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In this issue’s feature articles, we hear from microbiologists about the “bugs” in our water. Pathogens differ from other water contaminants in one very significant way: they are alive. That fact has a substantial effect on how they are identified, how we treat water to remove them, and their subsequent fate in the environment. Additionally, sanitation practices in other countries can impact us in our own homes: the globalization of commerce means that we frequently import more than just veggies for our salad. Finally, the increasing practice of using treated effluent to recharge aquifers in the Southwest calls into scrutiny what we are sending into the subsurface. I learned a lot from working with the feature authors – perhaps even more than I wanted to know in some regards – and hope you will find this issue enlightening as well.

Thanks to all contributors to this issue, and as always, we encourage you to send in your news and ideas for articles.

Betsy Woodhouse
Publisher

Clarification
The article, “A Brief History of Ancient Pyramid Lake” (Southwest Hydrology, Vol. 3 No. 4), stated that the Truckee Meadows Water Reclamation Facility contributes 40 million gallons per day (mgd) of treated wastewater to the Truckee River. In fact, the facility is permitted to treat 44 mgd, but currently discharges only 25 to 27 mgd.
Waterborne Pathogens

Given the many developments in water treatment technology over the past century, it may seem surprising that microorganisms have been the cause of more than 75 percent of all waterborne illnesses associated with drinking water in the past 20 years and that outbreaks have more than doubled in the past few years. Are the pathogens also getting more sophisticated? Perhaps not, but new ones do continue to emerge for a variety of reasons. And they present challenges that chemical contaminants do not. For example, they require a human to identify them, and if only a few pass through the water treatment system, they can flourish under the right conditions. In this issue, we look at the major groups of pathogens, how they are detected and treated, and how their abundance varies spatially and temporally in surface waters and groundwater.

14 Why the Concern About Pathogens in Water?
Charles P. Gerba

Disease-causing microorganisms, or pathogens, did not disappear with the introduction of filtration and disinfection techniques 100 years ago. In fact, new pathogens are being identified each year. What are the most prevalent waterborne pathogens and how is science itself partly to blame for this situation?

16 Controlling Pathogens in Potable Water
Joan Oppenheimer

Water utilities have two treatment options for removing pathogens from drinking water systems: physical removal, or inactivation by impairing their reproductive capability or killing them. However, not all methods work equally well for all pathogens, and some introduce new health concerns. On top of that, the pathogens continue to evolve...

18 Microbial Detection Methodologies
Morteza Abbaspazadegan

Microbial monitoring and identification is essential to ensuring safe drinking water. Cell culturing and polymerase chain reaction assays – the methods currently and most commonly used to detect bacterial, viral, and parasitic pathogens in water – each present specific drawbacks and advantages.

20 Introduction to Microbial Source Tracking
Mansour Samadpour

Microbial source tracking (MST) allows highly specific strains of bacteria to be “fingerprinted” using DNA sequences and other unique characteristics of the microbes. By comparing bacteria isolated from a contaminated water source against those from likely animal sources of pollution, the culprit can be identified. The method is commonly used to “solve” waterborne disease outbreaks, among other applications.

22 Pathogen Distribution in an Effluent-Dominated Stream
Norma L. Duran and Loren K. Spencer

Wastewater effluent from growing populations in Western states is being discharged into stream channels to recharge depleted aquifers. Researchers are studying the fate and transport of organic and microbial pollutants in effluent discharged to the Santa Cruz River near Tucson to determine their potential effects on groundwater quality.

24 Drought May Concentrate Pathogens in Surface Water
George D. Di Giovanni

Studies show that drought conditions and seasonal variations dramatically affect levels of Cryptosporidium and Giardia in the Rio Grande. In the non-irrigation season when river flow is predominantly effluent, pathogen levels are much higher. Increased streamflow from reservoir releases during the May-to-October growing season results in a 100-fold decrease in pathogens.
Groundwater Level Monitoring at Yucca Mountain, Nevada

H. Scott Page – Harry Reid Center for Environmental Studies, University of Nevada, Las Vegas

Yucca Mountain is a rather unremarkable, 5,000-foot high ridge located in the Mojave Desert 100 miles northwest of Las Vegas. Known by scientists associated with it as “The Project,” Yucca Mountain is a decades-long and controversial endeavor to characterize, license, and operate a deep geologic repository for nuclear waste in the United States. For this reason, Yucca Mountain has become one of the most scientifically studied places in the world and the focus of a hydrological monitoring program conducted by the Harry Reid Center for Environmental Studies (HRC) at the University of Nevada, Las Vegas.

Cooperative Agreement Studies

The Yucca Mountain groundwater level measurement program is conducted within the framework of a cooperative agreement between the University and Community College System of Nevada and the U.S. Department of Energy’s (DOE) Office of Civilian Radioactive Waste Management. Current studies include: collecting groundwater level measurements on a 30-borehole network using manual and electronic methods; collecting precipitation data from a 17-station network of tipping bucket rain gauges; monitoring seismic activity with a network of digital stations and strong motion accelerometers; and conducting groundwater chemistry and tracer studies. All scientific work is carried out under technical and quality control protocols based on nuclear industry standards adopted by DOE and used by the Nuclear Regulatory Commission. After technical and quality reviews, every measurement, report, model, and associated data package is submitted to a technical information database. The suitability of Yucca Mountain as a waste repository will be evaluated in large part on the quality of this data archive.

Groundwater Monitoring Network

To obtain data on local and regional water table elevations and fluctuations, the HRC obtains water level measurements at 30 monitoring wells, ranging from a 60-foot depth-to-water well in shallow alluvium to a 2,400-foot depth-to-water well deep within the volcanic aquifer that underlies most of Yucca Mountain. A single, deep carbonate aquifer borehole is open at a depth of more than 5,000 feet below surface; water level fluctuations in this well are of particular interest because of the well’s presumed hydrologic connection with the Death Valley regional groundwater flow system, extending over thousands of square miles to distant wells, springs, seeps, and other resources of concern in the Yucca Mountain region.

Seismic Effects Noted

Continuous monitoring of groundwater levels near the site of the proposed repository is of particular interest for recording seismically induced fluctuations. Accordingly, the HRC instrumented eight boreholes with digital pressure transducers capable of measuring rapid fluctuations in the 0.1 to 0.01-foot range as often as one measurement per second. Low amplitude,
short-term fluctuations induced by earthquakes as distant as the Aleutian Islands have been documented in Yucca Mountain boreholes. Hydrographs (shown at right) from two boreholes show water level fluctuations 16 minutes after the magnitude 7.9 earthquake on Nov. 3, 2002 near Denali National Park, Alaska, nearly 2,340 miles from Yucca Mountain.

While minor water level fluctuations from distant earthquakes may be inconsequential from a repository security standpoint, automation with sensitive instrumentation has demonstrated that seismically induced changes, or hydroseisms, are probably frequent but mostly unnoticed. That earthquakes produce temporary and sustained changes in well water levels has been known for some time. But the exact relationship between an observed groundwater level fluctuation in a borehole and its distance from an earthquake epicenter of specific magnitude is less well-documented. In 1979, a theoretical relationship was derived involving earthquake magnitude, distance from epicenter, and co-seismic strain; this has shown that when seismically induced strain exceeds a certain threshold, water level changes occur in wells that may be detectable with high-precision instrumentation. These very small changes produced by distant quakes are now being observed at Yucca Mountain.

**The Next Step: Network Automation**

Besides detecting seismic effects, continuous groundwater level monitoring also improves understanding of barometric and earth tide effects on deep groundwater by revealing long-term water level trends and offering the ability to develop simultaneous system-wide datasets on groundwater fluctuations. Scientists at the Nevada Seismological Laboratory at the University of Nevada, Reno are developing a high-speed data network that could enable remote transmission of groundwater level data directly from borehole to desktop. The logistics of data transmission in this remote, unelectrified environment are daunting, requiring line-of-sight radio via repeaters to a central data collection and processing center.

While the regulatory and political future of Yucca Mountain remains unclear, the environmental monitoring initiatives conducted by independent research institutions will continue to add to the scientific understanding of its physical systems.

Contact Scott Page at spage@unlv.nevada.edu. For more information on the Harry Reid Center for Environmental Studies, visit hrcweb.lv-hrc.nevada.edu.
PCBs—Still an Issue Three Decades Later

Jenny Sterling – Daniel B. Stephens and Associates Inc.

Despite the fact that polychlorinated biphenyls (PCBs) have not been manufactured since the 1970s, they persist in the environment and remain a source of environmental concern in the Southwest, including coastal California areas such as the San Francisco, San Diego, and Santa Monica bays. Inland, PCB contamination has been associated with natural gas pipelines and distribution facilities (USEPA, 1996); abandoned mining equipment such as transformers and capacitors are also considered a potential source of PCB contamination in groundwater (Bench, 2003). The U.S. Environmental Protection Agency (EPA) determined that PCBs are a carcinogen to animals and a probable carcinogen to humans. The agency set a Maximum Contaminant Level in drinking water of 0.5 parts per billion (ppb) and a Recommended Water Quality Criteria in surface water of 0.014 ppb.

PCB Production and Use

PCBs are a class of chemical compounds in which two to 10 chlorine atoms are attached to a biphenyl molecule. Some 209 unique PCB compounds or congeners have been produced (USDHHS, 2000). Monsanto Chemical Company, the primary U.S. producer of PCBs, manufactured and marketed the compounds from 1929 through 1977 under the trade name Aroclor. PCBs were also manufactured and distributed by other producers around the world (Versar, 1976).

Production and use of PCBs peaked in 1970, when Monsanto produced 85 million pounds. A variety of industrial uses were found for PCBs, primarily because they are relatively stable under a wide range of temperatures and resist degradation and alteration. Across all industries, the

Chemical structure of the molecule of one PCB congener.
largest use for PCBs was in capacitors and transformers. Applications included those considered to be: 1) relatively closed to the environment, such as in capacitors and transformers; 2) moderately closed to the environment, as when used in heat transfer and hydraulic fluids; and 3) open-ended applications, such as in the coating of carbonless-copy paper, inks, adhesives, plasticizers, wire insulators, metal coatings, pesticide extenders, and petroleum additives (Versar, 1976).

**PCBs in the Environment**
The San Francisco Bay provides an example of where PCBs concentrate in the environment today. Although PCBs are hydrophobic, their continued presence in the bay is thought to be derived from contaminated soil or sediments from a variety of industrial sources that were transported into the bay. The tendency for PCBs to sorb to particles is illustrated by results from a study undertaken in 1994 by the Regional Monitoring Program, which showed the median concentration in the particulate fraction of water samples from the bay (0.001197 ppb) was 3.5 times greater than the median concentration of dissolved PCBs (0.000341 ppb). The median concentration in sediment was 6 ppb, or 18,000 times higher than dissolved concentrations. Very low concentrations of PCBs in a water body, as in the case of the sub-part per trillion levels mentioned above, can lead to the bioaccumulation of significantly greater concentrations in organisms. Samples of bivalve tissue in the bay had concentrations of 61 ppb, 179,000 times higher than the concentrations found dissolved in water.

**Remediation: Challenging and Costly**
Incineration is the most commonly used method to remediate PCB contamination.

In recent years, however, concern has arisen that incomplete incineration could lead to the formation of dioxins and dibenzofurans. Other proposed PCB remediation methods include wet air oxidation, biodegradation, metal-promoted dehalogenation, electrolytic reduction (USDHHS, 2000), and capping.

The physical properties and the distribution of PCBs in the environment can pose unique remediation and cost challenges. For example, sediments on the Palos Verdes Shelf off the coast of Los Angeles have been impacted by a 17 square-mile plume of PCB and DDT disposed of Monsanto into the sewer system. The plume is at a depth of 100 to 2,600 feet in coastal waters. The proposed remediation method is a sediment cap to limit mobility of sediments and prevent impacts to organisms living in the area. The depth, size, and active environment of this plume made the choice of an appropriate remedy difficult and ensured that remediation costs would be high.

Because PCBs tend to sorb quite strongly to solids, they typically are a greater concern in soils than in groundwater. In large concentrations, however, PCBs can impact groundwater. For example, at Noranda Aluminum Site in Marston, Missouri, dissolved PCB concentrations in groundwater were as high as 1,164 ppb. When PCB-containing wastes are disposed of near lakes, streams, or oceans, storm runoff and soil erosion can lead to significant suspended and dissolved concentrations in those waters. Because many PCB plumes are submerged and cover a large area, effective remediation may be difficult and expensive.

Even though PCBs have not been used for three decades, their legacy lives on in the environment today. While the highest PCB concentrations occur in soils and sediments, dissolved plumes add to the extent of environmental impacts and the challenge of remediation.

Contact Jenny Sterling at JenSterling@dbstephens.com.

**References**


GOVERNMENT

EnviroMapper for Water Version 3.0 Released

The U.S. Environmental Protection Agency’s Office of Water recently released Version 3.0 of EnviroMapper for Water, a Web-based mapping link to a wealth of water data. EnviroMapper for Water allows the user to view and map water data, such as: the uses assigned to particular waters (fishing, swimming, etc.), waters that are impaired and do not support their assigned uses, the reasons why waters are impaired, water quality monitoring information, closures of swimming beaches, and the location of dischargers. Maps can be viewed at the national, regional, state, or local level. This latest release features several new layers of water data, including EPA’s national water quality database, STORET; National Estuary Program study areas; and the location of nonpoint source projects. Other enhancements make it easier to locate and view these data, and instructions are provided on how to incorporate the resulting maps into your own Web page.

Visit www.epa.gov/waters/enviromapper.

States, Feds Unite to Protect Colorado River Habitat

In September, U.S. Secretary of the Interior Gale Norton signed an agreement with representatives of Arizona, Nevada, and California for a 50-year, comprehensive initiative to protect species and habitats on the Colorado River from Lake Mead to the U.S.-Mexico border. In comments reported by the U.S. Department of the Interior (DOI), Norton said that the Lower Colorado River Multi-Species Conservation Program will also ensure the river’s water and power resources can continue to be used by the citizens of the three lower basin states to support their economy and quality of life.

The proposed plan would create more than 8,100 acres of riparian, marsh, and backwater habitat for 31 endangered species. DOI will provide half of the estimated $620 million cost of the program over its life span, and the states will provide the remainder, with California contributing $155 million and Arizona and Nevada each paying $77.5 million.

The partnership involved in the initiative includes the Bureau of Reclamation, Fish and Wildlife Service, Bureau of Indian Affairs, Bureau of Land Management, National Park Service, the three Lower Colorado Basin states, several Colorado River tribes, water and power contractors, and other stakeholders involved in Lower Colorado River management. Under the agreement, the partners will publish a final Environmental Impact Statement for the program by late December, and will have a Record of Decision in place to implement the program by early January.

The initiative has some skeptics. According to The Associated Press as reported in Newsday on Sept.15, Jennifer Pitt, a scientist with Environmental Defense, said the new plan may simply increase the numbers of animals and plants in an already damaged environment.


Arizona DEQ Leads Statewide Perchlorate Task Force

In May, Arizona Department of Environmental Quality (ADEC) Director Steve Owens announced the formation of an interagency task force to address the extent of perchlorate contamination in Arizona’s water resources and to develop strategies for reducing the risk of perchlorate contamination. The task force includes officials from ADEQ, the Arizona Department of Health Services, the Arizona Department of Water Resources, and the Arizona Department of Agriculture.

Perchlorate has been used since the late 1940s in solid rocket fuel, munitions, and pyrotechnics. Most contamination occurs in the soil and water near military bases, aerospace installations, and defense contractors who helped produce propellants. Perchlorate is soluble and mobile in ground and surface water, and degrades very slowly in the environment.

Arizona has set a health-based guidance level for perchlorate at 14 parts per billion in water. The guidance level serves as a benchmark by which officials and consumers can judge whether a drinking water source is safe for use. Federal safe drinking water standards for perchlorate are currently lacking, but the EPA continues to study the issue.

As part of the assessment, the task force collected water samples to test for perchlorate from around 100 locations throughout Arizona, including surface waters, canals, wells, underground storage facilities, and animal feeding operations, as well as background locations. Many agencies have been collecting perchlorate data since the late 1990s, and where the data are credible and scientifically defensible, they will also be incorporated into the group’s findings.

The task force was scheduled to report its findings to the governor this fall. The report will summarize: 1) the investigation into perchlorate occurrence, and levels found throughout Arizona, 2) the status of developing a water-quality standard for perchlorate, 3) the risk to the public from consuming drinking water supplies, dairy products, and produce that contain perchlorate, and 4) recommendations for future action.

Visit www.ev.state.az.us/function/about/perch.html.

California Farmers Create Water Quality Co-op

Farmers in California have found that a cooperative effort may be the best way to comply with new requirements to monitor runoff to surface water. Agriculture is exempt from federal discharge regulations. In 1983, farmers in California were waived from state requirements as well, but the
waiver expired in early 2003. The end of the waiver would have meant that any farmer who irrigates would have to apply for a discharge permit. However, new waivers were approved by the California State Water Resources Control Board early this year, which, under pressure from environmental groups, require water quality monitoring of agricultural runoff. Regional water quality control boards now have the authority to adopt specific requirements for their respective regions.

The Central Coast Regional Water Quality Monitoring Control Board adopted a new five-year waiver that requires farmers to: complete 15 hours of farm water quality education within three years; develop farm water quality management plans that address irrigation management, nutrient management, pesticide management, and erosion control; and begin implementing the management practices identified in their plans. Those who have completed the requirements by Jan. 1, 2005 will qualify for reduced reporting requirements.

Monitoring agricultural runoff is a required part of the management plans. Farmers may perform independent monitoring or they may join the Cooperative Monitoring Program. The latter option allows individual growers to pool resources and conduct group monitoring. In July, 23 central coast agricultural organizations agreed to implement the Cooperative Monitoring Program. The program is supported initially by a combination of settlement and grant funds. For the first few years, costs to participate are expected to be minimal or none. The agricultural industry is forming an agricultural committee to oversee the program. According to the San Jose Mercury News, the water board estimated costs will be $900,000 to $1 million a year to run the co-op program. If the cost is shared equally among all central coast farmers, individual costs will be about $400 per year.

Under the program, if ambient monitoring reveals water quality problems, follow-up monitoring is almost always necessary, unless only a single possible source of the problem exists in a watershed. The Regional Board will not be able to take enforcement action unless it can show which operation(s) are responsible for the problems. The Regional Board has a variety of options once it determines the source: assist the facility to come into compliance or implement alternate Best Management Practices; issue a notice of violation or civil liability complaint; or, in the rare case where compliance with waiver conditions will not adequately control the discharge, issue individual waste discharge requirements.

Visit www.swrcb.ca.gov/rwqcb3/AGWaivers/Index.htm

CA DWR Announces Local Groundwater Grants

The California Department of Water Resources (DWR) recently awarded new grants totaling $6.2 million under the Local Groundwater Assistance Fund. Twenty-eight public agencies throughout the state received grants to perform groundwater studies and conduct groundwater monitoring and management activities. Grants ranged from $110,000 to $250,000, with most falling between $200,000 and $250,000. This is the fourth year in which grants have been awarded under the program. So far, with $15 million in funding from the program, local agencies have completed 44 projects and another 26 are underway.

The goal of the Local Groundwater Management Assistance Act of 2000 (Assembly Bill 303) is to help local agencies better understand how to manage groundwater resources effectively to ensure the safe production, quality, and storage of groundwater. Intense interest in the program is reflected in the submission this fiscal year of 72 proposals requesting nearly $17 million.

A listing of the agencies and projects receiving grants is available at the Division of Planning and Local Assistance Web site at www.grantsloans.water.ca.gov/grants/assistance.cfm.

“Use it or Lose it” in Action in New Mexico

“Use it or lose it” is a phrase often used to describe water rights law in the West: if a right is not exercised by putting the water to “beneficial” use, the owner risks relinquishing that right. In New Mexico, Phelps Dodge Mining Company recently did just that. The Santa Fe New Mexican reported that Phelps Dodge planned to transfer a right of 20 acre-feet per year to the Village of Pecos as part of a compensation package for wells that may have been impacted by mining activities. However, mining ceased in 1939 and the water rights were put into a trust, according to the paper. In 1999, the mining company made a deal with the village that also included $65,000 for hookups, said the article, but it was not until 2003 that the request for transfer of rights was submitted to the Office of the State Engineer. The state engineer recently determined that because the water hadn’t been used since the 1930s, the right no longer existed, and that the remaining 2,200 acre-feet that Phelps Dodge claimed was also in question, according to the paper.

A Phelps Dodge lawyer interviewed by the New Mexican acknowledged that the company knew the transfer request would draw scrutiny, because it not only concerned water that had not been used for 70 years, but also would change the place and purpose for which the rights were issued. A spokesman for Phelps Dodge told the paper that the company would appeal the decision on the grounds that the state engineer does not have the authority to rule the water rights abandoned, because once a right is adjudicated, legal action, not administrative action, is required to rescind the right. The Phelps Dodge representative also noted that regardless of the outcome, by attempting the transfer, the company had made a “good faith effort” to comply with their agreement with the Village of Pecos.

Permanent Injunction Issued Against California “Water Witch”

From the CA Department of Consumer Affairs

The California Board for Geologists and Geophysicists (BGG) recently won a permanent injunction against a San Diego County man who had been illegally advising consumers in Southern California on where to drill for water.

Anthony Jamarillo, a self-described “water witch,” has been under a temporary restraining order since Nov. 19, 2003, when a San Diego County Superior Court Judge found consumers could be at risk if Jamarillo continued his activities. In California, only state-licensed professionals can provide geological and geophysical services to consumers.

Jamarillo has been the subject of five complaints to the BGG: two from consumers, as well as complaints from a licensed geophysicist and from San Bernardino and San Diego counties. Reacting to these complaints, the board cited Jamarillo in January 2003 for practicing geology and geophysics without a license and fined him $2,500. The board also ordered him to cease his activities.

When Jamarillo appealed the board’s ruling, the board asked the California Attorney’s General’s Office to seek the restraining order while the case was settled. On June 7, an Administrative Law Judge rejected Jamarillo’s appeal and ordered him to pay the fine. The case that led to the board’s citation was one in which Jamarillo advised a consumer on where to drill for water.

The BGG, which is part of the California Department of Consumer Affairs, works to enhance the quality, significance, and availability of geological and geophysical services to the people of California through licensing and enforcement.

Visit www.geology.ca.gov.

New Appointments to California DWR

On Aug. 8, California Gov. Arnold Schwarzenegger announced new appointments to the California Department of Water Resources.

P. Joseph Grindstaff, of Yucaipa, was appointed chief deputy director. He served as general manager of the Santa Ana Watershed Project Authority since 1998 and was previously general manager of the Monte Vista Water District from 1994 to 1998. Grindstaff told the Riverside Press-Enterprise that in his new position he will help oversee such issues as California’s tightening of its overuse of the Colorado River and restoration of the Salton Sea.

Peter S. Garris, of Orangevale, was appointed deputy director and chief of the California Energy Resources Scheduling Division (CERS). He held the position of deputy director since 2002 and has served as chief of CERS since 2001.

Gerald E. Johns, of Sacramento, was appointed deputy director of water resources and planning. He has been acting deputy director for statewide programs since January 2004, and previously served as chief of the water transfers office from 2001 to 2004.

Nancy J. Saracino, of Sacramento, was appointed chief counsel of the department. She served as a supervising deputy attorney general at the California Department of Justice since 2002.

The California Department of Water Resources forecasts future water needs, evaluates and inventories existing water supplies, and explores conservation and storage options to meet the needs of the state’s growing population. The department has a budget of $419 million with approximately 2,500 employees, and is under the aegis of the California Resources Agency.

Visit www.dwr.water.ca.gov.

Salton Sea Authority Directorship Changes Hands

From the Salton Sea Authority Restoration Update, June 2004

The position of executive director of the Salton Sea Authority recently changed from Tom Kirk, the first full-time director of the agency, to Ron Enzweiler, an environmental engineering consultant. Kirk left the position he had held since 1997 to join an urban planning firm. Enzweiler assumed the directorship in October, having left his former position as principal and owner of Watertech Partners, an environmental engineering and consulting firm in northern California.

Kirk is credited with developing the authority from a bare-bones operation with no staff or office and a $50,000 per year budget to the most visible guardian of the sea. He, along with the authority’s board, seaside locals, and supporters from the environmental community, spent months pressing to include the Salton Sea in a multibillion-dollar deal to divert Imperial Valley irrigation water to San Diego and the Coachella Valley. The effort netted a commitment by the state to set aside $300 million for the Sea as part of the pact. Kirk said the inclusion of the Sea in the 2003 deal to transfer Colorado River water from farms to cities leaves future caretakers on firmer ground from which to fight for the lake’s future.

After the water deal was approved, Kirk encouraged the Authority board to consider a restoration plan that would use money from the agreement to manage shrinking inflows as a result of the diversions. On April 22, 2004, the board unanimously endorsed the plan, which aims to shrink the Sea into a higher quality lake. This landmark decision was the first endorsed at any level of government despite decades of studies on the Sea. It has led to drafts of a plan estimated to cost $750 million to enact. The state of California also is considering plans of its own as it sees itself as the potential leader of Salton Sea restoration efforts.
At his former company, Enzweiler most recently worked on the San Francisco Bay Delta Ecosystem Restoration Program, focusing on resolving the agricultural drainage problems of farms in the San Joaquin Valley. That program is similar to the restoration effort envisioned for the Salton Sea: in both cases, high salinity levels, water quality degradation, and habitat impairment caused by agriculture drainage must be addressed. Both situations also involve coordination of work and consensus building among local, state, and federal agencies.


Sacramento Area Hires New Flood Control Director

Stein Buer has been hired away from the California Department of Water Resources (DWR) to become the new executive director of the Sacramento Area Flood Control Agency, reported The Sacramento Bee on June 17. Buer is an engineer who, according to the article, “made headlines last year when he revealed how budget cuts were hurting the state’s flood-control system.” Last fall, Buer prepared a 110-page report detailing how the previous four years of budget cuts had “hurt levee repairs, flood forecasting, emergency response and maintenance of key flood-control structures” across the state, wrote The Bee, and as a result, Gov. Arnold Schwarzenegger stemmed further cuts to DWR’s flood control budget. Buer worked for DWR since 1981.

At SAFCA, Buer will immediately focus on upgrading Sacramento’s levees, the modification of Folsom Dam, and regional flood control projects in Yuba and Yolo counties, said the newspaper. He filled the position occupied for the past 11 years by Butch Hodgkins, who is retiring but plans to consult for SAFCA part-time. SAFCA has a staff of 12 and an annual budget of about $29 million, according to The Bee.


New Manager for Arizona’s Pinal AMA

Arizona Department of Water Resources (ADWR) Director Herb Guenther announced in May the appointment of Randy Edmond as area manager for the Pinal Active Management Area (AMA), which covers about 4,000 square miles in central Arizona between Phoenix and Tucson. Edmond will succeed Dennis Kimberlin, who recently accepted another assignment at ADWR’s Phoenix office. Prior to this appointment, Edmond was the unit supervisor at the Pinal AMA. He joined ADWR in 1981 and was one of the earliest employees of the agency, created in 1980 with the passage of the Arizona Groundwater Management Act.

“I’m looking forward to the challenges of managing the Pinal AMA at a time when we are seeing the character of the area change from almost entirely an agricultural region to one with growing residential and industrial components,” Edmond said.

The Pinal AMA manages regional water resources to ensure a reliable and sustainable water supply to efficiently meet current and future water uses, while protecting the environment and economy.

Visit www.water.az.gov/WaterManagement/Content/AMAs/PinalAMA/

DePonty Joins AMEC in Phoenix

Jersy DePonty, R.G., recently joined AMEC Earth & Environmental in Phoenix as a project geologist. He has seven years of hydrogeology experience gained from public water supply projects and the private sector. His expertise includes technical oversight and project management of water supply well installation and design, groundwater exploration drilling, feasibility assessments, and hydrogeologic analyses such as aquifer testing and alluvial basin conceptual modeling. He was previously with Brown and Caldwell in Phoenix, and prior to that worked at the ASARCO Ray Mine in Hayden.

AMEC Earth and Environmental provides environmental, geotechnical, water resources, and materials engineering services from more than 90 offices in North America.


Kroopnick Joins Arcadis G&M

Dr. Peter Kroopnick, R.G., recently joined ARCADIS G&M in their South Phoenix office as a senior scientist in the company’s site evaluation and remediation practice. Kroopnick is a geochemist and hydrogeologist specializing in the application of fate and transport models to the design of soil and groundwater remediation systems. His recent experience includes conducting assured water supply studies and work on behalf of potentially responsible parties at hazardous waste sites. Kroopnick eventually hopes to further expand his practice into the ARCADIS Guaranteed Remediation Program (GRiP), in which, for a fixed price, the company commits to perform any remediation necessary for clients to achieve regulatory closure for the site, including known and unknown contamination. He came to ARCADIS from Brown and Caldwell in Phoenix.

Why the Concern About Pathogens in Water?

Charles P. Gerba, Ph.D. – Department of Soil, Water and Environmental Science, University of Arizona

More than 100 years have passed since modern water treatment was first utilized in the United States. In major U.S. cities, the introduction of filtration followed by disinfection led to a dramatic reduction in typhoid, cholera, amoebic dysentery, and other diseases associated with fecally contaminated water. This ended the age of waterborne epidemics in the United States — at least so it was thought. But suddenly in 1993 the largest such outbreak ever documented in the United States occurred in Milwaukee, Wisconsin. More than 400,000 people developed gastroenteritis and 100 individuals died.

Investigations revealed that the protozoan parasite Cryptosporidium parvum was responsible (Mackenzie et al., 1994). After a period of heavy rains allowed some of the organisms to penetrate the filtration barrier of the treatment process.

The annual number of drinking waterborne disease outbreaks reported in the United States has more than doubled in the last few years and the number of outbreaks associated with recreational water use has more than tripled.

Background: Cryptosporidium oocysts, typically 3-7 µm in size. Image courtesy of CH Diagnostic and Consulting Services, Inc., Loveland, Colorado.

DEFINITIONS

Enteric
related to the intestinal tract
Etiologic
related to the cause of disease
Outbreak
generally two or more people experiencing similar illness that can be traced to a single source
Pathogen
disease-causing microorganism

Etiologic agents associated with drinking water outbreaks, by water type - United States, 1989-2000

Groundwater (n = 131)
- Unknown: 47%
- Bact: 8%
- Chem: 18%
- Par: 16%
- Vir: 11%
- Algae: 2%

Surface Water (n = 44)
- Unknown: 25%
- Bact: 23%
- Chem: 25%
- Par: 43%
- Vir: 2%
- Algae: 5%

Cause of outbreaks in groundwater and surface water. Unknown = acute gastrointestinal illness of unknown cause (etiology); Bact = bacteria; Chem = chemicals; Par = parasites; Vir = viruses. n = number of outbreaks traceable to either a groundwater or surface water source. An outbreak is generally defined as two or more people experiencing similar illness traceable to a common drinking water source. From the Centers for Disease Control and Prevention.
city’s water source, the organism appeared in high concentrations. Because Cryptosporidium is extremely resistant to chlorine disinfection, these infectious organisms were able to reach household taps. Surveys from a decade ago showed that Cryptosporidium was common in surface waters and in 60 percent of the treated drinking water supplies in the United States (Rose et al., 1991; LeChevalier and Norton, 1995). It became obvious that Cryptosporidium was causing a low level of endemic illness via the drinking water. Since that time, new rules for protecting, treating, and monitoring surface water supplies have been put into place in the United States and the United Kingdom. Later this year, the U.S. Environmental Protection Agency is expected to release a final version of the Groundwater Treatment Rule designed to protect drinking water from disease-causing microorganisms, known as pathogens.

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The Three Primary Categories of Pathogens

BACTERIA
Bacteria are unicellular organisms that reproduce by binary fission and vary widely in size, with diameters ranging from 0.5 micrometer (µm) to 1.5 µm and length ranging from 1 µm to 6 µm. Infectious gastroenteritis may be caused by a variety of bacterial pathogens, including E. coli O157:H7, Legionella (Legionnaire’s disease), Salmonella typhi (typhoid fever), Campylobacter jejuni (Campylobacteriosis), Shigella (shigellosis), and Vibrio cholerae (cholera). The most common clinical symptom of bacterial gastroenteritis includes cramps, abdominal distress, diarrhea, nausea, and vomiting with occasional chills, headache and mild fever. Bacterial pathogens require food, are relatively less resistant in the environment than viral or parasitic pathogens, and can effectively be inactivated in drinking water by chlorination.

VIRUSES
Viruses are the smallest (0.02-0.07 µm in diameter) and most basic of known life forms. They are composed only of nucleic acid and a protein shell (capsid). Their simple genetic system consists of single-stranded or double-stranded DNA or RNA. They take over living cells and utilize the cells’ reproductive mechanisms to replicate and continue their parasitic life. After the subsequent death of the host cell, viral particles are spread to neighboring cells, resulting in the infection of the individual.

More than 140 different enteric viruses are known to infect man. These are excreted in high numbers in the feces of infected individuals (up to 1,000 per gram of feces) and may directly or indirectly contaminate drinking water. They are commonly found in domestic wastewater, even after disinfection. Once in the environment, they can survive for months under the right conditions. The enteric viruses include the enteroviruses, rotavirus, hepatitis A and E, noroviruses, adenoviruses, reoviruses, and others. They are transmitted by the fecal–oral route, infect the gastrointestinal or respiratory tracts, and are capable of causing a wide range of illnesses including diarrhea, fever, hepatitis, paralysis, meningitis, and heart disease. Ground and surface waters may become fecally contaminated from a variety of sources, including sewage treatment plant effluents, on-site septic waste treatment discharges, land runoff from urban, agricultural, and natural areas, and leachates from sanitary landfills.

PROTOZOA
Waterborne parasites have played a major role in shaping the history of mankind and continue to challenge human civilizations. Because of their relatively large size and visibility, they have been known since ancient times. Dracunculus medinensis (guinea worm), the “fiery serpent of Moses,” is mentioned in the Bible. Of nearly 20,000 protozoan parasites, about 20 genera are known to cause diseases in humans. Water utilities continue to face challenges posed by centuries-old and newly emerging parasites.

Numerous waterborne outbreaks of giardiasis and cryptosporidiosis have been documented. Low numbers of Giardia cysts and Cryptosporidium oocysts are usually found in water supplies. These cysts and oocysts are environmentally resistant and are the infectious units of the microorganisms. After ingestion, they reside in the human gut and cause infection. In healthy people, Cryptosporidium parvum causes subclinical infections and self-limiting diarrhea. Infections in immunocompromised people, or those with underlying illnesses, can be persistent and fatal. Duration of infection can range from seven to 14 days in healthy individuals and from 23 to 32 days in the immunocompromised. As few as one to 10 viable cysts or oocysts can cause human infection.

Prepared by Morteza Abbaszadegan, Ph.D. – Arizona State University

Water-related illnesses can be classified into three groups: waterborne, water-based, and water-related. Waterborne diseases are transmitted by drinking fecally contaminated water. Microorganisms transmitted by this route are referred to as enteric pathogens since they grow in the intestinal tract and are excreted in the feces. Water-based pathogens grow in the water. Some of these, like Legionella and Mycobacterium, grow in biofilms on the walls of pipes in drinking water distribution systems. Water-related

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Controlling Pathogens in Potable Water

Joan Oppenheimer, M.S.P.H. – MWH

The water treatment industry developed from the desire to curtail waterborne disease epidemics prevalent during the 1800s and early 1900s. The threat of disease from pathogens in drinking water has been reduced through a combination of source control, application of appropriate physical and chemical treatment processes, and storage and distribution of treated water with a chlorine residual. While waterborne-disease outbreaks are much less frequent now, they still occur and are usually attributed to unusual watershed events, compromised treatment conditions, or compromised distribution systems.

The water industry continues to enhance treatment process requirements as new information is gleaned from outbreaks. A case in point was the 1993 Milwaukee outbreak that affected roughly 400,000 people. Unusual watershed conditions resulted in a large concentration of Cryptosporidium parvum in the water system even though the treatment facility met all existing regulations. This outbreak demonstrated that chlorine, the most commonly used chemical disinfectant, was completely ineffective in inactivating Cryptosporidium parvum at conventionally applied dosages. New monitoring and treatment requirements were instituted to address Cryptosporidium and are expected to become even more stringent in the coming decade.

Regulatory Requirements
The U.S. Environmental Protection Agency has promulgated a suite of regulations to limit pathogenic organisms in potable water supplies. However, most disinfectants form carcinogenic disinfection byproducts (DBPs) by reacting with the organic precursor material naturally present in source water. As a result, water utilities must provide a combination of source control, treatment, and residual disinfectant that can achieve the specified reductions of bacteria, viruses, and protozoan pathogens while meeting standards for control of DBPs.

Water utilities routinely monitor the distribution system for total coliforms, bacteria that have been used for decades as an indicator of fecal contamination. While the absence of total coliforms is an indication of water treatment effectiveness, it does not guarantee all pathogens have been removed or inactivated. The small size and simple structure of viruses make them more difficult to remove or inactivate than bacteria. Viruses and protozoan organisms are more difficult to monitor on a continual basis, therefore treatment processes must be validated and real-time process efficiency monitoring employed at treatment facilities. For surface water supplies, a combination of source control, treatment, and disinfectant application must achieve a 99.99 percent (4-log) reduction of viruses and a 99.9 percent (3-log) reduction of the protozoan pathogen Giardia lamblia. Through physical treatment (e.g., turbidity), water utilities must also achieve at least a 99 percent (2-log) reduction of the protozoan pathogen Cryptosporidium parvum.

There are no treatment requirements for pathogen reduction in groundwater supplies, but disinfection requirements are being developed in response to groundwater survey findings that wells are more susceptible to pathogen contamination than previously believed.

Source Control
Protected watersheds and deeper groundwater supplies contain fewer pathogenic organisms than unprotected lowland surface waters or shallow groundwater under the influence of surface water. Watershed protection strategies consist of land acquisitions, best management practice controls, and even the use of genetic fingerprinting to identify and limit contamination sources within the watershed. In the future, state-approved watershed control programs will receive 0.5 log of credit toward the water supply’s required log removal requirement for Cryptosporidium parvum.

Treatment Technologies
The principal strategies for treatment rely upon either physical removal of the pathogenic organisms or inactivation by chemical or physical means. Inactivation
results from a modification to the pathogenic organisms’ cellular structure or metabolism, causing death or impairment of reproductive capacity.

Conventional removal methods include chemical coagulation and media filtration. Newer technology consists of membrane filtration processes. Properly designed and operated filtration systems can achieve the full reduction credits required for viruses, *Giardia*, and *Cryptosporidium*. Because continuous monitoring for viruses and protozoan cysts is difficult, proper filter operation is demonstrated by surrogate measurements such as turbidity for conventional systems and integrity monitoring for membrane systems. But even when full pathogen control can be accomplished through physical removal, an inactivation process is required to provide a second barrier.

Disinfectants must be applied at a residual concentration level “C” for a sufficient contact time “t” that is deemed capable of achieving the required level of reduction for viruses and *Giardia*. After review of many disinfection studies, the EPA crafted disinfectant “Ct” tables that specify minimum Ct requirements needed to achieve specific log reduction levels for viruses and *Giardia*. Ct tables for *Cryptosporidium* are coming soon. As the list of disinfectants and microbial pathogens of concern expands, it has been discovered that the relative efficacy of a disinfectant is not uniform. For example, UV light radiation can achieve a 4-log reduction of most viruses at a dose of 40 mJ/cm², but for one kind, a 160 mJ/cm² dose is needed to achieve the same reduction. Some utilities are considering use of multiple disinfectants with the possibility of synergism, whereby the inactivation efficiency of two disinfectants combined might be greater than that of the same disinfectants individually.

**Distribution Control**

Protection from regrowth or system contamination following treatment is accomplished by maintaining a detectable disinfectant residual concentration throughout the distribution system and by maintaining the system under pressure. Demonstration of adequate control is achieved by monitoring total coliforms, which can be easily assayed, at specified locations within the distribution system. The absence of total coliforms minimizes the likelihood that fecal pathogens are present. Systems are required to monitor for total coliforms at a frequency proportional to the number of people served, and consumers must be notified of any positive sample results. A specified follow-up monitoring schedule must be completed whenever coliforms are detected.

While the absence of total coliforms is some indication of water treatment effectiveness, it does not guarantee the removal or inactivation of all pathogens.

Chemical and physical disinfectants acceptable for use in potable water are chlorine, chloramines, chlorine dioxide, ozone, and ultraviolet light. Chlorine is the most widely used disinfectant in the United States. Utilities began to use other disinfectants during the 1980s and 1990s when *Giardia lamblia* and *Cryptosporidium parvum* were identified as causative agents of significant waterborne outbreaks. These protozoans, particularly *Cryptosporidium*, require significantly higher chlorine dosages than bacteria and viruses, resulting in unacceptable levels of DBP formation. Therefore, stronger oxidants, such as chlorine dioxide or ozone, or ultraviolet light, which is particularly effective for *Cryptosporidium*, are required whenever protozoan reduction levels cannot be achieved through physical reduction treatment methods and chlorine disinfection.

Images: Cryptosporidium oocysts (top) and *Giardia lamblia* cysts (bottom) courtesy of CH Diagnostic and Consulting Service, Inc., Loveland, Colorado. *Giardia* on rat intestine (center) courtesy of Randy Nessler, Central Microscopy Research Facilities, the University of Iowa.

Looking Toward the Future

Infectious disease patterns have shifted throughout history due to human migration and urbanization, shifting trade and agricultural practices, genetic mutations, and climatic changes. New waterborne pathogens are likely to emerge in the future as genetic mutations enable a microbe to increase its virulence or adapt to a new host. The water industry must remain continually vigilant to ensure that current treatment practices are modified to protect against newly discovered waterborne pathogens.

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Microbial monitoring and identification is essential to identify sources of contamination and to establish the level of treatment necessary to ensure safe drinking water.

Sensitive and rapid detection of microbial pathogens is a task that has always challenged microbiologists. Earliest efforts focused on parasitic pathogens, beginning in 1674, when Antony van Leeuwenhoek peered through his rudimentary microscope and found "animalcules" that later were identified as *Giardia*. Efforts to detect and identify bacterial pathogens began around 100 years ago with the inoculation and incubation of growth media in the laboratory. These efforts resulted in the development of an array of microbial cultivation techniques. Cultivation of bacteria in the presence of different energy sources, analysis of their macromolecular composition and their metabolic byproducts, and use of specific immunological reagents subsequently came to be used for bacterial classification and identification. Development of these methods opened up a previously unimagined world of microscopic life that largely remains uncharacterized, as less than one percent of bacterial types present in any ecosystem are culturable.
Microbial monitoring and identification is essential to identify sources of contamination and to establish the level of treatment necessary to ensure safe drinking water. The molecular era that emerged in the 1980s resulted in sequence-based molecular methods for detecting pathogens. Rapid alternative approaches were then developed to allow microbial identification directly from specimens.

**Bacterial Pathogens**

Conventional bacterial monitoring in water samples worldwide relies on a 100-milliliter grab sample. The sample is analyzed by standard membrane filtration techniques: the sample is filtered onto a membrane, the membrane is placed into a culture media where the bacteria grow into colonies, and the colonies are counted.

**Viral Pathogens**

Viral detection can be accomplished by cell culture assays, polymerase chain reaction (PCR), or serological tests such as immunofluorescence, enzyme-linked immunosorbent assay, and immunoelectromicroscopy. The conventional detection method is by filter-adsorption of a large volume of water (100 to 1,800 liters), eluting the viruses off the filter into a solution that is then concentrated, and then transferring a portion of the concentrate onto the host cell. If viruses are present, they will infect the host, and physiological changes in the host cells will be visible by light microscopy. While cell culture assay can detect infectious viruses in environmental samples, without additional tests the particular strain of virus present in a sample cannot be determined. Additionally, the length of time needed to detect infection in the cell culture can vary from a few days to several weeks, depending on the type and number of viruses present.

**Parasitic Pathogens**

Currently, routine detection of *Giardia* and *Cryptosporidium* in water relies primarily on microscopic observation of water concentrates using either phase-contrast microscopy or an immunofluorescent technique; neither method can distinguish viable from nonviable cysts. Viability detection methods include infecting animal models and use of cell culture techniques, both of which are costly, time-consuming, and lack sensitivity because they require large numbers of cysts for statistically accurate results. New methods, such as immunomagnetic separation of pathogens from polluted water and integrated cell culture-PCR, have been widely and successfully used in recent studies.

**Cell Culture Methods**

Conventional methodology for the detection of enteric viruses in the environment relies on a few established cell lines that are known hosts for the specific viruses, for example kidney cells in a particular type of monkey. Cell culture involves filtering large volumes of water sample (1,000 liters), eluting the viruses off the filter into a solution that is then concentrated, and then transferring a portion of the concentrate onto the host cell. If viruses are present, they will infect the host, and physiological changes in the host cells will be visible by light microscopy. While cell culture assay can detect infectious viruses in environmental samples, without additional tests the particular strain of virus present in a sample cannot be determined. Additionally, the length of time needed to detect infection in the cell culture can vary from a few days to several weeks, depending on the type and number of viruses present.

Cell culture has some limitations compared to more sophisticated methods. In cell culture, the minimum detection level of viruses in a sample is, by definition, one infectious “unit” per unit volume – a quantity that may range from just a few virus particles to many more – some of which must be infectious. In addition, when a sample tests positive for viral infectivity using cell culture, the infectious agent is not necessarily known. Cell culture protocols do not detect all human viruses present in the environment. Noroviruses, for instance, have not yet been successfully grown in cell cultures; therefore environmental samples cannot be assayed for this pathogen by this method. Finally, since each environmental sample is unique, little is known regarding possible sample components that may inhibit the viral infectivity in culture. Cell culture, however, offers the advantage of isolating an infectious viral pathogen, and is widely accepted as the standard method for viral detection in water.

*See Detection, page 35*
One of the major challenges in environmental and regulatory microbiology is to identify sources of fecal microbial pollution that impact bodies of water. The few successful methods developed over the years have gradually evolved from simple phenotypic methods based on characteristics of the microbe to relatively sophisticated molecular (genotypic) methods based on DNA sequences. Microbial source tracking (MST) techniques differentiate between particular characteristics of the pathogens excreted by potential sources. This article focuses on the MST technique using bacteria.

The MST method is based on two principles. The first is that the genetic structure of the bacterial population is clonal: bacteria divide by binary fission. The two daughter cells that are generated as a result of this cell division are virtually identical in all aspects, and all descendents of a common ancestral cell are genetically related to each other. MST makes use of the clonal population structure of bacteria to classify organisms based on their genetic fingerprints into groups of clonal descent.

The second principle behind MST methodology is the assumption that within a given species of bacteria, various members have adapted to conditions in specific hosts or environments. Consequently, there is a high degree of host specificity among bacterial strains seen in the environment. A bacterial strain that has adapted to a particular environment or host (such as an animal’s intestinal tract) is capable of colonizing that environment and competing favorably with members of its indigenous flora. Such a bacterial strain is called a resident strain. Resident strains are usually shed from their host over a long period of time, providing a characteristic signature of their source. A transient strain is a bacterial strain introduced into a new environment or host that cannot colonize and persist there. A host sampled over time for a given species of bacteria will show that a few resident strains are consistently being shed while a large number of transient strains are shed for brief lengths of time. A study by Hartl and Dykhuizen (1984) showed that, of fecal samples from a single subject collected over 11 months, two E. coli isolates were resident strains, appearing 252 times, while 548 were transient strains.

Two broad categories of MST methodologies are used: quantitative (otherwise known as library-based) and qualitative (known also as presence/absence [P/A] methods). The quantitative MST methodologies can be divided into genotypic- and phenotypic-based methods. Qualitative methods rely on collection of bacterial strains of known origin from a target species (the source library) to identify the origin of the bacterial strains that have been isolated in the study sites. These methods rely on the identification of target organisms that can be associated with specific sources of microbial pollution.

Quantitative MST methodologies recognize that in any given pollution scenario there are multiple contributing animal sources of microbial pollution, each having unique clones of bacteria that constitute their normal flora. Isolates from appropriate bacterial species are collected from the polluted sites and from the suspected animal sources of pollution, which are identified through a sanitary survey of the area surrounding the polluted site. An appropriate molecular subtyping or phenotypic characterization method is then used to characterize all bacteria in the collections. Finally, the genetic fingerprints or phenotypic characteristics of the bacterial isolates from the polluted site are compared to those of the bacteria from the suspected animal sources (the source libraries).

When a strain of bacteria with an identical genetic fingerprint or with identical phenotypic characteristics is isolated...
from both a polluted site and a suspected animal source, the animal is implicated as a contributor of that specific clone of bacteria to the polluted site. The figure below left shows the genetic fingerprints of *E. coli* strains isolated from various sources and determined by the PFGE method; ribotyping (right) is also used.

Ribotyping and PFGE are commonly known as DNA fingerprinting methods. Ribotyping exploits the variations in DNA sequences that produce ribosomal RNA, while in PFGE the entire bacterial chromosome is cut into a small number of large fragments; the fragments are then size-separated by electrophoresis and visualized.

**Qualitative MST**

The qualitative method concept is based on the assumption that microbial species (bacteria, bacteriophages, viruses) or biotypes within a species (groups that produce a given type of toxin): a) have host-species specificity, and b) have a target organism/molecule/gene that can be detected in the water samples. The challenge of this approach is that since bodies of water are impacted by numerous sources, a large number of host-specific targets must be identified and validated. Another challenge is the need to develop quantitative approaches to correlate the levels of the targets detected in P/A methods to levels of indicator organisms, the prime targets of any MST-based methods.

**Target organisms for MST studies**

Since microbiological standards for water quality are based on numbers of indicator organisms, those organisms are a natural target for source-tracking studies. Decisions to conduct MST studies are based mostly on finding elevated levels of indicator organisms. Among those commonly targeted are *E. coli*, fecal coliforms, fecal streptococci, and enterococci.

For library-based methods, the choice of target organism is crucial, since it impacts both the study design (number of samples taken and number of isolates to be analyzed), and the size of the library. For instance, *E. coli* has just a single species, whereas enterococci or fecal coliforms have several. A larger number of samples is needed for multiple-species targets to achieve accurate representation of the target organism in the water samples.

**MST at the Institute for Environmental Health**

Most of the basic approaches for MST studies have been developed by the MST team at the Institute for Environmental Health. This team has conducted more than 150 MST studies in the United States and Canada. These studies have focused on beach pollution, drinking water sources, watershed assessment, TMDL studies, storm water systems, and the impacts of various water and land uses, including tourism in national parks, grazing and water quality, feedlots and groundwater, septic systems and water quality, and wastewater treatment plant discharges.

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**Reference**

Rapid urbanization and a growing population in the semi-arid West have led to the production of large volumes of wastewater effluent and a concurrent decline in groundwater levels. Among the options available for effluent disposal is discharge into stream channels, through which effluent can help recharge the aquifer below.

Effluent discharge into otherwise dry or intermittent streambeds in the Southwest has created new perennial stream reaches. Although these streams cannot be used for recreation, they develop riparian ecosystems and contribute to groundwater recharge. Effluent-dependent streams may provide the benefits of riparian ecosystems, but they also introduce potentially poor-quality water to the environment with the possible presence of organic and microbial contaminants. Therefore, understanding the fate and transport of any pollutants released into the stream and their potential effects on groundwater quality is important.

The Santa Cruz River near Tucson, Arizona, is an effluent-dependent stream that supports vegetation and helps replenish declining groundwater levels in the region. Recently, researchers from the USDA Water Conservation Laboratory in Phoenix, in collaboration with the U.S. Geological Survey, investigated the temporal and spatial occurrence of indicator bacteria and pathogens in surface water along this river and in groundwater from monitoring wells adjacent to it.

### E. coli numbers increased with distance from the discharge point, contrary to what might be expected from bacteria die-off.

#### Surface Water and Groundwater Sampled
Surface water was sampled at four locations along the Santa Cruz River. Sampling sites included the Roger Road Wastewater Treatment Plant (WWTP) outfall, the Ina Road WWTP flume (4.2 miles downstream from Roger Road WWTP), the Santa Cruz River at Cortaro Road (6 miles downstream from the Roger Road WWTP), and the Santa Cruz River at Trico Road (13.1 miles downstream from the Roger Road WWTP). To analyze diurnal fluctuations in concentration, multiple samples were collected over 24 hours to coincide with low, rising, peak, and falling streamflow at each of the four sites. To evaluate the spatial distribution of bacteria, surface water samples were collected from three additional points between the Ina Road WWTP flume and the Cortaro Road site. Groundwater samples were also collected from three monitoring wells adjacent to the Santa Cruz River near three of the surface water sampling points.

All samples were analyzed for total coliforms and *E. coli* by standard membrane filtration and culture-based techniques. Groundwater samples were analyzed for *Legionella* by molecular-based techniques. Water samples were filtered, followed by DNA extraction and real-time PCR with *Legionella*-specific primers. In addition, water samples from two locations were analyzed for *Cryptosporidium* and *Giardia* by concentration followed by immunomagnetic separation.

#### Diurnal Fluctuations Observed
The Ina Road WWTP flume demonstrated diurnal variation in coliform numbers, ranging from more than 800 colony forming units per 100 milliliters (CFU/100ml) at 9:00 pm to less than 100 CFU/100ml in the early morning. *E. coli* numbers demonstrated similar diurnal variations. The high and low coliform counts were concurrent with the high and
low flows in the channel, suggesting a correlation between bacterial concentrations and treatment plant hydraulics. Samples from the Roger Road WWTP outfall showed similar diurnal fluctuations. These results suggest that when assessing microbial loads for regulatory compliance in effluent-dependent streams, sampling should be conducted during both low- and high-flow periods, with average daily load reported instead of a single daily measurement.

**Concentrations Increased Downstream**
Results demonstrated that *E. coli* numbers increased with distance from the discharge point, contrary to what might be expected from bacteria die-off. Although the survival capacity of *E. coli* and pathogens in the environment is controversial, this investigation corroborates other studies that suggest *E. coli* survives and can even flourish in the soil profile (Gagliardi and Karns, 2000). Hence, once *E. coli* are introduced and established in the environment, in-situ growth can elevate counts in an affected water supply to levels above what is expected from local sources.

Coliform counts initially increased downstream with distance from the discharge point to Cortaro Road, then decreased farther downstream. Highest coliform concentrations at Cortaro Road (6,900 CFU/100 ml) prompted researchers to investigate further. Samples were collected from three additional points downstream of the Ina Road WWTP and upstream of the Cortaro Road monitoring site. An order of magnitude increase (from about 300 to 3,000 CFU/100 ml) in coliform numbers over a short distance from the discharge to Ina Road was observed. This can be attributed to reactivation of injured bacteria or regrowth in the stream and sediments. Researchers have argued that standard chlorination of municipal wastewater does not completely kill bacteria but may result in injured bacteria that are viable but nonculturable. Therefore culture-based analytical methods may actually underestimate the number of viable pathogens in treated effluent. Such underestimation may contribute to the release of large populations of viable bacteria into stream water.

Understanding the microbial loads and the physiological state of microbes in streams is just one aspect of developing effective control strategies; understanding how the environment affects survival is another. While the temporal results indicate the need for sampling during a range of flows, the spatial results stress the need to better understand how environmental factors such as nutrient availability (nitrogen, phosphorus, total suspended solids, total organic carbon), pH, temperature, and the presence of organic contaminants, particularly antibiotics, in the effluent affect the survival, reactivation, and regrowth of bacteria in streams and sediments.

**Groundwater Impacted by Effluent**
Total and fecal coliforms have been used for many years as water quality indicators. However, some pathogens, including protozoa, have higher resistance to chlorine disinfection than indicator bacteria and can survive long enough to percolate into groundwater. Hence, groundwater samples were collected from shallow wells adjacent to the Santa Cruz River near Ina, Cortaro, and Trico roads and tested for total coliforms, *E. coli*, and *Legionella*. Low numbers of coliform bacteria were detected in two of the wells (Ina and Trico) whereas *E. coli* was detected in only one of the wells (Trico). *Legionella*

See Santa Cruz, page 31
Surface water resources in the semi-arid Southwest continue to be impacted by the ongoing drought in the region. While most attention has focused on water quantity issues, water quality, especially pathogen levels, also may be greatly affected by drought conditions. This is especially true for streams and rivers that receive wastewater treatment plant effluents.

The Rio Grande serves as a natural border between Texas and Mexico, and supplies water to nearby residents for agricultural, industrial, and residential uses. Although it is a major source of both drinking and irrigation water for counties in the Rio Grande Valley region, it also receives a significant volume of wastewater treatment plant effluent and agricultural return flow. Only limited research on waterborne pathogens in the river has been performed. The Environmental Microbiology Research Program at Texas A&M Agricultural Research and Extension Center in El Paso investigates the occurrence and control of waterborne pathogens, including those in the Rio Grande near El Paso.

Under a U.S. Department of Agriculture – Rio Grande Basin Initiative grant, the river is being monitored for *Cryptosporidium* and *Giardia* pathogen levels using both a recently developed U.S. Environmental Protection Agency method and state-of-the-art molecular methods. These methods were chosen because they can determine the levels of these pathogens, their human and animal source, and whether they can cause disease in humans.

The study area covers a 30-mile stretch of the Rio Grande from El Paso downstream to Fabens, Texas. River water, wastewater treatment plant effluents (treated wastewater) returned to the river, and irrigation canal water were monitored.
**Why the Rio Grande?**
The water quality of Rio Grande in the study area may be affected by several different sources, including agricultural return flows, urban runoff, wildlife, and effluent from local wastewater treatment plants. All these potential sources of pathogens are upstream from the American Diversion Dam and the head of the American Canal. Water diverted into the American Canal is used for irrigation and drinking water during the irrigation season, which typically runs May through October. Although Ciudad Juarez, Mexico, lies outside the current study area, sewage from its estimated 1.2 million inhabitants receives minimal treatment and may significantly impact downstream Rio Grande water quality.

**Regulatory Background**
Levels of *Cryptosporidium* and *Giardia* in the water supply need to be evaluated because high levels of these pathogens may pose a risk to drinking water quality and safe agriculture. Under the recently proposed EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2), drinking water treatment plants using surface water must adhere to treatment requirements based on levels of *Cryptosporidium* in their supply water. Although research has shown that *Giardia* is found at higher levels in the Rio Grande, *Cryptosporidium* is the focus of concern.

**Why Indicators Don’t Work**
Traditional microbial indicators of fecal pollution, such as fecal coliforms, *E. coli*, and bacteriophages (viruses of bacteria), used to monitor for the potential presence of waterborne pathogens are not good indicators of the levels of *Cryptosporidium* and *Giardia*. For example, chlorination used in conventional wastewater treatment easily kills all indicator organisms such as fecal coliform bacteria, but not *Cryptosporidium* and *Giardia*. Therefore, effluent may test negative for indicators but still contain high levels of potentially infectious *Cryptosporidium* and *Giardia*. Conventional wastewater treatment plant procedures remove about 99 to 99.9 percent of the *Cryptosporidium* and *Giardia* from sewage before the effluent is discharged into surface water. However, sewage can contain tens of thousands of *Cryptosporidium* and *Giardia* per liter, so effluents may contain tens to hundreds per liter. Livestock and wildlife also have been shown to be significant sources of surface water contamination with *Cryptosporidium* and *Giardia*.

*Cryptosporidium* oocyst (left) and *Giardia* cyst (right) under epifluorescent microscopy.

During the non-irrigation season, river flow in the El Paso area consists mostly of treated wastewater discharges (effluent) from the Sunland Park Wastewater Treatment Plant in Sunland Park, New Mexico and the Northwest Wastewater Treatment Plant in El Paso.
of the LT2 because it is the more difficult pathogen to disinfect with conventional treatment methods, and at one-third the size of a Giardia cyst, Cryptosporidium cannot be removed through filtration procedures as effectively as Giardia. Under LT2 guidelines, treatment beyond current conventional treatment may be required if average Cryptosporidium levels in surface supply waters are found to be higher than 0.075 per liter (roughly one in 13 liters).

**Seasonal Variations Indicated**
The research undertaken at Texas A&M has revealed large seasonal differences in levels of Cryptosporidium and Giardia parasites during irrigation and non-irrigation seasons. (Average occurrences from multiple 10-liter samples, normalized to one liter.)

<table>
<thead>
<tr>
<th>SITE</th>
<th>Irrigation (May-Oct)</th>
<th>Non-irrigation (Nov-Apr)</th>
<th>Irrigation (May-Oct)</th>
<th>Non-irrigation (Nov-Apr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>site 1</td>
<td>0.04*</td>
<td>0.19</td>
<td>0.10</td>
<td>11.18</td>
</tr>
<tr>
<td>site 2</td>
<td>0.01</td>
<td>0.00</td>
<td>0.03</td>
<td>2.45</td>
</tr>
<tr>
<td>site 3</td>
<td>0.09</td>
<td>0.01</td>
<td>0.07</td>
<td>0.48</td>
</tr>
</tbody>
</table>

*Potable water supply. US EPA action level only if > 0.075.

Average levels of Cryptosporidium and Giardia parasitaes during irrigation and non-irrigation seasons.

**Water Treatment Issues**
The presence of pathogens is not a problem unique to the Rio Grande; most effluent-impacted surface waters in the Southwest likely will face the same issues. Upgrading conventional wastewater treatment plants with technologies such as UV treatment and advanced filtration methods could help further decrease pathogens in wastewater effluents before they are discharged to surface water. When effectively applied, UV disinfection can greatly reduce the number of viable organisms in effluent. Water quality regulations are still trying to catch up with science on the occurrence of waterborne pathogens and protection of our water resources. Significant advances have been made in drinking water treatment, but additional preventive measures are needed at wastewater treatment plants to protect water quality.

Contact George Di Giovanni at GDiGiovanni@ag.tamu.edu
Pathogens, continued from page 15

diseases are associated with transmission by insects, such as mosquitoes, that breed in water. A familiar example is the West Nile virus, which has plagued central Arizona this year.

How Common is Waterborne Illness?
Over the last 20 years, microorganisms have caused 75 percent of all waterborne illnesses associated with drinking water. The annual number of drinking water-borne disease outbreaks reported in the United States has more than doubled in the last few years and the number of outbreaks associated with recreational water use has more than tripled (CDC, 2002). Data from 448 wells in groundwater production aquifers in 36 states showed that viral contamination of U.S. groundwater is common, with eight to 21 percent of samples testing positive (Abbaszadegan et al., 2003). Viruses are believed to be more of a problem than enteric bacteria and parasites in groundwater because they can travel further distances through soil and survive longer. Sources of viral contamination in groundwater are believed to be on-site disposal systems, leaking sewer lines, and animal wastes.

These outbreaks and the recent identification of new microbial agents that could be transmitted by water have resulted in several new treatment rules for their control. Amendments to the Safe Drinking Water Act in 1996 required EPA to review and publish a list of unregulated contaminants that are known or expected to occur in public water systems and that may pose a risk in drinking water. In 1998, the first of these lists, known as the Drinking Water Contaminant Candidate List, or the CCL, was produced. The CCL contains 10 microorganisms selected for their potential for transmission by drinking water (see upper table above).

Waterborne pathogens have continued to emerge for several reasons (see lower table above). Over the last 10 years, one new potential waterborne pathogen has been identified almost every year. The application of the polymerase chain reaction (see page 35) to pathogen detection in water was a major breakthrough. This technique allows the detection of microorganisms that cannot be grown in the laboratory. It also provides a method to demonstrate whether a pathogen in water is identical to one causing illness in the exposed population. The development of molecular source tracking has led to the new field of identifying sources of waterborne agents in water.

Why Waterborne Pathogens Continue to Emerge

- Increase in sensitive populations (elderly, immuno-compromised; cancer patients)
- Globalization of commerce and travel
- Development of molecular methods for detection and source tracking
- Changes in drinking water treatment technology
- Changes in food supply production
- Evolution (genetic re-assortment)

Water-related diseases will always present a serious challenge to those responsible for managing and treating our water resources. Even during periods when outbreaks of water-related diseases are rare, water managers and health professionals must remain vigilant to new problems that are likely to be introduced through increased globalization, new technologies, and the genetic evolution of pathogens, humans, and animals.

References


AROUND THE GLOBE

An Infeasible Transfer:
The Spanish National Hydrologic Plan

Aleix Serrat – University of Arizona

“An Infeasible Transfer”: with this title, the recently elected socialist government in Spain has issued a document denouncing the Spanish National Hydrologic Plan, while presenting a set of alternative measures to cover water demand in the coastal basins of eastern Spain. The national plan was originally proposed by the socialist party prior to 1996, at which time the conservative party, led by José María Aznar, took over and pushed the project unilaterally. When the socialist party regained power in March 2004 with the election of Jose Luis Rodriguez Zapatero as president, the plan was discredited by the same party that first proposed it.

The backbone of the project was a 600-mile water transfer of 1,050 cubic hectometers (hm$^3$) (851,200 acre-feet) each year from the Ebro River in the wet northern portion of Spain to Barcelona and semi-arid southeastern regions. The undertaking would involve 11 pumping stations and 60 miles of tunnels. Spain being the country with the highest number of dams per capita and per surface area in the world – about 1,200 in total – the plan also included some 889 water infrastructure works, of which 120 were to be new large dams.

Technology Questioned
In the last few years the project raised intense criticism from environmental organizations and academia, which categorized it as a project from the last century. According to Dr. Ramon Llamas, hydrological expert from Madrid University, “the transfer is overrun by technology.” The attitude of the previous Aznar administration – basically “we’ll do it come hell or high water”– didn’t help in the controversy.

Besides potential environmental impacts in the Ebro Delta – which many, including the Ramsar Convention on Wetlands (an international organization and treaty that promotes conservation and wise use of wetlands) judged to be severe and not properly evaluated – the water to be transferred is of very poor quality, exceeding European standards for pre-treatable waters in salinity and sulfate concentrations.

Costs Questioned
The Aznar administration had estimated the cost of transferred water would be 0.31 €/m$^3$ ($382 per acre-foot), spreading a cost of €4.2 billion over 50 years. However, a socioeconomic study made by the University of Zaragoza for the World Wildlife Fund argued that the real price of the water, accounting for full costs, would be at least 0.84 €/m$^3$ ($1,036/af). Zapatero’s new Ministry of Environment recently issued a study concluding that the real cost of transferred water would be close to 1€/m$^3$ ($1,233/af), double the price of seawater desalination. Furthermore, the Aznar accounting is misleading: it ignores the opportunity costs of water in the different regions and presents an average cost to justify the entire transfer. No cost-benefit analyses were made to compare alternative solutions. Furthermore, even the water demand estimations of the project have been disputed.

Spain enjoys some of the lowest water prices and highest water consumption per capita in Europe, while rainfall averages only 24 inches per year. Consequently, experts say much could be done to improve Spain’s efficiency in water use practices. The Spanish National Hydrologic Plan, they argue, would make water demand skyrocket and create a false sense of water abundance, as happened previously with the Tajo-Segura transfer. Initiated in 1979 to transfer water from the Tajo Basin in central Spain to the Segura Basin in the south, this project has a transfer allowance of 600 hm$^3$ (490,000 af) of water per year, but for its first 28 years was able to transfer only an average of 263 hm$^3$ (213,200 af), far less than the new demands that had arisen from the project’s high expectations.

Indeed, the Environment Committee of the European Union expressed concern over the national hydrologic plan in one of its consultation papers, stating that it was “deeply worried …as they do not address the issue of sustainable water use through pricing mechanisms and other water conservation measures.”

The new socialist administration, whose party initially proposed the idea of the transfer more than ten years ago, drew a lesson from the controversy and campaigned for alternative solutions. New proposals combine improved land management practices, water conservation strategies, water reuse, increased irrigation efficiencies, better local resources management, and seawater desalination, all while seeking regional consensus.

Contact Aleix Serrat at aleix@email.arizona.edu.
Heat Used to Study Surface Water-Groundwater Link

The U.S. Geological Survey recently released a new report, “Heat as a Tool for Studying the Movement of Ground Water Near Streams.” It describes the use of heat as a no-impact tracer to help discern the interconnections between surface water and shallow groundwater. According to the report’s abstract, “Exchanges between streams and shallow groundwater systems play a key role in controlling temperatures not only in streams, but also in their underlying sediments. As a result, analyses of subsurface temperature patterns provide information about surface-water/groundwater interactions.”

The first chapter describes the general principals and procedures by which the natural transport of heat can be used to infer the movement of subsurface water near streams. Subsequent chapters describe applications of the use of heat as a tracer in the Rio Grande, the Russian and Santa Clara rivers in California, the Willamette Basin in Oregon, Trout Creek near Lake Tahoe, and Rillito Creek in Tucson.

Los Alamos Looking at Possible Contaminant Flowpaths

Hydrologists from Los Alamos National Laboratory (LANL) are looking at how rapidly contaminants from the lab can move through subsurface soils, in response to the discovery of trace levels of tritium, chlorine, and perchlorate in springs in White Rock Canyon of the Rio Grande, less than 10 miles from LANL, reported the Los Alamos Monitor. According to the newspaper, state officials and laboratory watchdog groups such as Concerned Citizens for Nuclear Safety (CCNS) view the presence of contaminants as evidence that waste from the laboratory is reaching the regional aquifer. The New Mexico Environment Division (NMED) has suggested the contaminants are moving faster through the subsurface than earlier LANL models indicated, said the article. A September 2004 report released by CCNS cited two specific cases where spring data indicate a connection to LANL, although, according to The Monitor, the non-peer-reviewed report diverted somewhat from earlier CCNS findings in concluding data from other areas are questionable.

To address the uncertainties, LANL scientists have developed a new set of conceptual models to form the basis for additional testing to determine paths the contaminants are taking, according to The Monitor. One possibility is the presence of a very deep, fast pathway, but the fact that wells between the laboratory and the White Rock Canyon springs have shown no traces of the contaminants complicates the scenario. According to LANL scientists, this “may suggest the aquifer is recharging closer to the Rio Grande than the previous model indicated, or that the springs are not connected to the regional aquifer, but rather they are discharging perched or intermediate water by another pathway that has not been evident,” said the paper. The region under investigation is geologically complex, with several major fault systems, making a clear understanding of the relationship between the springs, nearby surface water, and groundwater elusive.

To narrow down the options, LANL scientists plan to study the age of the waters discharging into the Rio Grande, said the article. The presence of younger waters in the springs would imply a faster flowpath from the laboratory. By looking closely at all the compounds present in the water, the scientists also may be able to identify a unique tracer that could implicate a specific source, such as a sewage treatment plant or other contaminant source, that could further restrict flowpath options, according to the report.

NMED and LANL are in the process of drafting a court-ordered consent agreement that will determine much of the water testing and monitoring program over the next decade.

Visit www.lamonitor.com/articles/2004/07/14/headline_news/news01.prt

Scientists Announce Western Mountain Initiative

From the U.S. Geological Survey

On May 27, 2004, a group of federal and university scientists announced the launch of the Western Mountain Initiative, a five-year effort funded by the U.S. Geological Survey to better understand ongoing changes in the mountains of the western United States. Their aim is to unravel the causes of sudden, often unwanted changes in mountainous areas, such as the recent die-off of millions of acres of trees in New Mexico, Arizona, and Southern California.

Some changes can have particularly far-reaching effects on society. “Mountains are the water towers of the West, gathering winter snow that then feeds our rivers, supplying the water so vital to wildlife, agriculture, and cities,” said Jill Baron, a USGS scientist in Fort Collins, Colorado. “With rising temperatures, winter snow has been melting earlier. If this trend continues, there will be less water available during long, hot summers.”

Rising temperatures also may be partly responsible for another ongoing change the scientists will examine: the widespread melting of glaciers in western mountains.

The consortium will bring together more than a decade of research conducted in national parks and other protected areas in the West. Because these areas have experienced minimal direct intervention by humans, national parks and other protected areas are ideal laboratories for detecting the effects of climatic changes.

“In many ways, mountains are uniquely sensitive to sudden changes, such as those driven by climatic variability and change,” said Dave Peterson, a scientist with the U.S. Forest Service in Seattle, Washington.
“Western mountains are like the proverbial canary in a coal mine. By bringing together a diversity of past and ongoing research, we hope to detect broad trends, identify thresholds and triggers of change, and provide ways to minimize potentially undesirable changes to some of our nation’s most valued natural resources.”

For additional information about the Western Mountain Initiative, contact Craig Allen at 505-672-3861 ext. 541 or craig_allen@usgs.gov.

California Groups to Evaluate Wetlands Health

From the U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency recently awarded a $200,000 grant to the Southern California Coastal Water Research Project (SCCWP) to assess the health of wetlands in Southern California. SCCWRP will use the money, plus $70,000 of its own, to work with local, state, and federal organizations to assess the condition of wetlands in Southern California by collecting field measurements and evaluating existing data. Testing is underway at approximately 57 sites in five counties on the coast from Santa Barbara to San Diego. The information will be used to identify indicators, such as vegetation, hydrology, and landscape conditions that can be used to measure wetlands health statewide.

“In California, wetlands loss and degradation resulting from urbanization is being counteracted to some degree by a tremendous public investment in wetland conservation, restoration, and management,” said Dr. Martha Sutula, senior scientist at SCCWRP. “This project will contribute to a statewide effort to develop diagnostic tools and data needed to implement affordable monitoring of California’s wetland resources.”

According to EPA, more than 90 percent of the wetlands in California have been converted to urban, agricultural, and other uses. Numerous groups statewide, including public agencies and environmental nonprofits, are working to restore thousands of acres of wetlands in California. More than one third of the nation’s threatened and endangered species need wetlands for survival. Wetlands reduce flood risks, recharge aquifers, and protect drinking water from pollution.

The EPA also awarded $250,000 to the Association of Bay Area Governments to assess wetlands in northern California.


Regional Aquifer Study Funded in West Texas

Five universities in Texas have been funded by the U.S. Department of Agriculture to study water resources in West Texas, reported the Odessa American. Researchers from Sul Ross State University, Southwest Texas State University, Angelo State University, Lamar University, and Sam Houston State University will investigate West Texas aquifer systems, groundwater resources, conservation practices, and water use in the area. Preliminarily called the Sustainable Agricultural Water Conservation and the Rio Grande Basin project, work was scheduled to begin in June, according to the article.

The goal of the project is to determine how much water is in the aquifers and to provide information to help water managers in Texas and Mexico better allocate their resources. The Desert Mountain Times of Alpine, Texas reported that initial federal funding for the project is $1.8 million for the first year. According to the Times, Sul Ross Associate Professor Kevin Urbancyzk said the project will more than double the number of springs and wells being monitored in the area, and will include development of a regional groundwater database that is accessible on the Internet.


Land Use Reflected in Water Quality of Salt Lake Region

From the U.S. Geological Survey

Water samples collected by the U.S. Geological Survey in the Great Salt Lake watershed, including parts of Utah, Idaho, and Wyoming, generally meet existing guidelines for drinking water and the protection of aquatic life, although water quality in some specific areas has elevated concentrations of pesticides, volatile

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organic compounds (VOCs), nutrients, chloride, and elements such as arsenic and lead, according to the results of a five-year water quality study by the USGS.

Rivers and Streams
More than 80 percent of the samples collected from streams affected by agricultural and a combination of mixed land uses had phosphorus concentrations that exceeded the U.S. EPA desired goal of 0.1 milligrams per liter (mg/l) to prevent nuisance plant growth in streams. Although nutrients occur naturally in streams, additional and potentially elevated sources include agricultural and urban runoff and wastewater discharge.

In many streams near the mountain front, aquatic communities have been impacted by increased water temperature and nutrient and dissolved-solid concentrations as a result of water diversion, mainly for irrigation. Continued drought conditions and increasing demands for water in the areas surrounding the Great Salt Lake make this an ongoing water-quality issue, said Thiros.

At least one pesticide was detected in all but one of the 24 streams sampled. Insecticides — most commonly carbaryl, diazinon, and malathion — were detected more frequently in urban streams than agricultural streams. Diazinon was detected in about 90 percent of 42 samples from the urbanized Little Cottonwood Creek, but in only about 4 percent of 26 samples from Cub River, classified as agricultural. Thiros suggested that this is most likely because nutrients, pesticides, and VOCs accumulate between storms on impervious surfaces in urban areas and then are transported to streams in storm runoff. During the winter of 1999, for example, chloride concentrations in Little Cottonwood Creek often exceeded the EPA aquatic-life guideline following winter storms and the application of salt to area roads.

Aquatic-life guidelines for arsenic, cadmium, copper, lead, mercury, silver, and zinc were exceeded in sediment samples from streams that were affected by mine-tailing deposits and smelters (including some in urbanized streams). In areas with little mining or urban influence, such as the Bear River basin, trace-element concentrations were low compared to those measured in other parts of the nation.

Groundwater
The USGS study revealed that the median concentration of nitrate (6.8 mg/l) in shallow groundwater underlying residential and commercial land in Salt Lake Valley was almost five times the national median (1.4 mg/l) for groundwater studies in similar urban areas and was the highest measured in 34 urban studies across the nation. Thiros said that although nitrate does occur naturally in groundwater, elevated concentrations in urban and agricultural areas could result from leaking septic systems and sewer pipes, as well as from fertilizer applications. Even though this shallow water is not currently used for drinking, Thiros said the potential exists for contaminated water in the shallow aquifer to move downward to the underlying aquifer that is used as a public supply.

VOCs and pesticides were detected in water from 23 of 31 public-supply wells sampled in Salt Lake Valley, mostly at very low concentrations. The widespread occurrence of the VOC chloroform in Salt Lake Valley is likely a result of chlorinated public-supply water used to irrigate lawns and gardens in residential areas that then recharges the deeper aquifer. Although the concentration of these compounds measured in groundwater used for public supply is not a known health concern according to current standards, the occurrence of these compounds in the deeper groundwater presents the possibility that water with a higher concentration may enter this aquifer in the future.

This work was originally presented at the American Society for Microbiology 103rd General Meeting, Washington, D.C., 2003 (Abstract 03-GM-A-4075-ASM). The views expressed in this article are those of the individual authors and do not necessarily reflect the views and policies of the USDA, the USGS, or EPA. For more information, contact Norma Duran, now at the U.S. Environmental Protection Agency, at Duran.Norma@epa.gov. The authors wish to acknowledge Gaul Comly of the USGS for project development, data, and review.

References

Business Directory

HydroSystems, Inc. (HSI) has an opening for an entry- to mid-level groundwater hydrogeologist having 1 to 3 years experience. The successful candidate will possess a strong technical and office skill set to compliment an established, successful, highly productive, innovative team. Salary is dependent on education and experience. HSI offers competitive compensation and benefit package. For more information visit www.hydrosystems-inc.com. Fax or email resume to MM at 480-517-9049 or marla@hydrosystems-inc.com.

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NGWA Announces 2005 Ground Water Summit

The Association of Ground Water Scientists and Engineers, a division of the National Ground Water Association, recently announced the launch of a new technical conference, the Ground Water Summit, which will take place April 17-20, 2005 in San Antonio, Texas. The goal of the meeting is to “engage local, national, and international science partners in the exchange and dissemination of technical information and new developments, policy and regulatory issue discussions, and the promotion of goodwill among ground water professionals worldwide,” according to NGWA. Sessions planned for the summit include professional development courses, the Darcy and Birdsall lectures, a science and policy panel debate, and technical sessions. In addition, awards, a field trip, a student mentoring program, and networking events are in the works. Abstracts are due November 22!

Visit www.ngwa.org/e/conf/0504175095.shtml.

Digital Hydrogeologic Framework Model Published for Mesilla Basin

From the NMWRRI Divining Rod, July 2004

The New Mexico Water Resources Research Institute has published a new report on the hydrogeology of the Mesilla Basin. The report is one step toward the long-term goal of developing a state-of-the-art hydrogeologic model of the basin and contiguous parts of the southern Jornada del Muerto Basin in the El Paso, Texas region. It was produced by John W. Hawley and colleagues and funded by the Lower Rio Grande Water Users Organization and the New Mexico Interstate Stream Commission.

The report focuses on the hydrogeologic framework of the Rio Grande rift-basin and river-valley fills that collectively form the major aquifer systems, and how basin-fill composition and structural boundary controls influence groundwater flow and geochemical/geothermal conditions. Of special interest and importance are 17 new hydrogeologic cross sections and a map of the basal topography of basin-fill deposits in the binational, tristate Mesilla Basin area.

The 100-page report, “Creation of a Digital Hydrogeologic Framework Model of the Mesilla Basin and Southern Jornada del Muerto Basin,” by John W. Hawley and John F. Kennedy, comes with a CD containing several plates. Copies can be obtained from NMWRRI at 505-646-4337 or downloaded from wrri.nmsu.edu.

NWRA Upgrades Web Site

The Nevada Water Resources Association (NWRA) recently unveiled its new and improved Web site at www.nvwra.org. The site will be regularly updated with information on upcoming meetings (with online registration available), information about the association, its officers, membership options, and publications. Publications currently available include Water Rights in Nevada, by Michael D. Buschelman ($22) and The Nevada Water Law Book, by James H. Davenport ($40).

Continued next page
The site also has a “members only” section that provides access to the NWRA membership directory, NWRA newsletters, discount rates to events, and access to a new periodical, *Journal of the Nevada Water Resources Association*. Conceived and developed by Mike Strobel, NWRA Director and Associate District Chief, U.S. Geological Survey, this online journal intends to provide regional scientific information and political and public opinion views that impact water management in Nevada. The journal is to be published twice per year with six to eight papers per issue, and will be available only to NWRA members. Papers will cover a variety of Nevada water issues, including water resource management, water supply, water use, water quality, groundwater, surface water, modeling, and GIS applications. Papers will be peer-reviewed and approved by the journal’s editorial board.

**AZ, CA, and NM Groups Hold Annual Meetings**

Within the space of 10 days in September, the Arizona Hydrological Society (AHS), the Groundwater Resources Association of California (GRA), and the New Mexico Water Resources Research Institute (NMWRRI) all held their annual meetings. AHS’s Seventeenth Annual Symposium took place in Tucson, with the theme, “The Value of Water,” addressed by keynote speakers Gary Wolff of the Pacific Institute and Janie Chermak of the University of New Mexico. Gary G. Small, a founder of AHS and its first president, now a principal of HydroSystems, Inc., was awarded the AHS Lifetime Achievement Award. Field trips were offered to Kartchner Caverns and Arizona’s wine country (to discuss the hydrology, of course).

The Thirteenth Annual Meeting of GRA in Sonoma County, California, focused on “Managing Aquifers for Sustainability: Protection, Restoration, Replenishment, and Water Reuse.” John Bredehoeft, formerly with the USGS and now with The HydroDynamics Group, was awarded the GRA Lifetime Achievement Award, and the California Department of Water Resources received the Kevin J. Neese award for significant accomplishments during the previous year. The meeting also included a program on the geology of wine country and a pre-meeting wine tasting.

In Ruidoso, New Mexico, NMWRRI’s 49th Annual Water Conference focused on “Water Desalination and Re-Use Strategies for New Mexico,” with speakers addressing both technical and policy issues related to the desalination of brackish water and produced water from oil and gas wells. The meeting included a tour of the new Tularosa Basin National Desalination Research Facility. No wine was served. Needless to say, a good time was had by attendees in Arizona and California, and those at the New Mexico meeting may actually have learned something.

The Polymerase Chain Reaction

Since its invention, polymerase chain reaction (PCR) has become one of the most widely used biochemical assays. The speed, specificity, and low cost of the procedure have led to its use in such fields as criminal and pathological forensics, genetic mapping, disease diagnosis, systematics and evolutionary studies, and environmental science.

PCR can amplify to detectable levels nucleic acids associated with pathogens that may be present in low numbers in water samples. PCR assays detect viruses and other pathogens after concentration from large volumes (100 to 1,500 liters) of water. This usually is accomplished by a filter-adsorption and elution method, resulting in a concentrate containing microbes and organic and dissolved solids.

PCR is a process in which target DNA, polymerase enzyme, and the DNA subunits are combined in a test tube and subjected to temperature changes that spur DNA duplication. Through repetition of this process and under ideal conditions, millions of copies of a single DNA molecule can be generated in just 20 to 30 repetitions of the temperature cycle, each cycle requiring only a minute. The PCR assay can selectively amplify a portion of the target DNA that will allow the pathogen to be identified.

The advantages of PCR are numerous. Compared with techniques such as cell culture for the detection of viruses and parasites, the time required for the assay can be reduced from days or weeks to hours. Initial and recurring costs for PCR are much less than cell culture techniques and the technique is easily performed. Additionally, PCR can be used to identify specific pathogens found in water. Standard PCR, however, can only detect the presence or absence of pathogen-specific DNA or RNA, not the infectious state of an organism.

And in the Future...

While the technologies currently available to identify pathogens are state-of-the-art, sample processing techniques need further development. For example, to perform a PCR assay, a 1,000-liter sample is ultimately concentrated down to milliliters or microliters. If significant other material exists in the original sample, it will also be concentrated, with the result that the ability to perform PCR is impaired. Real-time detection is another area in which analytical developments are advancing. Using these and other microbial detection methodologies, researchers have developed databases on bacterial, parasitic, and viral occurrence in source and treated waters of the United States and other countries. Despite some difficulties and costs associated with microbial monitoring, the protocols provide data and quantitative approaches that can be used to screen and identify water systems at risk of fecal contamination.

Morteza Abbaszadegan is an associate professor and director of the NSF Water Quality Center at Arizona State University. Contact him at morteza.abbaszadegan@asu.edu.
From Monsoon Madness to Wildfire Adventures: Two Summer Camps

Elizabeth Hancock, Ph.D. — SAHRA, University of Arizona

Over the past two years, SAHRA and the Flandrau Science Center, both housed at the University of Arizona in Tucson, collaboratively designed and implemented hydrology-related camps for children of ages eight to 12. Each of the camps, Monsoon Madness in 2003 and Camp Wildfire in 2004, was offered three times as a one-week, full-day camp at Flandrau.

Monsoon Madness provided students with an opportunity to learn about water in the Tucson area through the annual monsoon phenomenon. Specific themes explored were the water cycle, weather, the desert monsoon, and human dimensions of the monsoon. All students were provided with rain gauges and thermometers to install at home so that data could be collected daily and recorded on a Tucson map. Camp activities included creating a cloud in a jar, decorating rain sticks, a visit from a local television weather forecaster, documenting learning in a field notebook, and visiting the National Weather Service. An additional field trip to the Santa Catalina Mountains north of Tucson to collect atmospheric data was planned but had to be cancelled due to the Aspen Fire.

Attempting to benefit from adversity, camp organizers selected wildfire as the theme of the 2004 camp. Camp Wildfire explored the causes and effects of the Aspen Fire, which burned approximately 85,000 acres in June and July 2003. Most campers had witnessed the billowing smoke from the fire, which was visible in Tucson for weeks. Campers explored the following questions: What is the role of wildfire in our local ecosystems, and how has this changed over time? What conditions are necessary for wildfire? What is the role of humans in suppressing or encouraging wildfire? How will the ecosystems on the mountain change after the fire? How did the fire affect our water supply and recreation areas? Camp activities included creating sun prints, simulating how trees compete for essential needs, interpreting tree rings, exploring the chemistry and physics of fire, and using a computer simulation to manage a wildfire. Campers participated in on-campus field trips to the Tree Ring Laboratory and the Center for Creative Photography. Each week culminated in a field trip to the Santa Catalinas to observe and collect data in recovering burned areas.

Camp organizers put considerable effort into attracting participants from low-income families and provided full or partial scholarships to 30 percent of attendees in 2003 and 65 percent in 2004. A collaboration with U of A’s Office of Early Academic Outreach provided transportation for many scholarship students.

Surveys from Monsoon Madness have been analyzed and indicate improvements in campers’ self-reported knowledge of the monsoon and the activities of water scientists. Campers most enjoyed the art activities, field trip, and experiments.

Contact Liz Hancock at ehancock@sahra.arizona.edu.
Review of HYDRUS-2D

by Scott Tyler, Ph.D. – University of Nevada, Reno

HYDRUS-2D is a fully interactive water, solute and heat transport, finite-element solver for unsaturated and saturated porous media. The code and associated GUI is widely used by researchers and professionals to solve a broad range of vadose zone problems. It is a particularly valuable learning tool, allowing more and more complex processes and problems to be incorporated when used in a semester-long course in soil physics or vadose zone hydrology. The underlying transport equations are written with sufficient breadth to allow investigation of the majority of processes governing transport in unsaturated media. The code can accommodate a wide range of boundary conditions including a robust precipitation/transpiration/root uptake simulator, making it applicable to “real world” simulations.

Water flow is represented using Richards’ equation, and users can specify hydraulic properties using default parameterization, neural network algorithms, or the Van Genuchten or Brooks/Corey functions. Hysteresis can be specified in both the retention and conductivity functions. Hydraulic properties can be a function of temperature via temperature-dependent viscosity and surface tension relationships. The solute and heat transport portions of the code are governed by the advection-dispersion equation (solute) and convection-dispersion equation (heat). Mobile/immobile solute transport can be simulated, as can solute diffusion in the gas phase. Reactive transport is simulated using either linear or nonlinear user-defined isotherms.

Two-dimensional finite element grids can be generated using a regular or unstructured grid generator, making the solution of complex geometries simple and efficient. The grid generator is easy to use and the mesh can be refined quickly in areas of steep moisture or solute gradients. The numerical stability of the solution algorithms is maintained through automatically adjusted time stepping, but can also be defined by the user. The code includes an inverse algorithm for estimating hydraulic/solute/heat transport properties from observed laboratory or field data.

The graphical user interface walks the user through the necessary input steps, making the code easy to use. In addition to test cases included with the software, technical support, short courses, and a book of excellent examples of HYDRUS-2D applications are available. HYDRUS-2D packaged with MESHGEN can be purchased from the International Ground Water Modeling Center, with single user licenses beginning at $1,200.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>November 4-6</td>
<td>California Groundwater Association. 56th Annual Convention and Trade Show. Reno, NV.</td>
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<tr>
<td>November 7-10</td>
<td>Geological Society of America. 2004 Annual Meeting and Exposition. Denver, CO.</td>
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<tr>
<td>November 16-18</td>
<td>Environmental Protection Agency. Pit Lakes 2004. (It's free!) Reno, NV.</td>
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<td>November 17-19</td>
<td>SAHRA. 2nd International Symposium on Transboundary Waters Management. Tucson, AZ.</td>
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<tr>
<td>November 30-Dec. 3</td>
<td>Association of California Water Agencies. 2004 ACWA Fall Conference and Exhibition. Palm Springs, CA.</td>
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<tr>
<td>December 6-10</td>
<td>National Ground Water Association. Fundamentals of Ground Water Geochemistry (Dec. 6-7), Understanding Migration, Assessment, and Remediation of Non-Aqueous Phase Liquids (Dec. 8-10). Las Vegas, NV.</td>
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<tr>
<td>December 7-8</td>
<td>Government Institutes. Arizona Environmental Law. Phoenix, AZ.</td>
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<td>December 13-17</td>
<td>American Geophysical Union. 2004 Fall Meeting. San Francisco, CA.</td>
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<td>January 27-28</td>
<td>CLE International. Texas Wetlands. Houston, TX.</td>
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<tr>
<td>March 7-8</td>
<td>CLE International. Colorado Water Law. Denver, CO.</td>
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<td>March 10-11</td>
<td>Government Institutes. Environmental Site Assessments. Las Vegas, NV.</td>
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<tr>
<td>May 2-13</td>
<td>Government Institutes. U.S. Environmental Laws and Regulations (May 2-4), Advanced Environmental Laws and Regulations (May 5-6), Environmental Compliance Bootcamp (May 9-13). Phoenix, AZ.</td>
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</table>
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