Southwest HYDROLOGY
The Resource for Semi-Arid Hydrology
Volume 3/Number 5 September/October 2004

Watersheds on Fire

Southwest Hydrology
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A few thoughts on land development:

Water has always been the linchpin to land development in the Southwest.

Ages ago, obtaining reliable water supplies was a stark reality for ancient peoples as it was later for the early settlers. It continues to be a harsh reality today, even though the comforts provided by technology have hidden this reality from many of us.

Now, we can no longer ignore the fact that our water resources are as limited as ever. Belatedly, policy is beginning to shift toward closing the disparity between what we know, and how willing we are to act on it.

It used to be relatively easy to demonstrate an adequate water supply for new land developments. It's not so easy anymore. Aquifer conditions at proposed developments must be thoroughly analyzed. Developers, municipalities, water purveyors, and other stakeholders must grapple with the realities of limited water supplies, water quality, sustainability, and legal availability. They must make informed, responsible decisions based on concise and reliable information that clearly spells out the opportunities and constraints presented by the available water supply.

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Volume 3/Number 5 September/October 2004
A bimonthly trade magazine for hydrologists, water managers, and other professionals working with water issues.

From the Publisher

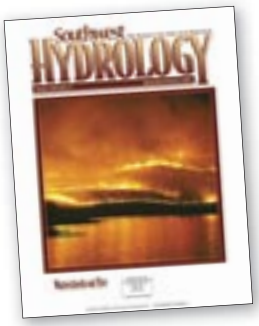
We've all heard about, if not personally witnessed, the catastrophic forest fires in the Southwest in recent years. Loss of homes and habitat is the most distressing result, but effects on the hydrologic system also impact human health and safety. Fire dramatically increases the potential for flash floods and debris flows, both of which cost lives last year. Large ash and sediment loads in streams can fill channels, reduce reservoir capacities, and challenge water treatment systems. In this issue, we look at the impacts to water quality and runoff, as well as emergency response efforts and rehabilitation treatments used, and options for watershed management.

Thanks to all who contributed articles and photos for the feature stories and for the departments. We depend on our contributing readers to ensure that this publication represents the work and interests of water professionals throughout the Southwest.

By the time this issue reaches your mailbox, we expect to have back issues of ***Southwest Hydrology*** *posted on our Web site at www.swhydro.arizona.edu in searchable pdf format. We will be adding indices in the future.*

Southwest Hydrology*'s Advisory Board will hold its first annual in-person meeting on Tuesday afternoon, Oct. 12, in Albuquerque. Interested readers are welcome to attend and provide feedback on the magazine and its goals. Contact me for details.*

Betsy Woodhouse
Publisher



Wonderland Lake fire near Boulder Colorado on July 19, 2002, the day the fire began. Photo by Mark Eret, courtesy of Anchor Point Group (www.anchorpointgroup.com).

Correction
In the article, Animas-La Plata Water Project 'A Mess'" (p. 12, July/August 2004 issue of ***Southwest Hydrology****), the U.S. Bureau of Reclamation was incorrectly abbreviated as BLM. The correct abbreviation should have been BOR. The U.S. Bureau of Land Management (BLM) is not involved in the project.*

Inside This Issue

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Watersheds on Fire

In recent years, wildfires have burned thousands of square miles of the Southwest, with wide-ranging consequences to hydrologic systems. In this issue, we consider the effects of fire on soils, stream discharge, and water quality, including the extent and duration of impacts. In addition, we review watershed rehabilitation and emergency treatment practices currently in use, and look at one city's evaluation of its pre-fire management alternatives.

This material is based upon work supported by SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) under the STC Program of the National Science Foundation, Agreement No. EAR-9876800. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of SAHRA or of the National Science Foundation.

Southwest Hydrology

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Southwest Hydrology welcomes letters and contributions of news, project summaries, product announcements, and items for The Calendar. Send submissions by mail or email as shown below. Visit www.swhydro.arizona.edu for additional guidelines for submissions.

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Delta Levee Break Heightens System Vulnerability

Aerial view of the flood scene shortly after the levee break. Photo from DWR.

On June 3, 2004, a 300-foot section of a levee in California's Sacramento-San Joaquin River Delta failed, flooding Jones Tract, a 12,000-acre island, and threatening a significant portion of the state's water supply. No clear cause was apparent. The flooding not only destroyed crops and displaced about 300 residents, but reduced the river flow that forms a barrier to saltwater intrusion into the lower delta. The U.S. Bureau of Reclamation was forced to increase releases of fresh water from Shasta Dam to help control salinity, and the California Department of Water Resources (DWR) had to reduce pumping from their export pumps to reduce the intrusion of seawater. Residents of many islands were evacuated, and estimated crop losses from flooding on Jones Tract were $10 million. Crop loss from seepage on other islands was also expected to reach several million dollars, and total damage estimates, including repairing the breach, approached $100 million. Crews from government agencies at all levels, the California Conservation Corps, inmate crews from the California Department of Forestry and Fire Protection, private quarry firms, and others worked around the clock to fill the break. On June 30, the gap was finally closed with more than 200,000 tons of rock.

According to the U.S. Geological Survey (2000), until the late 1800s the delta was a tidal freshwater marsh covered by peat and peaty alluvium. Then levees were built along the stream channels, and farming began on the newly protected land. Now a rich agricultural area, the delta is also an important source of fresh water for 22 million Californians. The delta lies in the center of an extensive water transfer system, and much of the water from the delta is pumped southward to the San Joaquin Valley and central and southern California. The tracts and islands maintained by the levees help protect water-export facilities in the southern delta from saltwater intrusion by displacing water and maintaining favorable freshwater gradients.

The levee break called attention to a situation that many people have been worrying about for some time: encroaching development into the flood plains and a dire need for levee maintenance. On June 16, *The Sacramento Bee* reported on comments made by Col. Michael Conrad, district commander for the U.S. Army Corps of Engineers, in an address to the Central Valley Flood Control Association. He observed that

communities continue to develop in poor locations such as flood plains where land is cheap, and when crises such as levee breaks occur, they turn to federal and state resources for help. According to *The Bee*, Conrad has become increasingly vocal about the need for a "big-picture policy to reduce flood damage." Further, he said flood-control agencies can't blame environmental requirements for delays in maintaining levees, and acknowledged that his own agency needs to work harder to facilitate levee repair.

The *Tri-Valley Herald* said the situation could have been worse. Had the cause of failure been big waves or an earthquake, a chain of failures could have been triggered across 1,100 miles of levees in the region. According to the article, the levees are currently in disrepair for a variety of reasons: most are privately owned and not part of a government-run flood control project, and conflicts between delta water leaders and Southern California water users have prevented regional collaboration on maintenance responsibilities.

On July 1, President Bush declared the area a federal disaster, freeing money from the Federal Emergency Management Agency for 75 percent of the costs to repair or replace damaged public facilities, remove debris, fund emergency expenses, and also for projects to prevent future disasters. State and local agencies will cover the balance.

Pumping of Jones Tract, which was covered by 10 to 18 feet of water, began in July and is expected to continue into October. DWR awarded a $3.8 million contract to a Lodi construction company for the dewatering work.

Additional Information

California Department of Water Resources delta levee break information page, calwater.ca.gov/Levee_Break/DeltaLeveeBreakInfo.shtml.

U.S. Geological Survey, 2000. Delta subsidence in California. Fact Sheet FS-005-00, available at ca.water.usgs.gov/archive/reports/fs00500/fs00500.pdf.

Technologies Evaluated for Treating Acid Mine Drainage

Ed Bates *– USEPA National Risk Management Research Laboratory and* ***Matt Udell*** *– Tetra Tech EM Inc.*

Intermittent extraction of copper sulfate, copper, and sulfur minerals from the abandoned Leviathan Mine in Alpine County, California, has resulted in extensive acid mine drainage (AMD) and acid rock drainage (ARD). Oxygen and water that contact the excavated waste rock and mineralized rock in the mine workings oxidize sulfur and sulfide minerals, leading to the generation of sulfuric acid. The acid dissolves toxic levels of metals, including aluminum, arsenic, copper, iron, and nickel. Releases of acidic waters and toxic metals have resulted in historic fish and insect kills in local creeks and the east fork of the Carson River. Actions taken by the state of California have significantly reduced the quantity of metals and acidity discharged from the Leviathan Mine. These actions included adding storm water controls, separating Leviathan Creek from the waste rock to reduce ARD, constructing five ponds to prevent discharge of AMD, and treating captured AMD.

The compost-free bioreactor at the Leviathan Mine treats up to 30 gallon per minute ARD flow year round before releasing it to Aspen Creek.

Over the past three years, the U.S. Environmental Protection Agency National Risk Management Research Laboratory (NRMRL), in cooperation with EPA Region IX, the state of California, and Atlantic Richfield Company, has evaluated three technologies for treating AMD and ARD at the site: active biphasic lime treatment, semi-passive settling in an alkaline treatment lagoon, and passive compost-free bioreactors. Conventional methods of treating AMD and ARD involve the capture, storage, and batch or continuous treatment of water using lime addition, which neutralizes acidity and precipitates metals. The biphasic treatment and alkaline treatment lagoon technologies are simply improvements to conventional lime treatment technology. The compost-free bioreactor technology nurtures sulfate-reducing bacteria, generating sulfides, which scavenge dissolved metals to form metal sulfide precipitates. Typical influent and effluent concentrations, removal efficiencies, and discharge standards for each technology are provided in the table at right.

The biphasic lime treatment system employs two-step lime addition to

The biphasic lime system treats an AMD volume of 3.5 million gallons each summer before releasing it to Leviathan Creek.

neutralize acidity and precipitate dissolved metals from the AMD at flow rates ranging from 50 to 185 gallons per minute (gpm). During the first phase, the pH is raised slightly from 2.8 to 3.2 by mixing lime slurry with AMD to precipitate iron as ferric hydroxide. During this first precipitation step, the arsenic "co-precipitates" or is adsorbed to the ferric hydroxide to form a small volume of arsenic-rich hazardous sludge. Precipitate from the first phase is shipped off-site for disposal. The pH of the partially treated AMD is then raised to between 8.0 and 8.4, and the remaining metals precipitate to form a larger quantity of nonhazardous sludge.

The alkaline (lime) treatment lagoon, a simplified version of the biphasic treatment system, is used to treat a low flow (12 to 30 gpm) ARD source. Single-step lime addition in combination with vigorous aeration is employed to neutralize acidity from pH 4.5 to pH 8 and precipitate metals. A series of bag filters captures large floc particles, while a multicell settling lagoon allows extended lime contact and fine particle settling prior to discharge.

Compost-free bioreactor technology, developed and operated by Glenn Miller and Tim Tsukamoto of the University of Nevada-Reno, relies on biologically mediated sulfate-to-sulfide reduction, attributed primarily to *Desulfovibrio* species, to neutralize acidity and precipitate metal sulfides from ARD (pH of 3.1) at flow rates ranging from 8 to 30 gpm on a year-round basis. Unlike compost bioreactors, this technology uses liquid alcohol as a carbon source fed continuously into the influent, and a rock matrix rather than a compost or wood chip matrix, which is consumed by bacteria and collapses over time. The benefits include better control of biological activity and improved hydraulic conductivity and precipitate flushing. The solids generated by this technology are nonhazardous.

NRMRL field studies found that all three technologies effectively promote AMD and ARD neutralization and metal precipitation, and consistently meet site discharge standards. Active biphasic lime treatment appears to be applicable in situations where flow rates are high and the treatment season is short, while the semi-passive alkaline treatment lagoon favors a lower flow rate and extended treatment season. However, the innovative passive compost-free bioreactor is not constrained by seasonal conditions and can be scaled to treat low to moderate flows, which are typical of AMD and ARD sites.

	Aluminum (mg/L)	Arsenic (mg/L)	Copper (mg/L)	Iron (mg/L)	Nickel (mg/L)
Biphasic System					
Influent	486	4.05	2.99	653	8.77
Effluent	1.09	0.0101	0.0101	0.0038	0.0389
Removal Efficiency	99.78%	99.75%	99.66%	99.99%	99.56%
Alkaline Lagoon					
Influent	31.6	0.533	0.0161	378	1.61
Effluent	0.21	0.0032	0.0041	0.32	0.0204
Removal Efficiency	99.34%	99.40%	74.53%	99.92%	98.73%
Bioreactor					
Influent	39.9	<0.005	0.765	120	0.484
Effluent	0.0258	<0.005	0.0065	0.105	0.0417
Removal Efficiency	99.94%	Not Calculated	99.15%	99.91%	91.38%
Discharge Standard	**2.0**	**0.15**	**0.016**	**1.0**	**0.094**

Performance data for the three AMD/ARD treatment technologies.

Additional information, including costs, benefits, and limitations of the lime-based technologies were presented in an innovative technology evaluation report (ITER), technology capsule, and demonstration bulletin in the summer of 2004. Documentation of the bioreactor evaluation will be available in the summer of 2005.

This article is excerpted from USEPA's Technology News and Trends Newsletter, May 2004, No.12. For the original article, visit clu-in.org/products/newsltrs/tnandt/. For additional information, contact Ed Bates (513-569-7774 or bates.edward@epa.gov) or Matt Udell (916-853-4516 or matt.udell@ttemi.com).

Agreement Reached on Rio Grande Water Accounting

In May, the International Boundary and Water Commission (IBWC) in the United States and Mexico announced that agreement has been reached on a water accounting procedure related to water transfers from Mexico.

The agreement addresses procedures for transfers of water from Mexican to U.S. ownership at Amistad and Falcon International Reservoirs on the Rio Grande in accordance with a 1969 IBWC agreement that provides for such transfers when Mexico has a deficit in Rio Grande deliveries to the United States.

The new agreement, "Joint Report of the Principal Engineers Concerning the Adoption of a Criteria for the Calculation of Conveyance Losses Associated with Transfers to the United States of Mexican Waters Stored at Amistad and Falcon International Dams," spells out how conveyance losses will be handled, taking into consideration the Mexican tributaries that are the source of the water, the distance the water must travel to the reservoirs, and actual climatic conditions during the months preceding a reservoir transfer. Because established criteria for determining conveyance losses were previously lacking, and varying climatic conditions and other factors can greatly affect losses, the agreement significantly reduces the potential for controversy over transfers.

Difficulty in reaching consensus on conveyance losses has sometimes delayed water transfers from Mexico. Depending on the criteria applied, conveyance losses can range from 2 percent to well over 30 percent, sometimes reaching tens of thousands of acre-feet. Whether those volumes are credited to Mexico or the United States has complicated negotiations for previous water transfers.

For more information, visit www.ibwc.state.gov/PAO/CURPRESS/2004/ConveyanceJtRptDWeb.pdf

Judge: ADWR Not Enforcer of Water Rules

Article originally appeared in Water Tech Online, June 15, 2004

The Arizona Department of Water Resources (ADWR) will not be the agency to tell residents or businesses when or how to use their water, according to a state Supreme Court ruling, *The Arizona Republic* reported.

That task will fall to water companies, whether private or municipal, the court ruled. If the court had ruled otherwise, "It would have cost quite a bit more money, because then we would have been designated as water cops," agency Director Herb Guenther said in the article, "and we would be out enforcing standards against homeowners and industry."

The case has been bouncing around the court system since 1990, when Arizona Water Co., a private concern that provides water in several Arizona communities, decided that ADWR's management plan violated the Arizona Groundwater Code, the paper reported.

At issue was the manner in which the state agency restricted water allotments to companies based on the populations they served, without taking responsibility to see that individual end users did their part in conserving water, the article stated.

"Our position in the trial court was that the department had the obligation in adopting a conservation plan not just to say you can just provide this much water," Timothy Berg, an attorney for the company, said in the report. "It had to at least provide some sort of regulation or guidance to individual users about what they were and weren't supposed to do."

"As a result of this court case, there will not necessarily be any direct conservation requirements imposed on them [water users] by the state," Ken Slowinski, an attorney for the Department of Water Resources, told the paper. "That's the bottom line. The state does not have to impose conservation requirements directly on homeowners and small businesses."

Visit www.watertechonline.com.

ADEQ Completes Emergency Cleanup of Nogales Wash

On June 8, the Arizona Department of Environmental Quality (ADEQ) announced the completion of the cleanup of a sanitary sewer spill into Nogales Wash, which runs north from Nogales, Sonora into Nogales, Arizona. ADEQ officials worked with the city of Nogales, Arizona, to clean and disinfect the spill.

ADEQ Director Steve Owens described the overflow as an accident, but said the incident illustrates the need for more work to upgrade the wastewater infrastructure in Sonora. According to *The Nogales International*, the main cause of the overflow was the carcass of a dog wedged into a main sewer connector three miles south of the border, causing overflow into the wash.

"This is one of the worst overflows we have seen, particularly in this region of the state," Owens said. "This incident focuses attention on the sanitary sewer needs on the Mexican side of the border, and we will continue to work with our state, federal, and international partners to address those issues."

Initial estimates of the overflow ranged from 12 million to 30 million gallons, based on average flow during the 12 days sewage ran into the wash. ADEQ officials removed an estimated 210 tons of sludge from the concrete-lined portion of the wash, and added approximately 600 pounds of chlorine to other portions of the wash to disinfect and help control odor. ADEQ also posted public health notices along the wash warning residents to avoid contact with the water.

For more information, visit www.adeq.state.az.us and www.nogalesinternational.com.

LADWP Moves to Restore the Lower Owens River

Los Angeles Department of Water and Power (LADWP) officials worked to meet their June 23 deadline for completing the environmental impact report and environmental impact study (EIR/EIS) for a much-anticipated project to restore flow in the 60-mile Lower Owens River. The deadline was met, but not everyone was happy with the result.

Under a court agreement filed in February, LADWP was also required to present the documents to the Board of Water and Power Commissioners for certification in August. The court agreement was reached among LADWP, Inyo County, the Sierra Club, the Owens Lake Committee, the California Department of Fish and Game, and the California Lands Commission, and provides environmental mitigation for the city's water-gathering activities in the Owens Valley.

To meet that deadline, LADWP officials decided early in June to complete the environmental reports on its own, incorporating as many of the comments and concerns of Inyo County and the Environmental Protection Agency as possible. Up to that time, the three agencies had been jointly writing the reports.

LADWP officials were concerned that a delay in the completion of the EIR could also delay the release of water into the Lower Owens River, scheduled to begin in September 2005. The agreement filed in February also requires LADWP to achieve base flows of 40 cubic feet per second by April 2006. The LADWP agreed to build a pump station with a capacity of 50 cubic feet per second to pump water from the Lower Owens River Project (LORP) into the Los Angeles Aqueduct or return it to the Owens dry lakebed for dust mitigation.

The LORP will return a steady flow of water to the entire length of the Lower Owens River from the intake of the aqueduct, below Big Pine, to the Owens Lake Delta. The project is expected to create a healthy riparian ecosystem along the river as well as spread additional water into basins to create wetland habitat for waterfowl and shore birds.

On June 24, *The Los Angeles Times* reported the newly released document was criticized by groups such as the Owens Valley Committee, who claimed LADWP went against the court order by working without the two other agencies, and as a result, the proposed restoration plan would likely be challenged.

Visit www.ladwp.com and www.latimes.com.

CA Water Company Hit with Record Fine

The Californian reported on May 27 that the Salinas-based Alisal Water Company was ordered to pay a $500,000 fine, the largest penalty ever imposed against a public water system, for violating the federal Safe Drinking Water Act. The fine was ordered by a judge from the U.S. District Court, said the article, for hundreds of violations over a 10-year period beginning in the early 1990s. The federal government originally filed the action in 1997. According to the paper, the fine was so large because of the number of violations and the company's ongoing refusal to cooperate with regulators; lawyers from the U.S. Justice Department had requested a $3 million penalty. The privately owned company serves about 25,000 consumers in Salinas, according to the article. The vice president of the water company told *The Californian* that the fine might be appealed and that the water system is currrently compliant with federal regulations.

Visit www.californianonline.com.

$12.5 Million Approved for NM Water Projects

New Mexico Gov. Bill Richardson announced on May 25 that the New Mexico Finance Authority approved more than $12.5 million for vital water projects statewide. The Finance Authority approved eight grants: three for watershed restoration and management projects in critical recharge areas, and five for regional water projects. The $1.1 million allocated for watershed restoration projects will enable continued restoration work in the Estancia Basin watershed, for restoration of native vegetation along Whitewater Creek in Catron County, and for eradication of about 842 acres of salt cedar along Ute Creek and its tributaries in eastern New Mexico.

Grants for the five regional water projects total more than $11.4 million, and will be used primarily to improve water distribution systems for the cities of Bloomfield, Española, and Gallup, and to develop the San Juan-Chama diversion project for the cities of Santa Fe and Taos.

Visit www.governor.state.nm.us.

15 CA Companies Fined for Groundwater Pollution

From the San Gabriel Basin Water Quality Authority

Fifteen groundwater polluters in the South El Monte area east of Los Angeles have been fined by the U.S. Environmental Protection Agency for groundwater contamination. The polluters include Aerojet-General Corporation, Allegheny Technology Inc./TDY Industries Inc., Astro Seal Inc., Chevron Research and Technology Co./Chevron USA, CraneVeyor Corp., Art Weiss/Del Ray Industrial Enterprises Inc., Shelly Linderman/The Linderman Living Trust, M&T Company, Mammoet Western Inc., Plastic Engineered Components Inc. dba L.A. Die Mold Inc., Quaker Chemical Corporation, Seachrome Corporation, Time Realty Investments Inc., Tonks Properties, and Jack Barry Zwahlen Family Trust.

The companies were notified by the EPA that they were in violation of the agency's August 2003 cleanup order because they had failed to negotiate a cleanup settlement. A May 20 letter from EPA told the polluters that negotiation and mediation efforts by the EPA had been terminated after the polluters submitted a settlement proposal on May 7 that the EPA described as "inadequate to discharge the [cleanup] obligations."

The letter said each polluter's case would be referred to the U.S. Department of Justice for legal action. Under the federal Superfund cleanup law, the EPA said, each polluter could now be liable for triple the actual cleanup costs and for daily fines of up to $32,500 per day effective May 7.

An EPA order last year gave the responsible parties in the area the opportunity to settle lawsuits with local agencies for cleanup costs and meet their federal Superfund obligations at the same time. Sixteen other parties have already settled, and an additional five have made good faith offers and are in the process of negotiating settlements.

The South El Monte-Monterey Park area is one of several areas in the San Gabriel Valley that were placed on the federal Superfund cleanup list in 1984 because of industrial contaminants found in the underground water supply. It took decades of investigation by federal and state authorities to identify the responsible parties. Meanwhile, plumes of contamination continued to move underground, forcing closure of dozens of public water supply wells.

The San Gabriel Basin Water Quality Authority (WQA) was created by the state Legislature to coordinate and accelerate the cleanup and preserve the public water supply during the federal Superfund investigation. The EPA was criticized by local officials in the late 1990s for not getting tough with the polluters, but the pace of the federal cleanup has accelerated in recent years.

In an unprecedented display of cooperation with local water authorities, EPA issued an order in August 2003 giving polluters in the South El Monte-Monterey Park area the option of meeting their federal cleanup obligations through a partnership with local water agencies, including the WQA, the City of Monterey Park, the San Gabriel Valley Water Company, and the Southern California Water Company. These water entities already have constructed millions of dollars in cleanup facilities, and they have collectively filed suit against the polluters for approximately $100 million in cleanup costs.

Visit www.wqa.com.

Motzz Laboratories Opens in Phoenix

Motzz Laboratories, specializing in inorganic soil, water, and plant analyses, opened in April 2004 in Tempe, Arizona. Soil services include elemental testing such as sulfate and chloride analyses, textural analysis by hydrometer, and pH and agronomy-related tests. Water analyses include major cations and anions. Plant, fertilizer, and mulch analyses are primarily geared towards the growing of turf, landscape plants, and agricultural crops.

The laboratory is owned and managed by Vicki Normandin and Thelma Sadang. Both have extensive experience in laboratory analytical methods pertaining to physical soil tests and inorganic analyses. Normandin's education and 25 years of experience focus on soil/plant/water interactions, while Sadang's strengths and education emphasize the physical and engineering aspects of soil science.

For more information, phone 602-454-2376.

USFilter Wins Perchlorate Removal Job

USFilter was recently awarded a contract to remove perchlorate from groundwater in the Rancho Cordova area near Sacramento, California. A Northern

California manufacturer engaged USFilter to remove perchlorate from nearly a dozen contaminated groundwater wells over the next five years, treating 2.66 million gallons per day.

USFilter will work to limit the spread of a perchlorate plume into the surrounding community. The project will protect uncontaminated drinking water supplies for an existing housing project and a new home development. The company will use disposable ion exchange resin technologies to treat the water. Once the media has reached full capacity, the resin and captured perchlorate is thermally destroyed, preventing future recontamination.

Working with technology invented by Rohm and Haas Company of Philadelphia, Pennsylvania, USFilter has employed ion specific resins that remove perchlorate from water supplies contaminated with up to one part per million concentrations to below detection levels. According to USFilter, the new resins provide significant improvement over former technologies, since they reduce the operating cost of the treatment systems to below $200 per acre-foot treated, avoid generation of contaminated brine waste, and provide substantially more total treatment capacity.

Visit www.usfilter.com.

SRP Sues Verde Valley Landowners for Water Theft

In late April, the Salt River Project (SRP), a major water provider for customers in central Arizona, asked a Maricopa County judge to stop landowners in the Verde River Valley from taking more than their share of water, reported *The Arizona Republic*. The Verde provides a critical source of water for the utility. SRP accused more than a dozen landowners of illegally taking water from the Verde River, according to the paper, and the company is worried that with the combination of continued drought and illegal takings, the river could run dry before their case is heard in court. In fact, SRP has asked the court to separate this case from a larger water rights case encompassing the Verde, Gila, and Salt rivers that has been in the courts for three decades, and to hear and rule on the Verde Valley case immediately, said the article. According to an SRP attorney, some landowners have ignored repeated orders not to take more than their share, in one case going so far as to sell parcels of land along the river with promises of irrigation, although the owner had no water rights for that land, reported *The Republic*. Most landowners contacted by the paper either had not heard about the complaints or denied the allegations.

On May 18, *The Republic* reported that the city of Phoenix had joined SRP in asking the judge to hear the claims immediately. Phoenix draws water from SRP, and holds separate rights to water from the Verde. Tom Buschatzke, Phoenix's chief water advisor, said that Phoenix gets as much as 24 percent of its water from the Verde, said *The Republic*, and SRP has already had to reduce allocations by one-third because of the drought.

Visit www.azcentral.com/arizonarepublic and www.srpnet.com.

JE Fuller/ Hydrology & Geomorphology Moves

JE Fuller/ Hydrology & Geomorphology Inc. recently moved its Phoenix area office to 8400 S. Kyrene Road in Tempe. The company's specialized engineering services include arid land hydrology, applied fluvial geomorphology, floodplain delineation, erosion hazard analyses, sediment transport and scour, drainage master plans, impact fee analyses, drainage cost assessment, and navigability studies. JE Fuller employs 13 professionals in its Tempe and Tucson offices.

Visit www.jefuller.com.

The BAER Team:
Responding to Post-Fire Threats

Greg Kuyumjian – *Santa Fe National Forest*

Looking downstream in the Middle Fork of Rendija Canyon, burned in the 2000 Cerro Grande fire. Sediment deposition is about one meter deep; note scouring of bark from trees. Photo by John Moody, USGS.

Many wildfires cause minimal damage and pose few threats to land or people, but some cause damage that requires immediate efforts to prevent later problems. These problems include soil erosion from loss of vegetation; flooding from increased runoff; and increased sedimentation downstream, which can damage houses or fill reservoirs, putting endangered species and community water supplies at risk.

The Burned Area Emergency Response (BAER) program of the U.S. Forest Service (USFS) is designed to address these emergency situations. BAER aims to prescribe and implement emergency treatments on federal land to minimize threats to life or property resulting from the effects of a fire, and to stabilize and prevent unacceptable degradation to natural and cultural resources.

BAER ... must focus on immediate threats and the time available before storms arrive.

The BAER team's work includes assessing post-fire conditions, recommending and implementing treatments, and monitoring. The entire process happens very quickly, usually within two to five weeks. In the Southwest, speed is required to get emergency stabilization and flood control measures in place before the onset of monsoonal thunderstorms in mid-July.

Assembling the Team

In the Southwestern Region of the USFS (Arizona and New Mexico), a BAER team is required for all fires greater than 300 acres. The BAER team leader is typically selected by the Forest Supervisor in late spring, at the start of the fire season. This leader initiates action when the fire is about 60 percent contained. After quickly evaluating the types of risks present, the leader assembles a core team of professionals such as hydrologists, soil scientists, engineers, biologists, vegetation specialists, and archeologists, primarily from the local area. For large fires like the 195,000-acre Rodeo-Chediski (eastern Arizona, July 2002), or complex fires such as the Aspen Fire (more than 300 homes lost and 85,000 acres burned, southern Arizona, July 2003), experienced BAER team members are brought in from the Southwest region. Within a few days of arriving on site, the BAER leader

What BAER can do:

- Install water or erosion control devices.
- Plant for erosion control or stability reasons.
- Install erosion control measures at critical cultural sites.
- Install temporary barriers to protect treated or recovering areas.
- Install warning signs.
- Replace minor safety related facilities.
- Install appropriate-sized drainage features on roads, trails.
- Remove critical safety hazards.
- Prevent permanent loss of threatened and endangered species habitat.
- Monitor BAER treatments.
- Plant grass to prevent spread of noxious weeds.

What BAER cannot do:

- Replant commercial forests or grass for forage.
- Excavate and interpret cultural sites.
- Replace burned pasture fences.
- Install interpretive signs.
- Replace burned buildings, bridges, corrals, etc.
- Repair roads damaged by floods after fire.
- Replace burned habitat.
- Monitor fire effects.
- Treat pre-existing noxious weeds.

The Cans and Cannots of BAER Rehabilitation Crews, from the Aspen BAER Web site.

selects core team members, develops an organization chart, and drafts logistics. By 85 percent containment, the entire interdisciplinary team has been assembled.

Assessing Conditions

The core team immediately begins gathering data about fire progression, fuels burned, and remote sensing imagery availability, and drafts a list of "values at risk." For large fires, a critical first step is setting a target completion date for treatment before the first damaging storm. Working backward from that date, the size and pace of assessment is defined, along with the scope and extent of treatments. Assessment is usually completed in five to eight days, during which time full containment usually occurs.

First and foremost, the team must evaluate the potential for threats to public safety, life, and property associated with post-fire conditions. What critical transportation infrastructure must remain open? Might any power, water, or sewer lines be cut off or affected by runoff and debris? Are any populations of threatened and endangered species or heritage resource sites listed in the *Federal Register* in the area? Most importantly, can anything be done about it? To answer these questions, the team gathers available data from the USFS and contacts other federal agencies, state and county governments, flood control districts, emergency services, adjacent or affected tribal entities, and anyone else who might be affected.

The first tool developed during assessment is a burn-severity map, which identifies areas of the landscape similarly affected by the fire. Typically, the first draft will be developed using LANDSAT or other remote sensing platforms, and field-verified by soil and water specialists. Burn severity maps are overlain with other coverages to evaluate expected changes between pre-fire and post-fire conditions for the same magnitude storm event. A variety of models are used to evaluate hillslope erosion, sediment delivery, and changes in the timing, peak, and total stream discharge. Potential problem areas are identified and treatment scenarios evaluated.

Recommending Actions

The USFS requires the BAER team to submit proposed actions (or a recommendation of no action) within seven days of containment. For the Rodeo-Chediski Fire, 35 individuals were involved in the assessment and recommendation process.

A variety of rehabilitation techniques may be recommended. The primary techniques used are reseeding of ground cover with quick-growing or native species; mulching with straw or chipped wood; constructing straw bale dams in small tributaries; placing fallen trees to catch sediments on steep slopes; and digging below-grade pits to catch runoff and store sediments. Recommendations may also include modifying drainage structures by installing debris traps; enlarging culverts; installing standup inlet pipes to allow drainage to flow if culverts become plugged; adding additional culverts; or constructing emergency spillways to keep roads and bridges from washing out during floods. The team may post warning signs and remove structures that could block flow, trap sediment, or impact water quality. Recommendations must be prioritized so the most critical threats are addressed first.

Trash rack constructed to prevent large debris from washing downstream in Carter Canyon, Santa Catalina Mountains, Arizona. Top: July 17, 2003, just after containment of the Aspen Fire. Bottom: Oct. 12, 2003, showing three months of regrowth. Photos from the Aspen BAER Treatment Monitoring Report, Appendix B.

Ash Happens

BAER treatments do not ensure problem-free post-fire precipitation events. Time, money, and terrain constraints may preclude sufficient treatment to make a difference. In the Southwest, closing an area during the monsoon or when heavy precipitation is forecast is not uncommon. Regardless of treatment, ash will run into the channel network. An early warning to downstream water users can reduce impacts. For example, water treatment facilities can be warned to close their intakes until ash-laden flows pass by.

Implementing Treatment

BAER cannot provide permanent solutions to temporary problems; the team must focus on immediate threats and the time available before storms arrive. The table at left shows the kinds of treatment BAER can and cannot do. In most cases, only a portion of the burned area is treated. Treatments focus on severely burned areas, very steep slopes, places where water runoff will be excessive, and fragile slopes above homes, businesses, municipal water supplies, and other facilities.

Where a dramatic increase in runoff and sediment load is expected, existing infrastructure can itself present a problem. Apparently harmless recreational features such as picnic tables or management tools such as riparian fencing can block drainages or trap sediment. In both the Rodeo-Chediski and Aspen fires, vault toilets

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FLOODING DURING A DROUGHT?
Climate Variability and Fire in the Southwest

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Last August, a flash flood from monsoon rains came crashing down Bonita Canyon in the Santa Catalina Mountains north of Tucson and muddy waters swept a victim from inside his home to his death three quarters of a mile away. Local residents were shocked that loss of life and property could occur from flash flooding at a time Arizona was experiencing multiyear drought. Flash flooding is always a danger in the desert, but as local resident Dean Prichard reported to the *Arizona Daily Star*, "I have lived out here 29 years and I have never seen it run like this. It is worse than the 1983 floods."

This flood came on the heels of the 2003 Aspen Fire that devastated much of the Santa Catalina range. New studies suggest that accumulated fuel loads and drought created conditions favorable not just for the Aspen Fire but for post-fire flash flooding,

Western forests accumulate underbrush and smaller trees during fire suppression. Photo courtesy of the U.S. Forest Service Fire Effects Laboartory.

and this situation is typical for most fires in the semi-arid Southwest. Researchers are increasingly documenting a strong relationship between climate variability, historical forest management practices, and fires in the Southwest.

Climate variability may precondition the desert Southwest to large catastrophic fires. Swetnam and Betancourt (1998) found a correlation between the climate phenomenon known as El Niño Southern Oscillation (ENSO) and large fires in the southwestern United States. ENSO creates alternating periods of wet (El Niño) and dry (La Niña) climate in the Southwest. Analysis of tree rings from the last three centuries shows a high correlation between drought and the number of acres burned. The most catastrophic and widespread fires immediately followed wet El Niño periods when the vegetation growth was enhanced. These large fuel loads burned extensively during subsequent La Niña droughts.

Swetnam and Betancourt also documented the influence that twentieth century fire suppression practices have had on the region. Natural small fires restrict undergrowth, leaving only the largest trees, whereas fire suppression allows underbrush to accumulate (see photos above). Ignition of these dense forests generates high intensity crown fires. Higher-temperature fires can vaporize organic debris within the upper soil, which condenses and fills the pores in the soil to create a hydrophobic layer that restricts the passage of water. Fire-induced hydrophobic layers can decrease infiltration, increase erosion, and increase surface runoff during rainstorms.

Climate variability may precondition the desert Southwest to large catastrophic fires.

USGS streamflow measurements in Sabino Canyon of the Santa Catalina range recorded flow response during early monsoon rain events following the Aspen Fire (Hirsch and Costa, 2004). Streamflow exceeded 2,000 cubic feet per second at the Sabino Canyon gauge in two storms within six weeks of the fire under the prevailing drought conditions. In historical comparison, from 1932 to 1999, peak annual streamflow exceeded this threshold 38 percent of the time. These early monsoon rains also suspended 10,000 milligrams of sediment in each liter of water in Sabino Creek, whereas end-of-winter rains carried only 30 milligrams of sediment per liter.

An Aspen Fire Study Team from the University of Arizona was mobilized to study links between vegetation and post-fire soil impacts on hydrologic response. The impacts were similar to those described elsewhere in this issue, including hydrophobic soil development, flash flooding, debris flows, and high suspended solid and nutrient loads during early post-fire rain events.

The Aspen Fire Study team confirmed observations by Chandler and others (1983) that shifts in soil infiltration capacity varied by vegetation zone. Field measurements to determine how rapidly water can move through soil were made on unburned and burned soils in the Santa Catalinas, using a soil corer air permeameter. In unburned soils, significantly more infiltration was measured in the woodland-chaparral zone than in the coniferous zone. However, burned soils in both zones were equally resistant to water infiltration.

These results suggest that the woodland-chaparral zone is an effective buffer of storm runoff before a fire, and that optimum protection from post-fire flooding may be achieved by focusing fire-fighting efforts to protect that zone. The upper Bonita Canyon watershed, severely burned in the Aspen Fire, is entirely in the woodland-chaparral zone, which likely contributed to the magnitude of last year's devastating flash flood.

The Aspen Fire Study Team includes UA co-investigators B. Ekwurzel, T. Ferré, and B. Nijssen with graduate students K.D. Chief, S.E. Desilets, and M. Guardiola-Claramonte. Contact Brenda Ekwurzel at ekwurzel@hwr.arizona.edu.

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Response to Post-Fire Flood Threat: California 2003

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During October and November 2003, wildfires burned more than 700,000 acres in southern California. Once the wildfires were contained, government officials turned their attention to effects of the wildfires on watersheds in the burned areas. The destruction of vegetation and the impacts of the fires on soils, combined with the geology in the burned areas, created conditions under which the threat of flooding, erosion, and debris flows was greatly increased. The severity of this threat was realized on December 25, 2003, when heavy rains in the burned areas of San Bernardino County caused significant debris flows. The flows resulted in 15 deaths and widespread property damage, and many of the county's flood control basins were filled with debris.

Local Warning System and Response

Local officials immediately realized the need to identify risks and coordinate response efforts. Management of flood control and flood warning systems is the responsibility of emergency services and public works departments in the affected counties. However, as the Christmas Day storm showed, the severity and widespread nature of the wildfires created conditions that exceeded the capacity of existing systems.

In San Bernardino County, county and city officials formed the Flood Area Safety Task Force (FAST) to identify specific threats, identify needs for protective measures, and develop response procedures. Ultimately, the FAST developed a Concept of Operations that the county Operational Area intends to use for future flood events. San Diego County conducted an immediate, comprehensive assessment of erosion risks, which was used to prioritize installation of emergency protective measures. The county also implemented a paging system to warn residents in high hazard areas of imminent danger.

State and Federal Support

State and federal agencies provided additional funding, as well as technical and operational support, coordinated by the California Governor's Office of Emergency Services and the Federal Emergency Management Agency (FEMA). Recognizing that post-fire conditions differed from typical flood threats, the California Department of Water Resources initiated efforts to outline resources, authorities, and mechanisms for response. Federal agencies, including FEMA, the Natural Resources Conservation Service, the Corps of Engineers, and the Forest Service, met extraordinary needs by funding and implementing emergency protective measures. Federal agencies assisted with efforts to upgrade local warning systems and identify hazards, the U.S. Geological Survey (USGS) installed additional rainfall and stream gauges, and FEMA and the USGS prepared flood hazard and debris flow maps.

Lessons Learned

The threats posed by flooding, erosion, and debris flows following wildfires require a fundamentally different approach to preparedness and response. Due to the rapid occurrence of these events, advance identification of risks, effective warning systems, and coordinated response efforts are essential. For an event of the magnitude of the 2003 fires, state and federal assistance can be expected, but the rapid occurrence and extreme nature of these events places a premium on effective preparedness at the local level.

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An Overview of Fire Effects on Soils

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Fires in forests and rangelands produce some of the most profound impacts on ecosystems of the Southwest. Wildfires and prescribed fires affect the vegetation, soils, wildlife, and water resources of watersheds. They impose a wide range of effects depending on the mosaic of fire severities and post-fire hydrologic events.

Changes in soils after fires produce varying responses in the water, floral, and faunal components of ecosystems because of their complex interdependencies. The effects of fire on soils are a function of the amount of heat released from combusting biomass – the fire intensity – and the duration of combustion. The impact of these factors on the physical, chemical, and biological properties of the soil is measured as severity.

Fire severity is defined in terms of: 1) the length of time fuel accumulates between fires and the amount of the accumulated fuels; 2) properties of the fuels (such as size, flammability, and moisture or mineral content); 3) how the fuels impact fire location and behavior (causing crown, surface, or ground fires); and 4) heat transfer in the soil during the combustion of above-ground fuels and surface organic layers (DeBano et al., 1998). High intensity fires – those that reach 1,200 degrees Celsius or more – do not always result in high severity impacts in the soil if their duration is short, but low intensity fires of just 300 degrees Celsius that smolder for a long time in roots or organic matter can produce large changes in the nearby soil.

Physical impacts of fire on soil include breakdown in soil structure, reduced moisture retention and capacity, and development of water repellency, all of which increase susceptibility to erosion. Chemically, fire-impacted soils experience changes in nutrient pools cycling rates, loss of elements to the atmosphere, and loss of organic matter.

Increased runoff on soils damaged by the Rodeo-Chediski Fire of 2002.

Biological properties are altered by changes or loss of microbial species and population dynamics, reduction or loss of invertebrates, and partial elimination (through decomposition) of plant roots. Although the most severe impacts on soils occur in stand-replacing wildfires, prescribed fires can produce local effects.

The effects of fire on soils are a function of the amount of heat released from combusting biomass…and the duration of combustion.

Physical Effects

When fire consumes vegetation and underlying litter layers, hydrophobic or water-repellant soil conditions can form. The hydrophobic zone appears as a discreet layer in the soil, at or parallel to the surface, where hydrophobic organic compounds coat soil aggregates or minerals. This phenomenon occurs at soil temperatures of 176 to 288 degrees Celsius (DeBano, 1981). Hydrophobic soils prevent water from wetting aggregates (see photo above right), essentially sealing off the soil during rainfall, greatly increasing surface runoff (see photo above) and erosion. The net effect is a reduction in soil moisture content, erosion of nutrient-rich ash and upper soil horizon sediments, and ultimately watershed drying. Drier soils also diminish the viability of microbes that are involved in biogeochemical cycling and can inhibit re-colonization by plants that stabilize soils.

One of the most important impacts on soils results from the combustion of organic matter. Consumption of organics can range from scorching (producing black ash) to complete ashing (producing white ash) (DeBano et al., 1998), depending on fire severity, moisture content, and thickness of the organic layer. Campbell et al. (1977) found that moderately burned areas maintained 38 percent of the vegetative and litter cover, while severely burned areas had none to 23 percent retention. Observations by the author following catastrophic stand-replacing fires in pinyon-juniper woodlands and ponderosa pine forests of Arizona also indicated a 75 to 100 percent loss of organic material. This loss of organics causes changes in soil structure and porosity. Soil structure degradation can persist for a year to

decades after a fire and is often responsible for reduced infiltration and increased runoff.

Water drops bead on a soil surface with fire-induced repellency.

Chemical Changes

Biogeochemical changes in the mineral soil are most pronounced when burning is of high severity, with carbon and nitrogen strongly affected. The significance of these changes is directly tied to the pre-fire productivity of a given ecosystem. Nutrient-limited forests, such as ponderosa pine, tend to be impacted more than nutrient-rich ones.

Recovery of soil nutrient levels after fires can be fairly slow in some ecosystems, particularly those with limited nitrogen, and in semi-arid regions where decomposition rates are slow. Klopatek (1987) determined that 35 years after a wildfire, nitrogen concentrations beneath pinyon-juniper canopies had not recovered to levels found in stands that had not burned in 300 years. In addition, soils beneath burned stands showed a twofold increase over unburned stands in the percent of total nitrogen that was changed from organic forms such as litter and humus to more mobile nitrates and ammonium. While these mobile forms of nitrogen are more accessible for plant uptake, they are also more prone to off-site movement in surface runoff and leaching (Neary et al., 1999).

Biological Impacts

The short- and long-term effects of fire on soil microorganisms, and the resulting effects on ecosystem sustainability, are uncertain and often debated. The effects of fire on soil microorganism populations and species composition depend on the severity of the fire, as well as the site conditions and pre- and post-fire weather. Low-severity, rapidly moving fires do not have a major effect on microbial populations, whereas high-severity fires with long durations have the greatest impact. Field studies by Klopatek et al. (1988) showed that ten years after burning, mycorrhizae numbers, soil nutrients, and vegetation with severely burned canopies had not recovered to pre-burn levels.

Invertebrates play an important role in litter decomposition, carbon and nutrient mineralization, soil turnover, and soil structure formation. However, the effects of fire on invertebrates and subsequently on belowground sustainability are difficult to assess because of variability in fire severity, invertebrate species present, and species response to fire (DeBano et al., 1998).

Wildfires definitely produce the largest soil impacts of any disturbance to ecosystems of the Southwest because they tend to be more severe and cover larger areas. Although much information exists about the effects of fires on soils and other watershed resources, efforts need to be made to put this information into a systematic context so that it can be useful to wildland fire managers.

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Postfire Rehabilitation Treatments: Are We Learning What Works?

P.R. Robichaud, Ph.D. – *USDA Forest Service, Rocky Mountain Research Station, Moscow, Idaho*

Wildfire is a major ecological process and management issue in the western United States. In recent years, more than 5 million acres of forest and grasslands have burned annually. Major post-fire concerns include increased erosion due to loss of the protective forest floor layer, loss of water storage, and the creation of water-repellent soil conditions. These conditions increase the potential for flooding, debris flows, and sedimentation, which are of special concern when urban areas are in proximity to the burned areas.

> *Given the choices (and the expense) of post-fire rehabilitation treatments, information on the effectiveness and limitations of these treatments is important to land management agencies and the public.*

Burned area emergency rehabilitation treatments fall into three categories: hillslope, channel, and road treatments. Of these, hillslope treatments are most common, as they attempt to reduce erosion at its source. A wide range of treatments have been used and new treatments are being developed and adapted for use on burned landscapes. Given the choices (and the expense) of post-fire rehabilitation treatments, information on the effectiveness and limitations of these treatments is important to land management agencies and the public. Scientists are monitoring and evaluating various treatments across the country.

Erosion and Recovery

Forests that have experienced relatively little disturbance have very small erosion rates, but these rates can increase dramatically after wildfire events. Sediment yields after wildfires range from very low, in flat terrain and in the absence of major rainfall events, to extreme, in steep terrain affected by high-intensity thunderstorms. First-year sediment yields of 1 to 150 tons per acre have been reported for burned mixed coniferous forests in the western United States. Consequently, postfire rehabilitation treatments that have an impact the first year can be important in minimizing downstream effects and watershed resources.

Erosion on burned areas typically declines in subsequent years as the site stabilizes, but the rate depends on burn severity and vegetation recovery. Erosion rates from high-severity burned sites in the Colorado Buffalo Creek Fire declined to background levels within three years. However, another study found that after a wildfire in ponderosa pine forest, sediment yield from a low-severity fire recovered to normal levels after three years, but moderately and severely burned watersheds took seven and 14 years, respectively.

Treatment Effectiveness

Hillslope treatments such as mulches, contour-felled logs (log erosion barriers), and seeding aim to reduce surface runoff and keep soil in place. These treatments are regarded as a first line of defense against post-fire erosion and unwanted sediment deposition. Rainfall intensity is a key factor in treatment success, however. Recent studies suggest that some treatments may help reduce erosion for some but not all rain events. A paired-watershed investigation at the catchment scale (five to 10 acres) under natural rainfall demonstrated that some erosion reduction from contour-felled logs and straw mulches occurred for low rainfall intensity storms, but not for high-intensity storms.

Broadcast seeding has been used for decades and is widely considered the most cost-effective method to promote rapid infiltration of water and keep soil on hillslopes and out of channels and downstream areas. However, studies are showing that grass seeding alone does not ensure increased ground cover during the first critical year after fire. In fact,

Aerial application of wheat straw at about 1 ton per acre after the Hayman Fire, Colorado (above). Cleaning sediment out of the research catchment sediment trap after a summer thunderstorm, Hayman Fire, Colorado (banner).

given the influence of rainfall amounts and intensities on the effectiveness of any hillslope treatment, especially during the first year, treatments that provide immediate ground cover are proving more effective than seeding alone. Immediate protection of the soil from overland flow and raindrop impact is essential in reducing first post-fire year erosion rates. Recent results indicate that a threshold of 70 percent ground cover is needed to impact erosion. For example, 70 percent cover with brown conifer needles that commonly fall to the ground following low- and moderate-severity burns reduced rill erosion by 30 to 40 percent and interrill erosion by 50 to 70 percent. Seeding can be combined with ground cover treatments, but re-establishing native vegetation may be preferable and as effective as planting annual grasses and legumes to establish plant cover in subsequent years.

Using low-intensity rainfall simulation and concentrated flow (rill) techniques, erosion from several postfire areas that had various rehabilitation treatments were compared to nontreated areas. Straw mulch, straw wattles, and contour-felled logs reduced erosion by 70 percent for small rain events. However, during intense summer thunderstorms (10-minute maximum intensity of 1.6 inches per hour) differences between treated and nontreated areas were smaller. Other treatments such as scarification and hand trenching were not effective.

Research in the Colorado Front Range

In a paired-watershed study installed on the Hayman Fire area (Colorado, 2002), first-year data showed that six rain events produced sediment in catchment sediment traps. The mean total sediment yield from these events was 10 tons per acre for three untreated control watersheds. Totals from the treated watersheds were 5 tons per acre from contour-felled logs, 3 tons per acre from wheat straw, and 7 tons per acre from hydromulch. The highest sediment yield resulted when the 10-minute maximum rainfall intensity was at least two inches per hour.

In a silt/sediment fence study also on the Hayman Fire area, four summer storms produced sediment in the 32 fences. The mean first-year erosion rates from the treated plots were all lower than for untreated plots, and mulch treatments (wheat straw and engineered wood straw) produced a much greater reduction in erosion rates. In addition, the mean first-year erosion rate for the plots on 20 percent slopes was about half that of the plots on 40 percent slopes.

Measuring ground cover on treated hillslope plots; silt fence in background.

What have we learned from these studies? Based on runoff and peak flows, erosion rates, sediment yields, and ground-cover measurements, aerially applied wheat straw was more effective than contour-felled logs or hydromulch during the first post-fire year. Although some benefits were observed from the aerial hydromulch, it was less effective than either of the other two watershed treatments. In the silt/sediment fence plots, engineered wood straw was most effective at increasing cover and thereby reducing erosion.

Future Post-fire Rehabilitation

As wildfires continue to grow in number, size, and intensity, concurrent growth has occurred in the treatment application and expense of post-fire rehabilitation efforts. Post-fire rehabilitation decisions must take into account the degree of protection warranted by the assets at risks, treatment costs, availability of treatment materials, short- and long-term effects of treatment applications, and the likelihood of treatment success in the area being considered. The choice to rely on natural recovery processes and not implement any rehabilitation treatments is often the preferable alternative.

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Fire Effects on Stream Discharge

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Increased flood potential is a commonly expected result of wildfires in the Southwest, but considerable uncertainty exists in quantifying that increase. Few sites exist in which stream gauges are in place before a fire. Sites with stream gauges that also have a lengthy, detailed precipitation record are more scarce. Where such data do exist, current drought conditions mean that post-fire rainfall intensities are often relatively low, and pre-fire drought precipitation records are needed for a statistically defensible comparison. Further, rigorous comparison of runoff for "similar" pre- and post-fire storms requires consideration of additional factors such as air and soil temperatures, antecedent soil moisture, slope, and aspect. Although a precise comparison of storms and runoff is therefore a challenge, several researchers have collected data that provide insight into the magnitude of changes that occur.

Rainfall Intensity – Runoff Relation

Moody and Martin (2001a) collected data from two mountain watersheds southwest of Denver, Colorado that were burned in 1996. In the Spring Creek watershed, they looked at the rainfall-runoff relation by comparing the peak discharge of a storm per unit area of watershed to the maximum 30-minute rainfall intensity (I_{30}) of that storm, beginning in 1997 and continuing for four years. Their results (see plot at right) show that, particularly for the higher-intensity storms with I_{30} between 10 and 30 millimeters per hour, events in 1999 and 2000 produced lower unit-area peak discharges than did similar events in 1997, suggesting a decrease in extreme flood events with time after the fire.

Moody and Martin (2001b) subsequently expanded their analysis to include two other burned watersheds. Bear Gulch in the Black Hills of South Dakota was burned in 1988 and Rendija Canyon in New Mexico was burned in the 2000 Cerro Grand Fire. In looking at data from all three watersheds, they found that the unit-area peak discharge is related to I_{30} by a power law. Further, above a threshold of about I_{30} = 10 mm/hour, the magnitude of flood peaks increases much more rapidly, suggesting that that intensity could be used to set threshold limits for precipitation gauges in emergency-warning systems in burned areas.

Pre- and Post-Fire Peak Flows

Gottfried and others (2003) presented results from north-central Arizona watersheds burned by wildfires in 2000 and 2003. As with most fires, fire intensity and severity varied among the watersheds. The Workman Creek watersheds were burned by the 9,644-acre Coon Creek Fire from April to May, 2000. A 15-minute rainfall at intensity of 2.6 inches per hour in June 2000 produced a peak flow estimated from field evidence to be more than seven times the 40-year historic high peak flow of 289 cubic feet per second (cfs), which had been measured in October 1972 following a five-day storm that dropped nearly 12 inches of precipitation.

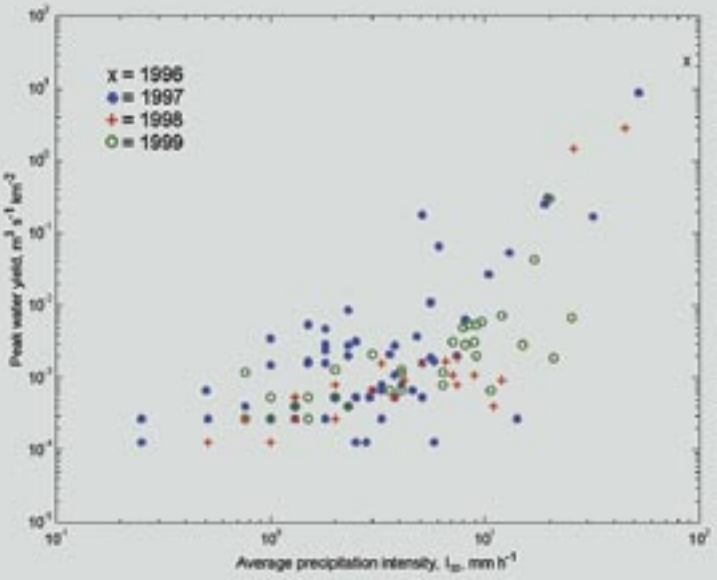
In two relatively flat Stermer Ridge watersheds, Gottfried and others reported that stream discharge measurements were made from 1972 to 1976, after which the flumes were "mothballed" but left in place. The highest peak flow recorded for a summer storm during that time was 0.10 cfs. The Rodeo-Chediski Fire then burned nearly 463,000 acres in June 2002, including the Stermer Ridge watersheds, with one watershed experiencing a high-severity stand-replacing fire and the other a low- to medium-intensity, stand-modifying fire. The flumes were reactivated after the fire, but precipitation gauges were not installed until after two storms had already occurred. However, discharges in the severely burned watershed were estimated

Post-fire peak flows, recorded during the year after the fire ... were about 160 times the maximum pre-fire floods.

Top: *View across Buffalo Creek of an alluvial fan deposited after a July 1996 rainstorm over the area burned by the 1996 Buffalo Creek Fire. Photo by R.H. Meade, USGS.*

to be 8.9 cfs and 232 cfs for the two storms.

Veenhuis (2002) studied the effects of wildfires in the Bandelier National Monument area of north central New Mexico. The June 1977 La Mesa Fire burned 15,270 acres, including Frijoles Canyon, and the April 1996 Dome Fire burned 16,516 acres, including Capulin Canyon. Post-fire peak flows, recorded during the year after the fire at the farthest downstream gauging stations in both canyons, were about 160 times the maximum pre-fire floods, at 3,030 cfs for Frijoles Canyon and 3,630 cfs for Capulin Canyon. Pre-fire peak discharge was 19 cfs for Frijoles Canyon and an estimated 25 cfs for Capulin Canyon. In the second year after the fires, peak flows decreased to 10 to 15 times the pre-fire annual maximums, and in the third year they were only three to five times as large as pre-fire flows. However, even 22 years after the La Mesa Fire, flood magnitudes had not receded to pre-fire size. Veenhuis also found that the frequency of larger stormflows increased following fires, particularly in the first three years. In pre-fire Frijoles Canyon, the maximum peak storm flow was 19 cfs; post-fire events exceeding that discharge numbered 15 in 1977 (seven events exceeded 100 cfs), nine in 1978, and five in 1979.



Relation between unit-area peak discharge and 30-minute rainfall intensity (I_{30}) following the 1996 Buffalo Creek Fire (from Moody and Martin, 2001a). Discharge was measured at the mouth of the Spring Creek watershed, and intensity is the average I_{30} intensities from two gauges in the watershed.

Terrain, Soil Make a Difference

Greg Kuyumjian of the Santa Fe National Forest estimates that after the Cerro Grande Fire (43,000 acres, Los Alamos, New Mexico, May 2000) post-fire runoff increased by more than two orders of magnitude. In Pajarito Canyon, with a watershed area of 1,275 acres, seven years of pre-fire data showed a peak flow of 2.4 cfs. In the first major rainfall event following the fire, a flow of 1,020 cfs was recorded, this from 755 acres of high or moderate burn severity. In the 57 years prior to the fire, sediment delivery to Los Alamos Reservoir averaged about 130 cubic yards per year, from a watershed area of just over 4,069 acres. In the first year following the fire, 23,000 cubic yards were delivered to the reservoir, and in the second year, 11,000 cubic yards accumulated, in part from 1,217 acres of high or moderate burn severity.

In areas where terrain is steep and rocky, Kuyumjian found that the magnitude of runoff and sediment load do not increase as dramatically after a fire. Following the 2003 Aspen Fire in southern Arizona, Sabino Creek experienced a post-fire peak flow of 3,140 cfs about a month after the fire ended. That discharge was considerably less than the pre-fire peak flow of 15,400 cfs in 1999. Although precipitation intensity after the fire has never been as high as that which caused the 1999 discharge, for the precipitation events that did occur, the changed watershed conditions caused streams to flow from precipitation at a lower intensity than under pre-fire conditions.

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Wildfire Impacts on Water Quality

Tom Meixner, Ph.D. – University of California, Riverside Department of Environmental Sciences and Pete Wohlgemuth – United States Forest Service, Pacific Southwest Research Station, Riverside Fire Laboratory

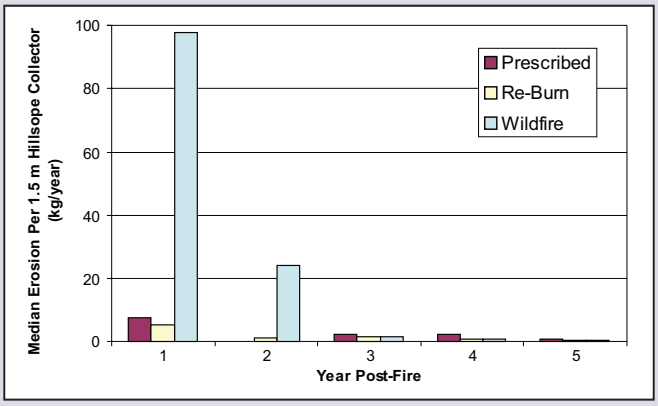
Much of the attention paid to wildfire and its impacts on the hydrologic cycle focuses on increased danger from flooding and mudslides during the immediate post-fire period. While threats to human health and safety posed by floods, debris flows, and mudslides certainly cause the greatest concern, water quality impacts and their associated risks are nonetheless critical for water utilities and regulatory agencies to address. Important questions are:

- What impact does wildfire have on surface water quality?
- How long does the impact last?
- How far away from burned areas can water quality impacts be felt?
- What beneficial uses can be affected by the changes in water quality induced by wildfire?
- How can adverse impacts of wildfire on water quality be prevented, mitigated, or otherwise minimized?

The quality of surface waters can be examined in terms of physical, chemical, and biological characteristics. Here we consider only the impacts of fire on physical and chemical water properties, based on research in the coniferous forests and chaparral watersheds of California. Biological impacts are inferred from the changes in the physical and chemical properties of surface waters.

Physical Impacts on Water Quality

Most impacts on the physical characteristics of fire-impacted streams are evidenced by changes in sediment load. Increased sediment flows following a fire can impact both ecological health and drinking water operations. The large quantities of post-fire sediment can overwhelm the biological habitat available for aquatic organisms such as fish, as well as organisms that depend on water for some life stage, such as amphibians and insects. This problem of habitat disturbance after a fire has motivated the U.S. Fish and Wildlife Service, the Forest Service, and the Park Service to focus on habitat protection and removal of threatened and endangered species from riparian systems following severe wildfires in Arizona and California.



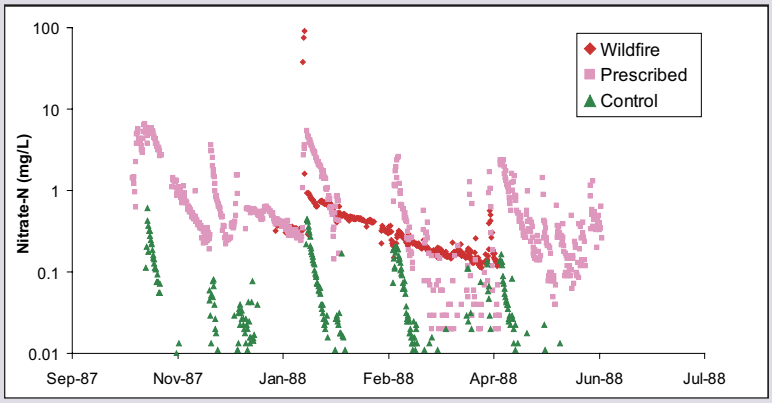
Post-fire sediment load data from the Santa Monica Mountains of Southern California. The prescribed fire occurred in 1988 and data for that fire represent the five years following that fire. The re-burn data are for the same locations as the prescribed fire data except following a wildfire that burned the entire watershed in 1993. The wildfire data are for sites that did not burn in 1988 but did burn in 1993 (from Wohlgemuth et al., 1999).

Large post-fire sediment fluxes impact drinking water systems two ways. First and perhaps foremost is the danger that reservoirs, infiltration basins, and treatment works will be filled, damaged, or otherwise disrupted by sediment. Second, high sediment load is likely to increase pre-treatment processing needs (and costs) for suspended sediment removal. These impacts are highest in areas immediately adjacent to fires. However, as recently documented by the Santa Ana Watershed Project Authority (www.sawpa.org), after the fall 2003 wildfires in Southern California, treatment works and reservoirs as far as 100 miles from the fire can be affected by increased sediment loads, particularly in the suspended fraction.

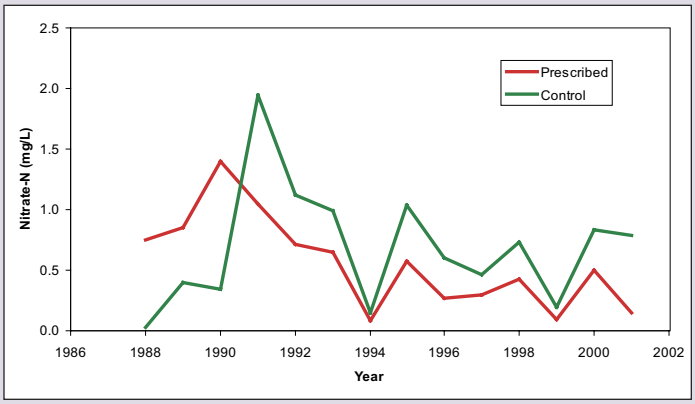
Management techniques can mitigate damages from post-fire sediment export. Permanent and temporary debris basins can be constructed to catch sediment, and earth-moving operations can be performed periodically to clean out basins and maintain their capacity. These methods are expensive in terms of both capital construction costs and maintenance costs. Increasing the fire frequency in a given area through prescribed fires has also been found to reduce post-fire sediment export (see chart above). Loomis et al. (2003) showed that since frequent fire reduces overall sediment loads, Los Angles County could save more than $24 million in annual debris basin cleanout costs through the use of prescribed fires.

Chemical Water Quality

The impacts of wildfire and prescribed burns on chemical composition of streams are not well-documented, but studies suggest that nutrient loads, particularly phosphorus and nitrogen, increase after fires, and that the effect may be greater



Seasonal variation in nitrate-N concentrations for two burned watersheds (wildfire and prescribed) and one control watershed. The fires both occurred in fall 1984; these data represent the fourth wet season after that fire. The two burned watersheds still have significantly elevated Nitrate-N concentrations compared to the control watershed.



Long-term nitrate-N concentrations from the San Dimas Experimental Forest burn study of Riggan et al. (1994) and continuing data, following a prescribed fire in fall 1984. For the first seven years, concentrations were higher in the burned watershed; the trend reversed in 1991.

from wildfires than from prescribed burns. Phosphorus export increases after wildfires, and to a lesser extent after prescribed fires. Since phosphorus is carried primarily in the sediment load, most of the increase is due to higher post-fire erosion rates, although some phosphorus is concentrated in ash as well.

Nitrogen is exported primarily as nitrate, and post-fire concentrations can exceed the federal drinking water standard of 10 milligrams per liter. A key study on the impact of fire on nitrate export in chaparral ecosystems was conducted at the San Dimas Experimental Forest (SDEF) in Glendora, California by Riggan and others (1994). The study involved six watersheds: two were kept unburned as control watersheds, two were burned under typical prescribed conditions, and two were burned under simulated wildfire conditions. The initial data following the fire in the winter of 1985 showed an increase in nitrate export with an increase in fire severity. Results three years after the fire indicated that fire increased nitrate concentrations in streams during the post-fire period, to concentrations as much as 10 times the federal drinking water standard (see chart above left) and that severity was not as critical in the longer term. Long-term data from SDEF also show that elevated nitrate concentrations can persist for up to 10 years after a fire; however, nitrate concentrations in previously burned watersheds were lower than their unburned counterparts (see chart above right). Note that all watersheds at the San Dimas experimental forest have elevated nitrate concentrations due to their proximity to the city of Los Angeles.

The effects of high nitrate concentrations on drinking water can spread beyond an area's immediate resources. Mountain areas of Southern California and elsewhere in the West provide what is generally considered the highest quality drinking water, which is often used to dilute drinking water resources impacted by industrial, urban, or agricultural activities. High nitrate concentrations in these "cleaner" waters can compromise the ability of water managers to control drinking water quality.

The results of the SDEF research suggest that wildfires may have a greater impact on water quality than prescribed fire; other studies have demonstrated the relatively benign effects of prescribed fire on water quality (Stephens et al., 2004; Richter et al., 1982). Taken together, these findings indicate that more frequent use of prescribed fire may have a beneficial impact on long-term water quality management in the western United States.

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Post-fire Seeding for Hydrologic Recovery

Samuel R. Loftin *– Los Alamos National Laboratory*

A healthy stand of seeded grasses from the Cerro Grande Fire. Photo by Sam Loftin, LANL.

Seeding has long been an important treatment for post-fire watershed rehabilitation. It has also become arguably the most controversial tool in the toolbox. Few topics generate as much heated discussion as choosing an appropriate seed mix or critiquing the seed mix chosen.

High severity fires often consume standing vegetation as well as the soil organic layers and associated seed bank. Consequently, soils are left unprotected and little seed reserve may be left to stabilize soils in the future. This increases the potential for substantial runoff, soil erosion, downslope flooding, and degradation of water quality. Seeding attempts to restore some stability to burned soils and watersheds. The decision to seed or not requires an evaluation of the risk to resources of either course of action. Frequently, it appears that fires are seeded as a standard course of action. Given the controversial nature of the issue, it is probably best to justify the need to seed rather than the converse.

How and Where to Seed

Considerations when designing a seeding project include seed application techniques, treatment location, choice of appropriate seed, seeding rates, availability, and cost. Application techniques can range from aerial seeding for large areas (by plane or helicopter) to hand application with or without mulching or other seedbed enhancement techniques. Although aerial seeding allows the treatment of large areas at relatively low unit cost, its outcome can be unpredictable, and often results in fat mice rather than stable soils. A more successful and cost-effective approach is to target or avoid specific landscape features. Areas with high burn severity are targeted, whereas areas with low and moderate burn severity often retain sufficient seed in the seed bank to promote regrowth, and needle fall following the fire can provide adequate mulch. Areas that are avoided include south- and west-facing exposures, because they are often too hot and dry for seed germination without mulch cover. Note that surface applications of seed without mulch cover often do not germinate the first season, so benefits may not be realized for nine to 12 months.

Choosing the Seed Mix

Choosing an "appropriate" seed mix is another tricky task. What are the environmental constraints? Will it grow? How long will it persist? Should natives or non-natives be used? A seed mix that works at the 10,000-foot elevation in the Sangre de Christo Mountains may not work at 6,000 feet on the Caja del Rio, even though they are both in the same Forest District. Local experts and seed distributors can match species with environmental conditions. Another concern is species persistence: How long will the seeded species survive in the burned area? Annual species such as annual ryegrass (*Lolium multiflorum*) or cereal grains are often used to provide quick cover to protect soils, then die

out in a year or two, thereby limiting competition and suppression of native plant species. Perennial species such as slender wheatgrass (*Elymus trachycaulus*) and mountain brome (*Bromus marginatus*) have been used successfully in northern New Mexico to provide cover for two to seven years before they die out. Some areas at Los Alamos National Laboratory (at approximately 7,000 feet elevation) that burned in the Cerro Grande Fire of 2000 were seeded with annual ryegrass, barley (*Hordeum vulgare*), slender wheatgrass, and mountain brome, and then straw-mulched. The seeded annual species came in strong by the 2001 growing season, seeded perennials were abundant by 2002, and by 2003 endemic native species dominated the site, with seeded species found only in protected areas. In contrast, the 1964 Wildcat Fire on the Apache-Sitgreaves Forest in Arizona was seeded with a mix that contained an African exotic, weeping lovegrass (*Eragrostis curvula*), and 35 years later the area was still dominated by lovegrass. The site is stable, but native plant and animal abundance and diversity is less in many areas than in native grassland. In general, the use of persistent non-native species is not recommended.

Although native species sound like the obvious answer, the issue is not that simple. Availability and cost are always of concern when dealing with native seed, particularly during the fire season when supply goes down and demand and cost go up. Non-native species are attractive because they often have higher germination and growth rates. But the real issue in the native versus non-native debate revolves around the introduction of new genotypes. Most people would consider blue grama (*Bouteloua gracilis*) a native species, but if the seed is collected in Oregon and cultivated in South Dakota, is it appropriate to use in Colorado? How are we affecting native populations by introducing genotypes adapted to other regions? Is it preferable to use non-native species that will die out in a few years rather than to introduce nonlocal genotypes of a species that can interbreed with the locals? Answers to these questions are being debated. Fortunately, many growers offer certified or "source-identified" seed. Certified seed verifies the specific seed variety, while source-identified seed has information on where the seed was collected, to allow a better match with local conditions.

Keeping Noxious Weeds Out

Another seeding concern is the inadvertent introduction of noxious weeds. This is a problem associated with all aspects of wildfire, from suppression to rehabilitation. Most noxious weeds have evolved to take advantage of disturbances such as fire. Treatments like seeding and mulching provide a pathway for introduction. Certified weed-free seed should be used for all applications and all major growers offer this service. Weed-free certification simply means that the samples taken from a particular seed lot contained no weed seeds listed as prohibited by the state where the seed is to be applied, and the amount of state-restricted weed seeds is less than some defined limit. Lists of prohibited and restricted species for each state can be obtained through the State Noxious Weed Seed Requirements link provided below. It is recommended that seed be tested for purity by an independent seed lab. Such labs often are associated with state agricultural universities and the analysis is usually fast and inexpensive. Be aware that certification and testing do not guarantee purity; some weed seed almost always remains, and with it the possibility of noxious weed introduction.

Burned area rehabilitation and natural resource management in general are all about managing risk. Risks associated with seeding or not seeding or the use of natives versus non-natives should be identified and documented before decisions are finalized. One way to reduce the controversy and gain consensus for treatment options is to engage local agencies and interested parties and develop strategies to be implemented in emergency situations before a crisis occurs.

Contact Sam Loftin at sloftin@lanl.gov

Additional Information . . . . . .

State Noxious Weed Seed Requirements: www.ams.usda.gov/lsg/seed/seed_pub.htm.

Pre-Fire Analysis of Management Alternatives: the Santa Fe Municipal Watershed

James T. McCord, P.E., Ph.D., and John Winchester, P.E. – Hydrosphere Resource Consultants

The loss of vegetation during recent wildfires in Colorado resulted in tons of ash and debris washing into municipal water supply reservoirs, disrupting water treatment operations and reducing reservoir storage. After the 1996 Buffalo Creek Fire, 600,000 cubic yards of ash, sludge, and debris washed into Strontia Springs Reservoir. Turbidity of water coming into the treatment plant rose from 1.5 to 800 turbidity units. Based on these and other experiences following catastrophic fires in New Mexico, Arizona, and Colorado, the city of Santa Fe's water supplies likely would be seriously threatened if a fire occurred in the municipal watershed.

What effects would a catastrophic fire have on the forest health and hydrology of the Santa Fe Municipal Watershed? Which management alternatives would best protect the watershed and its sustainable water supply? These questions were the focus of studies undertaken in 2000 by Hydrosphere Resource Consultants as part of an Environmental Impact Statement to assess management alternatives for reducing the risk of catastrophic wildfire. The watershed has been closed to all uses since 1931 except fire suppression, which has led to extremely high fuel loads.

Management alternatives considered ranged from no action to various thinning alternatives with or without low-intensity prescribed (broadcast) burning. For each alternative, predictions were made for: 1) erosion and sediment yield; 2) peak flood flows on the Santa Fe River; and 3) annual water yield from the watershed following a high-intensity, stand-replacement fire. Predictions were based on a combination of mathematical models and observations from other watersheds comparable to the Upper Santa Fe River watershed.

Erosion Analyses

Post-fire effects were studied with respect to the volume of sediment that could be eroded from the watershed and deposited in the riparian zone and the city's water supply reservoirs. An engineering erosion model, the Revised Uniform Soil Loss

Alternative Summary Description (acreage treated)	Sed. Yield from Watershed (maximum acre-feet in 8 years)	10-yr Peak Flow @ Arroyo Mascaras (cfs)	Water Yield (% change after treatment)	Water Quality (relative change)	Soil Nutirent Cycling (relative change)
No Action, following catastrophic wildfire	3,148	>15,000	>+100%	Significantly adverse	Significantly adverse
Limited Manual Thinning with Broadcast Burning (2,190 acres)	86	<1,000	<+20%	Negligible changes	Minor improvement
Limited Manual Thinning with No Broadcast Burning (7,270 acres)	79	<1,000	<+20%	Negligible changes	Slight adverse effects
Manual Thinning with Broadcast Burning (4,900 acres)	86	<1,000	<+20%	Negligible changes	Minor improvement
Manual Thinning with No Broadcast Burning (7,270 acres)	79	<1,000	<+20%	Negligible changes	Negligible changes
Machine Thinning with Broadcast Burning (4,900 acres)	86	<1,000	<+20%	Negligible changes	Minor improvement
Machine Thinning with No Broadcast Burning (7,270 acres)	79	<1,000	<+20%	Negligible changes	Negligible changes

Summary of soil and water effects for each of the key issues and parameters considered.

Equation (RUSLE), was employed with analog watershed data.

Seven watersheds were identified in the western United States with similar vegetative and physical settings and that experienced high severity fires. In these analog watersheds, observed post-fire erosion rates were 25 to 448 times pre-fire rates, with an average 216-fold increase.

The RUSLE analysis was performed for current conditions (sustainable managed use) and for conditions where vegetation is completely removed (post-fire). For post-fire erosion, the hydrophobicity (water repellency) multiplier developed by the U.S. Forest Service for the 2000 Viveash Fire east of Santa Fe was incorporated. The average analog watershed post-fire to pre-fire ratio was multiplied by the RUSLE erosion rate under current conditions to predict the post-fire sediment yield. Predicted accumulated sediment yields in the first eight years following a fire ranged from 500 to 3,100 acre-feet, which could significantly impact the 4,000 acre-feet of reservoir storage in the Santa Fe watershed. The treatment alternatives all reduced the predicted sediment yield to around 80 acre-feet for the first eight years, still greater than the current eight-year accumulation of 3.52 acre-feet.

… experiences following catastrophic fires in New Mexico, Arizona, and Colorado suggest that the city of Santa Fe's water supplies would be seriously threatened if a fire occurred in the municipal watershed

Runoff / Peak Flow Analysis

To analyze the risk of post-fire flooding in the Santa Fe River, including the downtown plaza district, an SCS Curve Number approach was adapted from the Burned Area Emergency Response team's analysis of the Viveash Fire. Post-fire peak flows for analog watersheds ranged from three to 386 times higher than pre-fire peak flows, depending on fire severity. Post-fire peak flows for the Santa Fe River were predicted by multiplying estimated unregulated peak flows in the Santa Fe Watershed by the peak flow ratio from the analog watersheds.

Under current conditions, a 10-year flood results in a peak flow of approximately 1,000 cubic feet per second. However, the results of the peak-flow analysis showed that the five-year post-catastrophic fire storm flow was predicted to nearly double the *100-year* storm flow under current conditions. Peak flows following prescriptive treatments in the watershed did not significantly differ from current conditions.

Water Yield Effects Analysis

Based on gauging records for the Santa Fe River, the annual water yield of the Santa Fe Watershed has declined approximately 20 percent over the past 70 years, adversely affecting the city of Santa Fe's water supply. This yield reduction is due to the unnaturally high vegetation density in the watershed. Reducing vegetation density would reduce losses to interception and evapotranspiration and increase stream flows. For this analysis, analog watershed data of gauge-measured water yields were used to determine how much the yield could be expected to increase following fires of a range of severities. Results show that with no action, water yield would double in the years following a severe fire, and would increase by about 20 percent with thinning and low-intensity burning treatment alternatives.

Overall, the results of the study (see table above) show that any of the proposed management alternatives other than no action would reduce the risk of large-scale watershed damage. The primary differences between the results were due more to the number of acres treated than to the efficacy of an individual treatment method.

Any of the "action" treatment alternatives would impart effects that range from negligibly adverse to obviously favorable to soil and water conditions, including:

- very minor sediment yield increases,
- very minor peak flow increases, and
- slight water yield increases.

In contrast, the no-action alternative, which includes the occurrence of a catastrophic fire, would likely cause:

- increased accumulated sediment yields in the first eight years following a fire, significantly threatening the city's reservoir storage;
- much higher peak flows, greatly increasing the likelihood of flooding in the city's downtown area; and
- twice as much water yield from the watershed in the years immediately after the fire.

Contact Jim McCord at jtm@hydrosphere.com and John Winchester at jnw@hydrosphere.com.

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GRA's Legislative Efforts

***Tim Parker** – Chair, Legislative Committee, Groundwater Resources Association of California*

Groundwater Resources Association of California (GRA) has been working diligently to position itself among state policy makers in Sacramento as an authority and reliable technical resource on groundwater issues. The GRA Legislative Committee, lobbyists, and many members are working to build relationships with California legislators and their staffs through personal meetings, by providing information on groundwater and educational programs, and by actively participating in crafting statewide water policy concerning the development, management, and protection of the state's groundwater resources. Nearly all these efforts have been voluntary, but recently GRA has found limited funding for two lobbyists, Chris Frahm and Jennie Carbuccia of Hatch & Parent.

The GRA Legislative Committee, composed of representatives from the water supply industry, business, water resources and groundwater contaminant consultants, state government, agriculture, and private landowners, meets monthly with GRA lobbyists to discuss key water and groundwater policy and legislation issues. GRA has developed legislative guidelines that address broad policy principles that cover groundwater management, water quality protection, watershed management, and groundwater funding issues. Based on these guidelines, the committee decides whether to support, remain neutral, or oppose groundwater legislation in development and determines which bills to take to the GRA board and membership for deliberation.

GRA conducts an annual Legislative Symposium and Lobby Day and annual to semi-annual legislative staff briefings. This year's symposium, held in May, provided attendees with an overview of groundwater policy under the Schwarzenegger administration as well as presentations and panel discussions on water quality standards and the issues of reliability and consumer confidence. The afternoon included visits to state legislators' offices, where GRA members and lobbyists met with members of California's Senate and Assembly.

Due to financial constraints, nearly all of these legislative efforts have been opportunistic; that is, they pertain to areas where GRA believes it can add value to ongoing legislative and policy development processes through its members' technical expertise and time. An example of this approach is AB 599, the California Groundwater Monitoring Act of 2001. GRA helped support this legislative effort through technical input and testimony, attended the technical and public advisory committee meetings during the development of the requisite work plan, and continues to monitor and update membership on the status of this monumental groundwater monitoring effort.

Visit www.grac.org.

IGRAC Proposes Groundwater Guidelines

Based on worldwide inventories of existing guidelines and protocols for groundwater monitoring, the International Groundwater Resources Assessment Center (IGRAC) has identified several areas where guidelines are needed for improving groundwater data collection. The following subjects were selected for developing new guidance:

- *Baseline groundwater monitoring*: The proposed guide will assist developing countries that lack systematic groundwater monitoring programs in setting up inexpensive baseline monitoring programs for groundwater assessment and management.
- *Evaluating groundwater monitoring programs*: The proposed guide will enable critical evaluation and improvement of existing groundwater monitoring programs. It will provide guidance in reviewing objectives, specifying data requirements and adjusting monitoring networks, parameter sets, and frequency of sampling.
- *Assessing the exploitable groundwater resources of an aquifer or area*: The proposed guide will aid in selection of the most appropriate method for determining the exploitable quantities under specific conditions.
- *Assuring quality in groundwater data collection and interpretation*: The

proposed guide will specify quality assurance methods for selected data fields, with the aim of improving collection, evaluation, presentation, and interpretation of data.

The proposed guides will be developed with the help of international working groups, to be formed and coordinated by IGRAC. Detailed information on the proposals and the working groups will be published on IGRAC's website.

For more information on the working groups, visit igrac.nitg.tno.nl/contact.html and type "working groups" in the comment field.

ACWA Presents Clair Hill Award

In May, the Association of California Water Agencies (ACWA) presented its prestigious Clair A. Hill Award to Carmichael Water District for its innovative microfiltration water treatment plant. The award was presented during the ACWA Spring Conference, a statewide event attended by more than 2,000 participants. Carmichael was selected from among six finalists to receive the award.

Faced with new filtration requirements for its American River water source, the Carmichael Water District in 1994 began a long and controversial public process to determine how best to comply. The solution was an innovative membrane microfiltration water treatment plant that produces 17 million gallons a day of ultra-high quality drinking water. Custom designed to be compatible with a densely populated, residential setting, the plant went on line in late 2001 and has drawn international attention for its technology.

ACWA's Clair A. Hill Water Agency Award for Excellence annually recognizes outstanding achievements by public water agencies. The winning agency receives a $3,000 scholarship to award to a deserving student in the name of Clair A. Hill, founder of the consulting engineering firm CH2M Hill.

Visit www.acwanet.com.

NMWRRI Convenes Research Symposium, Updates Web Site

On Aug. 10, the New Mexico Water Resources Research Institute (NMWRRI) hosted the 2004 Water Research Symposium at New Mexico Tech. Attended by nearly 90 people, the program featured 16 oral presentations and approximately 25 posters, focusing on improved efficiency and alternative water sources, characterizing surface water–groundwater interactions, modeling surface water and groundwater processes, quantifying evapotranspiration, and characterizing surface water contaminants.

Also during the summer, NMWRRI redesigned its Web site. The new site contains proceedings from past research symposia and water conferences (including the August meeting) and other NMWRRI publications, information on upcoming meetings, access to the reference library, sections for kids and university students, information on NMWRRI-funded research, water testing information, and more.

Visit wrri.nmsu.edu.

New AWWA Report on UV Disinfection Systems

The American Water Works Association (AWWA) announced the release of a new report, "Bridging Pilot-Scale Testing to Full-Scale Design of UV Disinfection Systems," by Erin D. Mackey, Robert S. Cushing, Marie-Laure Janex-Habibi, Nicolas Picard, Jean-Michel Laine, and James Malley Jr.

Much research has been conducted in the use of ultraviolet light in water disinfection: its effectiveness against pathogens, UV equipment reliability, system design and operation, construction and operating costs, and other basic issues. This report aims to develop and translate pilot-scale research to full-scale design. It describes:

- design scenarios, configurations, and capital cost estimates for retrofitting UV into an existing treatment plant;
- medium-power and low-power high output types of UV reactors from several manufacturers;
- long-term performance, process control, reliability, and operation and maintenance costs of UV disinfection in drinking water treatment;
- the impact on UV-system performance of flow rate, treatment chemicals, feed-water characteristics, and UV lamp fouling, aging, and cleaning; and
- regulatory agency acceptance of UV disinfection in drinking water systems.

According to AWWA, the report will help design engineers and water utility managers make informed decisions about the configuration, operation, and cost of several types of UV disinfection systems in drinking water treatment.

The softbound report costs $135 for members or $205 for nonmembers, and is available at www.awwa.org/bookstore/product.cfm?id=90991.

BAER, continued from page 15

were threatened with post-fire flooding, in turn threatening water quality and potentially creating human health concerns. As part of BAER treatment, the toilets were pumped, sanitized, and shut down.

Monitoring the Results

Monitoring may be conducted during and after treatments to examine implementation, effectiveness, and results. This process can include measuring the distribution density and mix of seed, photodocumenting the regrowth of vegetation, noting whether channels flow freely or become blocked once runoff begins, and noting how infrastructure holds up. Monitoring during the treatment period helps determine if additional efforts are necessary. After treatment, monitoring identifies successful methods as well as undesirable results.

The BAER process in the Southwest involves an intense work schedule, rapid decision-making, and a race against the weather. The team disperses once the emergency rehabilitation measures are in place, although some members may return a few months later for final monitoring.

Details of the actions taken and results achieved by the 2003 Aspen BAER team can be found in the monitoring report at www.volunteertaskforce.org/aspenbaer/Aspen_BAER_Monitoring_Home.htm. Contact Greg Kuyumjian at gkuyumjian@fs.fed.us.

Business Directory

JOB OPENING - Drainage Department Head: Wood, Patel & Associates, Inc.

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Pyrethroid in Creek Sediments Toxic to Organisms

Summarized from University of California, Berkeley, News Service, May 6, 2004

A family of pesticides used increasingly in place of more heavily restricted organophosphate pesticides has accumulated in many creek sediments to levels that are toxic to freshwater bottom dwellers, according to a new study. The pesticides, called pyrethroids, have been considered safe for fish and other organisms that live in the water column, but no one has studied their effect on sediment-dwelling organisms, such as midge larvae or shrimp-like amphipods, said University of California, Berkeley, biologist Donald P. Weston. These two organisms are used by the U.S. Environmental Protection Agency as indicators of fresh water sediment health.

Weston and colleague Michael J. Lydy of Southern Illinois University collected sediment samples from 42 rivers, creeks, sloughs, and drainage ditches in California's Central Valley and exposed amphipods and midge larvae to the sediments for 10 days. Twenty-eight percent of the sediment samples (20 of 71) killed amphipods at an elevated rate, and in 68 percent of these sediments, the pyrethroids were at levels high enough to account for the deaths. Thus, while other pesticides may well have contributed to amphipod deaths in some sediment samples, pyrethroids alone explain the toxicity in the vast majority of the sediment samples, Weston said.

Pyrethroids are a class of compounds represented by permethrin, first marketed in 1973, and various other chemicals usually ending in the suffix *-thrin*. Permethrin is found in many home and garden pesticides. Permethrin and its kin also find broad use in agriculture.

Though pyrethroids are used far less than organophosphates like diazinon and chlorpyrifos, their use in California has risen rapidly in recent years because of increased regulation of the spraying of organophosphates.

Weston noted that another chemical sometimes applied with pyrethroids may be making the situation worse. Piperonyl butoxide, or PBO, is a synergist that shuts down the enzymes that detoxify pyrethroids, making them last longer in an organism and increasing their killing potential. He and his colleagues now are trying to measure the level of pyrethroid that kills amphipods, which is around 3 parts per billion in sediments, and to determine whether levels of PBO should be considered in estimating the true toxicity of pyrethroid pesticides.

"I don't want to give the impression that pyrethroids are destroying the streams, since that has not yet been shown, but if we are serious about maintaining stream health, we have to consider the sediments and not limit our sampling just to the water above," said Weston. "While pyrethroids may be preferable to the organophosphates that preceded them, our work shows that the environmental effects of pyrethroids cannot be ignored and have had too little study for too long. We need to know more about pyrethroids, because if we don't, how can we regulate them?"

The study by Weston, Lydy, and postdoctoral researcher Jing You in the Department of Zoology at SIU was published in the May 15, 2004 edition of *Environmental Science & Technology*.

Visit pubs.acs.org/journals/esthag and www.berkeley.edu/news/media/releases/2004/05/06_pyrethroid.shtml.

Rainfall and Rio Grande Flow Link Studied

From the National Science Foundation

Rainfall in the mountains of New Mexico has a major influence on Rio Grande levels, and its effects can be seen as much as 50 years after the rain has fallen, according to hydrologists funded by the National Science Foundation. Christopher Duffy of Pennsylvania State University has shown that precipitation over the mountains, at least in the basin and range area of New Mexico, plays an important role in

Continued next page

recharging the water table and the Rio Grande River, although the river is far from the mountains.

Duffy used a computer model to investigate groundwater in central New Mexico. The terrain is variously classified as mountainous area, sloping bajada, and riparian or river area. Duffy incorporated the effects of environmental variables such as rainfall, snowpack, evapotranspiration, and altitude, as well as the porosity and permeability of the subsurface.

"The time between rainfall on the mountains and ultimate recharging of the riverine water table is about 50 years," says Duffy. "The seven-year, 1950s drought in the area is what is now affecting the Rio Grande and the water table.

"Developers of New Mexico's mountains and bajada regions need to consider a longer time horizon than a decade when planning to alter the natural environment. It may require a forward view of tens of decades to ensure sustainability. Even if no obvious year-round streams run from the mountains, they are still very important for the recharge of the water table and river."

Visit www.nsf.gov./od/lpa/newsroom/pr.cfm?ni=97

New Findings Reinterpret Perchlorate Risks

The Urban Water Research Center at the University of California, Irvine recently released a report stating that perchlorate in drinking water may pose no additional risks to healthy people. The report was prepared by a five-member panel of experts, including Richard Bull, adjunct professor of pharmacology/toxicology and environmental science at Washington State University and former director of the U.S. EPA's Toxicology and Microbiology Division; Andrew Chang, professor of agricultural engineering and associate director of the UC Center for Water Resources at UC Riverside; Carl Cranor, professor of philosophy, UC Riverside; Ronald Shank, professor and chair of community and environmental toxicology, UCI College of Medicine; and Rhodes Trussell, adjunct professor of environmental health, science and policy at UCI and president of Trussell Technologies.

The panel was charged with reviewing relevant peer-reviewed literature on the health effects, risk assessment, and risk management on perchlorate, essentially the same information the California Department of Health Services (CDHS) is using to determine the state maximum contaminant level (MCL) for perchlorate in drinking water.

The panel concluded that perchlorate concentration in drinking water as high as 100 parts per billion is not harmful to healthy adults. However, they stated that a conservative value for the perchlorate MCL is warranted even though direct benefits could not yet be demonstrated, because of uncertainties of the effects of the compound on people with lower than normal iodide

uptake (such as some pregnant women), uncertainties of how perchlorate might interact with certain other anions that also occur in drinking water, and uncertainties in how representative the study participants were in terms of body weight, environment, and lifestyle.

Finally, the panel recommended further research in several areas. Most importantly, more information is needed on perchlorate's health effects on populations other than healthy adults. In addition, improved detection methods are needed to measure perchlorate at lower concentrations, in reclaimed water, and in food and beverages. Research is also lacking on methods for reducing the problems of brine disposal where removal of perchlorate by ion exchange is used.

The 60-page report is available at www.urban-water.uci.edu/UCI-UWRC_Perchlorate_wCorrection061404.pdf

Sandia to Research Desalination, Arsenic Removal

From Sandia National Laboratory

Sandia National Laboratories in Albuquerque recently received a $6 million allocation from the FY2004 federal Energy and Water Development Appropriations bill for research in desalination and arsenic cleanup.

Desalination

The desalination program will focus on research and development of technologies addressing the technical, economic, and environmental issues associated with the treatment and utilization of inland brackish groundwater. Some of the research will be done at the Tularosa Basin National Desalination Research Facility in Alamogordo, now in the early stages of construction. Sandia, the U.S. Bureau of Reclamation, the U.S. Office of Naval Research, and others will use the facility to study new desalination technologies and the use of renewable energy in the desalination process, and to focus management and reuse technologies.

The Tularosa Basin in south-central New Mexico was selected as the desalination facility location because it contains a range of brackish water — from almost fresh to twice as salty as seawater — all within a five-mile radius. A set of wells already has been drilled at different brackish levels in the basin. The desalination facility will consist of six indoor bays where testing can be done side-by-side. Testing will also be conducted outside in three additional test pads.

Arsenic removal

The $3 million for research of arsenic removal from water stems from EPA guidelines that go into effect in 2006, reducing the allowable amount of arsenic in drinking water from 50 parts per billion (ppb) to 10 ppb. Albuquerque is one of many communities affected by the new ruling. Arsenic concentrations in drinking water in the area are highly variable, but average 15 ppb.

The American Waterworks Association Research Foundation (AwwaRF) and WERC — a consortium that includes New Mexico State University, the University of New Mexico, New Mexico Tech, and Dine College — will share the funding with Sandia. Besides the $3 million for the arsenic project, Sandia will receive an additional $1.8 million from another congressional appropriation.

Development of new arsenic removal technologies is the responsibility of AwwaRF. Sandia's role will be to pilot promising new technologies as they get close to commercialization. WERC will handle transfer of the technologies to companies that will commercialize them and sell them to water utilities.

The pilot-scale testing program will evaluate a variety of innovative approaches to reduce the cost of arsenic treatment for small communities, and will specifically address the needs of Native American communities. One of the best treatment methods is the use of adsorbents, natural or man-made materials that have been designed for the purpose of removing arsenic and other contaminants. These materials are packed into containers through which untreated water is forced. The arsenic is adsorbed by the material, and the water comes out with no detectable arsenic. The material then can be disposed of in landfills or regenerated for further use. Systems can be large enough to treat sufficient drinking water for large communities or small enough to fit under a kitchen sink.

Visit www.sandia.gov/news-center.

Albuquerque's Explora Offers Hands-On Water Education

***Edith Menning** – Explora*

In the desert Southwest, the maxim that water is life is evident everywhere. Agua de la Vida/La Vida del Agua, a multipart exhibit in Albuquerque's newly expanded Explora Science Center, invites visitors to experience water from a variety of interactive perspectives.

Visitors test water samples at the laboratory.

At the entrance to the exhibit area, a 20-foot erosion table cascades a stream of water over and through a landscape of plastic sand, which is endlessly rearranged by visitors, circumstance, and the simulated river itself. Land and water shape one another. The exhibit also illustrates water's capacity to carry other materials within it, a theme that can be examined in more depth in Explora's nearby water laboratory, where visitors can test water samples—their own, or ones from around New Mexico supplied by Explora.

Like a meandering streambed, Agua de la Vida wanders among interactive exhibits where visitors can create wave patterns on moving sheets of water, experiment with surface tension, or divert a faucet stream with static electricity. Another stream table offers opportunities to dam or control water flow through joined structures, some of which have surprising twists. As a corollary to the exhibit, Explora's two-story laminar flow fountain shoots coherent bursts of water into the air in complex patterns that are partially controlled by visitors.

The Agua de la Vida exhibit represents Explora's long-term commitment to the water theme. For the next three to four years, the exhibit will continue examining how water acts as a medium for natural and man-made materials. Future perspectives will consider the following topics: water as a necessity for life, focusing on how living things use water; water as a tool for agriculture, travel, power generation and other uses; and water as a dynamic force that sometimes behaves in unpredictable and uncontrollable ways. Interwoven throughout these primary perspectives will be opportunities to experience and learn principles of physics, chemistry, biology, and geology, as well as the social implications of water in arid lands.

Explora's mission is "to create opportunities for inspirational discovery and the joy of lifelong learning through interactive experiences in science, technology and art." In Agua de la Vida/La Vida del Agua, and in the more than 200 additional exhibits that fill the new building, visitors of ages one to 101 will find something to inspire them and bring them back to investigate further.

Visit www.explora.mus.nm.us.

Visitors can see stream patterns or reroute the water flow at Explora's erosion table..

IN PRINT

Valuing Ground Water: Economic Concepts and Approaches

by the Committee on Valuing Ground Water, Water Science and Technology Board, Commission on Geosciences, Environment, and Resources, National Research Council, National Academies Press, 1997, $42.95.

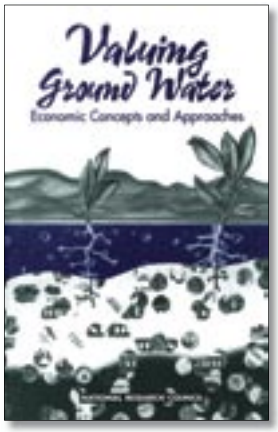
Reviewed by ***Gary C. Burchard, R.G.*** *– Metropolitan Domestic Water Improvement District, Tucson*

I must admit I was a little afraid to even begin reading a book written by a committee of a board of a commission of a council. I was certain so many layers of bureaucracy would have watered down the report sufficiently to make it worthless. I am pleased to report that my prejudice was unwarranted. *Valuing Ground Water* is hardly intimidating, comprising less than 200 pages, including index and appendices, and it has value.

The book's executive summary provides a clue to one of its important lessons: "Ground water in the United States is usually considered as either an invaluable good or as a 'free' good." Thus, this book meets head-on the paradox formulated by Adam Smith, who noticed that diamonds have little true usefulness, yet cost much; while water, which is essential, costs little. This book focuses specifically on the economic value of groundwater.

The book contains sections that cover groundwater resources, economic valuation, legal considerations, and case studies. Appendices contain a useful glossary of economic terms and a sample portion of a contingent valuation method questionnaire.

Valuing Ground Water provides a broad view of economic concepts as related to hydrology. For example, the total economic value (TEV) of groundwater includes not only the usual municipal, industrial, and agricultural (extractive) uses of groundwater that typically come to mind, but also in situ services such as buffering against surface water shortages, preventing or minimizing land subsidence, and providing base flow and thus habitat.



While reading this book, I felt I was being presented with a formal defense for valuing groundwater as an economic resource. Water utilities typically do not charge the full cost of the water they serve, but only charge for pumping, treating, and delivering water to their customers. True depreciation or consumptive costs of the water system are not passed on, and revenues do not pay for replacement of aging infrastructure. Because most city councils take pride in not raising water rates, our grandchildren will be saddled with the hefty costs of replacing worn-out delivery systems.

The authors of *Valuing Ground Water* point out that the picture for future generations is actually even worse. If groundwater is extracted faster than it is replenished, then an opportunity cost also exists: "Greater use of the resource today diminishes future opportunities for use. … Failure to take higher scarcity value of water into account will lead to extra costs to society by imposing extra scarcity on the future." Thus, the theme of intergenerational equity runs strongly through the book. Not only is increased scarcity of water resources imposed upon future generations, but also the costs associated with a depleted aquifer, including greater lift costs, deeper wells, and often lower-quality water.

The authors contend that adequate knowledge of a groundwater asset's true value is necessary for proper allocation of water among various competing uses and for proper allocation of state and federal funds to clean up contaminated aquifers. Numerous economic valuation methods are objectively provided, including strengths and weaknesses for each. The authors also assert that successful groundwater valuation efforts will necessarily be interdisciplinary, involving economists, engineers, hydrologists, and often health and biological professionals.

This book is not, however, without its weak points. While the chapter on legal considerations is interesting and illustrates the legal effects on groundwater's value, the contents are not clearly tied to the valuation methods themselves. Secondly, the authors admit that few projects have been completed where groundwater TEV has been determined. Even the elucidating case studies can provide only conceptual illustrations of what could or should be done in various situations.

If you need a handbook or manual for completing groundwater valuations, this book is not for you. However, the authors clearly and effectively present valuation concepts and approaches, and offer well-reasoned arguments on why groundwater TEV has the potential to become the standard. I recommend *Valuing Ground Water* for water professionals in all sectors.

Visit www.nas.edu/nrc. Contact Gary Burchard at gburchard@metrowater.com.

SEPTEMBER 2004

September 8-9	Nevada Water Resources Association. **Arsenic Symposium – "How Do We Meet the New Standard?"** Fallon, NV. *www.nvwra.org/news.asp*
September 13-14	CLE International. **Texas Water Law**. Austin, TX. *www.cle.com/upcoming/auswat04.shtml*
September 13-14	CLE International. **Western Water Law**. Denver, CO. *www.cle.com/upcoming/denwat04.shtml*
September 15-18	Arizona Hydrological Society. **2004 Annual Symposium**. Tucson, AZ. *www.azhydrosoc.org/Symposium.html*
September 16-17	Government Institutes/ABS Consulting. **Storm Water Discharge Regulations**. Phoenix, AZ. *www.govinst.com/Merchant2/merchant.mv?Screen=PROD&Store_Code=ACS&Product_Code=20101*
September 20-21	CLE International. **Environmental and Natural Resources Law on the Reservation**. Phoenix, AZ. *www.cle.com/upcoming/phxres04.shtml*
September 20-22	National Ground Water Association. **Introduction to Ground Water**. San Diego, CA. *www.ngwa.org/pdf/e/course/133sep04.pdf*
September 20-24	National Ground Water Association. **Natural Attenuation, Risk Assessment, and Risk-Based Corrective Action**. San Diego, CA. *www.ngwa.org/pdf/e/course/116sep04.pdf*
September 21-22	New Mexico Water Resources Research Institute. **49th Annual New Mexico Water Conference: Desalination**. Ruidoso, NM. *wrri.nmsu.edu*
September 23-24	Groundwater Resources Association of California. **13th Annual GRA Meeting: Managing Aquifers for Sustainability**. Sonoma, CA. *www.grac.org*
September 23-25	Arizona, California, and Nevada water associations and others. **20th Annual Tri-State Seminar on the River**. Primm, NV. *www.tristateseminar.com*
September 27-29	Groundwater Resources Association of California. **Parameter Estimation (PEST) Short Course**. San Francisco, CA. *www.grac.org*

OCTOBER 2004

October 5-8	Government Institutes/ABS Consulting. **Clean Water Compliance Institute**. Phoenix, AZ. *www.govinst.com/PDFFiles/2004/31109_Clean%20Water.pdf*
October 6-8	Water Education Foundation. **Southern California Tour**. *www.watereducation.org/tours.asp*
October 11-15	International Association of Hydrogeologists. **XXXIII Conference: Groundwater Flow Understanding from Local to Regional Scales**. Zacatecas City, MX. *www.igeograf.unam.mx/aih*
October 13-15	National Ground Water Association. **4th International Conference on Pharmaceuticals and Endocrine-Disrupting Compounds in Water**. Minneapolis, MN. *www.ngwa.org/e*
October 13-16	U.S. Committee on Irrigation and Drainage. **Conference on Water Rights and Related Water Supply Issues**. Salt Lake City, UT. *www.uscid.org/*
October 17-21	American Institute of Hydrology. **2004 Annual Fall Conference: Integrated Water Resources Management**. Las Vegas, NV. *www.aihydro.org/conference2004*
October 18-19	Groundwater Resources Association of California. **Arsenic in Groundwater 2004**. Fresno, CA. *www.grac.org*
October 21-22	CLE International. **California Water Law and Policy**. San Diego, CA. *www.cle.com/dev/seminars.php*
October 27-29	Western States Water Council. **146th Council Meetings**. Santa Ana Pueblo, NM. *www.westgov.org/wswc/meetings.html*

NOVEMBER 2004

November 4-6	California Groundwater Association. **Annual Convention and Trade Show**. Reno, NV. *www.groundh2o.org/events/events.html*
November 5-6	International Ground Water Modeling Center. **Modeling Water Flow and Contaminant Transport in Soils and Groundwater Using the HYDRUS Computer Software Packages**. Golden, CO. *typhoon.mines.edu/short-course/hydrus.htm*
November 7-10	Geological Society of America. **2004 Annual Meeting and Exposition**. Denver, CO. *www.geosociety.org/meetings/2004*
November 16-18	Environmental Protection Agency. **Pit Lakes 2004**. (It's free!) Reno, NV. *www.epa.gov/ttbnrmrl/pitlakes.htm*
November 16-19	SAHRA. **Second International Symposium on Transboundary Waters Management**. Tucson, AZ. *www.sahra.arizona.edu/twm*
November 30-Dec. 3	Association of California Water Agencies. **2004 ACWA Fall Conference and Exhibition**. Palm Springs, CA. *www.acwanet.com/events/FC04_conference.asp*

DECEMBER 2004

December 6-10	National Ground Water Association. **Fundamentals of Ground Water Geochemistry** (Dec. 6-7), **Applications of Ground Water Geochemistry** (Dec. 8-10), and **Understanding Migration, Assessment, and Remediation of Non-Aqueous Phase Liquids** (Dec. 6-8). Las Vegas, NV. *www.ngwa.org/e*
December 7-8	Government Institutes/ABS Consulting. **Arizona Environmental Law**. Phoenix, AZ. *www.govinst.com/Merchant2/merchant.mv?Product_Count=3&Screen=PROD&Store_Code=ACS&Product_Code=23020*
December 12-15	National Ground Water Association. **2004 Ground Water Expo**. Las Vegas, NV. *www.ngwa.org/e/expo/0412126010.shtml*
December 13-17	American Geophysical Union. **2004 Fall Meeting**. San Francisco, CA. *www.agu.org/meetings/fm04/*

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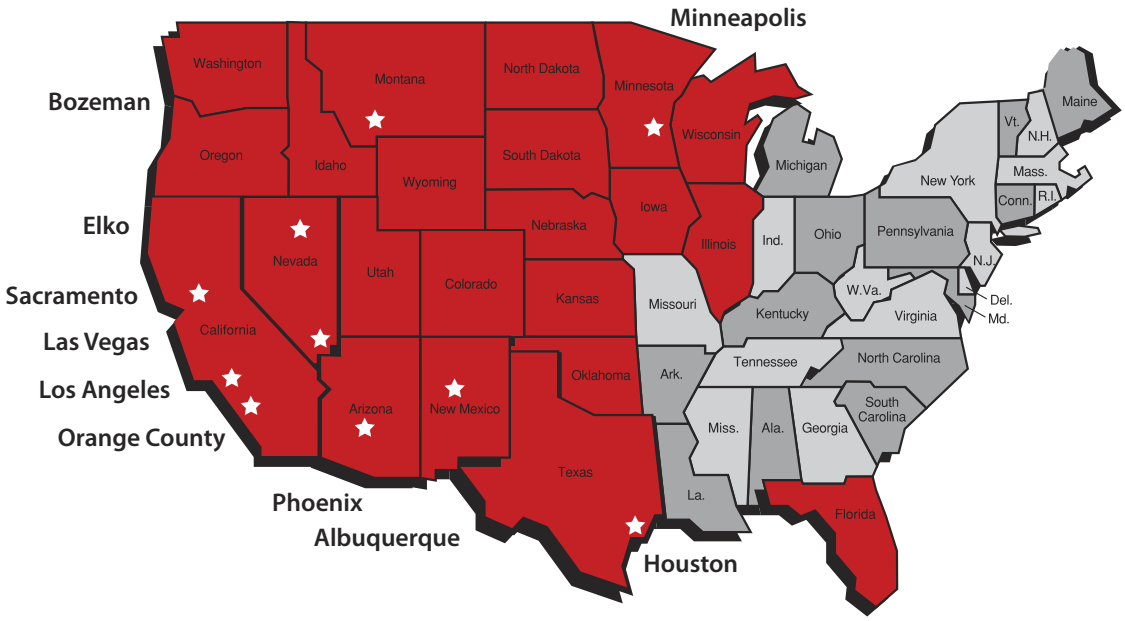

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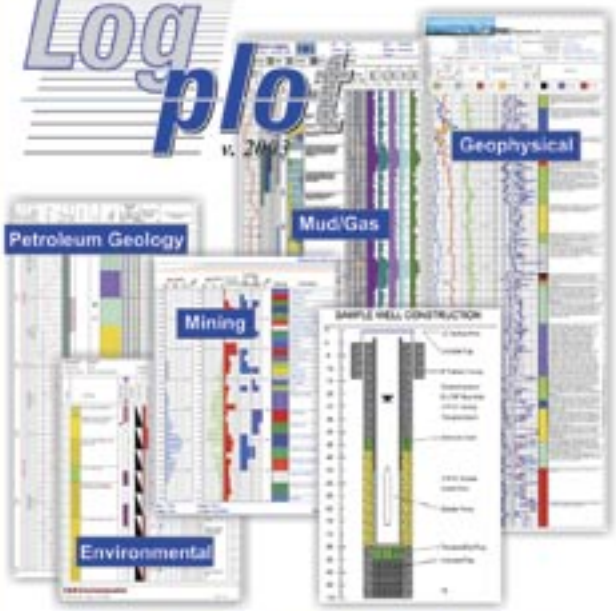

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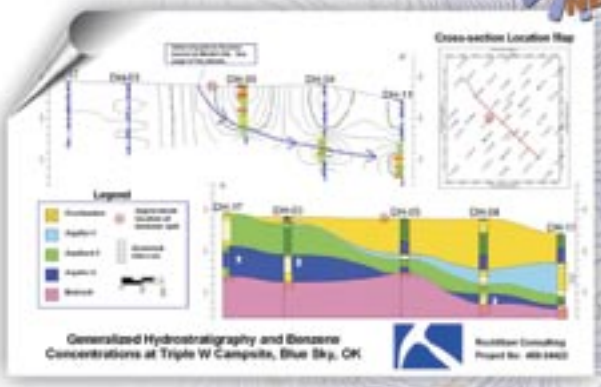

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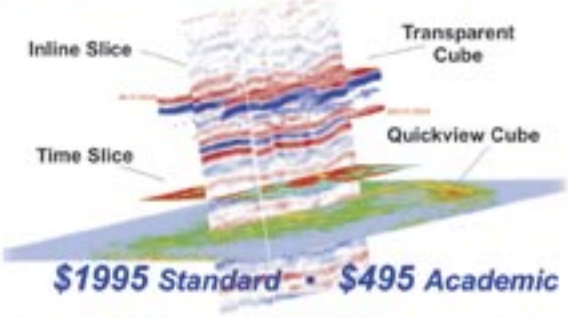

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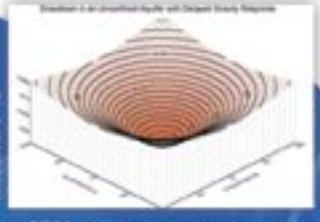

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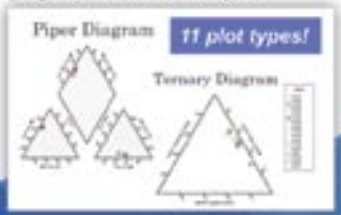

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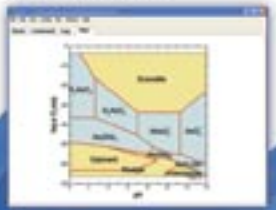

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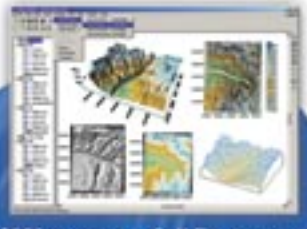

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