COLLEGE OF AGRICULTURE & LIFE SCIENCES
COOPERATIVE EXTENSION
WATER RESOURCES RESEARCH CENTER

In Bangladesh, village children pump water from a well installed by the Sustainable Arsenic Mitigation project.

Source: KTH Royal Institute of Technology, Stockholm Sweden

ARIZONA WATER RESOURCE

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This inaugural, all-digital version of the Arizona Water Resources newsletter features groundwater, the "invisible" water as characterized by WRRC Director Sharon B. Megdal in her Fall 2016 Public Policy Review column. Various perspectives and components of the large topic of groundwater are represented in an effort bring attention to its significance locally, nationally, and globally. We are pleased to present the work of guest authors as well as our own Graduate Outreach Assistant. Readers are invited to contact the editor with comments on our content and new format.

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Feature

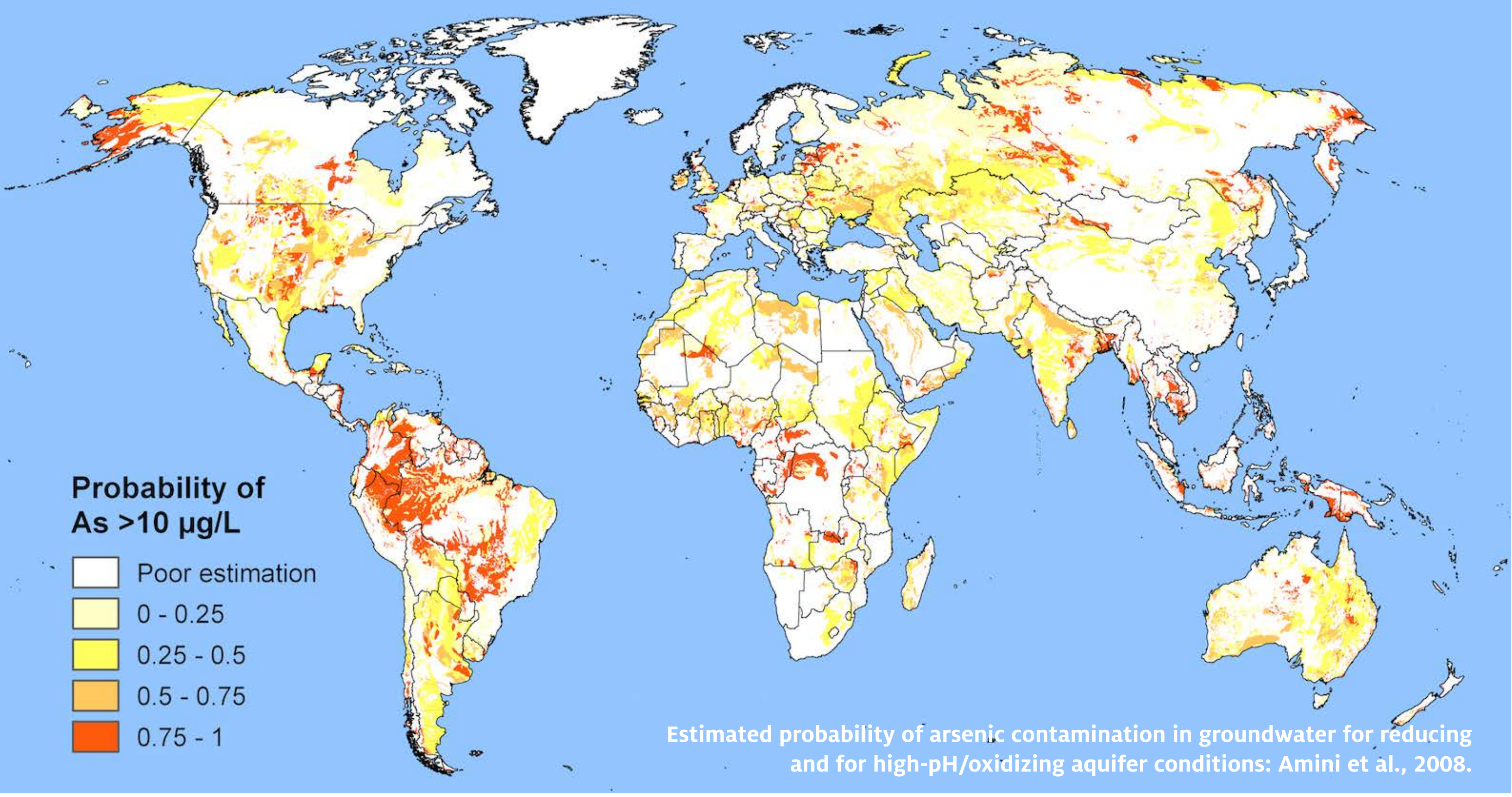
Arsenic in Groundwater Poses Ongoing Challenge

by R. Andres Sanchez, WRRC Graduate Outreach Assistant

Arsenic contamination of groundwater is a problem in many areas of the world, including Arizona. Exposure to arsenic in drinking water has been linked to negative health effects including cancer. Yet in many places, populations have little choice but to continue drinking arsenic contaminated water and in some places the problem is getting worse.

The World Health Organization (WHO) estimates that the water sources of over 200 million people worldwide contain arsenic concentrations that exceed the recommended drinking water limit. This problem is perhaps most severe in the southeastern Asia, but groundwater systems in the Rocky Mountains and the Interior Plains in the western United States also have high arsenic concentrations.

Groundwater contamination can originate from human activities; however, contamination of aquifers with arsenic often occurs naturally. Arsenic is associated with a variety of mineralized granitic and volcanic rocks and sedimentary rocks derived from those mineralized zones. Arsenic contamination of water occurs when geochemical conditions favor its dissolution from the solid aquifer materials. Its



Estimated probability of arsenic contamination in groundwater for reducing and for high-pH/oxidizing aquifer conditions: Amini et al., 2008.

concentration and mobilization through groundwater depend on geological characteristics of the soil, aquifer, and bedrock.

Aquifers in the Southwest United States are highly vulnerable to arsenic contamination due to geologic and climate conditions. Low precipitation rates and high evapotranspiration translate into slow aquifer recharge, and prolonged contact with arsenic-bearing aquifer materials allows dissolved arsenic in groundwater to reach high concentrations. A study conducted by the U.S. Geological Survey (USGS) in the main aquifers in the southwestern United States found that about 19 percent of the drinking water wells sampled exceeded the maximum contaminant level (MCL) for arsenic of 10 µg/L established by the U.S. Environmental Protection Agency (EPA).

In order to develop a regional understanding of groundwater contamination across the Southwest, the National Water-Quality Assessment (NAWQA) Program of the USGS developed a statistical model that provides estimates of arsenic concentrations in areas where measurements are not available. Predicted arsenic concentrations are higher in areas with low recharge rates that are surrounded by volcanic and crystalline bedrock near the upper basin margins and basin low-lands surrounded by carbonate and clastic sedimentary rocks. While the study found that most arsenic contamination occurs in rural areas, the NAWQA model also predicts high levels of arsenic within the metropolitan areas of Albuquerque (NM) Bakersfield, Sacramento and Stockton (CA), Phoenix (AZ), Reno (NV), and Salt Lake City (UT) which could affect future groundwater development as these cities grow.

Even though arsenic in groundwater is primarily derived from natural sources, human related activities can aggravate the problem. In Kolkata, West Bengal, India, groundwater is perhaps the most important source of water for the nearly 15 million people living within the metropolitan area. A study conducted by Kolkata's Indian Association for the Cultivation of Science found that arsenic contamination, once limited to central, southeast, and western regions of the city, is now spreading towards the north-central areas. The study concludes that the rapid urbanization in Kolkata has decreased groundwater replenishment rates, decreasing groundwater levels and increasing arsenic concentration in the groundwater.

These issues are being studied all over the world. Over-pumping of groundwater, particularly in cities built on river deltas, may contribute to increased arsenic concentrations in surface aquifers. According to a new study from scientists at Columbia University's Lamont-Doherty Earth Observatory, MIT, and Hanoi University of Science, large-scale groundwater pumping has reversed the natural flow of water in some areas so that rivers that once were fed by groundwater now recharge aquifers. In areas where surface water and riverbed sediments have a high arsenic concentration, such as the Red River in Vietnam, arsenic seeps into aquifers affecting communities that rely on these groundwater sources. A study conducted at Stanford University shows that the increasing irrigation rates in Cambodia, where groundwater is the preferred water supply, could worsen arsenic contamination and threaten domestic groundwater supplies for about 1.5 million people in Vietnam.

The WHO has reported that about 20 million people in Bangladesh are exposed to arsenic in their water supplies. While naturally occurring arsenic is high in shallow aquifers (less than 200 feet), deep wells (greater than 500 feet) have also shown high levels of arsenic, particularly in areas surrounding Dhaka, the capital of Bangladesh. University of Delaware researchers found that the current groundwater pumping rates in Dhaka have forced shallow groundwater, where arsenic is found, to migrate to deeper areas of the aquifer affecting deep wells outside the city limits.

Here in Arizona, many communities are grappling with arsenic issues. The vulnerability to arsenic exposure is high for the Navajo Nation population living in rural and geographically remote areas with limited water infrastructure. With a long history of mining operations, the lands of the Navajo Nation in the Four Corners area of the southwestern United States contain more than 500 abandoned mines with uranium, arsenic, and other metals. In an effort to help address this issue, the EPA has recently granted the Navajo Nation $3.71 million to fund two water line extension projects that will pipe water to nearly 100 homes in rural areas.

About three quarters of the population on the Hopi Reservation live in areas, such as the community of Sichomovi, which have water resources with twice the EPA limit for arsenic in drinking water. High cancer rates on the Hopi reservation have been reported and preoccupy the Hopi population. Even though they are aware of the presence of arsenic in their water sources, the struggle to fund projects that would guarantee safe drinking water has prolonged their exposure to this toxic metal. The EPA awarded the tribe about $6 million to drill two deep water wells, however, the tribe requires an extra $18 to $20 million to complete the project.

Many small water companies have struggled over the past decade with the high costs of bringing their systems into compliance with the EPA's standard, which were revised in 2006 from 50 µg/L to the current level of 10 µg/L. Removal of arsenic is typically achieved through an initial arsenic oxidation process followed by physical removal techniques such as filtration and coagulation-flocculation processes. The City of Surprise, Arizona (population approximately 120,000) has an arsenic treatment facility that uses a coagulation and filtration process to reduce the natural-occurring arsenic levels in water from its groundwater wells. Chemicals that induce formation of particles with the arsenic are added to water from the wells and a series of filters then removes the particles. The Town of Sahuarita (population approximately 25,000), on the other hand, chose to use a proprietary (Layne) resin-based adsorbtion method that minimized the demands on staff for operations and maintenance.

Researchers have achieved a broad understanding of the occurrence and mobilization of arsenic in groundwater systems. New and more efficient treatment options have been extensively investigated; however, the costs to cover the required physical infrastructure and equipment are often unaffordable. Technological innovations, developed recently or under development, seek to provide countries such as Bangladesh, India, and Vietnam with simple, low-cost arsenic removal. Some of these technologies have also been used by small communities in the United States. For example, at the University of Arizona, a team of scientists has combined a water purification technique called membrane distillation with solar panels to create a low-cost system that can be deployed on the Navajo. They are working with Navajo water users to construct a system that is easily operated and maintained by the community. A new technology, electrochemical arsenic removal, was tested by the developer, SimpleWater, in collaboration with the University of California, Berkeley and Lawrence Berkeley National Laboratory, on small community water systems in the United States as an inexpensive method to remove arsenic and other contaminants.

Research is providing many effective methods, but large-scale adoption lags. There is no known way to cure chronic arsenic poisoning, which makes solving the problem of arsenic in drinking water a critical issue for millions of people worldwide. More effort is needed to carry innovations from laboratory to use.

Feature

Whither Critical Area and Sub-AMA Groundwater Management in Arizona?

by Zachary P. Sugg, PhD, Visiting Assistant Professor, Southwest Studies, Colorado College

It is well-known that Arizona has made significant progress towards reducing groundwater overdraft where groundwater depletion has historically been most severe, the designated Active Management Areas. Nevertheless, achieving and sustaining the safe-yield goal of the three urbanized AMAs (Phoenix, Prescott, and Tucson) seems far from certain. It is also important to remember that safe-yield is assessed at the scale of entire AMAs. This means that as long as overall withdrawals are balanced by "deposits", compliance is achieved. This can potentially mask the unevenness of hydrologic conditions within AMAs. Areas of long-term decline may worsen while conditions in other areas improve. Even if safe-yield is attained by the time the last management period ends in 2025, important problems resulting from groundwater pumping may persist within certain parts of an AMA. In this short article I wish to draw attention to this issue, characterize the problem, and point out some ideas for responding to it.

During the past three years I conducted research comparing groundwater governance in the metro Phoenix region with the San Antonio, Texas metro area. Through this experience I had the opportunity to speak with a number of Arizona's water experts. Based on these conversations and a number of groundwater planning documents I reviewed, I recognized a key issue was the challenge of devising robust planning systems for addressing groundwater-related problems at the scale of critical areas and sub-areas within AMAs.

Various studies have documented water table declines in the Phoenix AMA. Groundwater pumping in both sides of the Salt River Valley has generated areas of subsidence, earth fissures, and aquifer compaction with irreversible losses in storage capacity. In the West Valley, major areas of depletion are located just east of the White Tank Mountains and under the city of Glendale. Areas of problematic cones of depression have also been identified in the East Valley sub-basin. A study conducted under the auspices of the East Valley Water Forum identified areas of significant drawdown. Based on modeling work by the Arizona Department of Water Resources (ADWR), the study projected that full use of recharge facilities may not be sufficient to ameliorate long-term water table declines in the East sub-basin.

Additionally, new issues may be developing. Some municipal water managers in the Phoenix metro area expressed concern about the hydrologic consequences of increased pumping in groundwater-dependent exurban areas on the outer fringes of aquifers in the Phoenix AMA.

Given these well-known problems, the need for more coordinated planning and management at the sub-AMA scale to address critical areas has been repeatedly identified over the last 15 years. In 1999, ADWR stated in the 3rd Management Plan for the Phoenix AMA that it was necessary "to address long-term water issues on a subregional or 'critical area' basis." The Arizona Governor's Water Management Commission also identified this issue in its 2001 final report. Although the Commission considered two different ways of addressing the issue, it was unable to agree on a single recommendation. A lack of action was pointed out by the 2004 report of the Arizona Town Hall and again in a 2008 study by Sharon B. Megdal and others. Following this series of reports, and public comments on draft 4th Management Plans, ADWR stated in its 2013 annual report its intention to recognize local conditions and sub-area issues.

Despite longstanding recognition from various reports, studies, and convened expert groups, there appears to remain a lack of robust formal groundwater planning at the sub-AMA level. How might it be addressed?

Several ideas and efforts are worth consideration. As noted above, the Governor's Water Management Commission considered two proposals. One was the designation of "critical areas" within the AMAs where a specific groundwater issue exists. Under this approach, "'critical areas' would be specifically identified and then programs developed and implemented to provide heightened levels of water management. For example, a potential new program might limit issuance of new withdrawal authorities within the boundaries of certain critical areas." This approach was opposed by some Commission members over concerns about "the adverse impacts on the value of land, potential legal implications, and the stigma that could become attached to areas identified as critical." The Commission also considered a "safety net" approach, which would consist of adding "conditions to current AMA wide programs that seek to prevent or mitigate particular localized problems."

One example of sub-AMA municipal cooperation is the West Valley Central Arizona Project Subcontractors, or WESTCAPS. However, WESTCAPS is primarily oriented towards water augmentation and infrastructure planning for groundwater-reliant West Valley communities. In the East Valley, the East Valley Water Forum (EVWF) was established in 2001 and has broader goals and representation than WESTCAPS, including not only municipal water utilities, but also the Salt River Project, irrigation districts, and Native American tribes. The EVWF has conducted planning exercises for the entire East Valley urban region with groundwater modeling support from ADWR. The organization identified critical areas and proposed ideas on how conditions, such as large cones of depression, may be improved under certain future scenarios of recharge and utilization of renewable supplies.

While some tentative efforts at facilitating sub-AMA and critical area groundwater planning do exist within Arizona, it may also be worthwhile for Arizona to look further afield for ideas. Elsewhere in the Western U.S. there is an emerging shift towards decentralized (i.e., localized or "bottom-up") forms of groundwater governance. Such bottom-up efforts now dot the West. They are sometimes officially state-sanctioned and in other cases are more informal. One example is the formal bottom-up system developed in Texas after decades of relatively minimal groundwater management. In this system, local groundwater districts are grouped into regional groundwater management areas by the Texas Water Development Board (TWDB), based primarily on hydrologic boundaries. State law currently requires joint groundwater planning at a regional scale by managers of local districts with input from the public. The public is able to voice concerns about proposed management goals (or revisions to them) at public meetings. Final management goals are submitted to the TWDB, which then uses hydrologic models to determine physical feasibility at the scale of the groundwater management areas and, in some cases, individual groundwater districts, and how much groundwater is available to allocate to users and still achieve regional goals. Goals are then revisited and revised, if desired, every five years. Although the planning system is still fairly esoteric (even within Texas), it represents a major shift towards more coherent, regional-scale thinking about groundwater management challenges in a state known for a highly hands-off approach. Features of the Texas system include:

- It does not require constant labor from state agency staff. TWDB's role is primarily one of oversight and technical support;
- It provides a formal, iterative goal-setting and revision process conducted by publicly elected representatives;
- It allows for public input on groundwater management goals;
- It creates a decision-making space within which special management goals could potentially be adopted to address critical area problems;

- It is premised on a broad focus on management and planning rather than strictly water augmentation and infrastructure.

This is just one example of a bottom-up groundwater planning system in the West and it is not without its limitations. Other states that have opted for decentralized groundwater governance approaches are Nebraska and, more recently, California, with the passage of the Sustainable Groundwater Management Act of 2014. These approaches may also be instructive.

As Arizona moves beyond safe-yield towards long-term sustainability more broadly, it will be critical to find ways to increase the capacity to address problems that can exist even in safe-yield condition. Arizona must also develop ways of effectively addressing critical area problems not just within AMAs, but statewide, as growth in certain areas continues to increase demands on groundwater where the resource is less strictly regulated. Arizona's water leadership may wish to revisit the work done 15 years ago by the Governor's Water Management Commission. The East Valley Water Forum may also provide an instructive example worth replicating in some form or fashion in other AMAs and perhaps outside of the AMAs. Arizona may also benefit from looking at efforts taken by other Western states in recent years to address similar types of groundwater problems. I have highlighted Texas's recently developed system as one example.

Feature

Making Groundwater Visible

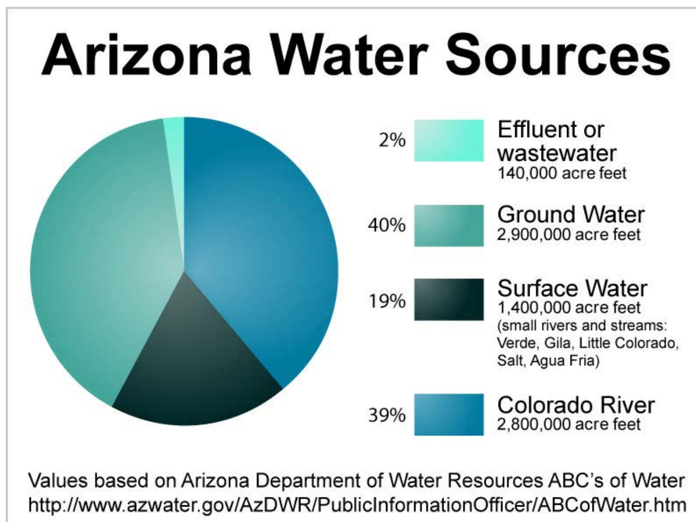
by Kerry Schwartz, Arizona Project WET

According to National *Groundwater Association's Facts about Global Groundwater Usage* (Oct. 2016), groundwater provides almost half of all drinking water worldwide and supports 38 percent of irrigated lands globally. Unseen beneath our feet, it remains not only the least understood part of the water cycle but the least considered. In a state where over 40 percent of the water supply comes from groundwater, Arizona Project WET (APW) set out to make groundwater visible through education.

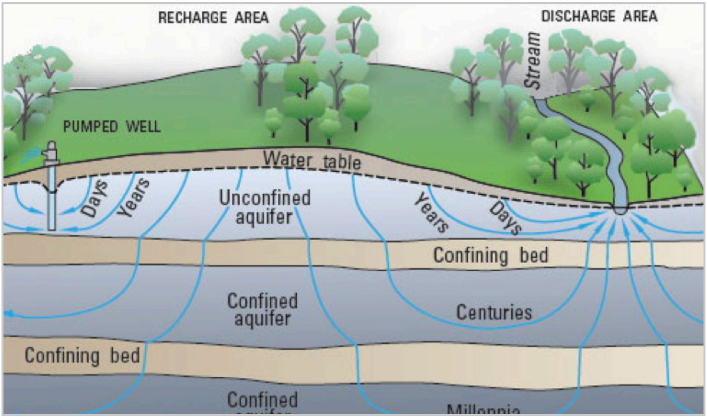
Through pre-lesson questionnaires APW was able to assess prior knowledge. In primary grade students, we saw that they just never had thought or heard about the groundwater system. Using pre- and post-lesson questionnaires with older students, teachers, and adult volunteers, we saw that not only were there huge misconceptions about the groundwater system, but they were difficult to change. Turning our attention to how people learned about the groundwater system, we found three main pathways: 1) they never did learn about the groundwater system, 2) they were taught through analogies or 3) they were taught with textbook diagrams.

An analogy is a comparison between two things, typically on the basis of their structure and for the purpose of explanation. Analogies connect to a person's prior knowledge offering an opportunity to build on that understanding and as such can be a useful tool to introduce learning on a particular topic. But when we use observations about water on the earth's surface to explain something that is underground, analogies can backfire. When we say, "It's like a river or a lake underground," it ties in to what we already know, but solidifies an erroneous picture of what water looks like underground and how it moves. Our analogies are one source of misconceptions about the groundwater system.

Diagrams in textbooks provide a visual image for understanding a system that you can't see, but they often imprint that image in the mind of the learner providing a strong association between image and reality. When the groundwater is depicted in textbooks and most other scientific diagrams as a blue lake underground, people believe that image equals reality. When foundational knowledge is



Primary grade student's concept of the groundwater system. Source: APW



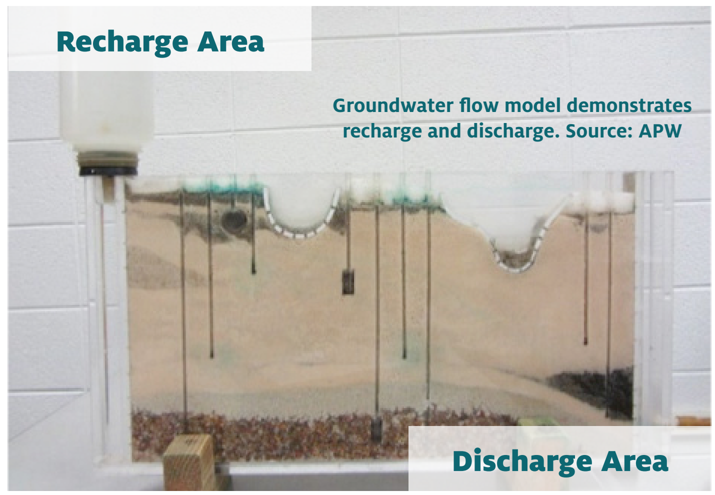
Goundwater diagrams may seem to show underground lakes. Source: U.S. Geological Survey

Students learn about groundwater through experiments with earth materials. Source: APW

incorrect, it's difficult to dislodge or redirect. So even today, textbooks and scientists' depictions are leading learners astray.

As you can see, the team at Arizona Project WET had our work cut out for us. We knew that we had to start with the simplest most basic concepts. By pouring water down through open-ended tubes filled with earth materials, learners can make predications and then observations. They observe not only that water moves through both gravel and sand, but how it moves through: through the spaces, the "pore spaces".

At a somewhat more sophisticated level, groundwater flow models help us to see groundwater as a system. Observations of parts include: gravel and sand, clay and silt, input areas called recharge areas and output areas called discharge areas, and water. Given that set of parts, the first question that we always ask is: *Where is the groundwater?* This is a difficult question because it's hard to observe. Eventually learners have to acknowledge that groundwater is clear, not blue as in the textbooks. And though this seems self-evident, dispelling misconceptions often requires "seeing it with your own eyes." Learners come to understand that the groundwater is between the grains of sand and gravel just the way it was in the earth material tubes experiment. That is a big idea! Groundwater is between the grains of sand and gravel (earth materials) and it is not a big lake underground. In systems thinking parlance this is called making a distinction.



Groundwater flow model demonstrates recharge and discharge. Source: APW

The most productive groundwater units or aquifers are sand and gravel systems like we have here in Southern Arizona in the Basin and Range Province. The question: *Where does groundwater come from?* elicits the answer "rain" sooner or later. And the follow up question, *Where does it rain most often around here?* gets us to the mountains, the source of our mountain front recharge. The bottle on the left side of the model simulates this mountain front recharge and, using dye, we can observe what the groundwater is doing. Learners observe that it is moving and it is moving in a particular direction, proof that groundwater is not a big lake underground and groundwater is moving laterally and from higher areas to lower areas. This is another big idea!

Dye shows how water moves simulating the lateral movement of groundwater. Source: APW

A smaller model, with parts that represent gravel, the land surface, a well and a lake, helps learners explore other aspects of the groundwater system. We use sentence starters to drive thinking, challenging students to make observations that assist them in completing the sentences.

Water below the land surface is called ... groundwater. When I make it rain on the land surface .... the groundwater level goes up and water comes into the lake. When I pump the well ... water comes from the groundwater and is pumped into the container. When I pump groundwater out ... the groundwater level goes down and the water level in the lake goes down. Learners are then asked to tell us the relationship between groundwater and lake water. Then we ask an even deeper thinking question: *What system is the groundwater system a part of?*

Through our work at APW, we know that a third grader can name processes that drive the water cycle: evaporation, condensation, precipitation. But all of that happens in the atmosphere; what are the processes that connect the atmosphere to the land? Some teachers do teach the processes of flow and collection, but very few teachers include infiltration and percolation; processes that connect the surface water and groundwater systems and necessitate the inclusion of groundwater as part of the water cycle.

Lastly, research shows that even when students understand all of the parts of the water cycle, they still tend not to see themselves as within, part of, and dependent upon it. So we ask them: *Why do we care about the groundwater system, this system that we can't even see?* They pump wells in both models demonstrating how water is extracted from the ground. Students come to realize that people need groundwater; that is, at least half the people in the world.

We use simple questions to drive inquiry and exploration. Learners make distinctions, divide concepts into parts, assemble parts into wholes, and connect ideas through relationships. Breaking down the concepts into observable phenomena helps learners to debunk their misconceptions about the groundwater system and build new understanding. They get that groundwater...

- is between the grains of sand and gravel.
- moves because gravity works underground just as it does above ground.
- is connected to surface water.
- is part of the water cycle.
- is an important part of our water supply.

Small model demonstrates groundwater-lake water connection. Source: APW

Exploration and discovery around these five basic concepts shift misconceptions and build a strong foundation for understanding the water resource issues and problems that face us today.

Student Spotlight

Andres Sanchez, Department of Hydrology and Atmospheric Sciences

Andres Sanchez is a second-year Ph.D. student at the University of Arizona in Hydrology and Atmospheric Sciences. He received his Master's degree in Hydrology from the University of Arizona, and his undergraduate degree in environmental engineering from the National Polytechnic School in Quito, Ecuador. Originally from Quito, he started working as a water quality laboratory technician and later became assistant professor at the National Polytechnic School's Department of Civil and Environmental Engineering. His interest in hydrology started when he had the chance to collaborate as a researcher in a project that investigated the impact of climate change on the glaciers of Ecuador. This motivated him to pursue a scientific career focusing on hydrogeochemical processes and water resources management, which ultimately brought him to the University of Arizona, where he is part of the research group at the Santa Catalina – Jemez Mountains Critical Zone Observatory.

At the WRRC he works as a Graduate Outreach Assistant where he assists with writing and production of the Arizona Water Resource newsletter and the Weekly Wave. His experience at the WRRC will inform his future scientific career at the intersection of science and communication.

Andres' current research focuses on understanding the impact of wildfires on hydrological flow paths in snow-dominated catchments. After completing his Ph.D., he would like to work on water-related research projects in the United States and/or internationally, providing reliable scientific evidence in order to guarantee proper management of water resources.

Guest View

How Much Groundwater Is Down There?

by Greg Hess, R.G., Clear Creek Associates

Access to Central Arizona Project (CAP) water, declines in *per capita* consumption, and reuse of treated wastewater have reduced the Tucson area's reliance on groundwater, putting our region in a better water resources position than it has experienced in decades. But even so, physical access to groundwater remains a requirement for much of the residential growth that will occur in southern Arizona in the coming years. So how do we know if there will be enough groundwater to support this growth?

The demonstration of sufficient water resources is the subject of Arizona's Assured and Adequate Water Supply (AAWS) regulations. Under the AAWS program, studies are conducted by hydrogeologists before land is subdivided and lots are sold, to evaluate whether enough groundwater will be available to supply the subdivision's needs for 100 years.

The hydrogeologic studies address the following questions:

- **How much water will the subdivision use?** The Arizona Department of Water Resources (ADWR) provides a simple spreadsheet tool that calculates all the reasonably foreseeable water uses in a proposed subdivision, including indoor water consumption, residential landscape watering, turf and common area irrigation, and other demands on the water supply – even the water that will be used during construction. In addition, existing demands and future demands from other planned subdivisions must be addressed.
- **What do existing data show?** The initial phase of the study involves a review of existing data. This includes an evaluation of whether groundwater supplies are already being depleted. If they are, this must be taken into account.
- **What is the nature of the aquifer?** If the aquifer can't be characterized using data from previous studies, a field investigation will be needed. This will likely include drilling one or more test wells. When a well is drilled, the depth to water and the minimum thickness of the aquifer are defined. The flow characteristics of the aquifer are also evaluated. This provides a preliminary assessment of how much groundwater is likely to be available. After the well is drilled, an aquifer test is conducted by pumping the well continuously at a constant rate for a specified duration. While pumping, the rate at which the water level drops in the pumped well and in nearby observation wells is monitored. The rate of recovery after the well is turned off is also monitored. The test results generate numerical values for two critical aquifer properties: storativity (its ability to store and release water) and transmissivity (the ability of water to flow through it).
- **What happens to the aquifer after 100 years?** The final step is to enter various data, including the transmissivity and storativity values from pumping tests, into computer programs that simulate an aquifer's response to long-term groundwater withdrawals. There are two types of simulations: analytical models and numerical models. An analytical model assumes that the aquifer has a single transmissivity value and a single storativity value, and that the aquifer has the same thickness everywhere. This type of model is appropriate for small projects where the geology is uniform. A numerical model is more complex. It consists of a 3-dimensional grid that looks something like an irregularly shaped Rubik's Cube. Values of transmissivity and storativity are assigned to each individual block throughout the model. A numerical model is necessary for larger projects and more complex environments. Both types of models simulate the effect of pumping groundwater, with the goal of predicting how far the water table will drop after 100 years.
- **Will there be enough water?** This question is answered by comparing the model simulation results to specific criteria. In the Tucson Active Management Area, a subdivision will not receive a Certificate of Assured Water Supply if the model predicts that, within 100 years, the depth to groundwater will drop to more than 1,000 feet below land surface or to the bottom of the aquifer (whichever is shallower). A subdivision in an AMA must have an Assured Water Supply demonstration for a plat to be approved. If a 100-year supply is not demonstrated, the size of the subdivision must be reduced or certain water uses (turf irrigation for example) must be eliminated. Outside an AMA the maximum depth is 1,200 feet. If the water table will drop below 1,200 feet, a subdivision can still be approved, but the buyers of lots must be informed that a 100-year Adequate Water Supply was not demonstrated.

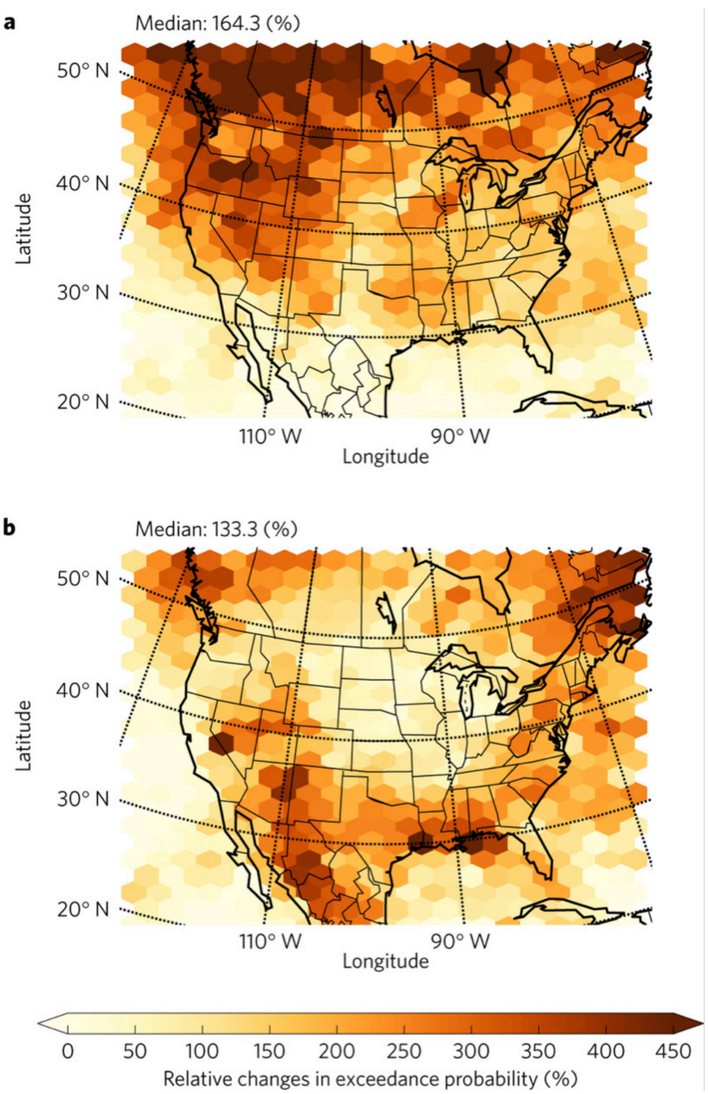
Arizona's AAWS program has helped direct growth toward areas where water supplies are more reliable, and it has provided investors with confidence in our state's long-term economic viability. Without the AAWS program, the answer to the question "How much groundwater is down there?" would in many cases be "We don't know." This is not an answer we want to give to anyone considering relocating to southern Arizona.

News Briefs

Research Projects Major Increases in Storm Frequency and Intensity

A study by researchers from the National Center for Atmospheric Research, published in the journal *Nature Climate Change* on December 5, shows more frequent intense rainfall events occurring across North America by 2100 if greenhouse gas emissions are not curbed. They project as much as a five-fold increase in storms producing potentially up to 70 percent more precipitation per storm in some places. Even here in the Southwest, where drier conditions are expected because of rising temperatures, an increase in the frequency and intensity of storms is foreseen.

The maps below display the simulated increases in the number of extreme storms by 2100 as compared to the control period, 2001-2013. During December, January, and February (a), the frequency of extremes increased substantially across Canada and the Western US. During June, July and August (b), extremes are shown to intensify in parts of the US Southwest and Mexico, as well as the Gulf Coast and Canadian Northeast.



Map Source: Andreas Prein, NCAR

The *Nature Climate Change* article, "The future intensification of hourly precipitation extremes," can be found at http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate3168.html.

Experimental Release from Lake Powell Creates 5-day Flood

The Bureau of Reclamation conducted a high flow experiment (HFE) in partnership with National Park Service, U.S. Fish and Wild Service, and the U.S. Geological Survey with the goal of mobilizing and re-distributing sediments in the Colorado River through the Grand Canyon. This is the fourth HFE carried out since 2011. These controlled flood experiments are designed to benefit the Colorado River ecosystem, rebuilding sandbars that support habitat for wildlife and beaches used for recreational purposes. For the experiment to start, optimal sediment load at the Glen Canyon Dam must be reached, which occurs when a Colorado tributary, the Paria River, discharges large amounts of sediment. The HFE in 2016 started on November 7th, when operators opened the bypass tubes at Glen Canyon Dam and began releasing water. The HFE continued with four consecutive days of releases at maximum capacity (36,000 cfs) and ended at 3:00 am on November 12. These experiments do not affect the total annual amount of water delivered from Glen Canyon Dam to Lake Mead. Water releases after the experiment are adjusted in order to compensate the high volume of water released during HFE.

EPA's CCL4 Released

The Contaminant Candidate List (CCL) is a list of contaminants that are currently not regulated, but there is evidence that they occur in water supply sources and they are suspected of having an adverse effect on human health. The Safe Drinking Water Act requires the Environmental Protection Agency (EPA) to release an updated CCL every five years. To date EPA has published four CCLs since 1998. On November 17, 2016, EPA released the Final CCL 4, which includes 97 chemical or chemical groups and 12 microbial pathogens. Most of the chemicals included in the CCL 4 come from industry and agriculture, as well as cleaning products and pharmaceuticals. After releasing this list, EPA must determine within five years whether or not to regulate at least five of the listed contaminants. To that end, the EPA will collect additional information and conduct research on specific contaminants that present the greatest public health concern. The CCL 4 can be found at https://www.epa.gov/ccl/contaminant-candidate-list-4-ccl-4-0.

New GWAC Committee Looks at Potable Reuse

The Governor's Water Augmentation Council (GWAC) has formed a reclaimed water committee to help in the process currently underway to revise the water reuse rules. At its October 28 meeting, the GWAC formed a reclaimed water committee that will examine options for statewide standards. John Kmiec, Utilities Director for Marana Water, will chair the committee. Human consumption of reclaimed water is prohibited by rule in Arizona. Part of the new committee's purpose is consideration of amending state rules to allow for potable re-use. According to Chuck Graf of the Arizona Department of Environmental Quality, Arizona water-treatment facilities produce some of the best-quality reclaimed water in the country, using highly refined and multi-level processes. Regulating potable reuse rather than prohibiting it will receive an added level of scrutiny through the newly formed committee.

Santa Cruz River Could Flow Again

While Tucson is preparing the public for eventual potable reuse of water from the regional wastewater treatment plants, they are making other plans for use of the water. The hope to see the Santa Cruz River flow again after more than 60 years could become a reality. Tucson Water announced the "Agua Dulce" plan (Spanish for sweet water) that would restore the flow in the Santa Cruz River through downtown Tucson using treated wastewater. Existing reclaimed water infrastructure would be used to transport the treated effluent into the Santa Cruz River. Tucson expects to accrue multiple benefits from the plan, which calls for the construction of a river channel feature through the Rio Nuevo development area. Such a project could bring tourism and economic development to the Tucson area by elevating the natural and historical importance of the Santa Cruz in Southern Arizona. In addition, the City would accrue credits from recharge of treated wastewater through the river bed. The City Council can formally consider the proposal once it has gained the support of neighborhood and business leaders, as well as Pima County.

EPA Study Estimates Value of Stormwater Recharge

Green infrastructure (GI) and low-impact development (LID) for urban areas generate multiple benefits including groundwater recharge. The US Environmental Protection Agency (EPA) commissioned a study to estimate the recharge benefits of implementing these practices across the United States for the 20-year period 2021 through 2040. Using a simplified methodology for estimating recharge volume and observed prices of water, the study produced groundwater recharge volume and value estimates for scenarios in which these practices are implemented where stormwater retention is not currently required. The stormwater retention practices were assumed to reduce runoff volumes to pre-development levels, the goal of GI and LID. Because broad assumptions and simplified methods were used, the results reflect the potential range of value for groundwater recharge. Estimates of cumulative volumes of recharge ranged from 6.8 million to 10.8 million acre-feet and cumulative, present monetary values ranged from $0.2 to $4.5 billion.

Although groundwater recharge is just one benefit among many, the study did not directly address the full range of potential benefits of these stormwater retention practices, and in fact covers only a subset of the recharge benefits. An appendix qualitatively discusses the total economic value of groundwater recharge, including potential direct and indirect benefits. The study can be accessed at https://www.epa.gov/green-infrastructure/estimating-monetized-benefits-groundwater-recharge-stormwater-retention.

Resources

Water Marketing Activities within the Bureau of Reclamation

U.S. Department of the Interior Bureau of Reclamation, December 2016

The U.S. Bureau of Reclamation report "Water Marketing Activities within the Bureau of Reclamation," presents examples of different water transfers and other water transactions involving Reclamation and draws general observations from these examples about transactions, focusing on Reclamation's role. Finally, it provides a set of recommendations showing Reclamation's intent to support future water market development. The report is of interest as a source of background information on water transactions of various sizes and through various institutional arrangements throughout the West. Recognizing the benefits of water transactions, it captures the plethora of locally-led innovations to increase flexibility in the use of water resources and/or facilities so as to achieve a broad range of water resource goals. Observations highlight needs to lower transactions costs, track transactions involving Reclamation, and use existing mechanisms to facilitate establishment of water markets. Recommendations focus on opportunities to address and remedy barriers to water transfers through internal evaluation and adjustments.

Final EPA/USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration

U.S. Environmental Protection Agency and U.S. Geological Survey, December 2016

This report, "Protecting Aquatic Life from Effects of Hydrologic Alteration," released by the U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS) in December 2016, discusses how hydrologic alteration can contribute to impairment of the water bodies upon which aquatic life depends. This Final EPA-USGS Technical Report presents a review of the literature on natural flow systems and a description of the potential effects of flow alteration on aquatic life. Natural flow regimes have multiple components including flow magnitude, timing, duration, frequency, and rate of change that occur in characteristic patterns. Altering the pattern can degrade the chemical, physical, and biological integrity of streams and rivers. Protecting aquatic life involves keeping the flow regime within its typical range of variation. The report goes on to provides examples of narrative criteria that some states have developed for supporting natural flow and healthy aquatic biota. In a final section, it offers a voluntary framework for states, tribes, and territories to use in quantifying the flow regime components that would protect aquatic life. The eight steps proposed in the framework begin with identifying goals and proceed through information collection and model development. Without prescribing any particular analytical approach, the steps emphasize the information and processes that are useful in evaluating relations between flow and aquatic life and developing numeric and narrative flow targets. The report also notes the amplifying effects of climate trends on altered stream flow and consequently aquatic life.

To access the report go to www.epa.gov/sites/production/files/2016-12/documents/final-aquatic-life-hydrologic-alteration-report.pdf

A Fact Sheet on the report can be found at www.epa.gov/sites/production/files/2016-12/documents/final-aquatic-life-hydrologic-alteration-factsheet.pdf

Global Surface Water Explorer

European Commission, Joint Research Centre, Directorate for Sustainable Resources, 2016

The Global Surface Water Explorer provides map visualizations showing change in rivers, lakes, and other surface water over the past 32 years and also provides access to the data used to produce the visualizations. Researchers from European Commission, Joint Research Centre, Directorate for Sustainable Resources led an international team to develop the Explorer. An article in the journal *Nature* describes the two-year project that produced the tool and assessed changes in surface water at a global scale. The data set used 1,823 terabytes of processed data from the Landsat 5, 7 and 8 acquired between 16 March 1984 and 10 October 2015, the entire archive, provided by the USGS and NASA. Each pixel of Landsat data was classified as open water, land, or a non-valid observation, by an expert system run in Google Earth Engine. The expert system employed techniques for big data exploration and information extraction. Google's Earth Engine, a computational infrastructure optimized for parallel processing of geospatial data, used 10,000 computers to complete the processing, which on one computer would have taken more than 1,000 years, in around 45 days.

On the Explorer web site, maps show water occurrence, change intensity, seasonality, annual recurrence, and transition from first to last year. These measures can be viewed in a choice of formats including time-lapse imagery.

The Global Surface Water Explorer can be found at https://global-surface-water.appspot.com/.

The Nature article is accessible at http://www.nature.com/nature/journal/v540/n7633/full/nature20584.html.

Looking Forward: Priorities for Managing Freshwater Resources in a Changing Climate

Water Resources and Climate Change Workgroup, November 2016

The November 2016 report, titled "Looking Forward: Priorities for Managing Freshwater Resources in a Changing Climate," updates the "National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate," which was published in 2011 and documented the work of the federal interagency Water Resources and Climate Change Workgroup. Rather than inventory the activities being undertaken throughout the federal government, this report addresses the highest priority actions planned by Workgroup member agencies for the next few years. Three thematic areas are covered: data and research, planning and decision support, and training and outreach. The Workgroup recognized the need for observational networks and the data they provide for understanding emerging climate change trends and applying that understanding to water resource management. Additionally, research is needed to increase water use efficiencies in all water using sectors. Collaboration and coordination among providers and users of decision support guidance is required to develop and apply new information and tools to decisions. To this end, federal agencies will be focusing on promoting and expanding existing mechanisms for outreach and training, including the Water Resources Research Institutes.

Sorek Desalination Plant, November 20, 2016

Bridging Through Water

by Sharon B. Megdal

Since my first professional visit to Israel in 2006, I have endeavored to connect that region and ours through sharing water management challenges and solutions. In late Fall I had the honor of traveling to Israel, the West Bank, and Jordan with the two International Boundary and Water Commission (IBWC) Commissioners, Edward Drusina (U.S.) and Roberto Salmón (Mexico). The IBWC addresses binational Colorado River and Rio Grande-Rio Bravo management, operates binational wastewater treatment plants, and is involved in environmental restoration, water desalination, and reuse efforts. IBWC has coordinated the Transboundary Aquifer Assessment Program, with which I've been involved since its inception. In September 2015, the Commissioners expressed to me their interest in visiting the Middle East to engage in dialogue through sharing experiences and knowledge. When in Israel the very next month to speak at WATEC, the biennial international water expo, I met with Gidon Bromberg, Israel Director for EcoPeace Middle East, a Jordanian, Palestinian, and Israeli environmental organization. At our meeting, we identified the anchor for the Commissioners' visit – their participation as speakers in EcoPeace's November 2016 conference on transborder governance and management of the Lower Jordan River.

With expert staff from the U.S. Embassy in Tel Aviv, Consulate in Jerusalem, and Embassy in Amman, we planned an intensive program of high-level meetings and site visits in Israel, the West Bank, and Jordan, respectively. Preceding these official meetings, we spent November 19 touring the Lower Jordan River with Mira Edelstein of EcoPeace staff. This day provided important background for the conference.

November 20, our day in Israel, included visiting the Yad Hanna Wastewater Treatment Plant, which is located just on the Israel side of the Green Line and wall separating the West Bank and Israel. Treating the wastewater from the West Bank communities of Nablus and Tulkarem and Israel's Emek Hefer region to avoid contamination of the Alexander creek and the surrounding aquifer currently lacks a comprehensive bilateral approach. We then visited Israel's (and the world's) largest reverse osmosis desalination plant, the Sorek plant. The plant's 16 inch vertical membrane design allowed for a much reduced plant footprint in a region where land scarcity is also a challenge. Desalinated water for municipal and industrial purposes, along with large-scale reuse of water for agriculture and continued conservation in all sectors, has enabled Israel to fulfill its master plan for addressing the water demands of the nation. We then met with Senior Deputy Director General Oded Fixler at the Israel Water Authority, the body responsible for water allocations and pricing, who introduced the first phase of the Red-Dead project, discussed below. Finally, we met officials with the national carrier Mekorot, who provided additional information on how Israel manages its national water and wastewater systems.

Our focus on November 21 was West Bank briefings and included meeting U.S. Consul General for Jerusalem Don Blome and Palestinian Water Authority Minister Mazen Ghonaim. Minister Ghonaim explained how water is a political issue. He noted that the Joint Water Committee between Israel and the Palestinian Authority has not officially met for six years, which impedes project approval. He suggested that our region could be of some assistance through special training of technical teams from their region. Our afternoon concluded with a visit to Halhul Reservoir, a large reservoir serving the Hebron area of the West Bank. USAID invested significantly in this project, designed to improve the reliability of the region's water supply.

On November 22, we crossed into Jordan to meet in Amman with His Royal Highness (HRH) Prince El Hassan bin Talal, U.S. Ambassador to Jordan Alice Wells, Minister of Water and Irrigation Hazim El-Naser and other top Ministry officials, and Minister of Planning Imad Fakhoury. HRH explained the multiple resource challenges Jordan faces and the importance of considering the human and physical environments holistically. HRH spoke to the importance of governance and partnerships and distributed to each of us the report "Cost of Non-Cooperation of Water: Crisis of Survival in the Middle East". We later visited the Samra Wastewater Treatment Plant, a huge plant south of Amman that processes 70 percent of the wastewater treated in Jordan. The outflows of this modern plant are mixed with surface waters before being delivered to farmers. This plant is the first Build-Operate-Transfer project in Jordan, with USAID among the list of sponsoring partners.

Later on November 22, we arrived at EcoPeace's conference, "Water Security and Sustainable Development for our Common Future", which drew over 300 participants. The next morning I had the honor of moderating the panel that featured the Commissioners and representatives of basin organizations from the Balkan Sava River Basin, Southern Africa, and the Rhine. Their presentations focused on the reasons for formation of the transboundary commissions and their accomplishments. It was interesting that disasters and/or major political events were a catalyzing force for collaboration. For the U.S. and Mexico, it was the April 4, 2010 earthquake. For the Rhine River basin, it was a pharmaceutical industry fire. The Sava River Basin became international upon the dissolution of the former Socialist Federal Republic of Yugoslavia. Following the panel, we participated in a discussion with representatives from the Jordan Valley.

Throughout the many dialogues, Commissioners Drusina and Salmón explained how IBWC conducted business and emphasized the importance of good and regular communication. Similarities between the two regions were discussed, including the differential in per capita incomes of the populations sharing borders and waters. I believe those with whom we met were impressed by IBWC's functionality and accomplishments. Truly significant agreements have emerged from the 1944 Treaty governing the Colorado and Rio Grande-Rio Bravo Rivers. I see opportunities for further interactions, including possible trainings. Our region can learn from how the Middle East has deployed large water projects involving state-of-the art technology and public-private partnerships.

It is encouraging that Israel and Jordan are collaborating on a desalination and water exchange project, something that has been discussed conceptually in the Lower Colorado River Basin. This project entails: (1) desalinating Red Sea water at a plant located in Jordan, with some water sold to Israel for use in the Arava Valley; (2) delivering brine mixed with Red Sea water to the Dead Sea to offset some of the Dead Sea's water losses, with possible hydroelectric power production that utilizes the elevation differences; and (3) selling freshwater

November 22, 2016 high-level meeting in Amman, Jordan. From left to right, H.E. Minister of Water and Irrigation Dr. Hazim El-Nasser, His Royal Highness Prince El Hassan bin Talal, U.S. Ambassador to Jordan Alice Wells, Commissioner Edward Drusina and Commissioner Roberto Salmón.

Sharon Megdal, Comissioner Drusina, Jerusalem Consul General Donald Blome, and Commissioner Roberto Salmón. November 21, 2016.

November 19, 2016 stop at the southern tip of the Sea of Galilee.

from Israel's Sea of Galilee to Jordan. An additional component of the project is the sale of water from Israel to the Palestinian Authority for the West Bank. The Red-Dead project is an example of how water management can be a bridge rather than a source of conflict.

Both regions face significant water challenges going forward. I am hopeful that continued dialogue and cooperation within and across the regions can lead to even more bridging through water.

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WRRC Director: Dr. Sharon B. Megdal

Arizona Water Resource
Water Resources Research Center
College of Agriculture and Life Sciences
The University of Arizona
350 North Campbell Avenue
Tucson, Arizona 85719 USA

Phone: 520.621.9591
FAX: 520.792.8518
Email: wrrc@email.arizona.edu

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