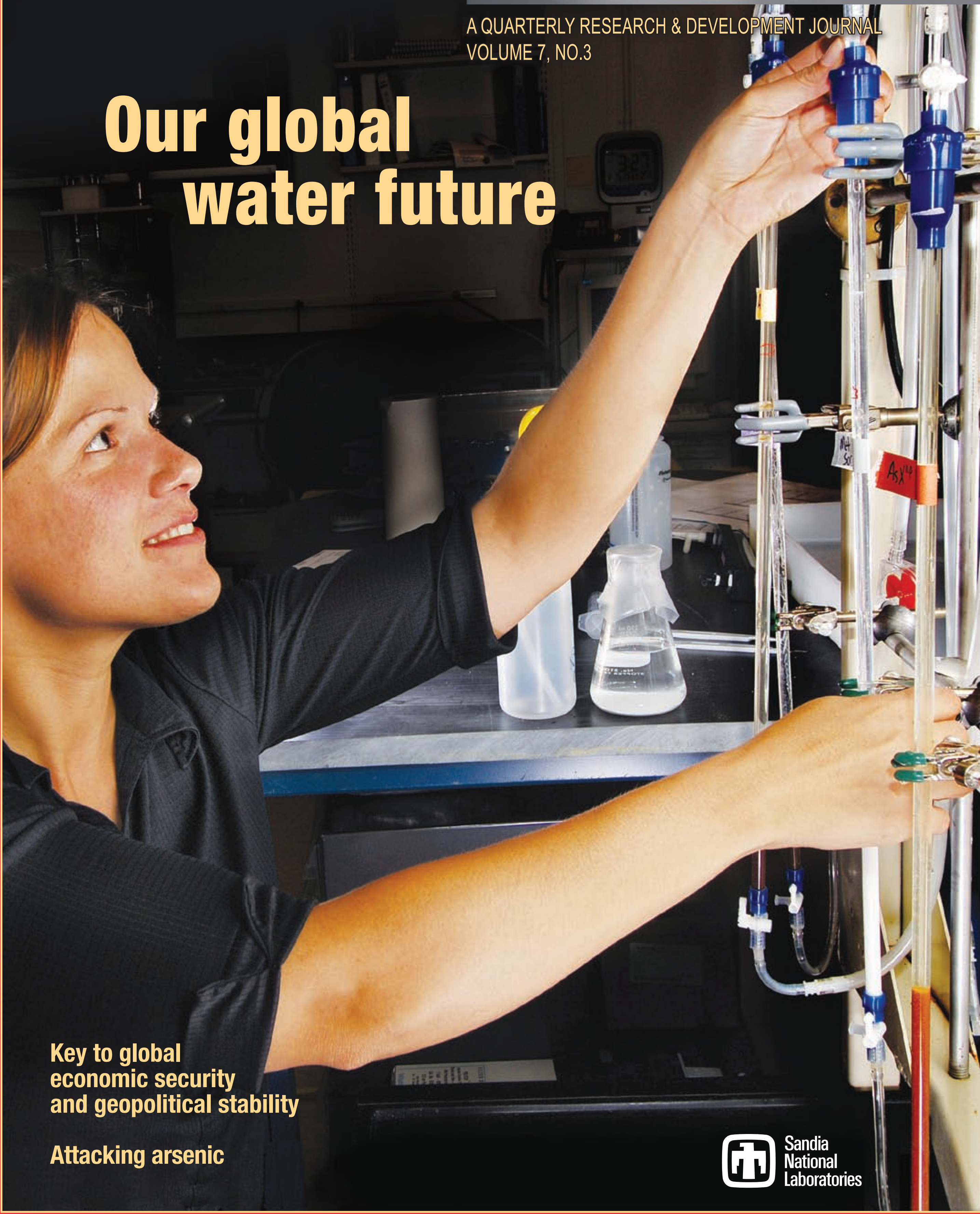
FALL • 2005

SANDIA TECHNOLOGY

A QUARTERLY RESEARCH & DEVELOPMENT JOURNAL
VOLUME 7, NO.3

Our global water future



Key to global economic security and geopolitical stability

Attacking arsenic

Sandia National Laboratories

What is LDRD

Sandia's world-class science, technology, and engineering work defines the Labs' value to the nation. These capabilities must remain on the cutting edge, because the security of the U.S. depends directly upon them. Sandia's Laboratory Directed Research and Development (LDRD) Program provides the flexibility to invest in long-term, high-risk, and potentially high-payoff research and development that stretch the Labs' science and technology capabilities.

LDRD supports Sandia's four primary strategic business objectives: nuclear weapons; nonproliferation and materials assessment; energy and infrastructure assurance; and military technologies and applications; as well as an emerging strategic objective in homeland security. LDRD also promotes creative and innovative research and development by funding projects that are discretionary, short term, and often high risk, attracting exceptional research talent from across many disciplines.

When the LDRD logo LDRD appears in this issue, it indicates that at some state in the history of the technology or program, LDRD funding played a critical role.

On the Cover:

Sandia researcher Alicia Aragon works on a laboratory project studying how best to remove arsenic from drinking water. (Photo by Randy Montoya)

Sandia Technology (ISSN: 1547-5190) is a quarterly journal published by Sandia National Laboratories. Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company, for the Department of Energy. With main facilities in Albuquerque, New Mexico, and Livermore, California, Sandia has broad-based research and development responsibilities for nuclear weapons, arms control, energy, the environment, economic competitiveness, and other areas of importance to the needs of the nation. The Laboratories' principal mission is to support national defense policies by ensuring that the nuclear weapon stockpile meets the highest standards of safety, reliability, security, use control, and military performance. For more information on Sandia, see our website at *http://www.sandia.gov*

To request additional copies or to subscribe, contact:
Michelle Fleming
Media Relations and Communications Department
MS 0165
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0165
Voice: (505) 844-4902
Fax: (505) 844-1392
E-mail: meflemi@sandia.gov

Sandia Technology Staff:
Laboratory Directed Research & Development Program
Manager: Henry Westrich
Media Relations and Communications Department
Manager: Chris Miller
Editors: Will Keener, Sherri Mostaghni,
Sandia National Laboratories
Writing: Mike Janes, Will Keener, Chris Burroughs,
Sandia National Laboratories
Photography: Randy J. Montoya, Bud Pelletier, Bill Doty,
Will Keener, Sandia National Laboratories
Design: Douglas Prout, Technically Write

FROM THE *Editor*

Dear Readers,

Water and its relationship to global stability, economic viability, and energy production are the focus of this issue.

The stories here describe dedicated scientists at Sandia, other national labs, universities, and in private industry hard at work on problems of water treatment, detection of contaminants, and better understanding the areas where energy and water intersect.

What isn't captured in these descriptions is the vision of New Mexico Sens. Pete Domenici and Jeff Bingaman and their drive for advanced science and technology to solve major water challenges. In the summer of 2004, Sen. Domenici wrote and Sen. Bingaman co-sponsored a comprehensive water technology bill, directing scientists to work toward providing safe, secure and plentiful water supplies. The two also played key leadership roles in the recently enacted Energy Policy Act, which included ideas outlined in the 2004 proposal. At Sen. Domenici's request, President Bush signed that bill at a ceremony at Sandia's Technology Transfer Facility in August.

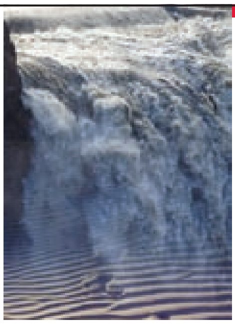
Sen. Domenici has been the force behind water research at Sandia and other institutions and has been an advocate for small communities facing increased costs of treatment to provide clean, safe, secure drinking water supplies. Sen. Bingaman has supported water research efforts, especially in areas along the U.S. — Mexico border, where water and international politics merge and good science can help resolve conflicts.

Perhaps El Paso water chief Ed Archuleta put issues of water quality and supply into the best perspective when he said, "The more we know about science, the closer we get to peace."

Will Keener, Editor

PS: Want to know more about Sandia's work with water? Check out this website: http://www.sandia.gov/water

TABLE OF *Contents*



Our Global water future: A critical strategic resource challenge

> *"Nations have gone to war over oil, but there are substitutes for oil. There is no substitute for water. We have about 300 million people who are living in areas with serious to severe water shortages right now. Twenty years from now, that will be 3 billion. It is just overwhelming."*
>
> Sen. Paul Simon, *Tapped Out* 1988

Globally, the statistics are daunting.

- One in five of our planet's human family — some 1.1 billion people — lack adequate water for their daily needs. "Adequate" is defined in this context as a mere five gallons a day.
- An estimated 2.6 billion humans lack access to improved sanitation.
- By the mid-1990s, 80 nations — comprising 40 percent of the world's population — suffered water shortages.
- Within 25 years, experts predict that two-thirds of the world's population will live in water-stressed regions.

While governments invest 90 billion dollars each year in global water supply development, seven million people still die from water-borne disease. Even more sadly, 2.2 million of these are children. In Africa, fifty percent of the population suffers from some form of water-borne disease.

"The bottom line here is that billions of lives across the planet will be affected by how well we manage to manage the strategic challenge of water," says Sandia's Peter Davies, director of the Labs' Geoscience and Environment Center.

Teaming with Erik Peterson, director, Global Strategy Institute of the Center for Strategic and International Studies, Davies presented a multimedia overview of the current global water situation, to experts and leaders from government and the private sector earlier this year. The conference's aim was to stimulate a discussion of policy approaches the U.S. might take to these global issues.

Conflict or cooperation

"You can see the water as the source of conflict or as a platform for cooperation," says Davies. "Increasing scarcity implies the possibility of future instability and conflict, but it also represents the opportunity for countries to develop joint approaches. Water can be a powerful currency for peace."

To understand the scarcity, Peterson suggests, imagine we could compress the entire volume of water on Earth, including its oceans, into one gallon. Half a pint from the gallon would represent all Earth's fresh water. And, because much of the fresh water is below surface or tied up in

Experts expect global shortfalls of water equivalent to 10 Nile River systems or 110 Colorado River drainages by 2025.

glaciers and snowfields, the amount available to humanity would be represented by a mere two drops.

While most conference-goers in the U.S. might not think twice about the pitchers of clean ice water at their tables, many other people in the world think a great deal about their water supplies, where the water comes from, how much it costs, and how clean it is, says Peterson.

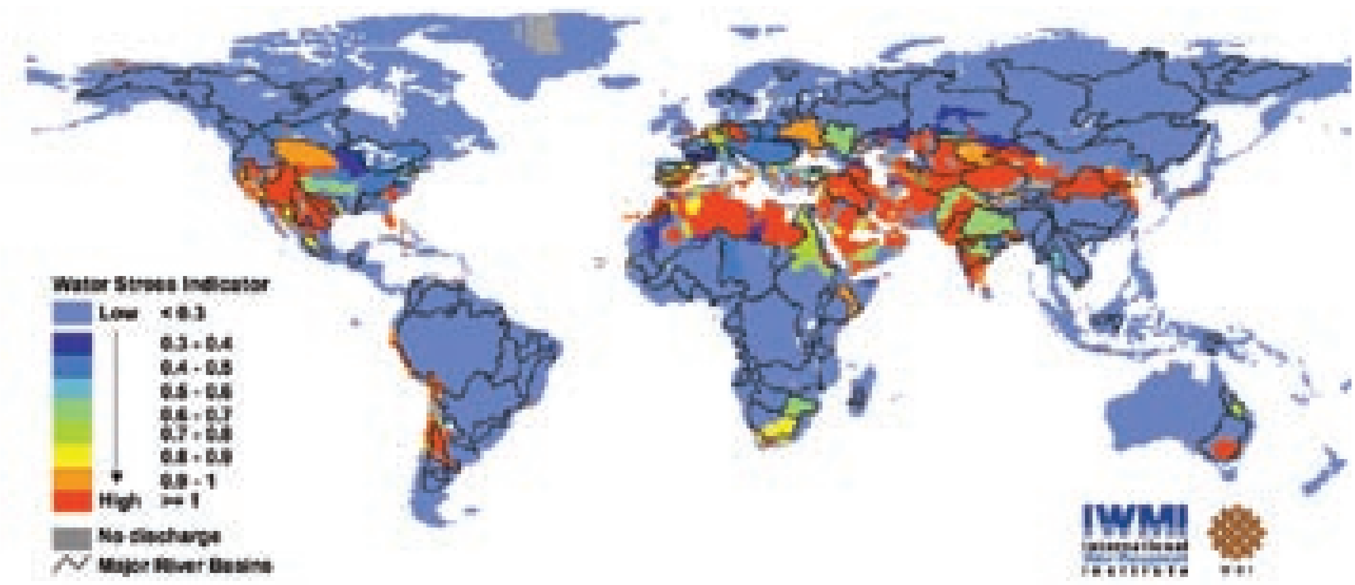
The map on this page, illustrating water stress — in terms of demand versus supply by 2025 — shows a band sweeping the Earth including the American West, North Africa, China, and the Middle East. These are notably places in the world where geopolitical stability is vital the Davies and Peterson note. Even in the Western U.S., we are already seeing interstate conflicts, sustainability issues, and competition for water between the agricultural and power generation sectors.

Sharper focus

Evidence is amassing to bring the overall picture into sharper focus. Experts expect global shortfalls of water equivalent to 10 Nile River systems or 110 Colorado River drainages by 2025. Landsat images of the Aral Sea in Central Asia show its

area reduced 40 percent by draw-downs, while salinity has tripled. The Dead Sea — one of the world's historic and ecological treasures — is dying, the water dropping more than 80 feet in the past 50 years, largely because stresses on the Jordan River have increased, from agricultural and drinking water withdrawals. In the next 20 years, the sea will fall at least 60 more feet, and experts say nothing will stop it.

Water stress map shows water withdrawal as a proportion of water available for human use.



> "...the statistics are staggering and should alarm any person with a conscience."
>
> Sen. Bill Frist, Tennessee

Like the Jordan, some of the world's other great rivers — the Indus, Ganges, Yellow, Rio Grande, and Colorado — at times no longer flow to the sea.

Water quality assault

The world's water quality is under assault from pesticides, fertilizers, and human wastes. An estimated 200 million tons of human waste are released into the world's rivers each day. Modernization and industrialization are contributing to these problems. In India, water-borne diseases cost 70 million lost working days per year. While global statistics on the impact of degrading water quality aren't available, the toll is predictably enormous.

Sen. Bill Frist, of Tennessee, speaking on the Senate floor, noted, "the statistics are staggering and should alarm any person with a conscience."

CSIS and Sandia hosted a second water conference in March, again bringing together influential politicians, water and environment experts, private industry representatives, researchers, and others in related fields working on these issues. Among the attendees was a representative of Sen. Pete Domenici of New Mexico, who delivered an address on behalf of the senator. Among his comments: "It is inappropriate and unacceptable to allow these conditions globally to continue. It is our task to try to unwind, to untangle this massive tangle right now, and to move things forward."

Other participants, looking to the future, spelled out a need for a mix between community-level and larger projects, high- and low-technology approaches, emergency and longer-term research responses. A mix of the expertise and knowledge from the many government, commercial, and other non-governmental agencies involved is a critical component to success, participants said.

This issue of *Sandia Technology* takes a look at some of the ways Sandia National Laboratories and its industry and university partners are moving forward in the work described by Sen. Domenici as "unwinding…this massive tangle."

For more information, go to: www.csis.org/gsi

Technical Contact: Peter Davies
505-844-3072, pbdavie@sandia.gov

Water a key to global economic security

Access to fresh water is a critical international issue that will get worse before it gets better.

From an international viewpoint, Sandia has national security responsibilities ranging from non-proliferation to regional stability. "In the relm of regional stability, we are concerned with economic and geopolitical security," says Ray Finley, manager of the Labs' Geohydrology department. "We enhance our own security by enhancing opportunities and economic viability of other developing countries. One of the things you need to do that is water."

Access to fresh water is a critical international issue that will get worse before it gets better. Some experts predict that in the next 10 years, almost half of the world's population — more than three billion people — will lack access to fresh water. Many of these people will be in the Middle East, South Asia, and China.

"There are countries where gross domestic product goes up when it rains and down without rain because they don't have storage or infrastructure to take advantage of water resources," says Finley. Developing countries also have a higher percentage of rural populations, where distribution needs become a large problem.

Severe water-related stresses, caused by inadequate supplies, pollution, and issues of transnational boundary management, limit economic development, threaten public health, and increase regional tensions, Finley says.

Finley and his staff have traveled extensively over the past year to understand the challenges of these situations and to help facilitate regionally designed and sustainable approaches to problems. Starting with some U.S. projects, including one in Sandia New Mexico's own backyard on the Rio Grande (see Cooperative modeling on page 8), Sandia is now providing tools and concepts that can help in other parts of the world.

In the Arab world, there is high interest in desalination, Finley notes. Partnering with the U.S. Bureau of Reclamation, Sandia has written a blueprint for desalination technologies and implementation, called the Desalination and Water Purification National Roadmap (see story on page 14). Arab states, through the Arab Science and Technology Foundation, have invited Sandia to help develop a roadmap focusing on the needs of the Arab world.

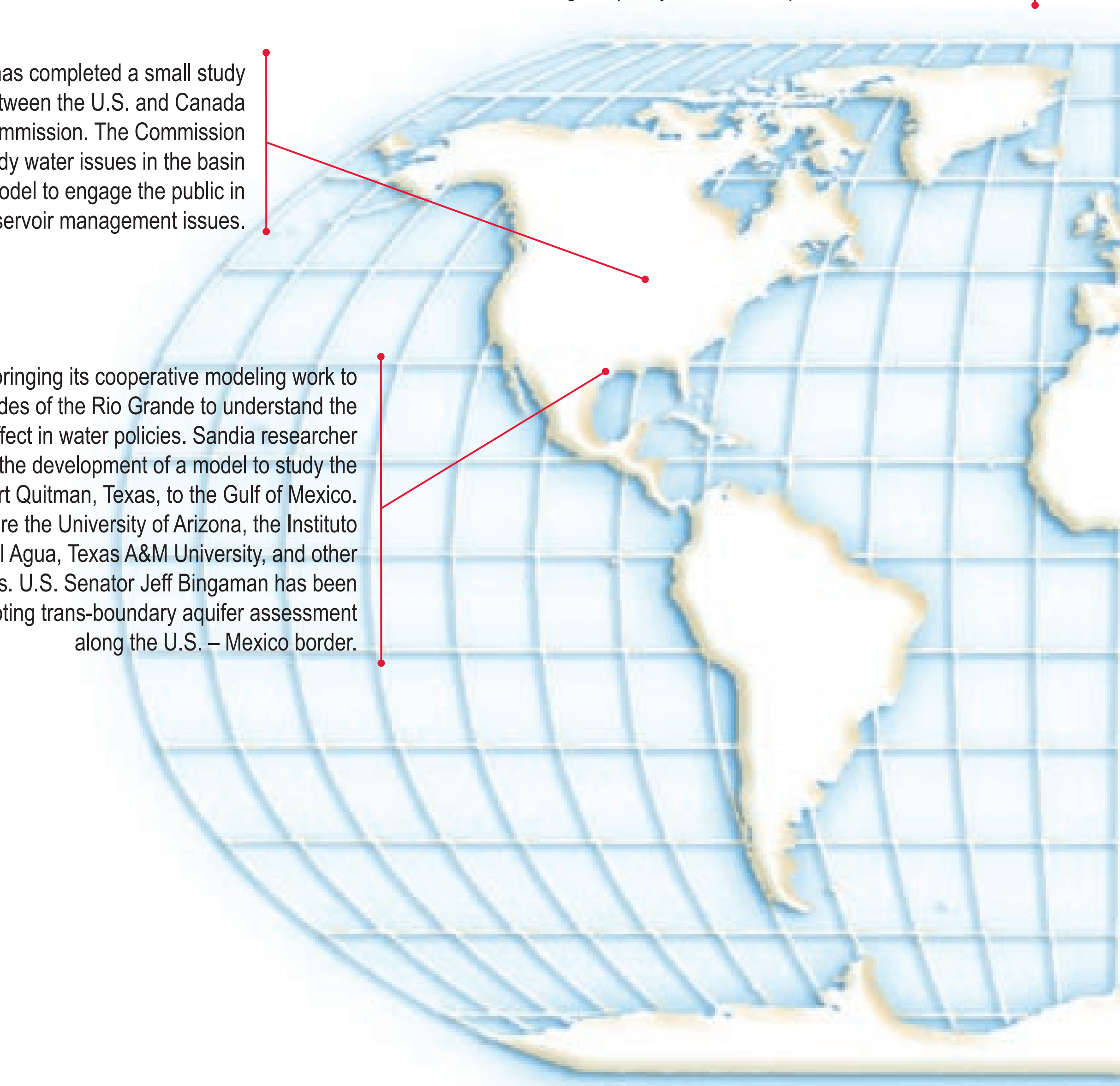
"There is hardly a part of the world that isn't touched by water issues," says Finley. "Our goal is to interact and create partnerships." The following pages show some of the projects under way or in planning stages.

A GLOBAL VIEW

• **Israel.** Sandia researchers and Environmental Protection Agency personnel met with representatives of Israel two years ago in Albuquerque to open discussions on water security programs. The Israeli officials expressed interest in Sandia's risk assessment vulnerability tools and sensor capabilities (see story on page 35). Last fall a Sandia group traveled to Israel to continue discussions, understand the nation's water sector, and study cooperative opportunities. On the table are model development for contaminate tracking, coupled with sensors for detecting biological pathogens. The model would help translate the sensor data collected. Labs researchers also visited a large-capacity desalination plant under construction.

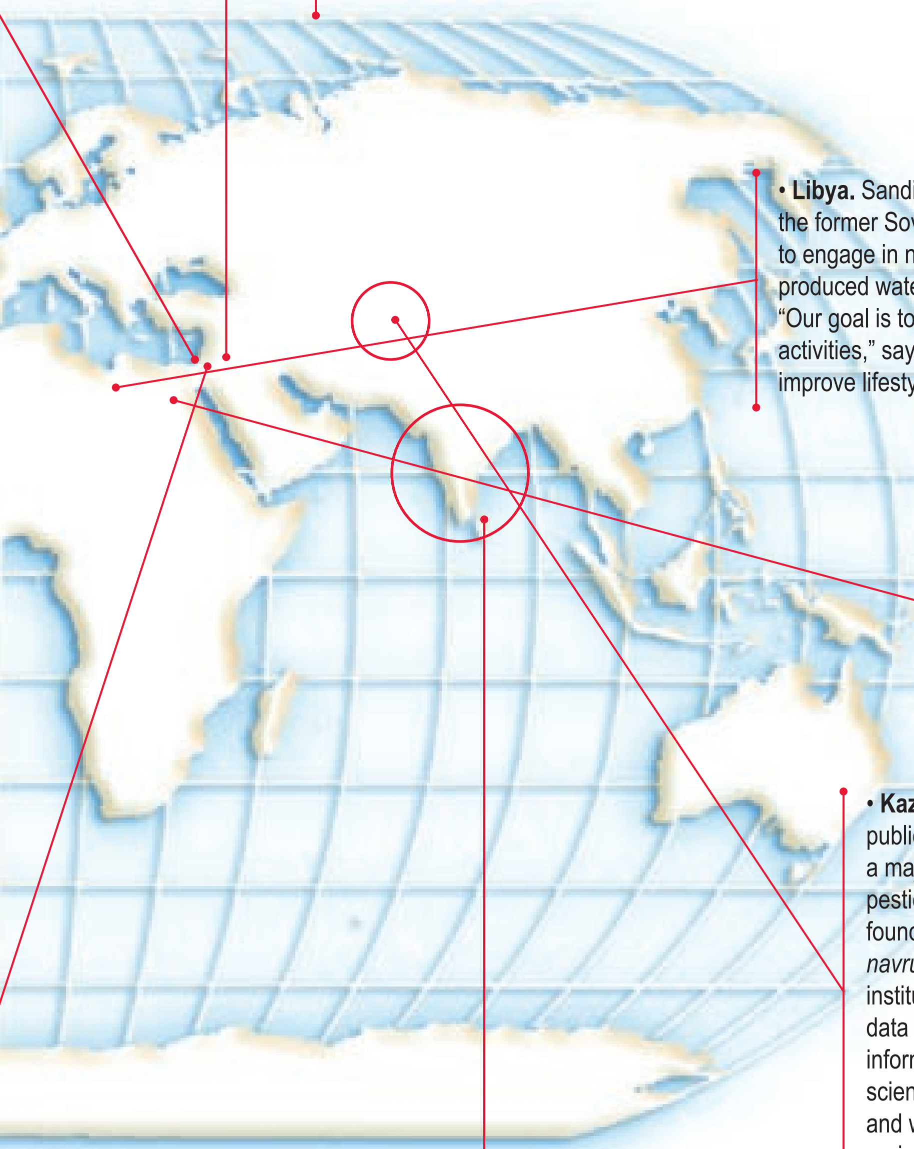
• **U.S. – Canada.** Sandia has completed a small study on the Rainy River basin between the U.S. and Canada for the International Joint Commission. The Commission asked Sandia to help study water issues in the basin with the goal of creating a model to engage the public in reservoir management issues.

• **U.S. – Mexico.** Sandia is bringing its cooperative modeling work to allow citizens along both sides of the Rio Grande to understand the dynamics of cause and effect in water policies. Sandia researcher Howard Passell is leading the development of a model to study the lower Rio Grande from Fort Quitman, Texas, to the Gulf of Mexico. Also working on the project are the University of Arizona, the Instituto Mexicano de Technologia del Agua, Texas A&M University, and other U.S. and Mexican partners. U.S. Senator Jeff Bingaman has been instrumental in promoting trans-boundary aquifer assessment along the U.S. – Mexico border.



• **Jordan.** Water quality issues are important in Jordan, and through Sandia's Cooperative Monitoring Center in Amman, researcher Vince Tidwell and others are interacting with water officials. Currently, Amman's water treatment facility is running at nearly three times design capacity. Officials there are interested in real technical-capacity building resulting in significant improvements in water quality. They also want to develop methods to better manage their resources with tools, such as Sandia's dynamic simulation models and advanced sensors.

• **Iraq.** Iraqi scientists, through the Arab Science and Technology Foundation and Sandia's CMC-Amman, have identified five technical areas for engaging the science and technology community. Water resources earn a high priority on this short list. Ray Finley and Howard Passell are among 20 international scientists partnering with 20 Iraqi scientists on the project. "The majority of surface water in Iraq doesn't originate in that country. They are concerned about water supply and quality flowing out of Turkey and Syria and are interested in using the systems dynamics modeling for decision making," says Finley. Sandia has proposed using a cooperative modeling approach to provide training and to develop internal expertise by coupling the model with real-time monitoring, using SCADA information links to upload data. The Diyala River Basin in East Central Iraq, which has agriculture, municipalities, waste water treatment, and hydroelectric dams, was selected for the study. "Our goal is that after two or three years, Iraq would be able to apply this approach to other areas and improve management of water quality across the country," says Passell.



• **Libya.** Sandia's Phil Pohl is working on problems similar to those faced by the former Soviet Union states earlier, that is, the need to retrain scientists to engage in non-weapons work. Managing water resources, treatment of produced waters from oil production, and desalination are promising areas. "Our goal is to engage scientists in non-WMD (weapons of mass destruction) activities," says Pohl. "We want to avoid creating another harbor for terrorism, improve lifestyles, and give Libya a stake in the global economy."

• **Egypt.** Phil Pohl has been invited to spend another sabbatical this fall as a USDA exchange scientist with the Egyptian Desert Research Center. The objective of his work there will be to develop and demonstrate controlled environment agriculture techniques for water conservation. The work is part of a larger sustainable development activity that the Egyptians have been working on recently.

• **Kazakhstan, Uzbekistan, Tajikistan, and Kyrgyzstan.** These republics in Central Asia share the benefits and problems of Syr Darya, a major river polluted with heavy metals, petroleum products, and pesticides. Through his work in Sandia's CMC, Howard Passell has found himself working on water issues in the area. In a project called *navruz* — a word meaning springtime, or new beginnings — the institutes of physics in these four nations are monitoring, collecting data on radionuclides, metals, and basic water quality, and sharing information along this important river in the Aral Sea Basin. "These scientists knew one another from their training in the Soviet Union and worked in the nuclear weapons effort," says Passell. "These projects are funded by the DOE and the State Department to employ nuclear weapons scientists in other endeavors."

• **Sri Lanka, India, Pakistan, Bangladesh, and Nepal.** In South Asia, researchers from these nations are collecting, sharing, and analyzing data from the Indus and Ganga River basins and coastal areas to promote trans-boundary water quality cooperation. Water management modeling and monitoring are priorities.

Cooperative modeling builds trust

Sandia's modeling team...succeeded in building a tool that simulated the complex relationships associated with regional water supply and consumption.

Computer-based dynamic modeling has been a powerful business tool for decades, used primarily for simulating flows of goods and resources, like labor and wages, and calculating related productivity information. In the past several years, a team of Sandia researchers has taken the system dynamics approach developed for these business applications and applied it to a spectrum of water resource issues.

A number of factors are needed to achieve a well-managed, sustainable water supply, explains Howard Passell, a Sandia scientist now using modeling tools for a number of projects around the globe. Among them, stakeholders need to:

- understand water supply and demand for the past and the present, and have projections for the future;
- understand the dynamic relationship among water, population growth, economic development, ecological needs, legal frameworks, and social/cultural needs
- evaluate the consequences of alternative water management strategies and develop water management plans; and
- be able to communicate their understanding and their plans to other stakeholders, managers, and policy makers.

Passell and his colleagues have developed a model that tackles all of these needs, an approach they call "cooperative modeling." Says Passell, "Over the last decade, more and more stakeholders have become involved in resource allocation, including agriculturalists, ranchers, environmentalists, urban developers, and others. They all want to be involved in the process. One of the challenges to establishing a process is establishing trust in the approach."

By working with the stakeholders to create a model — an effort first conducted with the Middle Rio Grande Water Assembly, the Mid Region Council of Governments, and the Utton Transboundary Resources Center in Albuquerque — Sandia's modeling team of Vince Tidwell, Steve Conrad, Dick Thomas, and Passell succeeded in building a tool that simulated the complex relationships associated with regional water supply and consumption.

"Everything we did was in collaboration with the stakeholder groups. We wanted them to understand how it worked, so that they would trust it and actually use it," says Passell. The Water Assembly used the model to create its regional plan, which the New Mexico state engineer approved earlier this year.

The development of modules will make cooperative modeling easier and much more widely applicable.

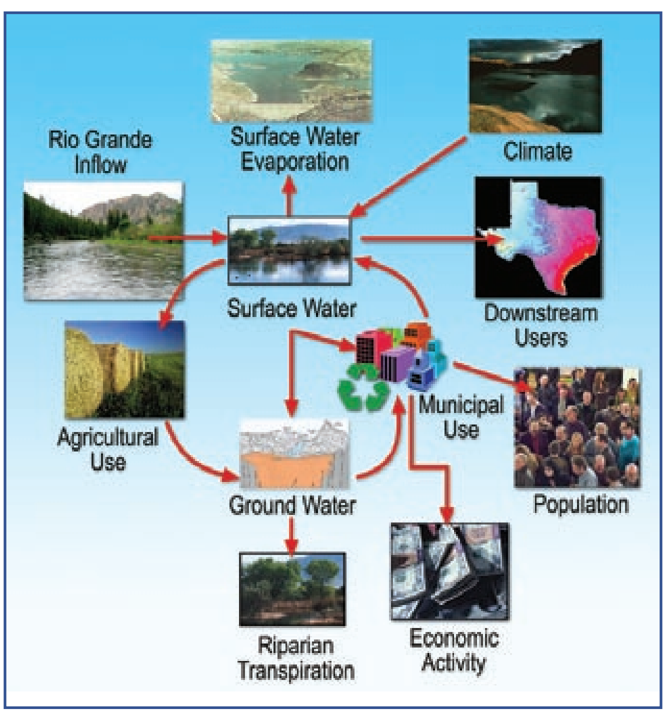
A web-based interface for the model is being developed, so that others around the globe may use it. And now variations on the cooperative modeling approach are being implemented in other regions, including:

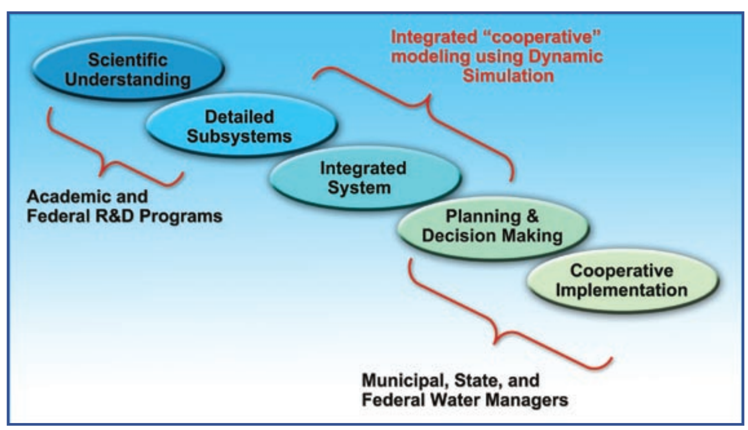
- A Bureau of Reclamation and Army Corps of Engineers project on the upper Rio Grande to consider environmental, cultural, and institutional features in the basin and communicate the impacts of water operations to the public.
- The Gila Basin region of New Mexico, where a water management plan is being developed for the state engineer.
- A recently established collaboration with the University of Texas at Barton Springs, near Austin, Texas, where Sandia's Tom Lowry is working with citizens to manage a fresh water resource.

An important spinoff project from cooperative modeling is called the System Dynamics Toolbox, directed by Vince Tidwell. "We recognized that we did not want to have to recreate the wheel every time we start work in a new basin," says Tidwell. "Our idea is to create a toolbox full of generic process modules, where users can set parameters for the modules and structure them in a way that reflects each unique watershed." Tidwell says the development of modules will make cooperative modeling easier and much more widely applicable.

Technical Contacts: Howard Passell
505-284-6469, hdpasse@sandia.gov

Vince Tidwell, 505-844-6025,
vctidwe@sandia.gov





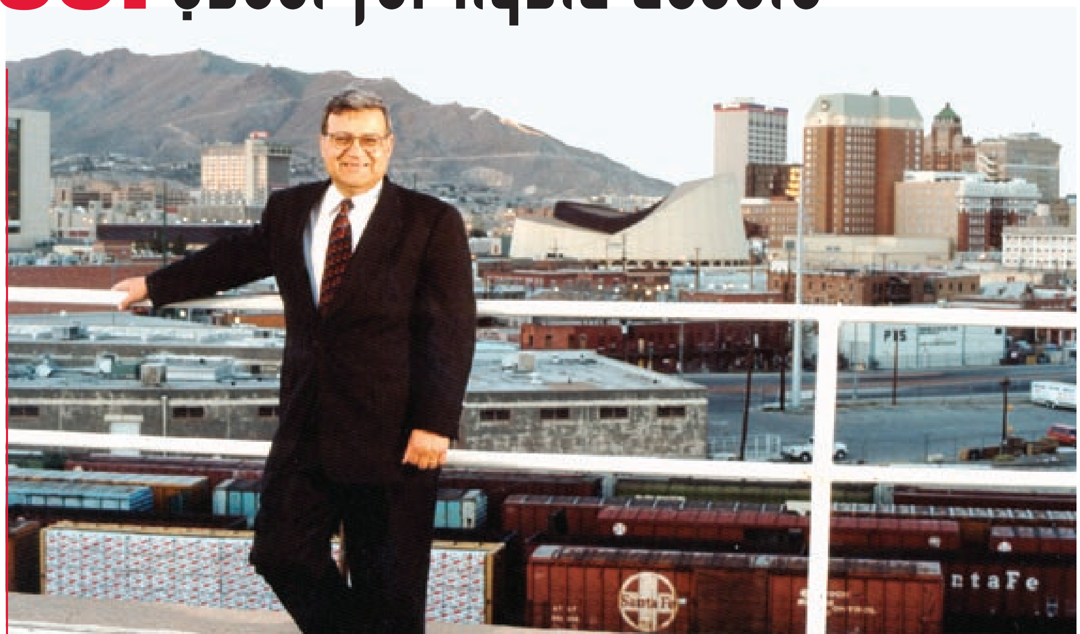
Integrated cooperative modeling fills the major gap between detailed research and models and decision making.

Dynamic simulation tools provide the software platform for direct stakeholder engagement in building system-level decision models

El Paso: Quest for liquid assets

There is no lack of water here [in the American Southwest], unless you try to establish a city where no city should be.... Time and the winds will sooner or later bury the Seven Cities of Cibola, Phoenix, Tucson, Albuquerque, all of them, under the dunes of glowing sand, over which…bedouin will herd their sheep and horses, following the river in winter, the mountains in summer, and sometimes striking off across the desert toward the red canyons of Utah where great waterfalls plunge over silt-filled, ancient, mysterious dams.

Edward Abbey, Desert Solitaire



Ed Archuleta, general manager, El Paso Water Utilities Public Service Board, in downtown El Paso.

From his El Paso office, with a fourth-floor view over this bustling city of nearly 700,000, Ed Archuleta is working hard to stave off the prophesy of Edward Abbey. Like Phoenix, Tucson, or Albuquerque, the City of El Paso is very much a part of the American Southwest. Founded four centuries ago, it rises out of the high Chihauhuan desert along the Rio Grande across the border from its international sister, Ciudad Juarez, Mexico.

In an average year, El Pasoans can expect 8.65 inches of rain. But, like much of the Southwest, this lack of water hasn't slowed sun-seekers moving to the region from other parts of the country. Groundwater reserves, which supply 50 percent of the city's water, have been tapped at an alarming rate and already some have become too saline — choked with various natural salts found deep in the aquifers — to be drinkable.

Archuleta, general manager of the El Paso Water Utilities Public Service Board, has led a multi-year fight for water conservation that has paid off with reduced levels of usage, despite population growth. His agency is building a 27.5 million gallon per day desalination plant and continues to expand the city's use of reclaimed water. He is constantly in search of new sources of water and innovative ways to get them. He has become known as a peacemaker among parties sometimes bitterly contesting this scarce, liquid asset. And he is continually examining an array of technological solutions.

With Ciudad Juarez sprawling to the south across the river, tripling El Paso's population, no one need call to Archuleta's attention the fact that water is both a domestic and an international problem, or that it is both a source of conflict and cooperation. "John Kennedy once said anyone who could solve America's water problems deserved two Nobel prizes: one for science, and one for peace," says Archuleta. "I think the more we know about science, the closer we get to peace."

Half of El Paso's water and all of the water for Ciudad Juarez comes from the Hueco Bolson, an aquifer underlying the area.

"In the future, with research, maybe we can find a better, less expensive way to dispose of the concentrate or perhaps a beneficial use for it. In desalination, this is the biggest research question we have."

Ed Archuleta

Desalination

The El Paso Desalination Facilities Project is an $87 million partnership between the city and neighboring Fort Bliss that will include the largest inland desalination plant of its kind. (In Florida, Tampa Bay produces 25 million gallons per day from ocean water desalination.) Construction is expected to get under way this year and will take about two years to complete. Following a 1992 pilot plant in the Heuco Bolson, a key city aquifer, Archuleta and his colleagues determined that the reverse osmosis approach, with membranes filtering out troublesome solids, would be workable for a larger plant. "Those (early) membranes were not as efficient as modern ones and power demands were higher," he notes.

Two other Texas desalination projects and others in Florida and California are being watched carefully. "We participate with Tucson, Phoenix, Las Vegas, and Southern California cities in a multi-state salinity coalition with Sandia National Laboratories and the Bureau of Reclamation and try to make our case at the federal level," says Archuleta.

The water utility plans to drill 16 new wells to intercept brackish water presently moving along a northeast-southwest line beneath the city. The wells will create a barrier, or curtain of wells, to feed to the plant. "We are taking a lost asset (the brackish water) and finding a use for it," says Archuleta.

He shows a visitor a series of jars, all clear to the eye, but actually ranging from 12 to 1,500 parts per million of various solids dissolved in the liquid. "If we reduce our brackish source water to 80 parts per million and mix it with other brackish groundwater to end up with water below 1,000 parts per million (the drinking water standard), we can stretch our supply," he says.

"The issue is how do we deal with the three million gallons per day of concentrate we will produce?" (Inland plants refer to the leftover solids as "concentrate.") "This is one of the areas where Sandia Labs is working. (See stories beginning on page 14.) The question is can we find a silver bullet out there, because we don't want to waste any water dealing with the concentrate."

Present plans call for concentrate at the Fort Bliss plant to be pumped 22 miles northeast to a desert site, where deep wells will inject it into a dolomite formation 2,200 feet below the surface. A shale layer deep in the earth confines the aquifer, which has even lower quality water in it now than the concentrate-laden water that would be pumped in. Operators will need permission from the Texas Commission on Environmental Quality to do this. "In the future, with research, maybe we can find a better, less expensive way to dispose of the concentrate or perhaps a beneficial use for it. In desalination, this is the biggest research question we have," says Archuleta.

Many approaches

While 50 percent of El Paso's water supply comes from aquifers beneath the ground, a number of other sources help fill in. The city is negotiating with farmers for groundwater reserves that would be transported to the city from outside its own basins. And since 1963, El Paso has been a pioneer in reclaimed water, operating some 50 miles of reclaimed water system, or "purple pipe" within the city.

El Paso's philosophy is that water is too valuable to be used only once. Leaders here think of reclaimed water as a valuable resource rather than a by-product that needs to be disposed of. About 11 percent

The Rio Grande above El Paso.

Up to 60 percent of El Paso's potable water comes from the Rio Grande in summer months, but with demands on the stream and upstream reservoirs like Elephant Butte from agriculture, river water can't be counted on.

of wastewater is currently reclaimed, with a goal of 17 percent by 2020. The water is used at city parks, school playgrounds, sports fields, nurseries, golf courses, for street landscaping, fire protection, industrial processes, and in a variety of other uses.

Reducing the use

With a continuing 3.5 percent growth rate, El Paso has done a very good job with conservation, using time-of-day and day-of-week restrictions, for its "stage 1" drought condition. A "stage 2" condition means reducing watering to once a week and that has caused some problems, Archulta says. "We can expect droughts for many years to come, if you look at the scientific data." During the past 12 years, conservation efforts have brought per capita use from more than 200 gallons per day down to about 140 gallons.

Up to 60 percent of El Paso's potable water comes from the Rio Grande in summer months, but with demands on the stream and upstream reservoirs like Elephant Butte from agriculture, river water can't be counted on. "It will take years for Elephant Butte Reservoir to return to normal levels," says Archuleta. During 2003, when the city faced a "stage 2" drought, Archuleta persuaded the utility's board members to purchase and mount 11 reverse osmosis units at wells near the Mexico border. The utility pushed ahead using $8 million to refurbish abandoned wells and produce 8 million gallons per day of usable water. The treatment units helped clean the water of high levels of dissolved solids and arsenic compounds. "By using reverse osmosis at each wellhead we can help prevent a "stage 2" condition. The $8 million allowed us to use another frozen asset."

Archuleta and the El Paso utility have been instrumental in the formation of a consortium for high-tech investigation of water and wastewater issues, which includes the city of Alamogordo, New Mexico State University, Texas A&M, and University of Texas at El Paso. Called by its acronym CHIWAWA, this group is also addressing agricultural and educational issues. "We need to constantly inform the

public about water and how to use it, its quality, the resource costs, and how to use less. The consortium is focused on research that will lead to technology transfer, training, and education through a learning center for the Chihauhan desert."

We can expect droughts for many years to come, if you look at the scientific data.

Mapping the water

Understanding the groundwater resources in places like El Paso is another important effort. Archuleta, who was involved in some of the first efforts to refine the mapping of groundwater in the Albuquerque Basin to the north, is working closely with legislators from both New Mexico and Texas on water legislation. He has applauded recent efforts by Congress to provide better groundwater maps along the U.S. border. "With modern instruments and technology like GIS, why not do a better job of mapping?" he asks.

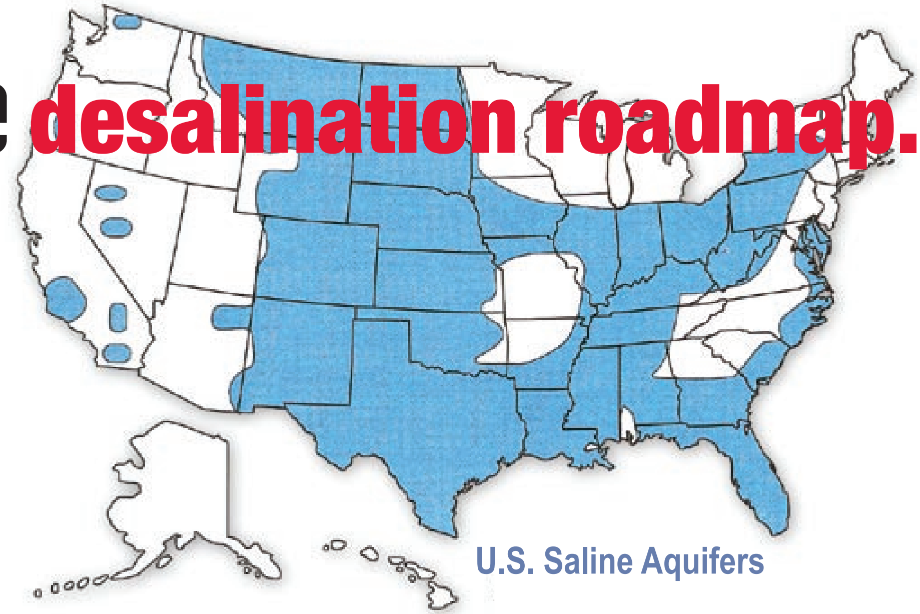
Two aquifers provide water for the El Paso area. One, the Mesilla Bolson, runs north from Santa Teresa across the Texas – New Mexico state line. Much more detail on resources of this basin is needed, Archuleta says. The other, the Heuco Bolson, provides up to half of El Paso's water and all of the water for Ciudad Juarez, in Mexico. A recent five-year project, sharing data with Mexican counterparts and using the same model, showed how groundwater flows in this basin. "The water model helped us to locate our desalination plant and find locations for our blend wells," says Archuleta.

The next step is a proposed 10-year project with the U.S. Geological Survey to map along the border, paving the way to better use of both fresh and brackish groundwater resources. Archuleta ventures into Juarez frequently to meet with water counterparts and share information on planning. "This has helped. We now have a Paso del Norte Task Force in place to look at these issues."

He is clearly supportive of cooperation over conflict. "Right now 40 percent of our worldwide population is without sufficient water resources — growth, drought, and pollution are all issues. We need to have the best minds and resources brought to bear. If you give us the right science, it can be used in policy implementation to address these problems. I consider the work of institutions like Sandia critical to our success."

For more information on El Paso's water activities, go to: www.epwu.org

Following the desalination roadmap.



U.S. Saline Aquifers

In addition to seawater, the U.S. and many other countries have major inland, brackish water resources.

Supplementing fresh water supplies through desalination technologies that are cost effective could provide relief to people in many parts of the globe.

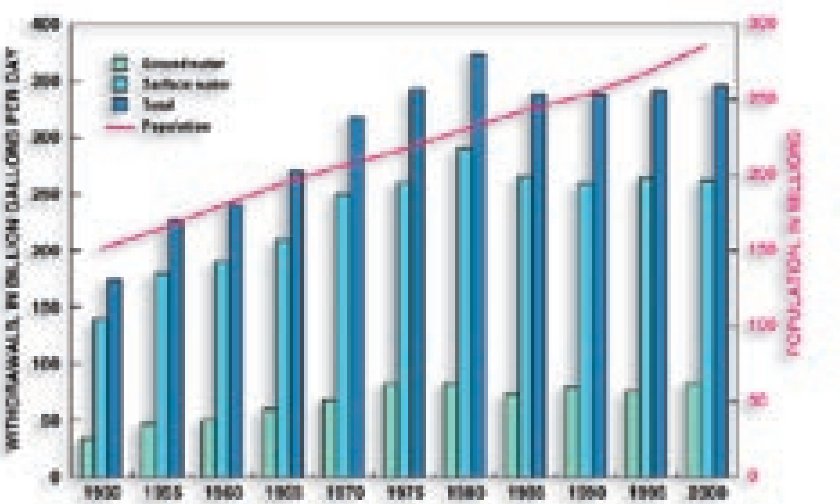
The road to sustainable water purification technology is the path to a vision. "When we started the process to develop a roadmap, we started with a vision," says Tom Hinkebein, manager of Sandia's Geochemistry department and one of the architects of the National Desalination and Water Purification Technology Roadmap in 2003. "The vision led to the idea of having water that is safe, sustainable, affordable, and adequate."

U.S. Geological Survey data show total withdrawals of water in the U.S. have been about 80 percent surface water and 20 percent groundwater during the last 50 years. However, the percentage of total withdrawals with saline, or salt-laden water, increased from only a minor amount in 1950 to nearly 20 percent by the millennium.

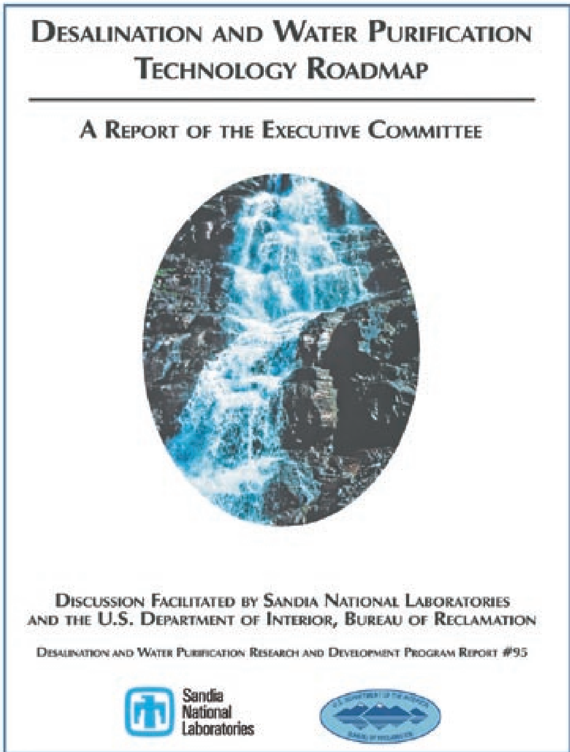
On a global level, more than 97 percent of the world's water is saline or brackish. Supplementing freshwater supplies through desalination technologies that are cost effective could provide relief to people in many parts of the globe.

The primary technological methods that continue to provide safe, sustainable, and adequate supplies are through desalination, enhanced water reuse, and recycling, water experts conclude. And, although treatment methods for purification of saline waters, or desalination, have existed for centuries, the drive to make treatment more affordable continues to be a major goal. Currently the treatment of brackish waters to supply municipal or industrial water customers is roughly twice the cost of treating other freshwater resources.

"The efficiency of desalination and water purification technologies is currently evolving at a rate of about four percent per year," says Hinkebein. "Continuing along this path will result in technologies that produce water that is too expensive for many applications."



Source: U.S. Geological Survey


Desalination and Water Purification Technology Roadmap

A Report of the Executive Committee

Discussion Facilitated by Sandia National Laboratories and the U.S. Department of Interior, Bureau of Reclamation

Desalination and Water Purification Research and Development Program Report #95

Revolutionary technology

The goal of the roadmap is to create efficient, cost-effective revolutionary desalination technologies to meet the nation's future needs. "We are looking at how we can plan a process that engineers creativity into the process. That is what a roadmap is all about: a planning document to engineer creativity into what we do," Hinkebein says.

Developing the desalination roadmap, which Sandia and its many government agency, national laboratory, university, and private industry partners are now following into a second phase, has been a people process, Hinkebein says. Roadmap creators agreed to look at both existing technology (essentially reverse osmosis) as well as novel technologies. As a result, participants in the roadmap implementation phase are moving forward in four basic research areas:

- membrane technologies,
- alternative and thermal technologies,
- reclamation and reuse, and
- concentrate disposal.

Developing the desalination roadmap, which Sandia and its many government agency, national laboratory, university, and private industry partners are now following into a second phase, has been a people process...

Following the publication of the roadmap in 2003, the National Resources Council of the National Academy of Sciences reviewed the plan and added its stamp of approval.

Phase Two

Sandia's Pat Brady and Sue Collins, of the Advanced Concepts Desalination program, helped coordinate a major step for Phase Two roadmap implementation this spring, with a meeting in Tampa Bay, Florida. "The key was to pool experts and end-users to direct the research and to assure a diversity of knowledge is being applied," says Collins. "In Tampa Bay, we looked at the wants and needs of the end-users to better focus the research and help the funding agencies understand the potential impacts."

The meeting, which involved collaboration with the Bureau of Reclamation, Water Reuse Foundation, American Waterworks Association, and the Joint Water Reuse and Desalination Task Force, included discussion sessions on inland and seawater desalination and on water reuse.

In fact, pushing forward on the roadmap on a national scale is only one of three major activity areas for Sandia in desalination research, according to Hinkebein.

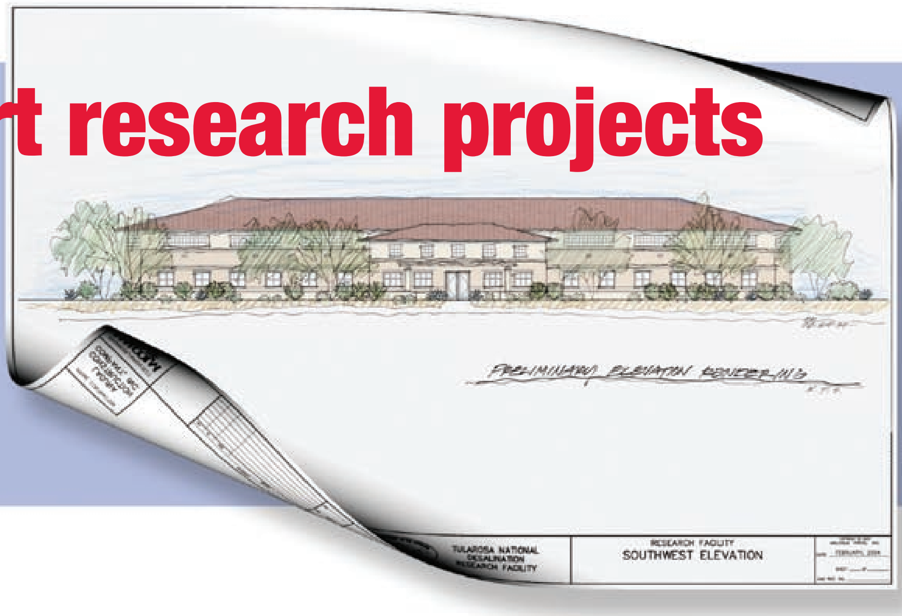
Other activities:

- Pilot-testing to accelerate the commercialization of new technologies in Sandia's "Jump Start" program (see story on page 16) and
- Performing and coordinating long-term research at Sandia and elsewhere around the U.S. to develop next-generation technologies (story on page 18).

In the case of the demonstration-scale work in the Jump Start program, Sandia will coordinate with the Bureau to select processes to make the best use of resources and avoid overlap. "We will increasingly take advantage of the Tularosa Basin National Desalination Research Facility, now under construction in Alamogordo, New Mexico, in this effort," says Hinkebein.

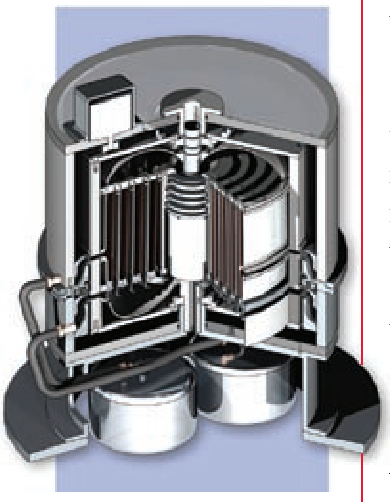
Technical Contact: Thomas E. Hinkebein,
505-844-6985 tehinke@sandia.gov

Jumpstart research projects target success



"The largest areas where we can contribute to desalination are with the problems of concentrate disposal and high energy consumption."

Advanced vapor compression offers a low-energy approach.



When Richard Kottenstette began working on Sandia's desalination projects, he started with a review of the many historic efforts to make pure water from saltwater. Now his job is to accelerate that history as project leader for the Jumpstart R&D portion of Sandia's Advanced Concepts Desalination program.

Kottenstette coordinates projects in desalination, water reuse (a subset of desalination), and produced water from oilfield production. He also is involved with planning and testing for the Tularosa Basin National Desalination Research Facility in Alamogordo, New Mexico, where the most promising technologies for inland, brackish water desalination will move to large-scale testing and possible commercialization.

His goal is to identify and pursue technologies that are poised for commercialization. "We are trying not to just monitor contracts here, but to add some value, and we're having some success," says Kottenstette. "The largest areas where we can contribute to desalination are with the problems of concentrate disposal and high energy consumption."

Concentrate, the salty residual liquid by-product of desalination, presents a number of problems to developers of new technologies. Currently Sandia is working on a "zero liquid discharge" project with experts in electrodialysis at the University of South Carolina. The hybrid process uses a reverse osmosis membrane with a proprietary electrodialysis system to purify salt with the goal of producing maximum amounts of clean water and a salable salt product.

Out of the box

"We are looking at innovative ways to manage concentrate," says Kottenstette. "We might be able to use or convert wastewater residuals to acids or bases for reuse in the treatment plant. Our goal is to minimize or eliminate by-product waste." Currently, Sandia is working with the University of New Mexico's Civil Engineering department on a survey to see where concentrate can be used in industry.

Another approach under investigation at UNM involves running a supersaturated solution of calcium sulfate to eliminate membrane scaling problems. In normal desalination, calcium sulfate and other minerals become insoluble and plug pores in reverse osmosis membranes. "The goal is to precipitate calcium sulfate and perhaps even silica offline and increase water production," Kottenstette says.

Construction of the Tularosa Basin National Desalination Research Facility is progressing. Sandia, led by Mike Hightower, played a major role in the concept and design of the facility.

Sandia is providing guidance on approaches to maximize production of clean water from oilfield produced water.

In the category of water reuse, Sandia is working with Montgomery Watson Harza, a firm specializing in water, wastewater, and environmental infrastructure design, on a water reuse program for the City of Rio Rancho, New Mexico. The system will involve a membrane bio-reactor combined with reverse osmosis to maximize reuse of the city's wastewater. "Wastewater typically has few dissolved solids and is less expensive to treat," says Kottenstette. However, issues related to public health and public perception must be addressed in this reuse program. Several cities now have such efforts under way (see El Paso on page 10).

A contract with Innovative Sciences Corp., of Agoura, California, calls for further research into a technology called advanced vapor compression. "This is an innovative approach involving a spinning drum prototype that spreads out water thinly and evaporates it on one side of the drum to condense on another surface. The process is of interest to researchers because of the relatively low amount of energy required to produce pure water. "It operates at lower temperatures, which reduce some of the scaling problems," says Kottenstette.

Originally designed for space applications, the company will now work on a larger scale version for civilian use.

Membrane plugging

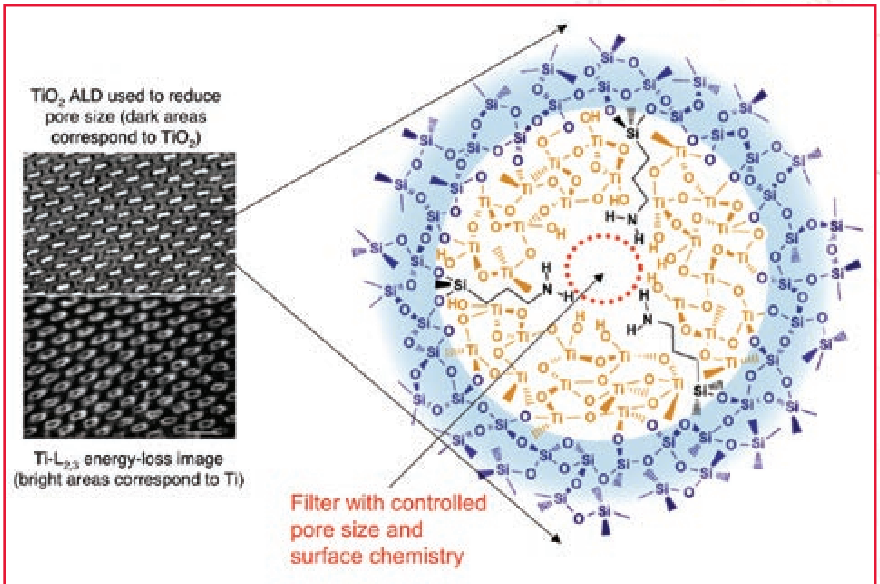
In another project, sponsored through Sandia's New Mexico Small Business Assistance Program, Kottenstette is working with Western Environmental Management Corp. LTD in the Permian Basin to address problems with reverse osmosis membrane plugging. Hydrogen sulfide and iron in water produced during the pumping of oil create chemical precipitates that reduce membrane performance. Sandia is providing guidance on approaches to maximize production of clean water from oilfield produced water at a wellhead pilot plant (see also Produced Water on page 22).

Part of Kottenstette's early reading included an article written in 1914 by the U.S. Geological Survey on brackish waters in the Tularosa Basin of New Mexico. Nearly 100 years later, the Bureau of Reclamation is now building a research facility to study technology for exploiting this large resource.

An executive committee made up of representatives of many groups, including non-governmental organizations, municipalities, and federal agencies, will be determining which projects move forward at the facility. "We are on the executive committee and we will help to decide which projects come in to the facility. In some cases it may be the extension of bench-scale projects at Sandia or projects from elsewhere. The aim is to use this facility for large-scale testing and, ultimately, technology transfer."

Technical Contact: Richard Kottenstette
505-845-3270, rkotten@sandia.gov

Desalination revolution: high risk/reward



The world of desalination has involved ... high-risk, high-reward explorations of nanotechnology, electrochemistry, and the basic science of ice formation, among other things.

To succeed in an effort to make saline waters available and affordable for beneficial use, revolutionary technologies, rather than evolutionary, will be needed. At Sandia, the revolution in desalination is the province of Tom Mayer. "My job is the long-range research to identify promising new technologies and to test them," says Mayer, of the Labs' Geochemistry department. To succeed, he works with a variety of researchers inside the Labs and with university experts and industry partners who can contribute to the selected areas of study.

The world of desalination has involved Mayer and his research colleagues in high-risk, high-reward explorations of nanotechnology, electrochemistry, and the basic science of ice formation, among other things. The aim, he explains, is for breakthrough results to dramatically reduce costs, increase efficiency, or impact the effectiveness of concentrate management.

Recognizing that there were other institutions with significant contributions to make, Sandia established a good relationship with neighboring Los Alamos National Laboratory and developed a number of collaborations. "We met in Santa Fe in the spring to brainstorm collaborative efforts and put together a proposal for joint work in both the near and the longer term," says Mayer.

The design for Mayer's long-range efforts is eventually to bring technologies through the Jump Start program (see previous story) and on to commercialization.

Biomimetic membranes

The discovery that living cells contain special "water channels," or aquaporins, in their membranes to transport water and exclude salt with very high efficiency was deemed significant enough in 2003 to merit a Nobel Prize. Now, Sandia's Jeff Brinker and Susan Rempe are working on the design and construction of a new membrane, based on the function of these aquaporins. "If we understand how these channels function and mimic them in a synthetic structure, we have the potential to build a practical device," says Mayer.

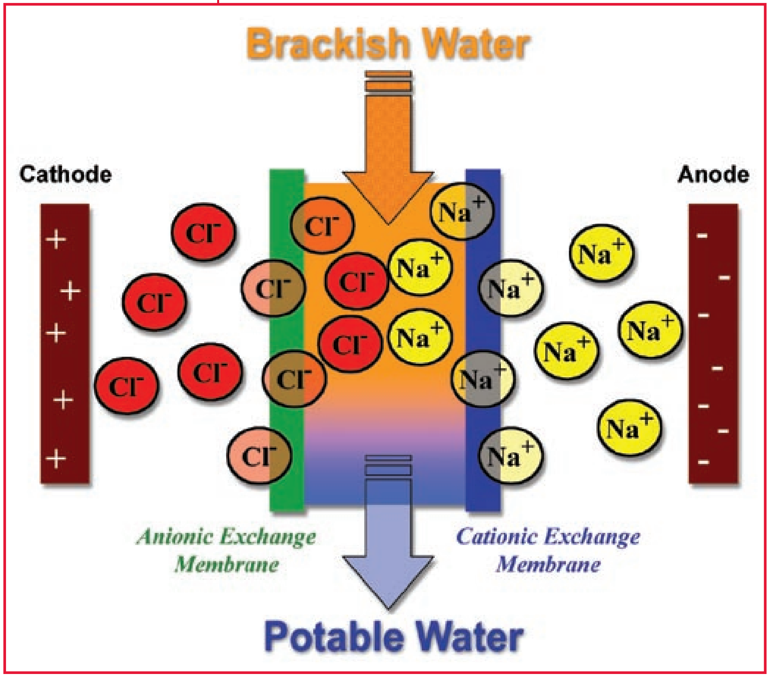
The potential is for a robust reverse osmosis membrane with much higher efficiency than existing membranes, resulting in higher pure water production and lower energy consumption. "Obviously, this is a complex high-risk problem," says Mayer, "but it is potentially high reward as well. It is exactly the kind of thing a national lab should be involved in."

The process works by flowing "salty" water through a small gap formed by cationic and anionic exchange membranes and an electric field.

"We saw that membrane fluxes haven't increased substantially in 20 years. We haven't really focused on super high fluxes, until now," says Brinker. Aquaporins are governed by a number of factors, he explains, that designers may want to pick and choose among. "Rather than operate under conditions established by life, we are not bound by those exact conditions. We want to understand the transport in the natural system and what features are important. We don't necessarily have to mimic all the features. So, we are doing detailed modeling of the transport, then we can take features out and study their impact on speed of transport and purity of the water. We might re-engineer our system for the boundaries we need. The aquaporin transport is very fast and pure compared to other membranes."

The size restrictions in the aquaporin mean that the pore is so small, water molecules go through in single file. Sides of the channel have different chemistry so that the molecule tilts. The result is that the channel excludes salt and does not allow positively charged hydrogen ions, or protons, to pass through.

A Sandia team is working to improve electrodialysis technology, shown here in a conceptual drawing.



"We can make thin films of silicon dioxide with huge densities of holes. If each hole had an aquaporin transport channel, we would have a filter with a dramatically large capacity."

Advanced electrodialysis

Chris Cornelius, of Sandia's Chemical and Biological Systems department, is designing and building a more efficient electrodialysis membrane. Electrodialysis is a process that removes salts or ions from water with an electric field and special ion-exchange membranes. The separation process is quite attractive for the desalination of brackish water versus other desalination technologies.

The process works by flowing "salty" water through a small gap formed by cationic and anionic exchange membranes and an electric field. The negative and positive charges within the polymer structure repel ions of the same charge and allow ions of the opposite charge to diffuse through the membranes via an electric field. This process selectively removes the salt ions and concentrates them in a reservoir that is separate from the entering brackish water. The result of flowing brackish water through the small gap formed by the selective "ionomer" membranes is production of water with a saline content significantly lower than the entering water. This technology is successfully used in Europe, but the technology has only seen incremental improvements.

The Sandia team of Michael Hibbs, Justin Marbury, Cy Fujimoto, and Cornelius are creating more mechanically and chemically stable ionomers with improved salt rejection to reduce the needed energy and material costs of electrodialysis-based desalination. Currently, the technology is based on thick fiber-reinforced, polystyrene-based ionomers. (Polystyrene ionomer membranes must be thick and fiber-

Photos illustrate a typical reverse osmosis filter (top) and fouling problems (bottom).

The goal is to reduce maintenance costs for reverse osmosis membranes while increasing efficiency and lifetime.

reinforced in order to provide structural integrity to the mechanically weak membranes.) Higher power loads are required to transport salt ions through these thick composite structures compared to a thinner membrane of the same polymer structure. While the thicker ionomer membranes significantly improve mechanical integrity, the power (and cost) to desalinate water also increases with membrane thickness. Consequently, reducing the cost of electrodialysis-based desalination is possible with improved ionomer membrane materials, says Cornelius.

The Sandia approach is to control the structure and thickness of the ionomer membranes using "structured" ionomer membranes as well as organic-inorganic composite structures to enhance mechanical integrity and improve ion transport to reduce the costs associated with the desalination.

Biofouling: the slime

One of the major problems facing reverse osmosis technology is biologic. "Biological materials in the water grow films containing cells and other material that hold them together," explains Mayer. "It turns into a slimy mess that's hard to get rid of. It is resistant to disinfectants and other treatments." The film ultimately results in a need to clean or replace the membranes or face reduced efficiency.

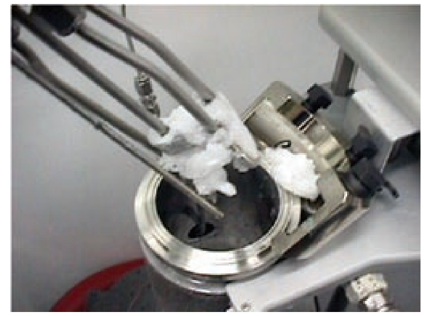
"We don't always have experts in every problem at Sandia," says Mayer. "Therfore, we are interested in identifying pioneers and building an infrastructure as we go along. We have researchers with know-how and lots of enthusiasm." In this case, Sandia researchers have teamed with experts at New Mexico Tech to identify processes that will degrade the biofilms. They are evaluating broad-spectrum enzymes for their effectiveness in removing the films.

The goal is to reduce maintenance costs for reverse osmosis membranes while increasing efficiency and lifetime.

(Additionally several Sandia researchers, through Laboratory Directed Research and Development LDRD projects, are looking in to issues of how the biofilms form on the filters and how their growth can be discouraged or disrupted.)

Hydrate desalination

Sailors have long known that freezing water to form ice naturally excludes salt. Many molecules will form solid "clathrate hydrates" above the freezing point and at moderate pressure, containing molecules of water surrounding a host molecule. These crystalline clathrate structures naturally exclude salt during the formation process. Separating the resultant solid hydrate from the remaining salt water would theoretically form a thermally and economically efficient desalination process.



Bob Bradshaw (top left) at work studying hydrate formation (top right) using pressure and temperature controlled lab equipment.

The Sandia effort will combine computational analysis at labs in New Mexico with expertise in hydrate formation from California and New Mexico researchers.

This is an old idea, being revisited by Blake Simmons and Bob Bradshaw of Sandia, as part of a Laboratory Directed Research and Development LDRD project. "It uses less energy than distillation," says Mayer, "but it has never worked in practice because it is difficult to separate the hydrate crystals from the remaining salt water." To make it work, researchers are conducting basic science studies of growth and control of hydrate crystals and separation of the hydrate and resulting brine. "You want to end up with a block of pure hydrate, rather than slush," says Mayer.

"In the past, hydrate desalination has taken an engineering approach, without understanding the basics of hydrate nucleation and growth," says Simmons. The Sandia effort will combine computational analysis at labs in New Mexico with expertise in hydrate formation from California and New Mexico researchers. "Hydrates form in specific temperature and pressure conditions," he explains, "and salt water is entrapped between the hydrate crystals when present. We want to solve the separation problem by placing the crystals in a different environment or by limiting their growth by chemical or physical conditions."

"We want to know what a structure will look like, given a certain host molecule," says Bradshaw, who is conducting experiments at Sandia's California site. "From five to 10 or more water molecules can organize around a host depending on the structure. We look to the computational chemistry work to provide such structural insights to help design a scaled-up process."

Technical Contact: Tom Mayer
505-844-0770, tmmayer@sandia.gov

Reusing oilfield water

Removing coal bed methane produced brine from a remote well location in the San Juan basin is expensive for producers.

One of the obvious places where energy and water intersect is the oil field. As gasoline prices soar and the U.S. presses ahead with the development of oil and gas fields to meet ever-increasing energy demands in all sectors of the economy, the issue of produced water becomes significant.

Produced water comes from the pores of sedimentary rock, where it has been trapped in association with hydrocarbon deposits for eons. While the amount of produced water from an oil or gas field varies dramatically, on average producers in New Mexico get seven to 10 barrels of water for each barrel of oil they pump to the surface. Water is associated with natural gas production as well — particularly in the case of coalbed methane, produced in areas where rich coal deposits are located within a few thousand feet of the surface.

Produced water comes from the pores of sedimentary rock, where it has been trapped in association with hydrocarbon deposits for eons.

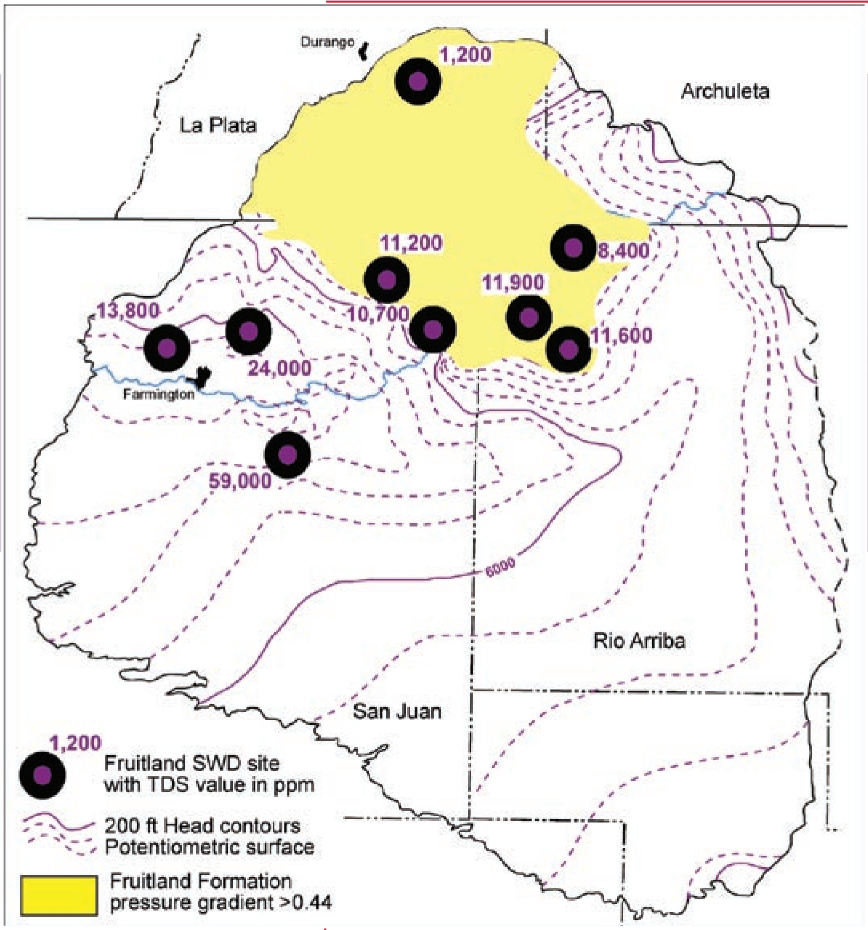
Produced water commonly varies from 2,000 to 60,000 parts per million in total dissolved solids. It can be even higher.

Present estimates indicate the U.S. generates more than five billion gallons of produced water a day. It doesn't smell good and it doesn't taste good, but it has potential for beneficial use, says Sandia's Allan Sattler, who is researching treatment technologies for produced water.

Reinjection wastes

Generally produced water is handled as a waste and reinjected into the ground, often at a significant cost to producers. At present, produced water disposal costs are approximately $6.00 per 1,000 gallons. If a company can treat the same water for $3.00 per 1,000 gallons and reuse it, it realizes a savings. "If the treatment impacts the bottom line positively, the oil and gas companies will certainly consider doing it," says Sattler.

Right now treating or eliminating the hydrocarbon content in produced water is a critical issue and an important research area, he adds. Sandia plays a role in this research, based on Labs experience in salt and brine chemistry, geology, engineering, environmental technology, solar energy, and materials science.In partnership with private industry and government agencies, the labs are addressing environmental



Plotting sample results (left) and checking well-head (below) in the San Juan Basin. Sandia is evaluating the Capacitive Deionization Desalination Technology shown in laboratory (bottom.)

In addition to dissolved solids, produced water has organic materials that further complicate the clean-up process.

and policy issues and looking at produced water treatment strategies.

- With the Bureau of Land Management and the Ground Water Protection Council, Sandia is assessing the potential of contaminating freshwater resources through abandoned wells.
- Sandia is providing assistance to the Soil Conservation Service on regulatory and policy issues associated with treatment and reuse of produced water.
- Labs researchers are looking at desalination and commercial treatment and pretreatment technologies for produced water and novel treatments for coalbed methane produced water in northern New Mexico.

"We are evaluating a desalination technology for use with produced water using capacitive deionization technology," says Sattler. The technology was selected because of its potential to use less power than reverse osmosis, its compactness and portability, and its ease of maintenance. Early studies of the demonstration unit, from BioSource, Inc., a Massachusetts company, have been quite promising.

"This may be the first actual laboratory experiments with desalination here at Sandia," says Sattler. We have done studies involving flow rate and ion concentration settings to optimize performance. Now we are proceeding with a second set of lab-scale experiments. The solar energy cost per barrel for desalination is well under $1 and, as it is optimized, costs will go down."

In addition to dissolved solids, produced water has organic materials that further complicate the clean-up process. Mechanical filters take out these hydrocarbons down to one micron in size and the capacitive deionization technology further reduces the chances of the system "fouling," or clogging up, by regularly reversing the polarity on the electrodes, keeping unwanted ions from clinging to them.

San Juan wellsite showing pump and 400 barrel tank for watering grass seedlings with produced water.

The San Juan Basin is the largest producing region for coalbed methane at present, although other areas, notably the coal-rich Powder River Basin in Wyoming, will surpass it in the future.

Moving to the field

Testing the system on real wells in the San Juan Basin is the next major step, says Dave Borns, who manages Sandia's Geotechnology and Engineering department. The San Juan Basin is the largest producing region for coalbed methane at present, although other areas, notably the coal-rich Powder River Basin in Wyoming, will surpass it in the future. "Produced water is a major issue limiting coalbed methane production right now. To test our system at these remote wells we need to connect it to solar. Much of the production is not connected to the power grid."

Sandia's Charles Hanley, a systems engineer in the Labs' Solar Systems department, has done preliminary studies as to sizes of photovoltaic panels needed to power the units, based on different salinities. "Although solar power is already a practical option for these remote applications, the size and cost of required solar energy systems will be smaller as Sandia researchers reduce the energy intensity (amount of energy per unit of water produced) of these units," Hanley says.

The solar technology will have broad applicability, far beyond the coalbed methane wells, Hanley notes. "If it works as promised, it can be used by communities in water-stressed regions throughout the world."

In the meantime, Sandia continues lab work using produced-water samples provided by San Juan and Raton Basin producers through a partnering arrangement with New Mexico Tech. "We want to work with producers and the manufacturer very carefully in the design of a field unit," Sattler says. "We need to fine tune it here in the lab before deploying it in the field."

In the field, Sattler's colleagues from New Mexico State University's Agricultural Station at Farmington, New Mexico study grasses suited to the harsh climate and soils of the area. If grass seedlings will germinate using produced water, lowering the salinity of the water should improve germination rates even further, Sattler suggests. Basically, produced water has been used to "jump start" the grass seedlings on a pilot basis. Only 2-3 waterings are necessary to help jump start these seedlings.

"We would like to look at sites with salinity from 2,000 to 12,000 parts per million for our desalination project," says Sattler. "Higher salinity numbers aren't economically feasible because they take too much energy. We have had some information discussions with BLM, which is very supportive of this work. They are suggesting target salinities in the 1,000 to 1,500 parts per million range."

For the time being, concentrate will still need to be reinjected, Sattler says. However, desalination will result in a reduced volume of produced water for disposal or reinjection. "We can reduce it by a factor of three or four, which means a lower cost," he says.

Technical Contact: Allan Sattler
505-844-1019, arsattl@sandia.gov

Sprouting of grass seedlings, started with produced water, is encouraging.

New arsenic standard costly

The data showed associations of arsenic with skin and vascular diseases and relationships with certain bladder and lung cancers.

Anyone who watches old movies knows that arsenic has been the preferred poison for assassins since the earliest days of recorded history. Doctors also used it in much lower doses in earlier centuries as a medicine, illustrating its positive benefit in some low-dose uses. In this century, naturally occurring arsenic's negative health impacts have again become an issue, tied to its concentration in some drinking water supplies.

After an extensive study by the EPA, the agency lowered the maximum limit for arsenic in drinking water from 50 parts per billion to 10 in 2001. For comparison, 10 parts per billion is equivalent to 10 drops of arsenic in a small, in-ground backyard swimming pool (10,000 gallons).

Much of the data used by EPA in determining the new limit came from outside the U.S. The data were from South America and Taiwan, where arsenic concentrations in water are hundreds or thousands of times higher. The data showed associations of arsenic with skin and vascular diseases and relationships with certain bladder and lung cancers.

While concentrations in the U.S. tend to be much lower, the standard was determined to be a prudent move by EPA officials, who used a straight-line projection from the higher-level concentrations to lower concentrations more typical of the U.S. With the new lower limits set to come into effect in January, the full impact of the legislation is only now beginning to be understood.

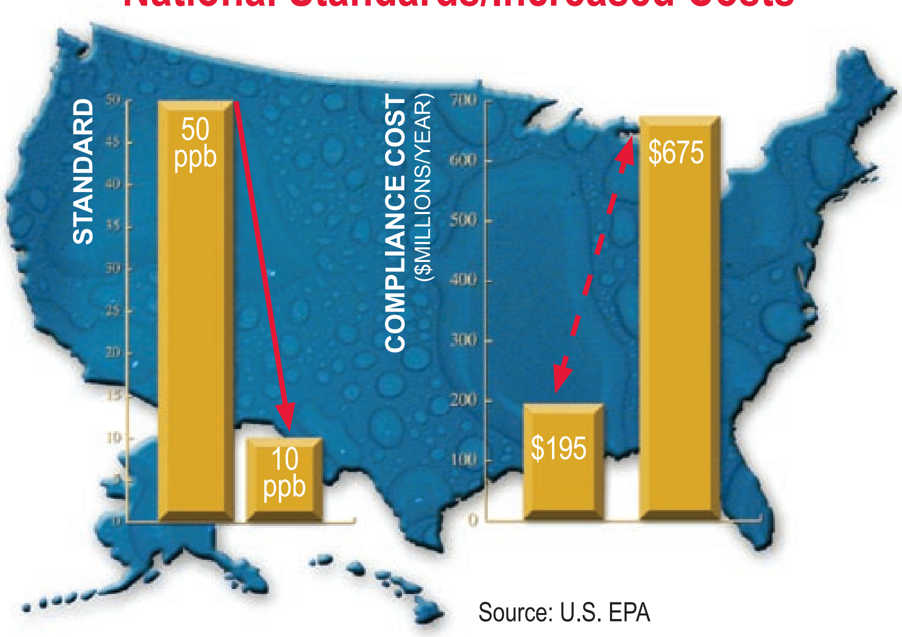
"When you ask small, rural communities without sophisticated water treatment to adopt a complicated treatment system, you increase the costs of drinking water by two or three times," says Sandia's Arsenic Treatment Program leader Malcolm Siegel. EPA's own estimates show that installing treatment systems will cost from $58 to $237 per household per year. "A lot of these communities (predominantly in the West and Southwest) can't afford these additional costs," says Siegel.

Other unintended consequences of the regulation include:

- higher risks to water treatment plant workers, who must handle chemicals and truck arsenic wastes from treatment sites, and
- the removal of beneficial minerals from the water as a result of the arsenic treatment. Examples include fluorides (dental health) and magnesium and calcium (heart-related health).

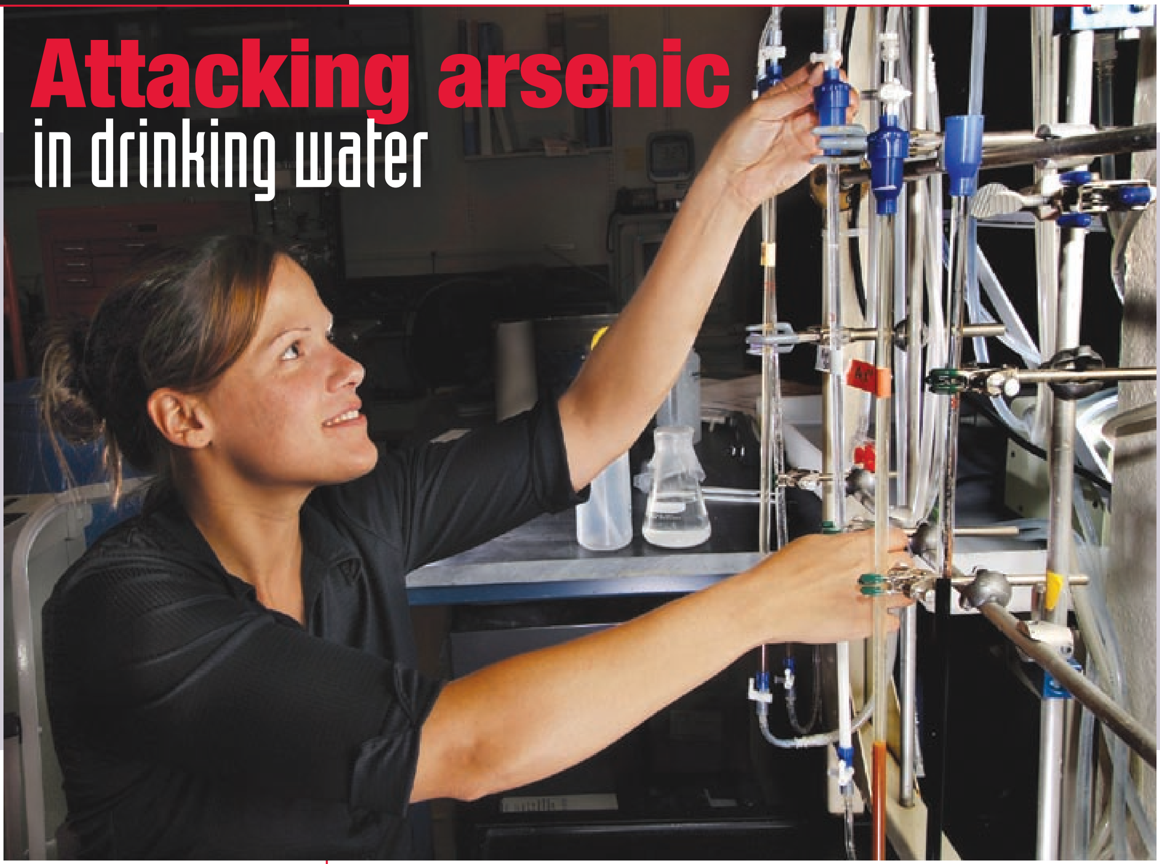
This combination of health- and economic-related objections has caused Sen. Pete Domenici of New Mexico to ask the EPA to reconsider the standards or at least postpone implementation until more cost effective treatments can be developed. Domenici, who is seeking funding to help disadvantaged communities, estimates that 5.5 percent of communities nationwide will have to treat water to meet the new standards.

National Standards/Increased Costs



Source: U.S. EPA

Attacking arsenic in drinking water



Alicia Aragon checks out equipment used to help develop cost-effective technologies for arsenic removal.

"We'll be looking at which method best adsorbs arsenic and how often the adsorption material needs to be changed."

Alicia Aragon
Sandia Researcher

Over the next several months, Sandia researcher Malcolm Siegel and his team will be studying different methods of arsenic removal at the Desert Sands Municipal Domestic Water Consumers Association near Anthony in southern New Mexico. The research is sponsored by Arsenic Water Technology Partnership, which includes Sandia, WERC (a consortium for environmental education and technology development), and the Awwa Research Foundation (AwwaRF).

"The Desert Sands project will supplement a full-scale demonstration by the EPA for evaluation of a removal technology using granular iron oxide to filter arsenic from water," Siegel says. "As water is pumped through the system, arsenic sticks to the iron oxide. The Desert Sands utility wants Sandia to compare the performance of the method it is using to other adsorptive methods. We should be able to give them some practical advice based on what we learn."

The Sandia field team includes lead engineer Malynda Aragon, field technicians Randy Everett and William Holub, post doc Alicia Aragon, as well as students from the University of New Mexico and the University of Texas at El Paso. The team will test between eight and 12 different arsenic removal systems at the Anthony site. "We'll be looking at which method best adsorbs

Malcolm Siegel (right), arsenic project lead, and Malynda Aragon, lead engineer, anticipate they will test between eight and 12 different arsenic removal systems at the Anthony site.

The Anthony research is a follow-up to work in Socorro where the Sandia team tested five arsenic removal technologies at a geothermal spring. The Socorro project, shown here, was fielded as a first phase and concluded this year.

"...the goals of the program are to develop, demonstrate, and disseminate information about cost-effective water treatment technologies..."

Malcolm Siegel, Project leader

arsenic and how often the adsorption material needs to be changed," Malynda Aragon says.

The treatment system, including monitoring equipment and plastic columns filled with adsorptive material, was built at Sandia, installed at the Desert Sands site, and is now operational.

Desert Sands serves a population of 1,535 from two wells in a rural community along the New Mexico-Texas line, north of El Paso. It has a new water treatment plant built by Severn Trent Corp. that uses the iron oxide treatment method.

The Anthony research is a follow-up to work in Socorro where a Sandia team compared five innovative technologies. These treatment processes were chosen from more than 20 candidate technologies reviewed by teams of technical experts at Arsenic Treatment Technology Vendor Forums organized by Sandia and held at the 2003 and 2004 New Mexico Environmental Health Conferences.

Siegel says that the goals of the program are to "develop, demonstrate, and disseminate information about cost-effective water treatment technologies in order to help Native Americans and small communities in the Southwest and other parts of the country comply with the new EPA standard."

Sandia's role in the Arsenic Water Technology Partnership started in late 2003 with a vendor forum in Albuquerque where firms were invited to describe their products and discuss innovative technologies with technical review teams. The teams evaluated technologies again in 2004 for possible use in pilot demonstrations. A third vendor forum will be held in November of this year.

In addition to the vendor forums, the Denver-based AwwaRF is working with an advanced concepts committee to look at new forms of material to improve exist-

"We need to stay ahead of the curve so communities can invest in proven systems that will address multiple contaminants."

Malcolm Siegel, Project leader

ing and new processes, such as the use of nanotechnology in arsenic removal. By the end of summer, a technical review committee will examine results of the initial proposals to AwwaRF; the best materials developed by the research will be implemented in the Sandia Pilot demonstration program.

Besides the Socorro and Desert Sands experiments, additional demonstrations, based on technologies reviewed at vendor forums and developed in laboratory studies managed by AwwaRF, are also being considered in consultation with the New Mexico Environmental Department, the EPA, the Indian Health Service, the Navajo Nation EPA, and the Interstate Technology Regulatory Council.

WERC, a consortium of research institutions in New Mexico, is evaluating the economic feasibility of the technologies, work on technology transfer activities, and conduct educational outreach.

With stricter arsenic requirements taking hold, there will be a need to help communities modify systems to perform better, says Siegel. Scientists are also looking at other contaminants that may be regulated in the future.

"We need to stay ahead of the curve so communities can invest in proven cost-effective systems that will address multiple contaminants," he says.

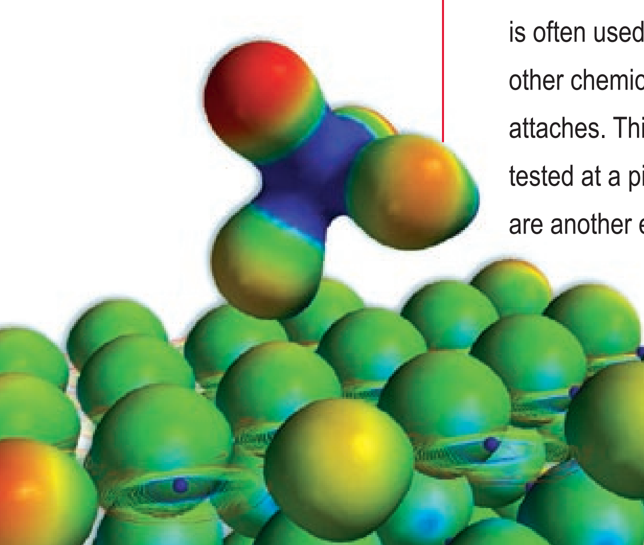
Technical Contact: Malcolm Siegel
505-844-5426, msiegel@sandia.gov.

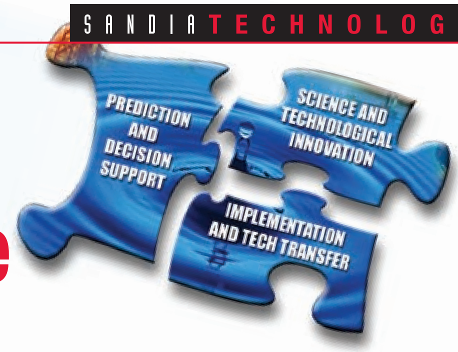
Arsenic removal 101

There are three basic types of water treatments for removing arsenic from water:

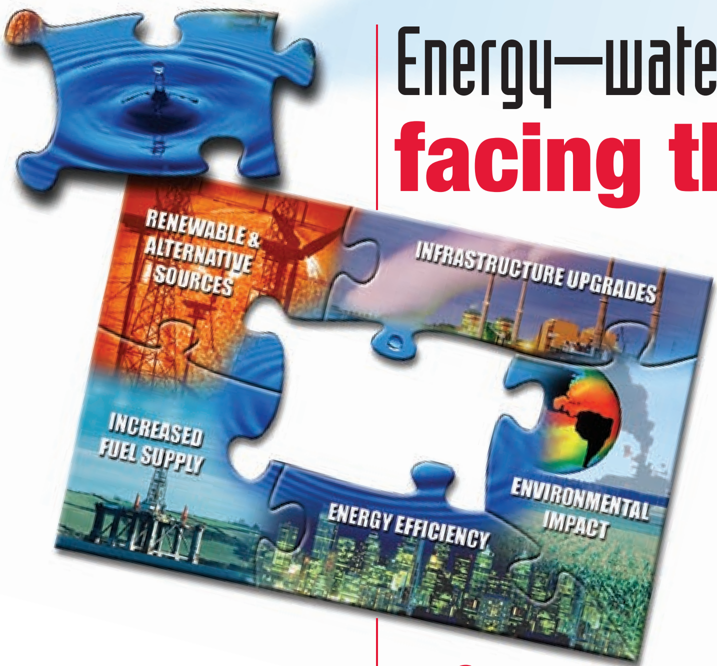
1. Absorptive media are placed in columns and water passed through them. The media absorb the arsenic and can then be disposed of, or the material can be cleaned, or "regenerated," to be used again, with the concentrated arsenic disposed of as a hazardous material.
2. In filtration systems, water is passed through a membrane under pressure, and dissolved substances, including contaminants, are retained on the filter. In coagulation/filtration, which is often used for treatment systems in larger communities, iron compounds, oxygen, or other chemicals are added to the water to form a floc of small particles, to which the arsenic attaches. This approach also works well in wells with high concentrations of iron and will be tested at a pilot-scale study on the Jemez Pueblo in New Mexico. Reverse osmosis systems are another example of a membrane filtration system.
3. Electrical current can be used to collect arsenic on an electrode or membrane or can cause it to change in form for easier collection. These systems tend to be small at present and are the most experimental of the three types.

Nano-engineered specific-anion sorbents aid in water purification.





Energy—water nexus: facing the future



The researchers illustrate their work with a puzzle, showing interlocking pieces, illustrative of sectors of the U.S. energy economy, surrounding a missing piece. The energy-water nexus is the missing part of the puzzle.

Consider this:

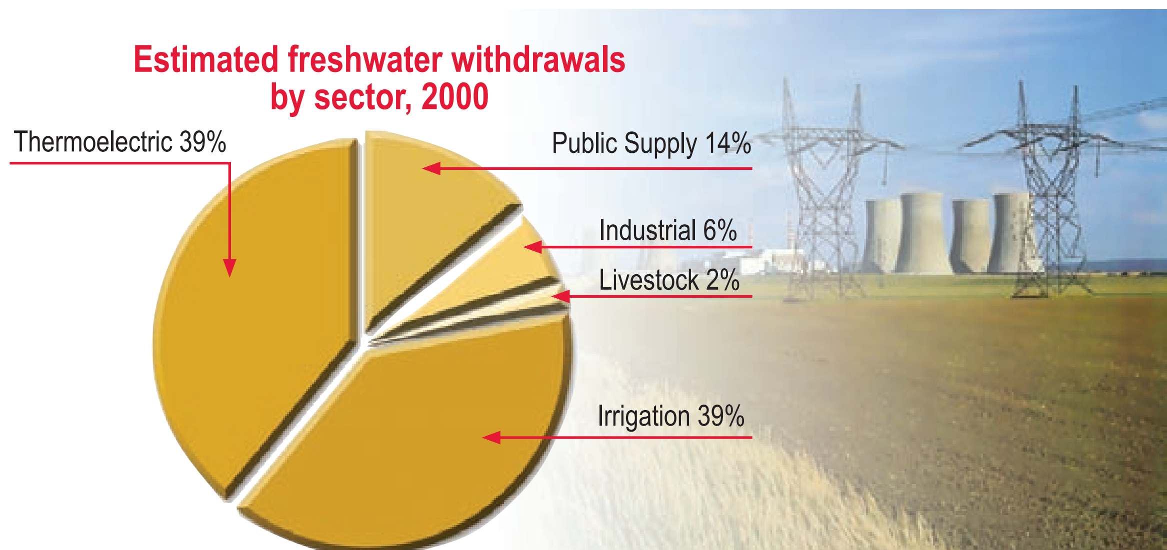
- Energy production requires a reliable, abundant, and predictable source of water.
- The electricity industry is second only to agriculture as the largest user of fresh water in the U.S.
- America's fossil fuel and nuclear power generation needs require 139 billion gallons of water per day, about 39 percent of all freshwater withdrawals.

Add the fact that, at present population growth rates, the U.S. economy will require 1,500 new power plants — almost one every other week — by the year 2020. Now answer this: Where's all the water coming from?

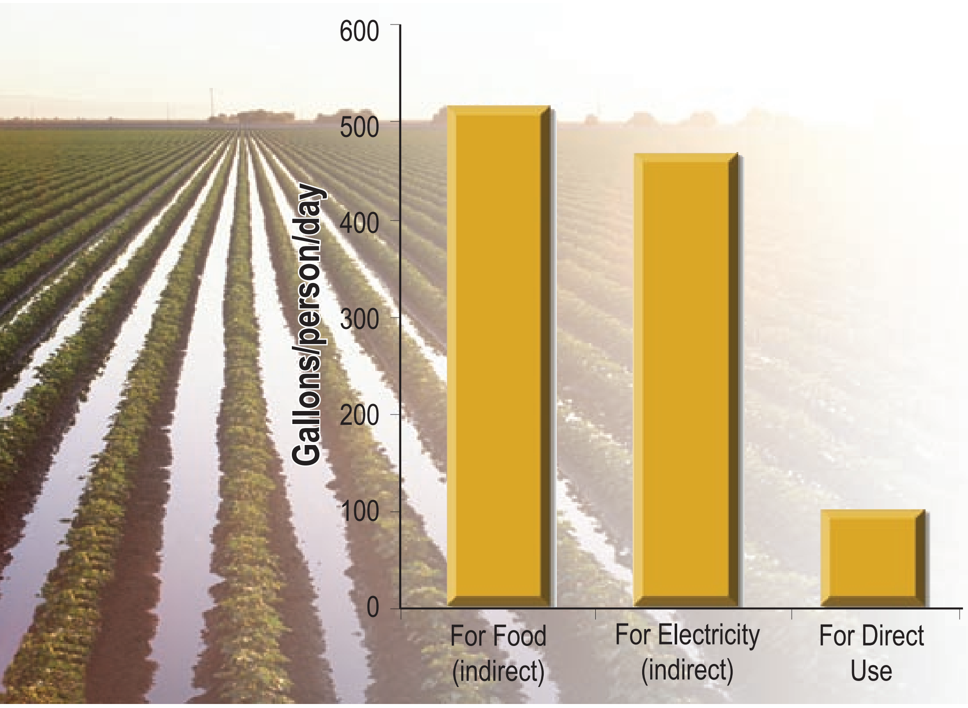
Scientists from 11 national laboratories and the Utton Transboundary Resources Center have come together to study how energy and water interrelate and answer this question. They refer to the impacts of water on energy and vice versa as a "nexus," suggesting a group or series of interconnections rather than a single link.

The researchers illustrate their work with a puzzle, showing interlocking pieces, illustrative of sectors of the U.S. energy economy, surrounding a missing piece. The energy-water nexus is the missing part of the puzzle.

"Our future energy security demands that we look at all of our natural resources, including water," says John Merson, program director for Sandia's Geoscience and Energy Center and co-leader, with Mike Hightower, of the Energy-Water Nexus team. "Too often, people planning water supply projects fail to take agriculture and energy into consideration. These linkages



Key sectors of water use, according to the U.S. Geological Survey.



Indirect uses of water — for electricity and food — are several times higher than direct water use for laundry, bathing, drinking, and other household activities.

"Energy systems we may rely on in the future — such as hydrogen, coal liquefaction, coal gasification, and biomass — are reliant on water, as well."

haven't been addressed at the level necessary for energy and water sustainability."

This is true of both current energy requirements and future requirements, Merson notes. "Energy systems we may rely on in the future — such as hydrogen, coal liquefaction, coal gasification and biomass — are reliant on water, as well."

Merson and colleagues from the National Energy Technology Laboratory (NETL) in Pittsburgh, Pennsylvania, and Los Alamos National Laboratory, in Los Alamos, New Mexico, began discussing energy-water issues about three years ago. A presentation they made at a Department of Energy meeting about a year and a half ago resulted in the present team configuration, says Tom Feeley, technology manager at NETL and co-leader of the national Energy-Water team. Feeley's NETL responsibilities include a water program focused on power plant issues. He hopes his lab will provide support to or become part of a larger energy-water program in the future.

At present the group is focused on two key objectives:

- A 15-month roadmap plan to better define research and development needs for energy-water issues, and
- A report to Congress, which the group hopes to provide early next year.

There are well over a dozen government agencies that have some responsibility for water in the U.S., says Dan Macuga, who holds program development responsibilities for LANL in its Office of Energy and Environmental Initiatives and participates on the Energy-Water Nexus team. Among the agencies are the Forest Service, National Oceanic and Atmospheric Administration, Department of Agriculture, Army Corps of Engineers, Environmental Protection Agency, the Bureau of Reclamation, and the U.S. Geological Survey.

"We concluded that none of the agencies look at the water piece of the energy puzzle. No one agency has responsibility for water-related impacts on energy policy, water used in energy production, or energy used by water systems," Macuga says.

"We've developed a compelling story about energy and water and why we think the DOE should establish this program, and now we're moving forward," Merson adds.

Technical Contact: John Merson
505-844-2756, jamerso@sandia.gov

Michael Hightower, 505-844-5499,
mmhight@sandia.gov

With inclusion of freshwater and saline water withdrawals for thermoelectric and hydropower, the energy sector is the largest water use sector. While part of these withdrawals is not consumptive, enough water must be available to ensure sustainable energy production. Almost without exception…our electricity production is dependent on water supplies.

Electric Power Research Institute, 2002

Energy-Water Nexus:
Roadmapping the research

The 11-lab Energy-Water Nexus team is working with a demanding schedule and limited resources to help develop a plan for research and development across multiple economic sectors.

The goal: a roadmap for future research and development across a number of federal agencies as well as other public and private sector stakeholders.

At a recent meeting of the team in Albuquerque, co-leaders John Merson and Mike Hightower reviewed initial plans for the roadmap project with other members. The team has tentatively planned to reach as many key stakeholders as possible, including industry, municipalities, and agriculture, with a series of "needs" workshops. "Ideally we want to find technologies with impacts in multiple sectors," says Merson.

Following the first round of workshops early in 2006, an executive committee made up of representatives from 20 institutions and organizations will begin to prioritize research needs. The committee is being established to guide this process. "Our far-reaching goal is to assess research gaps, implement the roadmap plans, guide the research, and provide technology transfer and education outreach," says Merson.

DOE officials believe the team is on track and has identified several key issues to this point, said team member Dan Macuga, of Los Alamos National Laboratory. "Now it's up to us to work with other agency programs and make use of their knowledge and expertise to be more productive in the time we have."

Team members represent Sandia, National Energy Technology Laboratory, Los Alamos, Pacific Northwest National Laboratory, Oak Ridge National Laboratory, National Renewable Energy Laboratory, Lawrence Livermore National Laboratory, Idaho National Engineering and Environment Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, and Argonne National Laboratory.

The Utton Transboundary Resources Center at the University of New Mexico School of Law has a lengthy history of working with stakeholders and researchers from many fields to prevent resource disputes. Represented by its director Marilyn O'Leary, the Utton Center will provide regulatory assessments related to program implementation.

Mike Hightower, of Sandia's Energy Systems Analysis department, and his team-mates see big changes ahead in the business of energy in the U.S.: all in the name of water. As they embark on a study of energy and water issues for the U.S. Congress, some of the big picture ideas are already clear. The study will help sketch in much of the detail.

Hightower and team are in the process of looking at regional population data, water data, and growth projections by region. They will also look at expected water demands from other sectors, including agriculture, industry, and municipalities. "We also want to look at mixes of technologies that could be considered to optimize transportation fuels. We are taking a systems analysis approach to long-term sustainability issues.

"When you look at the bottom line, one of the biggest withdrawals of water is for electrical power. We're going to have to look at distributed generation combinations with increased energy efficiency and a larger percentage of renewables. Coastal power plants will be supplying inland needs, resulting in extensive electrical transmission needs. Impaired water from power plant cooling, produced waters from oil and gas production, and brackish subsurface waters will be used. (See stories on page 22.) We will have to look in detail at energy efficiencies and renewable concepts for homes and buildings. We will have to look at transportation changes. We have to find ways of doing more with less."

Hightower and his colleagues on the Energy-Water Nexus team expect to complete this first-look effort in about six months. "This is not going to be a one-size-fits-all approach," Hightower continues. "We will concentrate on a regional basis at what the 'water-for-energy' issues are."

Energy-water report will include:

- Assessment of water needs for energy production for each major energy type;
- Examination of growing population patterns and associated concerns;
- Estimates of future energy needs and related availability of water;
- Analysis of issues associated with future energy and population expansions; and
- A look at what federal programs are in place to address these issues and what gaps exist.

"Armed with this information, it is going to be up to our political leaders to take address regulatory issues and provide research and policy direction," says Hightower.

Detecting toxins in the nation's water supplies

The United States has more than 300,000 public supply water wells, 55,000 utilities, 120,000 transient systems at rest stops or campgrounds, and tens of millions of hydrants.

Two technologies, both based on Sandia's development of the microChemLab, are expected to soon be detecting toxins and harmful bacteria in the nation's water supplies.

The microChemLab, officially called µChemLab, is a hand-held "chemistry laboratory." The liquid-phase prototype was designed and built at Sandia/California, while the device that measures in the gas phase was developed at Sandia/New Mexico.

Complete with the µChemLab, electronics, and sample collector, the detection system weighs about 25 pounds and fits into a box the size of a small suitcase. The only external parts of the two sensor technologies are water collectors. The units are completely portable.

"Our goal is to place these sensors within utility water systems and use them to quickly determine if the water contains harmful bacteria and toxins," says Wayne Einfeld, who heads the Sensor Development Focus Area within Sandia's Water Initiative. "This on-site monitoring approach would replace current utility monitoring systems that require water samples to be sent to laboratories for analysis, which sometimes takes days for results."

The United States has more than 300,000 public supply water wells, 55,000 utilities, 120,000 transient systems at rest stops or campgrounds, and tens of millions of hydrants. Up until now, real-time, remote water quality monitoring for toxins has been very limited.

The liquid µChemLab is currently being tested at the Contra Costa, California Water Utility, says Jay West, California principal investigator. Specifically, the team is testing to determine the steps necessary to identify toxins in drinking water, as well as expand its capabilities as an autonomous monitor. The device is presently collecting and analyzing a water sample every 30 minutes and reporting results via a real-time data link to researchers at Sandia.

Curt Mowry and the portable µChemLab water detection system.

Research partners

Sandia's cooperative research and development agreement partners in the California endeavor are CH2M Hill, a leading US engineering firm, and Tenix, an Australian engineering services company. CH2M Hill is a global engineering and construction management firm with particular expertise in sewer and wastewater treatment design. Tenix is a company with more than 30 years experience in water supply, sewerage, and drainage infrastructure.

The California µChemLab identifies proteins by separating samples into distinct bands in seconds to minutes. Separations occur in channels as narrow as a human hair coiled onto a glass chip about the size of a nickel.

Curt Mowry, principal investigator for the New Mexico project, says his team is seeking to develop a device that detects trihalomethanes, undesirable by-products of the chlorination process used to control

Jay West, Sandia California principal investigator, is working with the Contra Costa (California) Water Utility to determine steps needed to identify toxins in drinking water using the liquid µChemLab.

The µChemLab system is expected to help water utilities control the formation of trihalomethanes by functioning as a component of a process control loop.

the bacterial content of water. Trihalomethanes, which form naturally when surface water is treated with chlorine, are highly carcinogenic and can have adverse liver and kidney effects. The New Mexico project is funded through Laboratory Directed Research and Development LDRD resources allocated through Sandia's Water Initiative.

"The EPA has regulations for water utilities to monitor for trihalomethanes on a regular schedule," Mowry says. "Currently they have to collect samples and send them to labs for analysis. They get numbers back a few days later. This is a scary thing for us as consumers. The way it's done now, they might have measured high levels and there is chance someone has already consumed the water before the results return. Using the µChemLab will provide a way to bring the labs to the site and get results in a more timely manner."

The µChemLab system is expected to help water utilities control the formation of trihalomethanes by functioning as a component of a process control loop.

Bubbling air

New Mexico's portable unit analyzes a sample of water by bubbling air through it and collecting trihalomethanes from that air. The collector is heated, sending the trihalomethanes through a separation channel and then over a surface acoustic wave (SAW) detector.

"The collector and the separation phase can be purchased off the shelf, but the SAW detector is at the heart of the microChemLab," Mowry says. "The ultimate goal is to replace the commercial separation column with a Sandia microfabricated column made using microelectrical-mechanical (MEMS) fabrication technology to reduce the power needed and increase performance."

Commercial collectors are about four to five inches in diameter. Microfabricated collectors will be a half-a-square inch. They are in development stage and need further tuning for trihalomethanes.

The Sandia New Mexico µChemLab uses similar concepts to the California one — collect, separate, and detect. The main difference is at "the front end" of the device, where different capabilities are needed to be able to extract gases such as trihalomethanes from the water.

"Both systems will speed the analytical process and give the utility operator better information in a shorter time period," Einfeld says. "In addition to routine water quality monitoring, both are expected to be part of early warning systems that can alert utility operators to intentional contamination events that might occur at vulnerable locations downstream from treatment plants."

And finally, he says, "In both of these projects, Sandia has successfully leveraged MEMS-based core technologies nurtured by various DOE programs into the water security applications area."

Technical Contact: Jay West
925-294-3224, jawest@sandia.gov

Curt Mowry, 505-844-6271,
cdmowry@sandia.gov

Wayne Einfeld, 505-845-8314,
weinfel@sandia.gov

The American West: A delicate balance

Despite the rugged beauty and power of the mountains, they contain many delicately balanced natural systems, where the change of a few degrees in temperature can have huge implications.

The drought currently impacting the American West — along with the steadily increasing population made of people seeking its vistas and the promise they offer — bespeaks far-reaching change for the region. In the West, water is often called "lifeblood" for good reason:

- Water flows through complex systems of dams, spillways, and pipelines to pour out of faucets and squirt from irrigation sprinklers in fields and cities hundreds of miles distant.
- Water is intimately linked with power generation — as a generator at hydroelectric plants and as a coolant at thermoelectric plants, and produces power for industry (and attendant jobs) and lights the Little League baseball fields, businesses, homes, and streets of Western cities.
- Water supports natural resources, timber, wildlife, and recreational activities from high-country skiing to river rafting.

Only in the last couple of decades have we come to realize the economic value of ecosystems, says Howard Passell, a Sandia researcher who specializes in hydrogeo-ecology. "One way to think of the value is to translate it into dollars and cents," he says. The ecosystem provides oxygen, delivers fresh water, fertile soils, composts wastes, pollinates plants, and offers fish and forest products, and each of these services has monetary value.

The value of water can be calculated for whole regions — like the American West, he says, referring to the work of Robert Costanza, a University of Maryland professor and a founder of the field called ecological economics. "Once you recognize the very large economic value of water, it makes more sense to expend effort to figure out how to manage and conserve it."

Delicate balance

Despite the rugged beauty and power of the mountains, they contain many delicately balanced natural systems, where the change of a few degrees in temperature can have huge implications. Warming cycles impact glaciers, snowpack, snowmelt, downstream supplies of drinking water, availability of power, and reservoir levels for recreation.

This has become a familiar story in the West and participants at two recent scientific symposia have captured some recurring themes:

- While water supplies are impacted by drought-related phenomena, demand for water continues to increase.
- Increased susceptibility of trees to insects has resulted in massive, widespread "dieback" of forests.

Few large-scale studies have been completed to date so questions about actual water flow and species at risk or severity of fire seasons still can't be predicted.

- Suburban development and a push toward "exurban development" (homes on four- to 15-square-mile plots), is increasing scarcity of wild lands, increasing fire danger to these new developments, and accentuating air quality problems.
- Most obviously in recent summers, enormous, destructive wildfires have scorched the landscape, fueled by drought, extensive dieback, and an unsustainable policy of long-term fire suppression.

While wildlife habitat and biodiversity are clearly the victims of these changes, much more must be known in order to fully understand the big picture. Few large-scale studies have been completed to date, so questions about actual water flow and species at risk or severity of fire seasons still can't be predicted.

A handful of researchers centered at the U.S. Geological Survey's Desert Laboratory in Tucson, Arizona, have begun to tackle these questions with innovative approaches, using packrat nests and tree rings. "Based on our research, we need to consider the possibility that the drought will continue for some time and plan in the long term, rather than reacting in a short-term way," says Steven Gray, of U.S.G.S.

Tree-ring research

Tree-ring research shows that the current exceptional drought can be put into a longer-term perspective, reaching back for hundreds of years — past the chronology of living trees and historical records. The research shows two unusually wet events in the past 150 years punctuated a persistent cycle of 20- to 35-year droughts. Using the content of preserved packrat nests to get a view of the flora in past forests, Gray and his team have painted a picture of wet and dry cycles over several hundred years.

By applying equations to the cycles, the researchers show that the normal multi-decade drought cycles impact Colorado River flow by an estimated 2.5 million acre-feet per year. For perspective, 2.5 million acre-feet is the combined amount that the states of Colorado and New Mexico are legally entitled to each year, according to the Colorado River Water Compact. Further research ties this picture of climate to key social events, such as the abandonment of cliff dwellings during the Anasazi time and the establishment of the first Spanish colonial period, or encomienda system, in the Southwest.

"The late 20th century is the third wettest multi-decadal period in the past 400 years," says Gray. Yet during this time, rules for distribution of Colorado River system were set into law and the population of the region doubled. "No short window of observation gives us enough data to make a good set of rules," he adds. Better models are needed to help predict impacts of both climate and policy change to avoid significant social and economic impacts in the future.

For more information about the U.S.G.S.'s Desert Laboratory, go to:
http://wwwpaztcn.wr.usgs.gov/home.html

INSIGHTS

By Erik R. Peterson

'The stakes are tremendously high'

An estimated 2.6 billion people currently do not have access to sanitation, but the broader implications of the sanitation challenge far transcend the direct effects, as profound as they are.

Anyone taking a close look at the challenge of water — present and future — can easily become overwhelmed by the scale and complexity of the issue. First, the human dimensions of the challenge are more nearly indescribable. The empirical evidence only tells a small part of the story. An estimated 1.1 billion people across the planet currently lack access to safe water, but that metric alone, as daunting as it is, fails to reflect the much more significant costs associated with water access and quality. An estimated 2.6 billion people currently do not have access to sanitation, but the broader implications of the sanitation challenge far transcend the direct effects, as profound as they are.

The precursor to addressing this challenge, therefore, is simply to raise our level of understanding of the many complex dynamics at work in the global water calculus. Of these, two in particular are critical. First, a sharpened understanding of the role of technology — from the "high-tech, high-cost" side of the technology spectrum to the "low-tech, low-cost" end — is essential for us to develop a differentiated approach to the water challenge. Second, a sharper assessment of the ways in which we can better mobilize resources to bring safe and reliable water and provide sanitation — our capacity to improve our "governance" of water — is equally necessary.

Developing understanding of these two elements — technology and governance — is the basis of the partnership between Sandia National Laboratories and my organization, the Center for Strategic and International Studies, in an effort that we call "Global Water Futures." For the past 18 months my CSIS colleague, Laura Keating, and I have worked closely with colleagues at Sandia, led by Peter Davies, director of Sandia's Geosciences and Environment center, in the development of two major workshops in Washington, D.C., and in the writing of a joint White Paper that will be published this fall. This effort would not have been possible without the substantial expertise of the Sandia team with which we worked. The team's command of the many complex technology issues has complemented analysis from our side on the many governance challenges we face.

Ultimately, the goal of this Sandia-CSIS interaction is to generate fresh ideas and approaches that can be translated into policy and practice. The stakes are tremendously high. The United Nations is projecting that by the year 2025, some three billion people in the world could face life-threatening water shortages.

Erik Peterson is senior vice president and director of the Global Strategy Institute at the Center for Strategic and International Studies, a nonprofit and nonpartisan think tank based in Washington, D.C.

For more information, go to: www.csis.org/gsi

"While governments invest 90 billion dollars each year in global water supply development, seven million still die from water-borne disease. Even more sadly, 2.2 million of these are children. In Africa, fifty percent of the population suffers from some form of water-borne disease. The bottom line here is that billions of lives across the planet will be affected by how well we manage to manage the strategic challenge of water."

Peter Davies, director, Sandia's Geoscience and Environment Center.

Erik Peterson, director, Global Strategy Institute of the Center for Strategic and International Studies.

Sandia National Laboratories

LOCKHEED MARTIN

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

NNSA National Nuclear Security Administration

SAND-2005-5930P

Media Relations & Communications Dept.
MS 0165
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0165

PRSRT STD
U.S. Postage
PAID
Albuquerque, NM
Permit NO. 232