienced statistically significant mean annual precipitation increases of 12 to 14 percent due to urbanization. The author of the investigation, J.M. Shepherd of the University of Georgia, used a 108-year precipitation record, global climate observations, and satellite data to look for anomalies in monsoonal rainfall around two arid cities that have experienced recent periods of rapid growth: Phoenix and Riyadh, Saudi Arabia.

The Phoenix study used 4-kilometer resolution precipitation data for about 12,600 stations in and surrounding the city, obtained from the Spatial Climate Analysis Service at Oregon State University. In addition, data from the Tropical Rainfall Measuring Mission (TRMM) were used to study mean rainfall rates in central Arizona during the extreme drought of 2003 in order to try to detect the same anomaly under relatively homogeneous drought conditions.

The increase in Phoenix precipitation was observed from the “pre-urban” period of 1895 to 1949 to the “post-urban” period of 1950 to 2003, and occurred in the northeastern suburbs and exurbs of the Phoenix metropolitan area, in the lower Verde River basin. The anomaly also occurred during the 2003 drought. It “cannot simply be attributed to maximum topographic relief and is hypothesized to be related to urban-topographic dynamics and possibly irrigation moisture,” said the article.

Riyadh has also experienced increases in temperature and precipitation in the last 10 to 15 years, but the precipitation increase could not for certain be attributed to urbanization because other, less urbanized areas in the country showed similar increases.

Shepherd plans to continue this research through the use of “coupled atmosphere-land surface models to test the hypothesis that urban-topographic dynamics and increased moisture from irrigation practices alter precipitation in arid regimes.” He also noted that the role of aerosols must be considered in future research.


Report: CA Desal is Premature from the Pacific Institute

Having completed a year-long California-focused analysis of desalination, the Oakland, California-based Pacific Institute concludes that most of the state’s seawater desalination proposals are premature.

According to its report, “Desalination, With a Grain of Salt,” most if not all of the 21 desalination projects proposed in California fail to adequately address economic realities, environmental concerns, or potential social impacts. Recent gains in desalination efficiency are being offset by rising interest rates and increases in energy and construction costs. Even the cheapest estimates exceed the costs of conservation and efficiency improvements, fixing leaks, and other sources of new supply. As a result, desalination remains an extremely expensive source of fresh water for Californians.

“Desalination will be part of California’s water future, but the future’s not here yet,” said Peter Gleick, president of the Pacific Institute. “Most California communities can find additional water, quicker and for less money, by improving efficiency and management.”

Desalination is energy intensive, making its already high costs vulnerable to rising energy prices. Electricity accounts for 44 percent of the typical water costs of a reverse-osmosis plant. An energy rate increase of 25 percent increases the cost of produced water by 11 percent. Energy price uncertainty creates costs that are ultimately paid by water users, but project cost estimates often omit such considerations.

Statewide, proposals range in size from a small plant providing water for a private development in Monterey to plants in Southern California that would be among the largest in the country. The total capacity of the proposed plants could amount to approximately 450 million gallons per day, which would represent a massive 70-fold increase over current seawater desalination capacity.

In Southern California, interest in desalination is driven by concerns about drought, population growth, and the desire to reduce dependence on outside water sources. Concerns about drought, water supply limitations, overuse of water needed for ecosystems, and growth moratoriums are driving Central California’s projects. The purposes of the four proposed plants in Northern California range from improved reliability during droughts and emergencies to meeting anticipated growth needs and providing environmental benefits.

“While desalination can produce high-quality, reliable water, it can also have significant impacts on marine ecosystems,” said Gleick. Marine organisms can be crushed against intake-pipe screens or sucked in and killed by the desalination process. Further, the discharge of the highly
salty waste brine—which is sometimes laced with processing chemicals and toxic metals—can harm local fish populations and accumulate in the food chain.

The report also noted that desalination can have impacts on community development. New water sources along the coast can lead to unanticipated and unplanned growth there.


New Process Degrades Estrogenic Compounds in Water

Medical News Today recently reported that a new process has been identified that breaks down two types of estrogenic compounds rapidly and in an environmentally friendly manner.

According to the June 28 report, scientists from Carnegie Mellon University and the U.S. Department of Agriculture found that Fe-TAML® (tetra-amido macrocyclic ligand) activators and hydrogen peroxide together create a catalytic process that quickly and nearly completely breaks down the estrogens estradiol and ethinylestradiol in the laboratory. Fe-TAML activators are “synthetic catalysts made with elements found in nature,” originating at Carnegie Mellon’s Institute for Green Oxidation Chemistry.

Estrogenic compounds, which can mimic or block the actions of hormones, are increasingly being identified in surface water and groundwater, where studies have suggested they can impact the reproduction and development of fish, frogs, and other organisms. Estrogens enter the water primarily through incomplete wastewater treatment and in runoff from livestock farms.

The researchers’ findings show promise as a means of destroying estrogenic compounds in wastewaters. In fact, they found that the catalytic process degraded 95 percent of ethinylestradiol, the synthetic compound most common in birth control pills and typically resistant to most biological degradation processes, within five minutes, said the article. The next phase of the study will involve field-testing the process on swine wastewater.


Sprinklers Benefit Community and Colorado River

For nearly the past century, farmers and ranchers in Ferron, Utah, have been flood irrigating. In this arid and mineral-laden region of central Utah, flood irrigation has resulted in large salt accumulations in Ferron Creek—a tributary to the San Rafael and Colorado rivers—and caused extensive damage to agricultural soils. Now, a pressurized irrigation system continued on next page
R & D (continued)

allows water-saving sprinkler irrigation equipment to water nearly 9,000 acres of farmland. In addition, the irrigation system, funded by the U.S. Bureau of Reclamation-led Colorado River Basin Salinity Control Program (CRBSCP), has prevented nearly 30,000 tons of salt annually from entering the Colorado River.

In 1998, prior to initiation of salinity control efforts, Ferron water losses from ground transportation of water and on farm irrigation contributed to the salt accumulation in the Colorado River. The overall efficiency of flood irrigation of agricultural soils was about 30 percent.

Today, salt accumulation has been decreased by reducing deep percolation, eliminating canal and ditch seepage, and by improving efficiency of surface irrigation by installation of the pressurized sprinkler system. Efficiency has increased to 67 percent. And another benefit has been realized: a continued water supply in the fall. Prior to salinity control efforts, the water supply for farming would typically be depleted by late summer. But in 2005, irrigation water remained in the reservoirs until late November, and not all was used.

The goal of the CRBSCP is the basinwide reduction of salt mobilization and transport to the Colorado River while allowing water resources to continue to be developed. “The program is a great example of cooperative conservation at the grassroots community level,” noted Roger Barton, program manager with Utah Association of Conservation Districts. “Ninety-seven percent of the farmland has replaced flood irrigation with the sprinkler irrigation.”

Visit www.usbr.gov/uc/.

EPA Evaluates Wadeable Streams

The U.S. Environmental Protection Agency recently released the results of its Wadeable Streams Assessment (WSA), described as the first consistent evaluation of the streams that feed rivers, lakes, and coastal
Wadeable streams in the United States. Wadeable streams are those shallow enough to be adequately sampled without a boat.

Conducted between 2000 and 2004, the study sampled 1,392 sites selected to represent the biologic condition of all streams that share similar ecological characteristics in various regions; nine such ecoregions were defined. The collaborative effort involved dozens of state environmental and natural resource agencies, federal agencies, universities, and other organizations. More than 150 field biologists were trained to collect environmental samples using a standardized method.

WSA used benthic macroinvertebrates supplemented by chemical and physical indicators to determine the biological condition of streams. Benthic macroinvertebrates include such creatures as aquatic larval stages of insects, crustaceans (crayfish), worms, and snails. Some benthic macroinvertebrates are more sensitive to pollution than others, thus data on the abundance of various types of organisms can indicate the health of a stream. Chemical indicators that were measured included phosphorus, nitrogen, salinity, and pH; physical indicators were streambed sediments, in-stream fish habitat, riparian vegetative cover, and riparian disturbance.

In the xeric ecoregion, which covers much of the West, the survey showed that 42 percent of the streams were rated “good,” 15 percent “fair,” and 39 percent “poor” (4 percent were not assessed), compared to a national average of 28 percent “good,” 25 percent “fair,” and 42 percent “poor.” Category thresholds were developed separately for each ecoregion based on the condition at the best available regional reference sites. The leading causes of biologic stress in the xeric region were identified as riparian disturbance (high levels in 44 percent of stream miles), total nitrogen (high in 36 percent of stream miles), streambed sediments (32 percent having excess stream sediments), and instream fish habitat (poor in 27 percent of streams).

The WSA is part of a series of surveys to evaluate all of the nation’s waters. Coastal waters have already been sampled, and during the next five years EPA will sample lakes, large rivers, and wetlands. Then the process will be repeated to provide ongoing comparisons of the state of the waters and point to possible future action.

The 117-page report is available at epa.gov/owow/streamsurvey.

New Desalination Technology Uses Evaporation

Arizona Technology Enterprises LLC (AzTE) announced last spring that Altela Inc., an Albuquerque-based desalination product and service company, acquired the rights to a low-cost water purification technology, “dewvaporation,” developed at Arizona State University (ASU).

Specifically, Altela acquired the exclusive worldwide license for the core intellectual property relating to the technology.

Dewvaporation was developed by ASU chemical engineering professor Jim Beckman; it removes salt from water through dew formation and evaporation. According to AzTE, the technology removes 100 percent of the dissolved salts and other contaminants from industrial wastewaters and undrinkable brackish waters found throughout the world—representing the first new low-cost water desalination technology in the last 50 years. Altela plans to incorporate the technology into its AltelaRain™ water desalination systems.

AltelaRain also evaporates water from brackish, salty waste streams, and requires only minimal amounts of low-grade heat to drive the distillation process, according to Altela’s website. The system is six times more efficient than a single-pass boiler/condenser. Altela initially targeted the technology to the oil and natural gas production industry, where the large volumes of salt water coproduced with oil and natural gas currently are either reinjected into the ground or stored in large pits, incurring high disposal costs and environmental liabilities. Altela’s approach converts the contaminated water into clean water that can be used onsite. The AltelaRain system has successfully completed oilfield beta testing. The acquisition of dewvaporation rights will allow Altela to expand its market to industrial wastewater, saltwater, and other water purification markets.

AzTE is ASU’s technology commercialization company, working with university inventors and industry to transform scientific progress into products, services, and new companies. The group transfers technologies invented at ASU, Northern Arizona University, and their affiliated research institutes to the private sector by mining university research, pursuing patents, negotiating licenses, and forming spinout companies.


LLNL Also Developing Desal Tech: Nanotube Membranes

Not to be outdone by ASU and Altela, researchers at Lawrence Livermore National Laboratory (LLNL) and the University of California at Berkeley have created a membrane made of carbon nanotubes and silicon that may offer, among many possible applications, less expensive desalinization.

The nanotubes, molecules made of carbon atoms in a unique arrangement, are hollow and more than 50,000 times thinner than a human hair. Billions of these tubes act as the pores in the membrane. The extremely smooth inner surface of the nanotubes allows liquids and gases to rapidly flow through, while the tiny pore size blocks larger molecules.

The pores are so small that only six water molecules can fit across their diameter, continued on next page
However “the gas and water flows that we measured are 100 to 10,000 times faster than what classical models predict,” said Olgica Bakajin, the Livermore scientist who led the research. “This is like having a garden hose that can deliver as much water in the same amount of time as fire hose that is ten times larger.”

The common method of desalination, reverse osmosis, uses less permeable membranes, requires large amounts of pressure, and is quite expensive. In contrast, these more permeable nanotube membranes could reduce the energy costs of desalination by up to 75 percent compared to conventional membranes used in reverse osmosis, according to a laboratory announcement.

Simulations of water transport through carbon nanotubes predict that it should flow rapidly. Water molecules should slide through either because of the “slipperiness” of the carbon nanotube surface or due to molecular ordering induced by spatial confinement. The experiments performed by the LLNL team demonstrated the predicted rapid flow, but further research is needed to determine the exact transport mechanisms.

Visit www.llnl.gov.

**USGS Reports on National Assessment of VOCs**

In April, the U.S. Geological Survey released a report describing the occurrence of volatile organic compounds (VOCs) in groundwater and drinking-water supply wells across the nation. The report concludes that VOCs were detected in aquifers nationwide, however they were not detected in most of the sampled wells: about 80 percent had no detections above a threshold of 0.2 part per billion. The compounds were detected in some domestic and public-supply wells, but seldom at concentrations greater than U.S. EPA regulatory or USGS health-based guidelines.

Groundwater samples from nearly 3,500 wells representing 98 aquifer studies were analyzed. Most were sampled between 1985 and 2002. The study was not designed to evaluate localized VOC contamination of groundwater, such as at landfills and leaking underground storage tanks. The report also presents a USGS analysis focused only on drinking-water supply wells, including more than 2,400 domestic and nearly 1,100 public wells.

According to senior author John Zogorski, “VOCs were detected in drinking-water supply wells—specifically, in 14 percent of domestic wells and 26 percent of public wells, but only a small number of samples (less than 2 percent) had VOC concentrations that were greater than federal drinking-water standards. Concentrations greater than standards were accounted for by eight compounds, in large part by the solvents perchloroethylene (PCE) and trichloroethylene (TCE), and the agricultural fumigant dibromochloropropane (DBCP).”

VOCs were detected in 90 of 98 aquifers studied. Many had VOC concentrations less than one part per billion; their prevalence at low concentrations indicates the need for continued management and monitoring of the occurrence of these contaminants over the long term.

The most frequently detected VOCs were chloroform, the solvents PCE and TCE, and methyl tert-butyl ether (MTBE). An important source of chloroform appears to be related to the recycling of water that had been chlorinated or exposed to household products containing chlorine, such as bleach. Artificial recharge of water and wastewaters containing chloroform, most likely resulting from water chlorination, is an increasingly common practice, particularly in the West. MTBE has been intensively used in reformulated gasoline for only about 10 years, but its relatively high mobility and persistence has allowed it to reach groundwater. Production of PCE and TCE has been declining since the 1970s; monitoring over the long-term will help to track any changes in their concentrations in groundwater.


**Texas Institute to Analyze Critical Water Issues**

The Texas Water Resources Institute recently established the Office of Strategic Water Issues to provide non-biased, science-based analyses of critical water issues facing Texas, according to Allan Jones, the institute’s director. The office will develop consensus recommendations and communicate them to policy and decision makers to help them make informed decisions. These objectives will be accomplished by:

- Creating an advisory committee of legislative staff, state and federal agency staff, university water resources leaders, and the private sector;
- Soliciting and responding to requests for white papers and analyses of critical and contentious water resources issues in Texas (three to six per biennium);
- Inviting experts from regulatory agencies, interest groups, and universities to analyze the issues;
- Developing consensus recommendations regarding the issues;
- Communicating with policy makers, regulators, interest groups, and the public;
- Helping secure resources needed to resolve issues and solve problems.

“We see the office as inviting experts from regulatory agencies, interest groups and universities to analyze important water issues, using the best available science and most effective policies,” Jones said. “Issues could range from protecting our aquifers from overdraft and contamination or purifying and using the state’s extensive brackish and saline water resources.”

In the 1970s, the first link between consumption of chlorinated water and cancers of the digestive and urinary tracts was made. During the same decade, THMs became the first class of halogenated DBPs to be identified and regulated in treated drinking water.

In 1979, the U.S. EPA promulgated the Interim Trihalomethane Rule, establishing a maximum contaminant level (MCL) of 100 micrograms per liter (µg/L) for the sum of the concentrations of four THMs (THM4). The THMs are chloroform (CHCl3), bromodichloromethane (CHBrCl2), dibromochloromethane (CHBrCl3), and bromoform (CHBr3). Compliance was based on a running annual average of four quarterly samples collected at four locations in the distribution system of each plant: three locations of “average” residence time and one remote location. The rule applied only to community water systems that served 10,000 people or more because of concerns that smaller systems might compromise their disinfection practices in an attempt to comply with the rule. The 100 µg/L MCL was considered achievable with the best water treatment technology available at the time and at reasonable cost, without compromising protection from pathogenic microorganisms.

In 1989, in response to Safe Drinking Water Act requirements and the identification of hundreds of other DBPs, EPA renewed its focus on DBP regulation. But establishing appropriate regulations was complicated by the fact that alternative disinfectants to chlorine, such as ozone and chlorine dioxide, were coming into use, and they formed disinfection byproducts of their own, also with adverse health effects. Furthermore, conclusive evidence linking DBPs with adverse health effects was lacking. Due to these complexities, EPA utilized a negotiated rule-making process in 1993, which resulted in the eventual promulgation of an Information Collection Rule (ICR) in 1996 and a two-stage Disinfectants/Disinfection By-Products (D/DBP) Rule in 1998.

The Stage 1 D/DBP Rule reduced the MCL for THM4 to 80 µg/L and established an MCL for five HAAs (HAA5) of 60 µg/L. Unlike the 1979 rule, the Stage 1 D/DBP Rule applied to all community water systems, including small systems.

Meanwhile, the ICR provided for the collection of a large array of water quality, treatment, and DBP data, including THM4 and HAA5 concentrations within water treatment plants and in their distribution systems. The new data showed that the running annual average compliance calculation allowed a significant amount of sampling locations within the distribution system to have DBP levels appreciably above the MCLs, even in systems fully compliant with Stage 1 D/DBP. Likewise, appreciable DBP levels in excess of the MCL were observed at different times of the year. Over the next several years, these data, combined with new health studies linking acute DBP exposure to reproductive and developmental health effects, led EPA to establish the Stage 2 D/DBP Rule in 2006.

Under Stage 2, the THM4 and HAA5 MCLs remain the same, but concentrations are regulated as a locational running annual average of four locations in the distribution system for each treatment plant, rather than a system-wide running annual average. Additionally, new sampling locations are to be determined at which maximum levels of THM4 and HAA5 concentrations are expected. This is anticipated to provide for equity in terms of DBP exposure, and a reduction in DBP concentration peaks.

Gaining Perspective

Few issues in our professional lifetime have had such an impact on raw water source selection, watershed management, water treatment plant design and operation, and the distribution of finished drinking water as the occurrence of DBPs. Our knowledge of DBP formation and health impacts, as well as efforts to protect public health, advanced significantly during the past three decades, but we still have much to learn. Both control of pathogenic microorganisms by disinfection and control of disinfection by-product formation are critical to safe drinking water.

Contact Phil Singer at psinger@email.unc.edu.

Utilities are also considering alternative disinfectants to chlorine, such as ozone, ultraviolet (UV) irradiation, chloramines, and chlorine dioxide. However, each of these options has unique DBP issues, such as bromate formation during ozonation, or the fact that UV irradiation does not provide residual disinfection capability in water distribution systems. As regulations change, these and other technologies will be required in order to control DBP formation. Although a few research studies are currently underway in the Southwest (such as AwwaRF Project 3103: Localized Treatment for Disinfection By-products), removal of DBPs after they have formed is generally not considered economically favorable.

DBPs will continue to be present in all waters containing chemical disinfectants. The U.S. Environmental Protection Agency and other researchers have identified more than 500 DBPs, although fewer than a dozen are currently regulated. Ongoing toxicity testing with these emerging DBPs indicates that nitrogen-containing DBPs, including nitromethanes and nitrosamines, pose a significantly greater risk than currently regulated THMs or HAAs. Furthermore, switching from chlorine to chloramines and other strategies implemented to control THMs or HAAs may create higher levels of these potentially more toxic nitrogen-containing DBPs. As a result, control of DBP formation will continue to be a pressing issue for the water industry.

Contact Paul Westerhoff at p.westerhoff@asu.edu.
Recent data from an ASR well that stores reclaimed water in a confined aquifer at Chandler, Arizona, showed THM concentrations declining from 170 µg/L to 19 µg/L during two months of storage, while HAA concentrations declined from 96 µg/L to less than 2 µg/L (Clinton, in press). TOC during this period fell from 7.36 mg/L to 2.94 mg/L. Nutrient and pH changes indicated microbial activity. Chloride and total dissolved solids concentrations during recharge and recovery indicated no significant mixing between recharge water and ambient groundwater.

Research Areas
As we become increasingly dependent upon aquifer recharge to sustain our water supply, we will need to focus research on enhancing water quality through natural and sustainable subsurface physical, microbial, and geochemical processes, whether they occur close to the well during ASR operations or beneath a recharge basin during surface recharge. The current understanding of subsurface microbial and geochemical processes occurring during ASR storage is limited. Much can be learned from the hazardous waste field, where “push-pull” technology, very similar to ASR, is used to clean up contaminated aquifers. Genetic research is beginning to identify the microbes contributing to observed water quality changes so that their activity may eventually be enhanced or controlled. Geochemical research is needed, with monitor wells located very close to ASR wells so that water quality changes close to the well may be studied and better understood. ASR cycle testing, particularly with sampling every few minutes during the first few hours of recovery, can illuminate water quality changes close to the well. Further research is needed to confirm the breakdown products of DBP attenuation. Through these continuing efforts, we can improve our understanding of water quality changes during ASR storage.

Contact David Pyne at dpyne@asrsystems.ws. Information about ASR technology is available at www.asrforum.com.

References

Clinton, T.A., et al., in press. Reclaimed water aquifer storage and recovery: Potential changes in water quality, Carollo Engineers P.C. research investigation for WateReuse Foundation.


MWH Americas, 2006. City of Roseville Phase II aquifer storage and recovery demonstration testing, Report to Central Valley Regional Water Quality Control Board, Monitoring Report No. 4.


Record floods ripped through rivers and washes in much of southern Arizona last summer. In these photos, Pat O’Neill, park ranger for the Bureau of Land Management, captured the effects of two big floods in Aravaipa Creek that arrived three days apart in late July and early August. The photo at left shows the channel conditions early last spring. The one at right, taken days after the second flood, shows nearly all the cottonwood trees stripped from the channel.
AHS Looks Back, Ahead

The Arizona Hydrological Society focused its 19th annual symposium on the past, present, and future of water and water science in the Southwest. The Sept. 13-16 meeting, held in Glendale, was attended by nearly 200 participants. Prior to the meeting, optional workshops were offered on decision support for drought and climate change, technical writing, and stream restoration. A post-meeting field trip toured the Agua Fria National Monument. Speakers addressed a wide variety of topics, ranging from technical to policy and planning issues, groundwater to surface water, ecology to geology, and water quality to water supply. The Lifetime Achievement Award was presented to Gail Cordy, who retired earlier this year from the U.S. Geological Survey and has been an active member and officer of both AHS and the AHS Foundation. Visit www.azhydrosoc.org.

GRAC Addresses Limited Groundwater Supplies

The Groundwater Resources Association of California (GRAC) held its 15th annual meeting in San Diego Sept. 21-22, with a theme of “Assessment, Use, and Management of Groundwater in Areas of Limited Supply.” Approximately 160 people attended the meeting, with 10 percent coming from outside of California. Many of the talks addressed the theme topic specifically in San Diego County, where conditions range from an urban coastal metropolis to rural desert communities. Prior to the meeting, some participants visited the Sweetwater River Basin to learn about attempts to integrate the management of hydrology and endangered species over these varied areas.

GRAC presented the Lifetime Achievement Award to Glenn Brown, an expert on the geology, hydrology, and water resources management of Southern California basins. He spent part of his career with the California Department of Water Resources and was a consultant for many years as well. The Kevin J. Neese Award for “character, integrity, and dedication to the groundwater profession” was presented to Sheila Kuehl, Chair of the California Senate Natural Resources and Water Committee for her efforts to bring about water legislation that would strengthen water conservation policy, increase and centralize water use data, and enhance the accuracy of water resources planning in the state.


NMWRRI Meetings Focus on Research, Water Quality

The New Mexico Water Resources Research Institute (NMWRRI) recently held two meetings. In August, the group hosted the 2006 New Mexico Technical Water Research Symposium. This popular one-day symposium was attended by about 160 people on the campus of New Mexico Tech in Socorro. The annual event is designed to showcase all types of research being performed in the state, thus a diversity of topics prevails. Sessions included pollution prevention and water treatment; issues impacting wildlife; land/atmosphere interactions; surface water modeling, measurement, and forecasting; and groundwater-surface water interactions.

NMWRRI also hosted the 51st Annual New Mexico Water Conference in Albuquerque Oct. 3-4. About 120 people attended the meeting, which focused on “Water Quality for the 21st Century.” Perspectives on New Mexico’s water quality issues were offered by federal, state, and local agencies, as well as rural, agricultural, tribal, and oil and gas communities. Groundwater contamination by septic tanks was a pervasive topic, along with compliance with the more stringent arsenic standard implemented earlier this year. New Mexico is seeking primacy from the U.S. Environmental Protection Agency for National Pollutant Discharge Elimination System permitting; it is one of few states that have not yet taken control of such permits. The meeting was preceded by a tour of the Albuquerque Water Treatment Plant.

Proceedings from both meetings are available from wrri.nmsu.edu.
Global Water Giants Backing Off

Article originally appeared in WaterTechOnline, June 27, 2006

Finding the politics of running local waterworks not to their liking, global corporate giants like RWE, Suez, and Veolia are backing away from the multi-billion-dollar commitments they made only a few years ago when they purchased water companies in the United States and elsewhere, according to a June 26 front-page story in The Wall Street Journal.

Using as an example the problems the German-based utility giant RWE faced after it purchased the small Felton, California, water utility in 2002, Journal reporter Mike Esterl wrote, “Water turns out to be less like electricity than RWE hoped. It’s heavy and hard to transport, making it difficult for a big company to build economies of scale. Regulation is never predictable. In the U.S., RWE found itself fighting town referendums and state legislatures across the country, winning many battles but losing the war.”

The newspaper quoted RWE Chief Executive Harry Roels as saying that running a water utility is “a very local business” and that a large global company “just doesn’t have outstanding advantages.”

RWE and the other giants are either trying to sell, have sold, or are scaling back their expectations for running water companies in the United States and other nations, the Journal article said.

In his article, Esterl observes that “trouble quickly emerged” for RWE after it purchased New Jersey-based American Water in 2001. Final acquisition required approvals from the many states where American Water operated; regulators then moved slowly to approve RWE/American’s rate increase requests, and “rebellious territories furnished endless headaches for management.”

The company also encountered political battles in communities like Felton, where the group FLOW (Friends of Locally Owned Water) pushed for a referendum, approved by voters last year, which proposed that the town sell bonds to buy back its water system from RWE/American, the article said.

RWE now is planning to divest American Water in an initial public offering of stock. According to the Journal, RWE last year wrote down the value of its U.S. water business by $950 million.

The Journal adds that although the move toward privatization of U.S. water utilities has all but stalled, it could pick up again as municipalities increasingly feel pressure to seek capital sources for upgrading infrastructure.


Phelps Dodge Enters Consent Order for Sulfate Reduction

In June, Arizona Department of Environmental Quality (ADEQ) Director Steve Owens announced that his agency had issued a revised draft water quality permit for the Phelps Dodge Sierrita copper mine in southern Arizona, and that ADEQ and Phelps Dodge had entered into a first-of-its-kind consent order under the state Superfund clean-up statute—known as the Water Quality Assurance Revolving Fund (WQARF) law—that requires Phelps Dodge to mitigate the plume of sulfate contamination and protect the community’s drinking water supply from further sulfate contamination.

The Aquifer Protection Permit is designed to protect groundwater in the area by requiring Phelps Dodge to employ pollution controls at three principal drainage areas at the mine, at discharging facilities in the mill area and tailings impoundments, and at wash stations used to clean mine haulage trucks and other vehicles.

It also establishes a maximum allowable limit of 250 parts per million (ppm) for sulfate in drinking water affected by the mine’s operations, the toughest sulfate level that ADEQ has ever included in a water quality permit.

Elevated sulfate levels attributable to the Phelps Dodge mine have been identified in groundwater samples...
collected from wells in the area. Although sulfate is considered a non-hazardous substance under federal and state laws, ingestion of water containing levels of sulfate exceeding 250 ppm can cause diarrhea and other health problems.

The consent order represents the first time ADEQ has ever used its authority under WQARF to require a party to deal with contamination caused by a nonhazardous substance. It requires Phelps Dodge to characterize and mitigate the sulfate plume, conduct an inventory of wells in the area, and ensure that drinking water provided to area residents meets all applicable drinking water standards, including the 250 ppm sulfate limit. It also requires Phelps Dodge to conduct quarterly water quality sampling and establish a community advisory group to keep community members informed of the company’s activities.


Grahn Joins E.L. Montgomery
Errol L. Montgomery and Associates recently announced that Howard Grahn joined the firm’s Tucson office, where he will work with the mining operations team in support of North and South American projects. With 25 years of combined mining and hydrology experience, Grahn has most recently participated in the development of automated environmental monitoring systems for such applications as site management and closure, remedial actions, cover system performance, and leach process optimization. Grahn, co-founder of Southwest Hydrology, continues in his role as technical editor of the magazine.


URS Adds Senior Staff
The Phoenix office of URS Corporation recently added to its senior-level staff.

Karen Modesto joined as a senior hydrologist following 20 years with the Arizona Department of Water Resources’ Assured and Adequate Water Supply Program. At ADWR, Modesto specialized in analyzing the availability of groundwater supplies, determining well impacts from groundwater pumping, and reviewing and approving hydrological reports and water resource investigations for new developments.

Bill Nesgood is a new senior geologist on the company’s site investigation team, bringing 30 years of experience in soil and groundwater investigation and remediation. He was formerly a geologist with Exxon, drilling exploration wells in the Gulf of Mexico and Alaska, and most recently a branch manager with Environmental Resolutions, Inc.

Anne Williamson is the Phoenix office’s new mining practice leader, coming most recently from CH2M Hill. Prior to her consulting career, she spent 15 years with Phelps Dodge managing compliance, permitting, and remediation projects at mines in the United States and abroad.


Golder Tops 1,000 Employees
Golder Associates Inc., an international groundwater engineering and environmental services consulting company, topped 1,000 employees last June and was targeted to achieve well over $100 million in net revenue for the year. The workforce grew 15 percent over the past year. Smaller offices were grown to a minimum of 25 people, senior technical experts were added throughout the company’s 41 U.S. offices, and six new offices were opened across the country.

Golder’s offices in Albuquerque and Tucson played a large part in the company’s growth spurt, expanding nearly 50 percent in the last year, largely from increased work in the mining, oil and gas, and water resources sectors, according to the company.

**On the Road to Nanjing**

*Julio Cañon Barriga – The University of Arizona/Universidad de Antioquia, Colombia*

“We are pragmatic people,” Dr. Ge JiuFeng told me during a visit to a small hydropower station located in Guangzhou province, China, one of the activities in the water science summer camp held in June 2006 in Nanjing, China. JiuFeng was the coordinator of this month-long event, which hosted 20 foreign engineers invited by the Nanjing Hydraulic Research Institute (NHRI) to learn about the developments and research done at this multipurpose national hydraulic research complex and to experience life in China.

The institute, under the joint jurisdiction of the ministries of Water Resources, Communication, and State Power, undertakes theoretical and applied research in water conservation, water resources management, hydroelectric power, waterway transportation projects, and small hydropower technology. NHRI also provides safety monitoring and inspection services for the more than 85,000 dams currently operating in the nation for hydropower generation, flood control, and irrigation.

NHRI has been particularly engaged in the design and study of China’s leading water resources management projects: the Three Gorges multipurpose dam, which will provide up to 18 megawatts of electricity to the entire nation as well as flood control and navigation facilities on the Yangtze River; and the south-to-north water transfer project, a three-stage transfer system that will convey up to one-third of the Yangtze waters (approximately 40 billion cubic meters per year) upstream to the exhausted Yellow River Basin.

The pragmatism of which Jiu Feng was proud of is especially evident in the engineering enterprises undertaken by China in the last two decades. In this period, China has considerably improved its infrastructure to meet the requirements of modern competitive markets, perhaps at an environmental cost that is still unknown and worrisome.

With 70 percent of its population living in rural areas under conditions that may be considered decent but are nevertheless precarious, and huge new housing developments occurring in populated cities where seven to ten million inhabitants is considered just average, China is a nation of contrasts. You can perceive this by simply taking a ride along one of its modern highways. For miles across the nation, the landscape shifts repeatedly among western-style cities surrounded by huge apartment complexes, smoke-spewing factories, and traditional rice paddies labored by people in conditions similar to those of a thousand years ago. A detailed map of the brand new highways well resembles the challenging reality of China: you can go anywhere, but you must be sure about where you go, because you will hardly find a U-turn along the way!

I told JiuFeng about concerns heard in the United States regarding the increasing economic power of China and India and their rising political influence. “We are far from that point of influence, maybe one or two generations, and still have many things to improve, learn about, and experience. We welcome the USA but also are strengthening ties with Europe. You cannot trust your interests as a nation in a few hands,” was his answer, reinforced by a confident smile.

Chinese people may be pragmatic, but they also appear to be united and diligent. The quick and seemingly peaceful relocation of 1.2 million people recently caused by the construction of the Three Gorges Dam project, for instance, would be unthinkable in any other country. Despite the immediate ecological and social impacts, the project is intended to benefit the entire country in the long run: the switch from coal power to hydropower is expected to reduce the use of coal and wood from the forest, preserve landscapes, and reduce air pollution.

A lasting memory of my time with new friends and colleagues at NHRI will remain with me as a reminder that dialogue and common understanding between nations is the best way to make this world a better place to live, for us and future generations.

Contact Julio Cañon Barriga at jecanonb@email.arizona.edu; visit www.nhri.cn/english.
Public and Professionals Benefit at Water Education Center

Meggan Reed – Center for Water Education

In 2001, the Metropolitan Water District of Southern California formed an independent entity known as The Center for Water Education. Its mission is “to stimulate and promote an awareness and appreciation of water-related issues—past, present, and future—and to provide leadership for a better understanding of the history of water and its importance in our daily lives.” After five years of planning, the brand new Center for Water Education is now educating water professionals and is open to the public as a complete water educational facility, containing 23,000 square feet of interactive exhibits, meeting rooms and office space. The center now hosts visitors, school groups, and community outreach programs, and provides a venue for continuing education for municipal water professionals and water science research.

Located in Hemet, in interior Southern California near Diamond Valley Lake, the new facility is a LEED (Leadership in Energy and Environmental Design) Gold-certified campus, with water and energy conservation measures built into the design. The solar installation is the largest of its kind in the western United States, and includes a hands-on exhibit where guests can view the kilowatt hours generated by the facility and learn more about this alternative energy source.

To best serve water professionals, the center offers “Contact Hour Friday” workshops for professional development, and training courses for certification and certification renewal for water utility operators on various topics, including distribution, treatment, backflow, and cross connection. Review courses and workshops will also be offered before the state certification exams. More information on these courses can be found on the center’s website.

The center’s exhibits celebrate water in many ways, including the reception area’s twenty-eight foot waterfall. “Wonders of Water” exhibits feature large freshwater aquariums, a sick fish exhibit, and a complete hydrological cycle. Spillway gates lead into the “Odyssey of Water” where visitors explore a dam façade, a California aqueduct map, a desalination exhibit, a hydroelectricity house, an impellor, and a pumping station. The exhibits all reinforce the importance of water, and include a water play lab, a water well show, and a liquid timeline.

Although the main focus of the center is to serve the continuing education needs of water professionals and water utility operators, there are events and educational programs for everyone, including K-12 school groups, a high school-level “Career Explorers” program, a landscapers group, and the general public. Field trips of elementary school visitors can enjoy the water exhibits, and their teachers can utilize the new water curriculum created by the center, aligned to the California State Standards to help their students better understand this vital resource.

Most people never call their local water utility unless they experience a problem: their water tastes bad, their bill is high, or their water doesn’t turn on. Water delivery is truly a “silent service” and the center hopes to change that notion for the public.

Visit www.centerforwater.net.

Hydrology and Water Resources
University of Arizona

Are you ready to take your study of water to the next level?

The University of Arizona Hydrology and Water Resources Department is actively seeking applicants for the Academic Year 2007-2008. Come study with an outstanding faculty of scientists and engineers to gain a whole new perspective on the field of hydrology and water resources.

Competitive student assistantships and scholarships are available. Are you a prospective student and ready for an on-campus visit? Plan to attend our annual student research symposium and recruitment event, El Dia del Agua, on Thursday, March 1, 2007. Also look for us at the Fall AGU meeting.

- Learn more at www.hwr.arizona.edu
- Contact us at 520-621-3131
- Write to us at admissions@hwr.arizona.edu
- Apply online at www.hwr.arizona.edu/apply

Come study with the original.
Come study with the best.
Hydrology and Water Resources
University of Arizona

The University of Arizona -- EEO/AA - M/W/D/V
The U.S. Geological Survey’s MODFLOW is the most widely used model for simulating groundwater flow in saturated porous media. MODFLOW reads input from a variety of text files (e.g., .bas, .dis, .nam) and writes output to text files (e.g., .lst) and binary files (e.g., .bud, .shd). Several graphical user interfaces (GUIs), both public domain and commercial, are available to create input files for and read output files from MODFLOW. Visual MODFLOW Pro 4.1, developed by Waterloo Hydrogeologic, is one such commercial product.

Visual MODFLOW Pro 4.1 enables the user to employ MODFLOW, MODFLOW-SURFACT, MODPATH, ZoneBudget, MT3Dxx/RT3D, MGO, WinPEST, and SEAWAT-2000. The Visual MODFLOW interface consists of Input, Run, and Output sections. In the Input section, the user sets up conditions for groundwater flow and contaminant transport models using a graphical interface. In the Run section, the user translates the model conditions created with the Input section into the standard input files for the appropriate models. The 3D-Explorer in the Output section allows 3-D visualization and animation of model results.

In general, Visual MODFLOW Pro 4.1 has a practical design; however, we offer a few suggestions for improving the functionality. When assigning pumping well properties, the rates for each time period must be entered individually. An improved design would allow for transfer of pumping rates over multiple time periods. We also found that manipulation of grid data was difficult because copy-and-paste was limited to one cell at a time. A more efficient design would allow the grid editor to behave like an electronic spreadsheet. The help system could also be improved by adding help buttons and menus to pop-up windows.

Overall, Visual MODFLOW Pro 4.1 is a powerful package that makes model setup and manipulation easy and efficient. The interface is intuitive and easy to use, while giving the user the ability to simulate solute transport, particle tracking, and seawater intrusion. Users with adequate knowledge of MODFLOW can easily master Visual MODFLOW using the tutorials that are provided with the software. Compared with MODFLOW GUI 4.0 from USGS, another commonly used GUI, Visual MODFLOW Pro 4.1 may lack the same level of complexity and flexibility, but it provides a streamlined platform that is easier to tackle for most users.


**Review of MODFLOW Pro 4.1**

*Reviewed by Yi-Chang Lin and Kyle E. Murray – Department of Earth and Environmental Science, University of Texas at San Antonio. Software Review courtesy of International Ground Water Modeling Center and Colorado School of Mines*

MODFLOW can easily master Visual MODFLOW using the tutorials that are provided with the software. Compared with MODFLOW GUI 4.0 from USGS, another commonly used GUI, Visual MODFLOW Pro 4.1 may lack the same level of complexity and flexibility, but it provides a streamlined platform that is easier to tackle for most users.


**Geophysical Field Surveys**

*Basin Mapping, Fractured Bedrock, and Recharge Projects*

- Resistivity
- Gravity
- CSAMT
- TDEM
- MT
- Magnetics

**Zonge Engineering & Research Organization, Inc.**

"Celebrating 34 Years in the Business of Siting Driftholes!"

**www.zonge.com**

**US OFFICES:**
- Tucson, AZ
- Sparks, NV
- Denver, CO
- Fairbanks, AK

**INTERNATIONAL OFFICES:**
- Antofagasta, Chile
- Adelaide, Australia

---

*November/December 2006 • Southwest Hydrology • 41*
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location/Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 2-4</td>
<td>California Groundwater Association. 58th Annual CGA Convention and Trade Show. Lake Tahoe, NV. <a href="http://www.groundh2o.org/events/events.html">www.groundh2o.org/events/events.html</a></td>
<td></td>
</tr>
<tr>
<td>November 8-9</td>
<td>National Ground Water Association. Environmental Forensics: Methods and Applications (short course). Houston, TX. <a href="http://www.ngwa.org/pdf/e/course/184nov06.pdf">www.ngwa.org/pdf/e/course/184nov06.pdf</a></td>
<td></td>
</tr>
<tr>
<td>December 5-8</td>
<td>National Ground Water Association. NGWA Ground Water Expo. Las Vegas, NV. <a href="http://www.ngwa.org">www.ngwa.org</a></td>
<td></td>
</tr>
<tr>
<td>December 11-15</td>
<td>American Geophysical Union. 2006 AGU Fall Meeting. San Francisco, CA. <a href="http://www.agu.org/meetings/fm06/">www.agu.org/meetings/fm06/</a></td>
<td></td>
</tr>
<tr>
<td>February 8-10</td>
<td>Water Well and Ground Water Associations of AZ, CO, NV, NM, and UT. Mountain States Ground Water Expo 2007. Laughlin, NV. <a href="http://www.mountainstatesgroundwater.com/">www.mountainstatesgroundwater.com/</a></td>
<td></td>
</tr>
<tr>
<td>February 28-March 1</td>
<td>New Mexico State University. Symposium on River Terrace and Floodplain Hydrology. Las Cruces, NM. <a href="http://spectre.nmsu.edu:16080/water/welcome.html">spectre.nmsu.edu:16080/water/welcome.html</a></td>
<td></td>
</tr>
</tbody>
</table>
Welcome to the World of Total Drilling Services

Lang Exploratory Drilling
- Reverse Air and Mud Rotary Exploration
- Large Diameter Water Supply and Dewatering
- Environmental Monitoring
- Horizontal Dewatering
- Pump Testing

Environmental Drilling Division
- Sonic Drilling
- Auger Drilling
- Remediation Drilling
- Well Development
- Tailings & Heap Leach Sampling

Core Drilling Services
- Surface & Underground Drilling
- Underground Percussive Services
- Construction & Geotechnical Drilling
- Geothermal
- Coalbed Methane

Contracting Services Group
Environmental & Core Drilling
Dayton, Nevada - Phone: (800) 327-7049
Peoria, Arizona - Phone: (800) 808-2420

Lang Exploratory Drilling
Elko, Nevada - Phone: (775) 753-8710
Salt Lake City, Utah Phone: (801) 973-6667
RockWorks
3D Subsurface Data Management, Analysis, and Visualization
All-in-one tool that allows you to visualize, interpret and present your surface and sub-surface data. Now with Access Database for powerful queries, built-in import/export tools for LogPlot data, and LAS and IHS import. Free trial available at www.rockware.com.

StereoStat
Quickly Create Stereonets and Rose Diagrams, Perform Strain/Kinematic Analysis and Analyze Structural Datasets
An integrated platform for organizing, manipulating, visualizing and interpreting datasets. RockWare StereoStat is a must-have software for anyone who needs high quality rose diagram, stereo and tangent plots.

LogPlot

EnviroInsite
Groundwater Data Visualization
A desktop tool for the analysis and communication of environmental groundwater data. If you find other graphics tools too costly, too hard to use, or lacking the essential tools required for groundwater investigations, then EnviroInsite is for you. EnviroInsite empowers hydrogeologists to analyze their own data and communicate complex ideas to clients and peers. Free trial available at www.rockware.com.

Earth Science Software • GIS Software • Training • Consulting
www.rockware.com
303.278.3534 • F: 303.278.4099