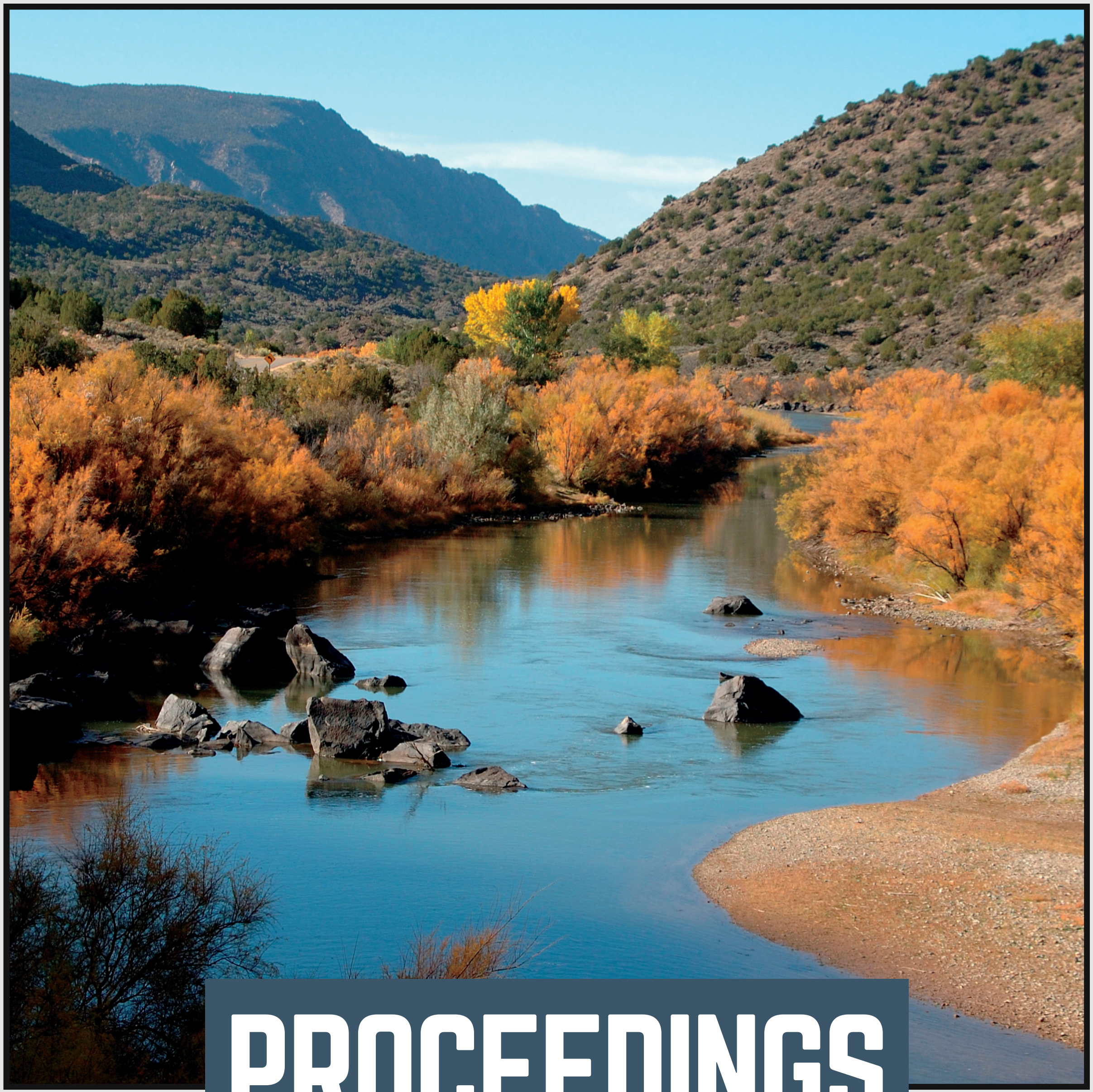
# HIDDEN REALITIES
## of New Water Opportunities

AUGUST 15-16, 2017

NEW MEXICO TECH, SOCORRO, NM



# PROCEEDINGS

62ND ANNUAL NEW MEXICO WATER CONFERENCE

NM WRRI Report No. 403

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62nd Annual
New Mexico Water Conference

NM WRRI Report No. 403

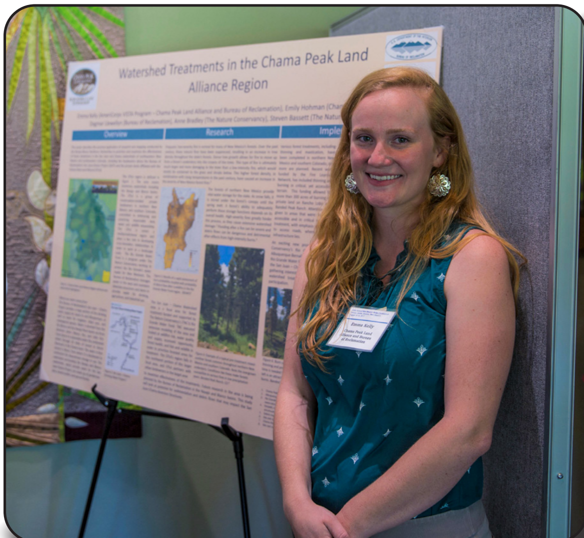
# Hidden Realities of New Water Opportunities

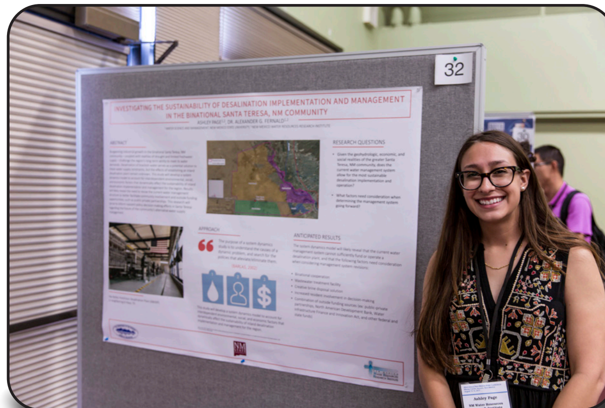
August 15-16, 2017
Macey Center, New Mexico Institute of Mining and Technology
Socorro, NM

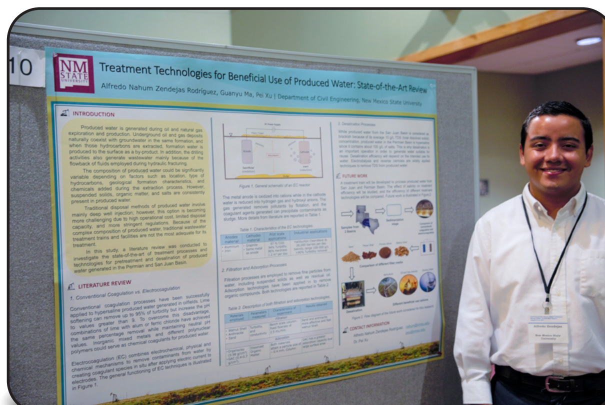
NEW MEXICO
WATER RESOURCES
RESEARCH INSTITUTE

# $62^{nd}$ Annual New Mexico Water Conference Field Trip

# 62nd Annual New Mexico Water Conference Poster Session

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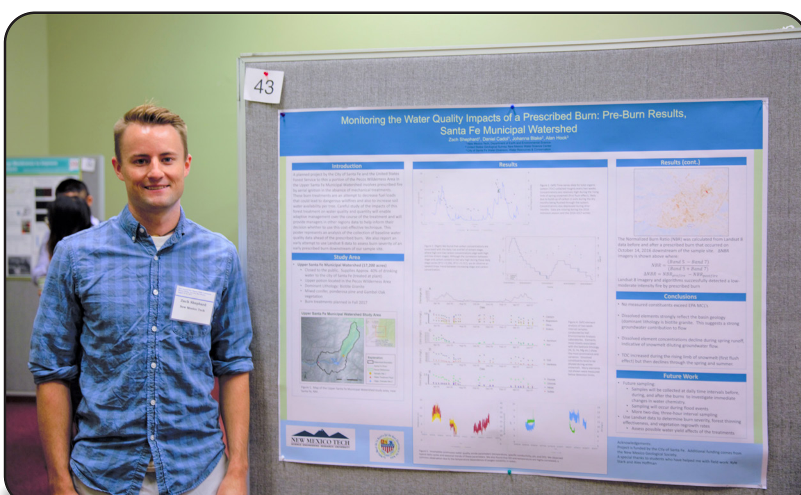


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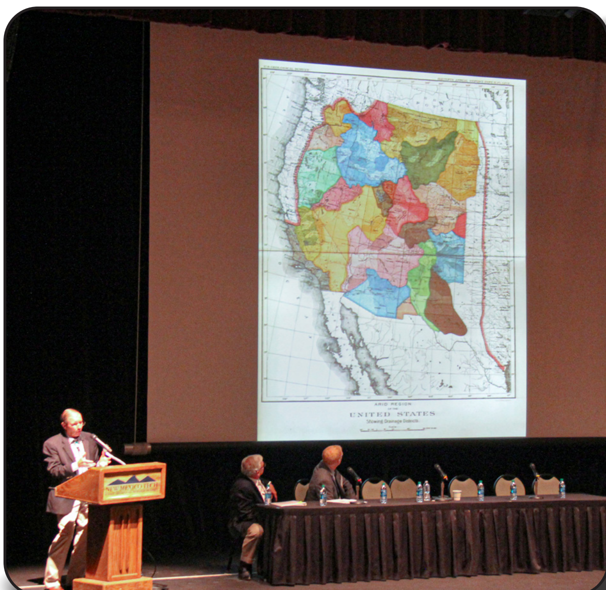
UNITED STATES


Project Complete!

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# PROGRAM

## *Hidden Realities of New Water Opportunities*

Macey Center, NM Tech
Socorro, NM
August 15-16, 2017

## Tuesday, August 15

**Morning Session**

| | |
|---|---|
| 8:15 am | Welcome<br>New Mexico Water Resources Research Institute, Director Sam Fernald |
| 8:30 | *The Landscape of Water - Past, Present and Future*<br>New Mexico Tech President, Stephen G. Wells |
| 9:15 | *Update on Efforts Associated with 2012 Conference Report, 57th Annual New Mexico Water Conference*<br>U.S. Senator, Tom Udall |
| 9:45 | **Break** |
| 10:00 | *Cross Cutting Panel of Water Interests in New Mexico: Addressing Hidden Realities of New Water Opportunities*<br>Panel moderated by Senator Tom Udall<br>Myron Armijo, NM Office of the State Engineer<br>Beth Bardwell, Audubon New Mexico<br>Terry Brunner, Grow New Mexico<br>John Fleck, University of New Mexico Water Resources Program<br>Paula Garcia, New Mexico Acequia Association<br>Tanya Trujillo, Colorado River Sustainability Campaign |
| 11:00 | *New Mexico Water Update*<br>Tom Blaine, New Mexico State Engineer |
| 11:20 | *Interview with U.S. Senator Tom Udall and Brad Udall, Colorado Water Institute, Colorado State University*<br>Moderated by Sam Fernald, NM Water Resources Research Institute |
| 12:00 – 1:30 | **Lunch at Fidel Center**<br>*Meeting the Challenges of the World's Growing Dependence on Groundwater*<br>William M. Alley, retired, USGS Office of Groundwater Chief, now with National Ground Water Association |

## Afternoon Session

1:45 pm *Management Aspects of Farmland Retirement*
Panel moderated by J. Phillip King, Elephant Butte Irrigation District/NMSU
Dale Ballard, Carlsbad Irrigation District
Aron Balok, Pecos Valley Artesian Conservancy District
Paula Garcia, New Mexico Acequia Association
Steve Guldan, New Mexico State University, Alcalde
Mike Hamman, Middle Rio Grande Conservancy District
Jan Hendrickx, New Mexico Tech

2:45 **Break**

3:00 *Hidden Opportunities – Innovations in watershed management to harvest water and improve watershed resiliency*
Panel moderated by Chris Canavan, New Mexico Environment Department
Patrick Lopez, Elephant Butte Irrigation District
Rich Winkler, Malpai Borderlands Group
Connie Maxwell, Alamosa Land Institute/NM Water Resources Research Institute
Candice Rupprecht, City of Tucson Water Conservation Program

4:00 *Panel of Former Rio Grande Compact Commissioners and Administrators*
Panel moderated by Steve Harris, Rio Grande Restoration
Scott Verhines, former New Mexico State Engineer
Norm Gaume, former New Mexico Interstate Stream Commission Director
Dick Wolfe, former Colorado State Engineer

5:00 pm **Adjourn**

# Wednesday, August 16

## Morning Session

8:30 am *Underground Storage and Recovery Project Implementation in New Mexico*
Panel moderated by Amy Ewing, Daniel B. Stephens & Associates, Inc.
Jim Chiasson, City of Rio Rancho
Michelle Hunter, New Mexico Environment Department
Jerri Pohl, NM Office of the State Engineer
Rick Shean, Albuquerque Bernalillo County Water Utility Authority
Tim Woomer, City of Hobbs

9:30 *Hydrogeology of the San Agustin Plains*
Alex Rinehart, NM Bureau of Geology & Mineral Resources

10:00 **Poster Session/Break**
Poster Session co-sponsored by Sandia National Laboratories

11:30 *Brackish Water and Desalination Efforts in New Mexico*
Panel moderated by Aron Balok, Pecos Valley Artesian Conservancy District
Jeri Sullivan Graham, University of New Mexico
KC Carroll, New Mexico State University
Stacy Timmons, NM Bureau of Geology & Mineral Resources
Katie Guerra, U.S. Bureau of Reclamation, Lakewood, CO

12:30 **Lunch at Fidel Center**
*Statewide Water Assessment Update*
Panel moderated by Sam Fernald, NM Water Resources Research Institute
Ken Peterson, Tetra Tech, Inc.
Anne Tillery, U.S. Geological Survey
Alex Rinehart, NM Bureau of Geology & Mineral Resources
Jan Hendrickx, New Mexico Tech
Talon Newton, NM Bureau of Geology & Mineral Resources
Francisco Ochoa, NM Water Resources Research Institute
Austin Hanson, NM Water Resources Research Institute
Lucia F. Sanchez, NM Interstate Stream Commission

2:00 pm **Adjourn**

# The Landscape of Water - Past, Present and Future

Stephen G. Wells, New Mexico Tech President

*Stephen G. Wells serves as the 17th president of New Mexico Institute of Mining and Technology (New Mexico Tech or NMT), a public academic and research university granting undergraduate and graduate degrees in science, engineering, technology, and mathematics, and he reports to the NMT Board of Regents. As president and chief executive officer, Dr. Wells oversees a university with 2,150 students (undergraduates and graduates) and 135 faculty and staff, providing leadership in the execution of the university's strategic plan and maintaining the budget as allocated by the state legislature along with grants received from various entities.*

*Dr. Wells served as president of the Desert Research Institute (DRI) of the Nevada System of Higher Education from 1999 to 2016, overseeing one of the world's largest multidisciplinary environmental research organizations with approximately 500 scientists, technologists, students, and other support staff. He built DRI from a $23.8 million per year operation in 1998, the year before he became president, to a greater than $50 million per year operation currently. Prior to joining DRI in July 1995, Dr. Wells was professor of geomorphology and chair of the graduate program in the Department of Earth Sciences at the University of California, Riverside. Dr. Wells began his academic career at the University of New Mexico in 1976 and ultimately served as chair of the Department of Geology from 1989 to 1991. He has held visiting appointments with the US Air Force Office of Research, US Geological Survey, Los Alamos National Laboratory, and the University of Liverpool as well as established consulting relationships with numerous federal agencies and private companies including the US Department of Justice, Sandia National Laboratories, and environmental and geotechnical firms in the western United States.*

*Dr. Wells has published approximately 60 peer-reviewed papers and book chapters and edited six volumes. These works focus on the geomorphology and Quaternary geology of arid and semiarid regions, geomorphic and hydrologic responses to Quaternary climate change, and tectonic and volcanic activity. He has a BS in geology from Indiana University as well as an MS and PhD in geology from the University of Cincinnati.*

I want to welcome all the participants to New Mexico Tech. What an honor and pleasure it is to have all of you on our campus, especially given that this is first time the Water Resources Research Institute (NM WRRI) has held a meeting at Tech.

As a geologist and geomorphologist, my research involves understanding the earth's surface and its associated processes over geologic time. I have applied this approach to understand how variations in hydrologic systems and their associated climatic regimes are recorded in the geologic record, specifically in the resulting landscape. It is an honor to be invited to speak on my research today. In addition to discussing examples of the types of landscapes resulting from surface and groundwater systems and the interpretations that can be made, my presentation will also include a brief review of humanity's role with regard to Earth's hydrologic system and what the future holds for water resources and related technologies. I will discuss the role that key institutional collaborations, such the Bureau of Geology and Mineral Resources at New Mexico Tech and the Water Resources Research Institute, can play in understanding and defining water resources and water technologies.

Research projects conducted by my former students, colleagues, and me in the Mojave Desert of Southern California have elucidated how variations in the hydrologic cycle are driven by weather and climatic patterns related to sea surface pressure anomalies in the Pacific Ocean and related atmospheric circulation patterns. Variations over the past 8,000 years in these patterns have produced ephemeral lakes at the terminus of the Mojave River that lasted from months to perhaps a century (Figure 1). Such ephemeral lakes and significantly larger and longer-standing late Pleistocene lakes (18,000 to 10,000 years ago) are recorded in a series of abandoned shorelines and basin deposits (Figure 1).

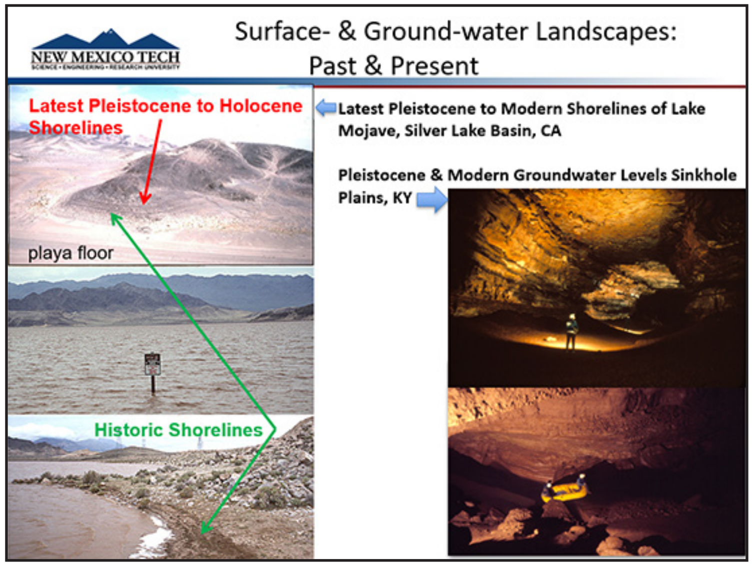



Figure 1. Landscapes resulting from variations in hydrologic-cycle from modern times through the geologic past.

Figure 1 also illustrates the type of groundwater landscapes that I researched during my master's degree in the Central Kentucky Karst region; these landscapes allow one to walk through modern, active aquifers (cave systems) and those ancient (inactive) cave systems that existed hundreds of thousand years ago. Research in these landscapes demonstrates the variations in groundwater levels over geologic time, and consequently, types of large-scale changes in flow direction and groundwater-basin boundaries that can occur during such changes. Both examples, surface and groundwater, illustrate (1) how variations in hydrologic systems can be recorded in different types of landscapes over different time scales, and (2) how geologists can use such landscapes to infer the nature of global scale changes in climate that drive such changes.

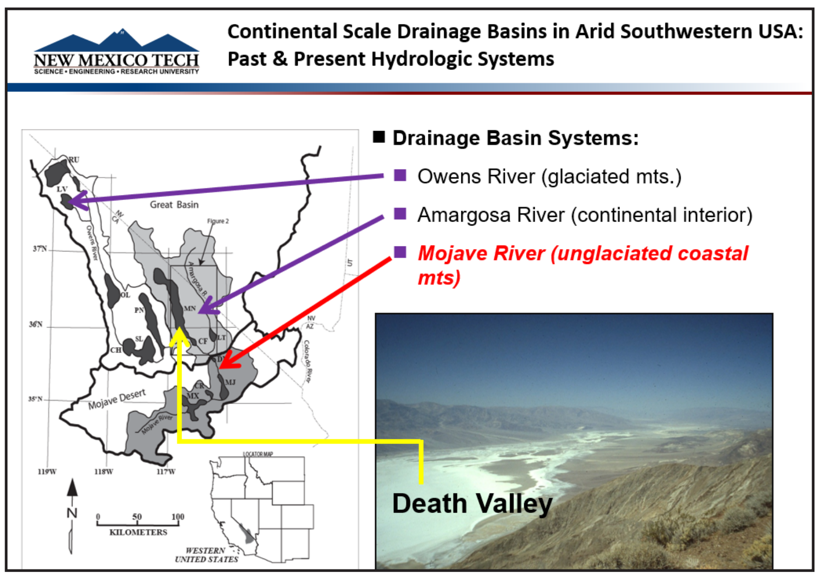



Figure 2. Continental scale drainage basins in the arid southwestern U.S. that were hydrologically connected during the Pleistocene. Past and present hydrologic systems.

Examining the hydrologic cycle over time using the geologic record allows one to assess large-scale changes in the sources, flow, and storage of water. In the western U.S., a large set of watersheds existed at one time during the Pleistocene that were hydrologically connected (Figure 2) and that produced significant runoff from the Sierra Nevada and other regions to large-scale lakes in a series of basins that ultimately ended (and continue to this day to end) in a terminal basin or sink of each closed watershed. The volume of runoff generated from the watershed source areas (typically mountains or uplands) resulted in overflows that ultimately drained into Death Valley. Each one of those watersheds, however, differ in terms of the source area, hydrogeological setting, and nature of the water produced in each area (Figure 2). The Sierra Nevada range runoff was derived from melting glaciers. The Mojave River was sourced in a mountain range that was not glaciated during the Pleistocene, and whose water was primarily derived from snowmelt and moisture flow from the Pacific Ocean. The Amargosa Basin, on the other hand, is a very interesting watershed as its major source of water was derived from a drier continental interior with very low mountain ranges and most likely major groundwater discharge points.

One of our studies, which was initially supported by the NM WRRI in the 1980s, focused on the Mojave River, which was unglaciated, very close to the coast, and therefore very sensitive to atmospheric-oceanic interactions. During the latest Pleistocene we know that it overflowed off and on, providing runoff to Death Valley as well (Figure 2). However, the ancient lake ceased to overflow to

Death Valley approximately 11,000 years ago, resulting in Silver and Soda Lake basins becoming the termini of the Mojave River (Figure 3).

The Mojave River basin provided the opportunity to examine both modern and ancient lakes through a series of shorelines that have been preserved over the past 18,000+ years (Figs. 1 and 3). In addition, the terminal basins of the Mojave River are flooded in the present day, producing ephemeral lakes in response to dramatic runoff sourced in the San Bernardino Mountains. Silver and Soda Lake basins are located in one of the most arid regions in North America, only receiving four inches of average precipitation. Such a study environment allows one to ask questions such as, what does it take to produce a large lake that will overflow to Death Valley, under what conditions are lakes being formed today, and what can we learn from the modern lakes that might help us understand the lakes that existed thousands of years ago?

In addition to the surface features such as shorelines, the deposits laid down in these terminal basins provide critical insights into the variations and timing of lake formation. Drilled cores were extracted and analyzed that recorded variations in the hydrologic conditions in Silver and Soda Lakes approximately over the past 20,000 years (Figure 4). The green shaded areas of the cores illustrated in Figure 5 represent lakes that were intermittent; whereas, the blue shaded areas represent deeper lakes or full-lake conditions that lasted for long periods of time (perhaps hundreds of years) and overflowed into Death Valley. The Holocene experienced overall drying of the region and it was a period of time when one would not expect enough water to form a lake. However, when we look at the record of the cores that span the Holocene, there are times when multiple lakes formed (Figure 5). Clearly climatic variations in the source area of the Mojave River were significant enough to produce runoff that reached all the way

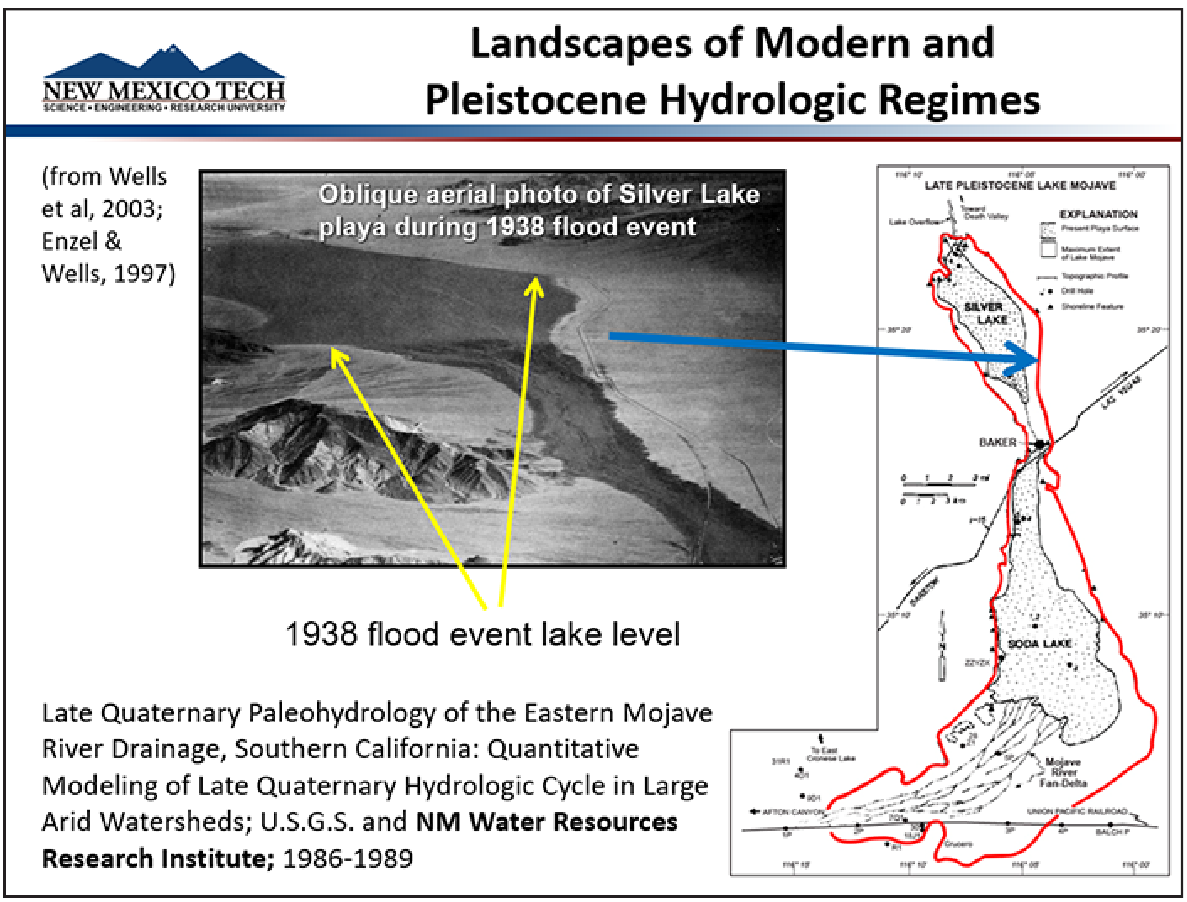



Figure 3. Landscapes of modern and Pleistocene hydrologic regimes in the terminal basins of the Mojave River, illustrating Pleistocene and modern shorelines.

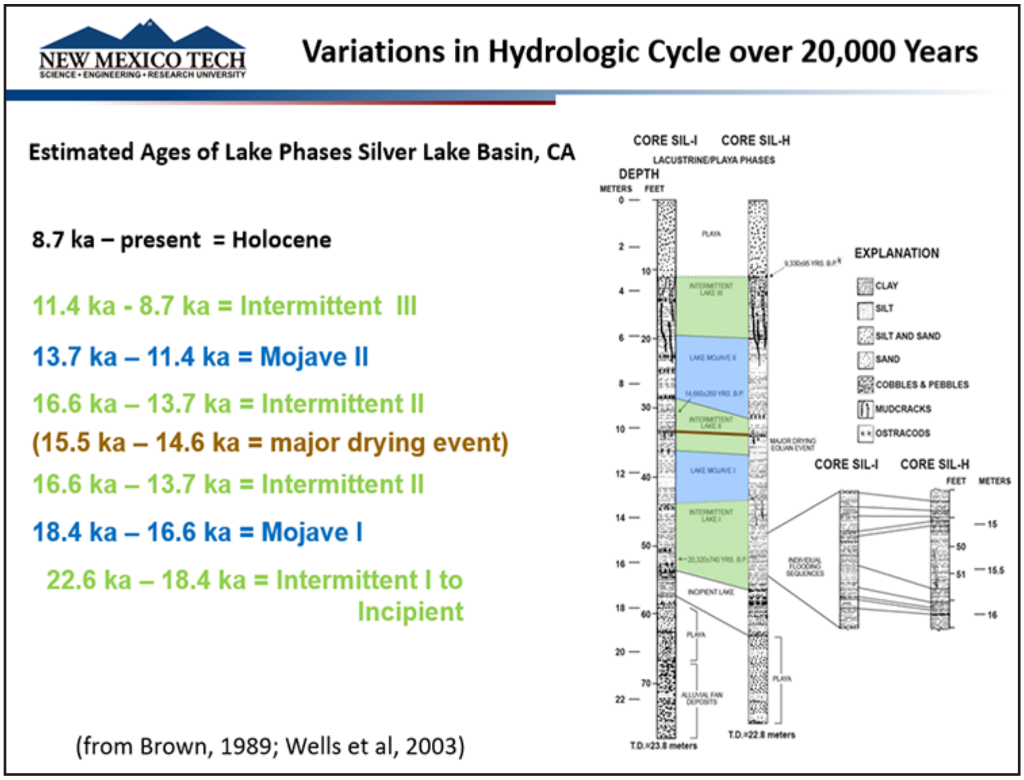



Figure 4. Variations in lake and playa conditions that reflect dramatic changes in the hydrologic cycle at the terminus of the Mojave River during the past 20,000 years.

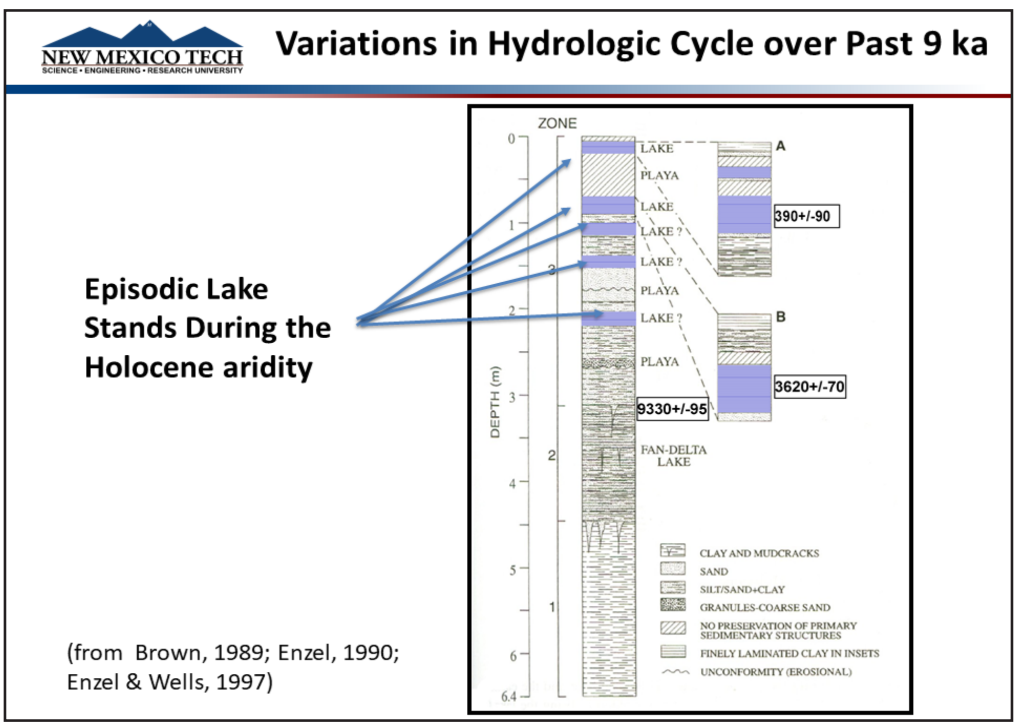



Figure 5. Variations in hydrologic cycle over past 9,000 years, showing ephemeral lake formation at the terminus of the Mojave River.

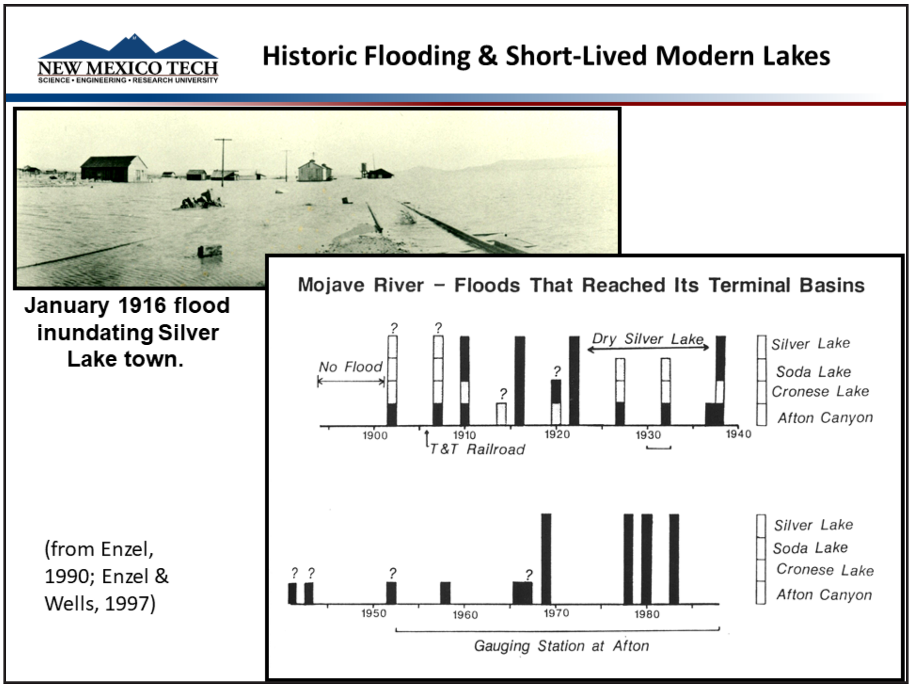



Figure 6. Historic flooding and short-lived modern lakes at the terminus of the Mojave River in Silver Lake basin.

into the Mojave Desert to produce lakes around 3,600 years ago and 400 years ago (of which the latter is very close to the timing of the Little Ice Age) (Figure 5).

In the Mojave watersheds there have been a series of historical floods that also produced ephemeral lakes that lasted at most about 18 months. Figure 6 includes a picture of the 1916 flooding at the town of Silver Lake. The chart on the lower right of Figure 6 depicts the known flood events that occurred along the Mojave River as well as those flood events that were large enough to produce lakes in Silver Lake basin such as the one illustrated in Figure 6; please note in Figure 6 that the y-axis of the histograms shows the downstream extent of flooding along the Mojave River with the ones reaching Silver Lake producing an ephemeral lake.

In attempting to understand the hydroclimatic conditions producing such modern lakes in the desert, if there were any anomalous atmospheric conditions that resulted the large runoff events, my former PhD student Dr. Yehouda Enzel, now a professor at Hebrew University, studied the composite sea-level pressures and the atmospheric circulation patterns of the Pacific Ocean during such times. He found that all the flood events creating lakes since 1900 AD in the Silver Lake basin occurred during an anomaly in the sea-level pressures and resulted in the displacement of the subtropical jet (Figure 7, black arrow is the approximate position of the subtropical jet during this anomaly).

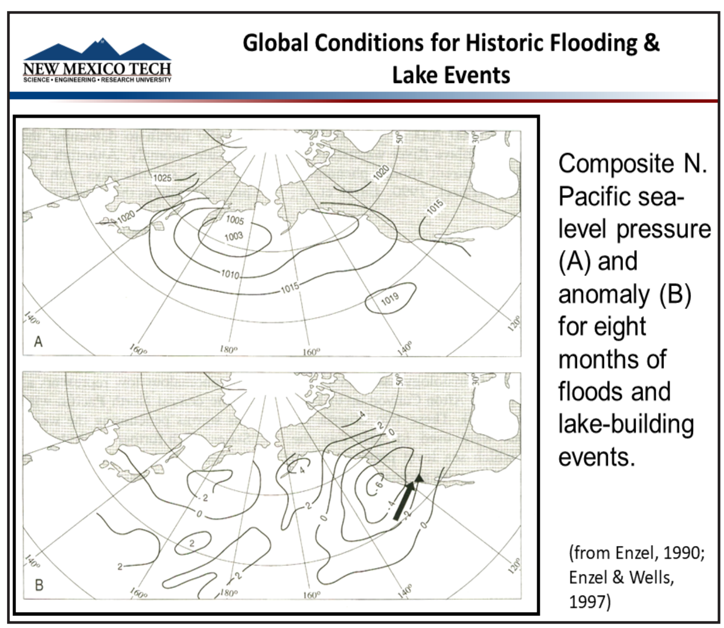



Figure 7. Global conditions for historic flooding and lake events.

This displacement forced a "river" of atmospheric moisture into the Mojave headwaters, profoundly increasing the runoff of the Mojave River and producing these modern lakes.

In order to reconstruct the hydroclimatic conditions that would be required to produce lakes at the terminus of the Mojave River, a very simple modeling process was constructed using data consisting of annual discharge of the Mojave River versus the elevation of a lake at the river terminus (Figure 8). Modern hydroclimatic conditions are shown at the bottom of Figure 8 (the line marked *D*). The top of the graph shows what conditions would be required for overflow of the late Pleistocene lake into Death Valley (Figure 8, line *A*). Estimating evaporation and precipitation conditions, one can model what discharges are required beyond the modern conditions (Figure 8, line D) all the way to late Pleistocene conditions (Figure 8, line A) in terms of the elevation of modern and ancient lakes. We concluded that utilizing modern flood and lake-filling data from modern extreme hydroclimatic events and a simplified evaporation-precipitation model allow one to estimate the types of conditions necessary in the Holocene (and perhaps the late Pleistocene) to create lakes in a hyper-arid region: if there is a 50 percent increase in rainfall in the catchment area, three times the flood discharge of modern extreme events, and a 50 percent decrease in modern evaporation, lakes will be produced. Or lakes could form under another set of conditions: 100 percent increase in precipitation within the Mojave River headwaters. This allows one to establish hydroclimatic boundary conditions that created these large flood events and the lakes within the terminal basin. We conclude that a 50 percent increase in rainfall in the catchment area, three times the flood discharge of modern extreme events, and a 50 percent decrease in modern evaporation is very applicable to the Holocene lake-forming events, except that the subtropical jet probably locked in and stayed in the position shown in Figure 7 for years to perhaps decades.

In summary, combining data obtained from hydrologic conditions recorded in the geologic record with modern hydrologic and climatic conditions and resulting landscape allow us to infer the nature and variations of Holocene, and perhaps late Pleistocene hydrologic and climatic conditions.

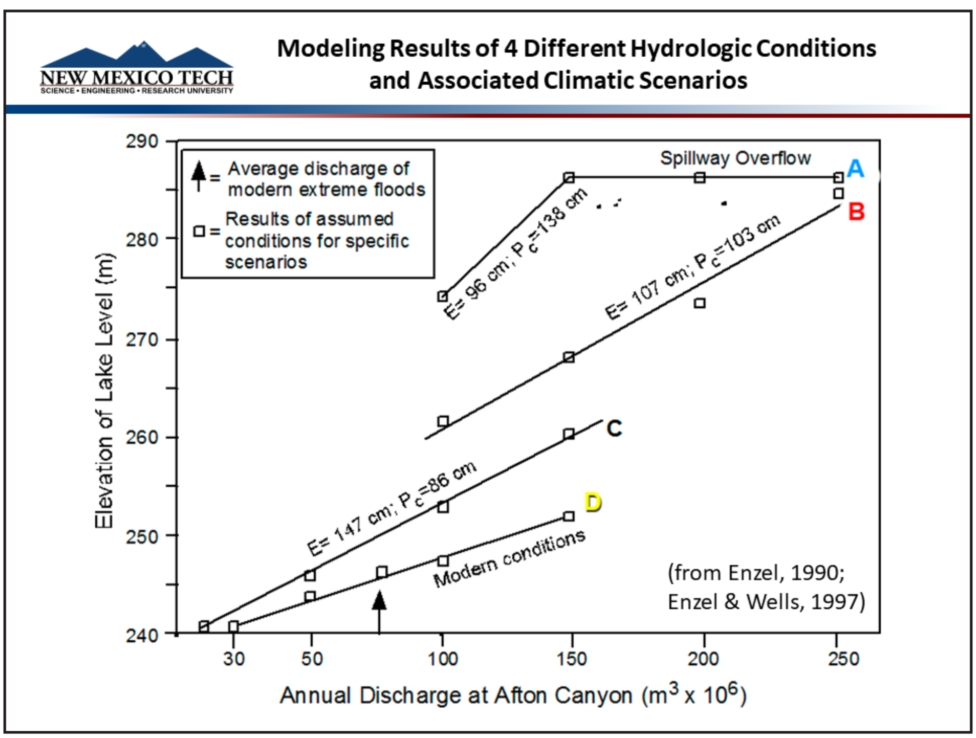



Figure 8. Modeling results of four different hydrologic conditions and associated climatic scenarios for the Mojave River basin of California and lakes forming at the terminus of the Mojave River.

Modeling such as the one described above can only happen in relation to watersheds and rivers that have human interference, such as dams or diversions. Although the impact of humanity on hydrologic systems is not my expertise, it is a critical factor when assessing past, current, and future trends in the conditions of hydrologic systems. What was the influence of humanity on the hydrologic system over time? Although we live in a "very, very watery" planet, 96.5 percent of that water is in the oceans, and humanity is delegated to and dependent on the other 3.5 percent. The National Academy of Engineering (Figure 9) has stated that one of the greatest challenges for our engineers and our scientists is providing clean water for humanity now and in the future. How did humanity get to the point that access to clean water is one of our planet's most significant challenges? The lack of clean water is responsible for more deaths than war. One of every six living people does not have access to clean water, more than double that number lack the sanitation, and approximately 5,000 children probably die every day just because of the lack of access to clean water.

Perhaps as human population has grown exponentially over time (Figures 10A-10E), we have taken one of Earth's most important resources for granted. The significance of population growth, specifically in semiarid and regions with respect to predicted changes in our climate and therefore our hydrologic system, illustrates why the challenges shown in Figures 10A-10E will only be compounded.

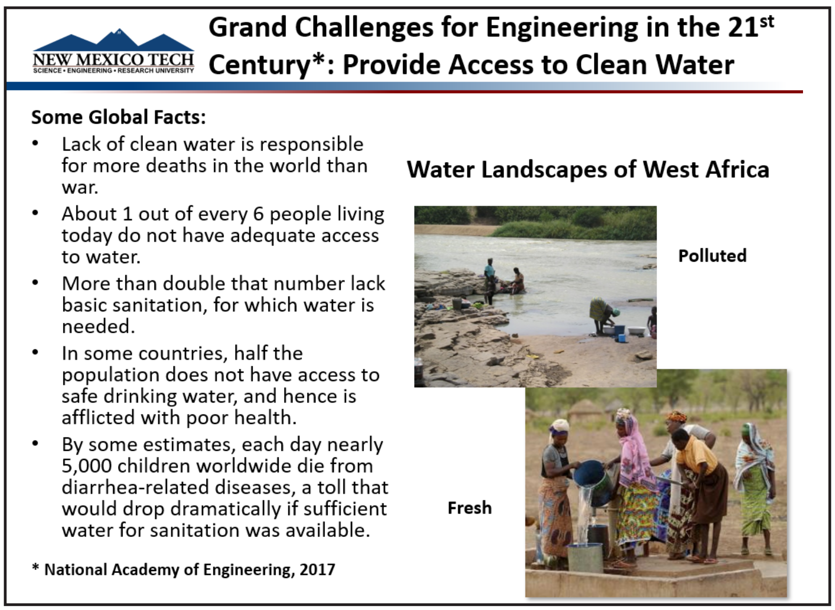



Figure 9. Grand challenges for engineering in the 21$^{st}$ century.

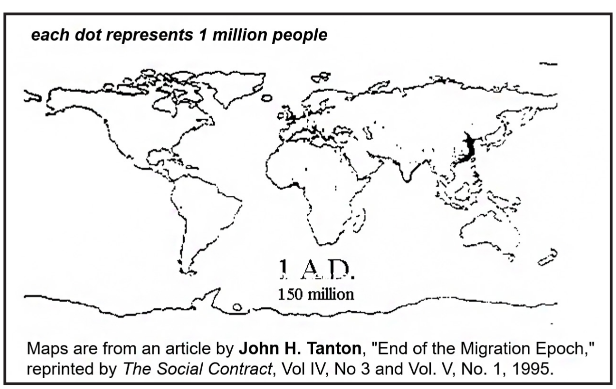



Figure 10A. The global change in human population.

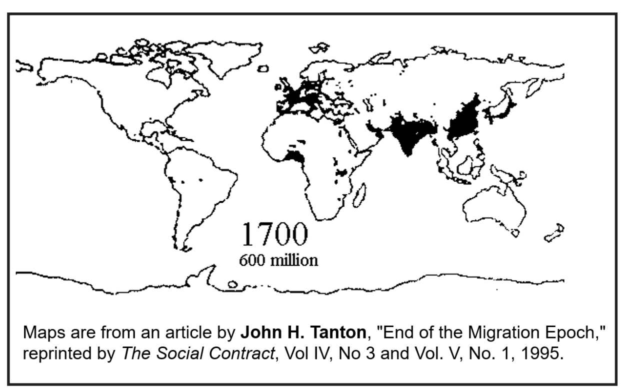
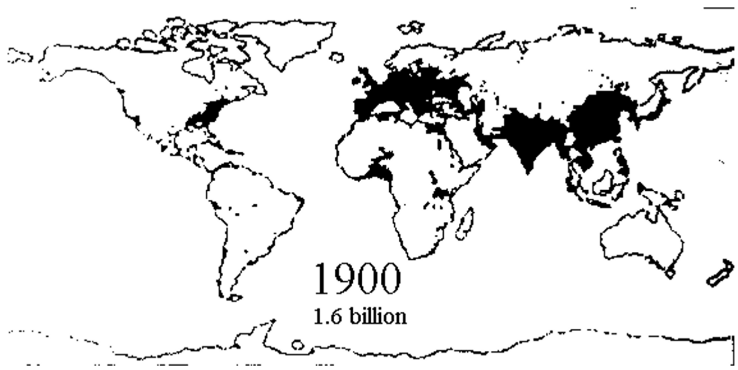
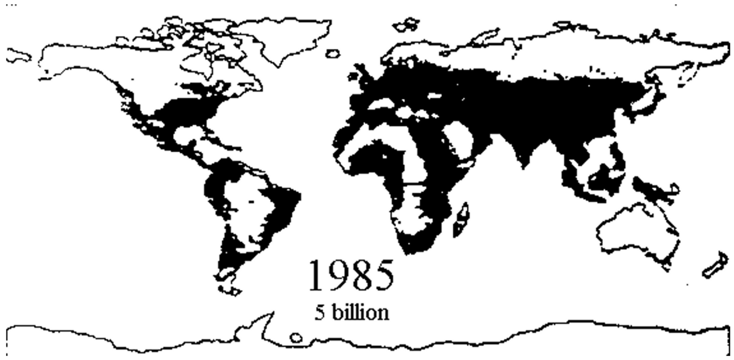



Figure 10B. The global change in human population (cont.).



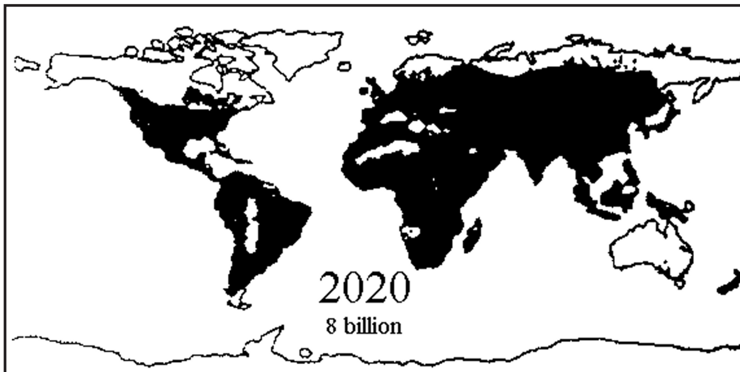

Maps are from an article by **John H. Tanton**, "End of the Migration Epoch," reprinted by *The Social Contract*, Vol IV, No 3 and Vol. V, No. 1, 1995.

Figure 10C. The global change in human population (cont.).




Maps are from an article by **John H. Tanton**, "End of the Migration Epoch," reprinted by *The Social Contract*, Vol IV, No 3 and Vol. V, No. 1, 1995.

Figure 10D. The global change in human population (cont.).




Maps are from an article by **John H. Tanton**, "End of the Migration Epoch," reprinted by *The Social Contract*, Vol IV, No 3 and Vol. V, No. 1, 1995.

Figure 10E. The global change in human population (cont).

Figure 11 is a graph that illustrates population growth over time, and that it didn't take long during the rise of civilization for humans to start manipulating the hydrologic system. Agriculture began somewhere around 9,000 years ago, flourishing over the next several thousand years. The first irrigation occurred about 8,000 years ago, with the first dam being constructed in what is now Jordan about 3,000 years ago. The first documented traces of river pollution appear to be from the Romans pumping their sewage into the Tigris River.

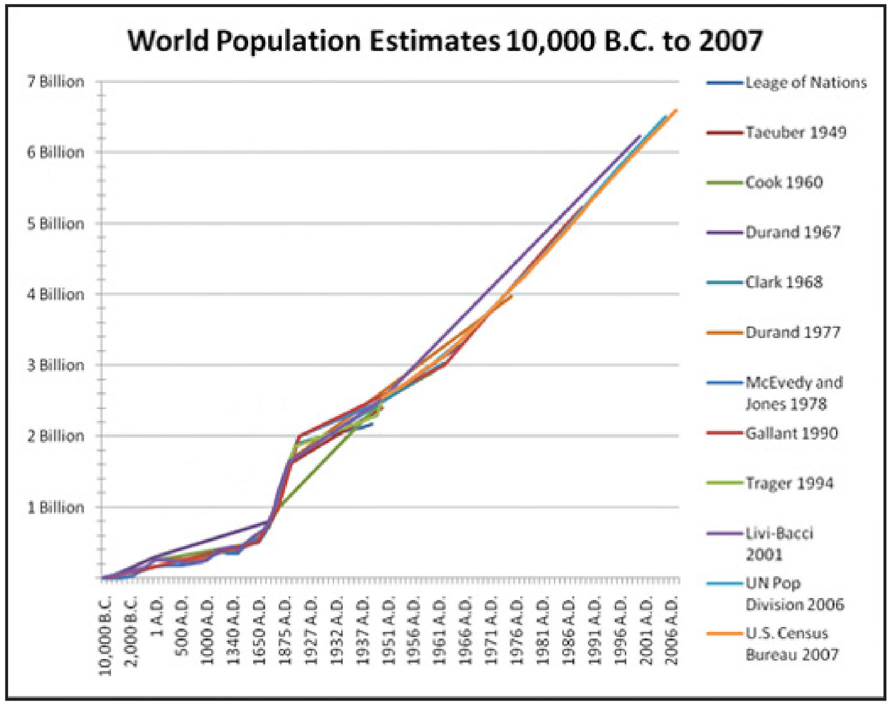


Figure 11. A new factor in the hydrologic cycle: humanity.

With every great challenge there is an opportunity through science and engineering to not only understand the impact of changes to the hydrologic system but also to help address and mitigate such issues. With the growth in humanity comes the growth in technology over the past century, allowing scientists for the first time to assess hydrologic and climatic conditions on a planetary scale. The Board on Earth Sciences and Resources with the National Academy developed the concept of Earth Science Services (ESS): an "array of benefits for humankind derived from the biogeochemical and hydrogeological states and flows" that "sustains the biosphere for existence of life." ESS best reflects how one can measure and assess the biochemical and hydrogeological states of flow that sustain life here on the planet and how it varies over time. For example, one way of measuring such fluxes is the difference between precipitation and evaporation which influence the infiltration and runoff of water and consequently the formation soils. Past changes in climate during the Holocene have impacted the depth of salt accumulation in soils (Figure 12A, McDonald, 1994), and in turn, salt has impacted the quality and functionality of the soil for plant growth. Figure 12B shows a model by Seager predicting global changes on the balance of precipitation and evaporation for the next two decades (2021–2040), and resulting potential changes in functionality of the ESS and the consequences for humanity. The balance between precipitation and evaporation is critical in assessing drought conditions.

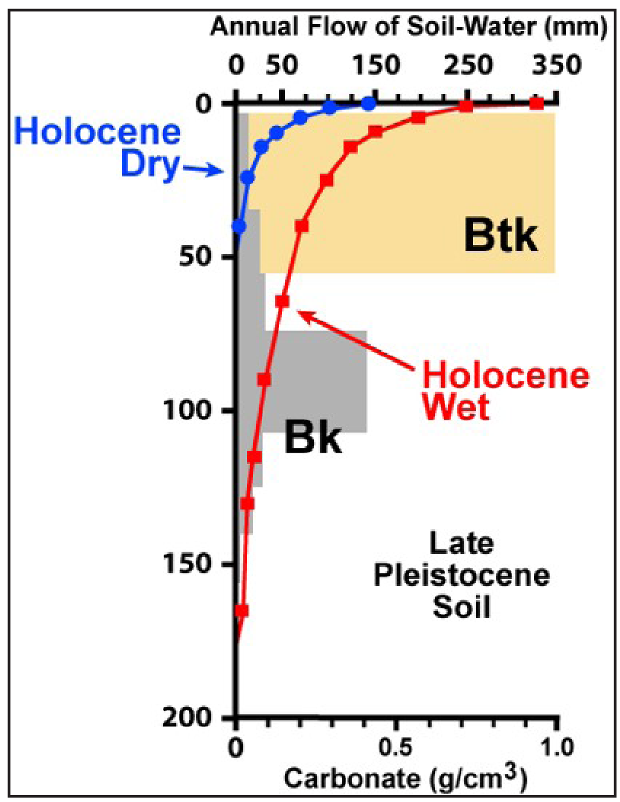


Figure 12A. Impact of past changes in climate during the Holocene on the depth of salt accumulation in soils.

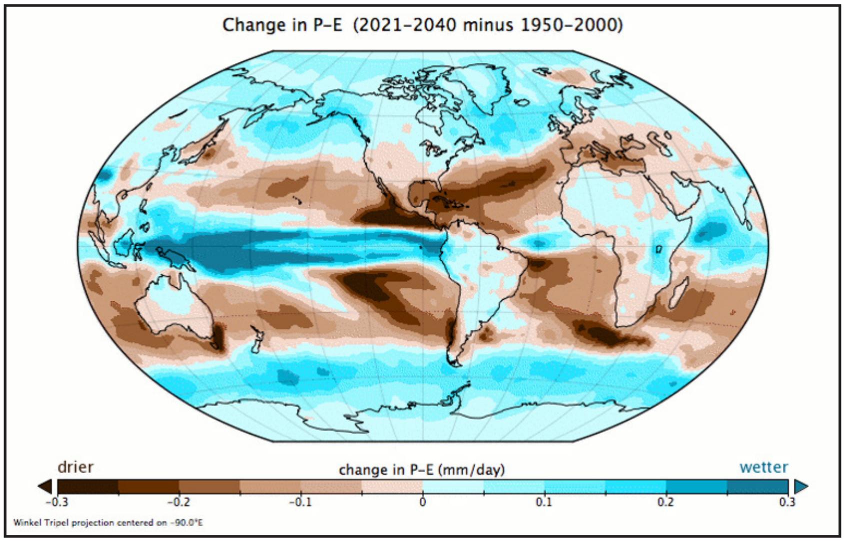



Figure 12B. Model by Seager predicting global changes on the balance of precipitation and evaporation for the next two decades (2021-2040).

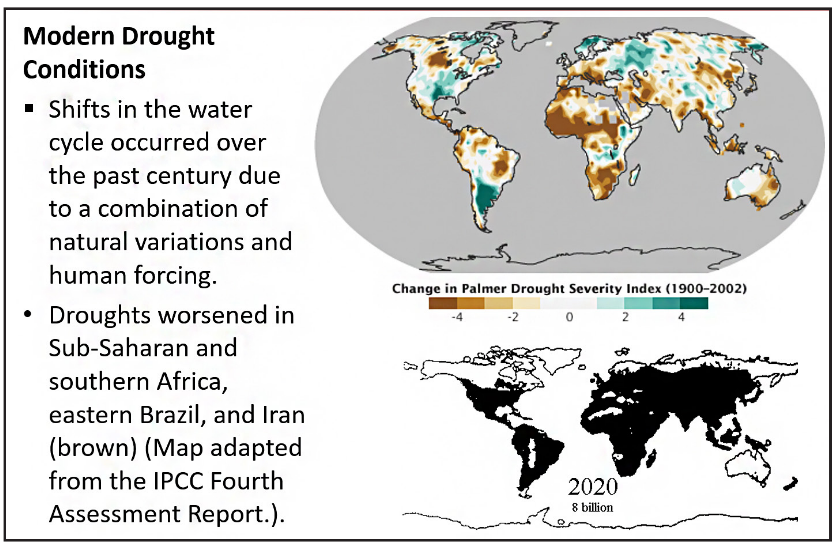



Figure 13. Changes in hydrologic cycle and earth system services functionality, predicting increasing drought conditions in the most densely populated regions of our planet.

Figure 13 illustrates that large areas of our planet are experiencing drought, and those droughts are occurring in some of those areas that are most densely populated with the least capable resources for managing their water resources.

Again, one can use historic observations and data to understand the rate of change in precipitation and evaporation balances and the consequences of drought in the United States. The 1930s Dust Bowl turned large parts of the western landscape into infertile land and lowered the productivity of our service systems very quickly. We were not immune from that here in New Mexico (Figure 14). Clearly these kinds of changes can happen very quickly over years and even over days, impacting humanity locally, regionally and globally.

As discussed earlier, changes in precipitation and evaporation also impact runoff and river discharge, another important measure of earth science systems functionality. What is the future of runoff on a global scale? Figure 15 portrays a global-scale model, predicting changes in continental-scale runoff, with decreasing runoff shown in the brown and increasing runoff shown in the darker blues. As shown before, many of the areas showing decreasing runoff occur in those areas with the largest population growth.

We can see the decrease in runoff on major rivers, such as the Colorado River in the southwestern United States. Figure 16 depicts the bathtub ring within Lake Mead near Las Vegas, Nevada which resulted from a decade-plus drought and the decreased runoff from the Rocky Mountains. Figure 16 also illustrates the decrease in the size of Lake Mead as well as the vertical drop by comparing satellite imagery from 1985 to 2010 imagery.

We are in a changing world where life itself depends very much on a functional hydrologic system and earth services system. Overall trends in these systems within the western U.S. are derived from different types of measurements and are not positive. These trends include:

- Warming – thermometers (National Oceanic and Atmospheric Association [NOAA] coop surface data network);
- Warming – thermometers (NOAA upper air data network);
- Warming – thermometers (subsurface, western boreholes);
- Snowpack decrease in spring months (SNOTEL network);
- More rain/less snow in winter months (NOAA coop network);
- Earlier snowmelt runoff pulse (date shift, US Geological Survey stream gauge network);
- Earlier blooming of lilacs and honeysuckles (phenology networks);
- Mountain glacier recession and mass loss;
- Upward movement of plant/animal habitat zones; and
- Warmer river and lake temperatures.

Those are real, measured, and observed data.


Figure 14. Landscapes of drought in New Mexico.

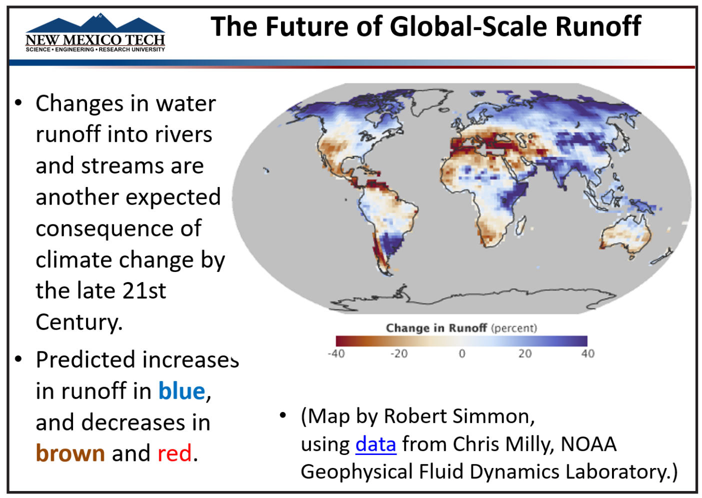



Figure 15. The future of global-scale runoff.

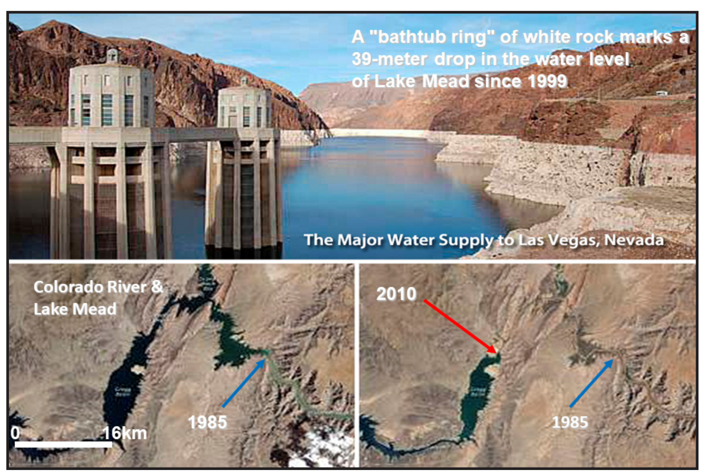



Figure 16. Changing runoff in the southwestern United States.

How do such changes relate to our life here in New Mexico? We have a mean annual precipitation somewhere between a little less than 10 inches and 20 inches, varying with elevation and geographic location across the state. Our state is blessed with several large river systems; however, these rivers only represent geographically one-quarter of one percent of our landscape. The flows in the rivers are highly dependent on changes in snowpack as well as other seasonal conditions. There is a strong connection between the surface water systems and the groundwater systems. In the northern parts of New Mexico, the groundwater tends to contribute to the river discharge, whereas in the southern parts of New Mexico, the rivers tend to lose discharge to the groundwater systems. In addition, there are significant spatial changes and variability in our groundwater systems and their conditions to be described later.

How does New Mexico use its water? Approximately 79 percent of all water use is for agriculture. As you might expect from previous discussions, the importance of the earth systems services is critical in this state for the agricultural system and trends for the future of water in New Mexico. Our state has experienced a 2°F increase in the average temperatures since 1990. Models show there will be reduced snowpack as well as increases in variability in monsoons that are typical of our state. There will most likely be lower storage of water in our aquifer systems, at the very time we are coming to depend on those groundwater systems.

Our state has to meet agreements and compacts; however, we lack accurate long-term data that can impact such agreements. I often refer to groundwater systems as a bank account for which we never balance the checkbook. We take and take, without understanding the balance of recharge and discharge. Data are fundamental in understanding and modeling the changes that occur now and that will come.

To paraphrase Brendon Burchard, challenge is a pathway to engagement and progress, and this is a good transition to the fact that we are blessed with collaboration here in this state.

At New Mexico Tech, there are two great entities working in the field of hydrological sciences: our Earth and Environmental Sciences Department and the Bureau of Geology and Mineral Resources. Across the state we have academic institutions, state agencies, federal agencies, various municipalities, and tribal governments partnering to increase our understanding of our water systems and resources. These entities are listed below.

**Academic Institutions**: New Mexico Institute of Mining and Technology, University of New Mexico, New Mexico State University, New Mexico Water Resources Research Institute, New Mexico Highlands University

**New Mexico State Agencies**: Office of the State Engineer/Interstate Stream Commission; Energy, Minerals and Natural Resources Department; Environment Department, Department of Health

**Federal Agencies and National Laboratories**: US Geological Survey, US Bureau of Reclamation, Los Alamos National Laboratory, Sandia National Laboratories, US Bureau of Indian Affairs, US Fish and Wildlife Service, US Bureau of Land Management, US Forest Service, NASA

**Counties, Municipalities, Irrigation Districts, Conservation Districts, Water Utilities, Tribes**

We deeply appreciate the role that the NM Water Resources Research Institute plays in such studies and the collaboration that New Mexico Tech has had with them. The Institute is an asset we have in this state at a very challenging time. Examples of collaborative partnerships in meeting the challenges we face as a state are summarized in Figure 17.


Figure 17. NM Tech collaborations toward state water challenges.

Another key collaborative project focuses on using New Mexico's river systems as an analog for those challenges facing riverine systems throughout our nation. This project is providing an understanding of biogeochemical processing along the Rio Grande corridor and the implications for the nutrients that flow through these types of river corridors (Figure 18). Such data are very important for agencies and their ability to be better stewards of riverine environments and perhaps ultimately to have the type of data needed for a national water policy.

Figure 19 lists various statewide partnerships related to groundwater recharge modeling, ranging from the groundwater around uranium mines in western New Mexico to the Plains of San Agustin west of Socorro. The list of talent and combined effort is very impressive.

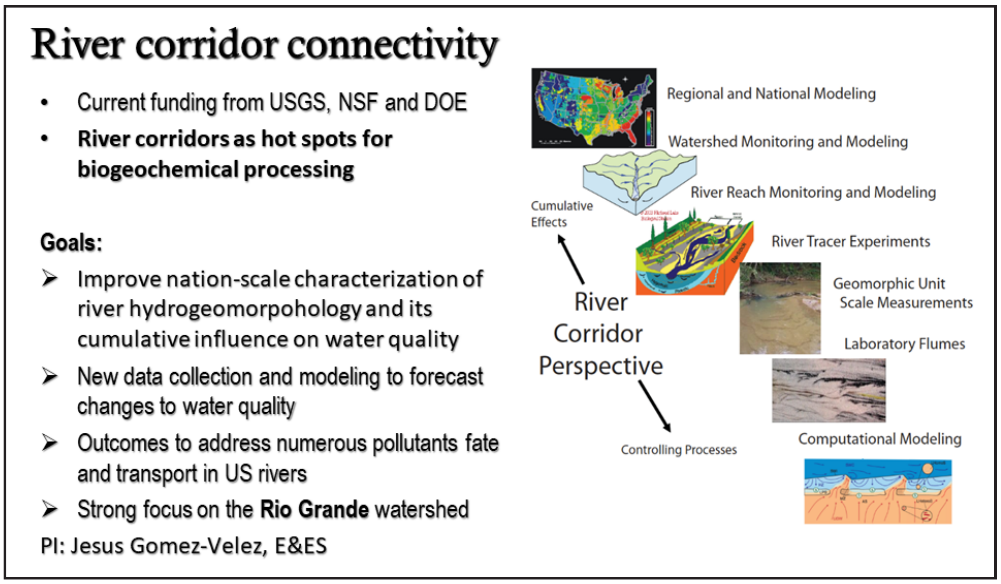



Figure 18. New Mexico Tech collaborations toward national water challenges.

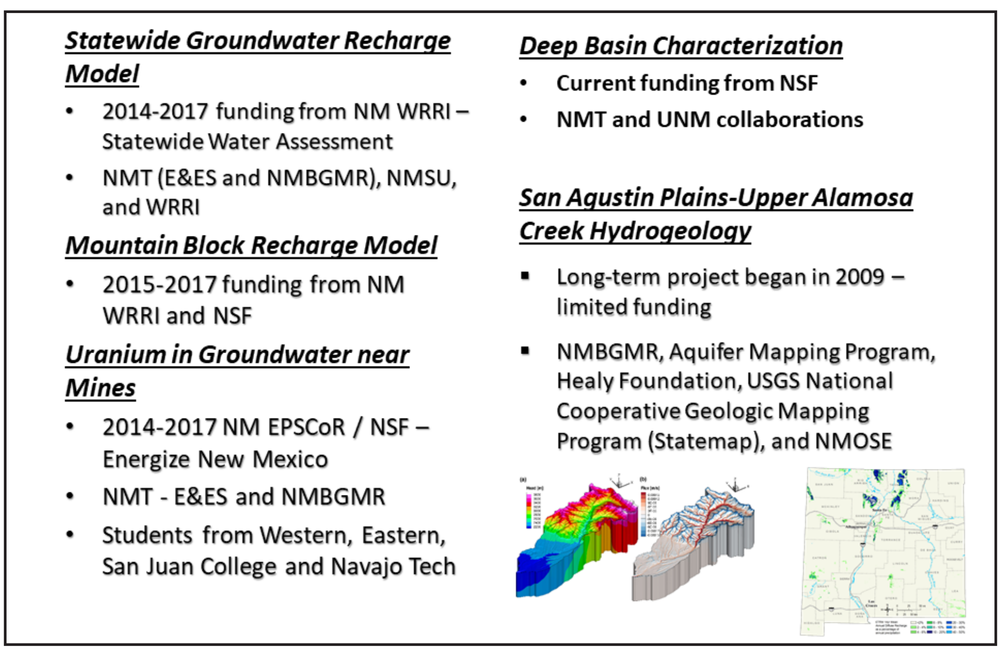



Figure 19. Significant statewide collaborations in groundwater studies.

In these challenging times, what is the opportunity? I would suggest that there is a great opportunity for the future of the water landscape not only through collaboration but also through innovation. The opportunity is essentially to use our state's talent and our knowledge of water sciences, engineering, and management to follow a pathway toward innovation-based economic development around water technology. When one of your most challenging situations is water resources, turn that around and make that an opportunity by gathering the talent in higher education and teaming with industry, attracting and nurturing businesses in that area, developing an advanced workforce, and then cultivating innovation. I believe there is a real opportunity for New Mexico to learn from efforts centered in Las Vegas, Nevada. Through state investments in higher education, a nonprofit called *WaterStart* was created to attract water technologies to Nevada, nurture innovation at universities in the water sciences and engineering, and provide creative testing facilities for such technologies. I was fortunate to be part of the team creating the nonprofit and serving as the chairman of the board. I know that we can create similar opportunities here in New Mexico given our talent and environment. Building a statewide New Mexico strategic plan that leverages our talents is a great way not only to better understand our water resources and how to steward them, but also to build a large-scale, effective water-technology economy in New Mexico.

New Mexico has an abundance of challenges, but we also have significant opportunities through our talent base, our ability to collaborate, and our resource base to create a knowledge-based economy around water sciences and water technology. With that, I will conclude, and thank you for the opportunity to offer insights into my research experiences related to hydrology, the current and future challenges to water resources, and the opportunities to leverage challenges into an innovation-based economy around water technology.

# Update on Efforts Associated with the 2012 Conference Report, 57th Annual New Mexico Water Conference

Tom Udall, U.S. Senator (NM)

*Senator Tom Udall has earned a reputation as a principled leader who has the integrity to do what is right for New Mexico and our nation. Senator Udall began serving as US Senator in 2009, after two decades of public service as US representative and New Mexico's attorney general.*

*Throughout his career, Senator Udall has been a strong advocate for the hardworking families of New Mexico, for a clean energy economy and the environment, for affordable and accessible health care, and for our nation's veterans. He cohosted the New Mexico water conference with NM WRRI in 2012 and, in the Senate, he is a leader in environmental sustainability, water conservancy in the face of severe drought in New Mexico, and the fight to combat climate change.*

*Senator Udall serves on five committees: Appropriations, Foreign Relations, Commerce, Indian Affairs, and Rules and Administration.*

President Wells, that was a special address, and I'm glad that I skipped my exercise this morning and came over here to hear you and Sam Fernald. It was very educational for me. The one statistic that struck me there was that more people are killed by the lack of potable water than are killed by war. It tells me that it is an incredibly important area that you all work in. A lot of people around the United States, especially outside the Southwest, might think working in water is an esoteric, intellectual thing. But it shows you how important the work you do is because it has real impacts on people's lives. I think the experience that Dr. Wells had up in Nevada with WaterStart is something we need to be working on here in New Mexico, so I am going to try to form a partnership with Dr. Wells and see if we can't find a way to get *WaterStart* down here the way he put it into operation in Nevada, and work with Sam, the WRRI, and others on that. If any of you are interested, many of my staff members are here. You can sign up; give them your card.

Let me give a huge thanks again to Sam and Cathy Ortega Klett and the team for organizing this important get-together, as they have done for many years running now. This audience has technical knowledge—matched with innovative ideas—to help ensure a sustainable future for New Mexico water. I have a great deal of respect for New Mexico's WRRI and the other states' water research institutes. As the cosponsor of the legislation to reauthorize these institutes, I am optimistic about its passage and about continued, solid bipartisan support for funding. I will do my part on the Senate Appropriations Committee. Once again, this is an area—water—where Republicans and Democrats in Congress work together. It isn't always covered in the media, but it is really true that it happens, and this particular piece of legislation is a good example.

I'm back here five years later to report on the progress we've made since the 2012 conference. At that time, we discussed many policies, and afterward we issued a full report of actions to take. Before we get into that, I'd like to briefly talk about today's water resource management landscape. Figure 1 shows why we need to come together and seek cooperative solutions.

I always like to start with John Wesley Powell's map of watersheds in the West (Figure 1). I have this map hanging on my office wall in Washington. Powell thought state lines should follow those boundaries. Rather than have a state line like we have with Colorado and New Mexico and Arizona and California, you'd have a state around the Colorado River, around the watershed basin. That's really what Powell advocated. We obviously didn't do that, and many of our water problems flow from that. I think he was absolutely right. Powell wasn't just serving up this idea as an intellectual concept. He came out here as a geologist; he was an explorer. He saw on the ground; he wrote that famous report on the arid lands. He went back to Congress. If you go back to the history and look at those debates that John


Figure 1. John Wesley Powell's map of watersheds in the West.

Wesley Powell had in Congress, he really pushed for this. He took on all the special interests. He took on everyone that was flowing in the other direction, and the doggone Congress didn't follow him.

We're kind of where we are today because of that, struggling to deal with watersheds with all these state boundary lines. On top of that, water in the West, I believe, has a nineteenth-century legal framework with twentieth-century infrastructure and twenty-first-century pressures of increasing demand and climate change. Our long-term water supply and consumption are out of balance, even with current conservation efforts. Water professionals here today know this in technical terms; farmers here know this in personal terms.

First, the legal system, based on the need to develop the West, rewards use, not conservation. Those laws are adapting but largely remain on the books. Next, our twentieth-century infrastructure is aging. Elephant Butte Dam just celebrated its centennial, and it is not alone. Water lines and treatment plants are many decades old. Across the country, we have more than $350 billion—*billion*, folks—worth of water infrastructure needs. Much of that is simply maintenance and repair.

Here are some of the quick statistics on why we should invest:

- For every dollar we spend on water infrastructure, we return $6 to our gross domestic product.
- Investment in water infrastructure contributes more than $150 billion each year to annual household income.
- Failure to invest in water and wastewater systems will lead to the loss of nearly 500,000 jobs by 2025 and 950,000 jobs by 2040.

The needs I'm talking about are not big new dams and pipelines. The era of guaranteed big federal investment in water projects is largely over. The budget pressures and environmental costs are just too large. We need to primarily focus on maintaining the water infrastructure we have. I hold out hope, and I'm pushing for a federal infrastructure package that would help address these needs, especially out here in the West and in the Southwest.

President Trump may not spend much time thinking about the Bureau of Reclamation, but Secretary of the Interior Zinke does. We're doing everything we can to work closely with Secretary Zinke on infrastructure. I even went on a horseback ride with him the other day in the Sabinoso Wilderness. By the way, this is the only wilderness with no public access. Hunters, fisherman, hikers, or whoever wants to get out into the Sabinoso, must cross private land, and we're working to make sure there is access for the public.

Finally, we face a twenty-first-century supply-and-demand situation. Regional water managers expect that in the coming decades we will see water shortages everywhere in our state except the San Juan Basin. In the south, growth around the border zone and Santa Teresa and Las Cruces will drive even more demand for municipal and industrial water. The climate is warming. In the Southwest, we've seen a 2.5°F temperature increase since 1971—2.5 since 1971. Last week, the National Oceanic and Atmospheric Administration reported that 2016 was the earth's warmest year on record, and it was the third year in a row that temperatures broke global records. The Bureau of Reclamation projects that the Rio Grande Basin will be hit the hardest over the coming century, warming five to six degrees by 2100. That would cut the water flow south of Elephant Butte Reservoir by half. That is on top of a similarly sized reduction from the San Juan–Chama Project, based on changes in New Mexico's Colorado River allocations in low-water years. These are big challenges. Tensions can run high over water in the West: interbasin transfers, endangered species, municipal versus rural users, acequias versus growing cities and communities, Texas versus New Mexico, the United States versus Mexico, and the list goes on and on. Many of you can see those conflicts and tensions in your community.

Cooperation will be the only successful strategy to prepare for drought, to adapt to climate change, and to modernize our integrated water system. We must balance agricultural use, urban areas, and ecosystems. You all know that at the last water conference I talked about cooperation. The key that came out of that—and you all hear this a lot, but it bears repeating—cooperation is really the key in this area and in so many areas we realize we are one planet. I love that old saying "Whiskey's for fighting, and water's for drinking—except in the West."

Five years ago, we came together to discuss policy options to manage water scarcity in New Mexico. At that time, the state was in severe drought. Your insight and investment helped produce a report. It identified problem areas and made consensus-based policy recommendations, primarily in areas where the federal government can help. The signature result was the 2013 New Mexico Drought Relief Act. This spring, I reintroduced the bill that flowed out of that conference for the third time along with Senator Heinrich. We renamed it the New Mexico Drought Preparedness Act. Figure 2 is the most recent map of New Mexico's drought conditions from August 8, 2017.

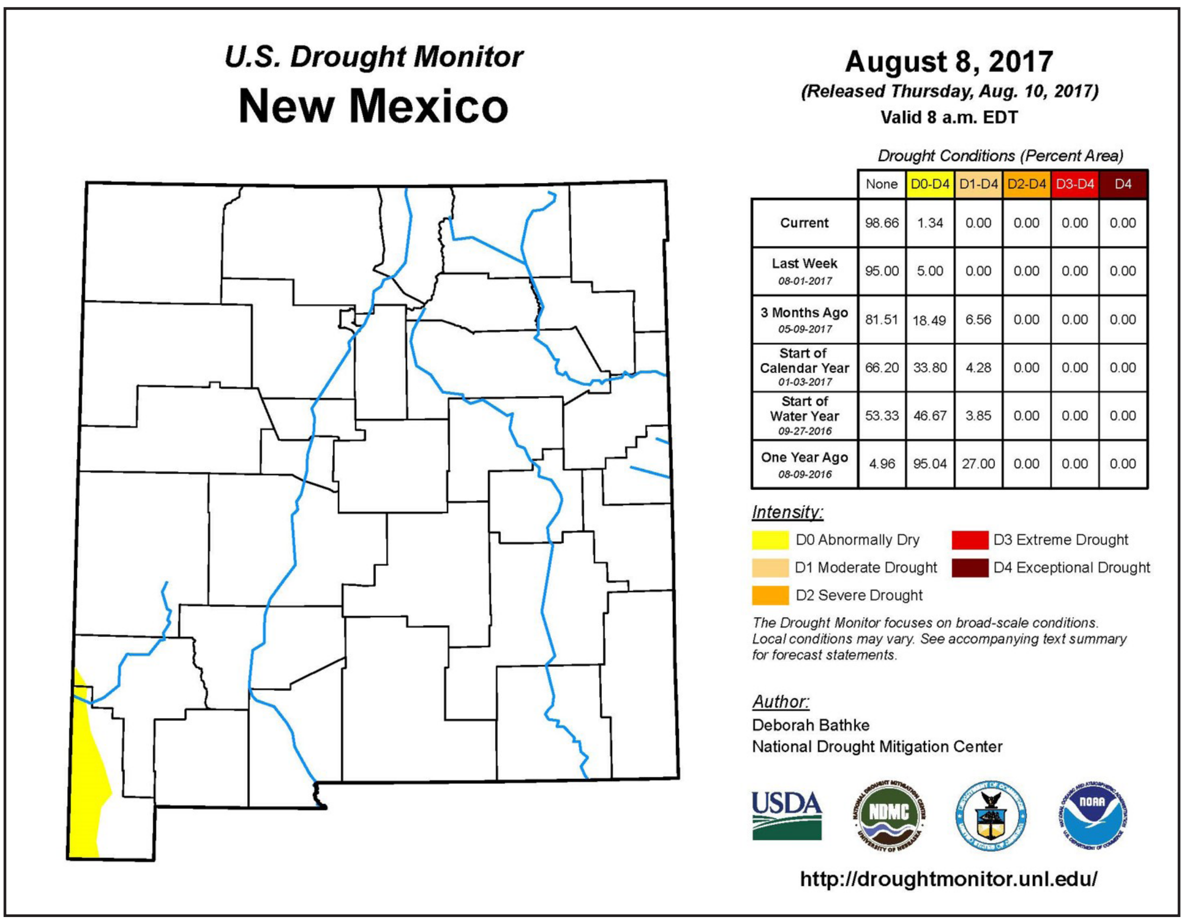



Figure 2. U.S. Drought Monitor map of New Mexico, August 8, 2017.

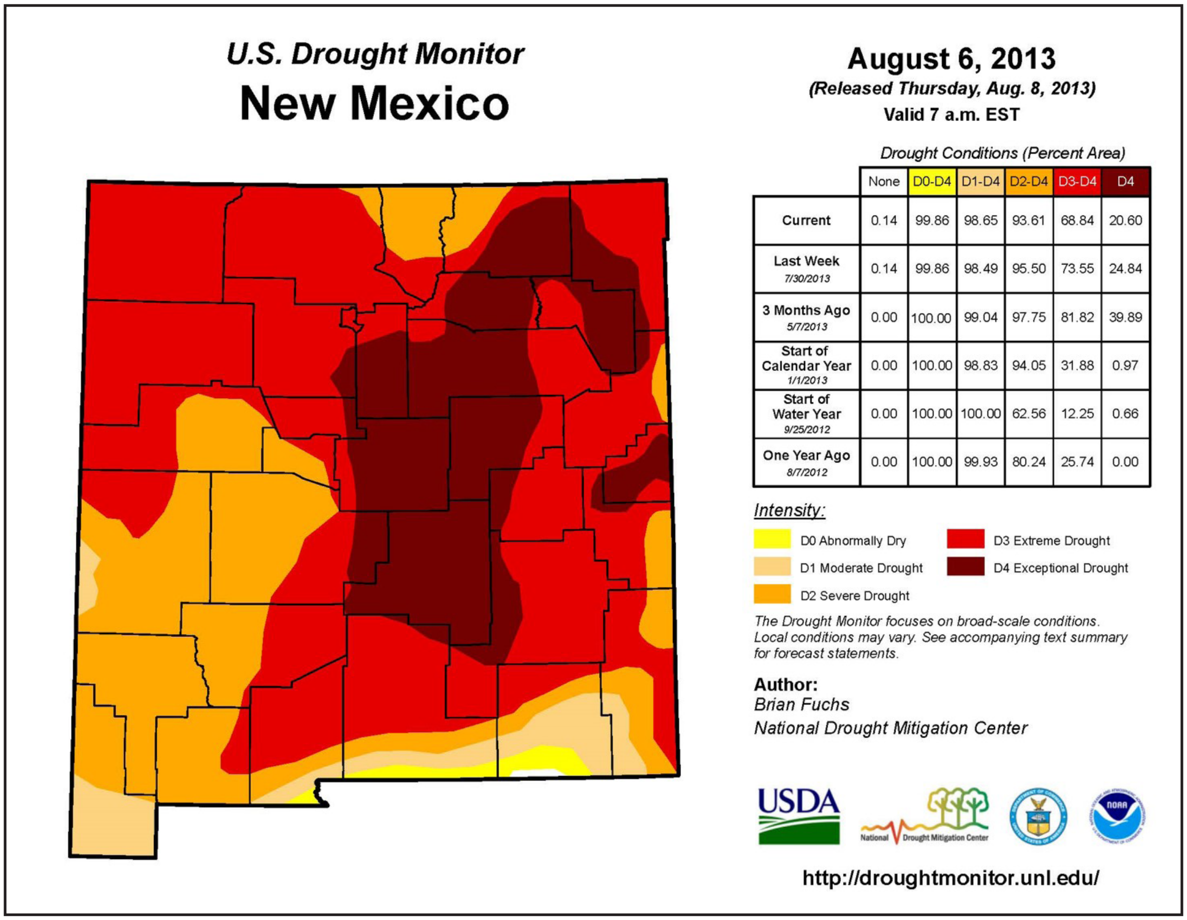



Figure 3. U.S. Drought Monitor map of New Mexico, August 6, 2013.

Figure 3 is a map from four years ago, August 6, 2013.

Pretty striking, folks. A marked and welcome change. But we should be honest with ourselves. With 16 of the last 17 years as the hottest years on record, this reprieve will be temporary. While the drought map looks much better, Dr. Phil King with New Mexico State University has made an important point recently: groundwater levels have been depressed since 2003. Elephant Butte and Caballo Reservoirs are just above 16 percent and 18 percent capacities respectively. Drier conditions are likely our new normal.

The Drought Act includes provisions to study the whole Rio Grande Basin with the National Academies of Sciences. It is a study for additional water storage opportunities to provide additional management flexibility, promote voluntary water sharing among stakeholders in the middle Rio Grande, extend the Emergency Drought Relief Act to allow the Bureau of Reclamation to adapt to strained water supplies, and use our current authorities more effectively. Those are the key recommendations from the report. We know drought will return. Now is the time to prepare.

We're making progress with the bill, but Congress is slow as all of you have observed. It's like pushing water uphill. The Senate Subcommittee on Water and Power has held two hearings on the bill, one in 2015 and one in 2017. We want to get the bill out of committee and through the Senate as part of a larger package of water bills. We had a real opportunity when a California water package went through, but the California senators managed to separate the other water bills that were in there and they got their deal done without ours. We're coming back, and we're going to get this done.

We've also seen parts of the bill in other ways. First has been the annual appropriations process. This year, I was able to extend authorization of the Emergency Drought Relief Act to 2022. We increased the spending cap for water projects by $30 million. We expect it will pass later this year and provide flexible operations and planning authority for the whole Reclamation system when there is drought. We have also included important language and funding to help Reclamation with voluntary water leasing efforts in the middle Rio Grande. This was one of the key pieces of our 2012 report. Voluntary water sharing helps compensate farmers for stream flows and avoids more difficult issues with endangered species.

In addition, two water efficiency bills came out of our 2012 effort. Both were in an energy bill that passed the Senate last year, and both bills are well positioned to move in any energy legislation again this year. One of the bills, the Smart Energy and Water Efficiency Act, addresses the energy-water nexus, treating water as an expensive and energy-intensive process. Leaks and breaks waste as much as two *trillion* gallons of purified drinking water, and that waste happens each year. That water takes a huge amount of energy and money to treat and to pump, and then it just goes into the ground. So, our bill supports investments in information technology that identifies decreases in water pressure and identifies leaks and breaks immediately, or even before they occur, to save water, energy, and money.

The second bill, the Water Efficiency Improvement Act, would make the Environmental Protection Agency's (EPA's) popular Water Sense Program permanent. For those who don't know, Water Sense is like the Energy Star label, but for water fixtures like water faucets and sprinklers. Since 2006, Water Sense products saved more than 2.1 trillion gallons of water and more than $46.3 billion in consumer water and energy bills. Each dollar spent on this program saved consumers an estimated $1,000. My bipartisan bill would make Water Sense permanent. This legislation is especially needed now because the new administration wants to limit Water Sense.

We've also made progress on some of our other proposals from our 2012 conference, including:

- Restarting annual funding to the Transboundary Aquifer Assessment Program, which allows for collaboration and data exchange between Mexican and US partners.
- Funding for the US Army Corps of Engineers for the Rio Grande Environmental Management Program to pay past commitments to New Mexico towns and cities for water infrastructure.
- Giving acequias and other agricultural users access to US Department of Agriculture funding through a Regional Conservation Partners Program to help unique New Mexico water users update their historic irrigation systems.
- Helping secure $150 million over the last two years for the Watershed Protection and Flood Prevention Program, which provides technical and financial help to support off-farm conservation projects.
- Dedicating a portion of EPA water funding for green infrastructure. This uses natural hydrology designs to reduce runoff and contamination at lower costs than traditional projects made of concrete. The Southern Sandoval County Arroyo Flood Control Authority completed a first-of-its-kind project with this funding last year.

In conclusion, in 2012 the threat of climate change underpinned our conference report. Climate change still informs all we do in terms of water resource management. The first natural system affected by climate change is water, and that threat is here and now. We have seen this firsthand in New Mexico: severe droughts, decreased snowpack, flooding caused by uncharacteristically warm winters and springs, and catastrophic fires causing severe erosion and damaging surface water. Climate change impacts are being felt throughout the West. The time to adapt is now. The science of climate change should not be political. We must make our policy decisions based on the science and our responsibility to future generations. You are a cohort of smart, technically savvy, and politically astute water experts. You can help think through the new round of challenges we have and work together to solve problems. The stakes are high, but as Margaret Mead famously said, "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has." As your senator, my job is to help groups of thoughtful, committed citizens like you effect that change.

I return to report on our progress, and I'm seeking your feedback for future work. We're looking for cooperative ideas, not taking sides in conflicts. Rest assured, we have plenty of conflict in Washington these days. We don't need that to flow back here to New Mexico. I'm also excited to hear about your success stories. Many of you have accomplished great things in the past five years and learned a lot that you can share. The Middle Rio Grande Conservancy District, Elephant Butte, our tribes and pueblos, acequia associations, our arroyo flood control authorities, water utilities, and other state and local agencies are working hard on these issues every day, as are conservation groups and academic organizations. I thank you and thank all of those organizations. My staff and I look forward to your insight and expertise today and tomorrow and to working together to make our state's water supplies more secure for our children and grandchildren.

# Cross Cutting Panel of Water Interests in New Mexico: Addressing Hidden Realities of New Mexico Water Opportunities

## Moderated by U.S. Senator Tom Udall

*Senator Tom Udall has earned a reputation as a principled leader who has the integrity to do what is right for New Mexico and our nation. Senator Udall began serving as US Senator in 2009, after two decades of public service as US representative and New Mexico's attorney general.*

*Throughout his career, Senator Udall has been a strong advocate for the hardworking families of New Mexico, for a clean energy economy and the environment, for affordable and accessible health care, and for our nation's veterans. He cohosted the New Mexico water conference with NM WRRI in 2012 and, in the Senate, he is a leader in environmental sustainability, water conservancy in the face of severe drought in New Mexico, and the fight to combat climate change.*

*Senator Udall serves on five committees: Appropriations, Foreign Relations, Commerce, Indian Affairs, and Rules and Administration.*

The experience of this panel is broad and deep, and I'm honored to moderate a group of such talented individuals here. Two reasons our panelists have been so successful: First, each has been dedicated to working toward what is best for New Mexico—all New Mexicans—despite representing various interests. Second, each is committed to working collaboratively with all stakeholders.

We're an arid state, but we need sustainable and adequate clean water supplies to survive. As we say in New Mexico, *agua es la vida*. Demand is anticipated to outpace supply all over New Mexico in the years to come. It is vital that all interests—agriculture; domestic, municipal, and industrial users; tribes and pueblos; local governments; and water districts—come together, recognize with clear eyes the water resource issues facing us, and work side-by-side to meet these challenges head on. That means we have a responsibility to future generations to roll up our sleeves and find innovative solutions, and it means compromise. I'd like to start off by asking our panel for their insight and analysis into the challenges before us.

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## Tanya Trujillo, Colorado River Sustainability Campaign

*Tanya Trujillo is a native New Mexican who is currently working on projects within the Colorado River Basin for a philanthropic organization called the Colorado River Sustainability Campaign. She previously worked in public service for the Colorado River Board of California, the Department of the Interior, the US Senate, and the New Mexico Interstate Stream Commission, and she started her career 25 years ago as a water lawyer in private practice in Santa Fe, New Mexico.*

Thank you, Senator Udall, for your leadership on water issues and representation of the state of New Mexico. We appreciate your guidance and assistance. I think you made a good statement earlier today when you said that Congress needs more engineers, so we can try to get that water moved uphill more easily. I appreciate the opportunity to be here and be on a panel with folks that I have worked with in different capacities over the past several years. I currently live in Bellingham, Washington, which is not in the Rio Grande Basin or the Colorado River Basin. I moved up there because my husband got a job, but I wanted to keep working on the Colorado River issues I had been focusing on for the past several years, and I was able to transition to a job working with philanthropy interests that are funding several Colorado River–related projects.

It has been a completely new experience for me and I'm learning a lot about that new world. Philanthropy has been very helpful in filling in funding gaps on some of the current deals in the Colorado River Basin on a case-by-case basis. We've been able to fund projects for nongovernmental organizations working on the Colorado River and have been able to provide funding for research institutions working on technical issues in the basin. We have also been able to fund some conferences and parties and help facilitate some of the fun collaboration that happens.

The highlighted challenge we face, I would say, is to think of creative, new ways of pooling resources together. Particularly in New Mexico, where we have all the same problems as folks have in California, where I came from most recently, but not the same amount of resources, hydrologically or financially. There are a lot of great folks here who have experience working in those multifaceted arenas that involve cities, tribes, farming, and environmental organizations. All of those elements have to come together to achieve a successful outcome. I'm happy to participate today, and I would be happy to focus on some of the Colorado River–specific examples that we have been working on later on as part of the dialogue.

## Paula Garcia, New Mexico Acequia Association

*Paula Garcia is Executive Director of the New Mexico Acequia Association (NMAA). During her years of service, acequias built a movement around the principle that "water is life—el agua es vida" and have achieved water policy changes to protect rural and agricultural water rights. The NMAA has created community education projects to strengthen local acequia governance and water management and to train new and beginning farmers and ranchers. Paula is also chair of the Mora County Commission, an office for which she was elected on a platform of ethics and good government. She recently completed a term as the president of the New Mexico Association of Counties, and she was appointed during the Obama administration to the USDA Minority Farmers Advisory Committee. She lives in Mora, where her extended family continues to operate a small-scale ranching and forestry business. Her son Joaquin is in the ninth grade at Mora High School.*

**Editor's Note: The following paper represents a transcription of the speaker's remarks made at the conference. Remarks were edited for publication by the editor. The speaker did not review this version of her presentation and the editor is responsible for any errors.**

Good morning, everyone. My name is Paula Garcia, and I'd like to thank Senator Udall and the WRRI and New Mexico Tech for this great conference. It is an honor to be part of this panel.

To open up, I was thinking about how much I appreciated the opening presentations by President Wells and Senator Udall, and it linked to a saying I saw yesterday at my son's school. It said, "Learn from the past, live in the moment, and hope for the future." The only addition I would make to that is to hope and plan for the future. I think this conference exemplifies that. As far as living in the moment, Tanya and I were joking during one of our breaks that we're having flashbacks from the eighties because that was the last time we remember it raining like this. We actually had a monsoon this year. In the eighties, that was how it used to be when I was younger. I even saw a turtle in Mora, and if you're a Facebook friend with me, you'll see that I keep posting a picture of that turtle. Live in the moment, but really hope and plan for the future.

I think to plan for the future we have to understand our challenges. In my experience working with the acequias, one of our greatest challenges is adapting to water scarcity. We have some experience in doing that through water sharing that has been going on for centuries, but we need to expand it to a wider breadth and depth. On the Rio Chama, there has been water sharing across the whole basin. It is more than just localized. Agriculture-to-agriculture water sharing has some things that are working, and agriculture-to-city water sharing is much more complicated. That is something I'd like to elaborate on at some point during this conference. There are challenges for research and data, and we have challenges with water issues in the policy that are difficult to resolve in the legislative process. Those are some of the challenges I've encountered working with the acequias.

## John Fleck, The University of New Mexico Water Resources Program

*John Fleck is the newly appointed director of the UNM Water Resources Program. He previously served as the program's writer-in-residence, where he wrote Water is for Fighting Over: and Other Myths about Water in the West, published in 2016 by Island Press. A former journalist, he has written about the science, politics, and policy of water management for nearly three decades.*

Thank you all for coming, and I thank the Senator for inviting me. The last four or five years, I have had the great opportunity to take what started as work on water politics and policy here in New Mexico and branch out across much of the western United States in my work in looking at and trying to understand how water governance is done in a bunch of different places, especially in the states of Colorado, Nevada, Arizona, and California. What models do they have there? How do they work? What is successful about them, and what isn't? How might that apply to us with the challenges we face here in New Mexico? Those other states and regions have a common, important characteristic that we lack, which leaves us with some of the problems we wrestle with day to day. We have a bunch of great suggestions in the Senator's report from five years ago, we have a bunch of pieces of legislation, and we have a bunch of technologies and innovations that we think we would like to apply. What we lack here in New Mexico that I have seen in other states is governance structures and institutions at the right scale to deal with this problem.

Tanya, for example, worked on the Colorado River Board of California, which acts as an umbrella, providing a governance and institutional framework for coordination across a bunch of different jurisdictions. The board provides those jurisdictions the opportunity to get together and work on these collaborative problems where implementation can happen. Southern Nevada, 20-plus years ago, created the Southern Nevada Water Authority. Arizona has the broad Central Arizona Water Conservation District. In Colorado, there are water conservation districts, which are a governance entity that kind of follows the Powell map. As Colorado wrestles with problems, it has a broad institutional structure where it can do these things that need to be done, where it can do water planning, and where it can work out the relationships between the smaller institutions, the cities, and the farm districts within these geographies.

When we try to do these things in New Mexico, we lack those structures. The problem is—and this is the frustrating part for me—I don't know how we make them. I don't know how we build them. In each of the other geographies, they are very situational, very unique, but they have provided much more effective frameworks for wrestling with these big problems than we've got here in New Mexico. That seems to me to be a really important underlying obstacle for us: having the necessary tools to implement the stuff that we all know we need to do.

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## Terry Brunner, Grow New Mexico

*Terry Brunner is the chief program officer with Grow New Mexico. After spending more than 20 years in New Mexico public policy and community development, Terry helped found Grow New Mexico to continue his work to advance New Mexico communities. Prior to founding Grow New Mexico, Terry spent seven years as President Obama's appointee to the position of US Department of Agriculture (USDA) New Mexico State Director for rural development. During that time, he managed investments of more than $1 billion in housing, small business, renewable energy, and utilities in rural areas throughout New Mexico. Before his time at USDA, he served as former US Senator Jeff Bingaman's State Director for seven years. Terry holds a BA in Latin American studies from the University of Arizona and an MA in Latin American studies with an emphasis in community and regional planning from the University of New Mexico (UNM)*

I too, like John, am concerned about sustainability and the future of the institutions that use and manage the water. So much is changing in the federal government and state governments. I know at this conference we have a lot of talk of engineering and hydrology and things like that, but we don't talk enough about how we're going to pay for all of that. The American Society of Civil Engineers rated New Mexico in their recent infrastructure report card and put out the number that we have $1.5 billion over the next 20 years in wastewater and drinking water infrastructure needs.

How do we pay for all of that at a time when the federal government is talking about cutting programs that finance water and water infrastructure? So you have that challenge on the money side for sustainability. But there is also the training, the education, the regulatory upkeep that has to go on locally. Who manages water in our state? If you look at our mutual domestic water users associations, you'll see that people are aging out of the process. Very often if you go talk to a local water board, there are many people in that room or sitting on that board who are in their sixties, seventies, and even eighties. You don't see a younger group of people coming in necessarily, but we need them to come in. What happens to these small systems when they don't have someone who knows how to run that water? The President suggested that small water systems in rural America should be privatized and that's how we should run water. If that's where we're going, that's a big change for New Mexico. How do we create a water system and water-user system that is up to twenty-first-century requirements on regulations but also financing and things like that? That's a challenge.

The final challenge that I see overall is leadership. Very often when I was with the federal government, we were dragged into local water disputes and we were dragged into trying to plan for water locally when that is the job of the state or the localities. We have a time in our state's history soon where we're going to be changing out a governor. We're changing out a couple key mayors and municipal officials. Are they going to have the capability to lead us on water, not just let everybody go off on their own but bring everybody together to collaborate like we've been talking about, and actually map out a sustainable future that takes into consideration these different trends, like the financing trend I'm talking about and the need for training and for people to come in and manage this water? So those are some of the big challenges for sustainability that I see on the forefront.

## Beth Bardwell, Audubon New Mexico

*Beth Bardwell is the Director of Conservation for Audubon New Mexico, the state office of the National Audubon Society. She oversees development and implementation of programs to conserve the state's rivers, grasslands, and forests with a focus on birds and other wildlife and their habitats. She received an MS in biology from New Mexico State University in 1999 and a JD from the University of Oregon School of Law in 1987. She lives in Las Cruces, New Mexico.*

**Editor's Note: The following paper represents a transcription of the speaker's remarks made at the conference. Remarks were edited for publication by the editor. The speaker did not review this version of her presentation and the editor is responsible for any errors.**

I'll add a couple of new threads to the conversation. I want to thank you very much for the invitation to be part of this panel. I remember five years ago—it's hard to believe it was five years ago—and it is still very much a challenging landscape out there for water. Either it is as challenging or I'm just getting older and don't have the energy to rise to the challenges we're facing.

Water is a common resource. New Mexico is a water-scarce state. From an environmental perspective when we look at how we are managing water across the state, obviously the institutions that develop water early on in the century were not focused on what the unintended consequences would be to the environment from water development projects. So here is the conservation community in this new century trying to determine how we can manage water that meets our existing needs. Obviously, food production is very important; urban growth is a big part of our economy now. How do we bring environmental considerations to the table as we continue to manage water moving forward? That's what I struggle with on a daily basis.

The biggest challenge I would like to highlight in response to this question is the decline in federal and state funding for basic science that informs water management, like the Aquifer Mapping Program. Yesterday we listened to reports on the collection of data and monitoring of water up in the Plains of San Agustin, and it was a clear illustration to me how important that data is and how it can inform management, whether it is there or it is the Mimbres Basin or the Rio Grande.

Collectively we need to think carefully about how we can increase funding for basic science to inform water management.

I also work a lot on environmental water leasing projects. Our approach has been to work collectively with the water managers, who deliver water for food production in the state, and talk to them about opportunities to temporarily reallocate some of that water to increase flows in our rivers. We know it is an important issue for New Mexicans. When we poll on this issue it rises very high on the list of people's concerns. What's happening to the health of our river?

We were looking at market-based strategies to work with water right holders—it's a private water right here in the state. How can we incentivize temporarily reallocating that water for environmental benefit? We think there is a lot of opportunity and benefit both to the irrigation community and to the state as a whole. We've run into problems moving that program along. Sometimes the agencies don't have the capacity to handle water transactions, so there may be something we can do to facilitate that. We have also been pursuing private water leases at this point and trying to use voluntary transactions between Audubon New Mexico and private water right holders to demonstrate the benefit and the interest in water leases for environmentalists.

## Myron Armijo, Office of the State Engineer

*In his role as tribal liaison, Myron works on a day-to-day basis with matters related to Indian water rights settlements and provides assistance with water issues related to each tribe, pueblo, or nation. His role is to educate Indians and non-Indians regarding the difference between state-based water rights and tribal water rights to facilitate future settlement negotiations, emphasizing conservation. He also works to resolve disputes without costly litigation by coordinating outreach activities, including state water planning through the State-Tribal Water Institutes.*

Senator, good morning. Senator, thank you for having me here this morning. I appreciate being here.

My challenges are going around the state and dealing with all 23 tribes across the state. I see water infrastructure and the need for it, not only on the reservations but also in areas where everybody else lives, areas like Magdalena where people's pumps go out and they have to boil water. I think Beth talked about shrinking dollars both at the state and federal levels. We have to convince legislators, congressmen, the governments to provide more money for these issues. In certain areas of New Mexico, people are living almost like in third world countries, having to deal with water shortages and not having enough water. Many of us can just turn on a spigot and have a glass of water or take a shower, but there are many areas throughout the state where there are water shortages and infrastructure is sorely needed. The fact that we don't have those funds available makes it tougher for those people to live a normal life like everybody else.

Second, I'd just like to say a little about the collaborative efforts by state and government agencies working with tribes, pueblos, and nations throughout the state. I think it is great that we do the outreach and get to those people who try to bring their ideas and their needs to a level where we can try to address them. However, we've had many of these sessions throughout the years. Like this session right here, right now, whatever the outcomes are, if there are ideas my concern is and question is do we act on these outcomes and ideas or do we not? Are there solutions to these water issues, and if there are, why don't we act on them?

Climate change is real. For instance, at Santa Ana over the course of last year, we had really good water in my area and then this year, we barely had enough rain to sustain the range. I think climate change is real, so we need to try to solve these issues, but when we have these conferences and meetings, we've got to take these ideas and act on them and find solutions and provide funding for those processes. Thank you, Senator.

**Sen. Tom Udall**: Myron, thank you. You bring up the federal government's trust responsibility to tribes in New Mexico. We have many of these settlements that people have worked on for years, litigation back and forth, and then finally a settlement at the federal level. One of the big pushes we have is to get the dollars in line to make sure to keep those projects going, whether it is Aamodt or it is the Navajo-Gallup pipeline. Eastern New Mexico has a pipeline they are pushing. All of those we are trying to juggle, and it is a tough thing to juggle when it comes to the federal budget and putting those resources in place. No doubt.

Several of the panelists mentioned the report that we did. My next question is about the things we highlighted coming out of that. Five years ago, we all came together and asked: What are the things on which we need action to be taken? The answers to that question included research, data, and monitoring; water sector infrastructure; water transfers and water markets; environmental restoration and water quality; water leasing; agricultural practices; water conservation; and water resource planning.

Here we are five years later. I ask the panelists: Where have we made progress? Where do we still need to work? How can we do better in the next five years and beyond?

**Paula Garcia**: Well, first I want to thank you for writing the report. It was an excellent report, and like Governor Myron Armijo, I think we all come to these gatherings hoping that there will be some actionable steps we can take. I think your report was a big contribution to that.

One research project I'd like to mention is some work done by New Mexico State University (NMSU) to study the connectivity between irrigation canals and aquifer recharge. That's just one example in which we had more of a traditional view of water. There was a heuristic sense that this was happening, that there was some benefit to having irrigated agriculture in these canals, that they were helping to recharge the shallow aquifer. But that idea needed to be backed up by science. Through a years-long process, NMSU was able to conduct that research, and we are still exploring how that research can be applied in a policy setting, but it is one example of work done in the last few years.

The report also gave a good assessment of how complicated water transfers are in the state. In agriculture, it is extremely complicated. The report identified that transfers can be controversial because they imply a zero-sum game if you're not careful—if you just take water from here and move it to there. What we're trying to move toward in New Mexico is a water transfer system that is not a zero-sum game, one in which there can be some mutual benefit or some collaboration on how decisions are made. It is a work in progress, and the panelists can probably share examples of where that works better than others.

Different regions of the state come at water transfers from different places. From the acequia perspective, most of the time acequias try to prevent water transfers. That is not to say that every water transfer is bad. They are all weighed on a case-by-case basis to see what the benefits are. Sometimes transfers are to mutual domestic water associations; sometimes they might benefit some other public good that the community deems important. Acequias have the opportunity to weigh in on water transfers because we have a layer of regulatory protection—we inserted ourselves into the application process through statute. It is complicated, and in a lot of cases, you still see agricultural communities protesting transfers.

One of the places objections to water transfers play out is in the legislative arena. Sometimes I look at the legislative process as a barometer of water policy issues in the state. In the last two years, there have been pieces of legislation dealing with transfers. There was one bill, related to San Agustin, dealing with interbasin appropriation of water from one area to another, a new appropriation. There was also a piece of legislation trying to democratize the Albuquerque Bernalillo County Water Utility Authority because of community concerns that they didn't have a voice in the commission and the council-appointed board. That was rooted in a conflict over the Santolina development. There was another bill two years ago on water leases, complications over how that is done, and debates over whether leasing should be expedited or to what extent stakeholders retain due process, so there is a natural tension between the need to move water and the need to protect the communities that are dependent on it currently, the move from communities.

Those tensions are definitely playing out in the policy-making arena. Sometimes even if bills don't pass, I still see a positive outcome when you build understanding and stakeholders are forced to interact with each other. Even if you reach a stalemate, everyone comes out of that with more understanding and where the issue might go in the future. I think that the report was a contribution to that kind of understanding. The issues are still developing and the work is still in progress, but we are still engaged.

**Beth Bardwell**: I'll speak to a couple areas where I think we have made progress. Credit goes to many of the people in the audience who have spearheaded these efforts. One area is integrated water management across the basin. Through the SECURE Water Act and WaterSMART grants, the Middle Rio Grande Basin and Bureau of Reclamation have prepared and submitted a plan of study for the basin, and it is awaiting a funding decision from headquarters. That type of effort—where multiple stakeholders convene, looking at what changes in water supply and demand can be anticipated because of climate change, how we are going to address those water shortages should they appear, where can we find flexibility across sectors, and where can we build resiliency in how we manage water in the state—deserves a lot of applause and recognition.

The Middle Rio Grande Conservancy District (MRGCD) and Bureau of Reclamation also worked together on a collaborative agreement for a $10 million, five-year study to look at opportunities for voluntary environmental water transactions in the Middle Rio Grande Basin and for improvements in irrigation efficiency, helping farmers who want to improve on-farm efficiency as well as system efficiency.

**Myron Armijo**: I think what makes a difference also is the leadership of people who manage the water. There is new leadership at MRGCD and the Bureau of Reclamation as well. I would like to see that collaboration with the tribes, pueblos, and nations not only in the middle valley but also throughout the state of New Mexico. We are all constituents of this great state, so if we were able to continue this collaboration, I think we would be able to better manage our water.

**John Fleck**: One of the interesting examples in the world I've been traveling over the last few years is the state of Colorado, which has a couple of governance creatures that provide tools to accomplish the kinds of things we're talking about. They have these large things called *water conservation districts*, which are these entities of government that span a watershed boundary. They have a second thing called *basin roundtables*, again a creature of government. In both of these cases, what you have is an existing governmental structure that was developed to provide an institutional framework for dealing with the issues arising from the competing and conflicting shared water interests among municipalities and agricultural users in the environment.

So when they want to do something like think about how to allocate water for an instream flow for environmental purposes, how to do deficit irrigation or fallowing, they don't have to build from scratch the institution to accomplish this. These things already exist, and really importantly, these things also serve as a centralized place to act on behalf of the interests of a basin, to defend the regional interests, when another basin wants to take their water. Colorado is really big on building pipes and canals to move water from one watershed to another, so they've developed this set of institutions that can look out for the interests of one region. And again, when we try to have that conversation here in New Mexico, we don't have the institutional structures. We have to build these one-offs. We try a new piece of legislation to deal with the Plains of San Agustin water transfer; we don't already have the existing governance institutions. These seem to work best at that regional or bottom-up level, rather than trying to ask the state governments to do it for us. I don't have a lot of confidence that we can do that from the state level down. Again, I throw up my hands—I don't know how to build these things, but they seem really important and we seem to lack them.

**Terry Brunner**: I have something to add to what John was talking about, thinking back to the report, which was written during the drought, and now we're in this wetter period. Many of us talk about the drought's effect on people's changing habits. How have agricultural users changed what they do because of the drought? How has the city of Albuquerque changed what they do? Are we going to learn from that and make the type of adjustments that we need to make to be more sustainable in the long run?

What John is talking about is important from my standpoint. I look at the institutions we have and the structures we have. Many of these structures were formed in the 1920s or 1930s, and we're relying on the same ones. Bill Richardson passed legislation to allow regionalization of domestic water use associations and cities and counties—regional water systems. We've only had a couple regions try it. It is fascinating to me that more have not jumped on board and said, "We want to regionalize, because it is more efficient, because we use water more wisely, because we are more sustainable financially." When these new types of ideas come along, we have to do a better job of jumping on that bus or checking it out or moving something forward, or we are going to remain behind the game, rather than ahead of the game.

In some states, you see them planning for the future with the knowledge that they've gotten most of what they need taken care of. We're still trying to take care of what we have to take care of before we can think about the next steps. How do we get to that better position, where we've advanced ourselves to the point where we can think about the future more than trying to remedy the problems from the past?

My big complaint is that we fund water systems piecemeal. A small community I worked with in northwestern New Mexico, a few thousand people, desperately needed a wastewater system. It was funded back in 2002, with USDA funds, and it is still not done. In that 15 years, regulations have changed, the Environmental Protection Agency (EPA) has changed, and how we treat water has changed. The community is constantly trying to catch up to get their project to be viable by today's standards. Part of the reason they have not completed the project is that the legislature would only give them $50,000 a year for a $6 million project.

We still fund things that way, which is not a sustainable practice. It is like herding cats to get these different pots of money and legislators and state entities and federal entities to play together to finish projects. My example of a finished project is the Ruidoso wastewater project, which is about a $10 million project for which they had been seeking money for years. When the Economic Stimulus Act of 2008 came around, they were ready to go. They built that wastewater plant. It was state of the art, and they are done. They are sustainable for a few more decades, and they reinvigorated the river in town through their sustainable, innovative practices. That's what we should strive to do. When somebody does have a wastewater project—Socorro has a wastewater project, for instance—we should finish it. We should get them in a good solid position to move into the future.

**Sen. Udall**: Thanks, Terry. I'm reminded by something Terry said in terms of talking about progress and how you change habits in a drought period. One of the things we've seen happen with New Mexico cities when they really hit a serious drought is that conservation efforts, including decreases in individual water users' usage, are dramatic. Las Vegas reduced water usage to 60 gallons a day per person, a real serious crunch. They stopped nearly all outdoor water usage. Santa Fe moved down to I think about 120 gallons a day per person. Albuquerque was higher up near 200 gallons a day per person. The progress that has been made on that conservation front is pretty striking.

**Tanya Trujillo**: I think that's right. There have been great examples of how we have made progress in several areas, but the challenges still exist. Trying to capitalize on, use, and build off of examples where things have been done well someplace else makes a lot of sense. I'd like to emphasize this concept of training the next generation. Places like New Mexico Tech, NMSU, and UNM are training students, but keeping those students here in New Mexico, giving them an opportunity to get their feet on the ground, and getting them into the districts where the senior folks will be retiring soon may be one of the most pressing needs.

I also wanted to comment with respect to some of the ongoing challenges on very sticky issues, like Indian water rights settlements or the other very contentious fighting that goes on sometimes in complicated settings. We need to use models from other areas where a neutral mediator has come in to diffuse the conflicts. We could also incorporate concepts such as the use of committee structures. The joke is that it is always great to have small groups, if you're in them -- but the problem is we have to have a large, inclusive process which means not everyone can be in the small group. One of the solutions has been to utilize committees or subcommittees that can report back to a larger group to help make sure there is an inclusive process in those types of settings.

**Sen. Udall**: Tanya, we've heard you and several others here mention the idea that experienced people are leaving and younger people aren't coming in. What this highlights for me is that today we are faced with a public and government service ethic problem. I see this being true in water resource management; it is also true across government. Many of these key government agencies—the EPA, agencies within the Interior such as the National Park Service and Bureau of Land Management—tell me the same thing. We're striving to find young people. This is one of the things I find disturbing about the tone of people who dismiss the government and make government the enemy and make government the bad guy. In so many cases I see, it is these experienced government people out there trying to pull people together, trying to collaborate, trying to get people to a solution. As leaders, we need to continue in every public service way possible.

Several of you mentioned it—our speakers in the beginning, Dr. Wells, and Sam Fernald always bring this up—we know we face significant challenges when it comes to climate change. What needs to be done in the next decade to address and adapt to the impacts of climate change? I hate to have you sandwich that in so quickly, but any final, quick comments on that would be greatly appreciated.

**Terry**: I want to emphasize what the Senator said about participation. It is crucial. You have to consider that most people in this state get their drinking water from a mutual domestic water user association, with a volunteer board and maybe a volunteer manager in a sense. Those folks are aging out of the process. Water is something that should bring the community together more than anything else because we all need it. We require it every day. What we see in our society is so much talk about individualism. It is hard to drag people in to volunteer to serve on a board where they bill their neighbors and have to collect payment from them for water. That's hard to do, and a lot of people resist that. I think most everybody in this audience understands how crucial that is.

Who is going to run these water systems? Are they all going to become private, or are we still going to have this community sense to them and how we conduct water management in the state? It is important that the message get out there—that these types of roles and jobs, serving on the board, serving on the neighborhood association, are important. But it is harder and harder to get people to do that. That concerns me greatly, so I wanted to put extra emphasis on it because the Senator brought it up. I think it is a really important point, because we do give government a bad name sometimes or we are dismissive of volunteering in the community when it should be the opposite. The opposite is sustainable, where we have people involved in their government, involved in their community, participating, having a voice.

One of the things that people always ask is how we can influence the next administration or mayor of Albuquerque or governor. I always tell them, *participate*. Join a board and commission. Get involved. Write a letter. Go to the meetings. Bring your son or daughter, or grandson or granddaughter. These are really important topics, and participation is crucial to making water run correctly in this state.

**Mryon**: Senator and panel, my position on this is that we need to start talking more about climate change. I know there are many forums discussing this issue. However, in the tribes, pueblos, and nations, right now as we speak, water is being used in some ceremony somewhere. It is Zia Pueblo's feast day today, and I guarantee you that the ceremonies included water this morning. On the Rio Jemez, we're seeing some issues of *E. coli*. Where is that coming from? Is it animals that contribute to *E. coli* in the river? That makes a difference to the people who do these ceremonies. They are apprehensive—do we use the water, or do we not? I think we have to start figuring out how we sustain these rivers and our watersheds going forward.

I have an interesting issue I came up on with two women from Michigan. They were looking for the capitol building. I was going to the state engineer's office, and they were standing outside looking around. I asked whether I could help them, and they said they were looking for the state capitol.

I told them they were standing right in front of it, to go in, look around, look at the art. I asked them where they were from, and they said they were from Michigan. I said, "What a deal I have for you! Why don't we build a pipeline from your lakes and bring it to New Mexico?" They said, "No way! No, we're not bringing water to anybody, to New Mexico." These are things that we really have to think about. I appreciate you, Senator, for bringing this forum together and Dr. Fernald for this conference. I think there are going to be some great ideas coming out of this conference. We just need to collaborate more and work with each other going forward.

**Paula**: Thank you for this great panel. What I think Governor Armijo was referring to is this urgency around climate change, around water scarcity. I want to affirm that there is important work going on, and at the same time there is a need to translate that into policy solutions. Even though I deal mainly with surface water rights, there is urgency around depletion of our aquifers. Getting a handle on that is important. I was participating in our regional water planning group in my area, and it was good to have a common technical platform to work with, but I think we all wished that we knew more. I think once we see more data, we will get a sense of that urgency.

I also think, speaking of that planning effort, something John said about governance and having different frameworks for governance resonated with me. The acequia association has been working for almost 20 years on our acequia governance project, because it is about instilling an ethic of service. There has to be a real generosity of spirit to be in public office and to be in public service. Here in New Mexico, I think we need to cultivate that through leadership development in all aspects of government, but in particular with water, so that people have some knowledge about water, know the vocabulary, can share a body of knowledge about water law to a certain extent and hydrology, so that we can make good decisions at the local, regional, and state levels. There is a lack of regional decision-making at the basin level. One way that the acequia association has addressed this is to form regional acequia associations. They are necessary in order to negotiate during the adjudication process, but to get them to participate at the level of policy-making is challenging because, again, they are all volunteer. You see a disparity between institutions that have staff and rural communities, mainly, who don't have staff. The mutual domestic water associations, acequias, and agricultural communities are run by volunteers, and they are very important water stakeholders. We need to build some better sense of equity into our planning and policy-making processes so that all voices are heard.

**Sen. Udall**: Thank you, Paula. Let's just think for a minute. Every day, when each of us turns on the tap and water comes out, we, as a society, should think about and understand the hard work that was required in communities and in ecosystems to make sure clean water came to the tap. And at the same time, recognize that the resource taken from the ground must be passed on to future generations.

# New Mexico Water Update

Tom Blaine, New Mexico State Engineer

*Tom Blaine is the New Mexico state engineer and is well versed in the critical water issues facing New Mexico, bringing a career of engineering experience in the private and public sectors to the Office of the State Engineer. He recently held the position of director of the Environmental Health Division in the New Mexico Environment Department. His background includes extensive experience in civil and transportation engineering, with service to the City of Albuquerque as a senior civil engineer as well as to the State of New Mexico with both the Department of Transportation and the Office of the State Engineer, and in the private sector. Between his years of public service, Blaine also owned and operated his own engineering firm, focusing on surface and groundwater hydrology and water distribution systems. He holds a BS in engineering from New Mexico State University.*

**Editor's Note: The following paper represents a transcription of the speaker's remarks made at the conference; no follow-up papers were submitted by the speaker. Remarks were edited for publication by the editor. The speaker did not review this version of their presentation, and the editor is responsible for any transcription and editing errors.**

Good morning. I see that this is going to be a monologue, not a dialogue. It is really a pleasure to be here this morning. Some of you will remember this from Sons of the Pioneers. Remember that singing group, back in the thirties?

All day I face the barren waste

without the taste of water

Cool water

Old Dan and I with throats burned dry

and souls that cry for water

Cool, clear water

Keep a'moving Dan, don't you listen to him Dan

He's a devil, not a man

and he spreads the burning sand

with water

Dan can't you see that big green tree

where the water's running free

And it's waiting there for you and me

I start this way because in New Mexico we have always had a precious resource in water. We've always had tension with water. In shortages, we have to come together and determine how we are going to share the little bit of water that is there. Typically, in New Mexico, we do that. We have shortage sharing agreements that stretch back to before statehood. Water is the one resource in New Mexico that is so precious that we need to be very cautious about how we develop it. Water rights are the basis. The state constitution says that beneficial use is the basis, limit, and measure of any water right. Water rights give you certainty to economic development, give you certainty to productivity in small businesses.

In this last year, I signed an order that licenses water rights in the Lincoln National Forest. This is to protect ranchers' water rights. The purpose of the order was to recognize long-standing uses of water in the Lincoln National Forest by cattle growers. In order to have a licensed water right for livestock watering, the allottee or the rancher had to have applied water to beneficial use prior to 1907 and exercised that right continuously for livestock watering, with some provisions to that. The license our office issued allows the rancher to continue the appropriation of water from streams and springs within their livestock grazing allotment. That may not sound like a revelation to anybody here. Ranchers have been stocking the land and grazing the land and, when necessary, developing water sources, but primarily if there is a stream running through the land, they just let the livestock drink directly out of the stream. This is significant, however, because we have licensed a water right for the appropriation of water that is not from a man-made or defined source. Ranchers can use water from any water source within their livestock grazing allotment.

New Mexico state law says you have to have a point of diversion to have a water right. The purpose of that point of diversion was that it gave notice to other water users in your area that you were going to appropriate water. Prior to 1907, the laws required that a notice of publication be advertised. The notice that you were constructing works was sufficient to properly notify other irrigators or other water users on that stream system that the water was going to be appropriated. If they felt like there was going to be impairment, then they could file a complaint in the district courts or the territorial courts. The order I signed licenses a place of use for surface water for livestock watering. There are significant limitations placed on this license because you cannot change the purpose of use. It has to remain as livestock watering under the license, and you can't change the place of use. You can't transfer the water; it has to remain on the land for the purpose it was developed for. That's significant because it allows that rancher certainty to that source of water and a continued use for cattle production.

This issue came up because of tension between the National Forest Service and the ranchers. The National Forest Service identified some habitat that was good for the New Mexico meadow jumping mouse, which is an endangered species in New Mexico. They constructed fences and fenced off stream water sources from the ranchers. Ranchers were not permitted to continue to exercise the process that they had developed over the last 150 years of grazing cattle of allowing the cattle to drink directly out of the stream system. They were restricted from that. In order to protect the rights of that rancher, we issued a license that identified the quantity and the location for water appropriation for that purpose.

I'd like to mention another significant thing that has taken place recently. I don't know if anybody has heard about the Aamodt Water Rights Settlement. If you haven't, it's only been going on for 50-plus years. It is an adjudication that was started under State Engineer S. E. Reynolds, and what he couldn't finish, I did. I'm just kidding! It was a long process. It was a process of adjudication, negotiation, settlement, and working with four pueblos in northern New Mexico and the general public to adjudicate and identify all of the rights within that stream system. The United States District Court entered its final decree in July 2017, ending that 51-year-long adjudication. Part of the adjudication was settlement of water rights for the pueblos. The San Ildefonso, Nambé, Pojoaque, and Tesuque Pueblos are all within that region, and negotiation and settlement of their rights had to take place for the final adjudication. As a result of the settlement, 4,000 acre-feet of water had to be transferred into that area from other places in the basin, involving retirement of rights, because the Rio Grande system is fully appropriated. Rights had to be retired and transferred in the amount of 4,000 acre-feet, 1,500 acre-feet of which is going to be used for a public water system that will serve both Indian and non-Indian needs within that area.

The construction of that water distribution system will primarily be paid for by the United States as part of the settlement. The estimated cost of that system is a little over $200 million. That's a lot of jobs and economic development coming into this state over that one project. Of the $200 million, about $60 million will be paid for by the state and county.

One of the commitments I made to the legislature in February 2015 was to reduce the backlog of water rights by 50 percent by December 2015. There were a lot of complaints about backlogs on water rights. At our highest backlog, we had over 1,500 pending applications. Once you get a stack of 1,500 applications that need action on them, you name the pile, and just say, "I'll put it on the orphan pile, because we're not going to get to it.". My staff screamed like a wounded panther at that commitment. They said, "We can't do that. No way!" I said, "You're absolutely right. You can't do it unless you get started."

We formed a team that reevaluated our review processes. I put a deadline in place: when an application was filed, my office had 10 days to review that application to determine whether it was complete. We also developed a template system that would allow us to review memorandums and develop recommendations quickly. We improved our peer review process. We blocked out hours where our water rights staff would work on nothing but the backlog. During certain hours of the week, that's all they did. We retooled the application forms, and we simplified them. We reduced the number of forms that had to be filed, and we developed new basin guidelines and new hydrological guidelines to help assist in moving through the evaluation process more rapidly.

Managing water in New Mexico in the future is going to take cooperation, collaboration, and people coming together with the same common goal. We have four million acre-feet of water that we use in this state every year. Two million is appropriated in groundwater and about two million in surface water. If we doubled the amount of water available to us, what would that look like? What could we do with that? The groundwater aquifers that are not tied to stream systems are under groundwater mining conditions. That says we are planning for them to go dry. That's a serious issue that we need to look at. What do we do? How do we get more water into this state? Because without water, we don't have economic development.

There are four things I say that we can do to improve our water situation in New Mexico. First is conservation. We need to conserve water. Second is water reuse. Pump the water once, and use it a couple times. Those two things just push the curve down the road a little bit. That's not sustainable. The third thing is desalination, a developing technology we see worldwide. New Mexico has tremendous resources in saline water. We need to look at developing those water resources to extend the life of our water in New Mexico. The fourth thing we can do is water importation. If you want to cause strife, go to Colorado and say that we need some more water to import into New Mexico. Well, they are fully appropriated. We can't reduce the amount of water that we deliver to Texas on the Pecos or on the Rio Grande. What do we do? We have to get creative on solutions for water importation.

I've heard chatter going back to the forties and fifties of building a canal from the Mississippi River all the way out to New Mexico and the Southwest and scalping floodwaters off of that river. Is that a stupid idea? I don't know. I've heard talk about building desalination plants in the Gulf of California and the Gulf of Mexico, desalinating seawater, and piping in that water to the Southwest. Is that a stupid idea? I don't know. Those kinds of projects become more feasible as water shortages become more critical. One of the current efforts in water conservation and water reuse is the aquifer reinjection and storage system. There are five projects in New Mexico totaling almost 10,000 acre-feet of water reuse and reinjection of water into the groundwater aquifer. It is wastewater that has been treated that will be repumped at some time in the future.

We heard the last panel talk about cooperation and consensus building to solve our water problems in New Mexico. One of the biggest areas high on my priorities is the Indian water rights settlement. That is one of our top priorities for New Mexico because it helps identify and gives us a baseline of how much water is going to be used and needed in the future by our tribes, pueblos, and nations and the citizens of New Mexico. That is done through the adjudication process. We have 24 tribes, pueblos, and nations in New Mexico. Out of those 24, there have only been 7 Indian water rights settlements to date. That means we have 17 more of these to do, and they are labor intensive. They are tough issues to negotiate. They are very difficult issues to solve, but these are things that we need to pour our resources into to ensure that they are completed in a timely manner.

I want to go ahead and wrap it up with that. I sometimes fashion myself as an unsophisticated poet, and I melded some verses from a song that John Hawley emailed to me a few months ago and kind of developed a new theme for New Mexico and water in New Mexico. It goes:

There is a place where nothing grows

'cept old mesquite and horny toads

It rarely rains and seldom snows

The goddern wind just blows and blows

But here I's born and here I'll stay

I'm too darn poor to move away

So I'll work all day
And at night I'll pray
To bring some green
to this desert state

Viva la New Mexico!
You are the place to be
With mountains high and valleys deep
And skies so blue to see

Where winter snow
brings springtime's flow
And blessing to the crops we grow

Our rios once so very grand
Are oft reduced to streams of sand
So we'll adapt and never leave
For our hearts are in this land

We do believe
But here I's born and here I'll stay
I'm too darn poor to move away

My well's gone dry
My dog's astray
But I love this state
'til it blows away

As the engineer of water, I shall take care
To ensure to all the resource to share
For water is sacred and shortage brings strife
But sharing the resource brings the spirit of life

# Interview with U.S. Senator Tom Udall and Brad Udall, Colorado Water Institute, Colorado State University

Tom Udall

*U.S. Senator, New Mexico*

Moderated by Sam Fernald

*Director, NM WRRI*

## Brad Udall, Colorado Water Institute

*Brad Udall is a senior water and climate research scientist/scholar at Colorado State University's Colorado Water Institute. His expertise includes hydrology and related policy issues of the American West. He has researched water problems on all major southwestern US rivers, including the Rio Grande, Colorado, Sacramento-San Joaquin, and Klamath, and has spent six months in Australia studying their recent water reforms. Brad has written extensively on the impacts of climate change on water resources. He was a contributing author to the 2014 Intergovernmental Panel on Climate Change report, was the lead author of the water sector chapter of the 2009 Global Climate Change Impacts in the United States report, and was an author of the 2008 Climate Change in Colorado report. He has provided congressional testimony, input to several National Academy of Sciences panels, and has given hundreds of talks on climate change impacts. Brad was formerly the director of the Getches-Wilkinson Center for Natural Resources, Energy, and the Environment at the University of Colorado Law School, the director of the CU-NOAA Western Water Assessment, and a consulting engineer and principal with Hydrosphere Resource Consultants.*

**Sam Fernald**: We're going to have a fireside chat here with the senator and Brad. We're going to hear a little bit about their perspectives. We're just going to start with some questions, and then they're hopefully going to take it away. We'll get through a number of these questions, but we certainly don't have the time to get through all of them.

Water policy has been a part of each of your lives since your earliest days, whether you wanted it to be or not. Your dinner table conversations probably had a little more water policy than some of ours, but much of what shapes our views of these natural resource issues is not just the policy we learn but the experiences and memories we have. What are some of your earliest memories or events that may have shaped your views on western water policy?

**Senator Tom Udall**: Brad, go ahead, but I just want to remind everybody how we're related since we're both Udalls. Stewart Udall is my dad and he had six kids. Mo Udall is Brad's dad, and there were six kids in their family as well. Our fathers were close but our mothers were very close, we grew up like brothers and sisters. This event was a good idea, and I am happy to be here.

The other qualification I want to make is that Brad is a real water expert. You can take everything I say with a grain of salt, but this guy is a serious water expert. He's done it all his life. Brad, why don't you lead off on that question?

**Brad Udall**: I'm a Modall, and he's a Sludall—Stewart Lee Udall being "Slu." Sam, first I want to thank you for having me down here, and I have a question for you. You had Tom give a speech, he's moderated a panel, and he's now on the hot seat. It kind of seems like you've got some really good compromising material on him. I'd kind of like to know what that is. I think they call that *kompromat*, maybe.

**Sen. Udall**: Don't reveal that, Sam!

**Brad**: My earliest memories are of my father, who at the time when I was a little kid was working on the Central Arizona Project in Arizona. This project was long a dream of the state, because it could not use over half of its Colorado River supplies without this 330-mile, 3,000-vertical-foot canal that they had wanted since statehood. My father, as a very junior representative in the early 1960s, was tasked with getting this project thru Congress. He was one of two representatives in the US House, and it was his job to get this thing through the House. In 1964, that became a possibility when the Supreme Court ruled on *Arizona v. California* and gave Arizona a defined water right to the Colorado River. My father and Representative John Jacob Rhodes then led the battle in the US House, which, frankly, was where the battle on this was. The Central Arizona Project bill had actually passed the Senate in the fifties, but at this point in time, California had something like thirty-four representatives in the US House and there were two lonely representatives from Arizona. California, by god, was going to defend its water rights on the Colorado River. My earliest memories are of him working with Wayne Aspinall, who in my father's mind was the dastardly chairman of the House committee through which this bill had to pass. He would tell stories about Wayne Aspinall when I was a little kid that I remember to this day. Those are some of my earliest memories.

Later I became a Grand Canyon river guide. I want to delve into this a little bit later—the story of my father and Tom and Stewart's education on the Colorado River and how they grew up in this little tiny town in northern Arizona, St. Johns. They were farmers, and water was the lifeblood of that community. They thought that dams in the Grand Canyon were, by god, a great ol' idea, and we needed that power to power the Central Arizona Project, and that's what they were going to do to get this thing done. David Brower, at the time the head of the Sierra Club, and the American public quickly disabused the two of them of the notion that dams in the Grand Canyon were going to work, and that this was a good idea. So that's some of my earliest upbringing, and there is a lot of material in there, but I'd love to hear from Tom.

**Sen. Udall**: I'm playing off a little of Brad here because the same thing was true in my family. First of all, my dad would always talk about St. Johns. St. Johns, many of you may not even know, is right on the Arizona–New Mexico border. It is a community that was settled by my great-grandfather, David King Udall. As a Mormon pioneer, he got the call from the church, and he led a wagon train of 40 families in the 1880s from Kanab, Utah, down to St. Johns, which as you know, you've got to cross the Colorado River to do. You do it at Lees Ferry. You're doing in the 1880s. I think it was a tough deal to do. You can imagine.

When they got to St. Johns, exactly what Brad's talked about, it was this hardscrabble community. I think the population peaked out at 1,500 all the way through my father's high school years all the way back there in the twenties and the thirties. He used to talk about the Great Depression. He said "There wasn't any Great Depression in St. Johns. We were depressed the entire time." The Little Colorado flowed right through St. Johns. In reading the history, one of the things that I think was remarkable, that everybody would talk about, is why anybody would stay in this community. Every couple of years, they'd set up earthen dams to irrigate as farmers and then they had cattle and their own gardens and everything. They were just living off the land. That's why they never got depressed; they just had the same lifestyle. Those earthen dams would wash away. People would say, Why stay there? This place was rugged; it was hardscrabble. You really had to work. Why didn't they leave? You always had Dad talking about that.

Later, on the river trip part that Brad talked about, we went down in 1967 as a family, all of us. We did joint family vacations and things. Dad was doing this as family business. He was Secretary of Interior, and he was looking at those dams. Just like Brad said, he was for Bridge Canyon, he was for Marble Canyon. When he took over as Secretary, they were already in the planning process. Commissioner of Reclamation Floyd Dominy was going to build those dams. My dad got educated on the crisis, and he listened and he had an open mind and he finally concluded that the dams shouldn't be built. That '67 trip and the experience of floating down the river seeing this majestic canyon—if anybody hasn't done it, you've got to do it—changed his mind. We got to the dam sites and realized water was going to back up into the canyon. My dad had organized the whole thing, so he flew out in a helicopter after being on the river and announced, "We're not building those dams." That was one of his proudest moments, but, boy, he had to eat a lot of crow—right, Brad—doing that, because the whole Department, Floyd Dominy, and all the dam-building folks at the Bureau of Reclamation were oriented in that direction.

**Brad**: Aunt Elma used to say that the most distinguishing feature of St. Johns, Arizona, was the sign that said Resume Speed.

**Sam**: Have any of those early views been reformed or reshaped in your time working in the academic and political fields that you each inhabit?

**Brad**: Sure. As a young person, you view the world right through black and white lenses, and as you grow up, you realize that the world is a very gray world and that there are all different kinds of people out there and that, frankly, ignorance reigns supreme and you need to educate yourself as much as you can. I think that is one of the themes of my father and Stewart. Because if you looked at those two in the 1960s, you would never come up with the term *environmentalist* with their names, and yet later through their careers, that was the moniker that got applied to them. I think they greatly grew through that harsh period in the 1960s when David Brower, for example, at the Sierra Club had formerly lost not one, but two battles on dams in historic places. Arguably three—Hetch Hetchy at the beginning of the Sierra Club, but that's not Brower. That's John Muir himself. Then there was Echo Park in what is now Dinosaur National Monument. Instead of putting a dam in Dinosaur, they went and put it in Glen Canyon, which no one knew about. Eliot Porter wrote this beautiful Sierra Club picture book called *The Place No One Knew*. Even the National Park Service didn't know the values of Glen Canyon. Glen Canyon is a National Park Service quality land we submerged, thinking it was a better trade-off than putting a dam in an existing national monument.

My father and Stewart got educated through this process. Barry Goldwater, who was one of the first people through the Grand Canyon in rafts and boats, was part of that education. David Brower beat sense into them with ads in the *New York Times*, full-page ads that said things like "Should we flood the Sistine Chapel so tourists can see the ceiling better?" The idea there is a reference to what my father would say: "You'll actually be able to see the Grand Canyon better from the lakes than you can from the rim." Folly, just idiocy, not understanding the resource that was down there.

One of my father's favorite statements was "I may not have seen the light, but I certainly felt the heat." I think that applied to some of the pressure he felt on the Grand Canyon. Again, understand, he was a representative from Arizona. This was a project that they have staked their future on, and it was his job to get this done.

**Sen. Udall**: The part that Brad's talking about here, in really broad picture, is that the federal government was just moving forward on these things like Glen Canyon, like when they finally passed the Central Arizona Project. I mean, people had been fighting for the Central Arizona Project for years. At the same time, what happened was the birth of the environmental movement. Rachel Carson wrote her book *Silent Spring*. It came out in 1962 on DDT and what it was doing. You had the Cuyahoga River catching on fire in Ohio. You had people getting mobilized. You had these westerners—Slu and Mo—that were out there, and to their credit, I think they had open minds and they were feeling the heat on this thing.

The story I have about Glen Canyon has to do with floating it when I was very young, before they shut the Glen Canyon dam. Frank Wright was one of the great river runners on the Colorado. You should look him up—just an amazing guy.

He took my father and my younger brother, Scott, and my mom down Glen Canyon before they shut the dam. The dam had been built, but they hadn't closed the dam and Glen Canyon was not flooded at this point. Frank Wright hoped to convince my father—I think he knew it was a long shot, and everybody hoped maybe Dad wouldn't shut the dam—but it was a done deal. My father after floating down the river was horrified of what would happen. He didn't see the great benefits of raising the level on Glen Canyon and looking up at the walls. It was just too marvelous the way it was, and so he always regretteed what had been done. The trade-offs in water are the big thing. We know Glen Canyon has created Lake Powell, which is an incredible recreational resource and the source for an unbelievable amount of power that goes to the various cities in the region and then regulates the water all the way down the Colorado from there. You have all these tensions coming together: conservation, cities growing, you know. Where do we go? That's a big one.

Then Dad always used to say—I don't know how true this one is, Brad, or if you heard this on the Central Arizona Project—he said you couldn't get elected in Arizona unless you were for the Central Arizona Project, just couldn't get elected. In his later years as he looked back, the thing he realized about the Central Arizona Project is the original promises on the Central Arizona Project were to have the water go to agriculture. That's the way they sold it to the public. They said, we're a fast-growing community, and we're pumping water. Phoenix is going to grow; Tucson is going to grow. We've got to protect our agriculture. The thing Dad always said he was mad about in his elder years was that we promised them that we were building this thing and the water was going to protect agriculture, and not one drop of the water went to agriculture.

My dad, as he got older, got crotchety. He was more rebellious and grumpy. At one point, he left Phoenix, Arizona. He had served on water boards there; he tried to educate people on his view of conservation and the way to move on water. He returned from Washington. My mom and dad were there in Phoenix; they were there about 10 years or so. Then he kind of made this announcement: I'm leaving Phoenix. You've ruined it, what you've done. There are no more orange groves, no more citrus. You haven't planned the city in such a way to make it livable. He said, I'm going to a city where I can walk around every day. And that's what he did. He moved to Santa Fe, New Mexico. Every day he walked five miles downtown, got his coffee, his newspaper, visited with friends, and practiced law in his office, and it was a pretty rebellious act for the state that he loved and that he was born in and that his ancestors were pioneers in.

**Brad**: The factual comment I would make is that a chunk of that water in fact does go to agriculture in central Arizona. That's agricultural water right now that is greatly threatened by settlement, climate change, and the like. Unlike other portions of the American West, where agriculture is often senior, in the Central Arizona Project scheme of things, it is the junior holder there and so most at threat.

**Sen. Udall**: Just to add on the same subject, just to give you some figures there of how fast the community was growing and what was happening: In Arizona by the 1960s, four out of five acre-feet used was from groundwater—2.2 million acre-feet per year of groundwater depletion. That's almost the size of Elephant Butte Reservoir, which I think has a capacity of 2.6 million acre-feet. In the dry years, they were pumping 4 million acre-feet of water in Arizona. Even 2.2 million acre-feet is more than all the river water in Arizona each year. It shows you how the pressures of population growth and the relationship with water were occurring. Brad, you've studied that a lot because you're on the Colorado. Your papers have been on the Colorado and looking at the Colorado. What is going to happen to the Colorado?

**Sam**: Speaking of what's going to happen, you've both spoken out in stark terms about how climate change will exacerbate our water shortages and add additional challenges to living and working in the desert Southwest. How have your experiences shaped how you have approached the issue of climate change, particularly in relation to water management or addressing this idea of where we are going and how climate change affects that?

**Brad**: I want to tie this back to the ignorance that I talked about earlier in both Mo and Stewart, and they had a lot of collaborators on that as well. My take right now, as a society we are remarkably still ignorant about climate change. We are potentially looking at very bad futures, not for humans themselves—humans will survive—but for human society with nine billion people, if we keep on the path we are on right now. The fat-tailed risk, which is to say the dangerous part of the tail, is higher than most people appreciate right now. Scientists have known this for quite a long time but have been unable to communicate it effectively. I'll mention a couple things.

In 1978, a paper was published in *Nature* called "West Antarctic Ice Sheet and the $CO_2$ Greenhouse Effect: A Threat of Disaster" by John H. Mercer. This is in *Nature*, one of the two top scientific journals. In it, Mercer describes how this ice in west Antarctica could actually melt from below if we continue to add $CO_2$, and if we did this, we would be looking at 15 feet, about 5 meters, of sea-level rise. Well, flash forward to 2010 and 2012, 2013, 2014, when a whole series of papers have come out basically saying that Mercer was right. We've now started to melt this ice in west Antarctica. West Antarctica, if you look at a map, is the left side of Antarctica. You look at all that white, and guess what? There is not land under there. There is ocean under there. If the ocean warms up just a little bit, it will start to melt these huge ice sheets from below. Ninety percent of the heat right now that the Earth is capturing from our additional greenhouse gases is going into the oceans. Of course, some of this is in Antarctica. It now looks like we've bit off about 15 feet of sea-level rise. The timing of this is somewhat uncertain.

Every time a new climate change assessment comes out, sea-level rise goes up. Just back in 2007, people were saying maybe 3 feet by 2100. The latest reports have 10 feet by 2100—10 feet. Do you have any idea what that does to Miami? It makes Miami uninhabitable. It makes south Florida a disaster. It makes New Orleans potentially uninhabitable.

The fat-tailed risk on climate change right now is something that people do not get. Frankly, they also don't get the unanimity of the scientific viewpoint on this. Yeah, there are 10 or 15 people out there that squawk about this that have a PhD on it. But if you come with me to the annual conference of the American Geophysical Union every year in San Francisco, where 25,000 Earth scientists come, there is not one panel on the hoax of climate change or how we've totally gotten it wrong or how we don't need to do anything. There is session after session after session on impacts, on what we can do about it, what the economics are, how we can move forward. This information just, frankly, has not made it out to the public in a way that I think would enable far better decision-making.

**Sen. Udall**: Brad, he's the scientist and the engineer. I'm not. The question that arises when you hear Brad's presentation or watch Al Gore's two movies (the new one is out in the movie theaters now) is, Why isn't the Congress doing anything? Why isn't the President doing anything? Where is the political will to tackle climate change? Just a couple of quick comments there. Congress almost, people don't realize, put a cap and trade in place in the early part of the Obama administration. As you know, the House passed the Waxman-Markey climate bill. It was a good cap and trade. It did the good thing Congress does: there was a lot of compromise in it. It took care of coal miners. When you have a transition on climate change, a lot of folks are going to be hurt, and you have to have a just transition, you need take care of people, and you need to publicly say that. Over time, as you put a whole bunch of coal miners out of business—and later it is going to be oil and gas folks—you must retrain those folks and open up opportunities for them. We almost did that in Waxman-Markey. We almost put something in place. We came through. The President chose to put health care first. We used up all the time on health care. President Obama only had a Democrat legislature until 2010, and then we lost the opportunity.

So, then the question is, Why haven't we acted since then? I'm just going to tell you the brutal truth here because this is what is going on. Businesses—big businesses—you see them all talking about climate change. They're redoing their websites. Their CEOs, you know, are talking about how they are climate friendly. Not a single one of those big CEOs will come to Washington and stand next to Republican senators and Republican House members and say that they support Congress doing something on this. The sad fact of it is that the big money, especially the big money in the Republican party, is coming in and influencing the system in a corrupt way. That's, to tell you the truth, why it isn't there.

I think if visiting person to person in the Senate—I don't know the House as well, because we're kind of separate in a way even though we're a couple football fields apart—there are a lot of Republican senators that would be willing to work on something, whatever the solution is. Let's just call the solution "Put a price on carbon." They'd be willing to work on that solution and try to do something that is across society and consistent with what we tried to do internationally in Paris. They tell you that personally. But a couple of the representatives that stepped out front in the House on this issue were defeated by the big corporate influences I'm talking about. The message is that if you don't have any backing, if you don't have these people at your back, then you don't have the party, you don't have the money, you don't have business, and then that's too much. That's too big a lift for many Republican senators and representatives.

**Brad**: I actually want to follow up here, Sam, if I can for a second. I recently got to listen to my senator, Michael Bennett, on a podcast by Ezra Klein called *The Ezra Klein Show*, and I would recommend you listen to it. One of the things Michael talks about on the show is the influence of corruption right now in the United States and about the Supreme Court when they issued the *Citizens United* opinion. The Supreme Court was thinking about overt corruption, like where somebody pays an elected official to carry out an official act. We now have this inverse of corruption, and it promotes inaction on things. We have now allowed rich, wealthy people to finance primary campaigns against candidates who want to do the right thing. They can put $300,000 or $1 million or $2 million or $5 million into a campaign to defeat a senator of either party who wants to do the right thing. That's what we're dealing with on this topic right now. This inability to get action, I think, is a problem of corruption in the United States, but it is not overt; it is covert.

**Sen. Udall**: Brad, just one more point. Let's remember going back a little over 100 years ago, to Teddy Roosevelt, the robber baron era, and the big huge interests out there. When everybody saw the railroads and oil and all these big interests were going to impact the government too much, Teddy Roosevelt passed a law in the early 1900s banning all corporate contributions to campaigns. That is what *Citizens United* overturned. That ban went all the way up into the 1970s. That's what made it so the government could do the right thing. Then there were the cases in the seventies, including Watergate, which opened the door a little bit, and then the Supreme Court opened the door all the way for the really big dark money. Now we have hundreds of millions of dollars in our political system. Nobody even knows where the money comes from. If someone is running for office, you want to know where the money they're getting—not only independent contributors, but also their own money—is coming from. We don't have a clue where an awful lot of the money in campaigns comes from. That's very destructive to our democracy. I think Democrats and Republicans in Washington know that and are seeing it unfold. Unfortunately, it is spreading down now to governors' races and local government. You see more and more money coming into these races.

**Brad**: Tom is exercised on this issue, with good reason. He spends far too much of his time, as do all of our elected representatives, raising money. We shouldn't pay him to go raise money. It is a stupid use of their time. [Spontaneous applause from audience].

**Sen. Udall**: Brad, look at that. Here is a scientist getting a standing ovation! That's excellent.

**Sam**: Brad, if you want to touch on the work you've done, that would be great, or we can move on to talking about water management.

**Brad**: Let me talk briefly about that paper Jonathan Overpeck and I just released. In March of this year, we published a peer-reviewed paper in *Water Resources Research* called "The Twenty-First Century Colorado River Hot Drought and Implications for the Future." The findings of this paper are as follows: You can't explain the current seventeen-year drought on the Colorado River, which is about a 20 percent decline in flow, solely by reductions in precipitation. You've got to pull something else into the equation. Well, guess what? The Colorado River Basin has warmed 2°F, and that 2° is critical to this decline. We say about a third of that 20 percent decline is due to the 2°F increase in temperatures. With that increase in temperatures, you get more evaporation from soil, more evaporation from plants, you now have a longer growing season. You have a bigger atmospheric demand for moisture, a greater suck. All that plays out in a way that reduces the flow in the Colorado River. You can then take these results and project toward the mid-point of the twenty-first century perhaps a 20 percent temperature-induced decline, and toward the end of the century perhaps a 35 percent temperature-induced flow decline, all of which is going to create enormous problems for users on the river.

In the paper, we go one step further, to a place where most scientists haven't gone. We say, quite frankly, we have got to stop all greenhouse gas emissions. Understand that what we have right now is a bathtub—i.e., the atmosphere—and a hose going in it. The hose represents the greenhouse gases we emit every year, and the level of the bathtub is the concentrations of $CO_2$ in the atmosphere. What has happened in the last few years—there's some good signs out there—is this hose has not gotten any bigger. That's actually good, because historically we've emitted more and more and more. The problem is the bathtub level is going up and up and up. It is the level of the bathtub—that is to say, concentrations of greenhouse gases—that determines the problem we are going to have for a thousand-plus years. We've got to shut off that hose. We've got to shut off those emissions, the sooner the better. Most people talk 80 percent by 2050, 100 percent by 2100. We're not even remotely close to that path right now. I project in about 10 years' time we're going to have a major panic that is going to cause all kinds of economic distress. We're going to pursue two things, one of which is any technologies that allow us to get carbon and other greenhouse gases out of the atmosphere—most likely growing plants on a massive scale and then stashing that carbon somewhere where it won't be released. The other is geoengineering, which scientists hate, and that is somehow trying to manage this climate system so that we actually don't heat up as much as we otherwise would. That is a very dangerous game, but I bet we are going to go down that pathway just because of the danger, the relative risk, of not taking action. That's very controversial, but I'll put it out there.

**Sen. Udall**: Sam, I would like to talk for a minute about the corruption issue Brad raised earlier. He's absolutely right when he says money has a huge influece on politics. This has been one of my passions since I was elected Attorney General of New Mexico. When I was Attorney General, I was joined by my coleagues in a letter to the Supreme Court, saying that when it ruled that money is speech in politics, it went in the wrong direction. That was *Buckley v. Valeo*. Then the cases following from that ended up in *Citizens United*. What I think we need to do—reform—is important at a water conference because for any reforms you want to see, you're dealing with a system that we both described. Just very quickly, I will outline what I think we need to do: you've got to have public financing of elections, you've got to take the special interest money and the big corporate money out, you've got to overturn *Citizens United*, and you've got to put limits in some way so that the wealthiest don't have the big impact they're having and give the voices back to the people. Let's go on with water here.

**Sam**: Really nice. [Applause.]

**Sen. Udall**: Oh, look at that!

**Sam**: The audience balanced that out great.

**Sen. Udall**: I hope it was all spontaneous and genuine.

**Sam**: We're coming to a close here. What do you think we can learn from water management decisions over the past one hundred years to inform our policy and planning for the next hundred years? Where have we been, and where do you think we can take that to where we're going?

**Brad**: There are reasons to be optimistic in this world right now. One of them, arguably I would say, is water management. I think John Fleck for the most part gets the story right here in the American West. As much as we've ragged on American politics right now, water governance is actually true governance. It typically doesn't involve elected officials, but it is doing what government should do, which is to allocate scarce resources. When we have water management institutions that work, arguably, as well as the ones we have in the West and they come up with reasonably good decisions, I would call that a success. I know there are some out there, and you can put me in this boat a little bit too: certain elements have not been part of American water management for a long time—tribes and the environment. Clearly, there are issues there to resolve, and we need to work harder on that. At least in my state, and John Fleck mentioned this, the roundtables and other governance institutions seem to be relatively strong and seem to allow people to participate, again with one caveat: it is hard for the public to participate in these highly technical discussions. They get chased out of the room. So perhaps a solution to that is to make sure that institutions are in place that can represent the underrepresented in these debates about allocating scarce resources.

**Sen. Udall**: Brad, when you talked about water and how water is produced through our various governmental entities for people, it reminded me of what Abe Lincoln used to say 150 years ago. He said the role of government is to do what people can't do for themselves. That's the really important role of the government. It is important in the area developing water. It is important in infrastructure — roads and bridges. It is important in terms of the endeavor we call public education — a public education system. These are all big goals, which people can not do for themselves. We have done something pretty extrourdinary when we undertake these activities.

Same thing goes with national parks. Rarely can an individual create a big, wonderful national park, but let's take Grand Teton. We've talked too much about Grand Canyon. But in Grand Teton, you have folks like Laurance Rockefeller, who owned a big chunk of land up there around the Tetons, and at the end of his life, he said, "You know, this is wonderful. I want to expand the Park. I'm going to give my ranch over to the Park." So, we always need to remember that that is a really important role for government, and that is why you saw me emphasize in both my talk and the panel that we need to encourage people. We don't need every person to be an elected official, but we need to encourage public service. We need people to work on water issues and in nonprofits and in public service and at these small water organizations that Brad is talking about that produce water at the most local level in our most rural communities. We need to keep encouraging that kind of public service.

**Sam**: OK, that's great. That's really been a great conversation. We're going to wrap it up, but I will just give each of you a chance if you have any closing thoughts or any kernels of water wisdom to tell us.

**Brad**: A guy by the name of David Wallace-Wells wrote a piece in *New York* magazine in July 2017 called "The Uninhabitable Earth." I'd encourage you all to go look at that piece. Many in the scientific community reamed him out on this issue. They thought it was too harsh. They thought it only told the story of what happens if we keep on the current path. There is this sense that we are doing better than that. But I encourage you to go look at that piece, because it will open your eyes in ways to the threat that we are facing right now. What Wallace-Wells doesn't talk about, and I want to mention this just a little bit, is that we have the technology to solve most of this right now. If we get to work at it in a way that we're not right now—we're doing about a tenth of what we need—the remaining technologies we need I am sure will come about. Just in the last 10 years, the price drop in renewable forms of energy is stunning. We can solve this problem. We lack the political will right now.

**Sen. Udall**: That's excellent, Brad. Excellent. My final comment has to do with the conflicts that we have where we come into conflict with nature itself. For the longest time—this is more of a Western approach than an Eastern approach in the big picture, in terms of the world—the Western approach has been for us to conquer. We're here. Nature is this hostile force, and we've got to conquer it. What we've learned over time is that we actually need to learn what the laws of Mother Nature are and try to work within those laws. One of the great western conservationists, you know, said it best: When we really treat the land and the water as part of our community, not outside of it, not something to conquer, that's when we'll really understand where we should be and what we should be doing.

**Brad**: That was Stewart, I think.

**Sen. Udall**: I think it was Aldo Leopold. Dad said it a little more pithily, Brad. He said, "Man is not outside of nature; he is part of nature." But Aldo Leopold, I think, talked about the community commons. Look it up. Thank you very much. You've been great. It has been wonderful to be with you.

# Meeting the Challenges of the World's Growing Dependence on Groundwater

William M. Alley, National Ground Water Association

*William M. Alley is director of science and technology for the National Ground Water Association. Previously, he served as chief of the Office of Groundwater for the US Geological Survey (USGS) for almost two decades. Bill has published over 100 scientific publications, and most recently coauthored with his wife, Rosemarie, High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater. Among other awards, he received the USGS Shoemaker Award for Lifetime Achievement in Communication and the Meritorious Presidential Rank Award. He holds a BS in geological engineering from the Colorado School of Mines, an MS in hydrogeology from Stanford University, and a PhD from Johns Hopkins University.*

When my wife, Rosemarie, and I wrote the book *High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater*, we had a few goals. Rosemarie wanted to make it read less like a USGS circular and more like a novel. We got a little bit of input on that first. As you might imagine, groundwater is not the sexiest topic in the world. Some of you probably have to deal with that issue. The first input we got was when we were riding with someone in a car, and they were talking to their friend on speaker phone and told them we were writing this book about groundwater, and the response we got in the most sarcastic tone you can imagine was "Well, that ought to be a real bestseller." We forged ahead despite that. The second goal is that groundwater is really a global issue. We wanted to tackle the book from the world standpoint, so we have about half and half—half the United States and half other countries around the world. The third is we didn't want it to be doom and gloom. So much that is put out about the world's groundwater today is doom and gloom, we're all running out of groundwater, and so on. It's a very serious issue, but we wanted to address stories of people who are making a difference and trying to address the issue. I'll mention a little of that along the way here.

Groundwater is distributed around the world. Figure 1 is a very simple map. The darkest colors show the most productive basins. Some of the major ones you've probably heard about are labeled there. Even in the light tan areas, which are labeled "region with little or no groundwater," groundwater is very important to people in many of those regions, particularly in rural areas. In sub-Saharan Africa, for example, groundwater is a very important resource.

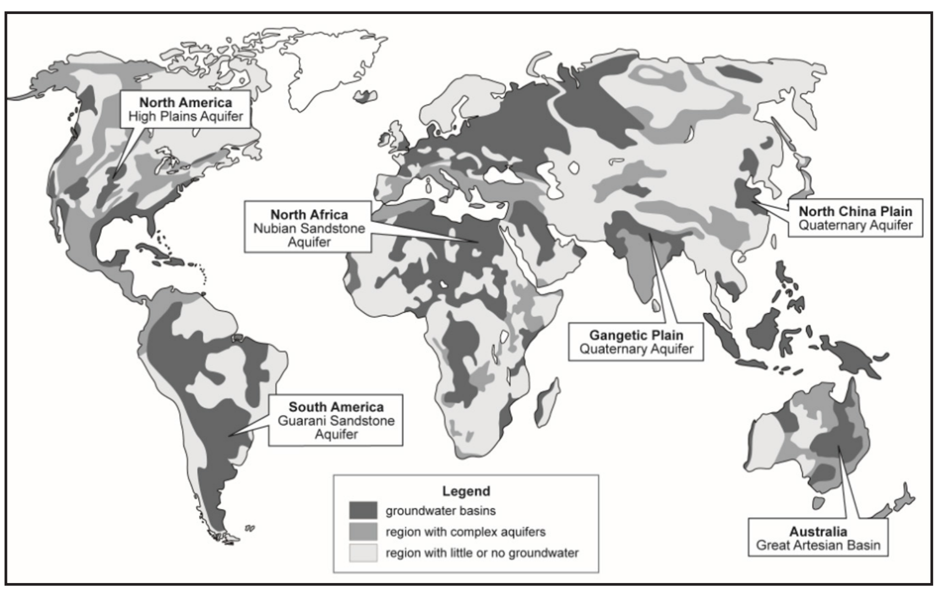


Figure 1. Groundwater aquifers around the world.

If you look at groundwater depletion around the world, it is not evenly distributed (Figure 2). Those peaks in blue and black represent groundwater depletion. Starting in the western United States, there is a blue peak coming out of the San Joaquin Valley, and it is the western United States where a lot of depletion is taking place, as well as Mexico, and then some areas toward the central part of the United States. Then you jump over to southern Europe, Spain, Italy, and the very northern part of Africa, you get to Saudi Arabia and Iran, and then you have this giant peak sitting over India. I'll get to that in a moment, and then you can see the North China Plain there. Groundwater depletion goes right across that central set of latitudes.

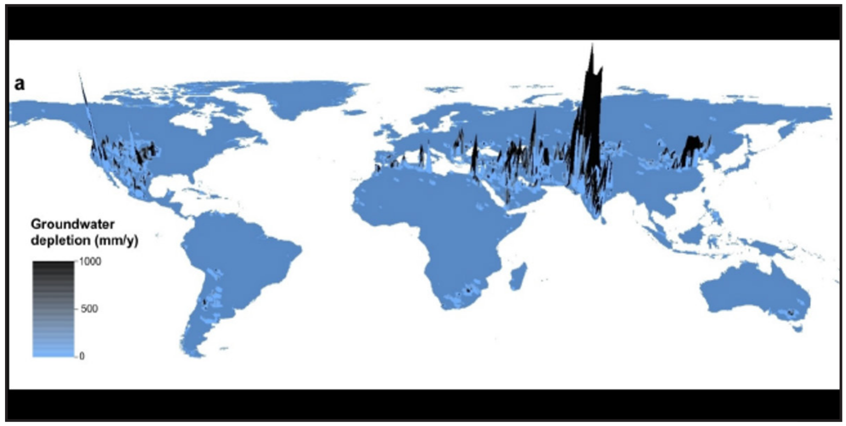

Figure 2. Global groundwater depletion.

Five countries in the world account for 60 percent of groundwater pumping (India, 25 percent; United States, 11 percent; China, 11 percent; Pakistan, 7 percent; and Iran, 6 percent). One-quarter of the pumping comes out of India, about 66 trillion gallons per year. If you built an 18-inch diameter pipe and you ran it to the moon, and then another one coming back, you could fill those pipes 2,000 times with the amount of water India pumps in one year, just to give you an idea of how large that is. It is twice as much as any other country. The United States and China vie for the number two position.

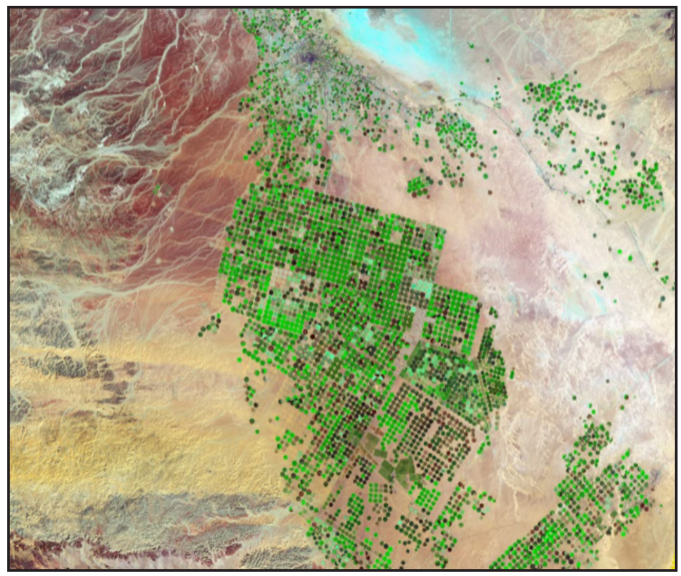
Figure 3. Irrigation in Saudi Arabia.

Everybody sees that everybody else has a problem. I like this quote from a High Plains farmer: "We can't wait another 30 years to get our policy right. The drought in California is showing what living in denial can do." I would say denial is spread more evenly around the United States.

When the Apollo astronauts were looking down on Earth, Figure 3 is what they really meant when they said they had a problem. Figure 3 shows irrigation in Saudi Arabia. In the 1970s Saudi Arabia began its quest to become independent in terms of wheat production. It also has a lot of dairy cows, by the way. By 1992 Saudi Arabia was essentially the sixth largest wheat exporter in the world. They were doing this at five times the cost of what they could have bought wheat for on the open market. They had gotten themselves in the position where farmers depended on this subsidy they were giving, but in the meantime they were depleting their groundwater. Somewhere around 2000, if you take all the depletion from nonrenewable groundwater around the world, Saudi Arabia was responsible for about 80 percent of that depletion. They were massively depleting their resource. They've moved away from wheat production. They still grow other things, but they basically abused their aquifer and pumped an awful lot of water out.

On the other hand, there are places where there is cooperation. The oldest democratic institution in Europe is the Tribunal de los Aguas de Valencia. They meet weekly, every Thursday, I believe. The jury doesn't take any notes or anything, and they settle disputes from people who have surface irrigation issues. It has worked. I guess it must have worked if it has lasted this long.

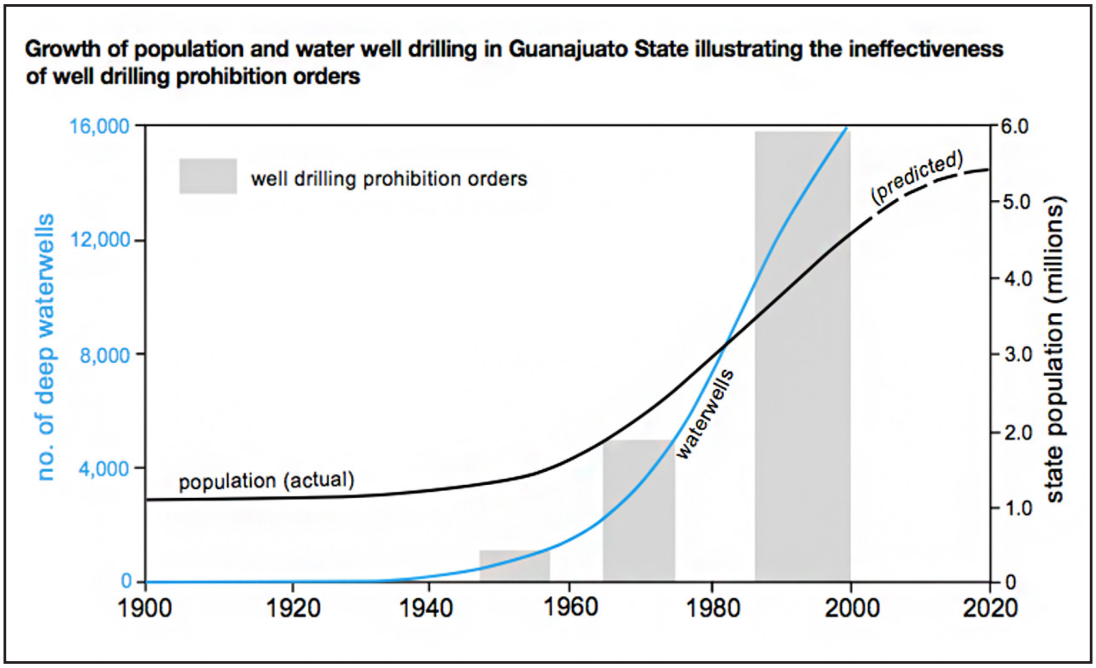


Figure 4. Water well drilling in Guanajuato State Mexico.

Another place in Spain in La Mancha district—that's a wetland—has what we might call *hydrologic insubordination*. If you remember the windmills in *Don Quixote*, well, those windmills were for grains. They've been growing things for a long time there. It also happens to have a lot of wetlands. It is a large birding area. They've depleted a lot of their groundwater. Even some of the wetlands have caught on fire for years on end because they are so depleted. They've tried to regulate groundwater depletion by forbidding new wells and implementing pumping restrictions, licensing, and so on, and they have been totally ignored by the farmers in this particular area. When they tried to take owners of 5,000 illegal wells to court, the owners just had the federal government fire the people in charge of the local basin authority so that they would not take them to court. This is a good example where top-down management doesn't work in terms of trying to regulate groundwater. When you get deeply involved, you have a lot of stakeholders.

Another example of ineffectiveness is in Guanajuato State (see Figure 4), where you can see the well prohibition orders in gray. They have no impact whatsoever on the number of water wells going in.

I mentioned India. Many of you have probably seen the Gravity Recovery and Climate Experiment (GRACE) photographs. GRACE is a gravity experiment NASA does in conjunction with the Germans that basically uses changes in gravity to detect changes in groundwater, if you can subtract out the effects of surface water and so forth. Figure 5 shows the extent of depletion in northwest India. Groundwater is being depleted, but it isn't quite that simple a story.

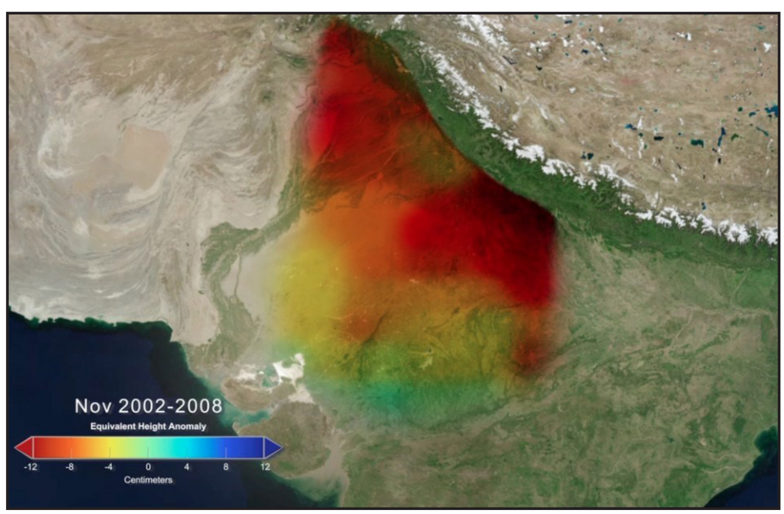


Figure 5. Groundwater depletion in Northwest India from GRACE.

If you look at the hydrologic map of India (Figure 6), the gray areas are essentially either Deccan basalts or Precambrian rocks, which have very low storage capacity. These areas of India are very dependent on monsoons, and they have major groundwater depletion problems. Those problems just don't show up in terms of the mass of groundwater depletion, but they are no less severe than the problems they have in the northwest. In fact, the northwest may have more of a water quality issue than a depletion issue in many cases, primarily due to salinity in the Indus Basin.

Then there is also the eastern part of India, where what's known as the largest mass poisoning of a population in history took place in West Bengal, India, and in neighboring Bangladesh. Something like 30 percent of the population was drinking water from tube wells that were installed to keep people from drinking surface water and getting cholera, but the well water was laced with arsenic above the 10 mg/liter World Health Organization standard. So, they have tried to correct the problem. They tested millions of wells around West Bengal and around Bangladesh, and they would paint them green or red. Green doesn't actually mean safe because they were using a 50 mg/liter standard. If they'd used the 10 mg/liter standard, all the wells would be red, practically. They've also had one heck of a time of getting people to stop drinking water from the ones painted red, simply because it is a chronic problem. It is a problem that develops over time, so people may think after drinking this water for a

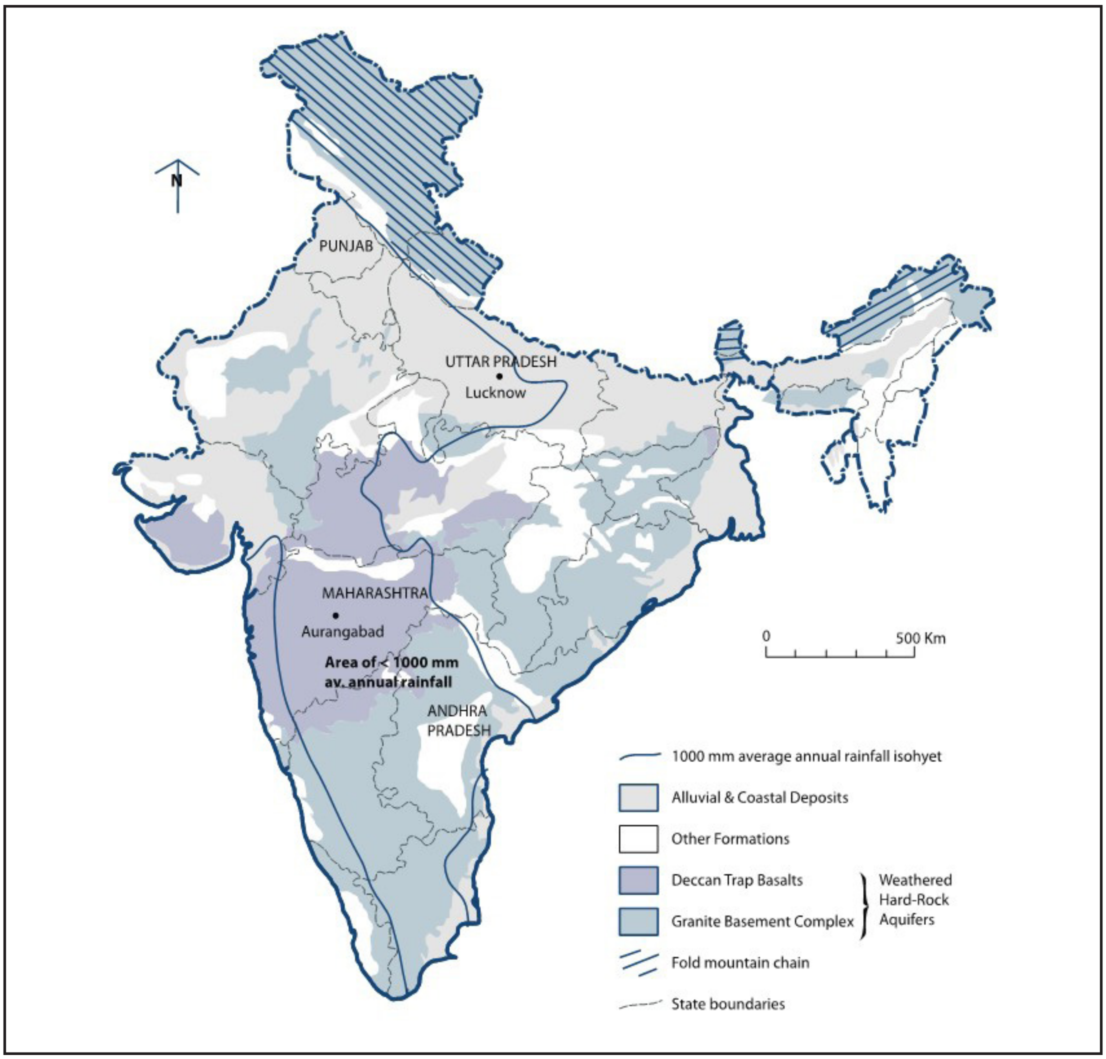


Figure 6. Main hydrogeological provinces in India.

while that it hasn't hurt them. So they have a hard time moving people away from the red wells to the green ones.

India has problems associated not only with groundwater depletion but also with water quality issues and so forth. Many of their depletion issues are tied up with electricity subsidies. They get very low electricity costs or just blanket costs for whatever they pump, so everybody pumps water all the time, which causes electricity shortages, which means the farmers turn their wells on so they are ready to go. If the electricity happens to come on at two in the morning, their wells start pumping. A lot of water gets wasted that way.

Let's look at some success stories. There are success stories in India today. They rewired one of the states in India so that there are separate electrical systems going to the farmers and to the urban areas, and then they could regulate the electricity to the farmers that way. You can imagine the cost of trying to have two separate electrical systems, but that is what it took.

Figure 7 shows the Great Artesian Basin in blue. It is a large aquifer. It is about 10,000 feet thick, with alternating clays and sandstones, shale and sandstone, basically. It has enough water to serve Australia's population for 1,500 years, if you could use it that way. Of course, you can't. It is a confined artesian aquifer, so as soon as you start pumping, the pressure starts to diminish.

A lot of the water around, particularly, the southern and eastern sides of the basin comes out of springs. Those springs have been used by indigenous people for thousands of years. They also have unique flora and fauna. In the course of developing these groundwater wells, they put the water into earthen drains, which leaked, to irrigate grazing lands. The estimates are that about 95 percent of that water was lost to evapotranspiration. While that was happening, they were also losing the pressure in their bore holes, their springs were drying up, and so forth. They had a large program over a number of years to convert 15,000 miles of earthen drains to pipe. They also capped about a thousand bore holes. In


Figure 7. Great Artesian Basin in Blue.

the process, some of their springs have returned, and some of their bore holes have become artesian. They save about enough water for two million people a year. The aquifer is not out of the woods, because it is a very sensitive aquifer. There are a lot of energy resources in that area. There is a lot of competition for that water.

Another example: Bangkok, Thailand. Bangkok has a subsidence problem, which started in the 1970s. They've had it for a long time. They are sitting in a big delta, the second largest in Asia. It is a series of sediments with a clay on top. The Bangkok clay turns out to be a fortunate thing. They also have a saltwater intrusion problem because of those same lowering water levels.

Figure 8 shows Bangkok's groundwater abstraction. Bangkok was able to control their municipal pumping system, as shown by the thick dashed line. The other major user in this case happened to be industry. As you can see from the thinner dashed line and then the top line, which shows the total abstraction, industrial use kept going up. Finally, around the late 1990s, they were able to put in place restrictions on wells. They charged a fee. There is a fee for how much water you use. They have done a considerable job, at least in the major part of Bangkok, of reducing their abstractions and helping to correct their subsidence problems.

If you look around the world, you can find a number of cases where people have dealt fairly effectively with subsidence problems. Examples of these include Houston, the Santa Clara Valley in California (which was the first place to recognize and deal with subsidence), and Bangkok, Thailand. By the way, that Bangkok clay is part of the reason they were able to control subsidence. It is too hard for an individual to drill through

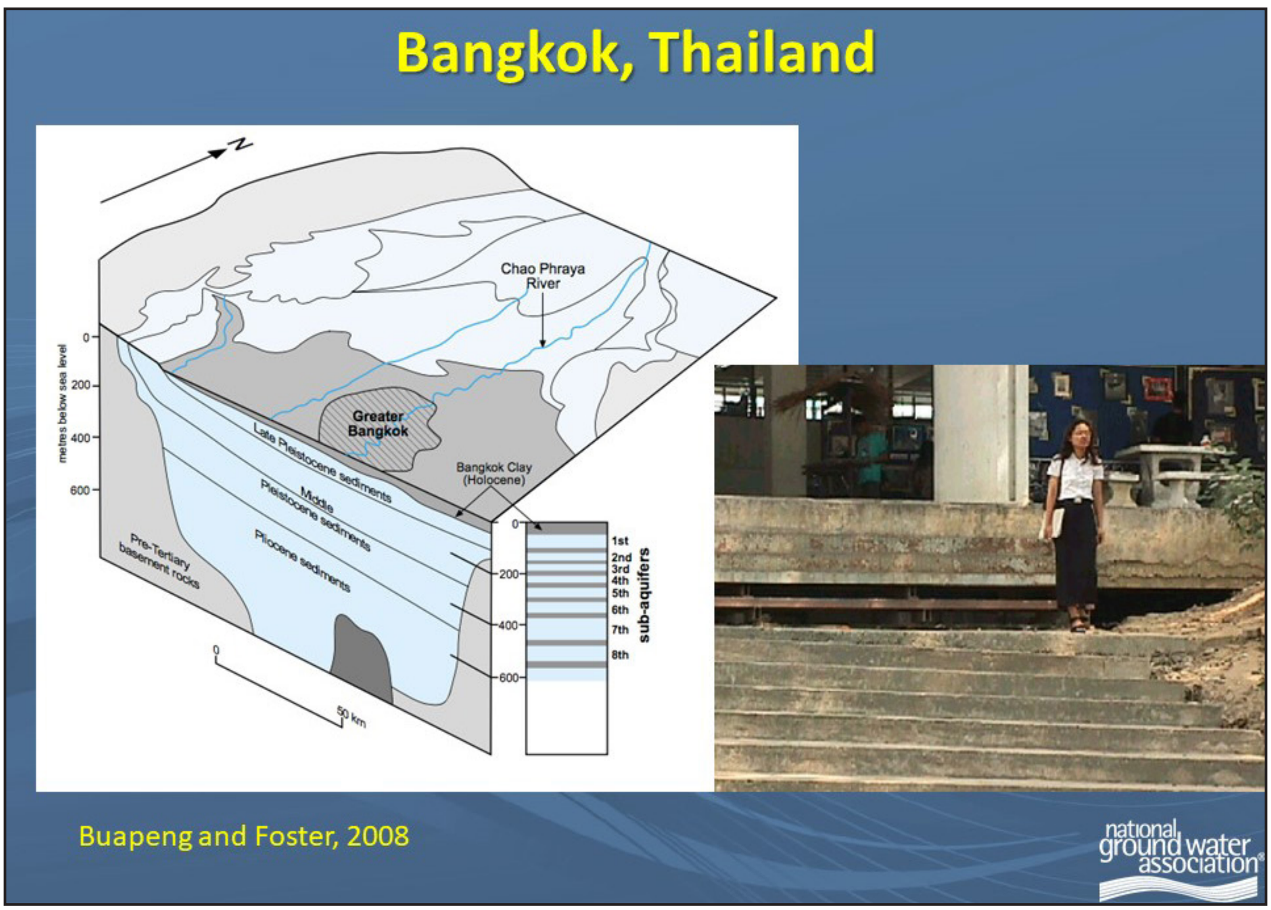


Figure 8. Groundwater abstraction in Bangkok, Thailand.

that and develop a well. They didn't have many individual wells. In other parts of Asia like Jakarta, basically everybody is putting in a well, and they have major, ongoing subsidence problems. The subsidence problem in the San Joaquin Valley has not been resolved, nor has Mexico City's been resolved. It is a tale of two types of places when it comes to controlling land subsidence.

Another example not far from here is the San Pedro River, which flows out of Mexico. In the book, we highlight both the collaborative modeling and the interesting citizen-scientist activity that went on in Sierra Vista and Fort Huachuca, which is a major employer in the area. Water issues affected the riparian area of the San Pedro River. There are a couple of endangered species. About two-thirds of the bird species in the United States migrate through the area. In this particular case, there was a main ingredient: an external force (the Department of Defense) pushing for change in the form of trying to keep Fort Huachuca. Funding for addressing these water issues helped establish the Upper San Pedro Partnership, which was a group of 21 agencies who worked to come up with a sustainable plan for their resource. The funding came from the National Defense Authorization Act, because of the concerns about Fort Huachuca. It is not easy problem to solve, because they already had a large cone of depression that is continuing to migrate toward the San Pedro River where the problem is. Their issue was to keep flow in the San Pedro River in the short term and to control groundwater pumping for the long term.

There are two activities I want to emphasize. First was a collaborative modeling approach, where the USGS did the modeling but met frequently with the other agencies in the partnership. By the end of the day (which was many days, actually), everybody had a sense of what the model did and what its uncertainties were, and most importantly they trusted it. When it came time to use the model to develop management strategies for the San Pedro River, they were able to come together pretty well and agree on strategies. The Nature Conservancy was also heavily involved. They provided funds to Sierra Vista to put in recharge for treated effluent from the city of Sierra Vista to the San Pedro River. Two of those are in place, and another two are planned to deal with the long-term issue.

Second, late in the 1990s when a person by the name of Holly Richter showed up, everyone was arguing. You would get stories all the way from "The river is the same as it was when my grandfather was here fishing" to "It's gone." You can imagine the range of ways people would view the San Pedro River. She set up what was called a wet/dry mapping exercise. Everybody would go out, and they would be assigned a section of the river. They would go before the monsoon and they would map the wetness of that section along the river, which is semi-useful information, but even more useful once you build it over time. I think there were 30 or 40 people who went on that first expedition. It is not an easy exercise to do because you have to give people snake kits and so on and so forth. She also paired up a city of Sierra Vista person with a Sierra Club person, so she paired up people with different perspectives during this exercise. It is kind of like an Adopt-a-Highway. Every year, people would come back and say, "I want to do my section again." It's a lot harder to call somebody a name if you've been out in the field with them for a little while. That was the theory, and I think that worked fairly well. They've done it for 15 or 16 years. They even go into Mexico now. I know they had a large contingent in 2016.

Finally, another example. If you want to look for a place that does wellhead protection better than any other country in the world, the place to go is Denmark. It's a small country, but they have their own set of problems. They have 5 million people and 25 million pigs. They've got a manure problem. They are 100 percent on groundwater. They only do minimal treatment. Only Copenhagen, I believe, gets any kind of chlorination, believe it or not. They basically say, "This is our resource. We want to keep it clean. We don't want to turn it into something that we've got to put all kinds of layers of treatment on."

Figure 9 shows Denmark's aquifer protection. The dark blue areas are the particularly valuable areas, the light blue are the valuable, and the brown are less valuable. There are no no-value type lands. For all of the particularly valuable land, they've mapped in fair detail the geology. They've installed a lot of bore holes. They've also done helicopter electromagnetic surveys, shown on the right of Figure 9, with the bore holes as the ground truthing. They have had a program, completed in

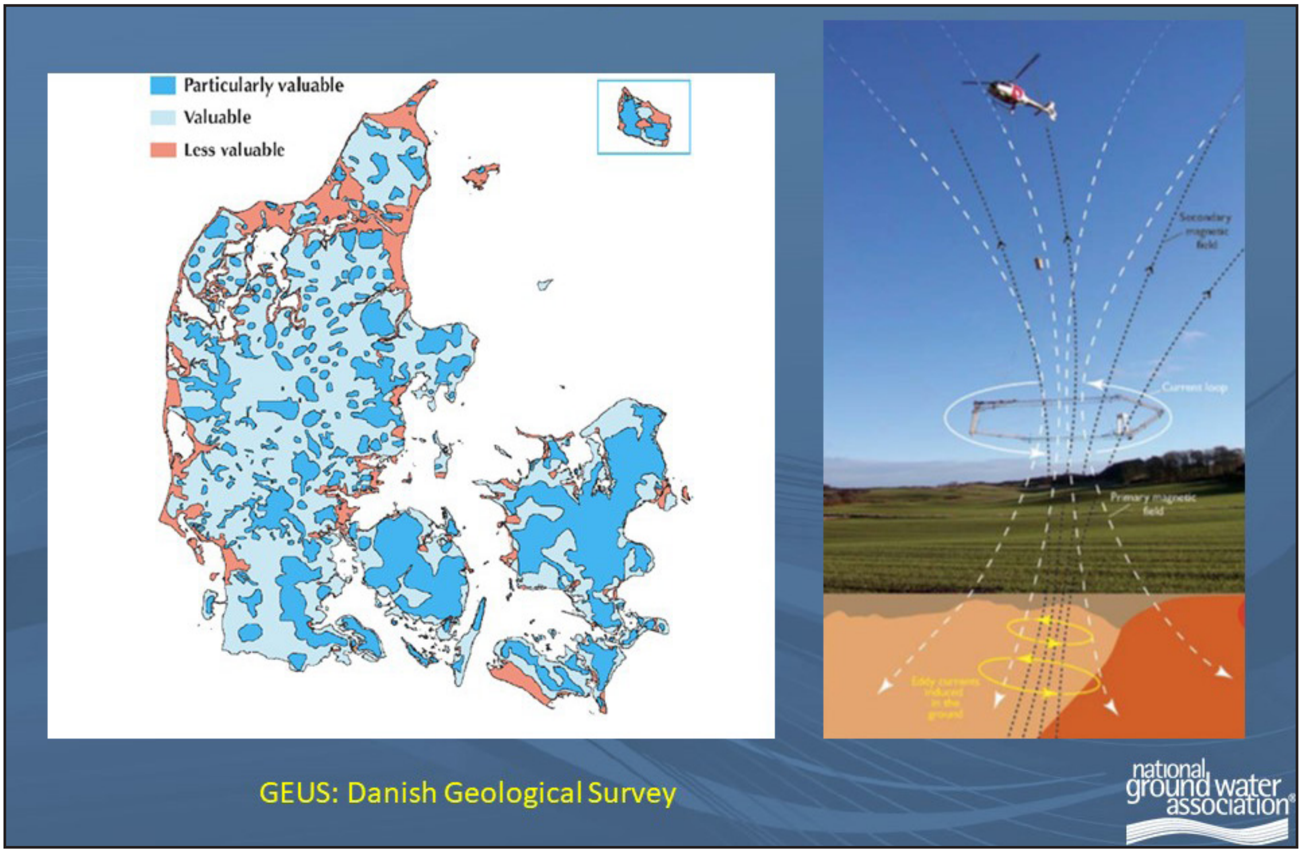


Figure 9. Denmark's aquifer protection.

2015, that they financed by a small charge people paid on their water utility bill. Now they have mapping of all their particularly valuable areas in terms of wellhead protection, and they know they can use that information to manage their system.

I want to say a little bit about resilience, because that seems to be a common idea these days. The National Ground Water Association defines resilience as "the capacity of the groundwater system to withstand either short-term shocks (e.g., drought) or longer-term change (e.g., climate change)." We tend to think of groundwater as a savings deposit. We assume it is going to be there when the droughts come. There is a large amount of groundwater storage relative to inflow, so we think we can just count on it when it gets dry. But how resilient are many of our groundwater systems?

Figure 10 shows groundwater storage change in the San Joaquin Valley in California. The red line shows the cumulative change in groundwater storage, and the green line shows surface water deliveries. This particular system gets a lot of surface water from the Central Valley Project and a little bit from the state water project, and they rely on that when they have it, which is when it is wet. Then they go back to pumping like wild when it is dry. You get these little bumps when it is wet, but the general trend is very obvious. Eighty percent of the basins California is dealing with through the Sustainable Groundwater Management Act are in the Central Valley, most of them in the San Joaquin Valley.

We need to analyze our groundwater systems for resilience and vulnerability to climate perturbations rather than just assuming they are going to be there. There is a definite need to raise awareness about maintaining groundwater as a reserve, both in terms of monitoring as well as use of managed aquifer recharge. I think the key idea here is to work toward laws, regulations, and incentives that encourage use of surface water during wet periods and prepare for the inevitable increased groundwater use during droughts. We don't really do that on many systems that I'm aware of today. We need to do a lot more of it.

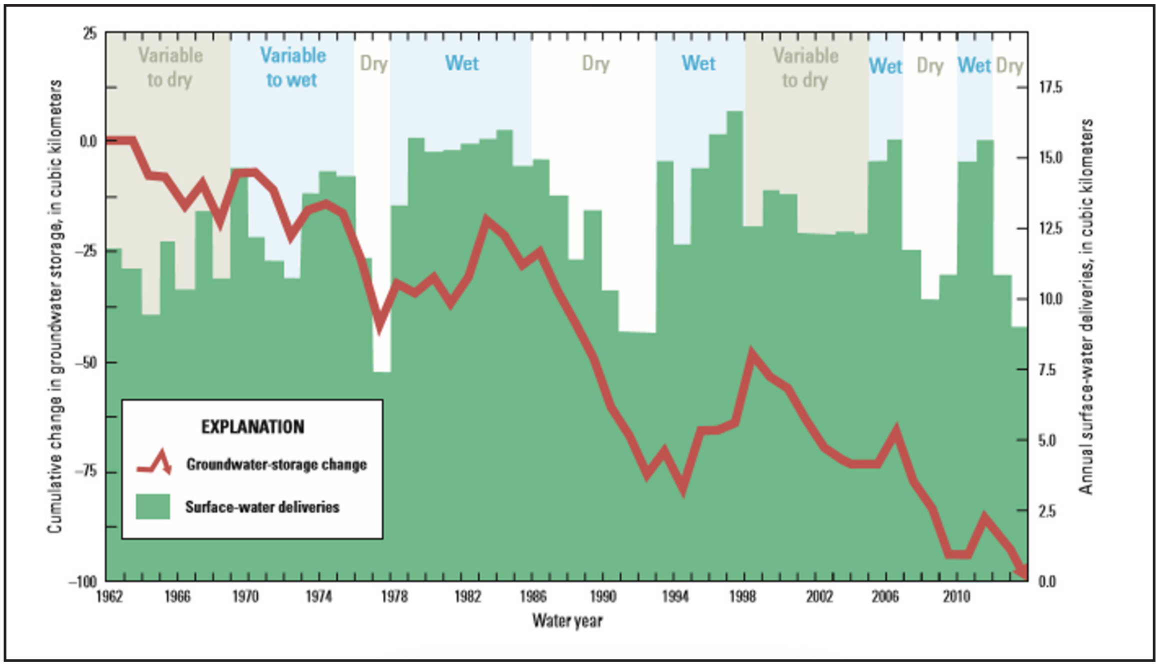


Figure 10. Groundwater storage change and surface water deliveries in the San Joaquin Valley.

The Central Arizona Project (CAP) is an example of what you can do if you think ahead. It has a very interesting story relevant to groundwater. To get CAP, Arizona had to agree to get its groundwater pumping under control in the active management areas (AMAs) shown on the map in Figure 10. Governor Bruce Babbitt and Secretary of the Interior Cecil Andrus, who were very good friends, played a good guy/bad guy role. Babbitt would tell the Secretary of Interior to come to town and threaten everybody that they wouldn't get CAP unless they got their groundwater under control. And then Babbitt would say, "What am I supposed to do? The guy's telling me that we have to get our groundwater under control." They played good cop/bad cop and eventually put in place the Groundwater Management Act in 1980.

California contemplated the same thing during Jerry Brown's first term at the same time, but they didn't have a Central Arizona Project they could be threatened with, so it never happened. It took Jerry Brown coming back 40 years later to come up with the California Sustainable Groundwater Management Act, and they are way behind the curve.

Figure 11 shows the effects of Babbitt's strategy. The top graph shows the average groundwater level in each of those AMAs. Throughout this period, which has included some dry times, their water levels have stayed pretty well consistent. The bottom graph shows average groundwater level for some other parts of Arizona outside of those AMAs. They are having major water problems—it looks like California, the Central Valley. Now granted, the key here for the AMAs is the availability of surface water. Surface water is much less available for those other areas of Arizona. The top graph demonstrates just how valuable managed aquifer recharge can be over the long term for drought preparation. Interestingly, by the way, included in that groundwater in those AMAs is about two years of Nevada's allocation to the Colorado River. Arizona has essentially banked water for the state of Nevada as a reserve, because Nevada does not have the same opportunities. Some of that water belongs to Nevada someday.

To close out, by looking at a number of these studies around the world some of the main ingredients or the factors leading to good groundwater governance include:

- Recognizing surface water and groundwater as a single resource
- Active engagement of local stakeholders in the decision-making process

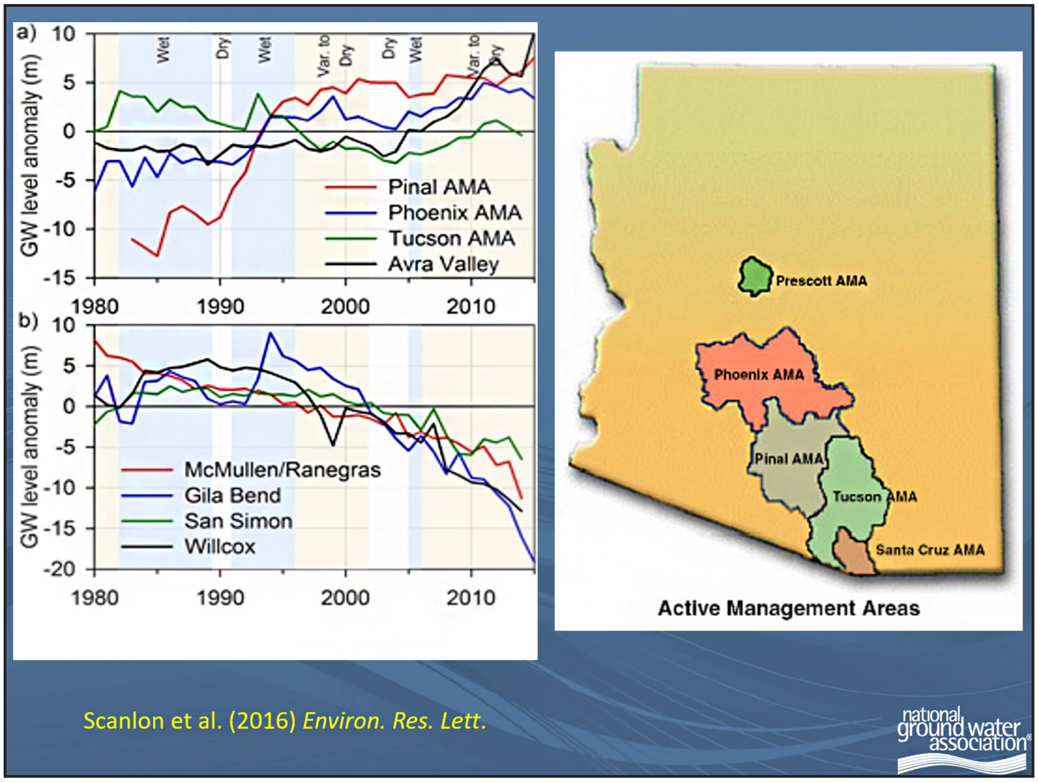


Figure 11. Arizona's Active Management Areas.

- Pressure from external bodies to achieve suitable and workable solutions
- Public education on groundwater and its importance
- An emphasis on public guardianship and collective responsibility
- Integration of groundwater considerations into other policies (agriculture, land use, regulation of hazardous substances, etc.)
- Adequate laws and enforcement
- Adequately funded and properly staffed groundwater management agencies
- Characterization of major aquifer systems
- Effective monitoring of groundwater status and trends by an independent agency
- Recognizing the long-term response of groundwater systems
- Recognizing the feedbacks between ground-water and climate
- Community leadership

I'm not going to cover them all in detail, but I will mention a few key things. While local solutions are the obvious choice, you need some kind of involvement of the stakeholders, and you need some sort of pressure—to keep the heat on—in most instances to achieve suitable and workable solutions.

More and more as we think about groundwater, we think about agriculture. Obviously, groundwater is extremely important for agriculture and land use decisions and the like. We need to get people thinking about groundwater in a whole range of areas besides just groundwater. Hydrology has tended to be a specialized subject, kind of off in a corner somewhere. It needs to come out and be involved very heavily in a public way with many of our activities.

Finally, a lot of these factors you'll see on lists of key ingredients, but the one I often don't see is the last one, which is community leadership. In most every case we talk about, there has been some entity, or person that has been a community leader in trying to do the right thing and organize. That is a key and an underestimated ingredient.

# Management Aspects of Farmland Retirement

## Moderated by J. Phillip King, Elephant Butte Irrigation District/ NMSU

*J. Phillip King is a Professor and Associate Department Head in the Civil Engineering Department at New Mexico State University. His research includes river and groundwater system modeling and management, optimization and decision theory, basin-scale management and policy, and hydrologic forecasting. His activities also include projects to enhance the diversity of the country's STEM workforce. Phil is also Principal Engineer for King Engineering & Associates, a small New Mexico-based consulting firm. Phil has worked with government agencies, irrigators, municipalities, Native American tribes, and environmental groups to develop new and innovative approaches to water management and education. He served as a Peace Corps volunteer in Malawi, Africa, and as a Fellow of the American Association for the Advancement of Science at the National Science Foundation. Phil has a PhD from Colorado State University, a BS from Berkeley, and an MBA from NMSU. He is a registered Professional Engineer in New Mexico.*

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## Dale Ballard, Carlsbad Irrigation District

*Dale Ballard was born and raised in Carlsbad, New Mexico. His family has been involved in the farm and ranch business for the past 100 years. He married Leanna Briscoe, his high school sweetheart in June 1973, and has two adult children and four granddaughters. Prior to accepting his current position in 2014 as the Manager of the Carlsbad Irrigation District, Dale retired after 33 years in public education as a classroom teacher, coach, and principal. He currently holds the following licenses issued by the New Mexico Department of Education, Level II Athletic Coach, Level III 7-12 Secondary, Level III 7-12 Secondary Vocational Technical, and Level III Pre K-12 Administrative. His formal education includes the following degrees, an AA in welding from New Mexico State University, a BA in business administration from Northwood University, and an MA in education administration from College of the Southwest.*

Thank you, Phillip. I first want to say that it's an honor to be among this esteemed crowd. I feel a little overwhelmed because of the experience that sits at the table. Obviously, the Carlsbad Irrigation District was not too particular about who they put in charge down there, so I came out of retirement. As I looked at the program today, it brought back being in the classroom. If you notice, we are arranged alphabetically, so I get to speak first and set the bar low, so everybody else can knock it out of the park.

Since we're sitting here talking about the fallowing of farmland, the Carlsbad Irrigation District (CID) holds the rights to just over 25,000 acres of Pecos River surface diversion rights with a priority date of 1887. The district was formed by entrepreneurs in the 1880s, and after several flood disasters in the late 1800s and early 1900s, the Bureau of Reclamation came in and helped rebuild some of the infrastructure destroyed by the floods of 1903 and 1904.

That brings me to what has happened a hundred years later. New Mexico found that they were not delivering enough water to the state of Texas south of our district. New Mexico began looking at different ways they could get water across the state line. This happened in the 1980s and 1990s. They had a lease program where farmers would sell unused water to the state. Then the state started looking for a more permanent way to not have to budget for that. They wanted to make a long-term investment, so a settlement agreement was reached. I believe it was in 2003 among CID, Pecos Valley Artesian Conservancy District, the Office of the State Engineer, Interstate Stream Commission (ISC), and the Bureau of Reclamation. With that, ISC was going to buy up to 6,000 acre-feet from CID and use that water for state-line delivery until an appropriate credit or overage was delivered to Texas. That part has been successful. This will be the second year since the settlement agreement that we have reached or exceeded the 115,000-acre-feet credit owed to Texas. ISC will not take delivery of their CID rights for state-line delivery.

The challenge when ISC was going to start buying up land was looking for willing buyers and willing sellers. The plan was to go as far down the system as possible from Avalon Dam where we divert into the canal and buy up 6,000 acres on the tail end. There were people who had been farming for generations who did not want to sell their farms. We've got five different divisions that we deliver water to, and ISC wound up buying water in every single division. We've got over 50 miles of canals and hundreds of miles of laterals. In some cases, at the end of a lateral that is 25 feet long, the guy at the end kept his water and everybody up to the main canal sold theirs, so the challenge then was CID still had to maintain that 25 miles of lateral. As that land was retired, the other challenge is that weeds started to grow. It is taking years, but some of it is beginning to return to its natural state.

For some of the land that was sold on the buyback, after ISC took the water off of it, the landowner could buy it back at a reduced amount, then they would sell that again, and then the new owner would find water rights and move water back to the land. So sometimes we are trying to rehabilitate a system that had not been used for several years. It has been a challenge in that respect. I will say the positive effect is that it has helped New Mexico with their state-line delivery to Texas on the Pecos.

## Aron Balok, Pecos Valley Artesian Conservancy District

*Aron Balok is the Superintendent for the Pecos Valley Artesian Conservancy District. Aron has a passion for New Mexico's agricultural heritage and a deep appreciation for the complexity of the water issues that face the state. He has been professionally involved in water related issues for the past nine years. Aron was raised on a small cattle ranch in northwestern New Mexico. He attended New Mexico State University, and in 1997 graduated with a Bachelor of Science degree in agriculture extension education. He and his wife Hayly and their three girls live in Roswell, New Mexico.*

I'm the superintendent of the Pecos Valley Artesian Conservancy District (PVACD), based out of Roswell. We have 110,000 irrigated acres within the district, and about 90,000 constituents live within the district. We do not have a membership to the district. If you own land, then you pay the mill levy, which funds the district. We were created with the novel purpose to manage the groundwater and to conserve the waters of the Pecos Valley. It seems simple enough. It is a humbling thought when I think of the people that came before. While I am following in their footsteps, I certainly am not filling their shoes. But we're trying to do what we can do. This idea of fallowing farmland is part of it.

I judge by the fact that you are here, you are probably interested in water issues, correct? How many of you own a water right? We do have some hands. That's encouraging. I go to way too many of these events where nobody in the audience owns a water right. The fact is we should have this room full of people who own water rights because we are here discussing policies that affect them. That's one of the complications that we have to deal with. I'm always reminded of the words of Baxter Black. He said, "In feast or famine, at least examine / the game we came to play / 'Cause win or lose / it's how we use / the cards that come our way." We're trying to decide what we're going to do with the water rights that belong to other people. We have to come up with a system that is equitable. This idea of buying and drying ultimately is too often where we end up. It's a natural progression if you think about how farmland is treated.

We start out with wilderness, and then we subdue it in some way. We put livestock on it, we graze it, maybe we start to cultivate it and grow some small grains, dryland crops. Maybe we figure out how to get water on it, and we can start growing some row crops, then it evolves even further, and we have orchards that grow up on it. The next step is we put houses there. Once we put houses there, we are never going to put another crop there. That's just the way it evolves.

In the Pecos Valley we are constantly faced with the question, How do we conserve the waters of the Pecos Valley and protect those interests? Agriculture is near and dear to my heart, but I also answer to constituents who don't care about agriculture. They just want to make sure their economy is doing well, that they have water for their lawn, they can water their pets, wash their car, and they're happy. We have to balance all those. When we get talking about how we can reduce the depletions, that leads to this fallowing idea. The idea that I've been circling around and my board of directors has been working actively on is developing a water bank: we have a government entity, the PVACD, that can own water rights and it can afford to take those water rights out of production when we hit times of drought.

In my area, we have 10 wells that we monitor three times a month. I can tell you what our aquifer levels are doing. We have an amazing aquifer system, not to sound like I'm bragging, but it is literally an inexhaustible resource if we can continue doing what we're doing. What we have been doing is we have been taking out no more water than has been coming in. Now granted, when we hit times of drought, we take out more than came in, but we've been recovering. In the long term, we've been doing a really good job of maintaining that. The last drought that we suffered showed us that we have the real potential to get into trouble. That's where we circle back to this water banking idea: when we get in those dry periods, we can withdraw some of that water from production, and then when we hit wet times again and our aquifer has recovered, we can put that water back to work in the economy and we try to avoid some of the pitfalls of buy and dry.

## Paula Garcia, New Mexico Acequia Association

*Paula Garcia is Executive Director of the New Mexico Acequia Association. During her years of service, acequias built a movement around the principle that "water is life – el agua es vida" and have achieved water policy changes to protect rural and agricultural water rights. The NMAA has created community education projects to strengthen local acequia governance and water management and to train new and beginning farmers and ranchers. Paula is also Chair of the Mora County Commission, an office for which she was elected on a platform of ethics and good government. She recently completed a term as the President of the New Mexico Association of Counties and she was appointed during the Obama administration to the USDA Minority Farmers Advisory Committee. She lives in Mora where her extended family continues to operate a small-scale ranching and forestry business. Her son Joaquin is in the ninth grade at Mora High School.*

Good afternoon. It is great to be here. My name is Paula Garcia, and I am the executive director of the New Mexico Acequia Association, and it is a great honor to be on this panel with such esteemed water experts who are in the field. It's humbling to be here. I am here to share with you a perspective from the acequias about this topic of farmland retirement. When I first heard about this title, I thought to myself, "I don't know if I belong on that panel." Because from the acequias' perspective, we're doing everything that we can to prevent any kind of farmland retirement, although it is complicated. I'll get into that in just a little bit.

To give you a little background about acequias: who can guess what a realistic priority date for acequias in New Mexico is? Any ideas? Any hands? 1760. That's a good one. Late sixteenth century. Well, there is an acequia called Acequia Chamita. We call it that, but it was part of the original mission near Okhay Owingeh. The Acequia Chamita is still there. When they were going through their adjudication process, they got a priority date of 1600. There is a little faction within that acequia that is adamant that it has to be 1598, just as a matter of principle, which gives you a feeling of how proud and how deeply rooted acequia traditions are. That's just the sense that, OK, we've got to get this date right.

I just wanted to share with you a few thoughts about this idea of farmland retirement and what's happening. I definitely see the rationale for farmland retirement and water rights retirement where systems are overappropriated. Arguably, that's probably most places. From a historical standpoint, acequia leadership feels we should do everything in our power to keep whatever farmland has been there historically, to keep it in use or to put it back into use.

There are a lot of complicated factors causing fallowing of agricultural land. Those are mostly socioeconomic. We're dealing with smaller parcels of land. Families have had a lot of shifts. Because of outmigration and economic restructuring in the villages, subsistence farming isn't something that is as common as it used to be. Market farming and ranching is something that some families have continued and some are gearing up to do, but there is a real mixed bag in acequia agriculture. Overall, we're seeing an uptick in the number of people who want to diversify their production, and we're hopeful about that. At the same time, we do have an issue with some fallow lands.

One way that we sought to address that in the early 2000s was to give people flexibility. The idea is to think long term that lands will go in and out of production depending on the status of that family and the status of the land tenure—depending on who is on the land and what it is being used for—so that if land was temporarily fallow and water rights were temporarily in nonuse, they could be banked. In 2003, we worked on a statute that defined acequia water banking and gave landowners, water right owners, the ability to put their water rights in an acequia-managed water bank and allowed that water to be put to beneficial use by the remaining water rights users, the remaining irrigators on that system.

Keep in mind that acequias are much smaller than irrigation districts. We've counted about 700 in New Mexico that have updated contact information. They range in size from three families to many hundreds. There are some in San Juan County that have over 600 members. They vary widely in size and scope and amount of acreage (from one acre to one hundred acres). There is a lot of variability, but overall we have been working on building capacity and doing work on acequia governance, so that local commissions are empowered to manage their resource better. Water banking is part of that. Water banking was established in statute. An acequia, to do water banking, should have some written rules and a record keeper. Our whole idea was to keep a paper trail so that if ever there were an argument to be made that water was forfeited or abandoned there was proof of the intent to keep that water right in beneficial use.

In terms of taking the long view, we're trying to hold out hope that in some of those fallowed lands, the land will be put back into production, or at some point, if it is contemplated that there will be a change in point of diversion, purpose, or place of use, that the change would be a community-based decision and it would be done for the greatest common good of that community. It's a long-term view. Thank you.

## Steve Guldan, New Mexico State University, Alcalde

*Steve Guldan has been superintendent at New Mexico State University's Alcalde Sustainable Agriculture Science Center since 1992. During this time he has also been a faculty member in the Department of Plant and Environmental Sciences at NMSU. His appointment is 60% research and 40% administration.*

*Steve grew up on a mixed crop and livestock farm in southern Minnesota, received an undergraduate degree in geography from Mankato State University, and graduate degrees in agronomy from the University of Minnesota. Before coming to New Mexico, he worked for two years at the International Maize and Wheat Improvement Center in Mexico, and four years at the Carrington Research Extension Center in North Dakota.*

*While at NMSU, he has led or collaborated on various research studies related to forages, horticultural crops, green manures, interseeding methods, and acequia agriculture hydrology.*

My name is Steve Guldan, and I work for New Mexico State University at the Alcalde Sustainable Agriculture Science Center, which is in the Española Valley, just north of Española. I'm sure some of you know where it is. Some of you may not. It is pretty much right in acequia country.

Just to follow up on some of the things Paula was saying: I was talking with Lucia Sanchez, who is a commissioner for our particular acequia, the Acequia de Alcalde. They are trying to keep land in agricultural production, and they have been discussing protecting the water right through water banking within the acequia, as Paula was mentioning. I think there need to be some kind of mechanisms worked out for leasing, upstream and downstream, which could be beneficial to producers. I, also, when I saw the title of the talk and it was on retirement, had a few observations on that and thought I didn't fit on the group talking about retirement, or at least I don't have experience in farmland retirement. But our acequia is trying to match up people who want to farm but don't have the land with people who have land that is not being farmed—maybe the owners are elderly and they don't have children, and their land is not being farmed. There are efforts going on with that.

In some of these communities, it is complicated both hydrologically and in terms of management of the acequias. It is not straightforward. Those who understand acequias in particular realize that for a given acequia, if a few people start to sell their water rights, the integrity of that system can start to break down pretty quickly, even when the great majority of people still own water rights. When a few people sell, there is less involvement in managing the acequia and paying fees in, and all of those things start to fall apart. If water to an acequia starts to be metered and now there is less water being diverted into the acequia, it can make it very difficult for those at the end of the acequia to get the water they need because there is a certain amount of head, or flow, that is required to get water through the whole system in many of the acequias.

I would like to make a couple other observations. I think this relates to farmland retirement but also to fallowing land. Jan Hendrickx, who is maybe going to talk about this in a minute, brought this up at a meeting, and it stuck with me strongly ever since. I have some personal experience at the station I work at. It may seem pretty easy to think that by fallowing land, the water is automatically going to become available downstream, but something is going to grow there. I'll let Jan talk more about that. To limit water use from plants will take management and expense. It will vary by site. Pretty much everything we talk about here is site specific.

Some of the research I've been fortunate to be involved in with Sam Fernald and others is a study to understand where the water goes in the upper reaches of the Rio Grande Basin. We're finding out in a general sense where the water goes; we'd certainly like to do more research to quantify better what many traditional irrigators have known, to put some numbers on it. Basically, like where we are in the Española Valley, irrigation season starts, irrigation recharges the aquifer, and the groundwater level goes up. At the end of the irrigation season, that water leaks back to the river slowly as groundwater return flow. It is a hydrologic function that agriculture is performing, because it puts water in the river late in the season instead of all the water going into the system early during snowmelt. If agriculture disappears, the water will rush to the river and run downstream. That may be fine for Elephant Butte. On the other hand, we know a lot of water is lost through evaporation off of Elephant Butte, whereas we think there may be some benefits to the water being stored underground up north in areas where the surface water and groundwater are closely connected. That's pretty much all I'll say. Just some observations. I think there are a lot of complications, as we all know, involved with fallowing land in a fair way, so that no one is unduly affected negatively by it. Thank you.

## Mike Hamman, Middle Rio Grande Conservancy District

*Mike A. Hamman is the Chief Executive Officer/ Chief Engineer of the Middle Rio Grande Conservancy District (MRGCD), located in Albuquerque, New Mexico and has served the District since January 2015. He possesses more than 33 years of engineering and water resources management experience with extensive knowledge of New Mexico water resource development projects and issues. Prior to the MRGCD, Mike was the Area Manager for the U.S. Bureau of Reclamation, a federal water management agency with 13 projects from the San Luis Valley in Colorado to Fort Quitman in Texas. As Area Manager, he lead a staff of 190 in six field offices that perform operations and maintenance of well fields, diversion dams, large dams, and reservoirs such as Elephant Butte, river channel maintenance on the Rio Grande and Pecos basins, water modeling and accounting for project water, and implementation of endangered species programs. In addition, Mike worked as a Regional Water Planner for the NM Interstate Stream Commission, Water Utility Director for the City of Santa Fe, and Water Administrator for the Jicarilla Apache Nation.*

*Mr. Hamman was raised in Taos and received a BS degree in civil engineering from the University of New Mexico. He and his family currently reside in Corrales.*

Good afternoon. I'm Mike Hamman. I've been the CEO of the Middle Rio Grande Conservancy District for a little over two and a half years now. It is interesting that I follow the two acequia presentations because the Middle Rio Grande Conservancy District is essentially a conglomeration of 77 different ditches and acequias and other types of headings for pueblo irrigation lands into one big irrigation district. But we also suffer from similar concerns as far as land fallowing and other operational issues related to water management.

On the establishment of the district, there was a recognition of just under 124,000 irrigable acres that would be served by the district's facilities. That was never truly achieved in terms of total production. The peak that was achieved through the development of the system occurred in the 1960s, where just north of 90,000 acres was in production at that time. The sad fact is that we are now south of 60,000 acres in production and dropping by 200 or 300 acres per year due to some kind of development or other kinds of fallowing because of economic situations or other concerns. People who have valid pre-1907 water rights served by the district are able to sever those water rights from the land and transfer those rights, typically toward some kind of municipality like Albuquerque or Rio Rancho or Santa Fe. There has been a lot of that occurring over the last few decades.

The loss of acreage is of major concern to the district, as you might expect, similar to the acequias. We want to keep the lands viable in an agricultural context. We want to keep a good agricultural economy in the area. We don't want fallowed lands everywhere, because fallowed lands grow weeds or other phreatophytes that continue to deplete water whether we like it or not and also create concerns, such as weed problems, for adjacent landowners that do want to farm. Those are major concerns of the district.

We're primarily a run-of-the-river district. In other words, whatever Mother Nature provides on the Rio Grande is our primary resource. We do have a supplemental storage reservoir way up in Chama, which takes about four days of river flows to reach the far end of the middle valley, that we use for supplemental late-season irrigation, if we can store there. It is a post-compact reservoir, and if we're in restrictions under the compact, we can't store water up at El Vado. We are also a San Juan–Chama contractor, which allows us to have up to 21,000 acre-feet of San Juan–Chama water to help us supplement late-season irrigation. That isn't a reliable supply in the context of providing enough of a base agricultural flow to get all lands through the irrigation season every year.

We have very little supplemental irrigation systems from groundwater in the middle valley due to the state engineer closing the basin in 1956 because of concerns of groundwater mining in the Albuquerque area and elsewhere. There is limited groundwater potential there. Some farmers can foresee the future: they have retired surface water rights into groundwater wells. Those of you that drove down from Albuquerque to this meeting here today probably passed a big pecan orchard in the Belen area. That is supported by groundwater. Those kinds of crops have to have some kind of reliable system. The fact we are run-of-the-river has shaped our agricultural economy here to a primarily alfalfa or forage crop type of agricultural economy. The other factor has been labor shortages. Agriculture just doesn't attract enough labor into the middle valley because there aren't a lot of harvesting crops here except for some smaller operators.

We've got a lot of challenges, but fallowing lands is one of the big ones. We are shifting our policies toward taking a hard look at the transfer of water rights from agricultural use to municipal and industrial (M&I) use. We just can't keep hemorrhaging away our agricultural foundation and our land base through the buy-and-dry concepts associated with M&I development. I like to say, too, the Albuquerque Bernalillo County Water Utility Authority and the City of Santa Fe are making policy shifts toward not pursuing the purchase of pre-1907 water rights as part of their portfolio.

We are also concerned, obviously, about lost revenue. We have got to have an income to operate as a district. We are also concerned about the treatment of the fallowed lands. They have to be replaced with some kind of low-water-use replacement crop to prevent weeds and other phreatophytes from moving in on those vacant lands. We also really need to support locally grown agricultural products. There is a trend in that direction, as Paula said. We're seeing a big uptick in small-scale agricultural development for the farm-to-table market, farmer's markets, and the like. It seems to be a growing trend. We want to encourage all that.

The other thing we are doing is working very closely with the six middle Rio Grande pueblos to ensure that they have the water resources and other resources the district can provide to help them advance their agricultural agenda for their communities. That is a cultural foundation to their existence.

Those are things that we are working on, and we are protesting those transfers to M&I on the buy-and-dry concept in order to get Rio Rancho and others to the table to help us deal with the fallowing lands problem. Thank you.

## Jan Hendrickx, New Mexico Tech

*Jan M.H. Hendrickx is an emeritus professor of "critical zone" hydrology who has investigated the hydrology of the Earth's Critical Zone since the early 1970s. The Critical Zone is defined as the Earth's outer layer from the top of the atmospheric boundary layer through the vegetation canopy to the soil and groundwater that sustain human life. His critical zone hydrology experience is global from northeastern Brazil where he designed inexpensive trickle irrigation systems as an OXFAM volunteer to Mali and Pakistan where he led research projects for the Dutch government on how to improve irrigation and drainage water resources management. In 1990, he joined the faculty of the Hydrology Program at New Mexico Tech. His research efforts are focused on groundwater recharge in the southwestern USA, the application of geophysical methods in soil hydrology, and the use of remotely sensed satellite imagery for the mapping of evapotranspiration and soil moisture. He has authored or coauthored over 100 refereed papers and book chapters. He is Fellow of the Soil Science Society of America (2002) and Fulbright Scholar (2000).*

Thank you, all my panel fellows. By now, most of it has been said about management of farmland retirement. There is still one aspect that has not been highlighted enough. Before I get to that, first of all, I am in favor of retiring farmland as long as it remains available to be converted back to farmland. With sea-level rise due to climate change, millions of hectares of good farmland will disappear before we know it. Who has to produce food? I think that the New Mexico farmer has a great future coming up as all these coastal irrigated lands disappear. Let's not retire farmland, or not without thinking twice about it.

To go back to the issue at hand, I think that the term *water bank* is completely wrong. What does a bank do for you? You go there, you put your money in the bank or the safe, and the guy that you give your money to gives you a receipt to say that the money has changed hands, but the money is in a safe place. In a water bank, the water is not in a safe place. If you have a deep aquifer, the water is relatively safe—until another state or a neighbor sinks another deep well and starts pumping. If you have shallow groundwater tables, your water is disappearing. In a legal sense, you can have water rights, but buying water rights in the middle Rio Grande valley, I think, is the worst investment you can possibly make because the water is still going away. In order to put this in perspective, let me give some numbers.

Figure 1 shows some work I did about 10 years ago with Nicole Alkov, one of my master's students. We look at the site here of the Mitchell Fire. I figured out that the ultimate conversion from agricultural land to M&I is to look at an area where the agricultural land has zero evapotranspiration (ET), and what is better than a fire going through the entire place and removing all the vegetation? The left image shows you one year before the fire, May of 2004. We see lots of ET going on. The blue colors are high ET, up to 8, 9, 10 mm. The red colors are low ETs, but red means 0–1 mm. In this place, you see the blue sites of high ET, and then see kind of a square in the middle. That area was treated with herbicide to remove the salt cedar. The third (from the left) image shows ET a year later, in May of 2005. These are Landsat images that we converted to ETs. What we see is the month after the fire, the ET came down to values below one meter a day, with some exceptions in the left corner. But then one year after the fire, the ET climbed up and was almost at 50 or 60 percent of the capacity before the fire, except in the areas treated with salt cedar herbicide. Then two years after the fire, ET was as high as it was before.

In other words, you may want to convert agricultural land to something else, but as long as there is water there, something will start growing and use that water, unless—as you see in that middle square—you take action like herbicide, burning, flooding, or mechanical removal to control regrowth. But that might be kind of expensive, and you never can eliminate evapotranspiration. You may sell, say, five acre-feet of water from your farm to Rio Rancho, and Rio Rancho will take that five acre-feet, but guess what? The farmland from which you sold the water rights still generates ET of one, two, or three acre-feet.

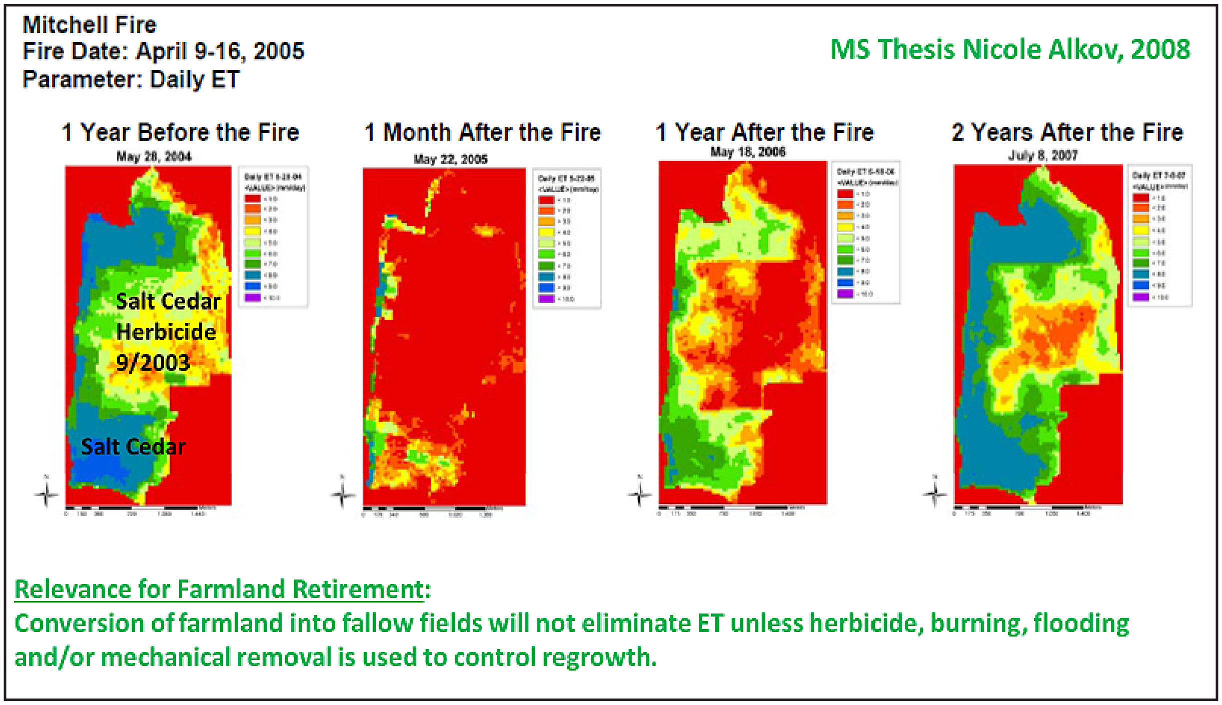


Figure 1. Comparison of daily evapotranspiration at Mitchell Fire site over two years.

Hendrickx et al., 2016

**Annual ET in Middle Rio Grande Conservancy District from MODIS Imagery (1 km pixel size)**

| Land Cover | 2007 Annual ET (mm/year) | Stand Dev ET (mm/year) |
|---|---|---|
| Irrigated Land | 927 | 172 |
| Grassland/Herbaceous | 790 | 155 |
| Shrubland | 744 | 244 |
| | | |

**Relevance for Farmland Retirement:**
**Capillary fluxes from shallow groundwater tables in the Middle Rio Grande Valley provide sufficient water for vegetation to grow and transpire even in the absence of irrigation.**

**Groundwater Table Management is a Possible Solution:**
**Lower groundwater tables decrease capillary fluxes into the root zone and will lower ET rates.**

Figure 2. Annual ET in Middle Rio Grande Conservancy District from MODIS imagery (1 km pixel size).

Figure 2 puts some numbers on how much ET might occur. This is a study we did in the middle Rio Grande. There is a publication I wrote with nine other authors in 2016. We used pixels of 1x1 km, and that means that our values are spread out a little bit. But let's look at the land cover. We have irrigated land, grassland, and shrubland. Some of the grassland, because of the way the city was organized, might have some irrigation. The irrigated land certainly has some unirrigated patches in it. The shrubland is probably what you would have if you let things go fallow, and you get some natural vegetation. The 2007 annual ET on the irrigated land on the 1x1 km pixels and the standard deviation is shown in Table 1.

Let's say that we take two standard deviations less the average ET of shrubland, and we still end up with about 250 mm/year of ET, which is 2 AF/year of water lost from fallow irrigated land. The significance of this for farmland retirement is that the capillary fluxions from shallow groundwater tables in the middle Rio Grande valley provide sufficient water for vegetation to grow and transpire, even in the absence of irrigation. So, transferring water rights is meaningless. The water will still be lost. So what is a possible solution? In this context, I like to mention that before I became a professor, I was an irrigation, rain, and drainage engineer with more than 10 years' experience in different areas of the world. I think a possible solution might be to lower the groundwater table, reduce the ET—we're never going to get it to zero, but within the right place we can reduce it quite a bit—and then try to manage the ET in the valleys by managing the groundwater table.

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**J. Phillip King**: Thank you. I can just say that in the lower Rio Grande, we figured out how to lower our groundwater table.

**question from audience**: The most common word I've heard used among the panelists is the word *fallow*, or as the title indicates, retirement, which I regard as euphemistic terms for the discontinued use of water in a beneficial way. We've recently learned through an article by Laura Paskus, published I think it was in *High Country News*, that there are more than 7,000 acres of land in the Gila–San Francisco Basin that have been fallowed, according to the annual studies of the water master in that basin. Now when you take a look at the actual records, they've been fallowed for close to 40 years. That to me is not fallowing. Three or four years is fallowing. Fallowing for 40 years is abandonment of irrigation. Why isn't the state engineer taking action to enforce forfeiture against folks who have discontinued the use of water and have retired from farming or died or moved away?

**Paula Garcia**: Tom Blaine is here, and he is the state engineer, but I think that is a fair question to ask. The state engineer has forfeited water rights through the adjudication process. For the Rio de las Gallinas Basin, between the Hope Decree of the 1930s and the current readjudication, there is a difference of over 10,000 acre-feet that were in the Hope Decree that didn't make it into the new hydrographic survey. I think there are, at least in acequia country, instances where water rights have been forfeited through the adjudication process. Part of your question is probably why they do not enforce the four-year rule, which is another question. There have been water rights forfeited in acequia communities. That is part of the reason we try so hard, and every single acre is precious.

**Dale Ballard**: A water right is a very volatile issue. Aron asked earlier who here owned water rights, and this place should be filled up with people that have water rights to sit here and discuss. The other side of that is that I'm not sure I'd want to be on this panel if this room were full of people with water rights. CID has asked the same question of the state engineer for some of our adjudicated rights in the district, not only on the Pecos River but also on the Black River. There is an instance where water had not been used on land for over 50 years. The owners of that right were never told by the state engineer that their right was lifted. There is a process that you have to go through in order to get that done. It is a very touchy situation because a water right in New Mexico is attached to the land, and the earlier that date is, the more valuable it is. When it gets right down to reaching a settlement or adjudicating a stream, people come out and they want to protect what the law says is rightfully theirs.

**question from audience**: It is my understanding that most irrigation on the ditch system is flood or furrow irrigation. Is there a disincentive to an individual water right holder to use water much more efficiently, for example, drip irrigation? What does that imply for decisions about retiring farmland or encouraging farmers to adopt different systems of water use?

**Aron Balok**: That's one of my favorite questions. It really is. I ask people from 8 years old to 80 years old. This simple question is what is conservation? If you search online, you'll probably come across a definition that I tend to follow, and that is "to make available for other uses." From my perspective, if I am encouraging conservation, I'm encouraging that farmer to do what he's always done and that is to grow more for the many with less. But I don't want to take the water from him, so what I'm actually doing is encouraging him to grow more with the same amount.

In some areas, drip irrigation works really well, and in some areas, it proves to be a net depletion to the aquifer when groundwater is used, depending on the communication between the surface and the ground. I promise you I could argue all day long on areas that where drip irrigation does or does not have that effect. In some areas, the communication between surface water and groundwater is direct. There are return flows that are critical for everyone else. In other places, there are just not enough return flows to measure depending on soil type.

That becomes the question: Why move to drip irrigation? Why move to a sprinkler system? Because then you are saving water for the state. That is why I feel strongly about the idea of an entity being able to take land out of production and actively manage the aquifer, rather than putting that burden on the individual. This kind of goes to the question before: if the government is going to limit a water right, that's essentially a taking and that gets into a whole legal proceeding. I do believe that the owner of a water right has some rights. Those are private property rights. I don't think it should be taken lightly when we're talking about infringing on those.

**question from audience**: I wanted to ask a question about the efficacy of rotational fallowing. Suppose in a lot of these systems where you're growing alfalfa, at the end of the effective life of the alfalfa, you plow it under for a year and then potentially those water gains might be an alternative to buy and dry. Does that make sense?

**Aron**: It ties directly to the previous question, and that is: What is the incentive? If you think about what people in agriculture are doing, they are selling water. I don't really care whether they sell that water in the form of a bale of hay, a bale of cotton, corn silage, or if they put a meter on it and sell it to the oil patch. It is their water. As long as they are not infringing on everyone else, I think they have the right to do that. So when you go into these better practices, it depends on what kind of farmer you're working with. In our valley, we've got farmers that run the spectrum. There are farmers that can tell you down to the minute when it is time to rotate that crop out because they know where that line is in efficiency of putting water on alfalfa. They've got rotation crops. I'm constantly in awe of a good farmer because they have to be able to manage that to make money, and over time, I guess the consolation is that it is kind of survival of the fittest. The poor farmers eventually end up going out of business because you can't afford to make too many of those kinds of mistakes where you're wasting the ability to earn an income.

**question from audience**: The question really was if a farmer takes an extra fallow year, and a number of people are on that cycle, would that be enough to reduce the pressure to buy and dry?

**Aron**: But what does that farmer gain out of fallowing for that year? Somebody has to pay for that. That's I guess in a roundabout way similar to what I'm talking about with an entity being able to purchase water rights, and then the entity can afford to fallow the land—that's why I'm advocating for what we're trying to get off of the ground. The district could afford to lose the income from that water on years when we needed that water out of production. You can't go to somebody whose livelihood is tied to that use of water and say, "You know what, it's dry. These next three years, we need you to just use less water." What they hear is, "We need you to make less money. Can you just operate on half of what you made last year?" When you put it in those terms, of course not. That's why I think if you have an entity that can afford to take that financial hit, then farmland fallowing is possible. In that sense, I think you could probably do something rotational or similar to that. It might be a management headache.

**Phil**: Aron, who incentivizes farmers to fallow in your area?

**Aron**: Right now, the way we're doing it is willing seller, willing buyer. We're purchasing the water rights. We own the water rights. Then if we want to see those water rights put back in production, we make them available for lease.

**Phil**: We're winding down here, but I had one quick question I wanted to ask Dale. You put nearly 25 percent of your district into this buy-and-dry program: 6,000 out of 25,000 acres.

**Dale**: It was up to 6,000. Right now, it is 5,000.

**Phil**: OK, so one-fifth of your acreage. One of the worries that people have is that if you put too much land into a buy-and-dry program, you fall below a critical mass of agriculture that makes the local economy sufficient to support that agriculture. Have you felt any of that?

**Dale**: Well, first of all, the land was retired, but the water right wasn't. What the Interstate Stream Commission takes for delivery to Texas is almost identical to what would be delivered to farmers. Now, the other thing I think Aron, and anybody in agriculture for that fact, would also say is that on the 20,000 acres still in production, there are probably another 3,000 to 4,000 acres that are fallow. People decide it is not profitable, and the land just sits there. If somebody leases their water, that's fine. If they don't, they've made their money and they just sit there. But the other side of that is, today, we're probably raising more crops on that 20,000 acres, or say 17,000 that's under cultivation, than we ever did when the full 25,000 was in production, because of better practices. We've got a farmer who must be doing something right. He's got the biggest and the best equipment, and he's basically no till. He plants winter wheat and cotton stubble and then harvests the wheat in March and then puts cotton right back in there, and he seems to make it work. I think we are still producing, we're realizing, as much production as we ever did. That is the same as our partners to the north, up the river, too, I imagine.

**Paula**: I wanted to respond to the question about rotational fallowing from Steve Harris. I think that's a really intriguing question, and I think the context is really different from what Aron described as far as management tools because the PVACD is bigger and a little more sophisticated from a technical standpoint. I can imagine a scenario in acequias where rotational fallowing might work as an alternative to permanent water transfers or permanent fallowing. Let's say you have 10 people in an acequia. Instead of buy-and-dry unfettered, you would have a voluntary leasing system. Let's say 3 out of 10 decided to participate in the leasing program, where they would rotate to provide water for other uses—for example, if a mutual domestic needs 10 acre-feet because of a deficit. This scenario is not unusual in northern New Mexico, where mutual domestics are in the red and they need to catch up and acquire some water rights.

I don't know whether the state lets you lease for those purposes, but just hypothetically, if you had a need for water rights, rather than permanently fallowing, you could rotate across lands to meet that need so that no lands are ever permanently put out of production. I think it is a novel idea, and I don't know that it has been tried. I think as we get to the point where there is more interest in growing crops and keeping land in production, it will be harder to find people who want to sell their water rights permanently. If you look at the difference in the water market between, say, the Middle Rio Grande Conservancy District and Alcalde, you don't see a lot of sales in the Alcalde market. It is not a very active market, where you see people just selling like hot cakes. It's not happening. You do have needs as the community grows and things change, and I can envision scenarios where temporary rotational fallowing along with leasing might be something that a community would want to explore as a possibility.

**Jan Hendrickx**: I have one final comment. I fully agree with all the issues about personal rights of the farmer. Of course those need to be respected. The point I want to make is that we can only move to a good, fair system if we start out with respecting the physics. In my sense, if a farmer sells five acre-feet of water rights to Rio Rancho, and Rio Rancho takes it up there, and three acre-feet of water still evaporates from the farmer's land, then somebody is damaged. We have the technology today that we can tell you exactly how much ET occurs in your district, when and where and how much. I think we need to work on the physics and know the physics, and then go to the attorneys and see how we can respect all the rights that everybody has.

**Mike Hamman**: I'll make one more point too, because I think you bring up a good point, Jan. In the middle Rio Grande, if you're looking at a fallowing concept for making water available for other purposes, we're run of the river primarily, so essentially—and you see it already—we're not irrigating 90,000 acres, we're irrigating less than 60,000 acres. We're diverting less water, and as a means to meet some Endangered Species Act requirements, we've tightened things up a lot from what the district used to divert historically. We're more of a scheduling outfit, so we would have fewer farms to schedule water to, and so, therefore, it would work its way upstream and we would divert less water. It doesn't necessarily mean that we would have extra water to work with, other than that the water, at that point in time, would stay in the river and go down to Elephant Butte.

I think where you're heading, Steve, is rotational fallowing for a targeted ecological purpose. I think you have to have a storage component to it, so that you can target the water in the late season when it is needed, similar to what we do with late-irrigation demands. Typically in the spring and early summer, there is enough water in the river to meet a lot of ecological purposes because we generally have a lot more water in the river than we need to divert. It is complicated, and we're going to try to start a process of looking at pre-1907 rights that people willingly want to put in a water bank for that purpose and see whether we can get some kind of storage right assigned to that water, so that it would be available later in the season when people could actually use it for ecological or late farming needs.

**Phil**: Thank you, colleagues.

# Hidden Opportunities: Innovations in Watershed Management to Havest Water and Improve Watershed Resiliancy

**Editor's Note: The following papers represent a transcription of the speakers' remarks made at the conference; no follow-up papers were submitted by the speakers. Remarks were edited for publication by the editor. The speakers did not review this version of their presentation, and the editor is responsible for any transcription and editing errors.**

## Moderated by Chris Canavan, New Mexico Environmental Department

*Chris Canavan has worked in the environmental field for over 20 years and is currently the field offices team leader for the Watershed Protection Section of the Surface Water Quality Bureau of the New Mexico Environment Department. He earned an MS degree in interdisciplinary studies from New Mexico State University in 1998, where his research involved examining total mercury and methyl mercury in water and sediment at Elephant Butte and Caballo Reservoirs in south-central New Mexico. As sole proprietor of Blue Heron Environmental from 1998–2004, he specialized in designing and implementing water quality studies for rivers and reservoirs.*

*Chris has been with the Watershed Protection Section since January 2005, and his duties include assisting in water quality surveys, working with stakeholders on watershed planning and restoration projects, producing the New Mexico Nonpoint Source Annual Report, and supervising two staff. He lives with his wife, Mary, in an old adobe on a small two-acre farm with 50 pecan trees in Las Cruces, New Mexico.*

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## Patrick Lopez, Elephant Butte Irrigation District

*Patrick Lopez is the hydrology director for Elephant Butte Irrigation District (EBID) in Las Cruces, New Mexico. He is also the information technology director and has held both positions for over three years. Prior to his time as director, he was the hydrology SCADA (Supervisory Control and Data Acquisition) supervisor for nine years. He began working at EBID in 2002 as a remote telemetry unit (RTU) technician. Patrick is a graduate of New Mexico State University, with a degree in business management. He also holds certifications for small water systems and sampling through the New Mexico Environmental Department and is a licensed radio operator and tower climber.*

*His department manages over 450 RTU field sites including diversion dams, river stations, EBID main canal diversions, lateral headings, drains, spillways, weather stations, rain gauges, flood control dams, groundwater monitoring wells, and farm irrigation pumps. Additional duties include directing and conducting all instream metering for the EBID portion of the Rio Grande Compact, overseeing the water quality program at EBID, and investigating all illegal dumping and hazardous spills in EBID facilities.*

Good afternoon, everybody. I'm here to talk to you about our stormwater capture program that came about because of a shortage in our surface water allotment. The Elephant Butte Irrigation District (EBID) surface water allotment from 1979 to 2002 (Figure 1) was 3 acre-feet or 36 inches. In 2003, we saw a dramatic dip due to the drought. Those first few years that we had drought, we were just trying to adjust to new methods of delivering water. Stormwater capture, although we had dabbled in it a little bit, wasn't the primary focus of what we were doing in the remote telemetry (RT) monitoring side of things. In 2008, we had a bounce back to full allotment. We thought the drought might be over at that point. We were hopeful for that, and then we were hit with 2011, where we had a four-inch allotment. Those were critical years. Obviously, when there is a shortage in surface water, our farmers have to kick on their irrigation pumps to supplement that water. We started looking at what's out there that we could do to help offset that pumping.

Stormwater was at the top of the list because we felt it is a free resource. It is something we could take advantage of. We understand that stormwater is not going to fix our problems. It is not going to eliminate groundwater pumping. In our estimation, we thought that at least we could do something to alleviate groundwater pumping due to the shortages. The other good thing was that we already have the infrastructure for it. We didn't have to spend a lot of money to build anything. We basically can capture the water at our diversion headings, reroute it to where we want it, and allow it to seep back in the ground. That's essentially what we've been doing. Divert water, put it into areas where we've identified there are issues, and allow it to seep back into the aquifer.

One of the big things to go along with that, though, is that our monitoring system wasn't quite built for that. Around 2011, we started adding weather stations to the watersheds of some of the larger arroyos in the district (see Figure 2). We also undertook updating our manual rain gauges that were useless for storm tracking. We added digital tipping buckets, and I put them on our RT system so that we could get early-warning alerts as storms moved through the system. As Figure 1 shows, we have seven more sites planned for this year for rain gauges, and we also plan to install a weather station but haven't determined where to place it yet.

We wanted to see if we did divert stormwater, whether we could see the real-time effects on the aquifer. We have 58 shallow groundwater monitoring wells that up to that point had been dataloggers, and so we had always been a month or two behind on collecting all that data. In 2015, we instrumented all of those, in addition to the rain gauges, with remote telemetry units (RTUs), so that if we did divert captured stormwater, we could put new wells in the places where we could see what the infiltration did to the water elevation. We also already had the structures for river stations, and we did have some of our main arroyos instrumented. We were trying to have a comprehensive view of a storm as it moved through the system: Where was it going hit, where could we send our personnel, and where could we divert the water?

We found a software company called OneRain Contrail that specializes in rainfall monitoring. We decided to purchase that software because it provides a large number of alarm features and alerts. It's a very user-friendly system. Anybody can navigate to our website (https://onerain.ebid-nm.org/home.php) and download the data and see exactly what we're doing. All these stormwater capture sites I'm going to talk about in a second are all posted online for you to see.

Adequate alerts are a big part of this system. We know that when water enters the system in the north regions of the map in Figure 1—up around the Hatch-Rincon Valley—and the rain gauges alert us, our personnel can get out to those areas, they can check the flood control dams, and they can look at what is coming into the river channel. We have about twelve hours before the water hits the in-between point for the Rincon Valley and the Mesilla Valley, which is up in Leasburg, New Mexico. When it hits our river gauging station there between those two areas, we know that we have four to five hours before it hits Leasburg. It allows us to put the personnel in the areas they need to be and to do the diversion.

As we were developing this program, the initial use for captured stormwater was to irrigate crops. We had some success in the early going with that, but a lot of times the farm fields don't want to take this type of water onto their crops. We've had a little better luck with pecan farmers. We still do that, but we started to change our focus to aquifer replenishment. We began to ask, What would be the best use of this water?

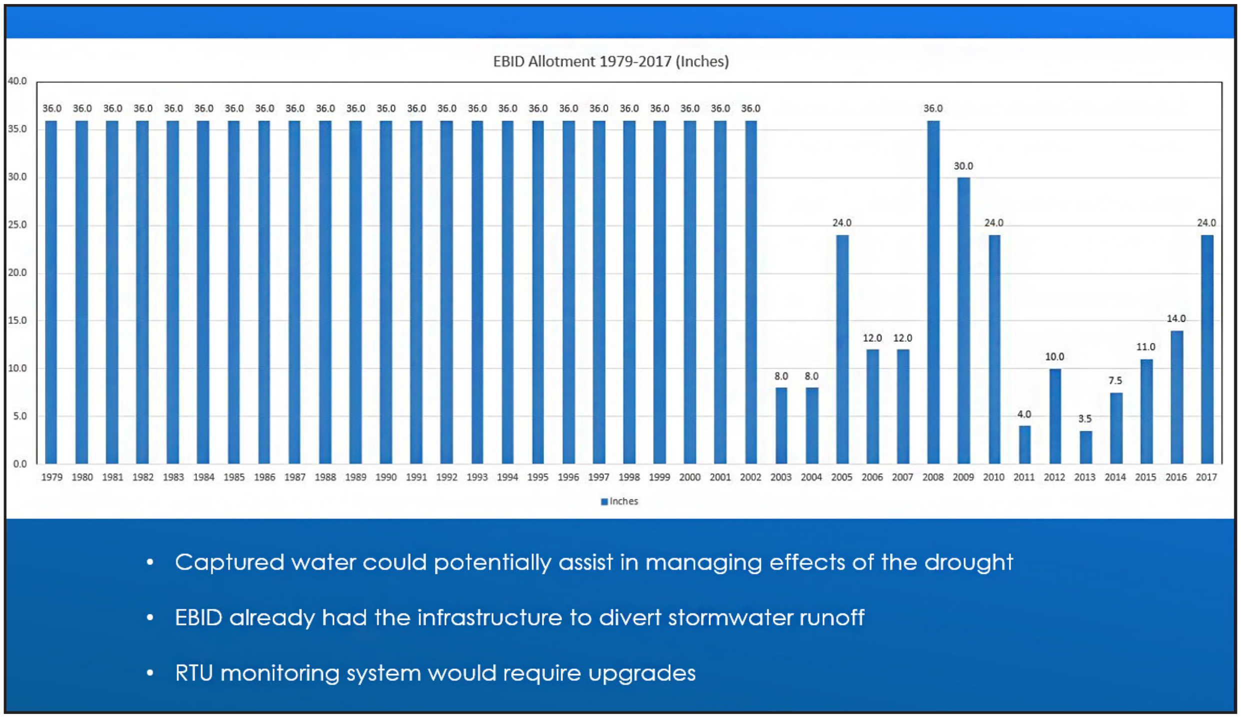



Figure 1. EBID surface water allotment.

I have a colleague here today, Eric Fuchs, who is our groundwater resource manager, and he started to do modeling a few years ago to identify key areas where the aquifer was dwindling faster than in other areas. Generally speaking, storms go by in 10 to 12 hours. In 2015 and 2016, we added stormwater discharge turnouts (that's their primary focus) to go into some of our drain systems. By diverting the stormwater into these areas, we can either capture the water completely and allow it all to soak into the ground, or slow it down to 30 or 40 hours where most of it soaks into the ground.

Figures 3A-3B show our targeted capture sites. The first site on the left map is up in the Selden area. We put that in at the tail end of the 2015 irrigation season, and we didn't get to test it with the irrigation season. Lucky for us, in October of that year, we had a storm out of season, and we were able to divert the stormwater, and we were able to capture about 12 acre-feet. Not that much, but at least it was a proof of concept that something like this could be done. The nice thing about it was that we saw an immediate jump in the aquifer level. In 2016, we went about adding the three other sites in green. We began to capture water in those areas. The eastside stormwater capture on the right side actually has to back up uphill, but we're able to back that water up approximately a mile into one of the areas that is the worst for groundwater pumping and decreasing aquifer levels. In 2016, we saw a rise in what we were able to collect, and 2017 has been even better. We're looking to add the red reach near San Pablo within the next 18 months.

We want to focus where we are capturing this water to put it in areas where we know that pumping is prevalent and our aquifer levels are lower than in other reaches. As an example, on the Selden—from August 9, 2016, to August 8, 2017—Figure 4A shows six to seven events where we have captured 25 to 30 cfs. You can see the immediate impact we're making on the groundwater.

We are just in the early stages of measuring the capture. Where I would say we go from here is to start putting numbers on what is happening to the groundwater. What radius is affected by the capture, and how much of an effect does it have? We need to compare our data with the lower Rio Grande pumps in the area to see how much water is being pulled out of the ground and how much we're putting back in. It was encouraging to see on all of our sites that when we dump that water in there, it has an immediate effect of raising

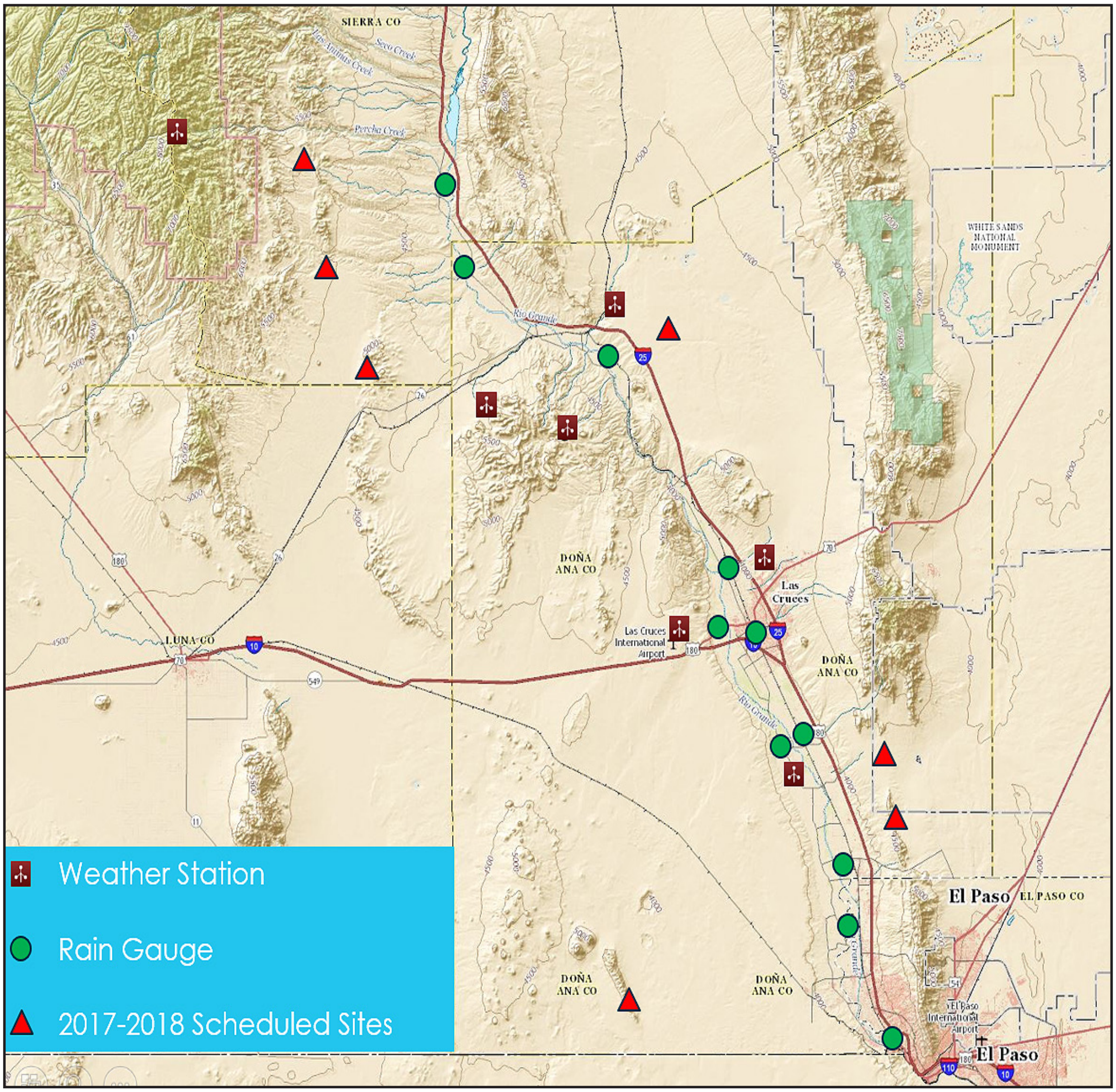



Figure 2. Upgrades to RTU system.

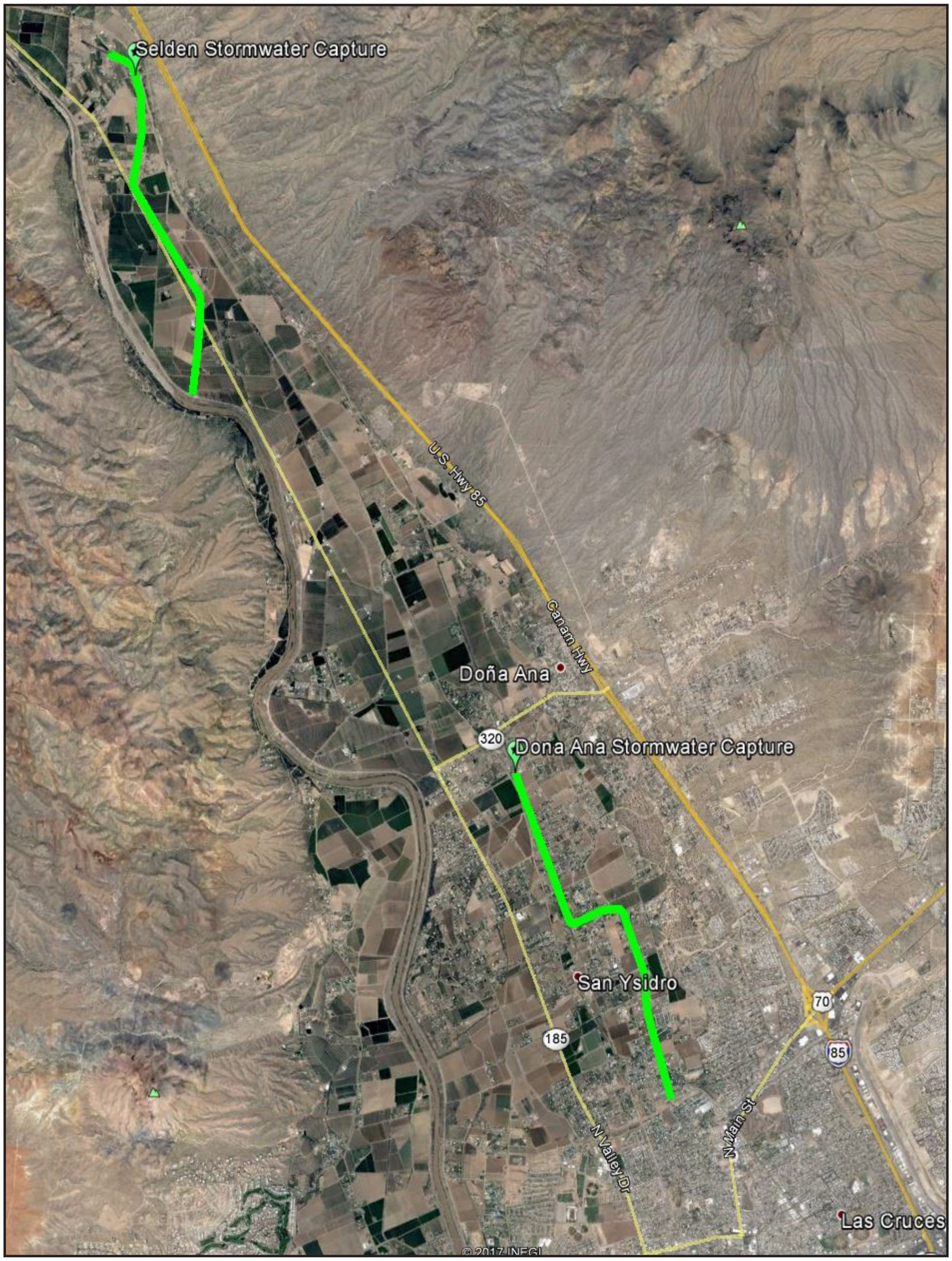



Figure 3A. Diversion off the Leasburg Canal, Leasburg and North Dona Ana.

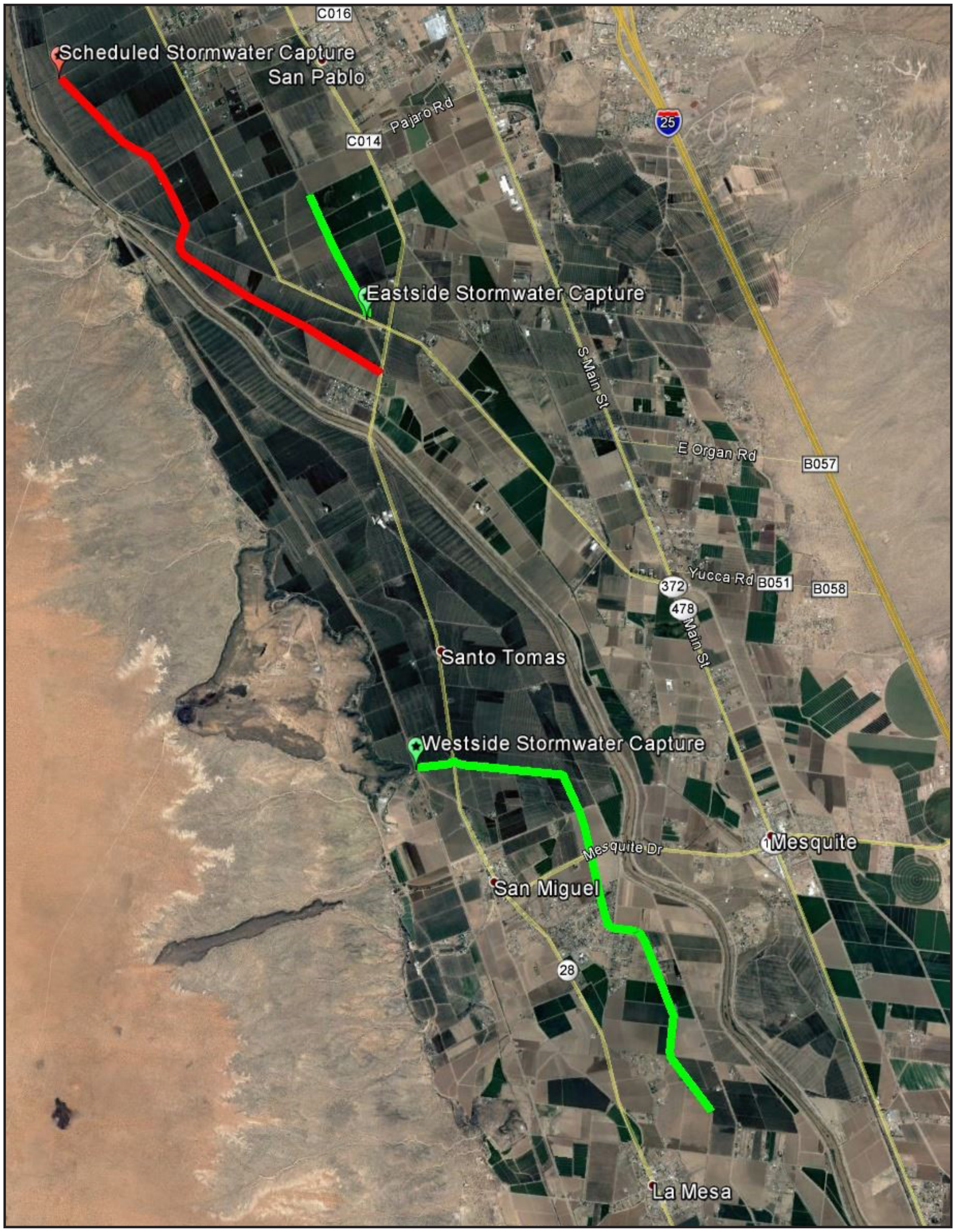



Figure 3B. Diversion off the Eastside and Westside Canals, Mesilla.

the groundwater elevation by two to three feet, and the groundwater has a sustained, elevated level for several weeks to months. It was encouraging to see this. The four sites have shown good data on this. For the last event shown in Figure 4B from July 22 through July 25, we captured water at the site but also irrigated crops. For about 40 hours, we were able to irrigate over 1,200 acres of crop with pure stormwater. It is very encouraging what we have been able to do with this program.

Figure 5 shows our stormwater capture totals. We had our 12 acre-feet that we captured in 2015. In 2016, we added the three additional sites. We were able to capture 562 acre-feet. So far this year (2017) from basically just two storms—the one I mentioned and then the one we had in January—we've already exceeded the 2016 total, and I'm anticipating that we'll easily go over 1,000. It is my hope that we will exceed 1,500 by the end of this year. In total, for three years, we captured 1,343 acre-feet.

Like I said, we know that this isn't going to fix all our problems, but we're using it as a tool to help manage certain areas where the drought has caused pumping to increase, and I hope we see more of this in the future because, to me, to capture almost 500 million gallons into an existing system is something we should be looking to do. To me it feels like it is irresponsible not to do something with this. We'll see where we go from here. Thank you.

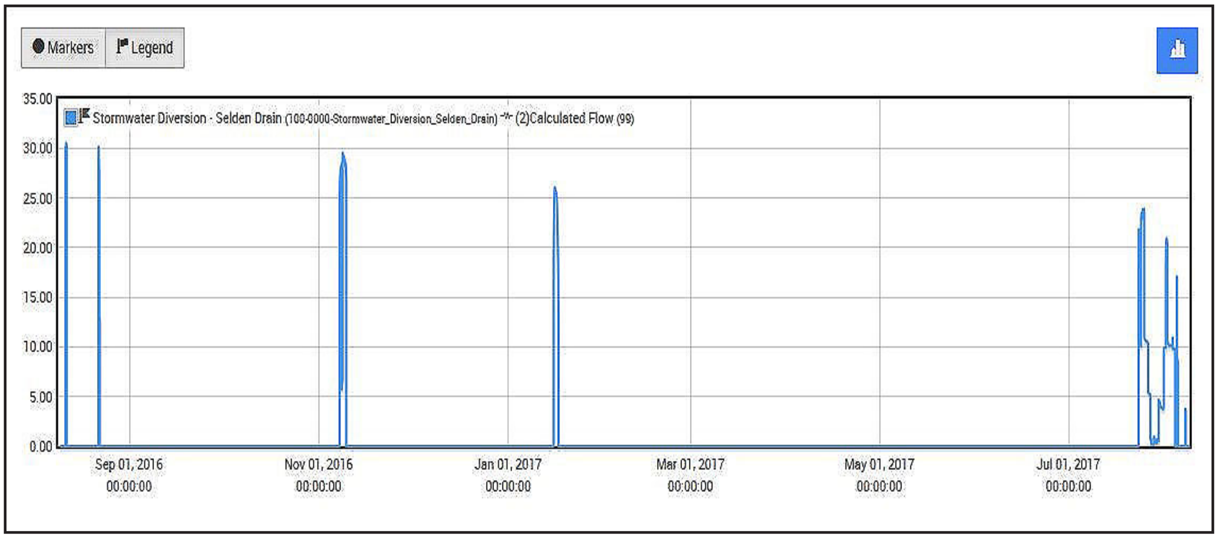



Figure 4A. Selden stormwater capture.

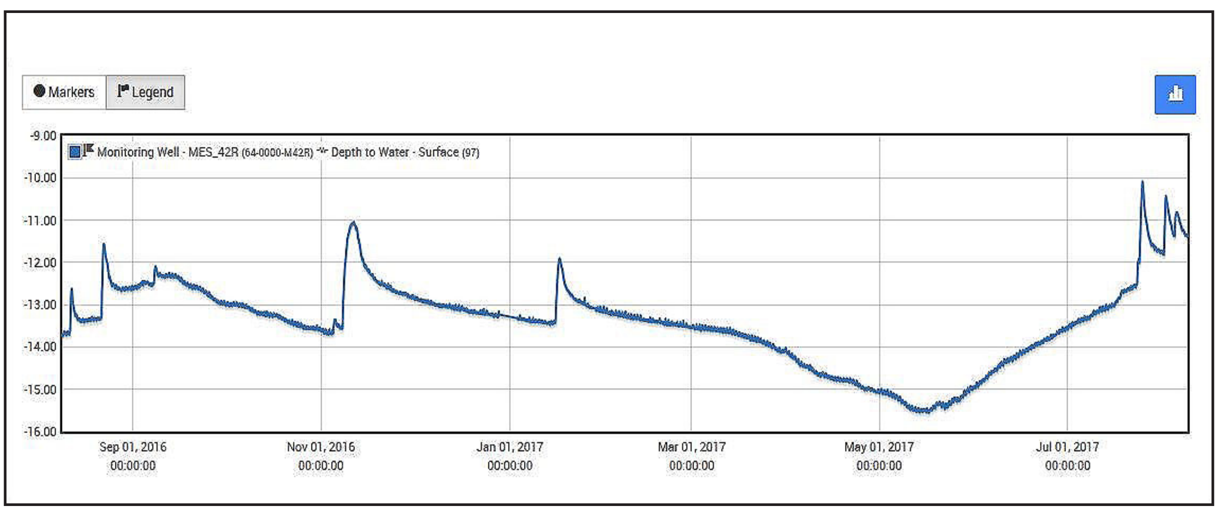



Figure 4B. Associated Groundwater Monitoring Well MES_42R.

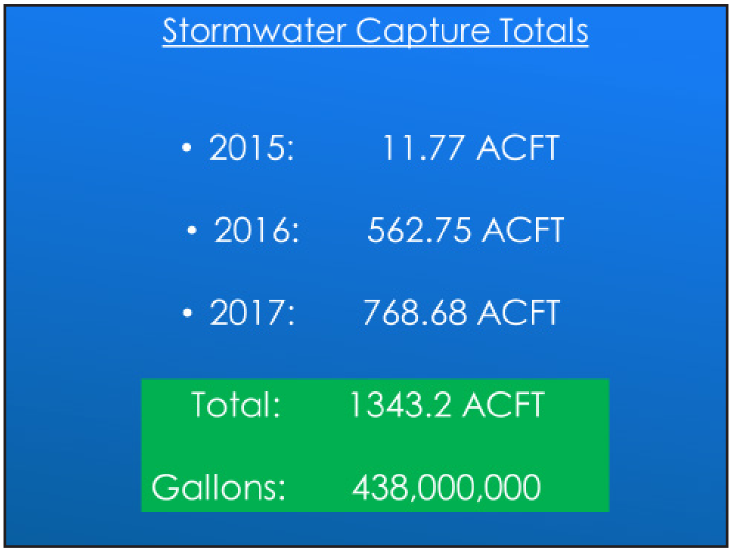
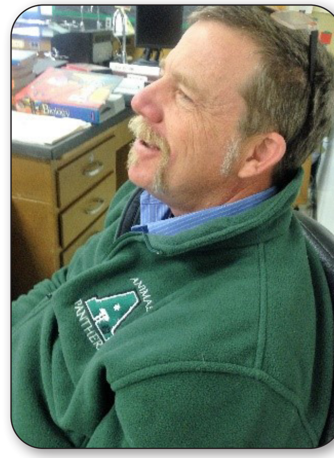



Figure 5. Stormwater capture totals.

## Richard Winkler, Malpai Borderlands Organization



*Richard Winkler will be the new executive director of the Malpai Borderlands organization. As the executive director, Rich will continue the work toward the Malpai's Mission: Our goal is to restore and maintain the natural processes that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant, and animal life in the borderlands region. Together, we will accomplish this by working to encourage profitable ranching and other traditional livelihoods which will sustain the open space nature of our land for generations to come.*

*Richard has been a lifelong rancher in the San Simon valley. He continues to work and operate his family ranch near Rodeo, New Mexico. He has finished 26 years of teaching in New Mexico's public schools and has been a board member of the Malpai Borderlands for the last eight years. Rich's family was one of the first ranchers in the area to participate in the grass bank program designed by the Malpai organization in 1995. Rich completed a BS at NMSU in geography in 1989.*

First I'd like to thank Chris and WRRI for inviting us and New Mexico Tech for hosting us. It is great to be here. My name is Rich Winkler, and I am the executive director of the Malpai Borderlands Group.

The Malpai Borderlands Group (Figure 1) is a working group of ranchers some of which have placed conservation easements on their deeded acreage of their ranches. We're a land trust, a 501 (c) 3 nonprofit. We also are an active land trust, which means that we work with many ranches in the working area on rancher's conservation goals. We live and work down in the bootheel. The Malpai Borderlands Group holds easements on sixteen ranches in the working area. Our area is bounded by Highway 80 on the west, Highway 9 on the north, and then the Continental Divide on the east. We share a working area of approximately a million acres with a patchwork of different entities, including the State land of Arizona and New Mexico, the U.S. Forest Service, U.S.F.W.S., and the Bureau of Land Management (Figure 2). There are different small watersheds along the Continental Divide and also along the Peloncillo Mountains (Figure 3). These watersheds are all connected by the backbone running between the San Simon Valley and the Animas Valley. The Playas Valley is to the east. Within these valleys, there is a bottom-up working communication structure, where ranchers have an idea about where and what kinds of structures would be most effective for saving runoff water from rainfall in July and August during the summer monsoon season. How can we improve pastureland and continue to work on our watersheds and our rangeland in a way that is best for our cattle and also for stewardship? During these monsoon events, as you know, most of our rainfall comes in—we can get one or two inches in one downpour—which can be a large percentage of our annual precipitation (Figure 4). So how do

- *"Our goal is to restore and maintain the natural processes that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant and animal life in our Borderlands region.*

*Together, we will accomplish this by working to encourage profitable ranching and other traditional livelihood which will sustain the open space nature of our land for generations to come."*

Figure 1. Mission of the Malpai Borderlands Group.

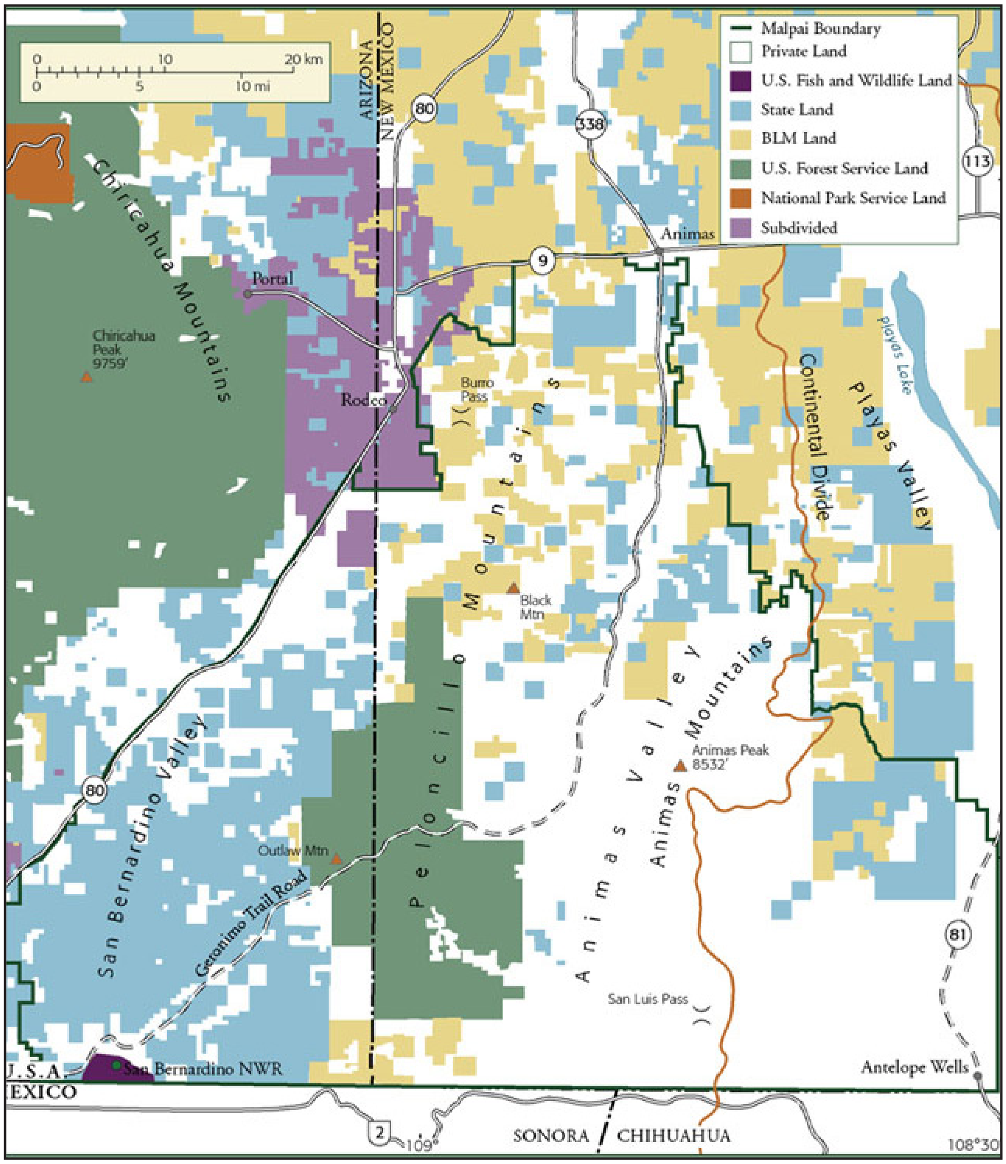



Figure 2. Places of work.

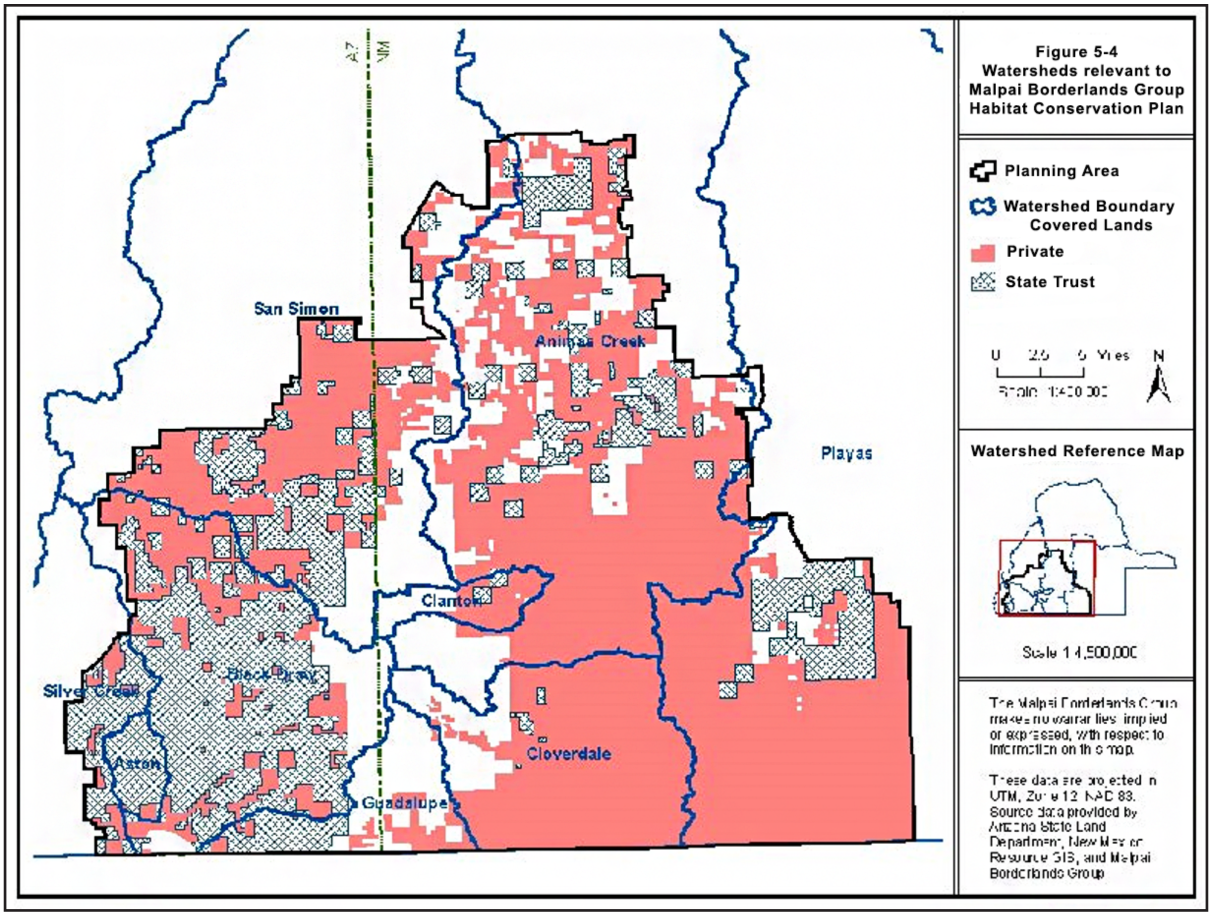



Figure 3. Watersheds relevant to the Malpai Borderlands Group Habitat Conservation Plan.

Figure 4. Typical annual water runoff.

we use that runoff water to help manage our ecosystems? What is the best way to increase infiltration rates and slow water runoff? This is not a new idea.

Figure 5 shows photos of rock structures built by the Civilian Conservation Corps (CCC) during the 1930s. These structures are down from my house. There was a CCC camp there. These structures are still there today. I stopped a few days ago and took these pictures. Although they have stopped erosion, you can see water backing up behind them. Most of the ranchers know that this technology has worked in the past. They wanted to apply it to our landscape today.

The goals of designing the rock structures are to slow water and increase infiltration rates of ephemeral streams, slow rates of erosion along streambeds and catch sediment, create areas for perennial grasses to grow, and slow water in areas after fire. We have prescribed fire in the area as well as wildfires. We wanted to identify areas where different types of structures would be more effective and also to monitor sites to measure effectiveness. How do these structures help prevent erosion and promote the growth of perennial grasses for us?

In large areas, in large drainages, it would take the gabion-style rock structures shown in Figure 6 to slow down large amounts of water in the San Bernardino National Wildlife Refuge. We got some aid from water specialists, geomorphologists, and others to look at the types of soil we had—the roughness and slope and what kind

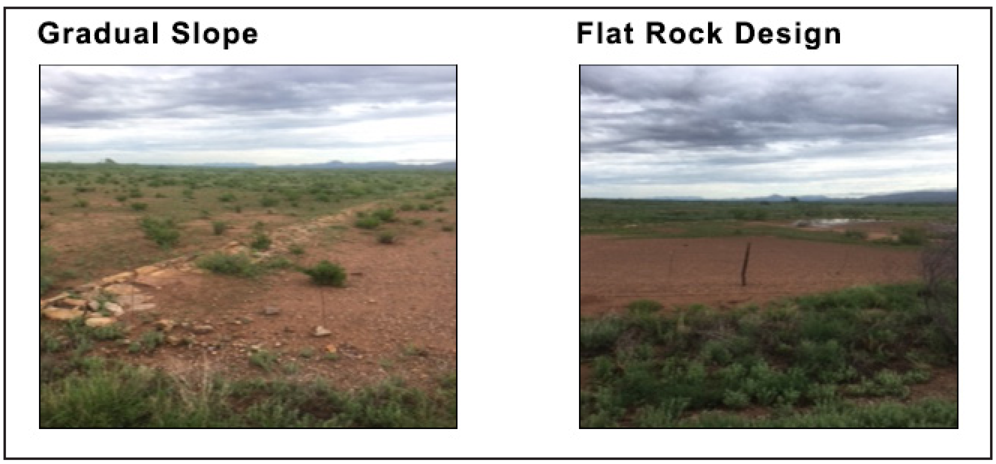



Figure 5. Civilian Conservation Corp built rock structures during the 1930s.

Figure 6. Gabion-style rock structures.

of downcutting we had in these pastures. We listened to what they said, and we used what they recommended. In some of the areas, to improve perennial grasses and reduce woody species, prescribed fire is used. In these areas, we also put flumes to measure the amount of water coming out of these arroyos, so we get an idea about what types of structures to build.

Ranchers wanted to use materials available to them in order to work on these structures. There are simple structures and sometimes wicker structures and weirs, along with rocks. Figure 7 shows the Peterson Ranch in Hay Hollow in March, and then March one year later. You can see that there is a difference in the type and amount of plant species holding soil to prevent erosion along these structures.

We build different types of structures, depending on the type of slope and terrain. Figures 8 and 9 show a rock structure, which is obviously not a dam-like structure, but it will slow water to eventually allow for grass seeds and small particulates to build up between the rocks and begin growing at least forbs and then grasses.

Figure 10 shows the change over one year at the first "media luna" structure at Glenn Ranch, Red Windmill Draw. Our organization has built over 2,045 of these structures, and yet only approximately 8 percent of them have failed within the first two years.

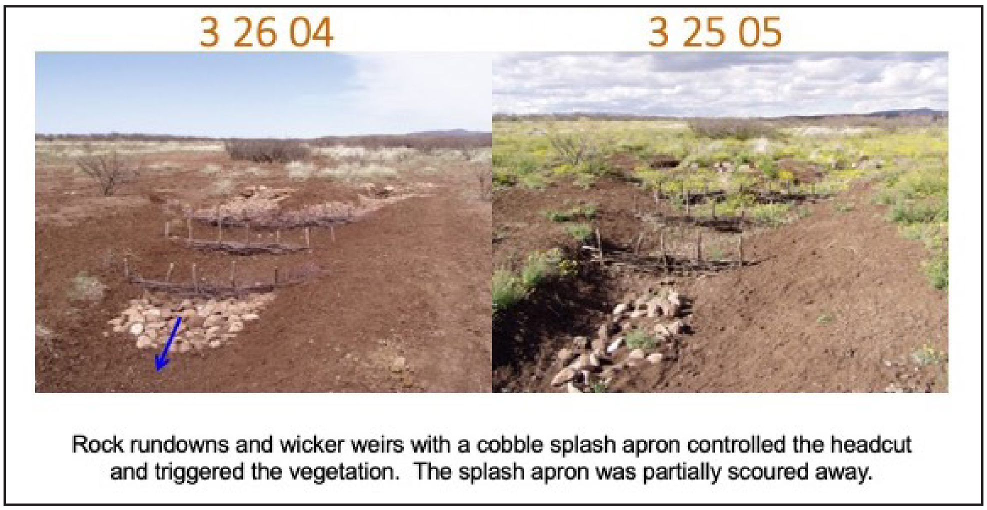



Figure 7. Peterson Ranch, Hay Hollow.

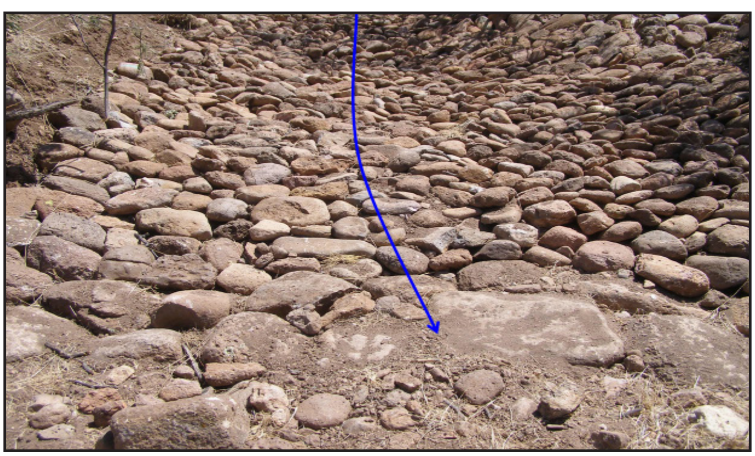


Figure 8. Rock structure.

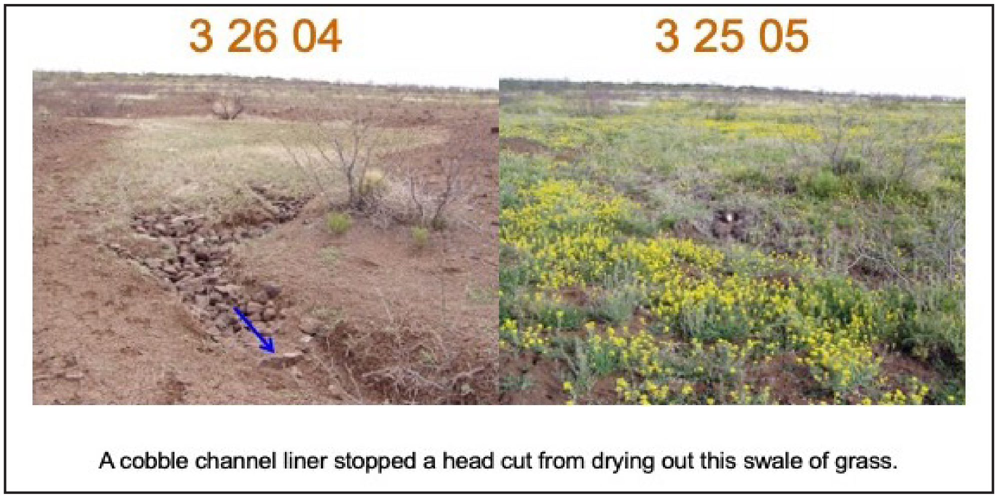



Figure 9. McDonald Ranch, Thomas Tank.

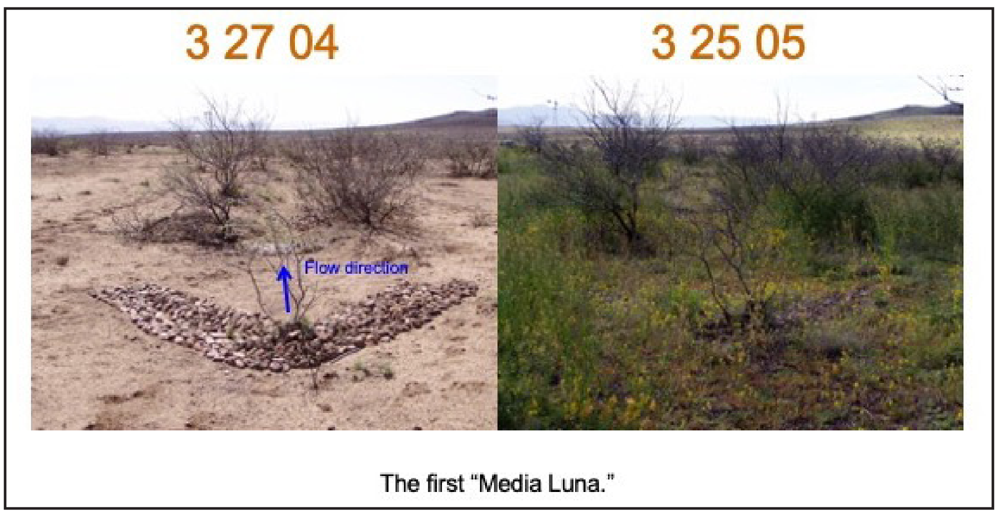



Figure 10. Glenn Ranch, Red Windmill Draw.

Figure 11. Sequence of rock dams.

Figure 11 shows a flatter area, where a sequence of rock dams is used. There is a crew out there placing them. Figure 12 depicts two different types of rock structures that are used in those areas. You can see that the flatter areas use one type of structure.

So, what are the lessons we learned (Figure 13)? Rock structures can be a management tool to enhance rangeland. Rock structures can be used in conjunction with fire. Infiltration rates are increased, and erosion rates are decreased as a result of properly constructed structures. The use of available materials is important when considering design features and locations. Labor costs are the largest obstacle when building these structures. Obviously, many ranchers built the structures themselves, but it doesn't take long before you've loaded up that truck several times and wonder, what am I doing here? You can visit us at www.malpaiborderlandsgroup.org, if you would like.

Figure 12. Two types of rock structures.


Figure 13. Lessons learned.

## Connie Maxwell, Alamosa Land Institute / NM WRRI

*Connie Maxwell cofounded the Alamosa Land Institute (ALI) in 2010 to engage in ecological planning and restoration with farmers and ranchers, looking at the interrelationship between the natural resources and the social systems upon which they rely. For the last seven years, ALI has been collaboratively introducing and testing innovative land management practices in rural agricultural communities that focus on restoring riparian and agricultural valleys through optimal use of rainwater and inhibiting evaporation. As a graduate research assistant with NM WRRI, she is currently collaborating with the South Central New Mexico Stormwater Management Coalition, which includes a broad cross section of stakeholders, to design and conduct restoration efforts on the Rincon Arroyo watershed. The Stormwater Coalition sees this as a pilot study for arroyo restoration throughout the Hatch-Rincon and Mesilla Valleys. Building on this collaboration, she has also spearheaded the newly formed Water and Community Collaboration Lab (WCC-Lab) at NM WRRI, which fosters links among the best science, communities, stakeholders, and students to inform decision-making and education on water and the environment. The WCC-Lab goals focus on using action research to collaboratively develop and test innovative and feasible approaches to the complex issues of water supply and usage in New Mexico.*

Thank you, Chris and fellow panel members. Obviously, this is an important topic at this time. Not only this whole conference topic—of new water opportunities—but this particular panel topic on water harvesting. It is no surprise that there are lots of talks on southern New Mexico and lots of activity down here. The issues here are very critical.

I'm here to talk about the Rincon Arroyo project. Patrick talked about the overall goals of the Elephant Butte Irrigation District, and those goals are part of what attracted me to come down to New Mexico State University and work with Dr. Fernald—who I first learned about on the New Mexico Acequia Association website many years ago—and to work with EBID and the South Central New Mexico Stormwater Management Coalition. This group has come together and recognized some of the challenges in this area and the opportunities that stormwater can provide.

The South Central New Mexico Stormwater Management Coalition is a broad coalition of quite a few members (Figure 1). It is EBID, it is the flood commission, it is soil and water conservation districts, it is villages, it is the counties of Doña Ana and Sierra. Those are the official members that have a memorandum of understanding. Then there are also lots of other entities supporting that group: the Bureau of Land Management is one that we work with actively because they are one of the largest land owners in the area. The Rincon Arroyo has been targeted as a priority project for the stormwater coalition, as we like

Stormwater coalition members:

- *Dona Ana County Flood Commission (DACFC)*
- *Village of Hatch*
- *Elephant Butte Irrigation District (EBID)*
- *Doña Ana Soil and Water Conservation District (SWCD),*
- *Caballo SWCD,*
- *Sierra SWCD,*
- *Sierra County,*
- *Sierra County Flood Commission (SCFC), and*
- *City of Anthony.*

Additional project stakeholders and supporters:

- *Farmers downstream of Rincon Arroyo*
- *Rincon community members*
- *Ranchers in watershed*
- *Bureau of Land Management (BLM)*
- *NMSU New Mexico Water Resources Research Institute (NMWRRI) & Water & Community Collaboration Lab (WCC-Lab)*
- *US International Boundary & Water Commission (IBWC)*
- *Paso del Norte Watershed Council (PDNWC)*
- *NRCS*

south central NM stormwater management coalition

NMWRRI WATER & COMMUNITY COLLABORATION LAB (draft logo) | New Mexico Water Resources Research Institute

Figure 1. Stormwater coalition members.

to call it. The Rincon Arroyo is a relatively large watershed: it is 135 square miles. It is one of the largest contributors of sediment within the Hatch and Mesilla Valleys. The question of my talk is whether an innovative strategy of flood control on ranching and farming lands can begin to restore our watersheds and refill our aquifers.

In the land of hydrology, we all know that vegetation is often an enemy, but in fact, if we look at the riparian system—the whole water drainage system as rivers that flow up through the canopies of our headwaters, we begin to recognize that groups like the Malpai Borderlands Group are onto something. It is our upper watersheds that can begin to harvest our stormwater. The faster we can get that water into the ground, the more evaporation we can inhibit. We are removing it from the air. The idea of there being a war on evaporation—where we transfer the consumptive use of the evaporation to the vegetative consumptive use of the new productivity—is a central strategy we're going to have to spend more time looking at in the future.

Figure 2 shows the watershed. You can see Elephant Butte Reservoir, the border with Mexico and New Mexico, and the Hatch-Rincon Valley and the Mesilla Valley. As you can see, it is quite a large watershed. The lines in the figure show the drainage area into the Rio Grande Valley.

I explained the stormwater coalition. I think this is a nice quote on their website: "Recognizing that stormwater does not respect political boundaries, it has become apparent that the needs of the region would be best served by a regional watershed management approach." I think that is very true, and I think it is something that I have heard quite passionately from many of the group members. I mentioned who they are.

The idea is the intersection between several management practices (see Figure 3). Agriculture, in terms of both ranching and farming lands, has historically done surface spreading. Flood control uses that strategy as well. With managed aquifer recharge, specifically looking at the surface spreading area, this is where these things intersect and can give us some real benefit. When it comes down to it, what we're doing is managing our flood plains and our aquifers, and we are

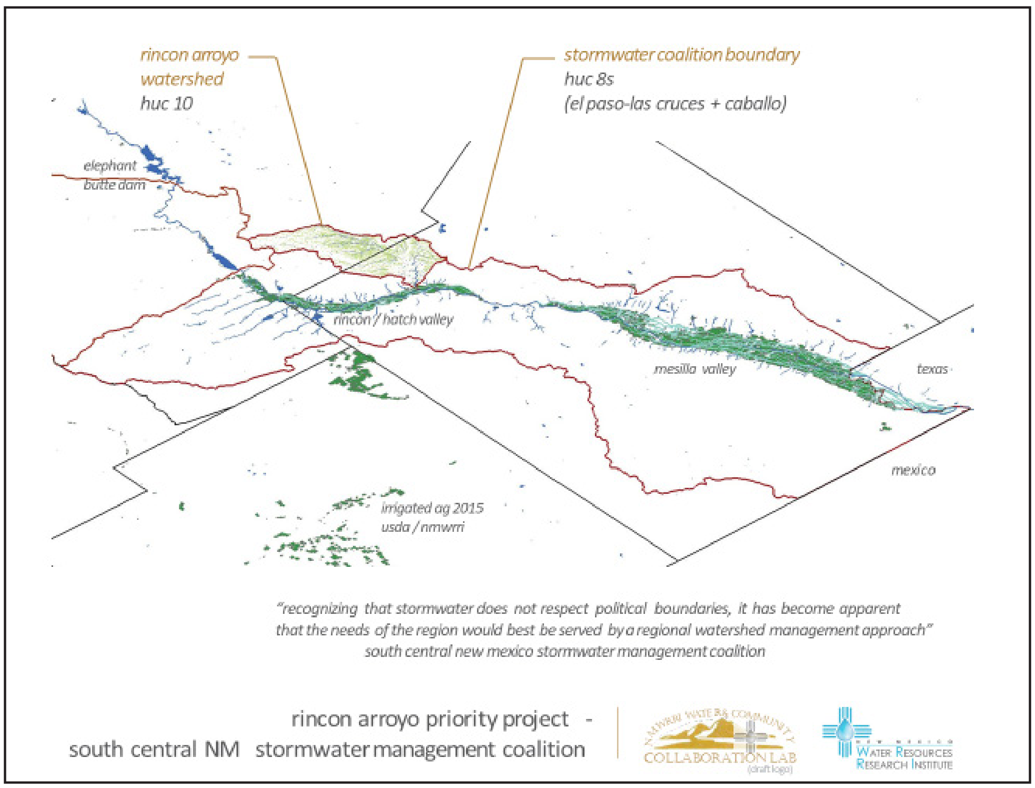



Figure 2. Rincon Arroyo watershed.

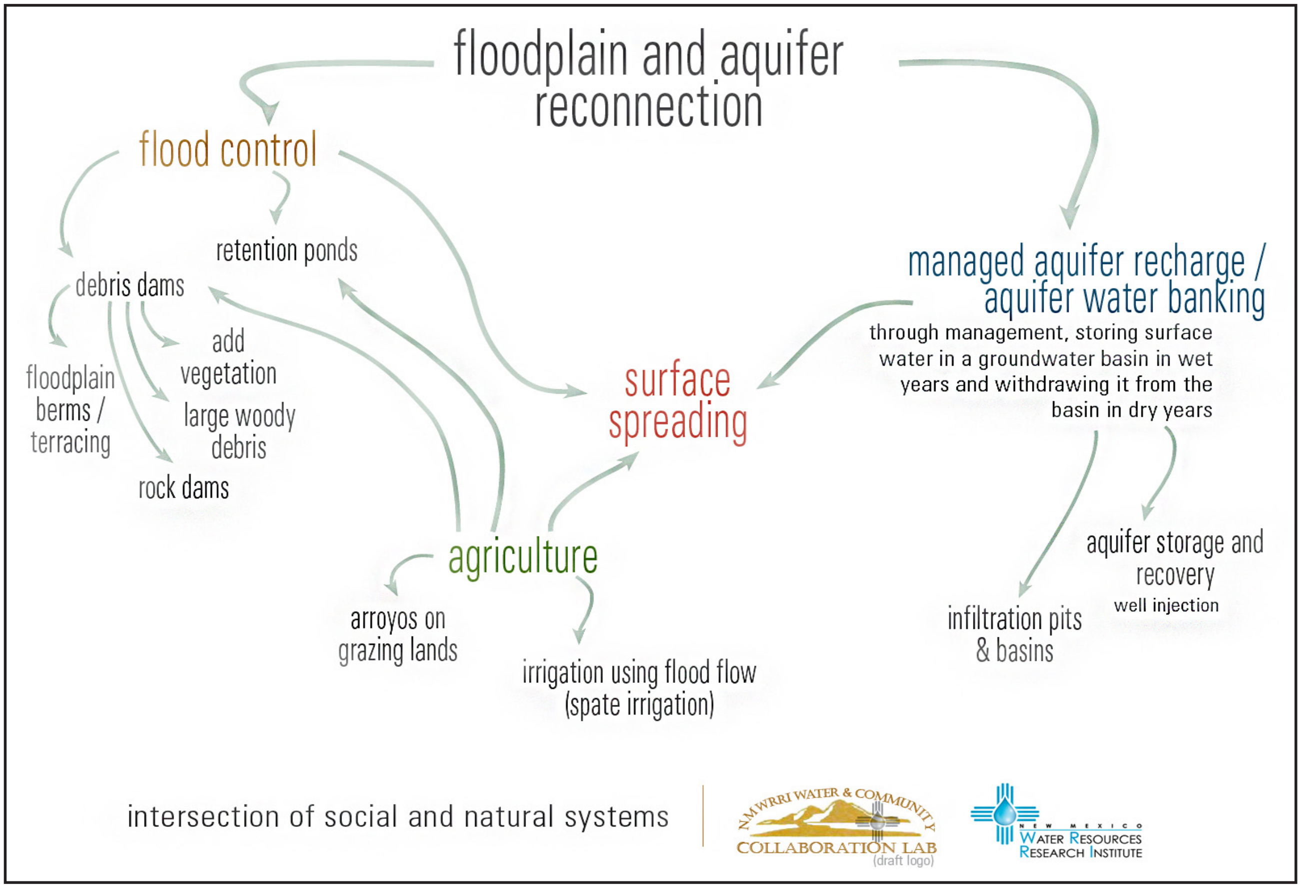



Figure 3. Floodplain and aquifer reconnection.

reconnecting both at the same time. What this group has also seen is that an intersection between the people and the systems is essential.

At the WRRI, we've newly started the Water and Community Collaboration Lab, where we are working with real people like the stormwater coalition to work on real problems—action research. This collaboration is really essential. We're helping with part of the scientific study of these areas, understanding how these watersheds function. So, of course, we are looking at land form and the soils that support the vegetation. Soils are probably one of the least looked at resources for alternative storage for water in replacement of snowpack. The more that we can restore vegetation in our drainage areas and our water zone areas (the blue areas, the flatter and wider areas, in Figure 4), the more we diminish our water energy, as Rich talked about, and the more we can get that water into the ground.

It is the arroyo valley bottoms that we tend to focus on, as was discussed in the last presentation. It is here we take these strategies of adding interventions, such as large wood debris, and we bump water onto the floodplains. That is how we get the vegetation to return and we get the water into the aquifers. The scientific strategy is to say, How much can we really get, and where should we target our interventions?

Figure 5 is a map looking at different areas. The darker green is a mid-range strategy. The lighter green would be the full extent of what we could possibly do. Then we look at this triumvirate: the vegetation, the soil, and the water. How do these three interact to reconnect our flood plains and refill our aquifers? How does that feed back, and does that increased vegetation productivity help those ranchers and incentivize the idea that new management can propel us into the long term?

Historically, it was agriculture that supported the natural systems in the riparian areas. Agriculture spread out the stormwater to refill our aquifers. It is a system that we have had to curtail because we have been obligated to meet compact requirements and get that water to the border as fast as possible. It is a system that we are going to have to bring back. The stormwater itself, it is working landscapes that manage those landscapes.
The goal for all of us should be to support increasing agriculture's role as a function that supports a resilient system for recharge and flood control. With that, restoring watersheds is an important part of that. Thank you.

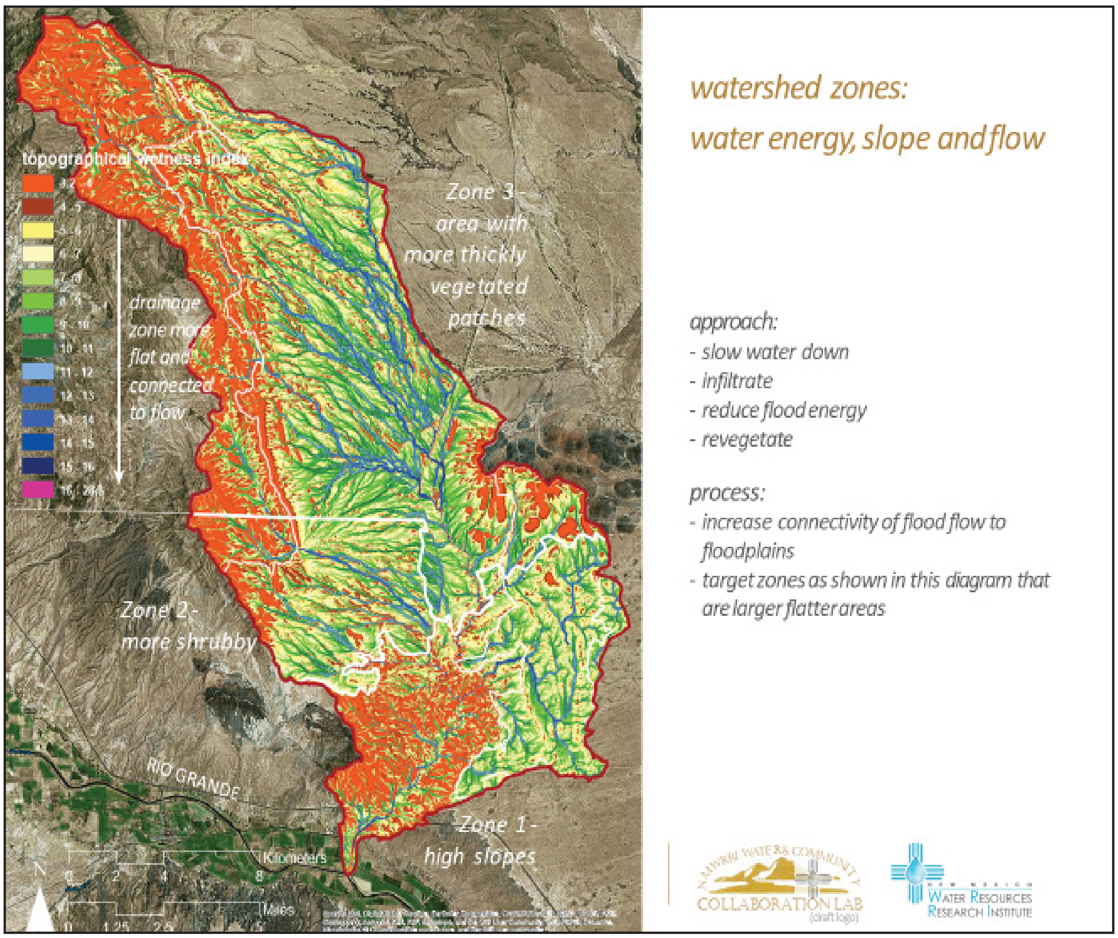



Figure 4. Watershed zones.

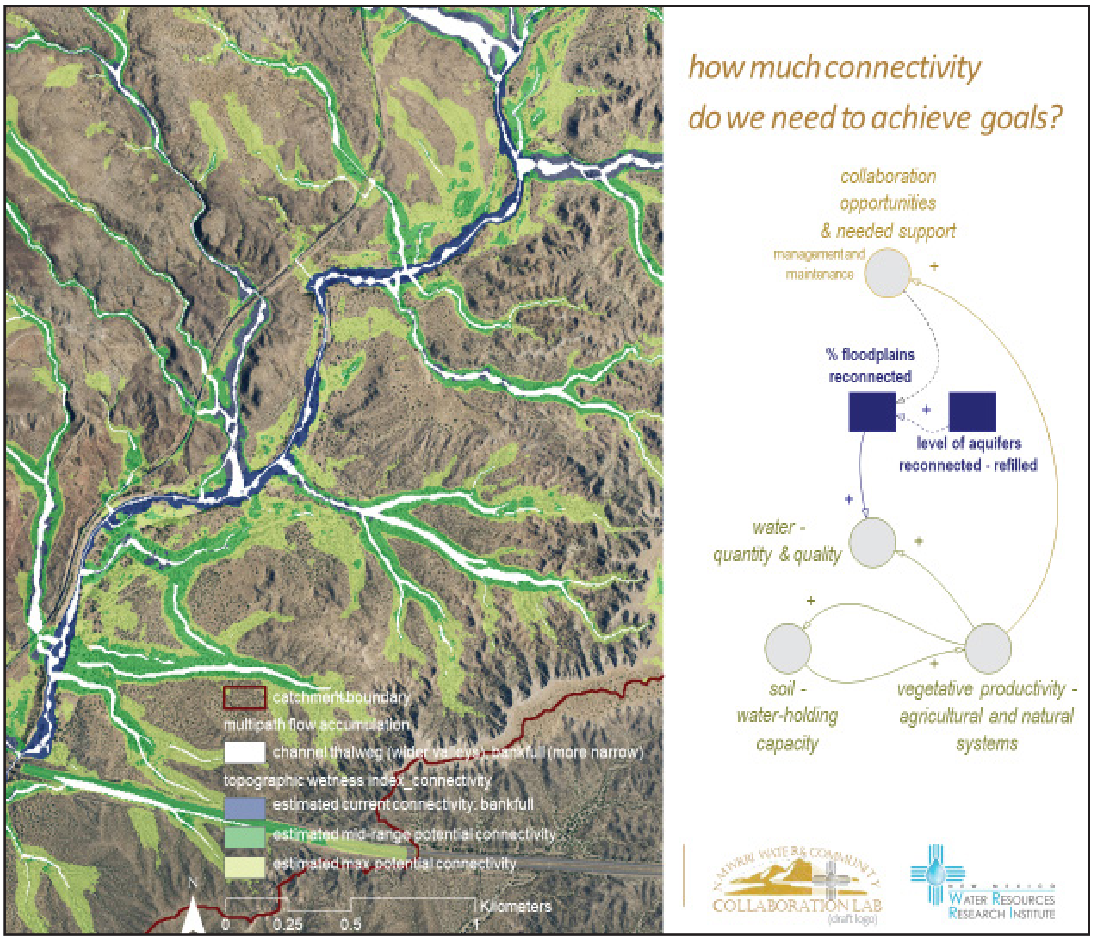



Figure 5. Map of connectivity strategies.

## Candice Rupprecht, Tucson Water Conservation Program

*Candice Rupprecht is the water conservation manager at Tucson Water, southern Arizona's largest public water utility. In this role she has primary responsibility for water conservation planning, conservation research, and the suite of education and efficiency programs offered. In her three years at Tucson Water, she has launched two new rebate programs, has partnered on several water-use analysis projects, and is leading a planning process to establish new water conservation goals for the Tucson community. Prior to working at Tucson Water, Candice worked at the University of Arizona Water Resources Research Center for seven years, where she focused on water education, outreach, and conservation research. She holds a BS in geosciences and an MS in hydrology, both from the University of Arizona.*

Good afternoon. Like all the other panelists we've heard from today, I'm honored to be here. I worked at the University of Arizona Water Resources Research Center for several years, so I know what it takes to put on a conference like this and I also understand the value of these conferences. I'm happy to be here, and I appreciate all of you being here.

I realized as I drove in last night that the last time I was in Socorro was for a volcanology field trip in college, and so it has been a long time. But it was nice to drive in last night and see the geology and the scenery and really appreciate these natural landscapes.

I'm going to be talking for a few minutes about Tucson's One Watershed Future. It is a similar idea to what Connie was sharing. Who has heard of One Water? Great—a few hands. That is the lexicon that Tucson Water has jumped on the bandwagon with, and I think it speaks to the goal of integrated water resource management. That's what we are working on in Tucson right now. I'm going to touch on the water harvesting efforts related to that today.

Does the view of Tucson in Figure 1 look familiar? It is not the Tucson that we know today. I don't know this Tucson, I didn't live there then, but my in-laws attest that this is what Tucson looked like at one point. Apparently, we used to have the ugliest street in America.

That's in our history, but the three photos in Figure 1 are the foundation of some important legal battles in Arizona related to water resources and water management that resulted in what we


Figure 1. Historic photos of Tucson, Arizona.

have today, which is known as the 1980 Arizona Groundwater Management Code, and also laid a foundation for water conservation work that started in the 1970s and has continued through today.

A typical landscape in Tucson in the 1960s and 70s looked like the photo in figure 2—a lot of nonnative trees and a lot of turf. We also had a lot of swamp coolers in Tucson at that time. There has been a big shift in the four decades since that photo was taken, and today landscapes have much more native vegetation and a lot less turf. We also have a lot more refrigerated air conditioning and much less swamp cooling. In fact, only one percent of homes today are built with swamp cooling in Tucson. You can imagine that as technology has advanced and as the culture has shifted toward accepting native vegetation, gallons per capita per day has dropped drastically. Outdoor use has dropped over 50 percent in the last three decades. Right now, we're saying that outdoor water use in Tucson is at about 27 percent. That is a historic low, and a number that we're really proud of because I think it speaks to the ethic that we've instilled in the community.

That said, we are beginning to drive a new approach to resiliency in Tucson that started with that landscape transformation and has resulted in the last decade of work toward integrating rainwater harvesting and stormwater harvesting into our water conservation planning (Figure 3). I'm going to walk you through a little timeline of what we've been up to the last ten years. In 2010, we put into place an ordinance for commercial rainwater harvesting that requires 50 percent of the landscape water need to be met on site with rainwater harvesting or stormwater harvesting. In 2012, we launched a residential rainwater harvesting rebate program. Customers can get up to $2,000 for active harvesting, which is putting water into tanks or cisterns, or for passive harvesting, earthworks on their landscape. Then in 2013, we launched a green streets policy in Tucson for new construction requiring the first half inch of stormwater to be captured and setting in place some vegetation requirements for street-side basins. In 2017, we are launching a neighborhood-scale grants program to scale up the rainwater harvesting and stormwater efforts happening in Tucson. This is allowing neighborhoods to come together; to create solutions that make sense to them for their street size and their areas that need traffic calming, landscape beautification, erosion control, or greening up of the canopy; and to compete for grant funds in the community to make that possible. As you can see, we are building on these efforts piece by piece, understanding that there are different scalable solutions we are trying to put into place as a community to increase the amount of water we are harvesting, both from the sky as well as from our streets.

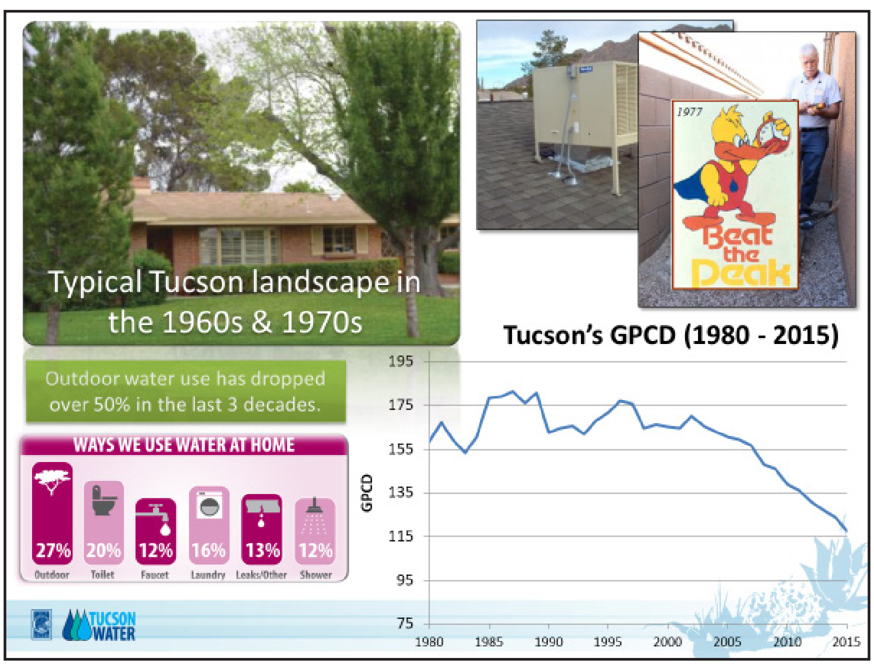



Figure 2: Changes in Tucson's water use.


Figure 3. Water conservation planning timeline.

Just a note on rainwater harvesting: unlike other ways we conserve water, it is a little more complex. People don't just say that they want to conserve water. They do it for a lot of different reasons: that the water is free, that they want better water for plants, that they want more shade, that they want to garden (Figure 4). We've tried to understand where these values and these motivations come from in Tucson. I think doing so speaks to allowing customers to implement the systems that make the most sense for them, while touching on this idea that we're focused on enhancing the quality of life in the community through these types of rainwater harvesting practices.

Figure 5 is a map showing the customers who have implemented rainwater harvesting to date. That's over 1,300 customers. They each get a nice sign that they put in their yard, so that's a way that we are promoting water harvesting in our community. I'll note that the purple and the blue dots represent a low-income program that we just launched this year. There has been a bit of an equity issue with this program in Tucson (Figure 6). We're offering a loan and grant program for limited-income customers, trying to address the fact that this residential rebate program has sometimes been referred to as a reverse Robin Hood program. We're trying to reverse the reverse Robin Hood. We want to serve all income classes with these rebate programs, and so we're doing our best to address equity issues through our water harvesting programs.

As I mentioned scalable solutions, we are working within the utility at an individual or neighborhood scale, but we're also working with flood control and with other community partners to start scaling up these solutions to address some larger-scale stormwater issues in our community. Then there are several organizations in town that are looking quite holistically at planning efforts for the whole watershed. We recognize that this is a piece of that larger planning effort, but we think a piece that really brings the community to the table and allows everyone to feel like they have ownership over the part they can with their own home. With that, thank you.

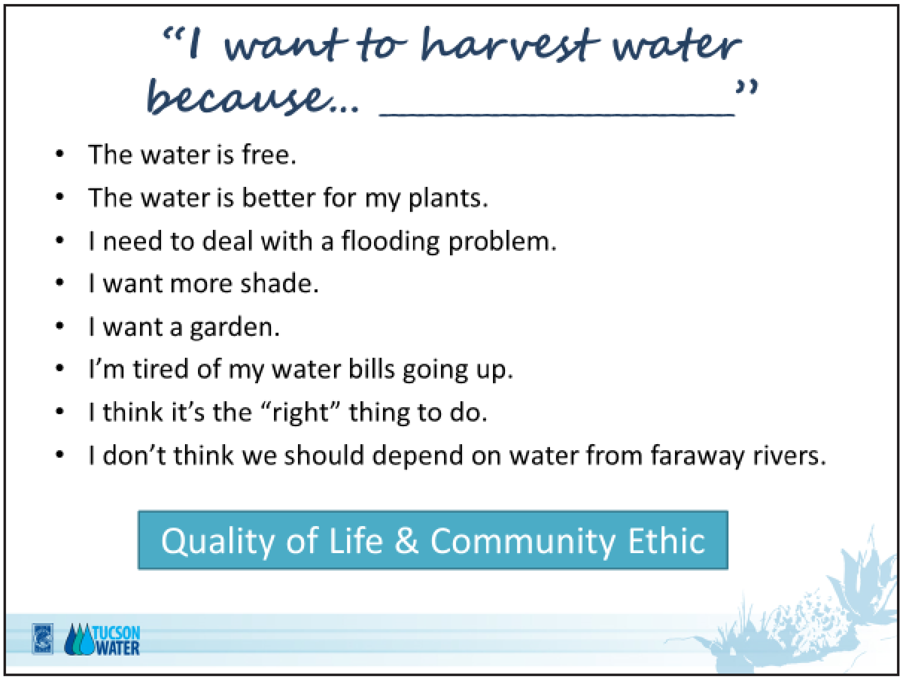



Figure 4. Harvest water reasoning.

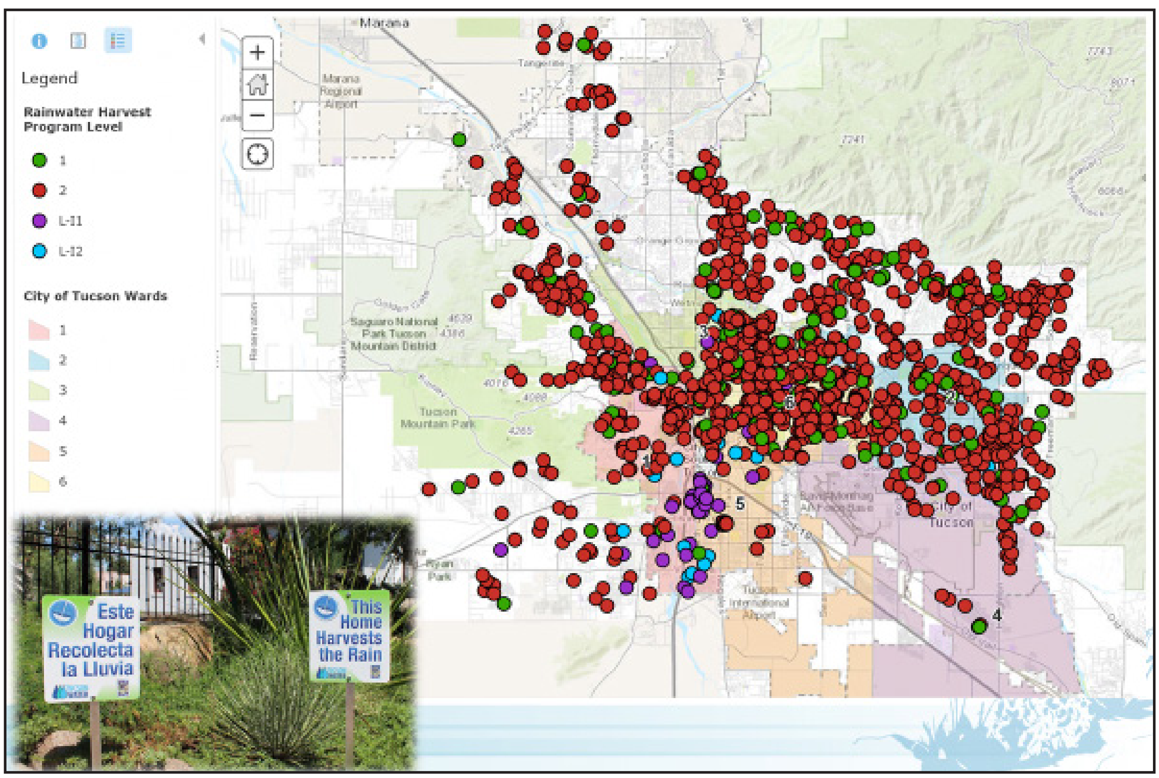



Figure 5. Residential water harvesting.

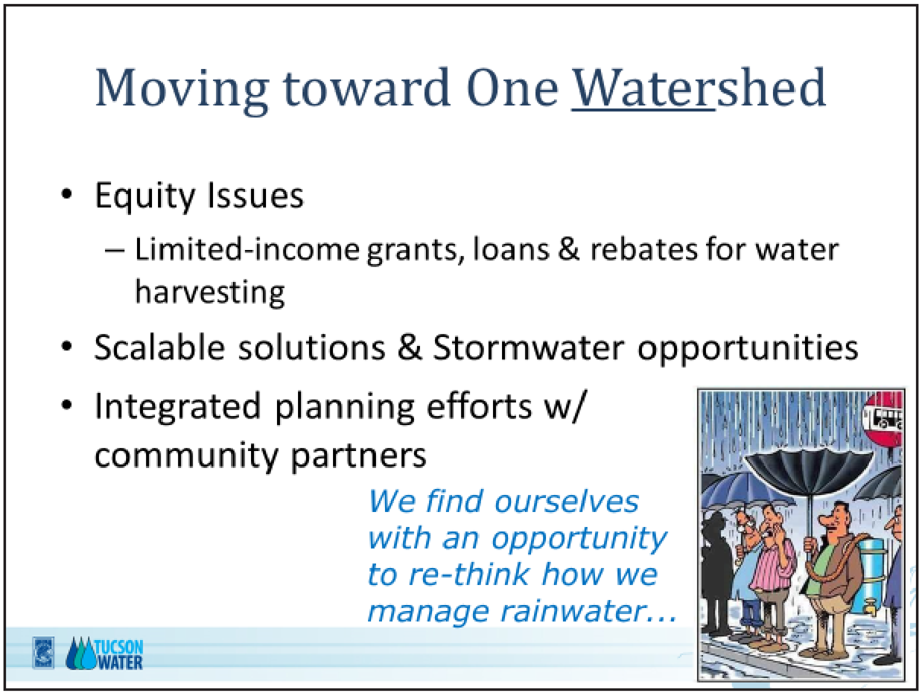
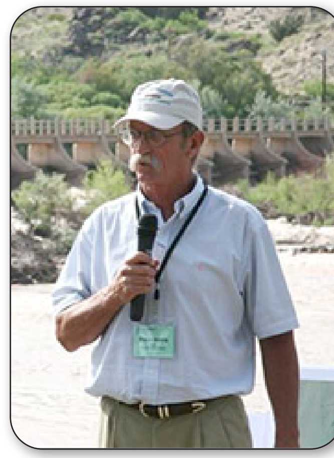



Figure 6. Movement towards one watershed.

# Panel of Former Rio Grande Compact Commissioners and Administrators

**Editor's Note: The following papers represent a transcription of the speakers' remarks made at the conference; no follow-up papers were submitted by the speakers. Remarks were edited for publication by the editor. The speakers did not review this version of their presentation, and the editor is responsible for any transcription and editing errors.**

## Moderated by Steve Harris, Rio Grande Restoration



*Steve Harris is owner and operator of Far-Flung Adventures, a river outfitting company based on the Rio Grande he has owned since 1975. In 1994, he founded Rio Grande Restoration, a nonprofit streamflow and watershed advocacy group. He resides in a riverside cottage in Pilar, New Mexico, from where he studies, speaks, and writes about the history of the river and promotes awareness of the importance of the Rio Grande.*

Here we have not just Rio Grande Compact principals from years past, we also have state water managers from years past. What we're going to be talking about is lessons learned in recent history about management of water. We've touched on some of the important issues today and, by all means, not all of them.

My perspective is that we are in a process of transition now. Our state water administrator is going from refereeing competing claims and perpetual conflict to collaboratively managing this hugely important common resource in a more watershed-friendly way. We're also somewhere on the continuum of graduating from the maximum utilization doctrine (where if water got out of our basin downstream it was a terrible thing) and moving into an age where all of the competing demands are recognized to be as closely integrated as the water system itself is. We're moving to, I hope, a future of sustainability, resilience, and adaptability.

## Scott A. Verhines, former New Mexico State Engineer

*Scott A. Verhines is president and CEO of Occam Engineers Inc. He is a lifelong consulting engineer in New Mexico and has been a practicing professional engineer since 1983. Scott served as the New Mexico state engineer and the Interstate Stream Commission (ISC) secretary from 2011-2014, where he was secretary of the Western States Water Council and chairman and member of the New Mexico Water Trust Board, and served on the ISC Gila Committee and the State and Regional Water Planing Committee. He has also been a commissioner for the Colorado and Upper Colorado Compact, Rio Grande Compact, and Rio Costilla Compact. Scott is a New Mexico native and resident of Albuquerque. He is a civil engineer with over 40 years' experience focusing on water resource, transportation, and drainage/flood control projects. His experience lends particular strength in the areas of program management, public involvement, collaborative decision-making, and coordination of multitask and multidiscipline projects involving a variety of local, state, and federal agencies. As the New Mexico state engineer, he served as the state's top water manager, overseeing a staff of 330 professionals in eight offices statewide. Scott has a BS in civil engineering from Texas Tech University, an MS in civil engineering from the University of New Mexico (UNM), and an MBA from the Anderson School of Management, UNM.*

I'm going to kick this off with four topics I want to share with you—recommendations for consideration for water management in the future.

My first topic is *be proactive rather than reactive*. I'll give you a couple of examples. Those of us who are engineers are always standing up and talking about dealing with these things not when they are happening but before they happen. Take the drought/flooding examples we've been talking about a lot today. I was fortunate to be the state engineer in 2011, 2012, 2013, and 2014. Three of those years were the driest three consecutive years on record in New Mexico. It was a very challenging time for New Mexicans. I don't know if you remember June of 2013: 44 percent of the state was in exceptional drought conditions. It was a rough time for the state overall. We convened a drought panel, and we were trying to figure out what to do about dealing with the drought and helping New Mexicans in the middle of it. That is the wrong time to try to address it. We need to be working on that. We've got a healthy monsoon shaping up this year. We ought to be working on those things now rather than later. It is really difficult to be dealing with flood control in the middle of the rain. We're sort of backwards, and how do we change our culture about that?

I'll use another example: In 2013, the Carlsbad Irrigation District invoked a priority call on the Pecos River. That was a big deal, and again that was really difficult on everybody up and down the river. We learned a lot of lessons about that on the Pecos system. We learned that we weren't ready to deal with a priority call. We were working our way through that issue when it rained like mad September that year and filled up all the reservoirs and everybody sat back, breathed a sigh of relief, and went on about doing other things. In discussions in later years with then acting director of the Interstate Stream Commission Amy Haas and then with Deborah Dixon after that, we had a lot of discussion about the importance of continuing that planning while water is in the reservoirs. It'll happen again; that's going to circle back to us one of these days. We ought to be trying to put in place the mechanism for dealing with drought now rather than later. That's my first topic: be proactive rather than reactive. A lot of good examples of that today.

The second one is *value planning*. We often hear people say, "Why are we spending all this time and resources on planning? Let's just go do it, or let's just go build it." Most of us recognize, if you have been through that a few times, that the effort and time and expense spent on planning will pay for themselves many times over down the road in implementation. We need to make planning robust, we need to support it, and then we actually need to use it. Done right, planning will save many times over its cost.

Regional water planning is the example in New Mexico—16 water planning regions. The task of the 16 regions recently was to look at policies, programs, and projects that would serve to address supply and demand imbalance in the region. We spend a great deal of time and resources on that.

And then way too often, those plans go on the shelf and we go back to this culture of conflict that we like in New Mexico rather than using those tools as a culture of solutions. We've had a lot of discussion about governance today—to me, the regions provide a great opportunity for governance down the road. The plans should be our primary decision-making tool in those regions.

The next one I had on my list was *alignment of the parties*. I think Dick may talk a little bit about this; certainly it came up in earlier discussions. When we have alignment across the water users group and across the executive, legislative, and judicial branches, we can get a lot done. I suspect that Dick may talk about some successes in Colorado when they've done that. I'll use the Oklahoma state water plan as an example.

Dick knows J. D. Strong from Oklahoma very well. During our time together, we all worked on the Western States Water Council. In 2012, Oklahoma passed their Water for 2060 Act (House Bill 3055). Essentially the bill said—and they had alignment across all of the parties we were talking about—that Oklahoma would use no more freshwater in 2060 than it used in 2012. That has been part of their decision process on everything they have been doing since. When you have alignment and everybody is moving the same direction, you can get a lot done.

The last topic I wanted to talk about was *where the challenges are coming from and what can we do differently*. We largely, although there are some great examples of this not happening today, have a culture of conflict versus a culture of solutions in New Mexico. We need to work toward a culture of solutions. When I first came into the state engineer's position, Dr. John Hernandez from New Mexico State University sent me an autographed copy of the book *One Hundred Years of Water Wars in New Mexico* and said, "You probably ought to read this because you'll get to deal with all these things again probably during your time." It was really a special treat to get that. A lot of conflict over the years.

Generally, we use poor decision tools. How do we take this diverse group of interests and focus us together on what is important down the road? Water is very personal. We're all coming at this from different directions. Too often, we're dominated by emotions and there is misinformation out there and we are trying to wade through all that to come up with a solution together, while trying to protect our little corner of the world. For every decision that we make in our daily lives and our business lives, in our external lives, we have subjective factors and quantitative factors. If I'm going to go buy a car, I prefer a light-colored car to a dark-colored car in New Mexico, and I want a car that gets 25 miles per gallon or more. Well, in the water world we can use those sorts of techniques. There are a couple of good techniques that we have been involved in for the last 15 years that have helped focus people on solutions and include the right parties around the table.

We often try to resolve conflict in the media. The media—journalists—often take one side of the story or the other rather than having a balanced position. I think that is an opportunity for us down the road. I would ask the media to consider that when reporting takes a side it causes additional conflict because people don't see the other side of all these stories. We also try to resolve conflict politically or in the courts, and very often the courts fall back on the science, on the physics, as Dr. Jan Hendrickx was talking about. We need to make sure that solutions make sense along the scientific path as well.

I'll try to use the Colorado River as an example of how that can be done. In the past, the Colorado River Basin, if you look back over its history, was one of the most litigated over river systems in the country. Probably in the last decade to two decades, the parties have tried to come together first on scientific, or technical, bases and go the litigation route as a last resort. Now, when issues come up, they convene the parties around the table, and they begin to work on solutions rather than letting those issues fester and extend over years and years. I was visiting with somebody the other day who spent almost their entire life in the judicial system. Too often when you end up in the court system, you lose your voice. The courts often have to go back to a technical basis, and they are often using precedent—what happened before—in order to make a decision. You often lose the opportunity to look for better ways. You lose the opportunity to innovate once you get in the court system. You lose your voice a little bit. If the courts remand that back to the scientific basis, why don't we just start there? That would be the last of my suggestions for water management in New Mexico.

I've been really impressed by most of what has been said today. I want to quote a couple of things I heard back to you because they set the stage for my remarks to you.

Myron Armijo, with the state engineer's office and former governor of Santa Ana Pueblo, asked rhetorically, Do we act on our solutions or not? And then he said that we don't. Climate change is real.

Terry Brunner said that we still need to take care of basics rather than improve functional systems to address our future problems. I think what he was saying is we do not have functional systems today, and I agree with that.

Senator Udall said that we need government officials doing the right thing, trying to collaborate, trying to get people to a solution. I couldn't agree more.

## Norm Gaume, former New Mexico Interstate Stream Commission Director

*Norm Gaume is a retired water resources engineer and planner and an avid whitewater canoeist and river runner. He earned BS and MS degrees in electrical and civil engineering from New Mexico State University. He was director of the New Mexico Interstate Stream Commission (1997–2002), engineer-adviser to the New Mexico Rio Grande Compact Commissioner (1998–2002), water resources manager for the City of Albuquerque (1990–1997), and water resources consultant (1974–1978 and 2003–2012). Norm received the New Mexico Foundation for Open Government 2016 Dixon citizen award for his "relentless" use of state transparency laws "to shine a light on controversial decisions by the government to divert the Gila River.*

I will tell a short story about the Pecos River Compact. When I was appointed director of the New Mexico Interstate Stream Commission in 1997, the state engineer told me that my top priority was to find a way for New Mexico to comply with the Supreme Court decree that resulted from Texas suing New Mexico and the Supreme Court over the Pecos River. I worked very hard at that, but it wasn't until we were at the brink of violating the decree—and New Mexico was enjoined not to do that—that we were able to have a credible enough threat to get people to the table. We developed a collaborative solution. It was then authorized in law by the legislature, and then my successors at Interstate Stream Commission had to implement it, which they have done successfully. An earlier panelist from the Carlsbad Irrigation District said that the objectives of the solution have been absolutely achieved. New Mexico credit is 115,000 acre-feet, which was judged at the time to be the target.

So building on what Scott said, do we have to have a crisis before we can be motivated to collaborate in good faith to reach a solution? My answer is I don't know. I have not seen much of the opposite.

The other thing that I noted with much interest is that many of the speakers today have mentioned ethics. They talked about applying ethics to a whole variety of aspects of water management, and I also think that is very important. I was asked to address climate change and Rio Grande Compact compliance. I'm also going to talk about ethical and fiduciary responsibilities of state water management officials.

But let's start with climate change, briefly. The conversation between Senator Udall and Dr. Brad Udall was a highlight of the conference as far as I am concerned. I'd like to share a couple quotes from Brad Udall and Jonathan Overpeck in a 2017 article in *The Conversation*:

> "The atmosphere draws more water, up to 4 percent more per degree Fahrenheit" from anything it can get.
>
> "We found that Colorado River water flows decline by about 4 percent per degree Fahrenheit increase, which is roughly the same amount as the increased atmospheric water vapor holding capacity . . . Thus warming could reduce water

> flow in the Colorado by 20 percent or more below the 20th-century average by midcentury, and by as much as 40 percent by the end of the century."

I was fortunate enough to hear Dr. Overpeck present at the University of New Mexico earlier this year. He was talking about 50 percent reductions in his academic remarks, and he said that the Rio Grande is equivalent to or worse than the Colorado River with regard to climate change impacts. Another quote from esteemed hydrologist and New Mexico climate change expert Dagmar Llewellyn: "We live in the red bull's eye." That's us.

Switching gears, I want to talk about administration of water for compact compliance. Following the Pecos problems, the legislature passed a law to implement what the Interstate Stream Commission, when I was director, called Active Water Resource Management. Let me just read a couple of sentences from the law: "The legislature recognizes that the adjudication process is slow, the need for water administration is urgent, compliance with interstate compacts is imperative, and the state engineer has authority to administer water allocations in accordance with the water right priorities recorded with or declared or otherwise available to the state engineer. The state engineer *shall* adopt rules for priority administration and ensure that authority is exercised" (my emphasis). That's a mandatory legal responsibility of the state engineer. "The state engineer shall adopt rules based on appropriate hydrologic models to promote expedited marketing and leasing water in those areas affected by priority administration." That's because many of the essential uses—the human uses—are junior and priority.

The state engineer promulgated general rules that are applicable statewide, which were then litigated and eventually upheld in 2012 by the New Mexico Supreme Court. Since then, as far as I know, there is no public evidence of progress toward implementation. None. Priority administration philosophy of the general rules is that a cooperative approach is superior and sought, but it is not within the state's authority. The philosophy is that priority administration will motivate superior cooperative solutions. I believe that that's the case based on my personal experience in trying to find a permanent solution to New Mexico's compliance with the Supreme Court decree on the Pecos River.

I'd also let you know that regulations specific to the lower Rio Grande have been prepared. But I don't believe they've seen the light of day although more than four and a half years have elapsed since the New Mexico Supreme Court upheld the law and the state engineer's general regulations.

Figure 1 shows New Mexico's compact allocations. The flat line, the line that flattens out in blue across the bottom, is the allocation to the middle Rio Grande, above 405,000 acre-feet of obligation. Every single marginal drop of water that flows across the Otowi gauge has to be delivered to the

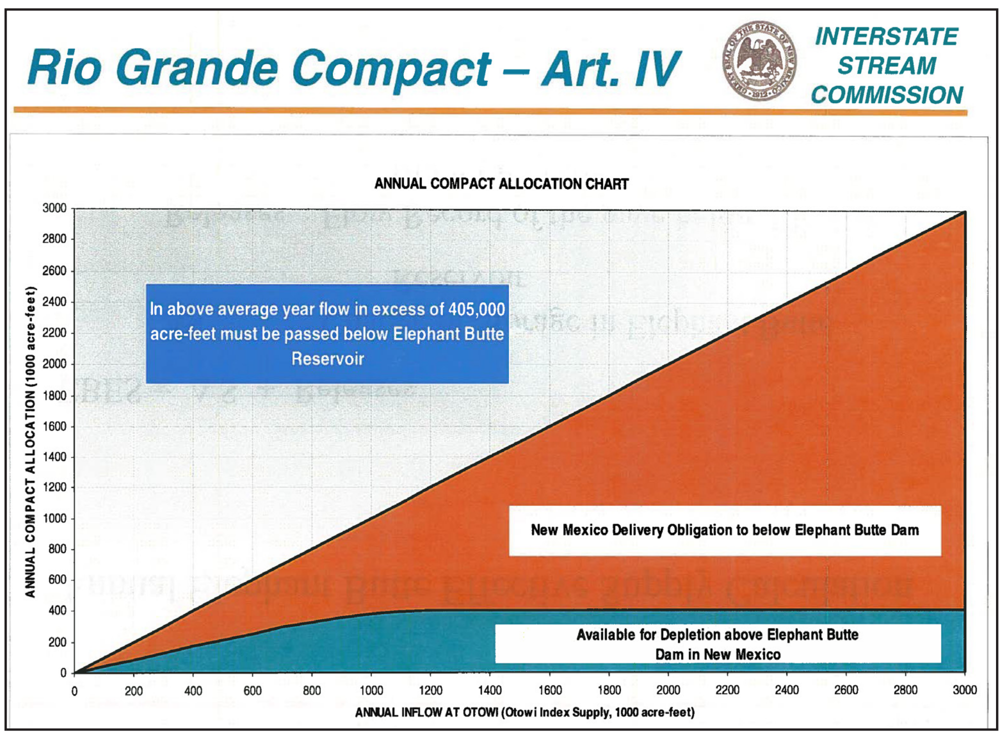



Figure 1. Rio Grande Compact Allocations.

outlet works of Elephant Butte Dam. One hundred percent. The other color in the slide shows the lower Rio Grande's entitlement to receive Otowi flows through the middle valley at the outlet works of Elephant Butte Dam. I'm going to come back and tie that into other things in just a moment.

What are the compact implications of climate change with regard to Figure 2? Well, increased losses between the supply gauge and the delivery index gauge due to temperature will reduce the amount of water that is available. In the middle Rio Grande where 50 percent of the depletions now go to nonhuman uses, those uses are going to go up, up, up, up, up. That includes the evaporation from Elephant Butte Reservoir with increased evaporation. How will we be able to deal with that in the future? That's a huge question.

In my view, current depletions in the middle Rio Grande exceed the average available supply. I personally believe that New Mexico's current compliance with the compact is fragile and transient. I think that climate change will bring about a whole new set of problems that will make our existing system much worse. It is not a stretch to say that New Mexico's compliance in the next few years will be achieved either through the good will of the Middle Rio Grande Conservancy District, who has been helping out the Interstate Stream Commission and the state engineer and making deliveries at the end of the year, or through big monsoon seasons that make it into Elephant Butte, because nobody else can take the water.

I want to close by making a couple of remarks with regard to the responsibilities of state water officials in New Mexico, and I want to illustrate my points by asking you a rhetorical, personal question that I'd like you to ponder: If you as a person entered into a contract after very careful consideration and due diligence, do you believe that you would have an ethical duty to comply with your contract obligations? My opinion is yes. I think when you enter into obligations with your eyes wide open and in good faith, you are ethically obligated to follow through.

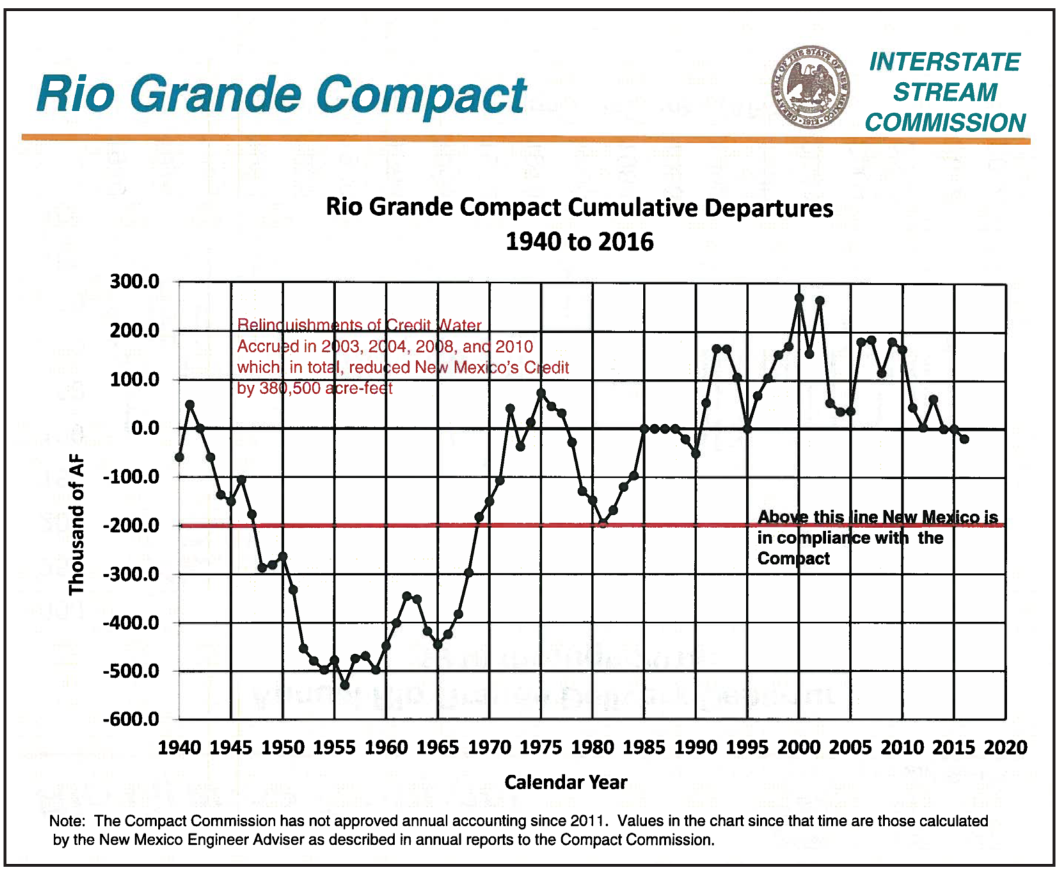



Figure 2. Rio Grande Compact cumulative departures, 1940 to 2016.

The Rio Grande Compact requires distribution of water within the state. There are three allocations. The first is above the Otowi gauge where depletions have to be maintained at what they were at the time of the compact (they're not quantified, but they can't exceed that)—and again, the natural, nonhuman depletions are going to go up there. There is an allocation to the middle Rio Grande, and then the rest of the water has to go through and provides the supply to Texans and New Mexicans below Elephant Butte Dam. At the time of the compact, that was an undifferentiated joint quantity. Now it is very different. Is it ethical for state officials to fail to exercise their authorities, namely the authority to prepare for priority administration, to make delivery of the downstream apportionment saved from the middle Rio Grande to the lower Rio Grande?

I also want to address the fiduciary responsibility of New Mexico state water officials. I believe they have a responsibility to avoid incurring huge state expenses by allowing water depletions by a few to cause compact violations that are then paid for by the state of New Mexico and all of its citizens. Another speaker just talked about preventing a reverse Robin Hood, and that is exactly what I am talking about here. The lower Rio Grande is a prime example. A few farmers and farming corporations have enriched themselves by using more water than New Mexico is entitled to, and a big bill is on the way for the people of the state of New Mexico. So the core question I would ask is this: Will New Mexicans learn the lesson in time to avoid a similar outcome in the middle Rio Grande, where I believe we have very fragile and transient compliance? Will we avoid a violation of New Mexico's delivery obligations through the middle Rio Grande to the lower Rio Grande, thereby avoiding expansion of the Texas lawsuit to also envelop the middle Rio Grande? Thank you.

## Dick Wolfe, former Colorado State Engineer

*Dick Wolfe was appointed state engineer and director of the Colorado Division of Water Resources on November 26, 2007, by Governor Ritter. As state engineer, Dick was responsible for the direction and management of the Colorado Division of Water Resources, which has a staff of approximately 260 employees and an annual budget of approximately $25 million. The division is responsible for distribution and administration of water in accordance with the state constitution, state statutes, and interstate compacts; the implementation of a statewide dam safety program; the permitting of the use of groundwater and construction of wells; and the collection and dissemination of data on water use and streamflow. The state engineer is Colorado's commissioner on five interstate compacts, executive director of the Colorado Ground Water Commission, and secretary to the Colorado Board of Examiners of Water Well Construction and Pump Installation Contractors. Dick began service with the division in 1993. His education includes a BS and MS in agricultural engineering from Colorado State University in 1983 and 1986, respectively. He is a native of Colorado and was raised on a farm in Weld County. Dick retired from state service on June 30, 2017.*

I wanted to give you a little bit of perspective on where I'm coming from. My experience is with Colorado, which is a headwater state. We have 14 agreements and compacts within our state. In reality, it is the tail that wags the dog. Two-thirds of the water that originates in Colorado goes out of state to meet our downstream obligations. I'm going to focus a lot on where we stand today. From my perspective in Colorado, I think we are in a very good position, but we've learned a lot of hard lessons through a lot of litigation. Norm and Scott have talked about the status of some of the current litigation that is ongoing in the state. We've learned a lot of lessons in trying to react to crises. It seems like it is just a natural thing as a democracy. We tend to react to things when they are in a crisis mode. I wanted to share with you some of the things that Colorado has done, what I think are some positive things that we have learned, and where we've positioned ourselves to be in a more proactive state of mind, which is what Scott was trying to focus on, I think, in his initial comments.

We've been in litigation over some of our compacts since the early 1900s. Our agency came around in 1881. We started administering water in Colorado five years after statehood, so we've gained a lot of experience, but through those times we've all seen a lot of changes. I'll highlight one of the comments that Norm made. When I started out in my professional career right out of college, I spent the first seven years working as a private consultant representing the State of Kansas against Colorado in the Arkansas River Compact litigation that started in 1985 and took 24 years to litigate. One of the things I learned in spades from that experience, not only representing Kansas for seven years as a consultant but also working for the State of Colorado on the other side for the last 24 years, is we have a fiduciary responsibility to comply with the compacts. The US Supreme Court has made that very clear.

After you spend that many years litigating and that much money—$34 million in damages and over $20 million in costs just to litigate the Arkansas River Compact—you tend to learn through experience that working through cooperation is a lot better than trying to litigate. We hear the buzzword *collaboration* a lot, but if you look at the derivation of that, right in the middle of that word is *labor*. Collaboration takes a lot of work. Colorado has learned from these expensive and long protracted stages of litigation that trying to be cooperative and trying to do things in a collaborative way is very important, and being cooperative and collaborative does position you to be proactive. We see a lot of challenges coming our way with the Endangered Species Act and climate change amongst other issues. I grew up as a farm boy, and I learned as a farm boy that if you don't plan in the spring to plant your crops, you're going to be begging in the fall from somebody. That is really about how we should do our business too. Scott highlighted how important it is to be proactive and to plan and to anticipate what is coming down the road. That's often hard.

One of the things Colorado has done well is we've aligned ourselves in our three branches of government in a positive way. It has taken a long time to get there, but the executive branch and the judiciary and the legislative branches work very well together. In the executive branch, we work very closely with the legislature when they enact laws. We work with them on committees. We work very closely with the legislators helping educate them on potential challenges, including climate change, and helping them understand the science behind what we do in managing water resources, so that when the legislature enacts laws those laws are based on sound science. This has been important for Colorado because when the Division of Water Resources uses its authority to enact the rules, the Colorado Supreme Court has been consistent supporting the division in those decisions whenever it has been challenged based on the statutes and its administrative discretion.

Colorado also enacted, in 2013, what they call the SMART Act, which has been an evolutionary part of aligning the three branches of government. The acronym stands for State Measurement for Accountable, Responsive, and Transparent government. The act formalized a performance management system, and it had a number of components in it including planning, management, data collection, reporting, and evaluation. It provided a framework where the legislative, executive, and judiciary branches were focused on customer-focused approaches to delivery of goods and services. A number of things came out of the act. The government has to be able to measure programs and policies to determine whether they were effective. Several departments set up performance plans. There are six or seven divisions within the Department of Natural Resources in Colorado, including the Division of Water Resources. One of the performance measures we have in this plan is that we have to be in compliance with our compacts. We are measured against that, and we have an annual performance evaluation. We have to go present to the legislature and the governor's office about how we are doing in that regard. There are a number of other parameters as well.

The legislature also set up through the SMART Act a regulatory agenda. We now have to review our rules, every one of them, every five years. The division operates under 17 to 20 sets of rules that we have to continue to evaluate whether they need to be modified or revoked, or whether new rules need to be enacted. The legislature has given the division a lot of broad authority to do rulemaking.

The governor's office was also consistent with aligning itself with this legislation through an executive order to set up advisory committees for rulemaking. This is something the division has been doing for a while, and it evolved in and got codified in the executive order as well as in the legislature. That may be something that happens in New Mexico as well. I'm not as familiar with the rulemaking process. But setting up advisory committees has been very effective.

Over the last 10 years that I've been state engineer, I can speak directly to three recent sets of rulemaking where we have set up advisory committees. We go through a process where we help educate the individuals on the advisory committees and help them understand the science, because we all have to have a common understanding before we decide what the rules should look like, and it builds buy in and trust with the local water users in that area. We did this in the Arkansas River Basin for our irrigation improvement rules, the Rio Grande Basin for overall use rules, and most recently in the Republican River Basin for our compact compliance rules. All of these were done in a proactive way without the threat of litigation or without being the result of litigation. We've tried to change our paradigm and not just react to do these things when somebody has sued us, particularly a downstream state.

We've also developed a helpful, extensive data management system that we call HydroBase. We've developed a lot of decision system tools over the years with models that have helped us with our decision-making and administration as well as some of our planning processes. There is always a lot of criticism of models, and we recognize that all models are wrong, but some of them are very useful. We've been able to develop comprehensive models that we continue to update. We have peer-review teams that continue to update these models. We do this through extensive data gathering of streamflow data, diversion records, water levels, geology—everything that will help us make better decisions—because you can't manage what you don't measure. It is important to have good data collection systems around, and I know they are expensive to do. We've learned that ignoring the facts doesn't change the facts. You've got to know what the facts are before you can make sound decisions.

Colorado a couple of years ago finalized their water plan, which is helping guide us into the future of how we are going to plan to meet ongoing demand and future resource needs in light of, for example, climate change. Colorado has done extensive studies on what climate change is going to be, but we recognize that our compacts, which were done in the 1920s through the 1960s, do not consider climate change. They do not consider endangered species issues. They do not consider well development. We've had to work with our sister states, our committees, and technical experts in the states to look at how we address this in light of the contract obligations we have. It is challenging, but I know there is a path forward, and it will work through cooperation and collaboration. We've seen some recent successes, I know, working with State Engineer Tom Blaine in regard to the compact litigation on the Rio Grande, working toward a solution, and trying to avoid litigation. Again, it is going to take effort, but we will get there. I know the states will if they continue to work on that. That concludes my remarks.

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**Steve**: I wanted to channel Herman Settemeyer briefly if I may and discuss a couple of things from the Texas experience that bolster this idea that data-driven science and real, honest-to-God stakeholder participation are the two biggest innovations in the twenty-first century. We've been using science, of course, since 1934 with the joint investigations that did a lot of good engineering to figure out where the water was used. Texas has an environmental flow and bay preservation program that was enacted in the Governor Perry administration. He's not exactly known as a paragon of environmental protection, but he signed this bill. It has a twin process: it's got a technical team with at least one of each type of scientist (e.g., engineer, several different kinds of hydrologists, aquatic and terrestrial biologists and so forth) that meets and does a process with some modeling to determine what it would take to keep the native fish assemblage alive in the rivers of Texas. Well, you can't enforce a deal like that, so at the same time, there is a parallel track where the stakeholders get together, and there is one of each: there's a groundwater user, there's a production farmer, there's a water authority person, there's an environmentalist. Everybody is seated at the table. By means of this process, the stakeholders are charged with taking what the science team says we ought to be doing to protect river flows for the future and coming up with how we can do this. The jury is still out on that process, but I think that is the twenty-first century process, and I think we need to be doing more of that here.

Let's give our panel a big round of applause.

# Underground Storage and Recovery Project Implementation in New Mexico

## Moderated by Amy Ewing, Daniel B. Stephens & Associates, Inc.

*Amy Ewing, P.G. is a hydrogeologist specializing in water resources investigations and planning, managed aquifer recharge, watershed management, permitting, and public involvement. She is the project manager for the Albuquerque Bernalillo County Water Utility Authority's managed aquifer recharge projects, which aim to establish a long-term drought reserve using surface water for recharge, as well as the City of Hobbs' recharge demonstration project. Amy has extensive experience in all aspects of water planning, including working with municipalities and water systems on water supply and demand analysis, water audits, conservation, drought management, reuse, and source water protection planning; regional water planning; and State water planning. Amy is a licensed Professional Geoscientist, and holds bachelors and master's degrees in earth science and water resources.*

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## Jim Chiasson, City of Rio Rancho

*Jim Chiasson joined the City of Rio Rancho in January of this year as the new Utilities Department Director. In this role he is responsible for managing the day to day operations of the City's water, wastewater, and recycled water systems serving a population of over 94,000. He spent the previous 16 ½ years with the New Mexico Environment Department's Construction Programs Bureau where he served in various capacities including the last six years as Bureau Chief. Jim also spent four years directing operations for the Santa Fe Solid Waste Management Agency and over 3 ½ years in the private sector working for an Albuquerque-based consulting firm. Jim graduated from Syracuse University with a BS degree in mechanical engineering and holds a master's degree in civil engineering from the University of New Mexico. He is a registered professional engineer in the State of New Mexico.*

Good morning. Amy and Cathy asked me originally to keep it to five minutes, and I said, "I can't give you directions across campus in five minutes. That's not going to be possible." I'll run through these slides as quickly as possible, and then I've got a short video that will explain better than I can the aquifer storage and recovery program that Rio Rancho has undertaken.

How many people have never been to the city of Rio Rancho? There might be a few in here. OK, well, you're going to get a quick geography lesson. Rio Rancho is rather big. We're over 104 square miles and quite spread out, which is challenging for us as far as infrastructure is concerned (Figure 1). The more densely populated areas are quite spread out. We have to feed water and wastewater and recycled water to many of these places, which is quite a challenge for us, both cost-wise and manpower-wise. Rio Rancho was founded in 1961 (Figure 2), but we weren't incorporated until 1981, which was a good year. It was the year I graduated from high school. The population is just under 95,000 people. That makes us the third largest city in the state behind Albuquerque, of course, and Las Cruces. We do have about a mile and a quarter of river frontage on the Rio Grande, but other than that, the city is basically landlocked.

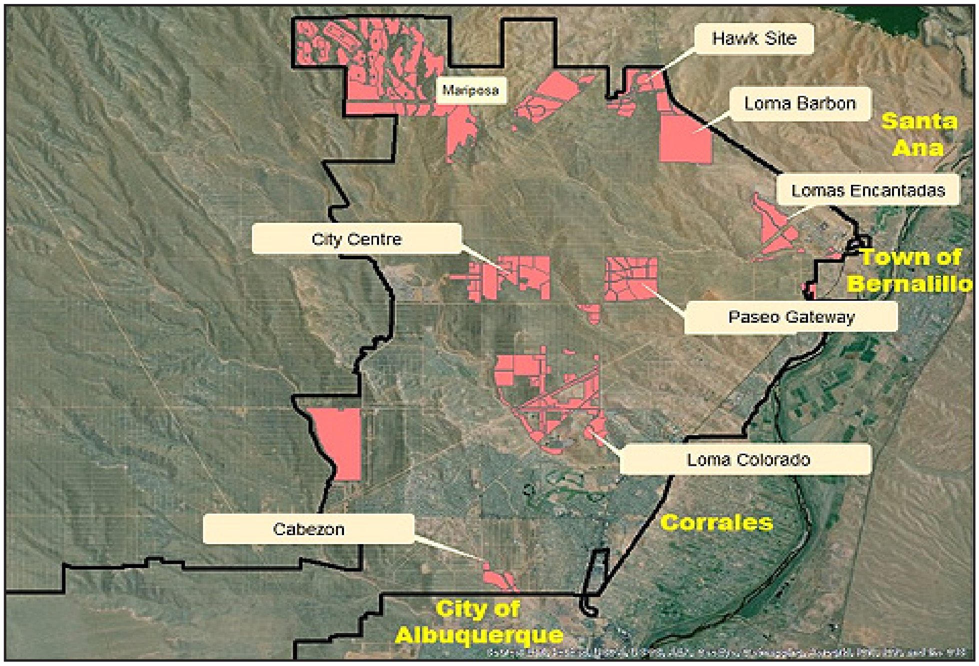



Figure 1. City developments.

A couple of statistics on the utility (Figure 3): We have over 33,000 residential accounts, 711 commercial water accounts, and 17 reuse customers. We have a fill station in our outer regions that services 236 customers and close to 30,000 wastewater customers. The city of Rio Rancho gets all of its drinking water from groundwater sources (Figure 4). We have 17 wells currently permitted and in operation, with a total capacity of just over 23,000 gallons per minute. We store that water in 18 strategically located storage tanks throughout the city, with a total capacity of about 42 million gallons. Because all of our drinking water comes from groundwater and we happen to be over an aquifer that has elevated arsenic levels—at least under the new (or not so new) rules of 10 parts per billion—we have to treat most, if not all, of our production water to remove arsenic below the maximum contaminant level (Figure 5). We have nine booster pumping stations, and we transmit the water to our customers through about 580 miles of line.

For water rights, the city has two permits (Figure 6) currently with the state engineer's office, one from 1979 and the other was negotiated and settled in 2003, with 12,000 acre-feet maximum per permit. We have an obligation under the permits to secure 728 acre-feet of water rights every five years.

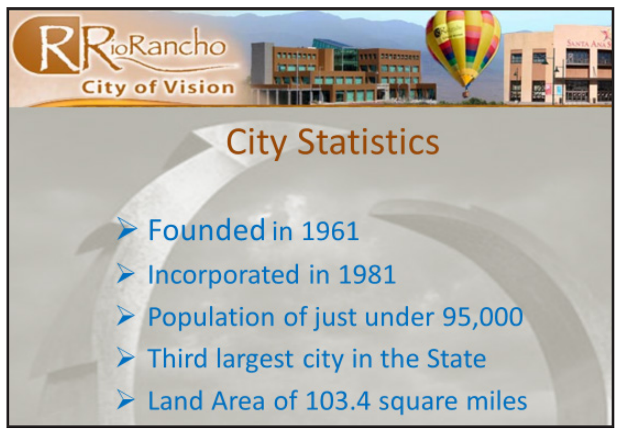



Figure 2. Rio Rancho statistics.


Figure 3. Utility statistics.


Figure 4. Rio Rancho water production.


Figure 5. Water treatment facilities.

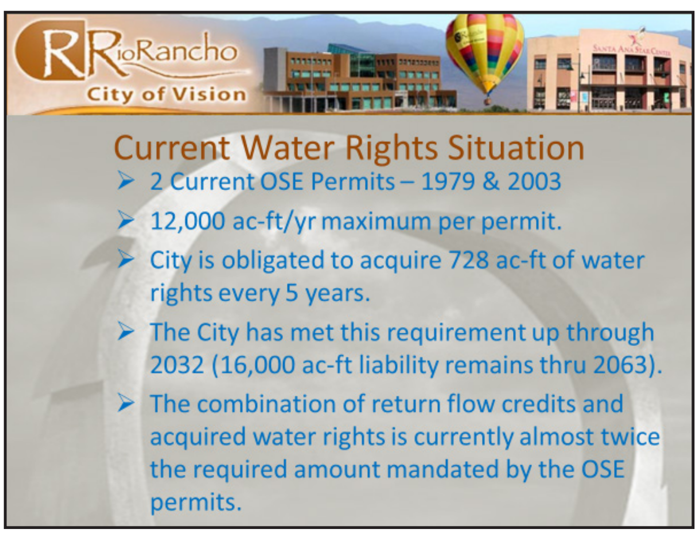



Figure 6. Water rights situation.

We've met that requirement to date and then some. We currently have that obligation met through 2032, although we have a remaining liability through the end of that period that runs until 2063. Having said that, our return flow credits currently to the Rio Grande are almost twice the amount mandated under these permits.

We do have reuse programs at the city. We have the Purple Pipe Program (Figure 7). We reuse effluent, which is sent to 17 customers and utilizes about 550 acre-feet of treated water. We have several membrane bioreactor (MBR) plants around the city, which I'll talk about in a minute. We treat our wastewater to Class 1A effluent standards. One of those customers, up until recently, was a golf course, which is now defunct, but we also have all the city parks, a cemetery, and a number of our medians and a few other places where we use the effluent.


Figure 7. Water reuse programs.

To the meat of the discussion: about 16 years ago, the city had the foresight to continue their reuse plan that was approved back in 1999–2000. That included an aquifer reinjection project—aquifer storage and recovery. That project included an MBR plant, which we call plant #6 at Cabezon (Figure 8), on the south side of the city—it's a standard MBR plant that treats wastewater to Class 1A standards, and then that water is boosted

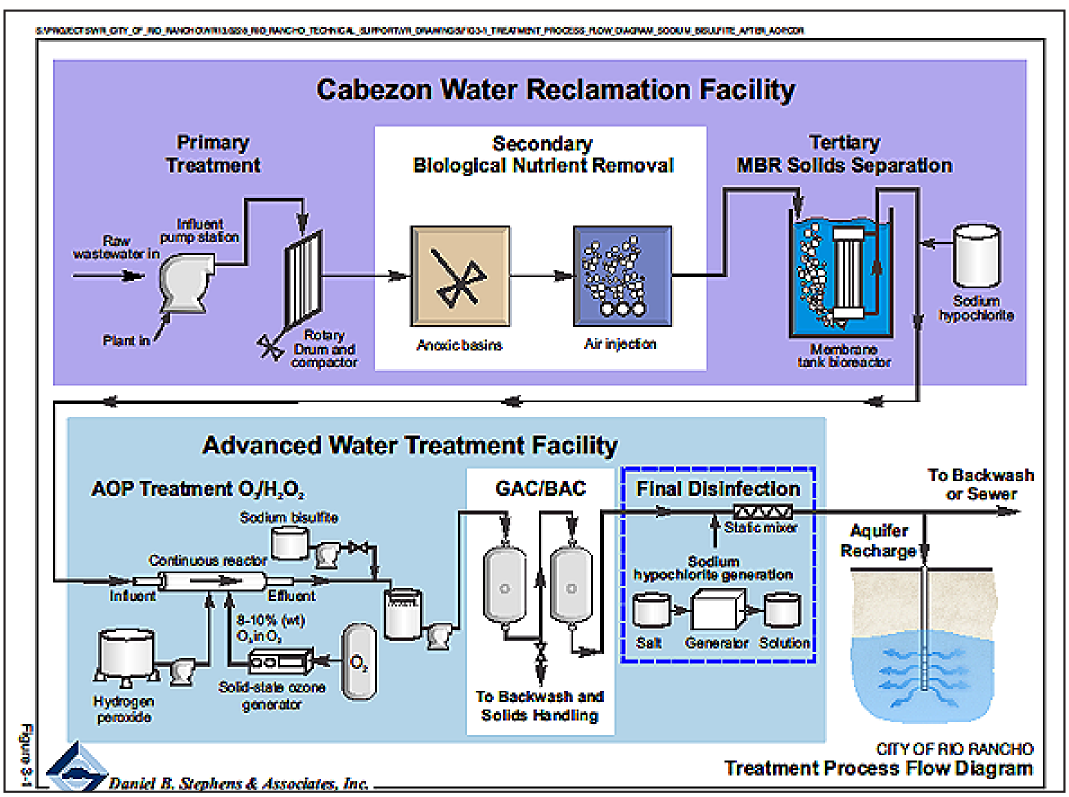



Figure 8. Cabezon Water Reclamation Facility.

approximately four miles north to our advanced water treatment facility (AWTF), which allows us to inject upwards of one million gallons per day under permit to the aquifer at our well site #10.

This is a brief overview of the process, and like I said, we'll see a video that will give you more detail. The Cabezon plant is fairly standard MBR with primary treatment, and then the secondary biological nutrient removal process goes through an MBR, then the water is disinfected with hypochlorite and it is sent about four-plus miles up the road to our AWTF, which includes advanced oxidation and granulated activated carbon for organic removal. We also degasify the water, and then we put it through a final 0.1 micron filter before it is discharged into the aquifer through a 16-inch stainless steel well at 1,700 feet via gravity. There is no pumping. It is a gravity well.

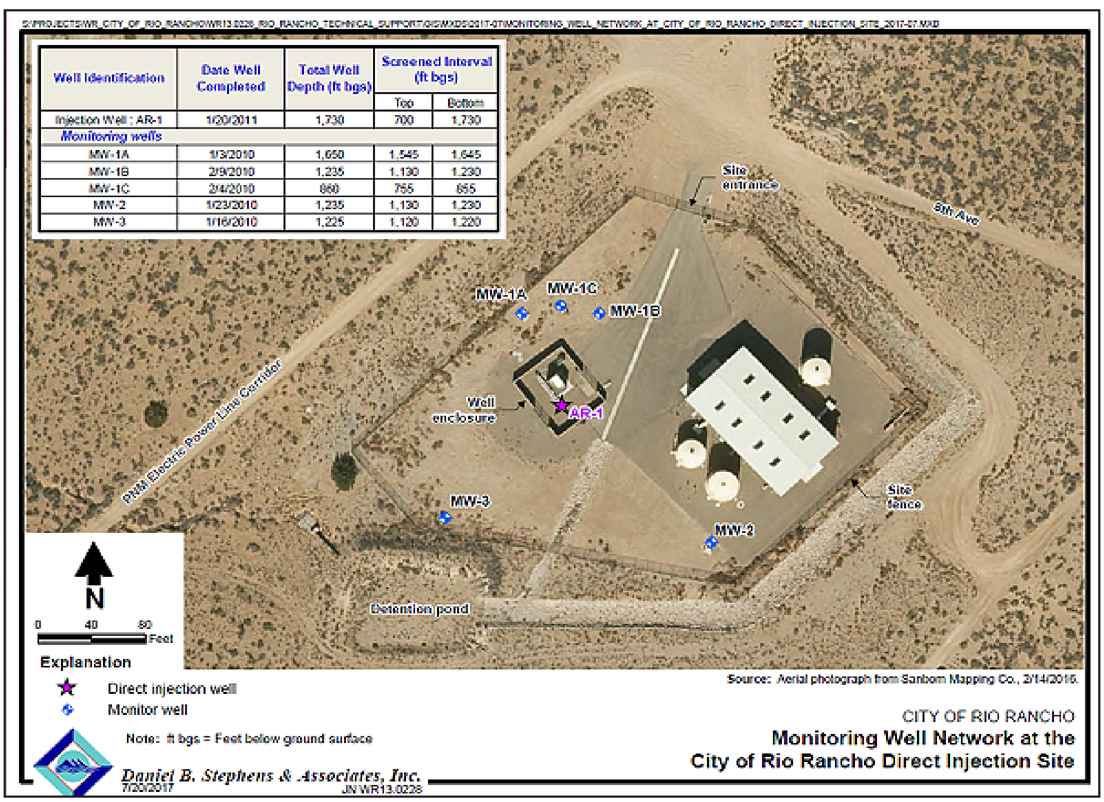
A couple of requirements: Obviously, this being the first permitted active facility in the state, the requirements were quite stringent. We have to monitor and take samples on a regular basis (Figure 9). At the AWTF we're looking at total organic carbon and total nitrogen on a monthly basis; *E. coli*, weekly; some other major constituents of concern—there's 96 of them—quarterly; and trace organics, annually. The entire monitoring process costs the city about $55,000 per year. That is mandated for the first two years. If there are no hiccups or any problems with the system, then we can go back to the New Mexico Environment Department (NMED) and perhaps renegotiate some of these mandated monitoring results and lower the cost.


Figure 9. Water monitoring requirements.

Figure 10 provides an aerial layout of the direct injection site. To the right is the AWTF treatment building. Water comes into the main holding tank to the lower left of the AWTF building. The water is fed into the building where it is treated through the process I just explained. Finished water comes to this 50,000-gallon tank to the upper left of the AWTF building, and then the wellhead site itself is marked with a star. You can also see the various upgradient and downgradient wells where we monitor on a regular basis.

With that, I think we'll run the video to give you a better overview of the process.

> **Narrator**: Welcome to the City of Rio Rancho's aquifer recharge system virtual tour. The City of Rio Rancho is the first city in the state of New Mexico to replenish groundwater by putting water back into the aquifer via direct injection. This advanced system will allow the City of Rio Rancho to put up to one million gallons a day of water back into the aquifer for future use. So please join me on this virtual tour of this incredible process that allows us to replenish the aquifer with fresh water.
>
> Our journey begins at one of the city's advanced wastewater treatment facilities. This facility is a membrane biological reactor facility. This facility treats 1.2 million gallons a day. The crystal-clear effluent from the MBR plant is now pumped to a 3-million-gallon storage holding tank. The tank area includes a pump station with four pumps that will send this treated water approximately six miles to its next destination. From the pumping station, the water now travels to the AWTF, or advanced water treatment facility storage tank. This tank is 2 million gallons capacity. This reuse water is now ready for advanced treatment inside this state-of-the-art advanced water treatment facility.
>
> The first process in the facility is the advanced oxidation process. This process utilizes ozone, which is generated onsite as well as




| Well Identification | Date Well Completed | Total Well Depth (ft bgs) | Screened Interval (ft bgs) | |
|---|---|---|---|---|
| | | | Top | Bottom |
| Injection Well : AR-1 | 1/20/2011 | 1,730 | 700 | 1,730 |
| *Monitoring wells* | | | | |
| MW-1A | 1/3/2010 | 1,650 | 1,545 | 1,645 |
| MW-1B | 2/9/2010 | 1,235 | 1,130 | 1,230 |
| MW-1C | 2/4/2010 | 860 | 755 | 855 |
| MW-2 | 1/23/2010 | 1,235 | 1,130 | 1,230 |
| MW-3 | 1/16/2010 | 1,225 | 1,120 | 1,220 |

Figure 10. Aerial layout of injection site.

35 percent hydrogen peroxide. By combining hydrogen peroxide with the ozone that is generated onsite, the process is more efficient as well as more economical. The water is now sent to the process tank for distribution to the activated carbon filters. The water now flows to the activated carbon vessels. These activated carbon vessels remove any dissolved organic material. Along with the dissolved organics, these vessels also remove any taste and odor compounds. The water now flows to the bag filters. These high-pressure vessels each contain five one-micron filter bags that filter out any material that may have broken through from the activated carbon filters. The next process is vacuum degasification. It is utilized to remove any dissolved gases such as dissolved oxygen, carbon dioxide, and nitrogen gas, and is capable of producing water with parts per billion levels of these dissolved gases. This type of equipment is part of a final polishing stage of water treatment and produces ultrahigh-purity water. This highly purified water is now ready to be injected back into the aquifer. This water will travel 1,700 feet down the injection well, via gravity, to the aquifer. This completes our tour of the City of Rio Rancho advanced water treatment facility, aquifer reinjection system.

Like I said, I didn't choose the music. I probably would have gone with a Chris Cornell tribute or something like that. I want to thank everyone for your attention and for the invitation this morning.

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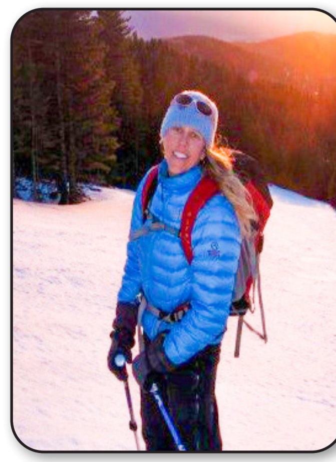
## Michelle Hunter, New Mexico Environment Department



*Michelle Hunter is Bureau Chief for the Ground Water Quality Bureau of the New Mexico Environment Department. Michelle serves as the state of New Mexico's top environmental regulator for groundwater in her position as Bureau Chief for groundwater quality. She leads a team of more than 55 scientists, regulators, and administrators to protect New Mexico's precious aquifers. Her earlier work in the Environment Department's brownfield program guided municipalities, non-profits, and for-profit developers on cost-effective redevelopment strategies for the economic redevelopment of contaminated "brownfields" sites for future business and jobs.*

*Michelle has over 20 years of experience in the environmental field, including 15 years as a consultant conducting site characterization, remediation, and handling all environmental issues associated with the redevelopment of contaminated properties. She has transitioned from the private sector into a regulatory setting while completing a master's degree in water resources at the University of New Mexico. Michelle enjoys back-country skiing and mountaineering and loves to spend time in the mountains during all four seasons of the year.*

My name is Michelle Hunter, as you know, and I am the chief of the Groundwater Quality Bureau at the New Mexico Environment Department. I am going to talk about our regulatory framework for permitting these types of aquifer storage and recharge projects. We have a permitting process and the state engineer's office has a permitting process that Jerri is going to touch on today. In general, you would start the state engineer's permitting process first and then complete it in parallel with ours. They are both processes that Amy has witnessed and had some real fun with the last few years. I'll just jump in here.

The state engineer calls these projects underground storage and recharge projects (USR) as opposed to ASR—aquifer storage and recharge. We kind of go back and forth. In order to be a unified couple of state agencies, I'll use USR. As of right now, we do not have USR-specific rules that we permit under (Figure 1). We use the Underground Injection Control Program that we have primacy for with respect to Environmental Protection Agency (EPA) rules. The Water Quality Control Commission discharge permit regulations are the framework we use for these underground injection control permits, for which we have had primacy from the EPA since 1982.

During the permitting process, we consider several things in a broad-based way. First, all groundwater in the state is protected (Figure 2). Unlike many other states, we don't designate different water for different uses. All groundwater in New Mexico is protectable. We have groundwater standards in New Mexico, and we use those standards. We're also in the process of changing those standards right now so that the vast majority of them will be the same as the maximum contaminant levels that the EPA uses for drinking water purposes. I think there are maybe four that won't be. We also require some modeling to make sure that there is geochemical compatibility between the two waters as they are mixed in the aquifer.

Additionally, we also consider whether the project is infiltration-based, which is what the Bear Canyon ASR project is, or injection-based, which is what the City of Rio Rancho is doing (Figure 3). Is it freshwater, or is it reclaimed wastewater like in Rio Rancho? What are the contingencies, and what are the financial and technical capabilities of the utility itself? Is it a large city? Is it a small city? What are the capabilities of the utility that wants to do this, and what kind of things do we need to consider in that realm as well?

Other aspects that we also consider (Figure 4): Are there any issues currently with the drinking water sources of that city or the utility? How is that drinking water or wastewater disinfected, and what kind of geochemical situation will occur with respect to that? We also like to think about emerging contaminants, even though we are not technically regulating them yet—pharmaceuticals and other things like that, personal care products. Those are on the horizon for regulation in drinking water and other uses. The City of Rio Rancho stepped up and said, "We'll look for these things to make sure that we're not putting them down into the aquifer." We also consider the


Figure 1. USR policies.


Figure 2. Permitting process.

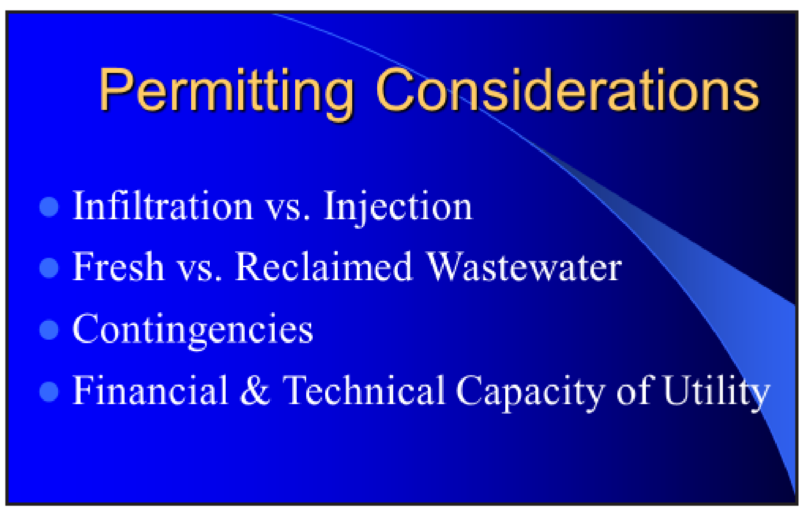



Figure 3. Project considerations.

naturally occurring recharge of the area and the fact that in this type of a situation where we are injecting water into an aquifer, we set the regulatory bar higher than for other discharges that may use the vadose zone to help filter out contaminants. There is always the link with the water resources management part of this as well.

Right now, we are in a regulatory rulemaking process where we are amending our 20.6.2 NMAC rules (Figure 5) to do things like I talked about earlier, to lower—which means make more stringent—our groundwater standards to meet the EPA's maximum contaminant levels for drinking water. We're also looking forward to making regulations regarding all types of reuse, including nonpotable reuse, indirect potable reuse, and direct potable reuse. We're also looking at what we might add to our regulatory framework for those types of projects. In looking at these types of recycled water uses, Pam Homer, who is the team lead for the recycled water section in our pollution prevention section in the Ground Water Quality Bureau, found some ASR guidance that many different stakeholders had participated in writing and developing. We're going to dust that thing off, and we're going to tweak it, and we're probably going to release that fairly quickly on our website, at a minimum. We'll also be talking with stakeholders to determine what in the guidance needs to be integrated into a new regulatory framework for these types of reuse projects that go from nonpotable reuse—recycled water at golf courses, purple pipe projects—to injection of water into the aquifer.


Figure 4. Other aspects.

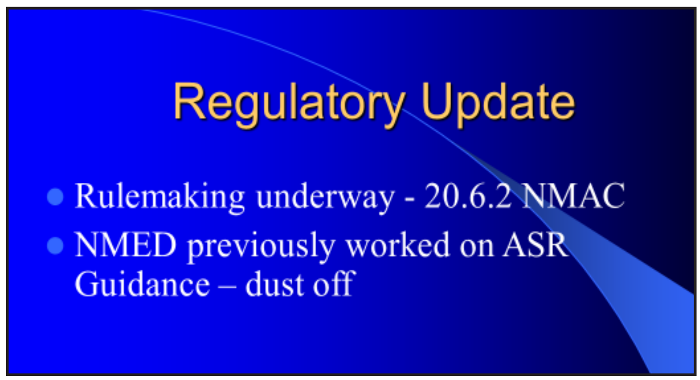



Figure 5. Regulatory rulemaking process.

## Jerri Pohl, NM Office of the State Engineer

*Jerri Pohl enjoys working for the Office of the State Engineer (OSE), serving the public of New Mexico, and protecting fresh water sources. Her initial work with the agency included abstracting historical water right files, which imprinted her with a rich perspective toward water allocation. She worked as the Upper Pecos Basin and Tucumcari Basin Supervisor administering Water Rights for seven years, changing positions to coordinate the well driller licensing program when it was moved from Roswell to Santa Fe. She was advanced to Supervisor of Statewide Projects whose duties include historical research, water right application tracking and statistics, rule revision, policy writing, internal and external training, public education, and coordination of statewide Underground Storage and Recovery applications to become projects. Her team recently promulgated new rules governing well driller licensing and construction effective on June 30, 2017. She and her team have successfully automated several legacy processes that were labor intensive saving agency resources and continue to improve business processes today. Jerri obtained her Police Training certification from Western New Mexico University in a prior life and later obtained her AAS in Environmental Safety & Health from New Mexico TVI and BS in environmental science from the College of Santa Fe before being hired by the OSE.*

Good morning. My name is Jerri Pohl, and I work for the Office of the State Engineer (OSE). I work in the statewide projects, and aquifer storage and recovery, among many other projects, is one of the projects we manage. Our statutes were put into place in 1999 by a piece of legislation for groundwater storage and recovery. Our statutes (Chapter 72) do not call it *groundwater*, they call it *underground water*. That's where the acronym *USR* comes from. They're not called *aquifers* in the statutes; it's called *underground water*. USR is a way for us to help conjunctively manage both the surface water and the groundwater in the state. While the intent of the statute is to help with flood control and water scarcity in our state, we do have some statutory limits to recovering floodwaters, which I'll address here in a minute. The statute 72-5A-2 (1999) gives us the legislative power to do these types of projects (Figure 1).

In Article 5A, where the statutes are located, Statute 72-5A-6 tells us about the application process, and because there are 17 different sections to this statute, it tells us the state engineer's first responsibility is to make sure that the applicant can meet the financial responsibility of the project (Figure 2). That is stated in probably 4 or 5 different sections of this article. The first thing we look at is the capability report to see that the project is technically and financially capable of coming to fruition. Then we have to go through the same processes that we do for any other application. We have to look at impairment and whether the project is contrary to conservation or detrimental to the welfare of the state. The first limitation to gathering floodwaters for USR is that the water right has to be quantified by one of these methods: either it has to be an adjudicated water right or it has to be mentioned in a consent decree or it has to be validated by an act of Congress or it has to be part of a contract pursuant to 43 USC 620, which is the Colorado River Compact, or there has to be an agreement with somebody who has a valid water right that is subject to a change in place or purpose of use.

Floodwaters in this state, as you know, are subject to prior appropriation and so in order to appropriate any floodwaters (for USR), you must first make an application to appropriate. It is very difficult to get an application to appropriate on a surface source of water in the state of New Mexico, because if the water is not appropriated, it is overappropriated. But that is not taking into account torrential floodwaters where making a priority call may be a futile call, if somebody were to call for priority on that water, and there is more water than what everybody can take on the system. That is the first limitation to the way the statutes were written back in 1999. Even though the intent of the underground storage and recovery act was to allow the capture of floodwaters, the statutes for prior appropriation are limiting to that factor.

Then we make it even more difficult. Two years after the statute was written the regulations regarding USR were written, and those regulations limit who can make application to have a USR

**72-5A-2 Legislative findings. (1999)**

The legislature finds that:

A. conjunctive use and administration of both surface and ground waters are essential to the effective and efficient use of the state's limited water supplies; and

B. ground water recharge, storage and recovery have the potential to:

(1) offer savings in the costs of capital investment, operation and maintenance and **flood control** and may improve water and environmental quality;

(2) reduce the rate at which ground water levels will decline and may prevent overstressing or dewatering aquifer systems;

(3) promote conservation of water within the state;

(4) serve the public welfare of the state; and

(5) may lead to more effective use of the state's water resources.

**History:** Laws 1999, ch. 285, § 2.

Figure 1. Statutes 72-5A-2.

**72-5A-6. State engineer; powers and duties; permit; monitoring requirements.**

A. The state engineer shall issue a permit to construct and operate a project if the applicant has provided a reasonable demonstration that:

(1) the applicant has the **technical and financial capability** to construct and operate the project;

(2) .....is hydrologically feasible;

(3) .....will not **impair** existing water rights or the state's interstate obligations;

(4) .....will not be **contrary** to the conservation of water within the state;

(5) .....will not be **detrimental** to the public welfare of the state;

(6) the applicant has completed applications for all permits required by state and federal law;

**(7) the applicant has a valid water right quantified by one of the following legal processes:**

- **(a) a water rights adjudication;**
- **(b) a consent decree;**
- **(c) an act of congress, including a negotiated settlement ratified by congress;**
- **(d) a contract pursuant to 43 USC 620 et seq.; or**
- **(e) an agreement with an owner who has a valid water right subject to an application for a change in purpose, place of use or point of diversion; and**

(8) .....will not cause harm to users of land and water within the area of hydrologic effect;

Figure 2. State engineer requirements.

project to begin with: according to 19.25.8.10 NMAC (2001) (Figure 3) only governmental entities defined as Indian nations, tribes, or pueblos, or state political subdivisions, including municipalities, counties, acequias, irrigation districts, or conservancy districts may apply for a permit. They purposely omitted the federal government it appears. So nobody from the federal agencies can make an application, and also the regulations limit applicants to irrigation districts or conservancy districts. Many water user groups are actually incorporated, so they are not considered a political subdivision of the state. The Lower Rio Grande Public Water Works Authority, through legislative action, became a public water authority, so they are a political subdivision. Some water user groups fall into that category to be able to make an application, but we have other water user groups that are simply corporations. By this strict definition, they would not result in being able to make application.

**19.25.8.10** NMAC 2001

Only governmental entities defined as Indian nations, tribes, or pueblos, or state political subdivisions, including municipalities, counties, acequias, irrigation districts, or conservancy districts may apply for a permit.

Figure 3. Authorized applicants.

Figure 4 shows the projects that have been approved so far. We are missing USR 5. That was an application that was made by a municipality. It was protested by the acequias, and the application was withdrawn. If the approved projects were to be built out to their potential, we would have evaporative savings (if this water were to be stored above ground) of 3.1 billion gallons of water.

| | | |
|---|---|---|
| **USR-1 Rio Rancho Mariposa Infiltration Demo** | 336 acre-feet per annum | **109 million gallons** |
| **USR-2 ABCWUA Bear Canyon Infiltration Full Scale** | 3,000 acre-feet per annum | **997.5 million gallons** |
| **USR-3 Rio Rancho Direct Injection Full Scale** | 1,120 acre-feet per annum | **364.9 million gallons** |
| **USR-4 ABCWUA WWTP Direct Injection Demo** | 5,000 acre-feet per annum | **1.6 Billion gallons** |
| **USR-6 Hobbs Direct Injection Demo** | 160 acre-feet per annum | **52 million gallons** |
| *Statewide USR permit amounts approved* | **9,616 acre-feet per annum** | **3.1 BILLION GALLONS** |

Figure 4. Approved projects.

## Rick Shean, Albuquerque Bernalillo County Water Utility Authority

*Rick Shean works with the Albuquerque Bernalillo County Water Utility Authority as a water quality hydrologist, monitoring threats to the community's ground and surface water resources. Recently Rick participated on the Water Authority's water resources management strategy team in development of the utility's "Water 2120" plan. Rick has worked on groundwater quality issues in the Southwestern United States for nearly 20 years, specializing in groundwater investigation and remediation project oversight, brownfields revitalization, watershed and erosion studies, and water resource planning and policy. Rick has also worked with the New Mexico Environment Department, Bernalillo County Water Resources Group, and the University of New Mexico Alliance for Transportation Research Institute. Rick has a BS degree in anthropology and earth and planetary sciences, a master's degree in water resources, and is currently pursuing an MBA from the University of New Mexico.*

Good morning, everyone. I am Rick Shean from the Water Utility Authority and probably the third best person in the water authority to give you an overview on the policies for our ASR hopes and dreams that we have established in the last 20 years.

This story actually starts in 1997 (Figure 1), when I was still an undergraduate acclimating to the weather out here in New Mexico from Georgia. The water authority first put a water resource management strategy plan in place in 1997. An ASR was identified as a way to establish a groundwater drought reserve. In over the 20-year history, we have shifted and transitioned from looking at the ASR as a drought reserve to looking at it as actual storage and a conjunctive reuse. In 2007, we did a 10-year update to the water resource management strategy. The updated strategy called for an ASR program and for the necessary pilot studies to begin.

If you recall between 1997 and 2007, we started construction on our drinking water plant and our Alameda diversion, so we could start capturing our San Juan–Chama water allotment. In 1997, we were using groundwater unsustainably and had to pump the brakes on the use, and we had to start using our surface water. In 2007, we continued to use surface water, but conservation was

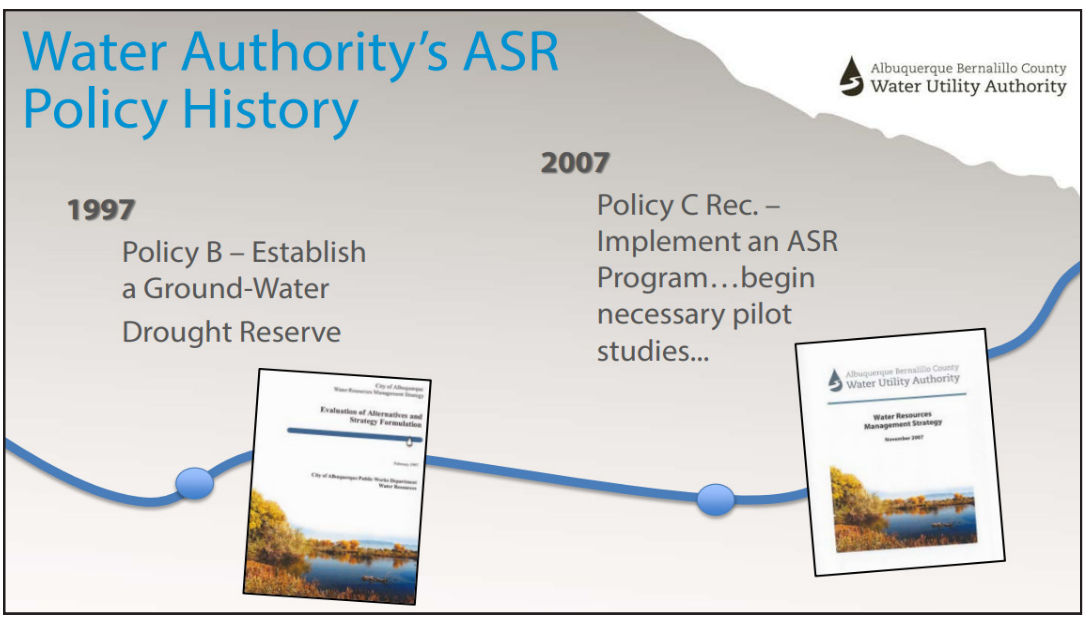



Figure 1. Water Authority ASR policy history.

ticking up and we were becoming very successful in lowering the use of water around the city of Albuquerque. Now fast forward to 2016 and the second update to the water resource management strategy: Water 2120 (Figure 2). We stretched out the horizon for the strategy 100 years. Typically we were planning for 40 years. This time we took it an additional 60 years out, so we transferred and changed and transitioned the language of how we see ASR. We moved from what it was—emergency drought use—to now, storage in the ground, and a part of a storage system that we would have locally.

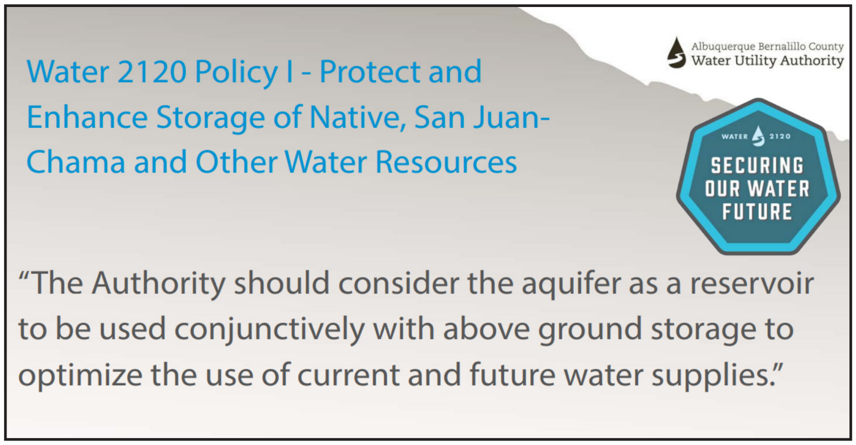



Figure 2. Water 2120 water policy.

Figure 3 depicts the benefit that we see. This was a graph that was drafted at the time. Demand goes up from 2000 to 2120. The fuchsia shows what we expect our ASR to add, starting with our Bear Canyon Recharge Project at 3,000 acre-feet. We're looking at about 5,000 up to 10,000 acre-feet of usage per year. Now let me introduce Amy Ewing. She's going to talk about how we've gotten our policies implemented. Of course, she's going to touch on today what we have—Bear Canyon that is in place—and then tomorrow (that's the future) and what is already started in construction, our large-scale projects.

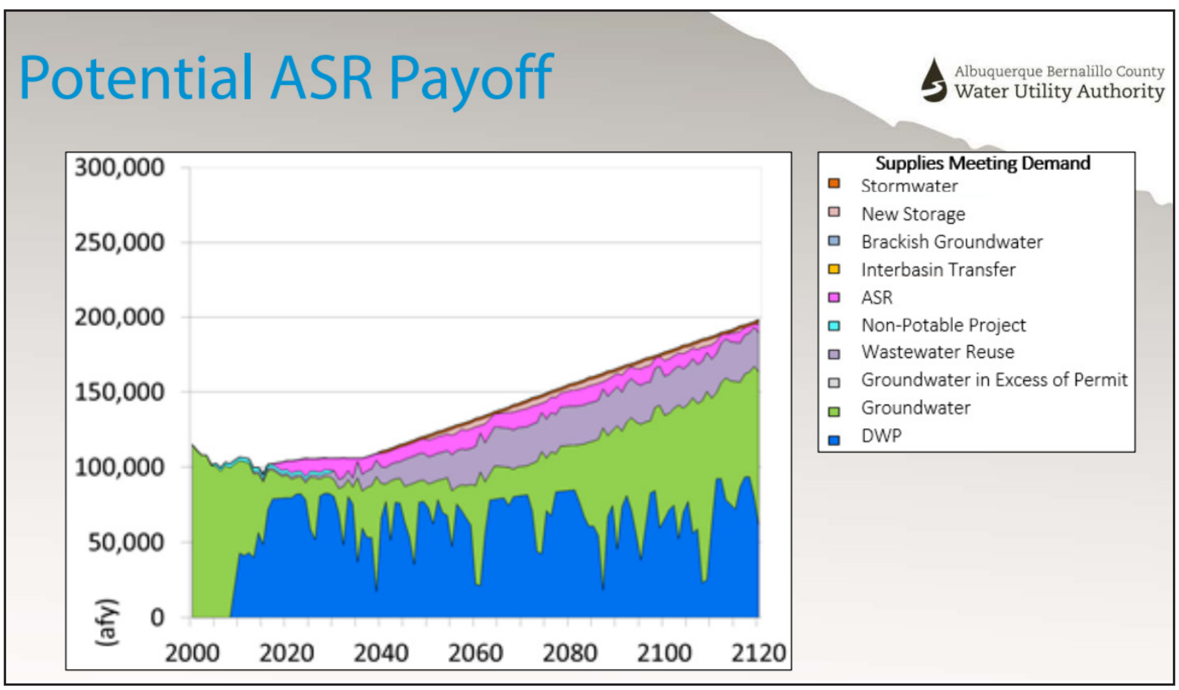



Figure 3. Potential ASR payoff.

**Amy Ewing**: I'll be brief. A lot of you have heard about this a few times, but we have an update on permit number USR-2 for Bear Canyon recharge. There are six permitted demonstration projects; two of them have gone to full scale. Rio Rancho's direct injection is one of them that has gone to full scale. Bear Canyon is the other project that has gone to full scale. The source water is different. Rio Rancho is using treated wastewater, and Jim spoke about the very extensive treatment that they are doing for the treated wastewater. Bear Canyon uses totally different water. For Albuquerque's recharge, we're using San Juan–Chama water, so that is imported surface water from the Colorado River Basin, not wastewater yet. That could be a future project at some point.


Figure 4. Albuquerque projects.

Both projects for Albuquerque—Bear Canyon and the DWTP Large-Scale Recharge Demonstration Project—use San Juan–Chama water, but the treatment is different for the two projects (Figure 4). With Bear Canyon, we're using bank-filtered, chlorinated river water, and that is water that was already part of Albuquerque's existing reuse project that is used to irrigate a lot of green space, especially in the northeast of Albuquerque (Tanoan, the Arroyo del Oso golf course, which is right next to our site, and many other green spaces).

The project is permitted for 3,000 acre-feet per year (Figure 5). That is the full permit volume for all the irrigation and for our project. The actual amount is on the order of about 550 acre-feet per recharge season. We're operating in alternate years. We just operated the second full-scale event, which was October 2016 through March 2017. Doing two calendar years' worth of recharge in one

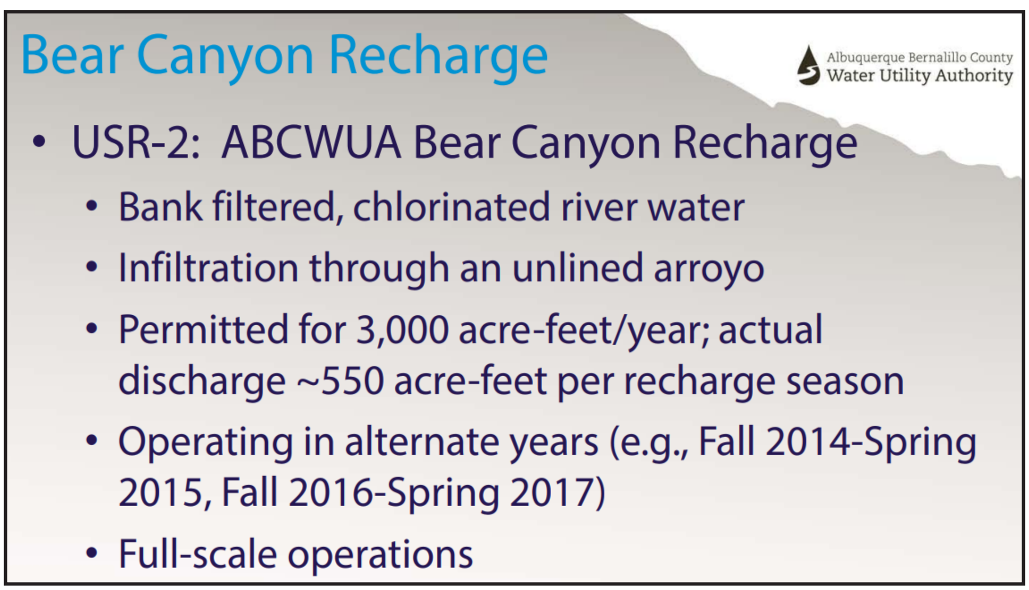



Figure 5. Bear Canyon Recharge information.

season is the most efficient way to operate these projects because of the reporting and monitoring required. If you do that for two calendar years in one event, it works really well. Jerri spoke about all the permits and what the total volumes are. We're on the order of 12,000 acre-feet per year in permits, but that is in no way what is actually being put in the ground. At Bear Canyon for the two demonstration projects and the two full-scale projects done so far, we're at about 2,200 acre-feet total. And we have also done some recovery at Bear Canyon.

Figure 6 is a map of northeast Albuquerque showing the existing infrastructure for the city's reuse project. Because this was one of the first projects in the state, we wanted to use existing infrastructure as much as possible and keep the costs down until we proved the concept worked, rather than laying a bunch of new waterlines. We used the existing infrastructure shown in Figure 4. There are rainy wells near the river where water is diverted, and then the water flows in the existing infrastructure down to our Arroyo del Oso pump station and then we overfill the tank (Figure 7) into the arroyo, so the system is pretty low tech. Figure 8 shows what it looks like in Bear Canyon when we are running. This is only being done in the wintertime.

For the second project we have, we're drilling right now. Since you've last heard about this project, we're drilling, which is really exciting. USR-4 (Figure 9) is the second project for Albuquerque, and we call this the DWTP Large-Scale Recharge Demonstration. DWTP stands for drinking water treatment plant. Large scale just means "Hey, Bear Canyon worked great. Let's do a bigger project, and we're going to call that large scale and there will be many subprojects under that title." This one is at the drinking water treatment plant, so it also uses surface water, but the water

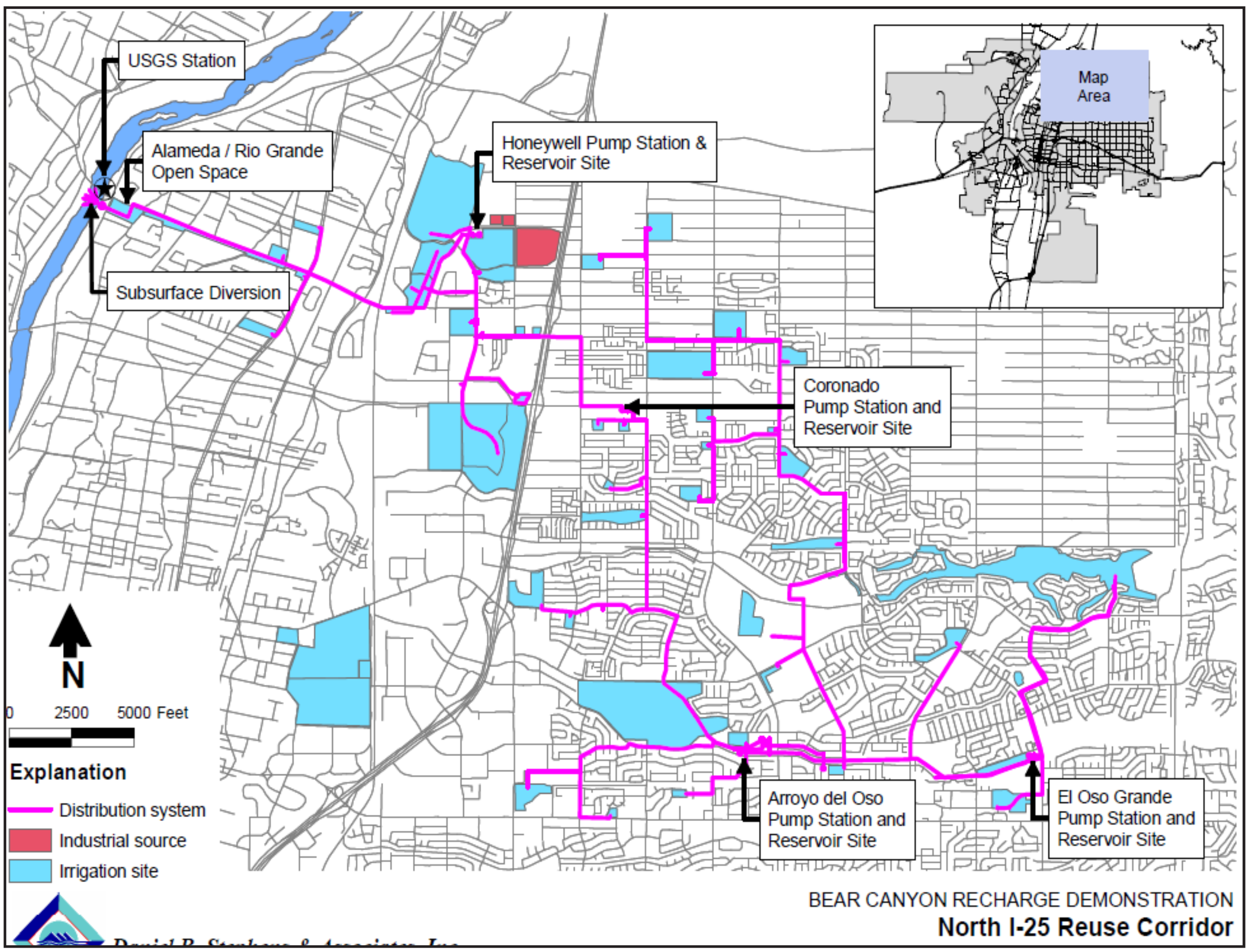



Figure 6. Map of northeast Albuquerque.

Figure 7. Arroyo Del Oso pump.

Figure 8. Running water in Bear Canyon.

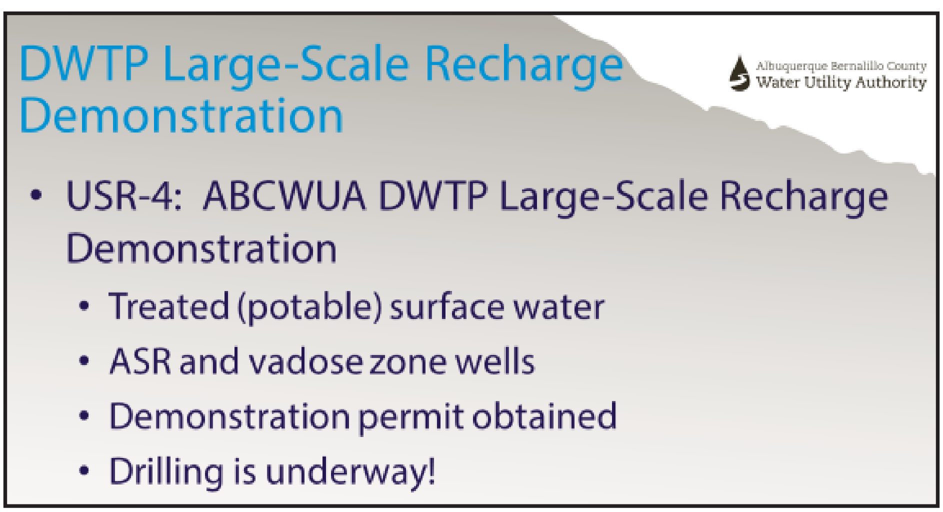



Figure 9. USR-4 project.

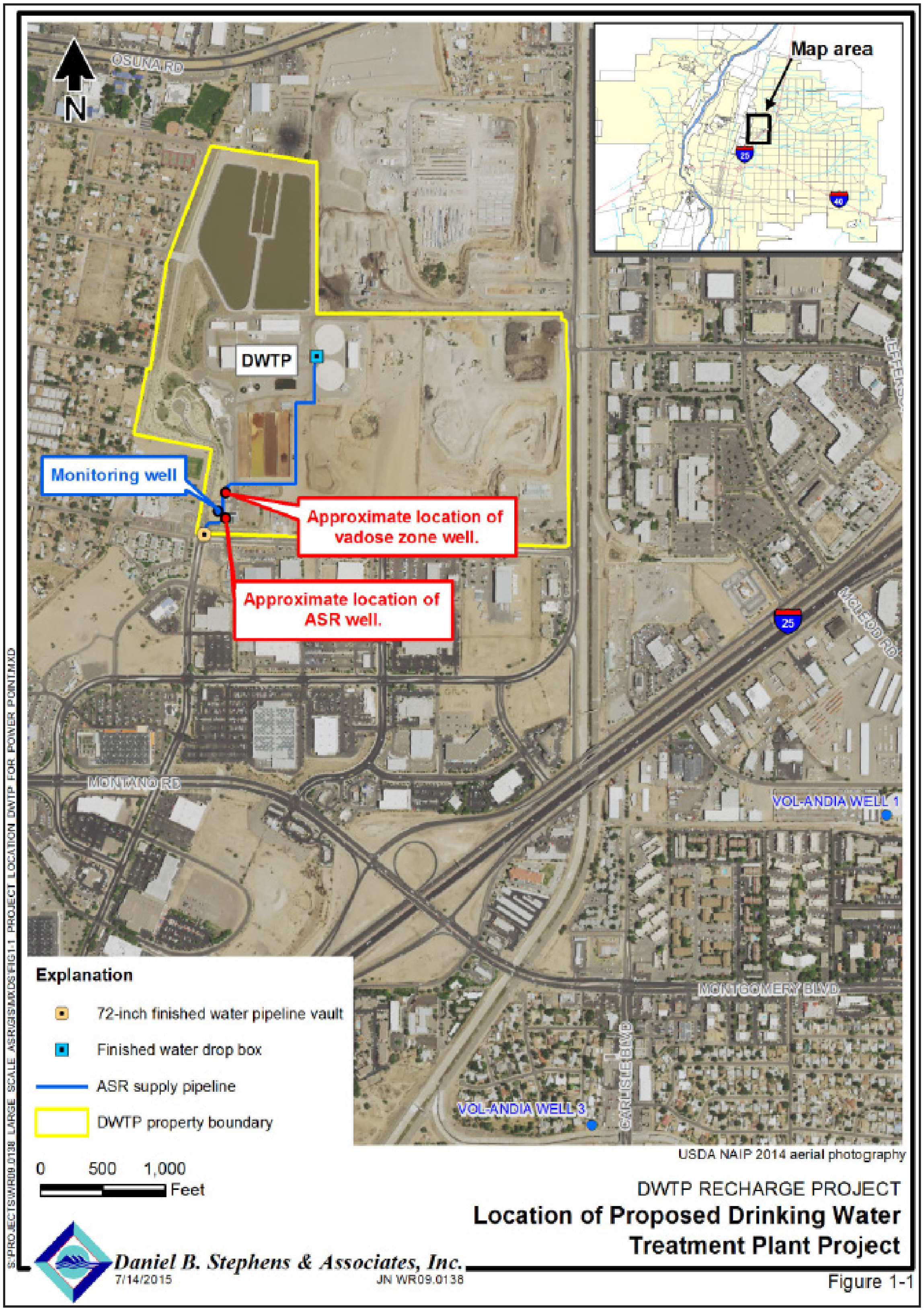



Figure 10. Plant site and location of wells.

is treated to potable drinking water standards and dechlorinated before we inject it into the aquifer. We are going to be using ASR and vadose zone wells. Jim has a direct injection well in Rio Rancho, so that means he injects only in that well and recovers with other existing production wells. This well is actually going to be an ASR well, which means we will both recharge and recover out of the same well. We'll also recover using other production wells in the area, but this will be the first ASR well in New Mexico.

Vadose zone wells are dry wells, so they are much shallower. You can move a lot less water in one of those wells, and they also cost a lot less, so if they work well at your site dependent on the geology, then that is a good thing to use. We're going to test one vadose zone well as a part of this demonstration project. If it works well, we will drill more of them. The permits are obtained, we are drilling right now, and Figure 10 shows the plant site and the location of our wells (in red). We have a monitoring well (in blue), and then the line shows how they tie the recovered water back into the distribution system.

Figure 11 is a recent photograph of the vadose zone well drilling underway. That is a bucket-auger rig being used for that. The total depth to that well is 130 feet. Water is at 150 at that site. Our ASR well site is also at that plant. We're going to do a stainless steel well with silica-bead filter pack. It is going to be a terrific well that we hope one day will be permitted, as a supplemental well for more than just recovery of the recharged water, but for now it will just be used for this project.

I'm going to change gears and give a brief overview of the City of Hobbs's project (USR-6). That project uses reclaimed wastewater. For the communities that don't have surface water available, they use what they can. They are planning to put in an infiltration basin. They want to recharge treated wastewater and then recover it for use for irrigation. The project will be a net-zero annual project where they put water in the ground when there is excess as a part of the reuse project in the wintertime and then pump the water right back out in the summertime and use it to irrigate grass, which reduces the amount of pumping of potable groundwater for irrigation grass. The project is in the design phase. It is about 95 percent complete. This is an expansion, which adds storage, of the reuse project. Their demonstration project is 275 gallons per day, so about 160 acre-feet per year.

Figure 11. Vadose zone well drilling.

We have the permit from the OSE, and we're working with the Environment Department on the discharge permit before constructing that project.

One other comment that I had on Jerri's presentation is that another applicant we can't have, per the regulations, is a private applicant. The City of Clovis is looking at doing a project, but that water system is owned and operated by EPCOR Water, which is a private company. The city is the wastewater operator. They own and operate the wastewater treatment plant, but not the water system. In the case of Clovis, the city will have to be the applicant for that project and work closely with the water provider. We're learning all the intricacies of water in New Mexico as we get deeper into these projects.

We will now talk about lessons learned and what we see for improvements with the program going forward.

**Jim Chiasson**: Obviously, I've only been with the city for about seven months now, so I don't have the historical background on this particular project, only what I've read and seen up to date. Right now, the injection well is running about 9 to 10 hours a day. We're going to ramp up to nonstop operation in the next week or two. The project is under a supervisory control and data acquisition control system, so it can operate on its own. At that point in time, we'll get to see exactly how much water the well can take. It is permitted up to one million gallons per day (MGD), which is a bit optimistic from what we see both from modeling and actual results to date.

The city moving forward would look at either a sister well near or at the same site. We do have a well that was drilled about three miles away to the tune of 3.2 million gallons that ended up being in a very saline section, so it was never used. Another option is to use that well for both injection and possible recovery. When I was at the Environment Department with Michelle, we had been working on indirect potable reuse (IPR) and direct potable reuse (DPR) regulations and looking at what the scope might be. Looking out 8 to 10 years, I can see the possibility of taking water that is in excess of what the current well can take, sending it right over the hill back into our well site #10, and directly injecting it into the water system. Of course, that would be a first in this state. Cloudcroft is still under construction and under regulatory review. I know the authority has some longer-term plans for something similar.

At 1 MGD, the injection well represents about one-tenth of the average water use by the city on a daily basis. In the winter, it is probably 8 MGD; in the summer, it is probably around 12 to 13 depending on the weather. At an average of 10 MGD throughout the year, the injection well, the permitted capacity, represents about one-tenth of daily water use. I could see at some point taking some of that water and mixing it and injecting it directly back into the water supply, because if you take the cost of that well and that facility and drilling additional wells at that cost, the common sense thing is forgoing that cost and putting it directly back into the water system. Looking forward, I think that is one thing that probably will happen. It might not be in my tenure, but I could see that occurring as well. Other than that, we'll see how the well performs here over the next six months. We're charting that data, and maybe in six months to a year, I will be able to come back and show you some graphs of how it is performing compared to what we had anticipated through modeling.

**Michelle Hunter**: As far as recharge projects for nonpotable use go, we will work with the applicants and work our way through a regulatory framework that isn't necessarily designed for these kinds of projects, but we can fit them into that underground injection control world. As Jim was talking about with IPR and DPR, that's a whole different ball game with respect to planning and what the regulatory framework would look like for that kind of a use—putting treated water directly into a water supply as a source water. There are some projects in the state that use treated effluent from remediation projects. For example, if a well becomes contaminated, you can put a treatment system onto it and then put that treated water back into the drinking water system, which is quite similar to treating either a remediation site's water and using it as a source water or taking treated wastewater and using it as a source water in a drinking water system.

But there is a difference. Looking at one as a new source, which is how we have to look at these kinds of projects when they come online like this, is different from having a contaminated drinking water well taken down for a while to put a treatment system on it in order to put that water back into the system. Strangely and interestingly, those two things are completely different with respect to how they are viewed in the regulatory world. Thinking about how we would design rules for those kinds of projects is an interesting exercise at this point, but we do need to start focusing on how we would do that. Other states have taken different points of views with respect to this. We are working on these things with the state engineer. We're trying to get some better communication and some working groups together in order to be able to dually permit these kinds of projects.

**Jerri Pohl**: I just want to agree with Michelle. I've been working with Pam Homer because we have been overburdensome with some of the initial permits that were issued because we wanted to gather a lot of data. For neutron logging, the events were costing like $5,000 a hit, so we have modified all of our permits to try to make it more reasonable. Because if it is not adding value, if we are simply asking for testing for the sake of testing, it is not providing any benefit to any of us. We're also looking at combining the reporting requirements for OSE and the NMED, so that the municipality would only have to provide one report a year as opposed to two different reports with two different sets of information.

There is one farmer in King County, Texas. I keep following King County because they are on it when it comes to USR, and there is a scientist—he is a pomologist, which is actually somebody who studies fruit—and he wants to do an aquifer storage recovery project on his almond orchard. He has been fighting tooth and nail, and he put two million dollars of his own money into the project. That is another state that allows for private people to make application for USR, so we just need to change our laws in order to make that happen.

**Rick Shean**: I would defer project-specific learning lessons to Amy since she has been intimately involved with our ASR, but I would say that the approach the water authority has taken has been with caution and slowly and carefully planning this and thinking through it. We have learned from others, successes and failures. There are plenty of other ASR projects out there to look at in other parts of the West, particularly California and Arizona. That's what we see, moving forward. We are excited about this ASR well that we're putting in—the injection and then the extraction well. But we have a lot to learn about it, so we are cautiously optimistic it is going to work. It works in other places. Every ASR site is its own unique situation.

**Amy**: The last thing I'd say about Albuquerque is that they have a lot of production wells that are 50-plus years old and they are looking now at potential replacement well locations, so I think the thought going forward is that when they put in new production wells they'll make them ASR wells. The distribution system is all connected now, so you can move San Juan–Chama water anywhere around the city. By doing that, you can put water in the ground at an ASR well wherever that is in the city. First, we'll install this ASR well, test it, and report on it, but there is a lot of storage. There is a lot of dewatered area in the Albuquerque basin. There is plenty of space, and we just plan to fill it up as much as possible with future projects, though they'll all have to be permitted separately—each of those wells—but that is the thought going forward for Albuquerque.

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## Tim Woomer, City of Hobbs

*Tim Woomer, is the Public Utilities Director for the City of Hobbs. Tim has been in this position for 17 years following a 19-year career in underground mining throughout the United States, Canada, and Mexico. By harnessing the best cutting-edge technologies and ideas available, the City of Hobbs is building a best-in-class utility by bringing together a wide array of data and information to power decision making and drive investments in order to conserve capital and natural resources. Tim received a BS in mining engineering from West Virginia University.*

**Editor's Note: This presenter did not have a powerpoint to accompany their presentation, and transcription was unavailable.**

# Hydrogeology of the San Agustin Plains

Alex Rinehart, NM Bureau of Geology
and Mineral Resources

*Alex Rinehart is a hydrogeologist in the Aquifer Mapping Program at the New Mexico Bureau of Geology and Mineral Resources (NMBG). His research interests focus on unexpected intersections between water science, and Quaternary geology, geophysics, data mining and rock mechanics. After graduating with a BS in mathematics from the University of New Mexico in 2004, he completed an MS in hydrology in 2008 at New Mexico Tech focused on snow. After earning his PhD in 2015 in geophysics at NM Tech, he was hired by the Bureau as a hydrogeologist in the Aquifer Mapping Program. He has led research in estimating groundwater storage change in the aquifers throughout New Mexico as part of the NM WRRI statewide water assessment. The goal of this effort is to generate data-driven, rather than model-driven, consistent estimates of water table changes and changes in the total groundwater storage of New Mexican aquifers.*

I'd like to thank WRRI for inviting me, and I'd like to thank Cathy Ortega Klett and Jesslyn and the rest of the WRRI staff for organizing this conference. This is the third conference or workshop they have put on in the last four months. They have been pretty swamped, and I am always impressed by the job that they do.

I'd like to start off with some caveats about this work. As you'll see, this is going to be a technical talk—probably the most technical scientific talk of the conference. It's going to be focused on qualitative results. I will talk about the overall architecture of the basin, the direction water flows in the basin, whether there is recharge in the system, and the connections between the San Agustin Plains Basin and neighboring basins as far as we can tell.

I've been on this project for about two and a half years. Daniel Koning is the geologist on the project. Stacy Timmons has been the common thread over the last nine years of the project. She makes sure water quality measurements are taken and works with the landowners.

To make another thing really clear, the New Mexico Bureau of Geology and Mineral Resources is a nonregulatory scientific state entity. We don't take sides in the water fights of the state. We try to provide a neutral scientific perspective on water issues and other energy and mineral resource issues in the state.

With that, let's start out with some acknowledgments. We measured water levels and water quality in a bunch of wells across the San Agustin Plains. You can't do that without the well owners giving you access to their property. The community members of Datil, the ranches, the VLA, and the Augustin Plains Ranch, LLC, have given us access since 2009. John Shomaker and Associates ran some of the reconnaissance work, some of the pilot wells, and some of the modeling work for the Augustin Plains Ranch, LLC. They gave Dan Koning access to their well records and cuttings for the geology study. I'd like to thank the folks on the Aquifer Mapping Program (AMP) staff, particularly Talon Newton, Trevor Kludt, Brigitte Felix, Kittie Pokorny, and Sara Chudnoff.

We at the bureau and AMP have paid for the vast majority of the work. We cover the costs for water quality testing and the carbon-14 dating. We have covered a fair amount of the water level measurements. This is not a contract-driven project. We are trying to answer an important question for the state.

So, what are the San Agustin Plains? The San Agustin Plains are a 70-mile-long by 30-mile-wide basin, about 70 miles west of Socorro. The basin is split into two subbasins, eastern and western, separated by a bedrock high or horst. The eastern San Agustin Plains extend from just beyond a bedrock high near Magdalena (which is not in the San Agustin Plains) to Datil. The Very Large Array (VLA) is about halfway across the eastern graben—

the eastern basin. The western San Agustin Plains stretch southwest from the VLA about 70 miles toward Reserve.

I will talk mostly about the eastern San Agustin Plains. Because of the funding restraints we had and also because of the history of the project, we had to choose to focus on the eastern San Agustin Plains.

Why are we talking about this? If you follow water news in New Mexico, you have probably heard of this project. The Augustin Plains Ranch, LLC, has for the third time submitted a permit application to the Office of the State Engineer (OSE) to remove half a million acre-feet over the course of 10 years—about 54,000 acre-feet per year. They want to pipe the water from near Datil to Magdalena, and then to Socorro and up to Albuquerque and then finally to Rio Rancho. Their proposed well field is shown by the red dots in Figure 1. They have proposed 36 wells, about a well a section over their entire property.

There is enough head in the system that it would be a completely head-driven system. There wouldn't be any pumps other than the wells. There is so much head in the system, they are talking about having a hydroelectric power plant in the bottom of the well around Socorro. It's in the permit application. Their latest permit application states that they have spent about $3 million since 2007 in modeling work, to test wells, and other legal costs to get the project off the ground.

Figure 2 shows all the drilled wells, according to the OSE in 2015, that are around the proposed wells. As you might suspect, and as you probably sensed from the news articles, the local community is a little bit wound up about the proposed project. Figure 2 also shows a postcard a friend of mine found at El Camino Restaurant in Socorro that says "STOP THE WATER GRAB!" and "Fight for the water hole." Things have been a little bit tense out there. Folks are very nervous about having their wells go dry in the eastern San Agustin Plains because of the large withdrawal.

One of the common threads throughout this talk is that there is not a lot of data. There are two previous hydrogeologic studies—one done in the seventies and one in the nineties—and now ours. There are a number of scientific studies looking at paleoclimate. But in terms of water information,

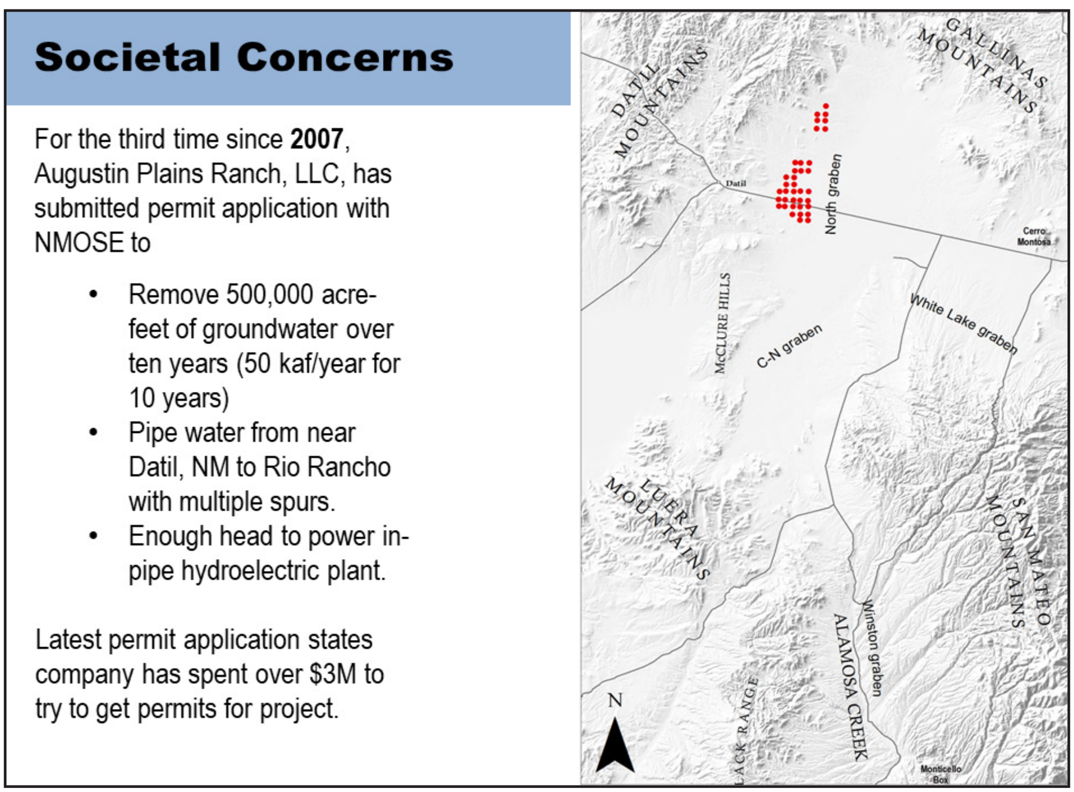


Figure 1. Proposed well field in eastern San Agustin Plains.

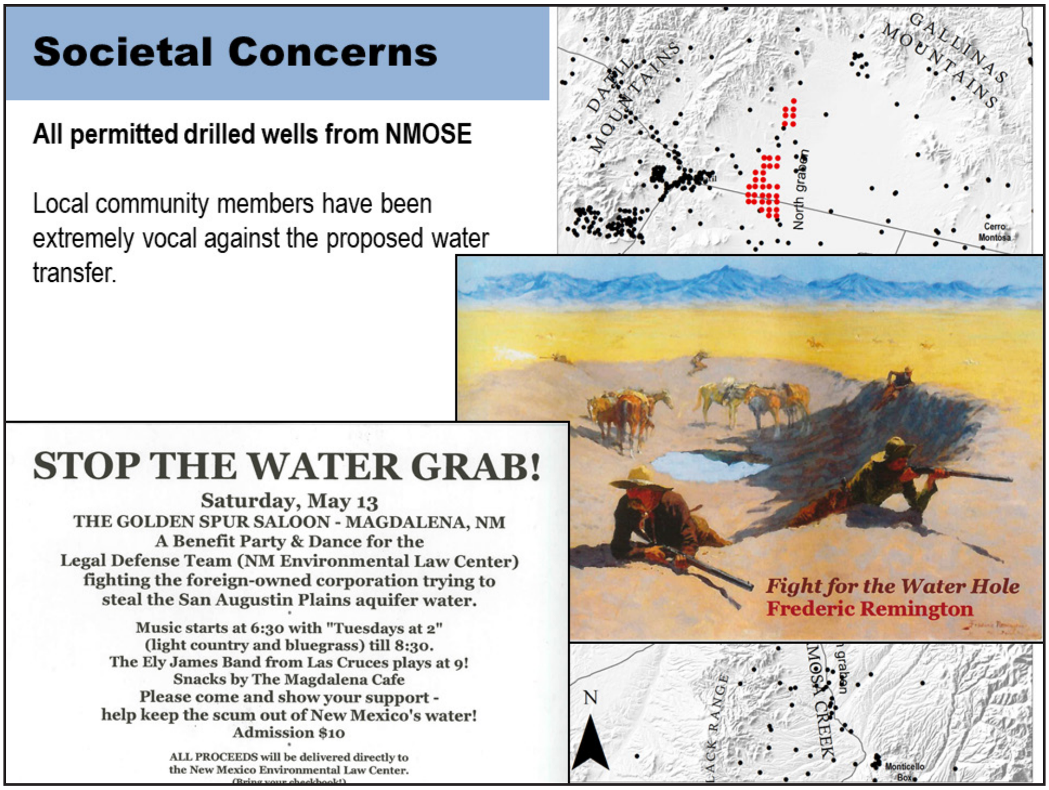


Figure 2. Local concerns over the proposed water transfer.

subsurface information, and geophysical information, there is not a whole lot known about this basin.

I tend to be a little bit detail oriented as you probably can tell. I'm going to start with the conclusions, and then we'll end with the conclusions. These are the drumbeats through the rest of the talk. We found, and previous studies have found, that the water is moving from east to west, from south of the VLA west and then due south into the Gila Basin. Currently the OSE considers the San Agustin Plains to be part of the Rio Grande Basin, but we don't see any evidence for a connection between the San Agustin Plains and the Rio Grande. It is pretty well documented that the water is very slowly leaking into the Gila Basin. By very slowly, I mean on the scale of thousands of years, the scale of Roman civilization. The water isn't leaking over 10 years or 50 years. This is very slow-moving water.

There appears to be a hydrologic separation in the North graben, which is a sub-subbasin of the eastern San Agustin Plains, that happens to be where the proposed well site is. We think, and this is a little bit speculative—we need a little bit more data to nail this down—that the North graben has some bedrock highs that separate it hydrogeologically from the rest of the basin. That's an important point. It means that the proposed pumping would be focused in that area and would more strongly impact that area than expected.

The groundwater in the eastern San Agustin Plains is old. We think it is Ice Age water, about 10,000 years old. There are some older waters there. The waters that are in the Rio Grande Basin to the south, including Alamosa Creek Basin which I will talk more about in the chemistry section in particular, are much younger. Their chemistry, isotopes, and carbon-14 age are different from the San Agustin Plains. They are very distinct waters.

Finally, once again, while we have done quite a bit of work out there, it is a huge basin—70 miles long, 30-miles across—there is a paucity of data. It is difficult to say anything quantitative. When I talk about this project, people ask me for rates and quantitative numbers. It's very difficult to make those estimates, and I won't be talking about quantitative estimates today.

Figure 3 shows a picture looking from the Gallinas Mountains, which is at the northern tip of the eastern San Agustin Plains, south toward the San Mateo Mountains. You can see the VLA; it's the little white specks out in the middle of the plains.

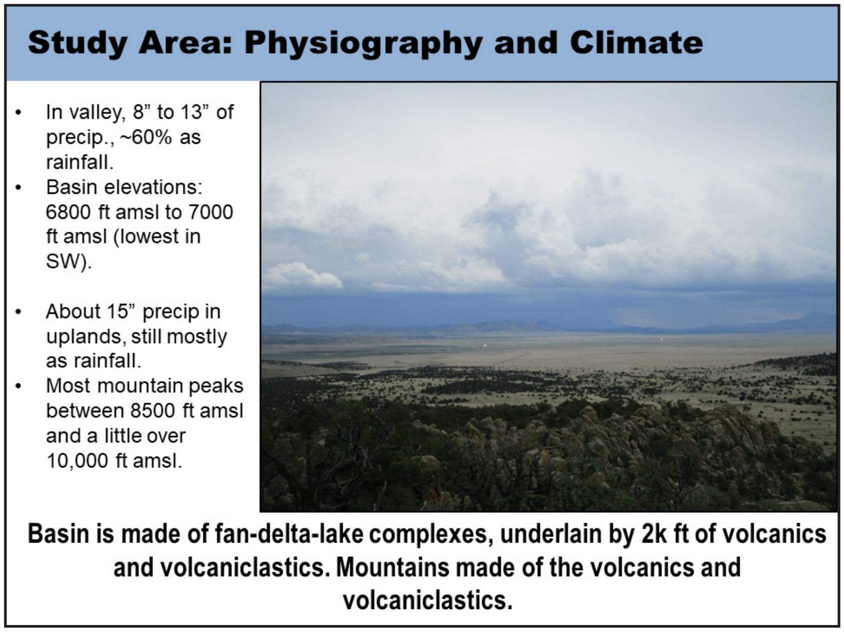


Figure 3. Physiography and climate of the San Agustin Plains.

The plains go from about 7,000-feet elevation in the east and then down to about 6,800 feet in the west. The plains are completely rimmed by mountains—the San Mateo, Datil, Gallinas, Luera, and Tularosa Mountains, as well as the Pelona Mountains and the Crosbys and a couple other small chains. The San Mateo Mountains are the highest. They have a peak at a little over 10,000 feet. Most of the rest of the mountains in the basin are about 8,500 feet at peak elevation.

This is a semiarid region. It has between 8 and 13 inches of precipitation in the valley bottom, and precipitation is highly variable. Most of that comes in during the monsoon. It is a similar story in the mountains. Most of the precipitation comes in during the monsoon; there is very little annual snowpack. The mountains are basically all made up of volcanic rocks and eroded volcanic rocks or volcaniclastics. The basin is made up mostly of alluvial fans and deltas. There are lake deposits in the western basin. There are very limited lake deposits or playa deposits in the eastern San Agustin Plains.


Figure 4. Major Geologic Units.

Figure 4 is an example from one of the very few outcrops of the basin-fill in the basin—a gully that cut into an alluvial fan in the western basin. It is a muddy, poorly sorted sediment. Some of it is quite coarse. There are probably paleochannels in it. We need a lot more information to nail down the high-conductivity paths.

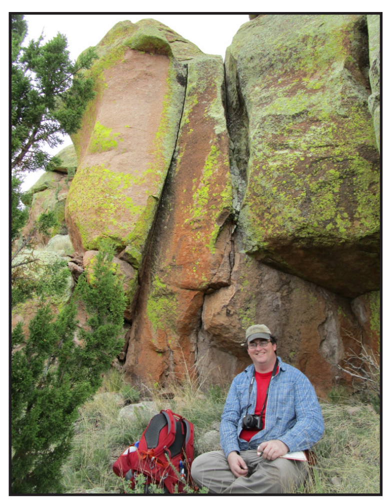

Figure 5. Mogollon-Datil Group Volcanics. Conductive where fractured, tight elsewhere.

Then there are the volcanics. Figure 5 shows Hell's Mesa Tuff, which is one of the best fractured volcanics in the eastern San Agustin Plains. One of the other take-home messages is that there is limited conductivity between the volcanic aquifers in the mountains and the bedrock highs in the basin. The fractures shown in Figure 5 are not formed by faults, but instead by cooling. In the volcanic rocks, if you are close to the caldera, you have a thick unit that is deposited hot. When it cools down, it fractures. As you move away from the caldera, the lava flow thins and it is cooler when it is deposited. It doesn't fracture. These are really good fracture networks, but they are limited in areal extent. They don't remain fractured throughout the basin.

Then there is the aquitard—the Spears group—or the volcaniclastics. The mountains are formed by giant calderas. The calderas pile up. The lava flows erode, and then they form sedimentary rocks. These rocks have silica cements, calcite cements, and zeolitic cements. There is very little active pore space in them; they have low permeability. There is very little groundwater flow from what we can tell. The volcanic stack has about 2,000–2,500 feet of volcanics and volcaniclastics. The permeable volcanics make up probably 200–300 feet of that. It is a very limited high-conductivity aquifer in the mountains. In order to get recharge through the volcanics into the basin, you have to hit one of those volcanics or go over the volcaniclastics in a stream.

The volcanics and the volcaniclastics formed the mountains. The San Agustin Plains are a closed basin. There was an Ice Age lake in the basin. The groundwater, the lake water, has been slowly draining out of the basin for about 10,000 years. The last lake in the area was about 8,000 years ago, way down at the southwestern end of the basin.

Figure 6 is a gravity anomaly map. The dark colors show where the basins are. The west basin is off the screen, the North graben has the proposed development in it, the C-N graben has a good chunk of the VLA in it, and the White Lake graben has very little data in it. We can't say very much about the White Lake graben. I also want to point out Alamosa Creek and the Winston graben. Originally it was thought that Alamosa Creek got a fair amount of water from the San Agustin Plains. We included it in the study; we tried to trace whether water was coming from the San Agustin Plains into the Rio Grande Basin. Alamosa Creek drains out right at Elephant Butte.

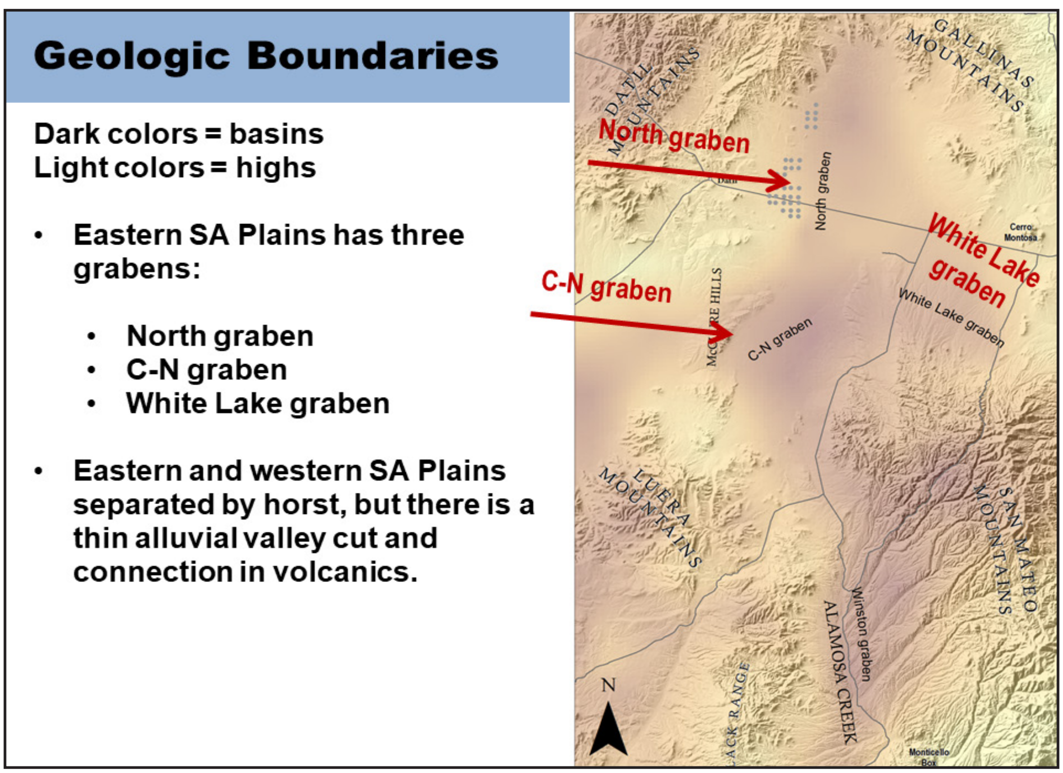


Figure 6. Gravity anomaly map of the San Agustin Plains.

Related to Alamosa Creek, Figure 7 shows faint red lines in the San Mateo Mountains. Those are caldera margins. About 34 to 28 million years ago, the volcano blows up, and then it settles, and the lava flows go out. And then hot water flows up next to the caldera. There is usually a fair amount of silicification and other cementation associated with caldera margins. The divide between the San Agustin Plains and Alamosa Creek has three separate caldera margins. The surface outcrop, which is limited, is basically completely silicified. There is very little pore space. There is going to be very limited conductivity through that divide.

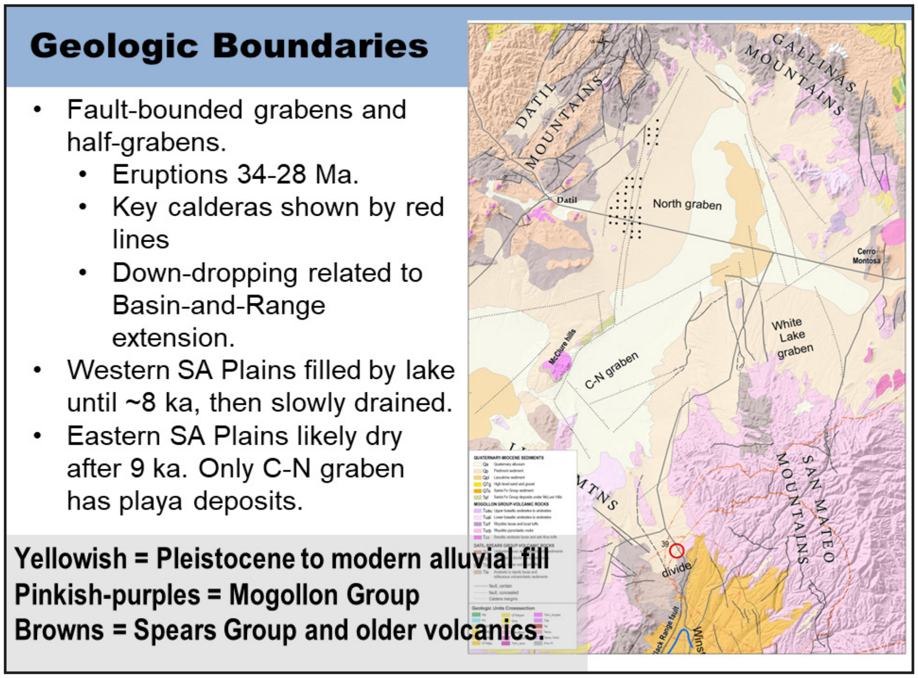


Figure 7. Geologic boundaries of the San Agustin Plains.

Let's talk a little bit about previous work, which focused on groundwater levels. The first study was by Blodgett and Titus in 1973. They found good water qualities and a very low gradient across the basin. The water is flowing from east to west and then south into the Gila Basin between the Pelona and Tularosa Mountains. Frank Titus and his student said that in 1973.

Then there is the big study by Bob Myers et al. in 1994, which is the largest and most coherent study that's been done in the basin. Myers ran geophysics, tested water quality, and measured water levels. The story is essentially the same. The water is going from east to west, then out through the Gila. There is a low-gradient to no-gradient area up around the proposed site north of Highway 60, in the North graben.

Water quality is pretty good in most of the basin. There may be some brackish water in the western basin. It's a little bit poorly constrained. Myers identified a connection between the volcanic aquifers and the basin-fill aquifer. It is very difficult to quantify that connection.

Myers also made storage estimates that the OSE and the Augustin Plains Ranch, LLC, use. He estimated there is about 34 million acre-feet of water in the eastern San Agustin Plains, and in the western San Agustin Plains, there is 19 million acre-feet. But those are optimistic estimates in all likelihood. In Myers's paper, you see this estimate of 50 million acre-feet in the basin, so the half a million acre-feet in the permit application doesn't seem that big. Bob Myers, however, had a lot of qualifications for these storage estimates, and started the water-storage section of his paper with the statement "Lack of sufficient aquifer-test data and well-logs makes accurate estimation of water in storage difficult." This is the same story we have at the AMP. There is simply not enough data. The storage estimates Myers made were not corrected for compaction, and the bottom of the aquifer was defined through electrical resistivity in a very coarse gravity survey. These are very rough estimates. Probably most importantly, all of the hydraulic parameters for the basin—for the 70-mile by 30-mile basin—were taken from five pump tests and literature values. There is a lot of uncertainty with this storage.

We've been going out and doing water level measurements since 2009. Trevor Kludt has done most of this work. He goes out every year, and it takes him about a month because of road conditions. We take static water level measurements, and we try to make sure the site isn't affected by pumping. If a site is affected by pumping, we note it. All of the analyses that follow are in the median water level elevations over the last eight years that aren't flagged for pumping. These are very stable measurements. One of the limitations of the previous studies is they went out for a year and grabbed all the water level elevations, which produced noisy estimates. Our estimates are as clean as we can get.

Our measurements show the same story: water goes from east to west and out into the Gila (see Figure 8). We see a pretty strong groundwater divide between the eastern San Agustin Plains and Alamosa Creek. The two dots that are between the 6,800-foot contour and Alamosa Creek at the end of the arrow are a little bit above 7,000 feet. And the basin drops from 7,000 feet to 6,500 feet over about a mile. Then there are drainages that drain into Alamosa Canyon that cut below the measured water level and those two wells. Those canyons are well below the water level and dry; there are no springs. In terms of water level elevations, it looks like Alamosa Creek is disconnected, and it looks like the San Agustin Plains have a very low gradient going from east to west and then into the Gila.

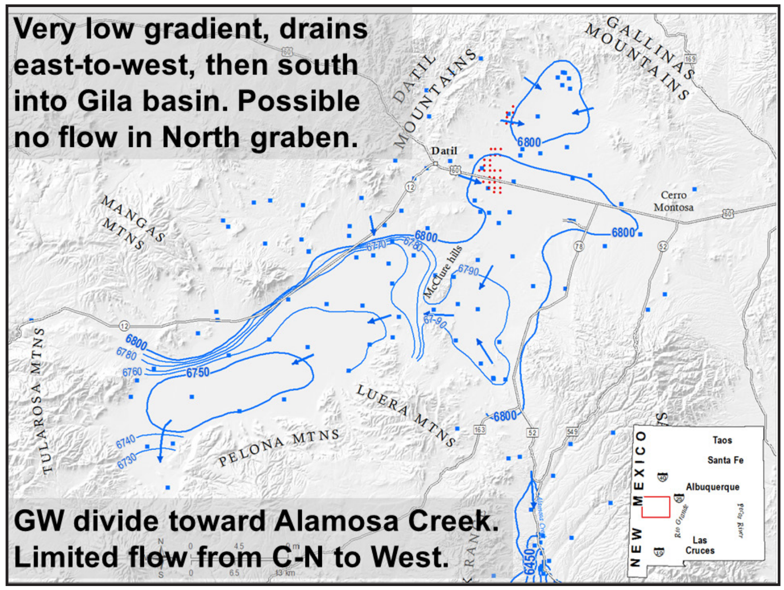


Figure 8. Groundwater flow in the San Agustin Plains.

Figure 9 shows water elevation changes in the basin. The yellow dots and light orange dots have a change in groundwater level of less than an inch per year over the last 10 years. This is consistent with the long-term rates of change. We also did this analysis over the last 40 years. The take-home message from Figure 9 is that the water levels

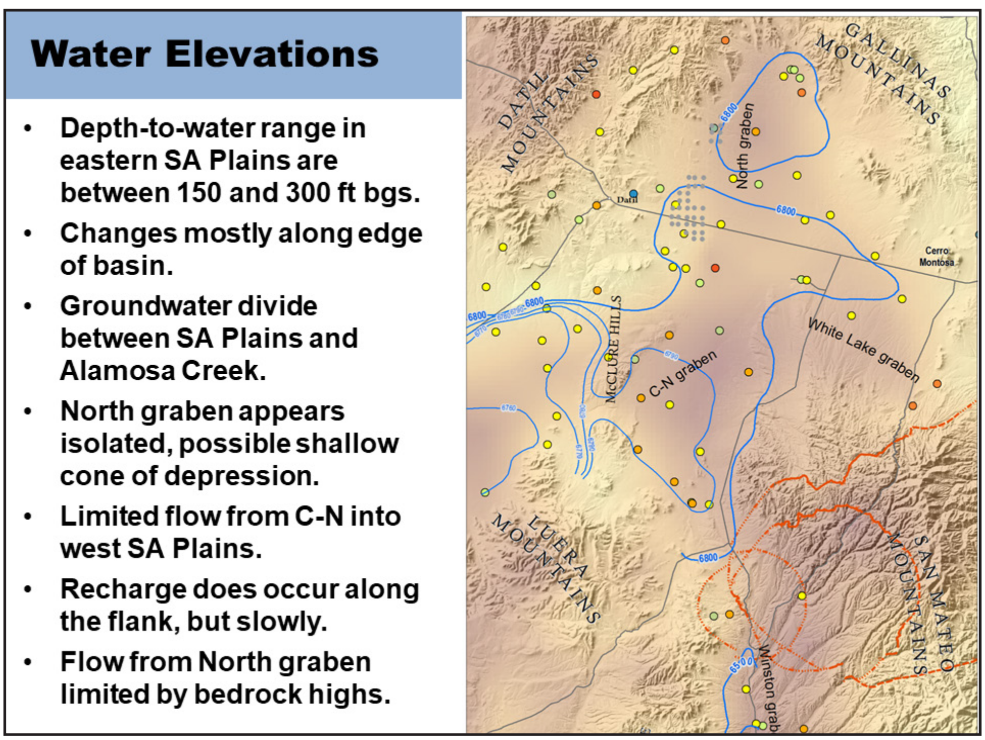


Figure 9. Water elevations in the San Agustin Plains.

are basically at steady state. There is a little bit of recharge coming in along the major streams. There is a roughly linear gradient from east to west with a couple of focus points, and then static water is very slowly being drained in the North graben. The dark orange dots way up in the North graben are from center pivot irrigation covering about two sections.

Then we did water quality estimates of major ions, stable isotopes, trace elements, and carbon-14 age. The take-home messages are that the San Agustin Plains are separate from Alamosa Creek. The basin-fill aquifer and volcanic aquifer are connected. It's a very limited connection because of the thinness of the permeable volcanic units. You can see this with the temperatures, as shown by the circles in Figure 10. The red circles are above 25°C. You can see that there is a well right next to the divide between the eastern and the western San Agustin Plains that is warm. It also has 20,000-year-old water and heightened trace elements. Basically all around the edges of the basin with the faults, there are warmer waters with higher trace elements. The volcanics are draining very slowly into the basin-fill aquifer. Alamosa Creek also has some of this. There are some warm springs down there that are coming out of the San Mateo Mountains.

Figures 11 and 12 show the differences in major ion chemistry and stable isotopes between Alamosa Creek (in red) and the San Agustin Plains (in blue). Alamosa Creek has nice, clean waters with low total dissolved solids. The San Agustin Plains water is a little bit richer in chloride and so quite a bit richer in sodium. The waters are chemically and isotopically distinct. One of the interesting side notes is that we don't see a lot of lithologic control. Dan Koning very doggedly figured out the lithology that each well was completed in. We don't see a whole lot of controls in terms of isotopes or other chemistry by lithology.

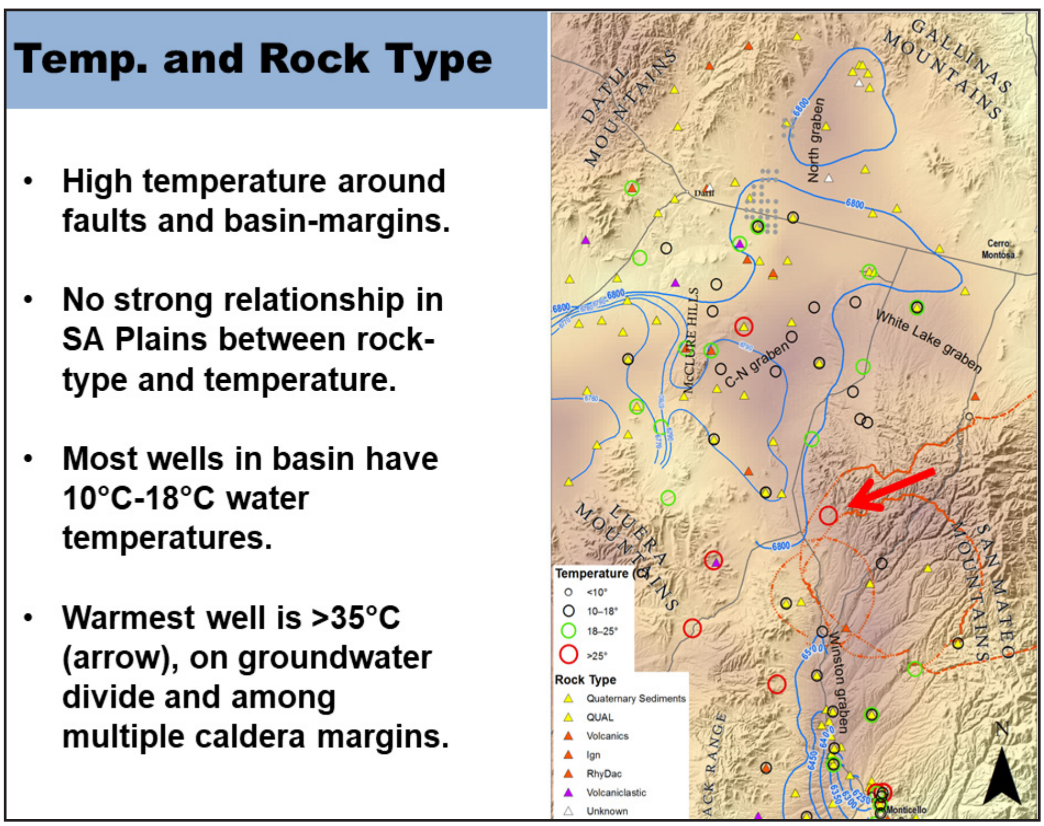


Figure 10. Temperature and rock type.

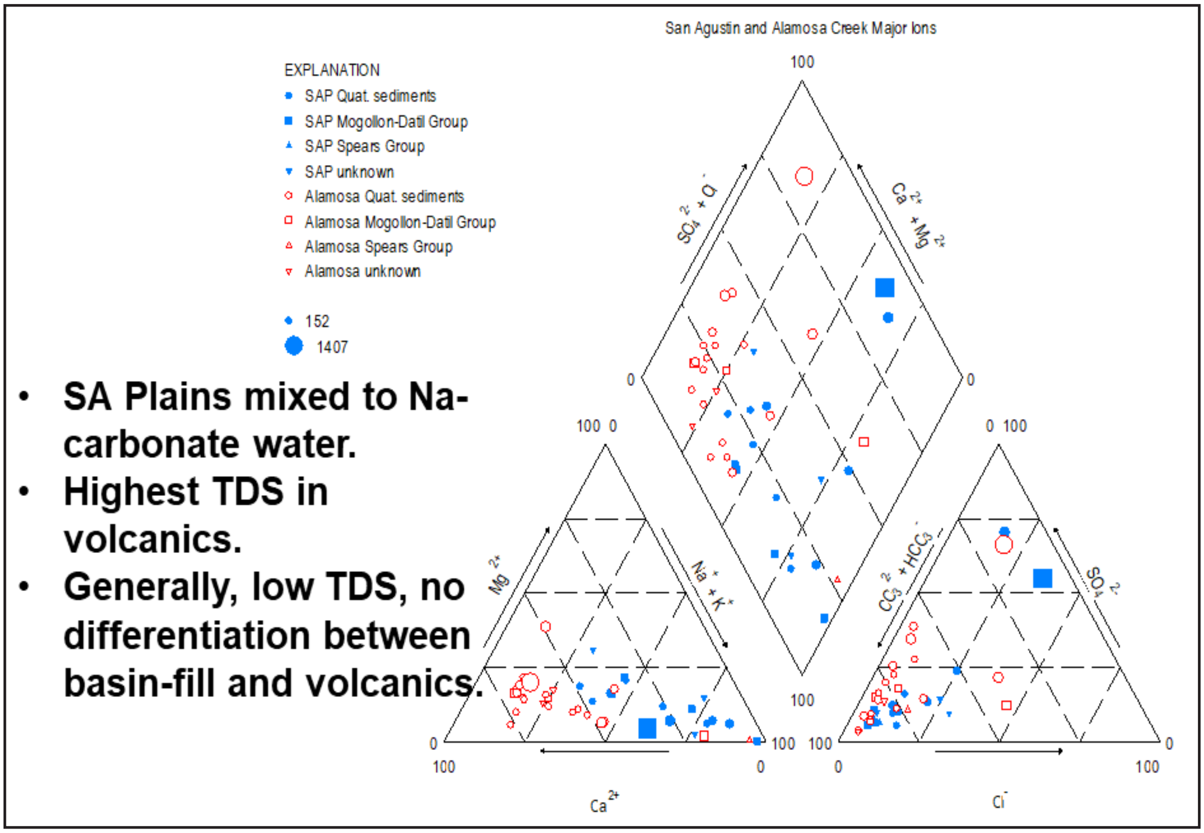


Figure 11. Water chemistry: paper diagrams of Alamosa Creek and the San Agustin Plains.

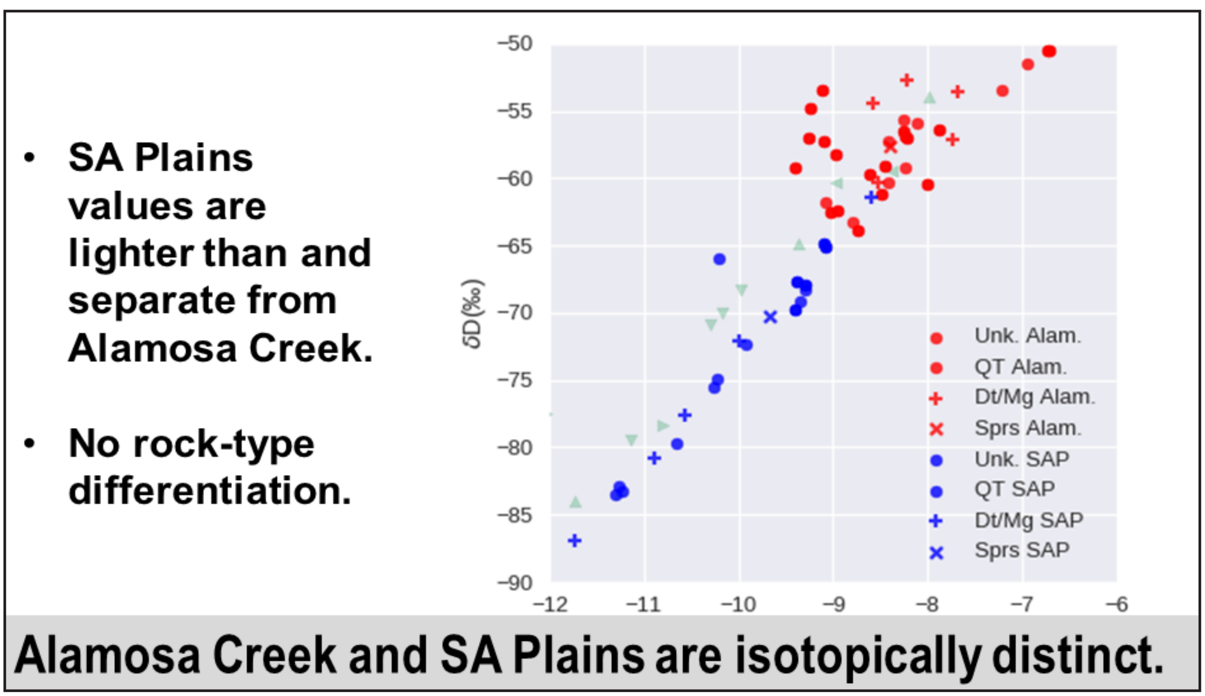


Figure 12. Stable isotopes of Alamosa Creek and the San Agustin Plains.

In terms of groundwater ages as I mentioned at the very beginning, the San Agustin Plains has 10,000–12,000-year-old waters (see Figure 13). The waters coming in from the volcanics are about 19,000–20,000 years old. The waters at the groundwater divide, in the caldera margins near the San Mateo Mountains, have heightened temperatures, heightened trace elements, and a groundwater age of 22,900. Alamosa Creek and the San Agustin Plains are distinct in age. Alamosa Creek has about 2,000–3,000-year-old waters. These are modern waters as estimated through tritium. The waters in the San Agustin Plains are tritium dead.

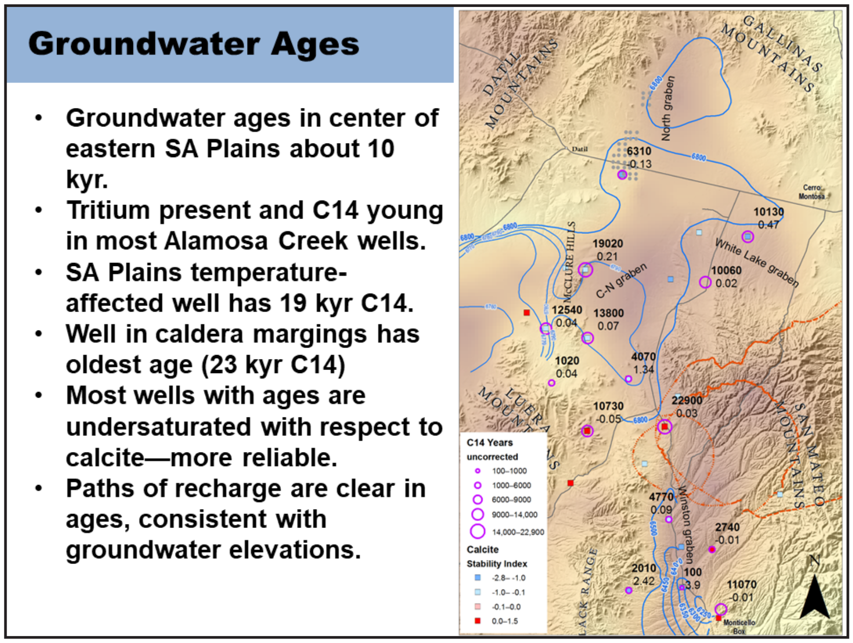


Figure 13. Groundwater ages of the San Agustin Plains.

These carbon-14 age dates are uncorrected. Except for the volcanic-dominated wells, which are saturated with respect to calcite, the rest of these ages are not saturated with respect to calcite. There is no source of old carbon in the system, so these ages are probably reliable even without the correction.

We do see evidence of recharge. We have 6,300-year-old water coming in by Datil where the proposed well project is. There is slow recharge coming in through the groundwater system through the volcanics and the shallow alluvial aquifers into the San Agustin Plains.

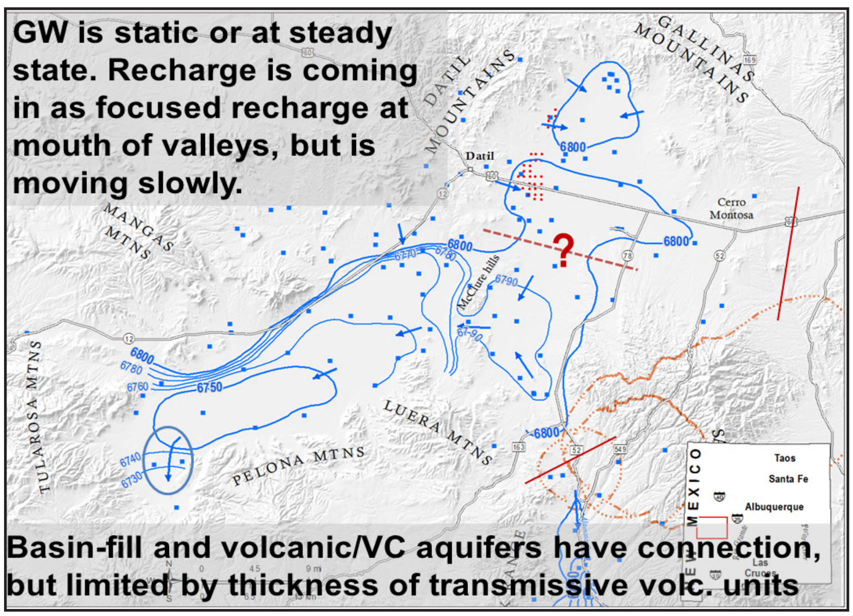


Figure 14. Conceptual model of groundwater flow in the San Agustin Plains.

Finally, Figure 14 shows a conceptual model of the points I've covered. The water is draining out into the Gila. Though we're not saying for sure, the North graben where the proposed development is may be hydrologically separate from the rest of the basin. The San Agustin Plains are not draining into the Rio Grande system through Alamosa Creek.

# Brackish Water and Desalination Efforts in New Mexico

## Moderated by Aron Balok, Pecos Valley Artesian Conservancy District

*Aron Balok is the Superintendent for the Pecos Valley Artesian Conservancy District. Aron has a passion for New Mexico's agricultural heritage and a deep appreciation for the complexity of the water issues that face the state. He has been professionally involved in water related issues for the past nine years. Aron was raised on a small cattle ranch in northwestern New Mexico. He attended New Mexico State University, and in 1997 graduated with a Bachelor of Science degree in agriculture extension education. He and his wife Hayly and their three girls live in Roswell, New Mexico.*

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## Jeri Sullivan Graham, University of New Mexico

*Jeri Sullivan Graham is a Research Professor at the University of New Mexico, Center for Water and the Environment. Formerly she was a senior scientist in the Chemistry Division at Los Alamos National Laboratory for 17 years. She is a hydrogeologist and geochemist with 30 years of experience in environmental chemistry studies. She has developed considerable expertise in produced water chemistry, treatment, and regulation over the last 15 years of her research. Jeri most recently was a science advisor to Secretary David Martin of the New Mexico Energy, Minerals, and Natural Resources Department from 2014-2016, where she evaluated brackish and produced water resources for use in place of fresh water in New Mexico. She is a certified professional geologist, and earned her PhD in earth and environmental science from New Mexico Tech.*

I was lucky enough to be asked a few years ago to help Secretary David Martin at Energy, Minerals and Natural Resources with a set of problems related to brackish and produced water. Secretary Martin was keenly interested in water issues even though Energy, Minerals and Natural Resources isn't necessarily a water department. So I got to sit with him and work with a number of different people throughout the state to look at issues surrounding brackish water and produced water use as a potential supplement for fresh water.

At the time, we were coming out of a major drought. It was on everybody's mind. Of course, now we're not in a drought, and I'm going to leave that punch line to Stacy. I was whacked earlier and told, "Don't use that! That's mine." We had a group that got together and met several times and looked at different issues surrounding brackish water. We weren't able to produce a final report, but we are going to have some funding here very soon to put together a final catalog of everything we did. I am hoping we'll have that out in a few months.

I thought I'd throw out some history of brackish water studies related to New Mexico to frame this topic. Of course, the big study that everybody is familiar with, which includes the map everyone has seen with various shades of pink, is one done by Feth in 1965. That map has had such staying power that if you go to the new website for the new brackish water survey that was just finished and posted on the US Geological Survey (USGS) website in mid-2017, they still have that map up there. We can't get away from it, but it is a good map.

Some of the work we relied on in our working group was the paper by Rick Huff in the 1990s, and there was quite a bit of work done in the 70s through the 2000s by a number of researchers, particularly folks from the Bureau of Geology, the USGS, and some others at different state institutions—New Mexico State University (NMSU), University of New Mexico, and others. Kelly 1970 and 1974 are a couple of iconic studies and papers.

There was also a groundwater assessment program workshop in 2004 that did a really great job. The report is available online. They identified a number of priority basins. They looked at a number of issues surrounding brackish water because they were also following up from a drought. We keep having this trend in New Mexico where we have a drought and say, "Oh my gosh! We've got to look at it!" Many of us involved with this working group decided we need to do better than that. We need to make brackish water a continuing issue. We need to look at it all the time. Issues like infrastructure investment and the groundwater studies required to back up this kind of work need to go on over time. They can't just happen in fits and starts.

We did our working group, and we were able to find some funding from the Environmental Protection Agency (EPA) and New Mexico Environment Department (NMED), and so we were able to fund a couple of studies on produced water and brackish groundwater in 2016. Those studies are available through the Bureau of Geology's website and through the NM WRRI website. There is also a new study that has just been started—KC will talk about that a little bit more—in Mesilla Basin. I'm very excited to hear that we have a new study getting started in a prime area for brackish water. Like I mentioned, the USGS brackish water survey just came out, and it is available online at https://doi.org/10.3133/pp1833.

Our working group existed from 2014 through 2016. We had a wide variety of participants, many of whom were interested in brackish water and produced water. Mostly brackish water was the focus. We had folks from academic and research institutes. We had consultants. We had a little bit of everybody. We had a series of meetings to develop priorities, and we eventually presented a set of priorities to the state in December 2015.

We did get the funding to do some of the work. However, we had agency leadership changes—and this is one of the challenges that occurs. These agency leaders will move, they will change, and their priorities will change. Secretary Martin retired. Tom Blaine went from NMED to being the state engineer. His focus got dispersed. That was one of the stumbling blocks we had as a group. I think we could have done a lot more if we had been able to hang in about six more months. We would have been able to finish up something nice, but we didn't have funding. We had a sense that we knew what to look at and where to look, but we didn't have the funding for more data and that policy direction went away. We have to keep up with our folks at the state to keep that policy direction focused and to help route funding to the groups that want to do this kind of work.

I thought I'd throw up some barriers and possible solutions to get the conversation going and tee things up for the other panelists. One of the things we agreed on as a group was that there simply was not enough spatial or temporal data both in terms of the depth to saline water and the changes in volume of saline water over time. Some of the solutions for this might be to extend our currently funded studies to look a little bit further, a little bit deeper. Maybe you could drill a well a little bit deeper. Maybe you can take that extra sample and add some of this information in. We may not be able to do the big studies that we'd like to be able to do, but we might be able to extend smaller studies. We also need to keep visiting locales of interest over time, so that we can get that temporal time frame.

The paradox with drought is that when we have a big drought, everybody wants to study brackish water, and as soon as that drought goes away, we decide we don't need it anymore. That is unfortunate because we really need to be able to look at this over time and have that longer period of information. Unfortunately, slower growth in the state—we've don't have as much population growth anymore—has deprioritized brackish water development and the long-term thinking and long-term policies that are needed. This is where the top-down drive needs to come in. If anybody works for the state, I'm looking at you here. We need to look at ways to expand our long-term water storage. Maybe we need to be able to do water swaps. That would be something that would make desalinating brackish water more feasible over the long term.

We also need to consider our closed basins versus open basins. We have a lot of closed basins in this state. If we are going to extract brackish water from closed basins, we will be mining water. The deeper you pump, the longer you pump, the more you mine, the more expensive it gets. This is a problem. However, if you're only using brackish water for short periods of time to get through a drought, perhaps that problem won't be quite so bad. Understanding that and doing a risk-reward analysis for those basins would be a useful thing to do. There is going to be some level of extraction that we probably can do with a little bit of risk but not too much risk. Then, of course, open basins. We could prioritize those for development. KC will talk about that a little more. With mining evaluations, we need better hydrologic studies and need to understand our pumping cost effects.

The other thing that is important with brackish water is understanding intermittent versus permanent needs in terms of infrastructure investment. Brackish water use, extraction, and desalination require a lot of infrastructure. You have to drill a well, you have to construct a desalination plant, and you have to have a way to get rid of the saline waste. This means you have to spend some money. However, the needs for this are often intermittent. Perhaps a different locale might need a desalination plant for a period of time, but maybe they don't need it over a long period of time. This is where we can perhaps learn from the oil and gas industry. They are starting to do a lot of interesting things with respect to mobile units that can be brought in on trucks, set up on a pad, and operated for a year or two years, then deconstructed and moved to the next site. I'm thinking that would be one way to let us do this intermittent desalination work or treatment work, such as for treatment like arsenic removal. We should also consider what I call "low and slow" treatment. We can spend a lot of money with fast treatment. Running water through a reverse osmosis plant, we spend a lot of money pushing water very quickly through those membranes. What if we could do solar desalination, lower our flow rates, reduce our energy costs, make this more affordable, and store that water for the long term? We would treat the water over a long period of time and save that water. I just want people to think about different ways we could make it more feasible to use brackish water in a safer, less risky manner.

Waste disposal is another challenge. We need flexibility for disposal of salt wastes. Texas has had an idea to take saline brackish water brines and dispose of them in oil and gas disposal wells. That took some legislation to change their process, but they are now able to dispose of saline water through their oil and gas infrastructure. That might be something we could do as well.

We also need ownership and water rights clarity. We have some good rules in this state. However, they aren't used very often with respect to extracting brackish water, so there remains some confusion. People don't always understand what the rules are, what the ownership is, or what the water rights are for brackish water. The state engineer could perhaps publish some scenario analyses for extracting brackish water. Who owns it? When do they own it? What is the water right associated with it?

Finally, the last challenge is funding priorities. Let's keep up the pressure on the state and federal agencies and other sources. This can be a priority; it can be a value add. I'll stop there and let the people who really know what they are talking about say something good.

## Stacy Timmons, NM Bureau of Geology & Mineral Resources

*Stacy Timmons manages the Aquifer Mapping Program with the New Mexico Bureau of Geology and Mineral Resources at New Mexico Tech, in Socorro. Working with the Aquifer Mapping Program, she has been involved with several large-scale, long-term hydrogeologic studies focused on geologic influences on recharge, and groundwater movement and occurrence. Stacy has worked in diverse locations over New Mexico, including San Agustin Plains, Magdalena, Tularosa Basin, Truth or Consequences hot springs district, La Cienega wetlands, and southern Sacramento Mountains. Stacy has B.S. and M.S. degrees in geology and has worked in hydrogeology for the Bureau of Geology since 2004.*

Thank you, Jeri, for starting that off. I think we're going to hear some similar themes throughout the panel. I really appreciate you all sticking through the nearing lunch hour. Just to give you a little bit of background: The Bureau of Geology is the state geologic survey. We are a research and service division of New Mexico Tech. We have a group at the Bureau of Geology working on hydrogeology projects of various sizes and scales, big to small.

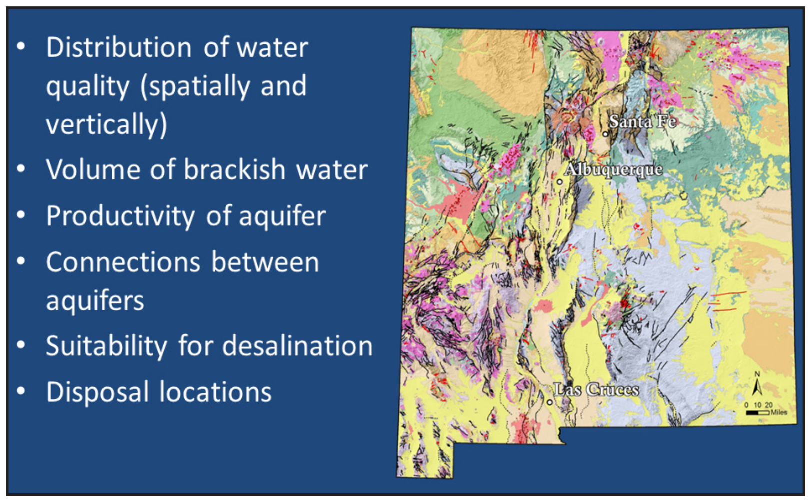



Figure 1. Brackish water: it all relates to the geology.

Being a geologist myself, I think it is really important to mention that nearly everything water related points back to the geology. Figure 1 is our lovely geologic map, a simplified version, of course, of New Mexico's geology. The concept is that the different colors represent different geologic formations, and those formations have different hydrologic and water quality properties. With regard to brackish water, where it is found and how brackish it is, is a reflection of the geologic formation it is in. Where it occurs spatially around the state is a reflection of the geology. How it occurs at depth is also a reflection of that particular geologic formation. For example, in the San Juan Basin, we have a number of different aquifers at different depths with different degrees of salinity going down into the basin. How much water is available in a particular region is going to be a reflection of the geologic structure in that area. How productive that aquifer is, whether it is connected with other nearby aquifers or surface waters, and how suitable that water is for desalination (e.g., if it is extremely salty or if it has very high silicas and things like that might be a consideration for the exact type of desalination process that would be used) point back to the geology. As Jeri mentioned, waste disposal is an issue to consider; we also need to look into the geology as we select sites for disposal.

There has been a lot of previous work in New Mexico related to brackish water. When we started talking with Jeri and the brackish water working group back in 2013, I sent an email to John Hawley. I asked him for his top 5 references that one must read to understand the brackish water resources of New Mexico. I got eighteen pages of ten-point font listing his top 400 favorite references that I must read, with the top 100 highlighted. "These are really, really the good ones. You've got to read these!" The document says "Key References." Thanks, John. Please let him know that I said that.

Anyway, the gist of it is there is a lot of information on brackish water distributed in a number of different reports and resources. The trend I observed in reviewing some of these documents is that, as Jeri mentioned, there is a spurt of publications and research every time we have a significant drought. On the bottom of Figure 2 is the annual average precipitation chart for New Mexico, which shows the different periods of drought in the 1940s and 1950s. Number 1, the big box, is a pretty significant drought here in New Mexico and then subsequently in the 1950s and 60s, we see a huge uptick in the number of reports and publications done on brackish water. Again, in the early 2000s. This is when the brackish water taskforce was put together and started working on brackish water again. It was a direct reflection of a drought. Then recently in the 2013 time frame is another several years of drought continued again in New Mexico. If I could project this into the future, I would suggest there will probably be more droughts. I'll come back to that as a point here in the next few slides.

In working with this brackish water group from 2013 to 2016, we reviewed a lot of the existing documents and reports and came to the conclusion that we needed to work on a big compilation of what is out there and put it together into digital format. With direction from some of the people in the brackish water working group and some funding from the Environment Department's Drinking Water Bureau, we began to digitize the legacy data that existed at the Bureau of Geology and some of the other agencies in the state and put together a large digital dataset of brackish water. We had students from New Mexico Tech painstakingly digitize nearly illegible documents into a useful digital format (Figure 3). Those poor students now need glasses. We put this together into a digital dataset and combined it with existing USGS water quality data, NMED public water system water quality data, and then other study area water quality data we had across the state. The main reason for this is that we were trying to get a better handle on claims like "There is this large quantity of brackish water in New Mexico, and it has higher concentrations of salinity here and over here." Do we have any electronic data to support that sort of claim?

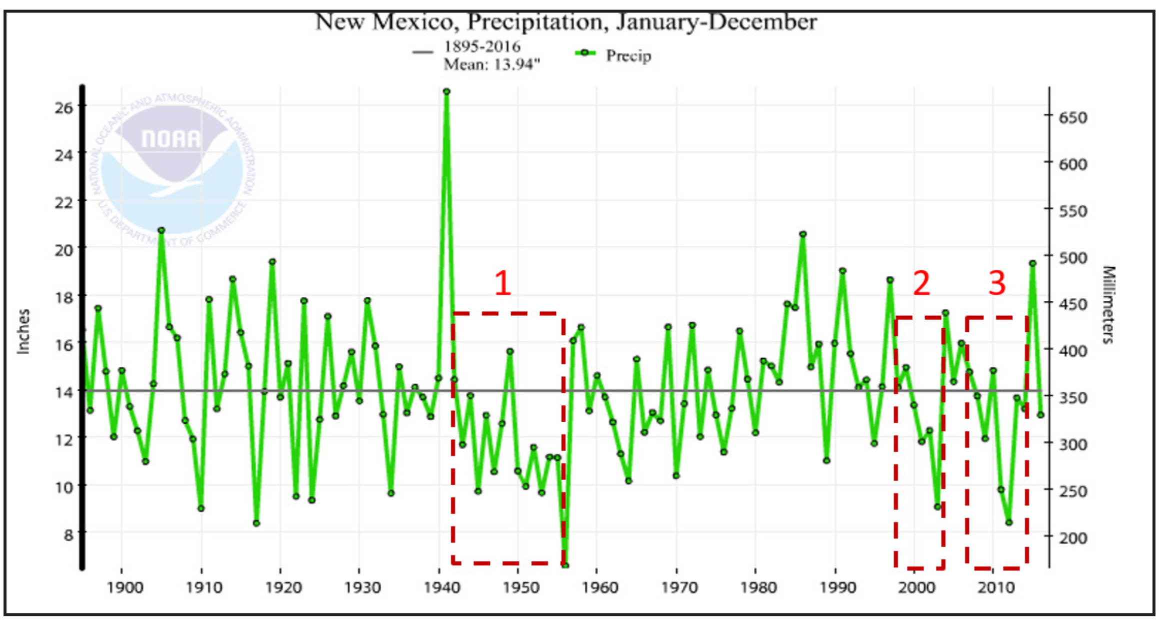



Figure 2. Drought periods in New Mexico correlate with increased work on brackish water.

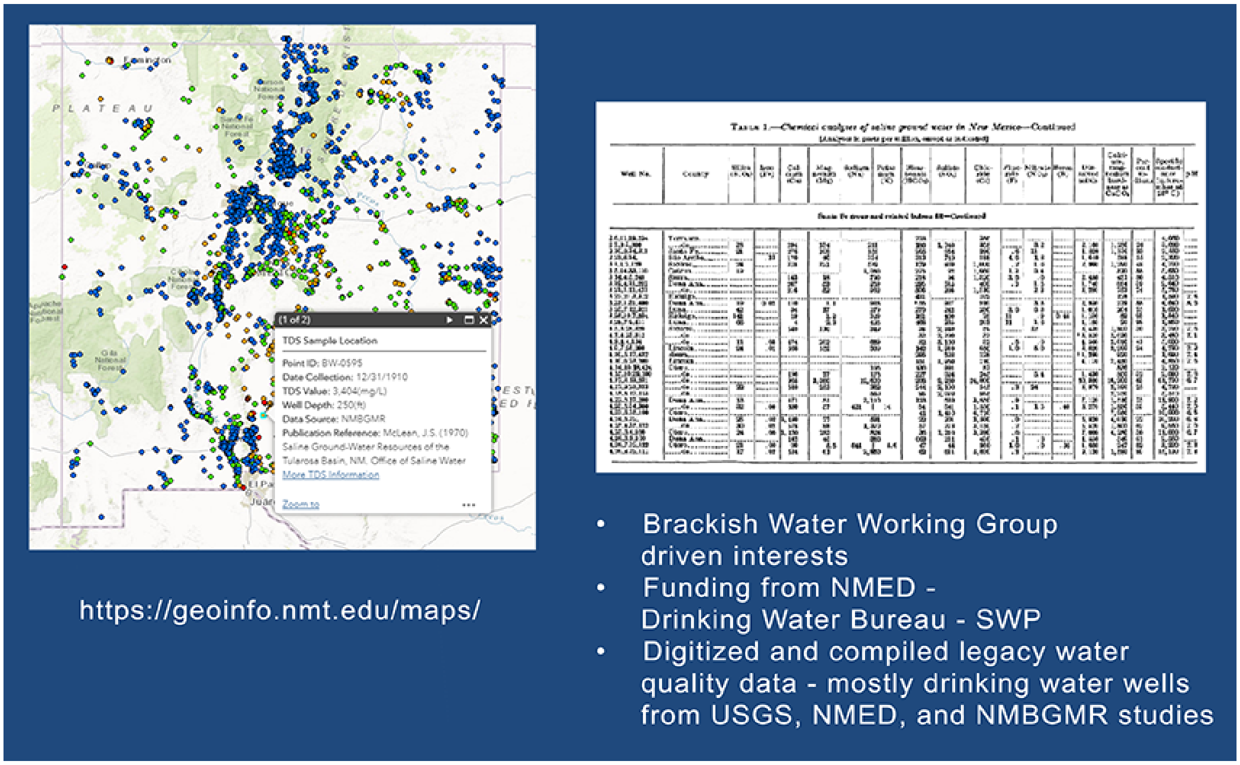
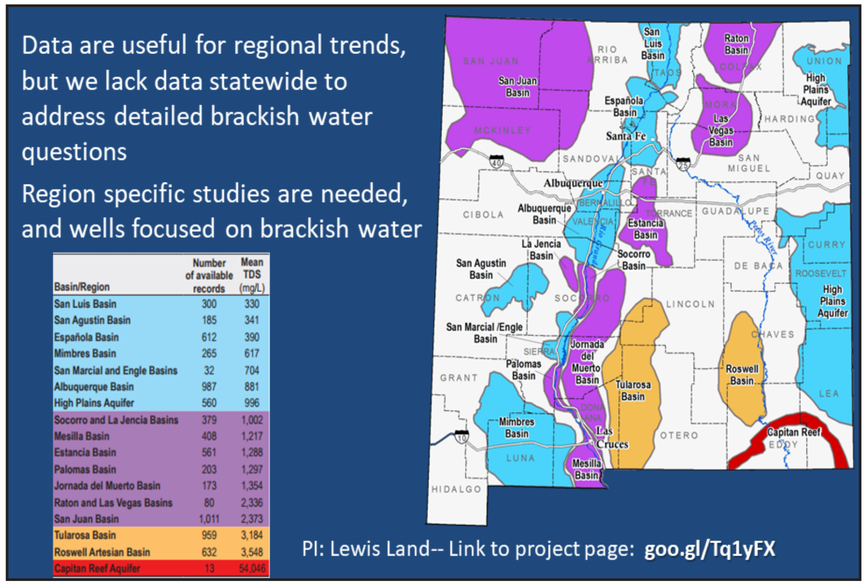



Figure 3. Statewide brackish water assessment.

The map in Figure 3 shows total dissolved solids (TDS) across the state. The blue and green points are lower TDS waters, and the orange and red points show high-salinity waters in some parts of the state. This map is available online at https://geoinfo.nmt.edu/maps. On the website, you can click on a data point to get information about that particular well, including a sense of its water quality, and go to a link for more information where you can find the connection to the USGS database or to the Environment Department's public water system for that particular location. This all came together as a web map product so that people can take a look and see what kind of water quality they have in their area. This is just TDS that I have here, but there are a lot of other major ion constituents in the web map feature. On that web map, there are also all sorts of cool geology and energy resources and asbestos mine locations—all sorts of cool stuff. So check it out!

Another part of that brackish water assessment was putting together all of this data and trying to get a sense of whether we have enough digital data to quantify those claims of large amounts of brackish water across the state. The take-home message is that we lack a lot of the information we would need to quantify our brackish water resources for the whole state. Because when people drill wells, they are aiming for drinking water. The data that we had available is obviously more of a reflection of drinking water wells. The map in Figure 4 shows the average amount of TDS as a reflection of the salinity of entire aquifer basins or regions. The table in Figure 4 shows the number of records we had available in any given region. The blue areas are TDS less than 1,000 milligrams per liter. Purple is 1,000 to 3,000 average milligrams per liter TDS. The yellow is the Tularosa Basin and the Roswell Basin. Those had somewhere between 3,000 to 10,000 milligrams per liter. And then the Capitan Reef Aquifer in red had over 54,000 average milligrams per liter, but only thirteen data points to represent that region. I don't know that that's a very good representation of that area.

This is the data that we have, and this is a summary we put together as a statewide picture of what our water quality looks like in some of these areas. On the whole, Figure 4 gives you a sense of the brackishness of the water in a particular region. We would really need a lot more site-specific, region-specific data to move ahead with some of the concepts of switching to brackish water. There is a slight misconception here in the state that when we run out of fresh water, we're going to simply switch over to brackish water. Figure 4 shows we don't quite have that put together yet. The quick link to the website where you can get more information on this project is goo.gl/Tq1yFX.




| Basin/Region | Number of available records | Mean TDS (mg/L) |
|---|---|---|
| San Luis Basin | 300 | 330 |
| San Agustin Basin | 185 | 341 |
| Española Basin | 612 | 390 |
| Mimbres Basin | 265 | 617 |
| San Marcial and Engle Basins | 32 | 704 |
| Albuquerque Basin | 987 | 881 |
| High Plains Aquifer | 560 | 996 |
| Socorro and La Jencia Basins | 379 | 1,002 |
| Mesilla Basin | 408 | 1,217 |
| Estancia Basin | 561 | 1,288 |
| Palomas Basin | 203 | 1,297 |
| Jornada del Muerto Basin | 173 | 1,354 |
| Raton and Las Vegas Basins | 80 | 2,336 |
| San Juan Basin | 1,011 | 2,373 |
| Tularosa Basin | 959 | 3,184 |
| Roswell Artesian Basin | 632 | 3,548 |
| Capitan Reef Aquifer | 13 | 54,046 |

Figure 4. Statewide brackish water assessment by aquifer and region.

If we were to do brackish groundwater assessment the right way, the first step of compiling the existing data and identifying and prioritizing regions we have pretty well covered with the different periods of brackish water working groups and the task force. The two different working groups had selected several regions that would be higher priority. The next step would be to go out and get that basic hydrogeologic data and interpret it and characterize that brackish water resource and how it relates to the freshwater resources. To do that, you would need to drill wells, get geophysical data, and interpolate the subsurface resource between the well points and then do a lot of sampling, both point locations but also with depth. How does that change as you go deeper? The next thing would be to move into the hydrogeologic characterization and build a model to see how feasible this is and how it might project into the future, and then go into the plant design and pilot project phase. As you can guess, that would cost a significant amount of money, which is why it hasn't been done here in New Mexico with the fits and starts of brackish water interest in the state.

New Mexico Tech, I just want to point out, has some of these resources right here. A number of the universities have the capabilities of answering some of these important brackish water questions. Here at Tech we have people working on hydrogeophysics actively. We have a group that can do gravity. We can use that to understand the basin boundaries, how faults interact and control groundwater and its water quality. The tools called Transient ElectroMagnetic and Magnetotelluric devices are available here, and a research project was recently completed by a master's student. Figure 5 includes an image from that project that shows that we can use these tools to characterize changes in water quality with depth. What's interesting about this—you can't really read any of it—but areas where you see yellow align with this cross section are up by the Sevilleta. The yellow is areas where we see basin fill, and where it is extremely red are areas where they confirm that they have brackish water. We can build resources for the state of New Mexico to answer some of these important brackish water questions.

The other thing that we have the capacity to do is to evaluate how old that water is in these basins. We also have a network that is growing across the state right now where we are measuring groundwater levels. If we want to understand how much of our freshwater resources might be affected or how much water is possibly available, having this data in hand is also important.

I like to think of our brackish water resources as an overdraft account. I had to look up exactly how you would define an overdraft account. I grabbed a definition off of some lending institution's website, but, basically, it is an extension of credit. It is something to have as a backup when we don't have any other water available. If you use your overdraft account, it comes with some pretty hefty fees. That is a similar analogy to what we would experience if we were to rely too heavily on brackish water in New Mexico. Many areas that have brackish water don't actively get recharge and so we would experience groundwater mining in those areas. That is something to consider going forward.

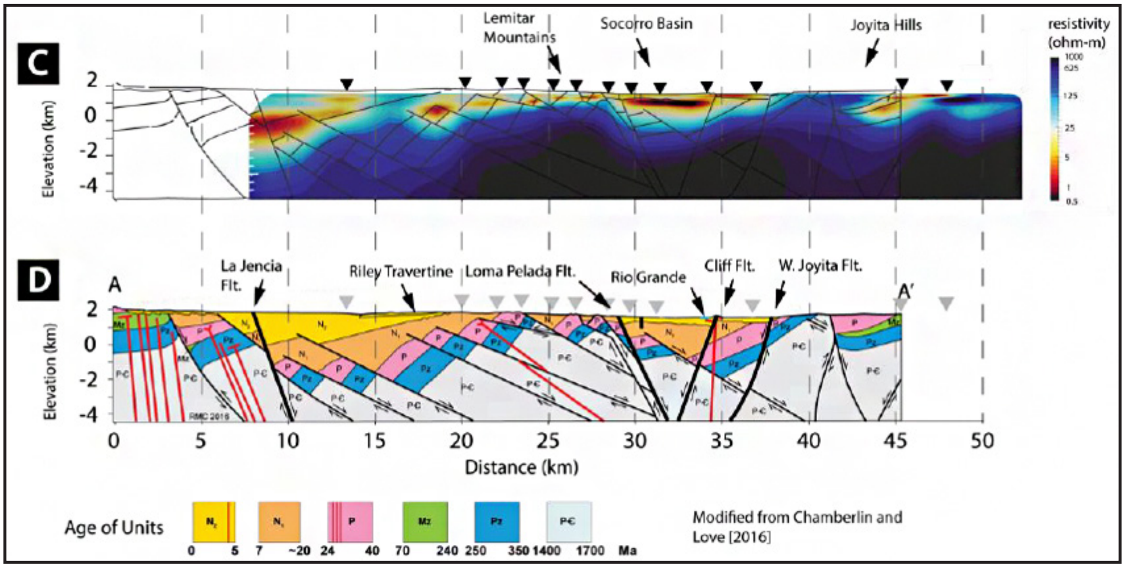



Figure 5. Brackish water assessment techniques available at New Mexico Tech.

As Jeri mentioned, treating brackish water is a pretty expensive process to take on, especially for an inland facility. They have mastered desalination in many places near the coast and are actively using that. Inland we have other considerations such as the fact that groundwater tends to have higher silica. That often gunks up the membranes that are used to desalinate the water. Putting away that waste someplace on the land rather than in an ocean is another consideration. And just the simple cost of pumping water from deeper formations and treatment are energy considerations. That is costly. We also have to consider how pumping brackish water might affect surrounding freshwater resources. Those are the hidden fees that we must consider in using this brackish water as our overdraft account.

So, as I started out with, I think it is important to look at brackish water as a long-term answer or solution to some of our water issues. We will certainly face harder droughts ahead. I think that was a message I heard several times yesterday in the conference. Figure 6 shows our annual average precipitation and our average annual temperature, which is continually seeming to increase—about 2.5°F since the late nineties on this graphic. We need to consider brackish water as a possible resource.

As Jeri mentioned, continuing to put a little effort into understanding this resource in the state would be a good next step. Conserving the freshwater resources we have is probably the best thing we can do right now considering where we are with our brackish water understanding. Considering brackish water as a supplement is a better concept than thinking we will flip the switch and completely change over to using brackish water. The message, I would say, is that a good step forward is not to take a whole statewide approach but to go region by region and try to improve the characterizations of our aquifers, both fresh water and brackish water. I will leave it at that.

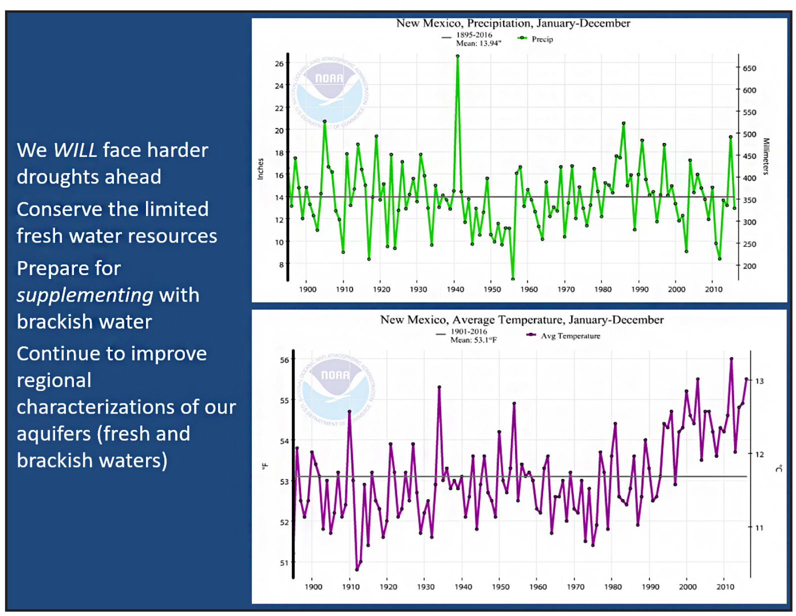



Figure 6. Looking ahead.

## Kenneth Carroll, New Mexico State University

*Kenneth (or KC) Carroll is an Associate Professor in the Plant & Environmental Sciences Department and the Water Science & Management Graduate Program. KC also supports the Interdisciplinary Water Science & Management graduate program at NMSU. His teaching and research focuses on environmental science and geochemical hydrogeology. KC's research interests include the development of innovative water resources, environmental-remediation, carbon-sequestration, and energy-production alternatives covering a broad range of cross-disciplinary areas that pertain to soil, water, and environmental science. He earned his PhD in hydrology & water resources at the University of Arizona. In addition to international consulting industry and postdoctoral experience, KC was a research scientist at the Pacific Northwest National Laboratory for three years prior to joining NMSU in early 2013.*

I'm really pleased to be part of this panel. I think brackish water is an important topic for the state. I am going to have similar themes to what has been discussed by Jeri and Stacy as well. One of those themes is there is a lot of interest in brackish water, but we have to figure out how we can use it, where we should use it, and what the impacts are. I'm going to talk about using brackish groundwater as the source water for inland desalination.

We have brackish water. We live in a desert. Everybody here knows that New Mexico is in a desert. We have drought, and we have water scarcity issues. We have population increases, so there are increases in demand for water. We need to conserve water; we also need to look at potential alternative water sources. We need to look at diversifying our water portfolio. We know that we have a lot of brackish water in this state, so we have those two things aligned. We need water, and we have brackish water, both across the state and in the Mesilla Bolson in the south-central part of the state. One thing to think about is what would happen if we started using brackish water. We haven't used brackish water in the past very significantly. One thing I was thinking about, Stacy, with your plot was sting the droughts with the brackish water well permits. I wonder if there would be a correlation there. People realize we have brackish water, but it is expensive to develop. Once we're running out of water, however, people want to jump into brackish. That is a concern that we need to think about. We need to do more long-term planning instead of just jumping and switching in a drought situation.

Brackish water could be a new water source, but we need to think about what the potential issues are. What are the potential impacts? I have listed some of the issues here, which Stacy and Jeri mentioned. We do have a lot of brackish water, but we have very complicated geology and we have not, I believe, truly assessed our subsurface water resources, both the fresh water and the brackish water. We have a lot of uncertainty in the availability of our brackish water: where it is, how accessible it is, how connected it is with our freshwater resources. So, we need to be a little concerned about switching over to brackish water. What could be the potential impacts on our existing freshwater resources? We don't want to switch over to brackish and then have it affect our freshwater resources.

Here is some general, simplistic conversation about potential impacts. What about different hydrologic units? We've got surface water and groundwater. We know there is the potential for surface water–groundwater exchange. As you start pumping groundwater, you may have some exchange from the surface water system to the groundwater system. One example is irrigated agriculture in New Mexico, both using surface water and groundwater. There may be a potential for capture of surface water flow or return flow due to groundwater pumping. That's currently a discussion for the special master for the Supreme Court. We're talking about freshwater and brackish water as separate hydrologic units, but there may be connections between the two, so we need to consider those connections. Brackish water and freshwater in this part of the world haven't been discussed very much. There is not a lot of research on what the potential impacts are.

I would argue that we can use as an analogy coastal and island systems where there is seawater intrusion or underlying brackish water that might intrude into freshwater aquifer systems, and there has been more research on coastal saltwater intrusion in the past compared to inland desalination. Figure 1 shows a cross-section conceptualization of pumping in a freshwater aquifer system. You can see the cone of depression where the water table is dropping around the well system. You can also see that there is an upwelling of salty water at the bottom of the well due to the pumping in the freshwater aquifer. If we start pumping in our freshwater aquifers, we could bring brackish water up into those freshwater aquifers. Once you do that, it may be difficult to get that salt out of those freshwater aquifers. You can have adsorption of some of the cations. You can have diffusive mass transfer into some of the lower permeability zones. It may not be as easy as just stopping pumping to clean out our freshwater aquifers. Another thing to consider is that if the pumping well were down a little bit lower in the saline groundwater system and you started pumping, you might have a cone of depression that draws overlying freshwater into that salty aquifer system, and again you might potentially contaminate or increase the salinity of our freshwater resources.

Another issue to be concerned with is subsidence. We have a lot of alluvial aquifers here, and as we pump out groundwater, we have seen in the past, the land surface elevation drop due to pumping of groundwater. What happens is you decrease the pore pressure and the porosity decreases and the land surface decreases. That can cause issues with infrastructure. It can also damage our aquifers for future groundwater storage.

As some of the other speakers noted this morning, there are also issues of what to do with the waste. We start off with salty water that typically in the past hasn't been useful for a lot of water resources. We clean it up, we make it usable, but we also concentrate the salt into a concentrated wastewater that has to be disposed of. We often look at subsurface deep injection of the wastewater. How does that affect the fluid flow system and the geochemistry of our aquifer systems? We have to be concerned about that.

Well, there are also a lot of people working on this. As was mentioned earlier, we've been working on this over time. There is renewed interest in

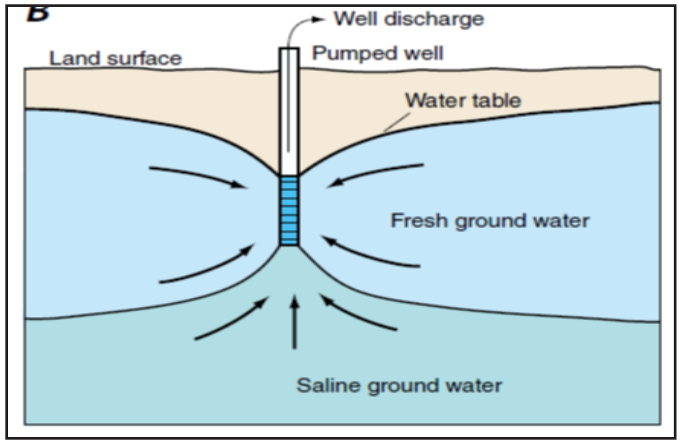



Figure 1. Sea water intrusion.

brackish water and using that as an alternative water source. Two 2017 papers from the USGS are an example. Scientific Investigations Report 2017–5028 ("Geophysics- and Geochemistry-Based Assessment of the Geochemical Characteristics and Groundwater-Flow System of the U.S. Part of the Mesilla Basin/Conejos-Médanos Aquifer System in Doña Ana County, New Mexico, and El Paso County, Texas, 2010–12") looks at the Mesilla Basin aquifer system specifically. It adds some geophysics, some geochemistry, some isotopic age-dating data, and it helps us inform our conceptual model of the subsurface. Professional Paper 1833 ("Brackish Groundwater in the United States") is a nationwide brackish water assessment. We've been talking about the statewide water assessment. We also have a nationwide one, which has some regional analyses that might be useful. The USGS is definitely working on this, and as we've mentioned, the brackish water working group. There has also been some work through the statewide water assessment. I realize, I know, as we were talking earlier, their funding was cut recently, but we are hoping to get it refunded. It has had a lot of excellent projects on water across the state.

There is also a collaborative project between the USGS and the water resources research institutes in several states along the US-Mexico border—the transboundary aquifer assessment. The NM WRRI is working on riparian evaluation, evapotranspiration modeling, and evapotranspiration measurement. I don't know how much longer this will survive with budget cuts going forward, but the USGS in New Mexico is working on collecting data and age dating of groundwater that is brackish and fresh in areas.

I will also note there is a proposal of developing an inland desalination plant near the US-Mexico border in Mesilla. The work being done for the transboundary aquifer assessment is going to help support some of that evaluation.

In addition, we have an ongoing cooperative agreement between NMSU and the US Bureau of Reclamation. There are six new start projects that just started this year specifically looking at brackish water for desalination. The first one is looking at what to do with concentrate and concentrate management. That's led by Manoj Shukla, and they are looking at using concentrate for irrigated agriculture. The second project run by Tanner Schaub is looking at new ways to analyze the chemistry of brackish water. The third one, led by Sarada Kuravi—she is in our engineering college—is looking at developing new desalination water treatment systems and utilizing renewable energy such as solar to treat brackish water. Phil King is leading a project looking at an engineering design feasibility study of a desalination plant that could be placed on the US-Mexico border in the Santa Teresa area. Brian Hurd is looking at an economic analysis for that proposed inland desalination plant along the US-Mexico border. Then the final project is one I am leading, and we are looking at source water for inland desalination along the border as well. We're looking at the brackish water in the Mesilla Bolson aquifer system. The last three act as a collaborative program to look at the feasibility of an inland desalination plant in the southern part of the Mesilla Bolson aquifer along the border. I'll talk a little bit about each one of those.

"Assessment of Brackish Groundwater Desalination for Municipal and Industrial Water Supply in Santa Teresa, New Mexico" is Phil King's project. Santa Teresa is adjacent to El Paso along the border. They are collecting samples and analyzing the chemistry of the water. They are designing a pilot-scale treatment system that can be used as an example. They are doing the engineering feasibility analysis to look at whether we can put a desalination plant along the US-Mexico border that will work for that area. Figure 2 includes some pictures of pilot-scale desalination plant treatment systems. They have been working on both sides of the US-Mexico border, working with the stakeholders. They have been collecting samples and looking at the water chemistry, and they are working on their pilot-scale project.

"Valuing the Potential Contribution of Desalination and Water Reuse to the Water Supply Portfolio of Southern Doña Ana County, New Mexico" is the second project, which Brian Hurd is working on. He is doing an economic analysis, but it is not just an economic analysis. He is coupling hydrology with economics, and he is looking at scenarios with systems dynamic modeling.

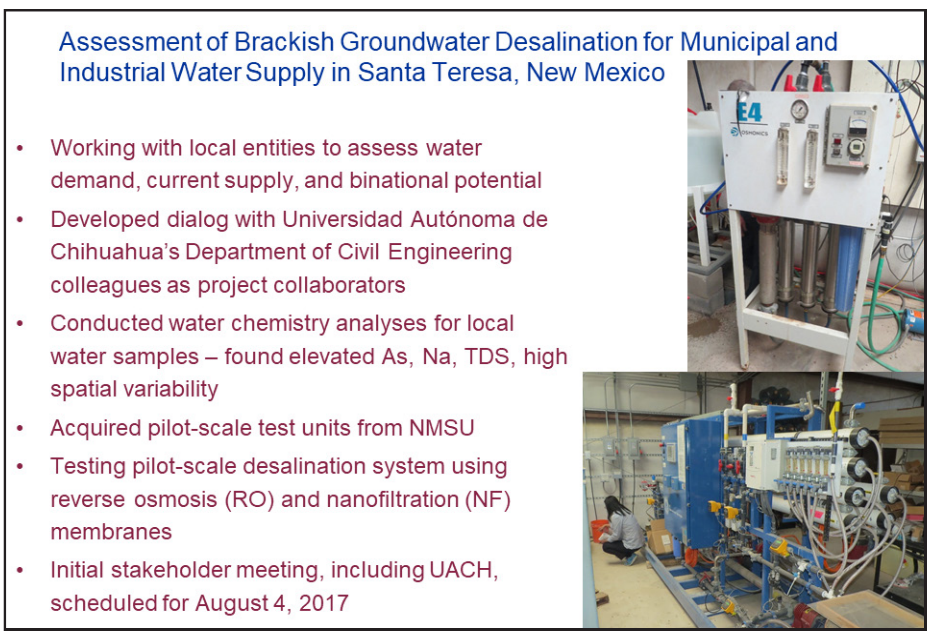



Figure 2. Pilot-scale desalination plant treatment systems.

Figure 3 shows you an idea of what he is doing in terms of his conceptualization. He is looking at population scenarios, climate scenarios, and hydrology scenarios, including surface water and groundwater, to look at the potential hydrologic and economic feasibility of a desalination plant in the Santa Teresa area.

"Isotopic, Geochemical, and Modeling Evaluation of Source Water, Extraction Potential, and Potential Impacts of Using Brackish Water for Desalination in the Mesilla Basin, New Mexico" is the final project, which I'm leading. We're looking at using isotopes. We're looking at geochemistry and doing some modeling to look at the source water for brackish water inland desalination specifically along that Mesilla border region and looking at where the salty water is, where the brackish water is, and how sustainable will that source water be for an inland desalination plant. Figure 4 contains pictures of sampling. The pictures on the right are of a dissolved gas separation and sampling apparatus. We are sampling for noble gas isotopes. This uses a membrane contactor. We pump groundwater through this membrane, and it separates out the dissolved gases, and then those gases get pumped into a sampling container.

The reason we're doing that is there are many options for looking at age dating of groundwater, but the noble gas isotopes haven't been used a lot in this area of the world. There are some new advances with the chemical analysis, and they work really well specifically for groundwater and for brackish water. Figure 5 is a graph that shows the groundwater age on the x-axis, and then the bars show the time periods in which some of these age-dating isotopes may be used. The krypton-85 is for younger groundwater. Krypton-81 is for the really old groundwater, and then there is argon for the middle range. This is from about 50 to 500 years. There is kind of a gap here with a lot of these standard or traditional age-dating methods. We are hoping the noble gas isotopes can help fill that void.

In general, to follow up and follow on with what the other speakers were saying, I believe we do have a lot of brackish water resources. We do need to look at diversifying our water resources portfolio, and yet we still have a lot of uncertainty. We have a lot of data gaps. We have a lot of uncertainty in the potential impacts, and so we need to do more research. We need to collect more data and do more characterization, do more feasibility analysis, and evaluate these potential impacts.

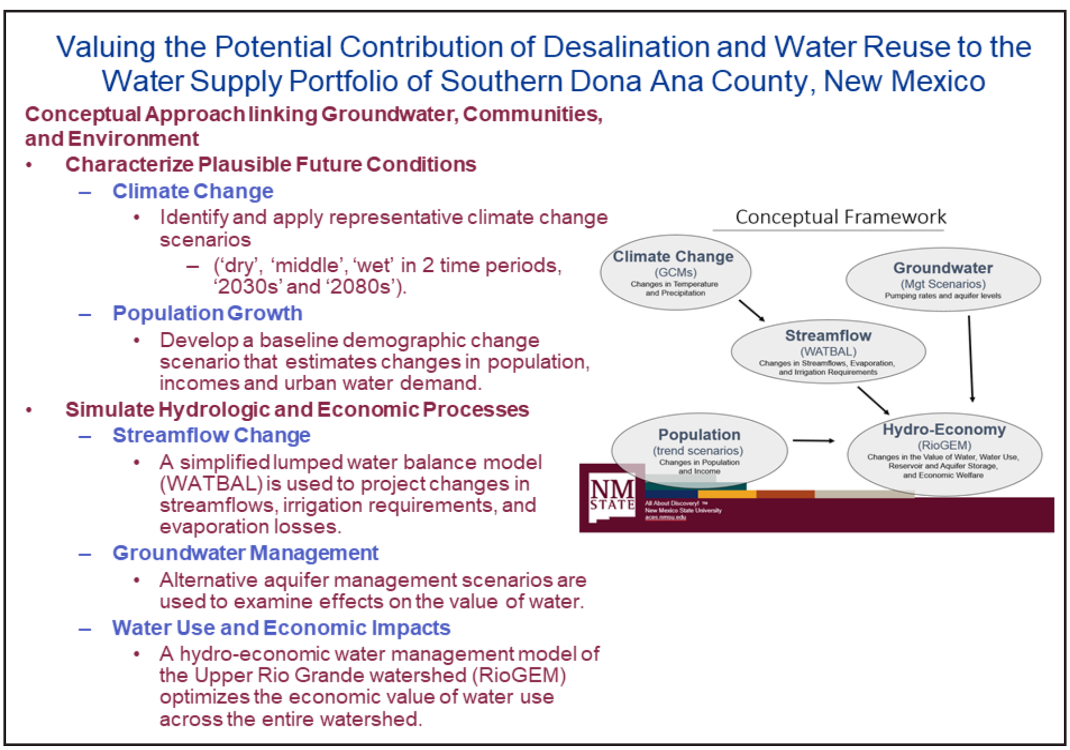



Figure 3. Conceptual framework for the economic feasibility study.

Last, I'd like to acknowledge the this work has been supported by and made possible by the NMSU Agricultural Experiment Station and US Department of Agriculture Southwest Hub for Risk Adaptation and Mitigation to Climate Change; the statewide water assessment funded by the State of New Mexico through the Water Resources Research Institute; the US-Mexico Transboundary Aquifer Assessment Act (Public Law 109- 448); the US Bureau of Reclamation cooperative agreement with NMSU; and the USGS, especially Andrew Robertson. Thank you.


Figure 4. Sampling of dissolved noble gas isotopes from groundwater.

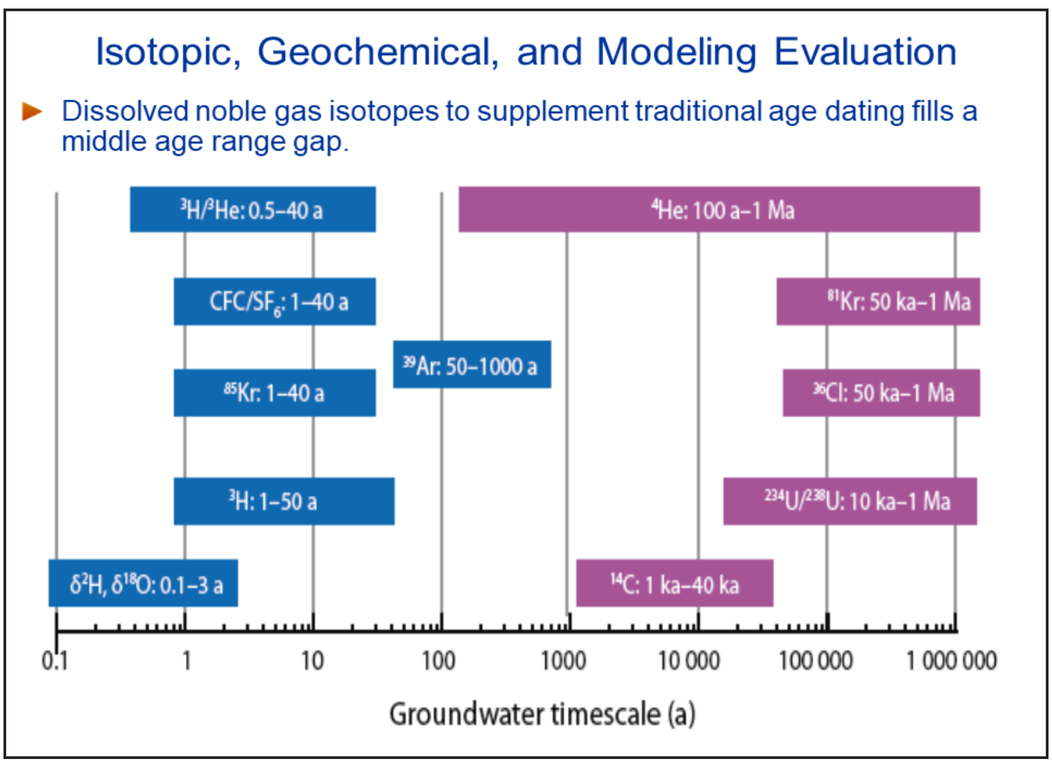



Figure 5. Isotopes used for age dating groundwater.

## Katie Guerra, U.S. Bureau of Reclamation, Lakewood, CO

*Katie Guerra is a chemical engineer at the Bureau of Reclamation in the Water Treatment Group in the Technical Service Center in Denver. She has 16 years of experience in research and design of water treatment technologies. Her work at Reclamation has focused on evaluating the technical, practical, and economic benefits and limitations of utilizing existing and novel water treatment technologies. She also has expertise in water quality assessments and understanding the implications of water quality in the use, storage, and treatment of water supplies. Katie is a project manager and senior engineer and serves as Grants Officer's Technical Representative for a $5M cooperative agreement between Reclamation and New Mexico State University. She has a bachelor's degree from the University of Colorado and a Masters and PhD from Colorado School of Mines.*

As Aron mentioned, my name is Katie Guerra, and I am a chemical engineer with the Bureau of Reclamation in Denver. I have gathered from a lot of the conversations I have heard and posters out in the hallway that you all are fairly familiar with the work the Bureau of Reclamation has done, especially locally here. We have our Albuquerque area office here that it seems like many of you work with quite closely. What I am going to talk about today is some of the work that we are doing out of Denver related to developing new technologies that can be used for desalination and advanced water treatment.

I would like to acknowledge Yuliana Porras-Mendoza. She is Reclamation's advanced water treatment research coordinator. She controls the funding and manages the budgets for our programs that fund this type of work. Yuliana is the visionary. She comes up with the cool ideas of where we are going with desalination research, and then it is up to people like me—project managers—to assemble technical teams and help make that vision come to life.

Desalination isn't a silver bullet. It cannot solve all of our water supply issues, but it can be used to augment existing freshwater supplies. One thing I do want to add to the conversation about desalination's benefits, something we've heard from a lot of stakeholders, is that desalination provides them a locally available supply of water that they feel like they have local control over. That's an important aspect to water supply and important to water managers. Desalination can also be used in a wide variety of applications (see Figure 1). I'm showing a picture of the brand-new Carlsbad desalination plant as an example that desalination is quite widely used for large metropolitan areas. The other picture shows pretty the other end of the spectrum: desalination can be used to help remote and small communities.

The picture on the left of Figure 1 is a project in the Navajo Nation. We are looking at desalinating brackish groundwater to provide a locally available supply of freshwater for the people out there. Currently, they are driving long distances to haul water back to their homes to use for potable drinking water and household use. They have one of the highest water rates of any location in the country because of the cost of hauling water back to their houses, and they also have one of the lowest capacities to afford that high water cost. Implementing desalination of groundwater in

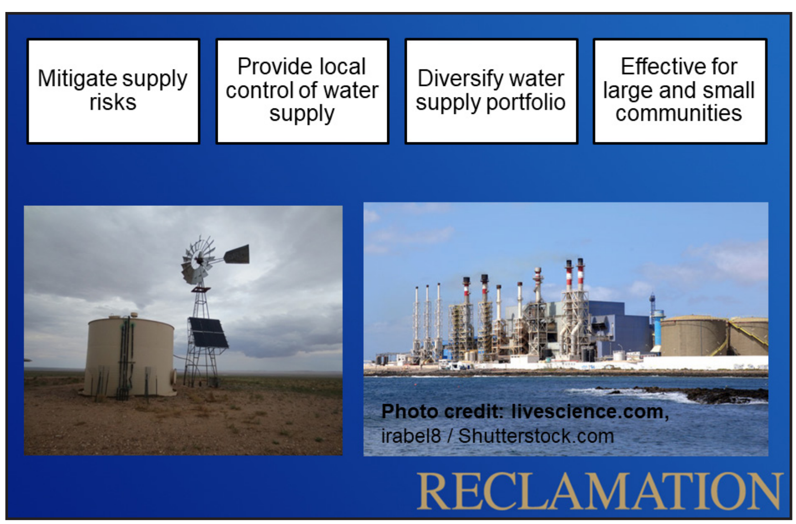



Figure 1. Benefits of desalination.

this area could significantly reduce those costs. It is also important to note that in areas like that they don't have access to a water distribution system or access to grid electricity, so there are opportunities to couple renewable energy to power these desalination technologies and help get them many more systems to reduce the driving and the water-hauling practices.

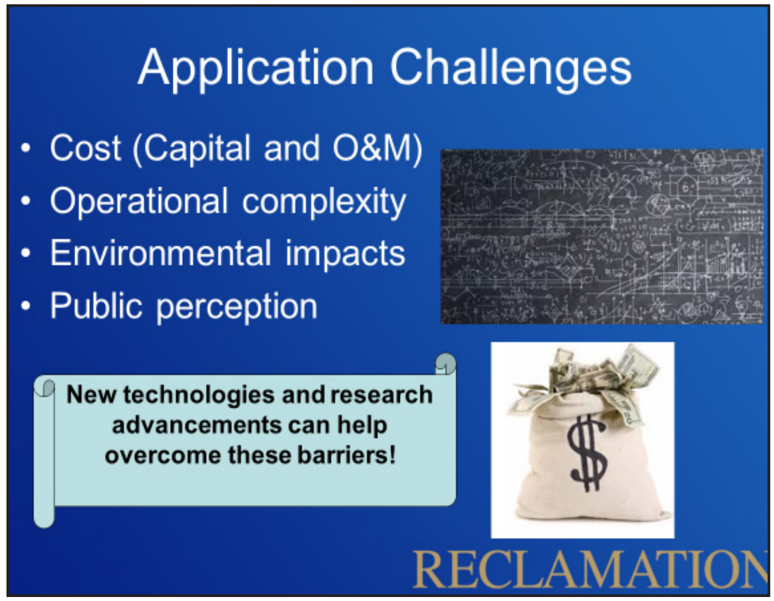


Figure 2. Implementation of desalination challenges.

There are some challenges we see with implementing desalination (Figure 2). If it is so great, if it can provide all these benefits, and it can work for a wide range of people, why isn't everybody doing it? Costs. I think Jeri mentioned that one. One thing I do want to add to that conversation too is operational complexity. They aren't always the easiest technologies to operate, and certainly when we look at removing constituents from more saline water sources or managing the concentrate and treating that, it often require multiple treatment technologies to put together a treatment train that provides a water treatment solution. Operational complexity is definitely a hurdle that needs to be overcome. Environmental impacts were mentioned as well. There are substantial energy requirements to power these technologies and dispose of the waste byproducts. And then public perceptions is another challenge. I do want to point out also that a lot of these barriers and hurdles exist for traditional water supply approaches. I think you could make the same argument for pipelines and building new dams.

Our goal at Reclamation is to conduct research through our various programs to develop new technologies and also improve the existing technologies we have to remove some of these barriers. I'm going to talk about some of the programs and facilities we have to carry out this research.

Our Brackish Groundwater National Desalination Research Facility might win an award for worst acronym ever (Figure 3). It is in Alamogordo, New Mexico. The facility produces brackish groundwater from four different wells on site to provide a whole range of water qualities for conducting tests. It is always really nice for researchers to be able to test technologies on a real water source. We also have outdoor test bays there to allow researchers to test systems outside and make use of the abundant solar and wind resources there to look at coupling renewable energy and desalination. We have indoor test bays that allow for a more controlled laboratory setting for testing as well as friendly staff at the facility who would be more than happy to give you a tour and provide support for the testing conducted there.

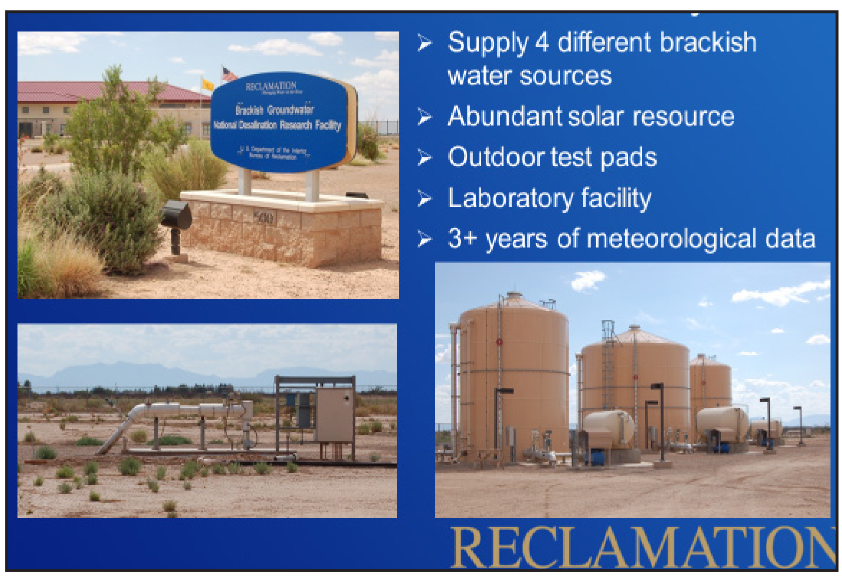


Figure 3. Brackish Groundwater National Desalination Research Facility.

In terms of our research programs, we have an internal research program that funds researchers like me to conduct desalination research (Figure 4). We are strongly encouraged to partner with outside entities and collaborate with others through this internal research program. This past year funded about $2 million worth of internal research. Our desalination and water purification program funds research by external entities, so the private sector and universities. Basically anybody nonfederal can apply to this program. This program funds research at the bench scale, pilot scale, and then full-size demonstration scale. This past year we had $5 million to award for research projects from this program. It is also important to note that this line item in our budget covers operation and maintenance at our facility in Alamogordo.


Figure 4. Internal and external research studies.


Figure 5. Research collaborations.

As KC mentioned, we have a cooperative agreement with NMSU, and thank you, KC, for covering details of the specific projects. We have nine currently funded projects through this agreement, the first of which should wrap up in 2017, and then you'll see reports from the following projects over the next two to three years (Figure 5). In addition to the research that we're funding for faculty at New Mexico State, we have what we call our directed research project. This was an opportunity for Reclamation and New Mexico State to get together and say, "We have this nice chunk of funding to conduct research. Let's craft a project together that is useful to both organizations and utilizes the capabilities and expertise of each." So that directed research project looks at the impacts of desalination in the water budget and at how implementing desalination will affect water supplies in the lower Rio Grande. Another thing I really like about this cooperative agreement is the relationship New Mexico State has with the stakeholders in the local community. A year ago we conducted a workshop where we brought in community members and talked to them about what their water supply and water quality challenges were, and we looked at how we could match the expertise at each of our organizations to solving those problems. We identified some relevant water supply challenges that we could tackle with this funding.

We also have a few innovative projects where we try to reach desalination technology innovation through other channels (Figure 6). Last year—2016—was our inaugural year of what we call Pitch to Pilot. If you have seen the show *Shark Tank*, it was something like that, where we invited researchers in, put them up on a stage and let them give us a pitch, and then the judges asked them some hard-hitting questions. When we review proposals a lot of times questions arise: Why are they doing it this way? Have they considered such and such? This gave us a real-time way of interacting with the proposers and getting from the proposal phase to testing in our facility in Alamogordo a lot quicker than a traditional funding approach. There are three projects funded through this, and those researchers are testing their technologies in Alamogordo as we speak.


Figure 6. Pitch to Pilot.

We also have water prize competitions, which are kind of like XPRIZE if you are familiar with that concept (Figure 7). It is a crowdsourcing technique of soliciting solutions to some of our tough challenges from the general community. We have three different categories for which we fund prize competitions: water availability, ecosystem restoration, and infrastructure sustainability. An example of a prize competition we recently completed in one of these areas was looking at new ways to detect internal erosion in earthen dams. We also ran a prize competition looking at downstream fish passage from tall dams. So the competitions look at some cool things, some challenges that Reclamation has always experienced but is looking for new, crazy, innovative ways of solving those challenges.

The other unique thing about prize competitions is that we are able to reach new people. With a traditional grant program where someone submits a proposal, we say "Yes, OK, I think you have the credentials. You have a solid proposal, a solid budget to conduct this work. Here's your money, go and do it." A prize competition says, "You do the work upfront, submit your idea to us, and if we like it, we fund it." This gives us the opportunity to work with and reach out to people who couldn't necessarily pass that tall hurdle to get a traditional grant. We're able to access the general public or people who have worked in other disciplines who might not have thought to apply to a desalination grant.


Figure 7. Water prize competition center.

We have done two prize competitions in advanced water treatment and desalination: "more water, less concentrate" and arsenic sensors (Figure 8). In "more water, less concentrate," we were looking for cool, crazy, innovative ideas to deal with the concentrate that some of the other panelists talked about. This has been a sticky, difficult challenge for those of us working in this industry. We also partnered with the EPA and funded the arsenic prize competition. Arsenic detection is really important to make sure that water treatment technologies are removing arsenic and that drinking water is safe. We put out this prize competition to identify new technologies—easier, quicker, less subjective ways of monitoring arsenic in water. Both of these prize competitions requested ideas. All applicants had to do was write a white paper and submit an idea. Based on this, we saw some really cool ideas, and we're excited to test some of these ideas out. Phase two is going to be inviting people to build a prototype and come to test it with us.


Figure 8. More water, less concentrate challenge.

Something new that we are working on is partnering with USGS. They recently completed their brackish groundwater assessment. In working with Reclamation, we decided it would be really cool to have an interactive mapping tool, kind of like what Stacy Timmons was talking about, where users can see brackish groundwater locations and characteristics across the United States (Figure 9). We want to add a beneficial use component to it. So users can say, "I'm interested in using brackish groundwater in a certain area for irrigation or for drinking water" and get some feel for what kind of treatment would be required and what kind of constituents need to be removed. We are very early on in the planning stages for this tool, but we think it would be useful for viewing that USGS data and hopefully help the USGS get a new map so we can stop using that old one pink one Jeri talked about.

I hope I have shared with you some of our cool ideas, some of the ways we are hoping to overcome these hurdles with implementing desalination. We are really excited about the programs and activities we are funding.

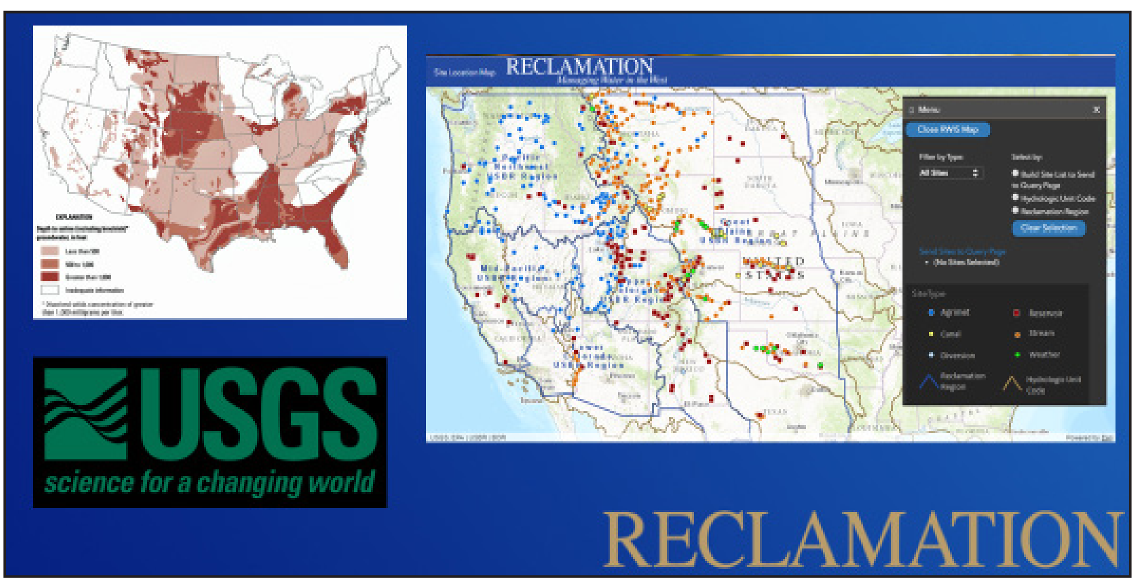



Figure 9. Interactive map-based tool to evaluate brackish groundwater sources for common beneficial uses.

# Statewide Water Assessment Update

**Editor's Note: The following papers represent a transcription of the speakers' remarks made at the conference; no follow-up papers were submitted by the speakers. Remarks were edited for publication by the editor. The speakers did not review this version of their presentation, and the editor is responsible for any transcription and editing errors.**

## Moderated by Bob Sabie, NM Water Resources Research Institute

*Robert Sabie, Jr. is a research scientist at the New Mexico Water Resources Research Institute. Robert's research centers around applying geographic analyses to help solve water issues in New Mexico and other arid landscapes. His particular interests include using aerial and satellite remote sensing for land cover mapping and measuring evapotranspiration, produced water decision modeling, and participatory research. He holds a BA in environmental policy and planning from Western Washington University, a Master of Applied Geography from New Mexico State University (NMSU), and is currently working towards completing his PhD in the Water Science and Management Program at NMSU.*

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## Ken Peterson, Tetra Tech, Inc.

*Ken Peterson is a Water Resource Scientist for Tetra Tech in Santa Fe. He has worked for two years as a Hydrologic Technician with the Alpine Hydrology Research Group at the USGS Colorado Water Science Center in Lakewood, Colorado. There Ken was involved in collecting water quality samples as well as making stream discharge measurements to assess the response of soil and water chemistry on mountain pine beetle induced tree mortality. After working with the USGS and receiving a master's degree in water science and management at New Mexico State University, Ken worked as a hydrologic modeler at the New Mexico Water Resources Research Institute for two years. There he worked on developing a statewide dynamic water budget model, that is designed as an accounting and planning tool to track the origin, fate, and use of New Mexico's critical and limited water resources. Ken has continued in guiding the development of the New Mexico Dynamic Statewide Water Budget as part of his role at Tetra Tech.*

I'm going to talk about the dynamic statewide water budget model I was working on at WRRI and continued working on this past year at Tetra Tech. The goals of the project are to provide a water accounting process for the state of New Mexico; identify where the water is, how the water is used, and where it goes; and identify gaps in knowledge about water in New Mexico. The project also aims to present regional and statewide water data in a comprehensive and consistent visualization platform, estimate future water supply and demand through modeled scenarios, and connect science to decision-makers and stakeholders.

The model operates at a variety of spatial scales. The model operates at the seven major river basins, the 16 water planning regions in the state, or the county level, which is the finest spatial scale in the model.

There are four main storages in the model. There is land surface, which is a conceptual representation of soil moisture. There is the surface water system, which just includes open riverways. The reservoirs are included in the human storage distribution system in the model. And then, finally, there is the groundwater storage.

And then there are 10 fluxes that would quantify the water movement through time among the different storages in the model (see Figure 1):

- Precipitation
- Runoff
- Surface water in/out from USGS stream gauge data
- Groundwater flow between the spatial scales
- Evapotranspiration (ET) from groundwater
- Human use (surface water diversions, groundwater diversions, groundwater returns, and consumptive use)
- Recharge
- Land surface ET
- Surface water ET
- Surface water to groundwater interaction

Precipitation is provided from PRISM data. We don't currently have a good handle on groundwater flow between spatial scales yet, but we'd like to address that in future work. Within consumptive use, or even for all the diversions/returns, under human use, we categorize the water use by the nine Office of the State Engineer (OSE) water use categories. Agriculture and reservoir evaporation are considered part of that human use. Land surface ET is ET from all nonirrigated areas in the state.

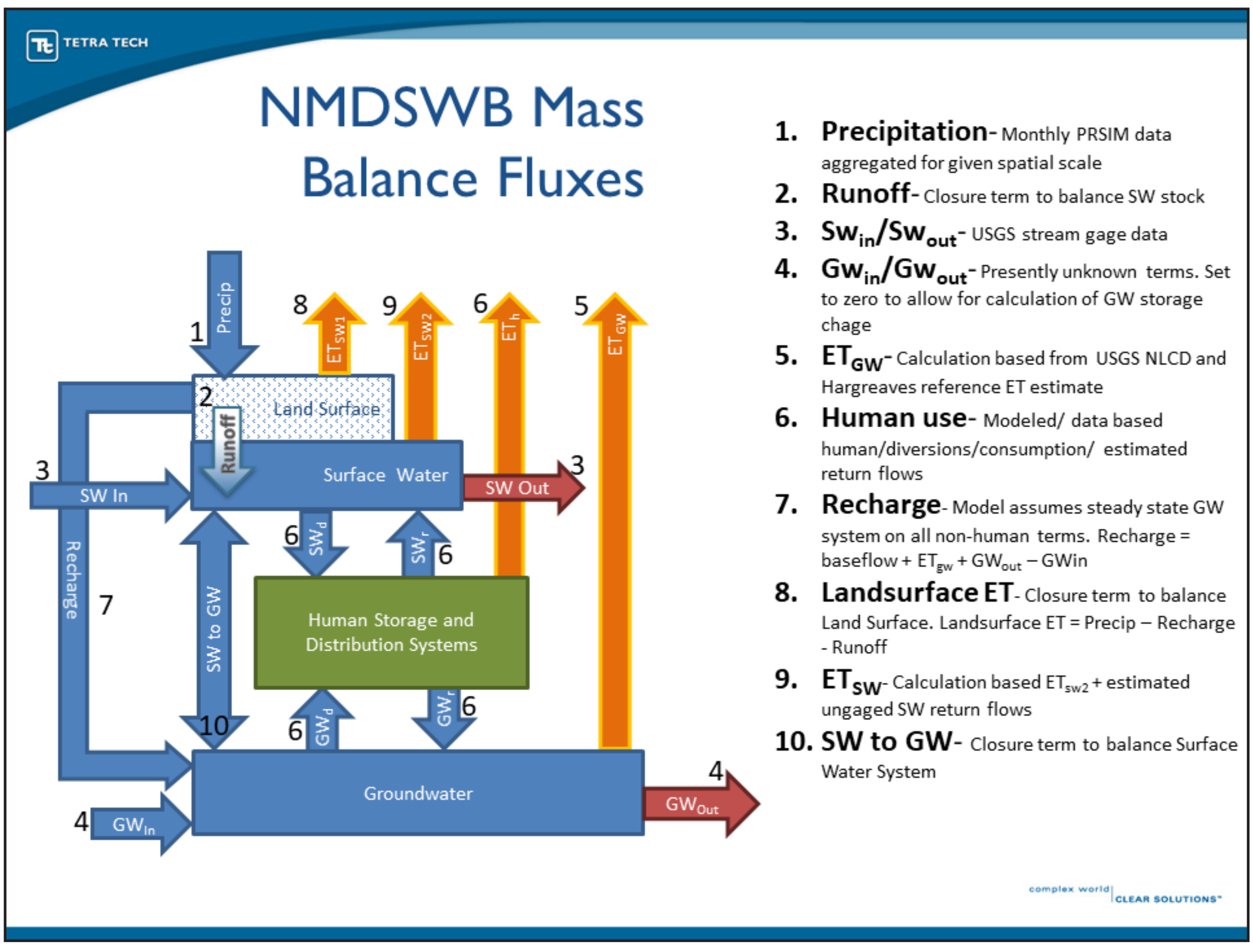


Figure 1. NMDSWB mass balance fluxes.

In this past year, we just added some future scenarios. Previously the model ran from 1975 through 2012. Now there are some future scenarios that allow user inputs and some climate change scenarios. The model can be run now through 2099. Within the climate change scenarios, there are four different generic circulation models a user can select. There are some different human population growth estimates that change the rate of municipal and domestic water use in the state. The user can manipulate the population growth forecasts up or down 20 percent. Then there are some changes that users can make in water use efficiency as well. Austin will go into a little bit more detail on the user interface.

## Anne Tillery, U.S. Geological Survey

*Anne Tillery is the Surface Systems Specialist with the USGS at the New Mexico Water Science Center in Albuquerque. Anne's research focuses on stream flow statistics; the hydrology, hydraulics, and geomorphology of flooding in desert ephemeral channels; and debris flows following wildfires. Anne has BS and MS degrees in geology and has worked with the USGS since 2007.*

Hello. As you all know, the USGS is charged with monitoring streamflow in our nation's rivers and streams. This data is used by a wide variety of people for a wide variety of applications. I'm sure a nuber of you have cited it and used it as inputs to models or predictions. If you have a stream gauge with a long enough record—and, of course, here in New Mexico we have the oldest stream gauge in the nation, which was installed in 1889 at Embudo—then you can start doing statistics like determining the 100-year flood at Mogollon Creek for example.

In the early 2000s, the USGS developed StreamStats, which is an interactive website where anyone can go and zoom in to a stream line of interest in New Mexico or any state that has a StreamStats application. You can zoom in to where you are interested and click on a point on a stream line, and StreamStats will delineate the upstream watershed area, and you can then download that basin area. StreamStats also computes different basin characteristics, like area, average rainfall, elevation, and other basin characteristics that are used in regional regression equations used to compute estimates of various streamflow statistics.

In New Mexico we have regional regression equations for computing flood frequency—the 100-year flood event, the 2-year, the 10-year, etc. We also have a regional regression equation for some low-flow statistics, but we do not have a regression equation for mean annual flow. Mean annual flow estimates will help us better understand how much water we have had on average in NM and provide a baseline for regional and statewide water planning efforts.

Our part, the USGS part, in the statewide water assessment was to develop a regional regression equation for estimating mean annual flow at ungauged stream locations. This is a three-part study over three years, so one year for each part. It is also a cooperative program with the USGS, which means USGS can match funding put in by WRRI providing double the bang for the buck, which is a benefit.

Part one, which was completed in 2017, was to isolate those stream gauges throughout New Mexico and surrounding areas that we could use for this study. They would have to be perennial streams that were unregulated. We identified 169 stream guages, and then computed mean annual flow for those gauges and also computed a giant suite of basin characteristics—anything that might be useful for doing a regional regression equation. It is pretty simple to batch compute these basic characteristics with the availability of modern geographical information systems tools. We computed 65 individual basin characteristics: annual rainfall, winter rainfall, spring rainfall, all measures of soil and landcover, etc. The first part of this study was published June 30, at the end of the state fiscal year, as a data release on the USGS ScienceBase-Catalog: https://www.sciencebase.gov/catalog/item/592ed653e4b092b266f13e39.

Part two will be to develop the regional regression equations, and part three will be to write up the analysis and publish it, so that equations are available to the public, and to integrate them into StreamStats. Once this is done, a user will be able to estimate mean annual flow at perennial streams anywhere in the state, at any boundary you are interested in. Mean annual flow is useful information for statewide and regional planning purposes when determining a baseline for how much water we've had on average in these channels throughout the state is needed, so very useful information for statewide and regional planning purposes. Thank you.

## Alex Rinehart, NM Bureau of Geology and Mineral Resources

*Alex Rinehart is a hydrogeologist in the Aquifer Mapping Program at the New Mexico Bureau of Geology and Mineral Resources (NMBG). His research interests focus on unexpected intersections between water science, and Quaternary geology, geophysics, data mining and rock mechanics. After graduating with a BS in mathematics from the University of New Mexico in 2004, he completed an MS in hydrology in 2008 at New Mexico Tech focused on snow. After earning his PhD in 2015 in geophysics at NM Tech, he was hired by the Bureau as a hydrogeologist in the Aquifer Mapping Program. He has led research in estimating groundwater storage change in the aquifers throughout New Mexico as part of the NM WRRI statewide water assessment. The goal of this effort is to generate data-driven, rather than model-driven, consistent estimates of water table changes and changes in the total groundwater storage of New Mexican aquifers.*

We—myself, Ethan Mamer, and Geoff Rawling—have been working on mapping groundwater storage change throughout the state for three years. Geoff did the study out in Clovis and Portales. He did that in 2017, partially with WRRI and partially with an aquifer lifetime map that he did for Clovis. We have done or tried to do groundwater storage change estimates for all of the unconfined basin-fill aquifers in the state. Ethan piloted the estimates for the confined and variably confined aquifers in the San Juan Basin and in the Pecos slope, and then Geoff and I did the Quay, Roosevelt, and Curry Counties and the Lee County areas and the southern High Plains.

Groundwater levels are going down across the state, where we have enough data to make the estimates (see Figure 1). The vast majority of the state does not have enough data to actually make these estimates. As Geoff told me during the poster session, we need to start saying, "We need tons more data!" The Aquifer Mapping Project with Sara Chudnoff and Stacy Timmons is working to fill some of these gaps in rural communities.

So the main point from this, and I'll have a few examples, is that if you have a trunk stream like the Rio Grande and you don't overpump your aquifer, the trunk stream will buffer the groundwater storage. If you overpump the aquifer and you have a trunk stream, then you essentially turn it into a closed basin. We've been mining the groundwater in closed basins throughout the state, especially out by Clovis and Portales. They've had about 8 million acre-feet lost over the last 50 to 60 years. The Mimbres Basin has lost about 3 million acre-feet. The Estancia Basin has lost about 1.5 million acre-feet.

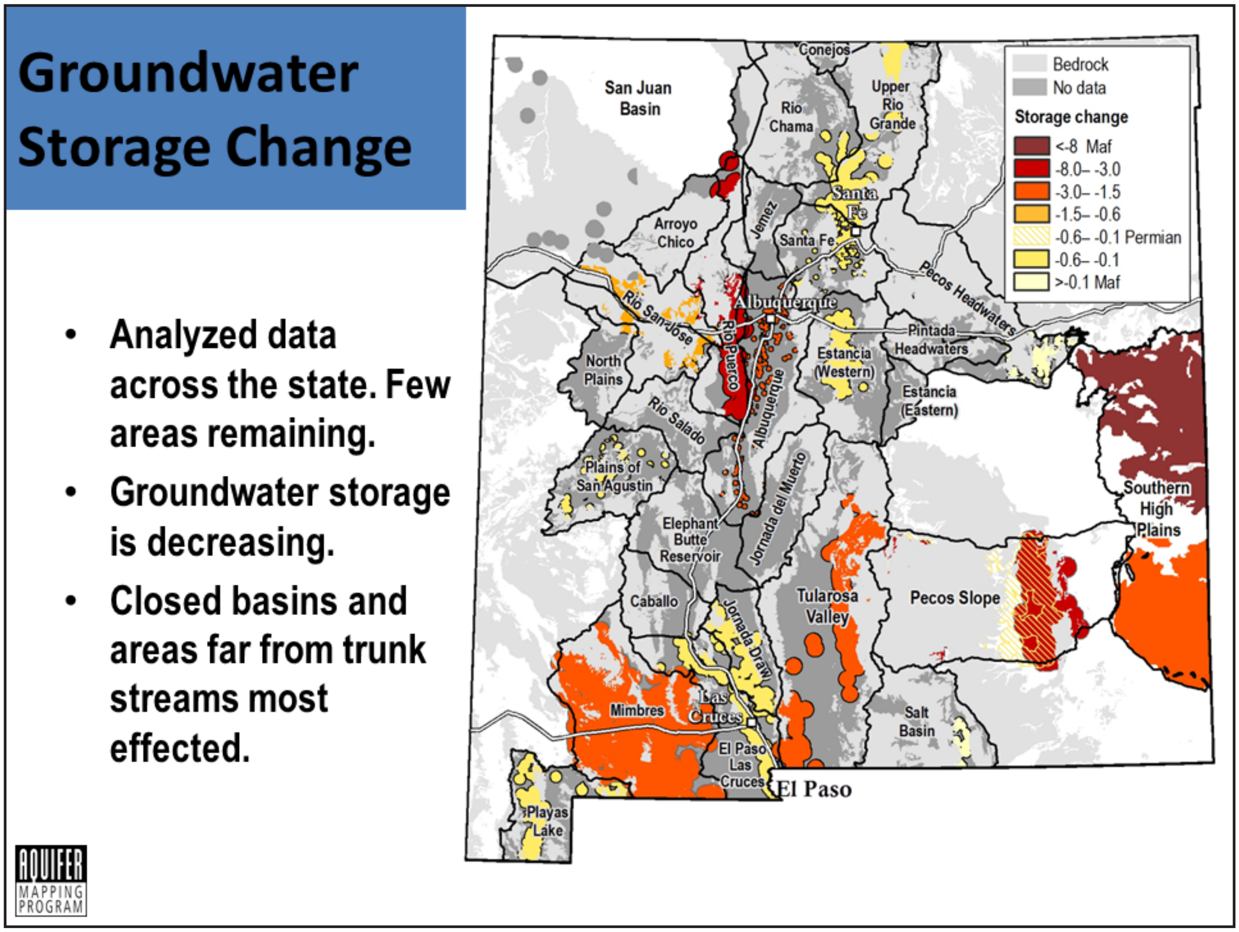


Figure 1. Groundwater storage change in New Mexico.

Figure 2 shows the Mesilla Basin, which is one of the more interesting stories that came out of this. The Mesilla Basin essentially had static groundwater storage since the 1960s—this is the flat part of the line—until the 2000s. Between 2003 and the middle of the 2010s, they lost about half a million acre-feet. That coincides with compact enforcement and reliance on groundwater pumping. You can see that drop-off clearly on a basin-wide average, and you can see the drop-off in map form on the right of Figure 2.

Then Estancia Basin, which is a closed basin, has been pumped steadily for the last 40 years. Over time the OSE and USGS have had increasingly restricted funding, and we have had increasingly sparse data. In some cases, we can no longer make consistent estimates today because the well networks have gotten so sparse. The Estancia Basin, since the 1950s until the 2000s, lost about 1.2 to 1.5 million acre-feet (Figure 3). Apparently in portions of the northern part of the Estancia Basin, they are essentially through their saturated thickness. They are looking for new groundwater resources to exploit.

Then there is the southern High Plains. Figures 1 through 3 have shown change maps. Figure 4 isn't a change map; it is probably the most important map I have. All the red areas have less than 30 feet of saturated thickness left in the Ogallala Aquifer, which is the only aquifer in the region. Thirty feet is the rule of thumb. It is the heuristic for the minimum saturated thickness required for large-scale, large-capacity irrigation pumps. The white areas are where there is either no saturation remaining or where there never really was consistent saturation. The red areas are where they are having trouble producing irrigation water. That is the primary economic driver of the region.

There is no surface water source. Lea County started out with a thicker saturated thickness. The aerial photos and satellite photos make it look like they have less center-pivot irrigation. They are more reliant on oil and gas. They are actively protecting their water resources from oil and gas exploitation for frack jobs, for slick water fracking. They have had some areas that have had substantial decreases. In the Quay, Roosevelt, and Curry County areas, they have had about 8 million acre-feet lost in the last fifty years.

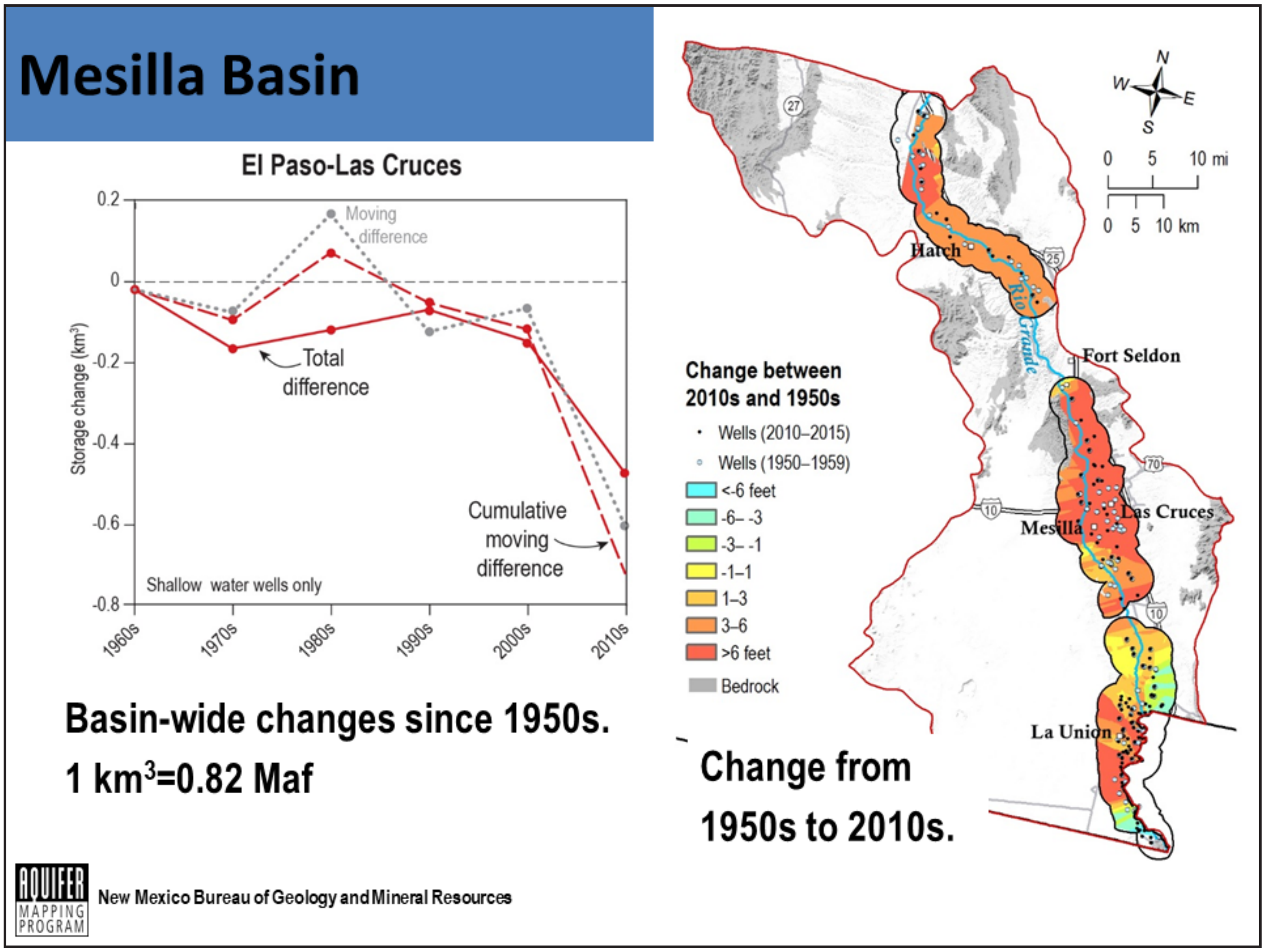


Figure 2. Groundwater storage change in the Mesilla Basin.

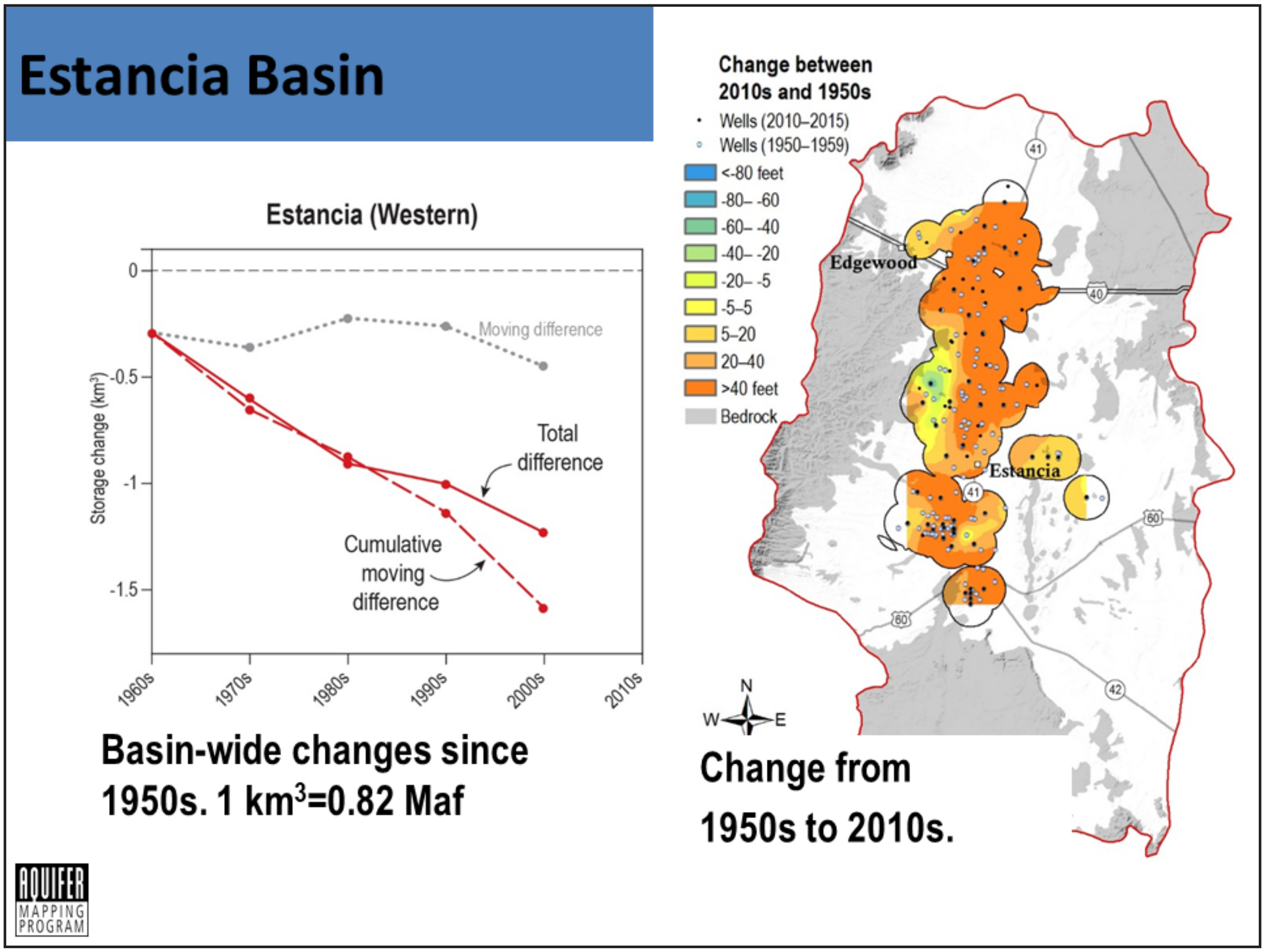


Figure 3. Groundwater storage change in the Estancia Basin.

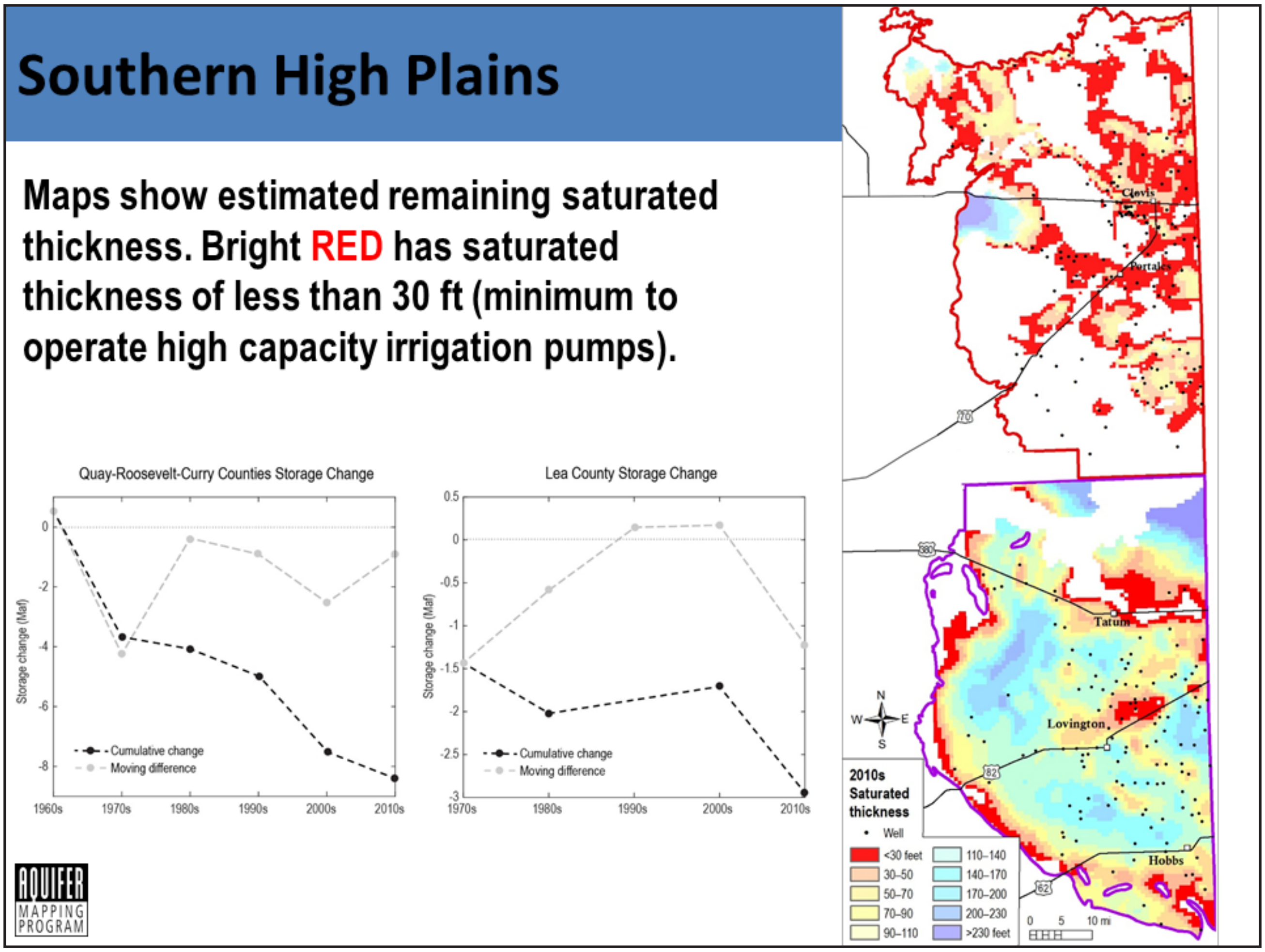


Figure 4. Saturated thickness of the Southern High Plains.

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## Jan Hendrickx, New Mexico Tech

*Jan M.H. Hendrickx is an emeritus professor of "critical zone" hydrology who has investigated the hydrology of the Earth's Critical Zone since the early 1970s. The Critical Zone is defined as the Earth's outer layer from the top of the atmospheric boundary layer through the vegetation canopy to the soil and groundwater that sustain human life. His critical zone hydrology experience is global from northeastern Brazil where he designed inexpensive trickle irrigation systems as an OXFAM volunteer to Mali and Pakistan where he led research projects for the Dutch government on how to improve irrigation and drainage water resources management. In 1990, he joined the faculty of the Hydrology Program at New Mexico Tech. His research efforts are focused on groundwater recharge in the southwestern USA, the application of geophysical methods in soil hydrology, and the use of remotely sensed satellite imagery for the mapping of evapotranspiration and soil moisture. He has authored or coauthored over 100 refereed papers and book chapters. He is Fellow of the Soil Science Society of America (2002) and Fulbright Scholar (2000).*

I will talk for a few moments about mountain evapotranspiration. Why do we have an interest in mountain evapotranspiration? The main reason to care with regard to the statewide water assessment is that most of the groundwater recharge occurs at higher elevations in the mountains. The difference between the amount of snow that falls there—precipitation—minus the evapotranspiration tells us what the groundwater recharge will be. Of course, runoff also has to be subtracted from the incoming precipitation. It is critical to have a good estimate for mountain evapotranspiration. It is not so easy.

Evapotranspiration is easy to determine in flat areas like the Mesilla Valley. We put a weather station here, and the measurements for this weather station will tell us in a circle of 30 or 40 miles what the air temperature is, the humidity, the incoming radiation, and so on. But in the mountains, like the San Gabriel Mountains in California shown in Figure 1, you would have to place a weather station at each elevation, also at each different slope and aspect, and so there would not be money enough to install all the weather stations we need.

Therefore, we have to come up with another method, and the only other method available is using a combination of remote sensing imagery and national weather databases, like the North American Land Data Assimilation System (NLDAS) database of NASA. However, this database gives you no point values at each point along the slope and elevation. It gives you an average value for a square of 12-by-12 kilometers. Also for the incoming radiation, we see that the south slope or the north slope will be very different, and so something else needs to be done.

What we have done is develop an algorithm that, first of all, will calculate the incoming radiation on each 250-by-250-meter pixel, and we can downscale that easily—the same algorithm—to 30-by-30 meters. And if you do that, you see that there is a great difference in the incoming radiation on the south slopes (shown in red on Figure 1) and the north slopes (shown in blue). Incoming radiation is the main driver for evapotranspiration because evapotranspiration needs energy to evaporate the water, and the more incoming radiation you have, the higher the evapotranspiration.

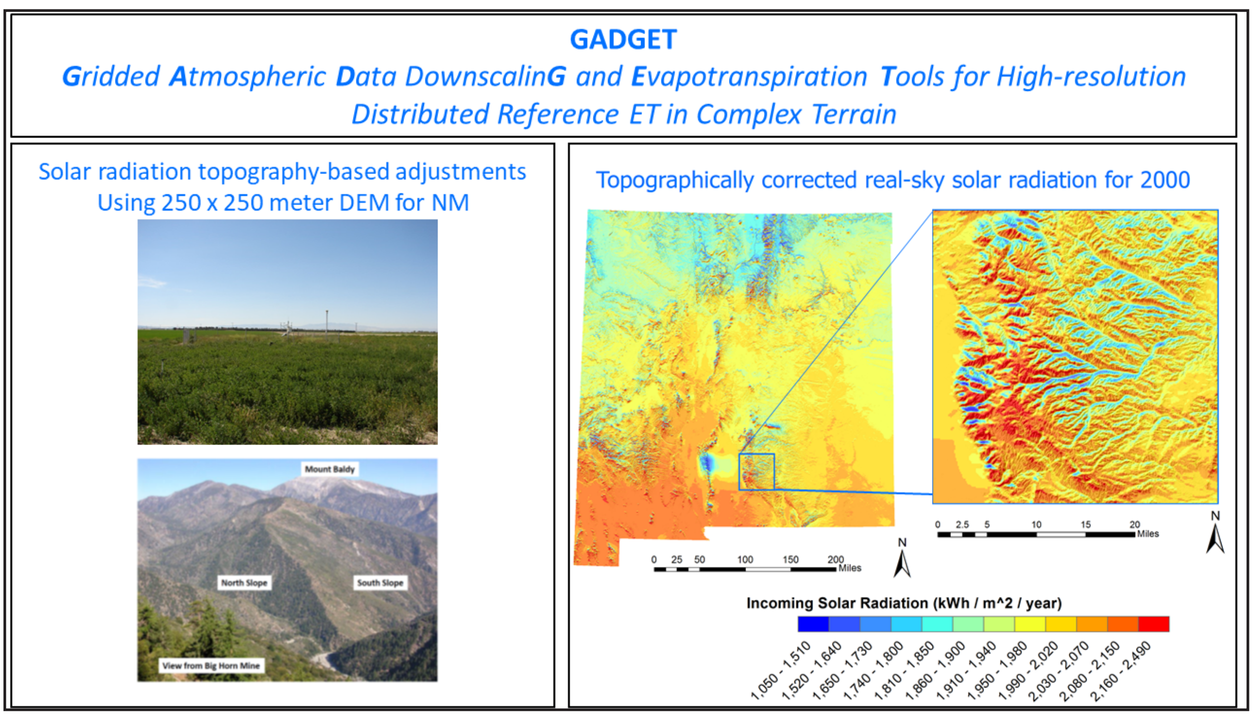


Figure 1. Measuring ET in complex terrain.

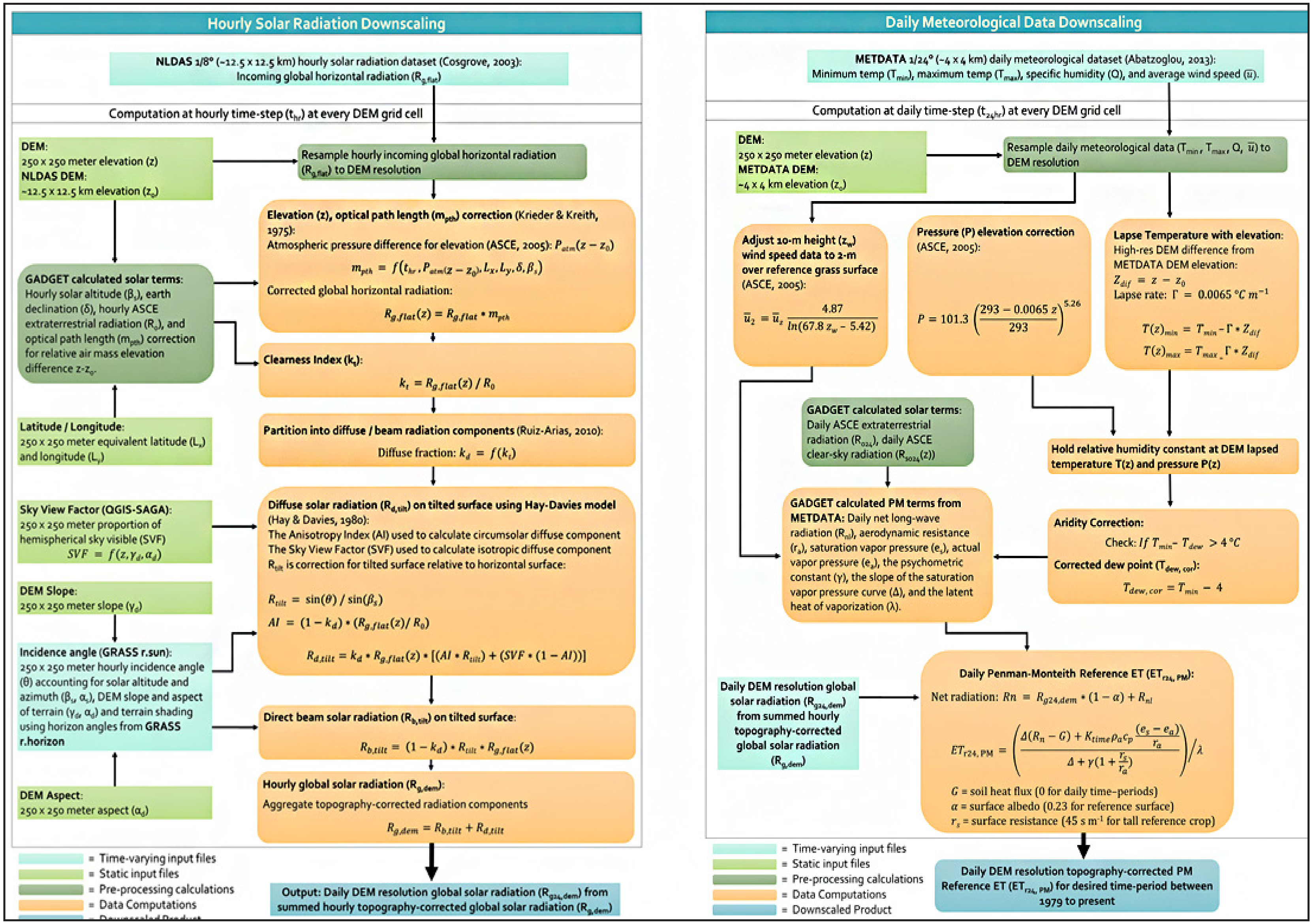


Figure 2. Hourly solar radiation downscaling.

Once we have the incoming radiation on the different slopes and aspects, we can take the weather database and downscale the air temperature to know at each location along a slope, at each elevation, what the air temperature is. We do that by assigning a lux rate, and we do something similar for the relative humidity of the air that also will change as a function of elevation.

Figure 2 provides a quick overview of what we are doing. On the left side, you will see hourly solar radiation. The incoming solar radiation is determined on an hourly basis, and then we sum it all up to a daily value, and then we combine the daily incoming radiation with daily downscaled values from the NLDAS database of air temperature, humidity, and also the wind speed, and that then gives us the reference evapotranspiration.

But we need the actual evapotranspiration (see Figure 3). We calculate the actual evapotranspiration by starting with the reference ET that we just calculated in the way that I described, then we need to know the basal crop coefficient. We estimate that from normalized difference vegetation index satellite imagery by multiplying it by 1.25 to give us the basal crop coefficient, and then we find the stress coefficient and the evaporative crop coefficient by running a simple soil water balance model called the Evapotranspiration and Recharge Model (ETRM), which Talon will discuss.

**The daily actual evapotranspiration ($ET_{c\,act}$) is**

$$ET_{c\,act} = K_{c\,act}ET_r = (K_sK_{cbr} + K_{er})ET_r \quad [1]$$

**where $K_{c\,act}$ is the "actual" crop coefficient that includes the effect of environmental stresses; $ET_r$ is the reference ET for a tall crop (mm/day); $K_s$ is a dimensionless transpiration reduction coefficient [0.0 - 1.0] that reduces $K_{cbr}$ when the average soil water content in the root zone is not conducive to sustain full plant transpiration; $K_{cbr}$ is the basal crop coefficient that represents the ratio of $ET_c/ET_r$ under conditions when the soil surface layer is dry, but where the average soil water content of the root zone is adequate to sustain full plant transpiration; $K_{er}$ is the soil evaporation coefficient that represents the majority of evaporation from soil following wetting by precipitation or irrigation.**

$$K_{cbr} \approx 1.25 \times NDVI_i \quad [2]$$

**where $NDVI_i$ is the daily Normalized Difference Vegetation Index.**

Figure 3. Calculating actual daily evapotranspiration.

# Talon Newton, NM Bureau of Geology and Mineral Resources

*Talon Newton, a hydrogeologist with the Aquifer Mapping Program at the NM Bureau of Geology and Mineral Resources, conducts research that is relevant to New Mexico's water supply and future water management. Talon holds a bachelor's degree in geology and a master's in hydrology from New Mexico Tech and a PhD in civil engineering from Queen's University Belfast. Over the last nine years, his projects have ranged from basin-scale hydrogeologic characterization to watershed scale ecohydrology. Talon uses a variety of hydrogeologic, geophysical, and geochemical techniques to evaluate various hydrologic processes. He has significant experience in the use of aqueous geochemistry and environmental tracers to examine soil water dynamics, recharge processes, and groundwater/surface water interactions. Current projects include the development of a soil water balance model to estimate groundwater recharge for the entire state of New Mexico, and the evaluation of impacts of the Gold King Mine spill on shallow groundwater near the Animas River in New Mexico. As an adjunct faculty member of the NM Tech Earth and Environmental Sciences Dept. Talon has advised several graduate students on their thesis research, and he provides presentations on numerous projects as public outreach to help the general public understand important water issues in New Mexico.*

Over the last three years, we developed the ETRM, which is a distributed soil water balance model at a resolution of 250 meters. We use daily precipitation data from PRISM to drive the model, and then we estimate ET as Jan Hendrickx just talked about. We also estimate runoff, and then we close the water balance to get deep percolation or recharge. The soil parameters such as storage coefficients and soil texture come from, at this point, existing GIS datasets.

Figure 1 shows what we have so far. We have a running model that shows in-place or diffuse recharge relative to annual precipitation between 2000 and 2013. This is the recharge from precipitation that falls on the ground and fills up the field capacity and then goes down below the soil to recharge the groundwater system. Not surprisingly, most of the recharge happens in the high mountains. As Jan was saying, that's why it is so important to understand or to estimate ET in the mountain areas, which is very challenging.

We designed ETRM in Python, and we're trying to design it to make it easily adaptable to other study areas and at different scales. One thing that makes this model stand out among similar models is the daily reference to ET that is corrected for topography, which Jan just described.

One of the main things we are doing is trying to add focused recharge—recharge that happens at perennial streams—which we're sure in many areas is very important here in New Mexico. It is kind of challenging. Figure 2 shows model estimates for the Rio Puerco watershed from 2000 to 2013. The green line is diffuse recharge, cumulative recharge as percent of cumulative precipitation. The blue line is our model runoff, and the red line is the measured discharge at the gauge near Bernardo. So we need to calculate the difference between our modeled runoff and the measured runoff, and we need to figure out how to distribute that as recharge and ET. But we can't even begin to do that until we know these numbers are accurate. We have tried to do some calibration and comparing our recharge and ET estimates to other recharge and ET estimates from different methods, but it is pretty difficult.

Next, our grad student Esther Xu is going to set up the ETRM for the Walnut Gulch Experimental Watershed, which is in Arizona. It is very heavily instrumented, and the topographic and geologic setting is similar to a lot of the rangeland here in New Mexico. We are hoping this will help us to get an idea of how to calibrate and validate some of these results.

As I said, we are working on focused recharge. We are working on improving our soil water parameter estimates and calibration and validation, and then we're also putting some work into adding the ability to forecast recharge rates for different scenarios, including climate change scenarios, land use change scenarios, different vegetation densities, and that type of thing.

I just wanted to acknowledge a few. There are so many people that we worked with on this project.

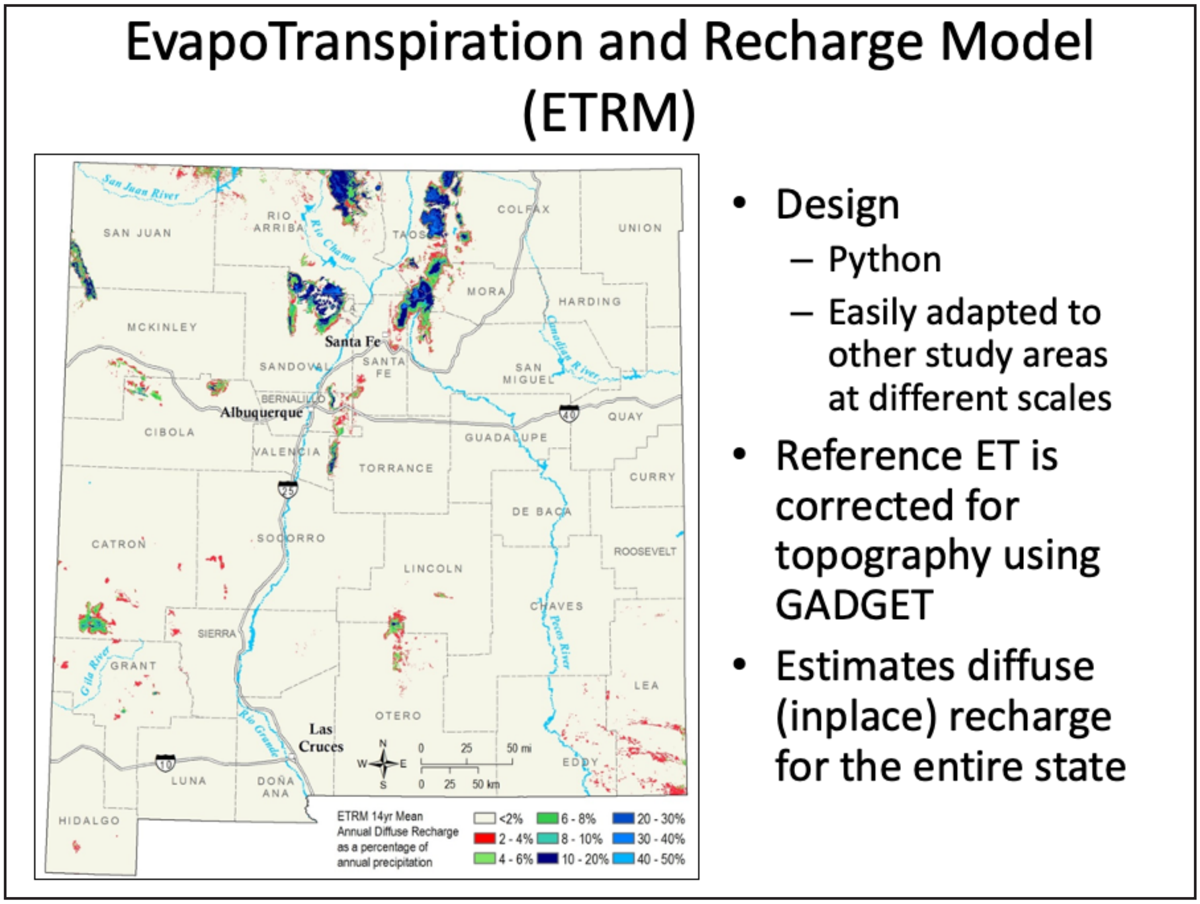


Figure 1. ETRM 14-year mean annual diffuse recharge as percentage of annual precipitation.

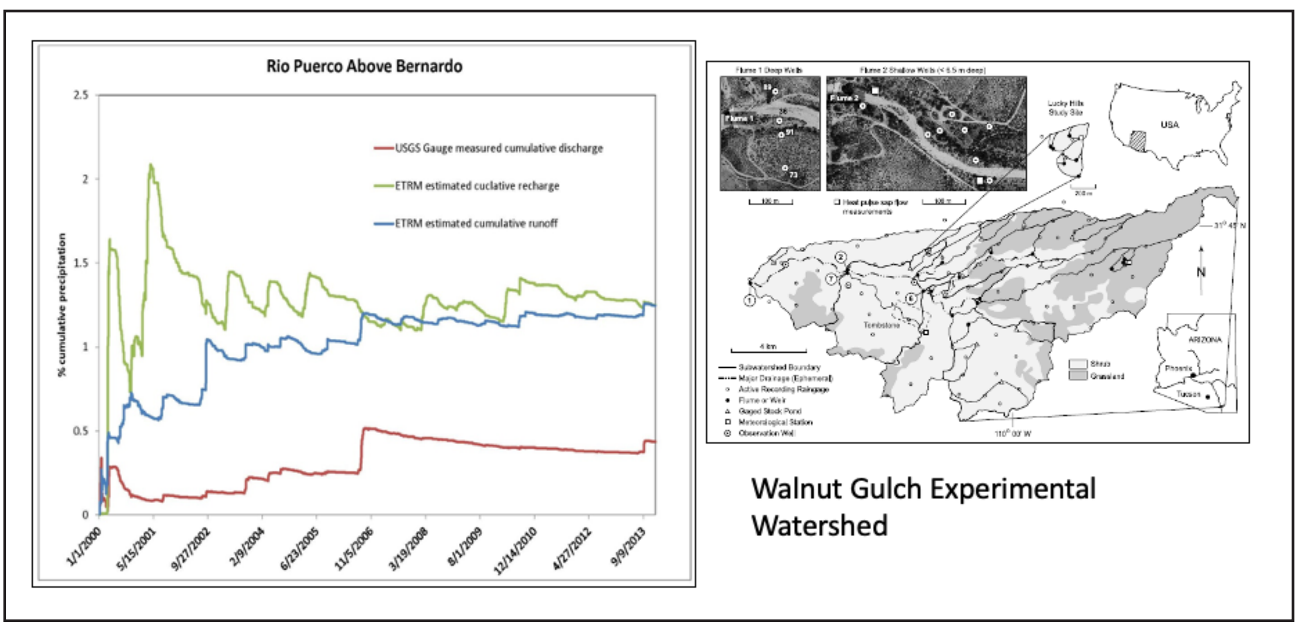


Figure 2. Calculating focused recharge.

That's what I really enjoyed about the statewide water assessment. It was this collaboration between all these different universities and agencies. I really want to thank Sam and WRRI for the funding and the WRRI staff. We've been working with them a lot. We've had over the last two years lots of meetings and conference calls. I'd also like to acknowledge the other people at New Mexico Tech directly involved in this: Fred Phillips, Dan Cadol, and Jan Hendrickx. And then we've funded four graduate students—David Ketchum, Peter ReVelle, Esther Xu, and Gabriel Parish. Gabe Parish and Esther Xu are still working on their master's degrees. I really hope this gets more funding, because I think it is a worthy project.

## Francisco Ochoa, NM Water Resources Research Institute

*Francisco Ochoa has a BA in geography, history, and Latin American studies from The University of Texas at Austin. Francisco works with the remote sensing of evapotranspiration (ET), focusing on researching and developing different ET models to implement across New Mexico. Francisco has been working along with Dr. Tom Schmugge, NM WRRI, validating and interpreting results from different ET models. Francisco's research interests include human-environment interactions, remote sensing, ET, environmental biophysics, and climate change*

I am a GIS analyst at the New Mexico Water Resources Research Institute. Today I'll be talking about the evapotranspiration component of the statewide water assessment. But before I jump in, I just want to give a huge thank you to our partners and collaborators from New Mexico State University, New Mexico Tech, National Oceanic and Atmospheric Administration (NOAA), US Department of Agriculture (USDA), and US Geological Survey (USGS), but above all, Dr. Tom Schmugge because without him, I don't think the ET project would have been able to reach the state it is in today.

So how do we do ET? Well, we map the invisible. We use remote sensing. Most of our modeling efforts, as Dr. Hendrickx said, are based on remote sensing, which is the observation of the earth from space-borne satellites. Onboard these satellites, there are different instruments that allow us to see different parts of the electromagnetic spectrum, and we're able to derive land surface temperature, various vegetation indices, sulfurous albedo, and emissivity, and we are able to see how that interacts with the actual physical environment.

We are also using a multidisciplinary approach. We consulted with various experts in ET. We had a whole ET conference about which model to use in New Mexico with experts in remote sensing and hydrology. We have also collaborated with federal agencies, such as the USGS, USDA, and NOAA. They've been really helpful in sharing their models. What's really neat is that the research we are doing is at the current edge of science. We're trying to produce the best and most accurate estimates for New Mexico. We're also trying to use the best technology that's available.

How do we calculate ET? Well, we have all these models. We have the Regional Evapotranspiration Estimate Model (REEM) from NMSU, produced by Dr. Zohrab Samani. We have the Mapping Evapotranspiration at high Resolution with Internalized Calibration model (METRIC) by Dr. Rick Allen at the University of Idaho. We have the ETRM produced here at New Mexico Tech by all of the wonderful faculty, and then we have the Simplified Surface Energy Balance model (SSEBop) from USGS produced by Dr. Gabriel Senay, and then the Atmospheric Land Exchange Inverse model (ALEXI) from the USDA and NOAA.

We have a lot of models. Which one works best? Well, during our validation process, we've come to the conclusion that these different models behave differently in different ecological zones. For example, REEM might work better in an agricultural area than, say, in a mountainous area. With that conclusion, we developed this joint ET model research approach. We basically divided New Mexico into irrigated lands and nonirrigated lands. For irrigated lands, we're using the Landsat version of the SSEBop produced by Dr. Senay. We're using that to calculate the ET in irrigated lands, and then we're going to use ETRM in nonirrigated lands to calculate ET there. The way we split these up is to use the USDA data crop layer, so we are able to produce a mass for irrigated and for nonirrigated lands across the state of New Mexico.

One of the products that came out of this project is the ensemble evapotranspiration tool. This tool is being coded in Python. It is still under development, but it is able to tell us mean monthly ET in irrigated and nonirrigated lands in the watersheds, the planning regions, and the New Mexico counties. It's a little hard to use if you don't really know Python, but we are trying to get it to work where you can use it in ArcMap or other GIS software.

What are the outcomes from this project? Well, we have a better resolution and understanding of our statewide ET in New Mexico. For example, Figure 1 is an ET map of the Mesilla Valley produced from Landsat. Blue areas represent higher ET, and then orange areas lower ET. This is at 30-meter resolution by the way. So we're able to produce higher spectral and temporal resolution data of ET from remote sensing, but what is also important is that we can start to incorporate that data into the New Mexico Dynamic Statewide Water Budget model for a better understanding of how our hydrological cycle works. What I think is most important, too, is that we are developing these tools and these ensemble methods that can eventually be used by stakeholders who want to map out and create water budgets for their planning regions, counties, or watersheds.

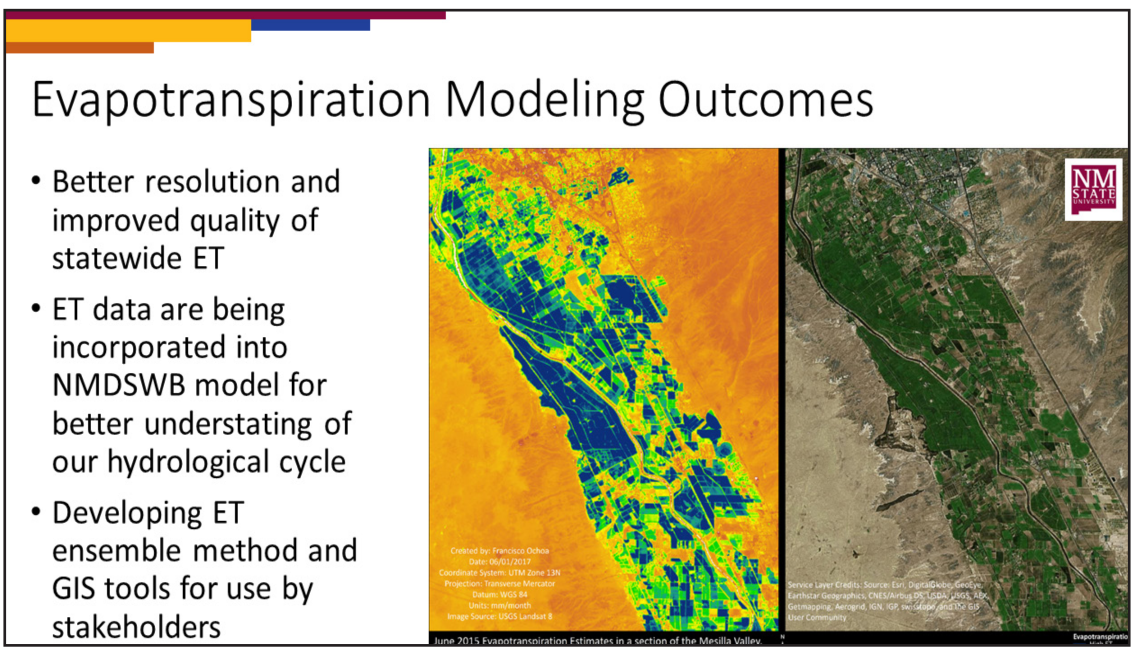


Figure 1. Evapotranspiration modeling outcomes.

# Austin Hanson, NM Water Resources Research Institute

*Austin Hanson is a research assistant with the New Mexico Water Resource Research Institute, where he is collaborating with others and working on the Dynamic Statewide Water Budget for New Mexico. His research interests include hydrology, Quaternary geology, and geomorphology. Austin has a BS in geology and is currently an MS candidate with the geology department at NMSU.*

I'll be talking about the interactive visualization tool for the statewide water budget model. Before I begin, I would just like to acknowledge some of the people who put in a lot of time and effort on this: Josh Randall, Fereshteh Soltani, Ken Peterson, and Jesse Roach.

One of the main goals of the statewide water budget is to provide information that can be used to inform water management. Figure 1 is from the Bureau of Reclamation, and it shows historical and future water supply in blue and historical and future water use in red for the Colorado River Basin. Really, the take-home message here is that water demand is expected to exceed water supply sometime within this century. We feel that the statewide water budget model can be used to show past and future trends, which can help predict where, when, and what sectors of water use shortages will be most prevalent in New Mexico's future. Hopefully the tool can be used to assist in the proper planning of water resources to avoid potential water shortages in the future.

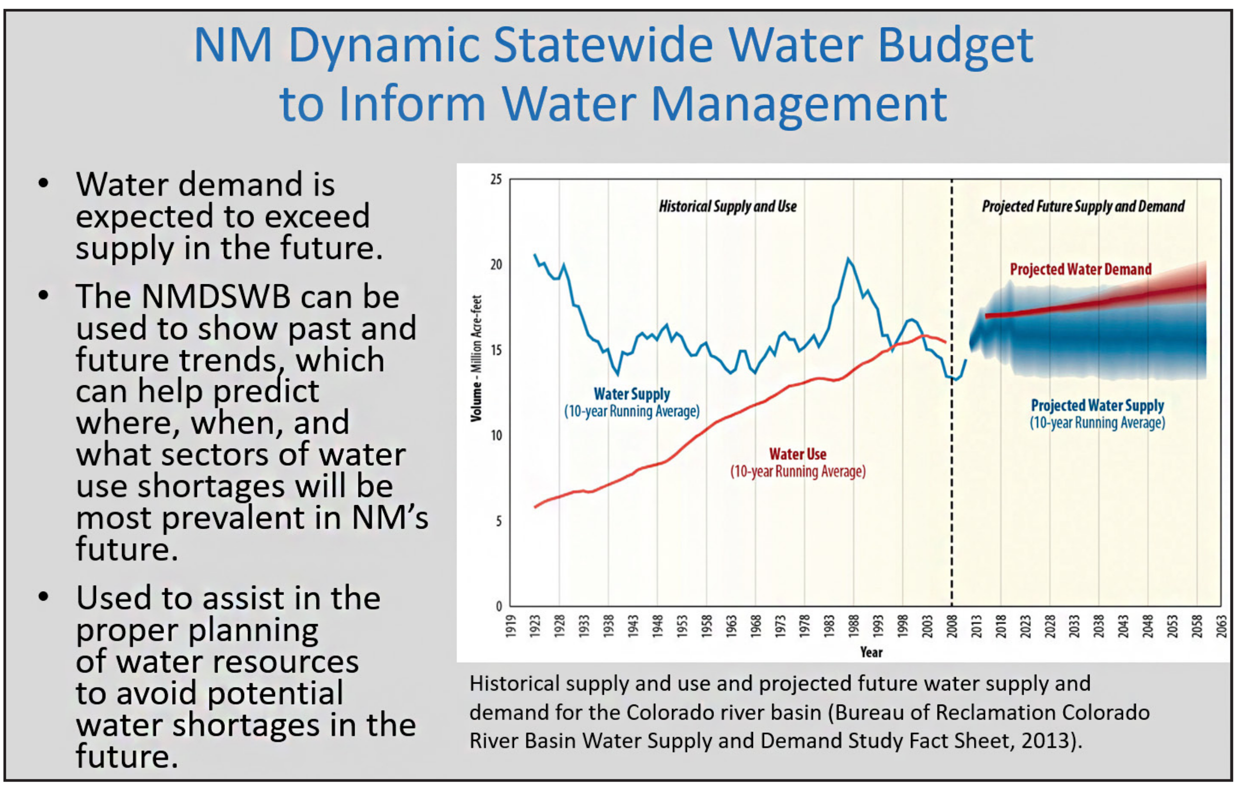


Figure 1. Historical and future water supply and use in the Colorado River Basin.

We are thankful for the funding that we have received from the state and from EPSCoR. More funding would be great. Because a model is only as good as the science that goes into it, I would just like to point out some of the sources of data currently used in the model, such as surface water flow statistics from the USGS and a population growth rate model from the University of New Mexico. We also use data from the OSE water use category reports. One of the goals too is to stay connected to the science. We would love to incorporate into the model everything that the people before me have been talking about and future efforts.

The model, like Ken said, takes a system dynamics approach and uses Powersim. Figure 2 is an example of a graphical user interface in Powersim showing statewide results for one potential future scenario. One of the problems with using Powersim to visualize the modeled results is that you have to reset the model before every run, which makes comparing multiple scenarios very difficult.

To address that issue, we ran the results for 60 different scenarios, and then we reorganized the roughly 95 million data outputs from that using MATLAB scripts, and we uploaded that into Tableau to create the interactive visualizations, and then we uploaded that to the website. As a result, users can compare multiple variables and scenarios for numerous spatial extents like Ken mentioned.

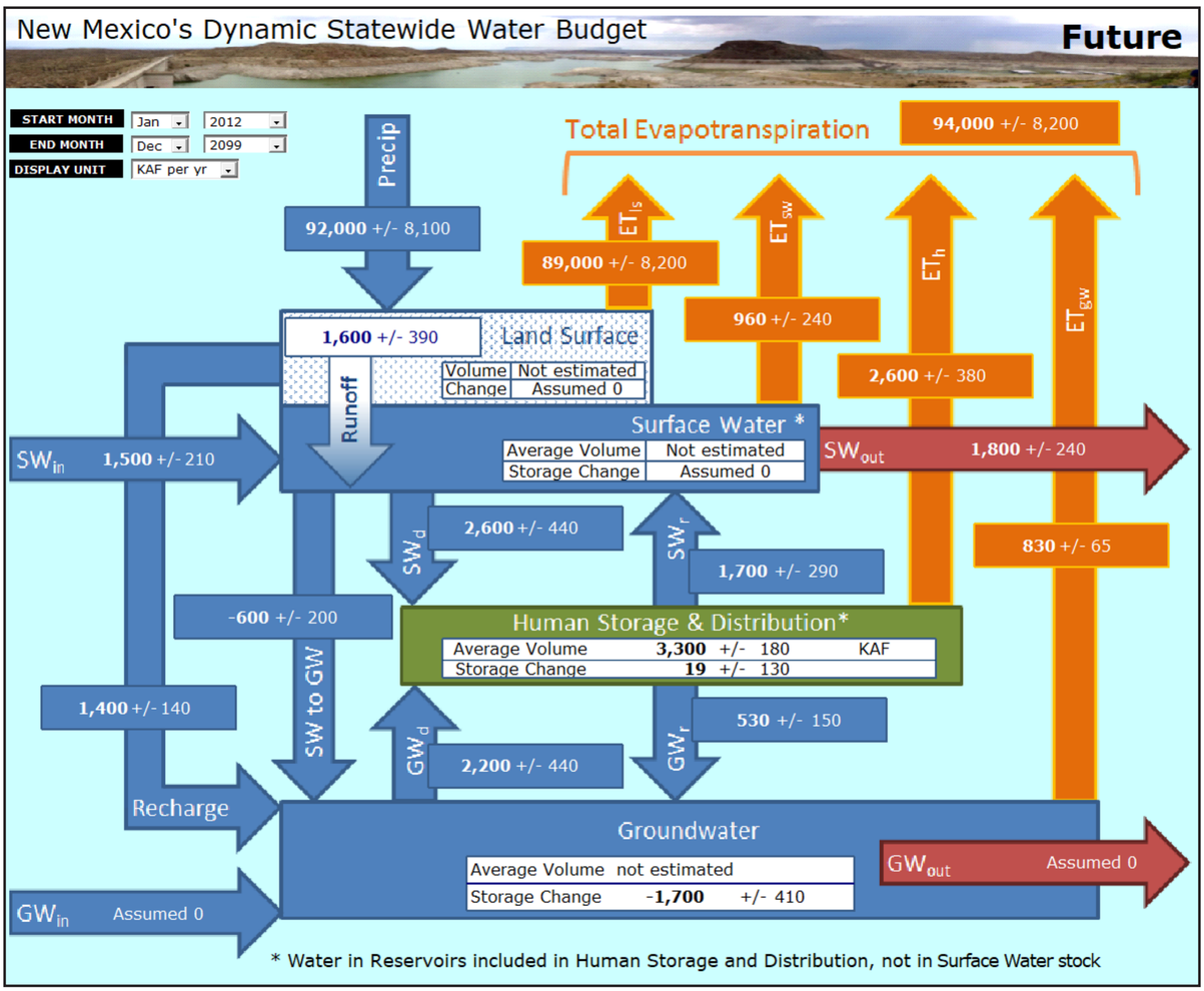


Figure 2. Graphical user interface (GUI) for the NMDSWB model. An example of a GUI in Powersim showing statewide results for one potential future scenario.

Figure 3 is an example that shows groundwater storage change for Bernalillo County. The historical estimates are shown in orange, ending in 2011, and hopefully we can bump that up here shortly. The future groundwater storage estimates are shown in two shades of blue, both of which are associated with the same climate model and the default population growth rate. The difference between the two is the water-use efficiency, where the dark blue model is associated with a high water-use efficiency and the lighter blue trend is associated with a low water-use efficiency. Overall, these results, with a couple of exceptions, show a negative groundwater storage change for Bernalillo County, and on average the difference between the high and low water-use efficiency is about 30 kilo-acre-feet per year.

This is just one example of what you can use. We're also going to have the modeled results available for download and a link to the technical report for those of you who want to get under the hood of the model. I think it is important that we keep the assumptions and limitations and uncertainties of the model as transparent as possible. I would also like to thank everyone that tried the model and provided feedback either online or during this conference. I had a lot of really good interactions with people, and the interactive tool is going to improve because of that.

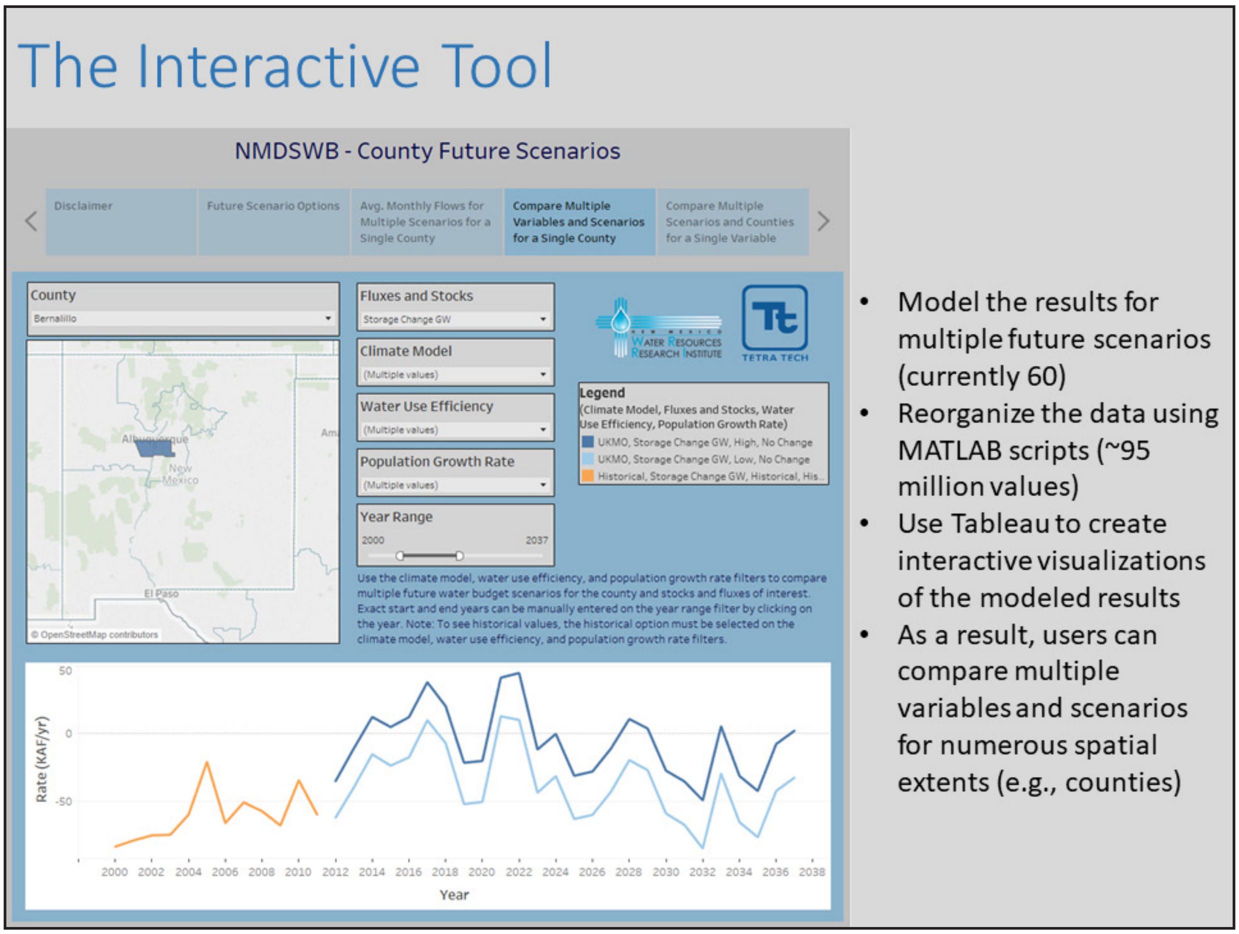


Figure 3. The NMDSWB interactive tool.

## Lucia F. Sanchez, NM Interstate Stream Commission

*Lucia Sanchez is the Water Planning Program Manager for the NM Office of the State Engineer/Interstate Stream Commission. Prior to her work in water planning, Lucia worked as the Planning and Zoning Director for Rio Arriba County. She has been involved in many land use projects including the oversight and coordination of development projects and land use plans for compliance with local, state and federal regulations. She also has prior land use and community development experience working for the NMSU-Cooperative Extension Service Northern New Mexico Outreach Project/Rural Agricultural Improvement and Public Affairs Project.*

*Lucia is a native of Alcalde, NM. Like several generations before her, Lucia is a farmer who raises many traditional agricultural crops and livestock with her family. For the past 13 years, Lucia has served her traditional community irrigation system as an elected official on the Acequia de Alcalde commission. The Acequia de Alcalde is one of many centuries-old irrigation and water governances systems in New Mexico. Lucia's earned degrees include a BA in anthropology and a BA in Spanish from the University of New Mexico. In 2014, Lucia was selected by the New Mexico Floodplain Manager's Association as Floodplain Manager of the Year for outstanding dedication and achievements displayed in floodplain management.*

I'd like to give you an update on the efforts related to regional and state water planning. I will provide an overview of where we are and how important our partnership with WRRI is on the statewide water budget.

Going back to the beginning, regional water planning began in 1987, and we have seen several images of what the 16 water planning regions look like throughout the state during today's presentations. The Interstate Stream Commission (ISC) led an effort over the last three years to update those regional water plans and they were recently completed and accepted by the ISC. When the first round of regional water planning began, it took some regions more than 10 years to complete their regional water plan. There was no common technical platform to compare data to. It was apples to oranges how each plan compared to an other. Now with the common technical platform used in this second round of regional water planning, we can compare apples to apples, and we have a better understanding of what is happening at the regional level. The regional water planning process was able to inform us about some of the key issues related to water planning across the state, including the statewide water supply and demand and information about the gap between the two. You have heard throughout the conference that by 2060 the demand for water is going to far outweigh the supply and this is very well a possible scenario.

We are relatively young in New Mexico when it comes to state water planning. The first state water plan was completed in 2003 in a fast and furious process under then Governor Richardson. I think I remember hearing that it took the agency eight months to pull it together, and it included 29 meetings across the state. Out of those meetings came several policy recommendations. Today, we are compiling that information from the regional water planning process, and we are integrating new information. State statute says the state water plan is supposed to be a strategic management tool. It is supposed to be something that helps people on the ground, the grassroots, those water managers, get projects done.

Hopefully legislators can start understanding all the work that we're doing collectively—like what we have heard throughout the last three days—and be able to apply it, whether it is to advocate for changes in existing laws, create new laws, develop new policies, fund projects or support the water budget for whatever people want to use the tool for. Everybody knows that you use the hammer to drive a nail into a board. That's really what is implied, but if you lock your keys in your car and all you have is a hammer and no cell service and New Mexico is quite rural, you're going to get that hammer and you're probably going to break a window. People use tools for different uses. People may intend to use the water plan in a variety of ways. What we want to do is make sure that there is valuable information in the state water plan that people can use for implementation or innovation, to create new projects or to get projects going on the ground.

Back in December 2016—I came on board with the Interstate Stream Commission in November—I met up with Sam Fernald immediately, and we started hearing about the water budget, the project he was working on. Our collaboration has bloomed from there. We see the state water plan being a living document, not a doorstop, not a big thick document that someone throws on the shelf and forgets about until they need to look something up to be able to make their case on any particular topic. We want to make sure that people can go to the state water plan and be able to have valuable, useful information.

The New Mexico Dynamic Statewide Water Budget is one of those tools that we will feature in the state water plan. We already had presentations from Stacy Timmons from the NM Bureau of Geology and Mineral Resources (NM&BGMR) and the team at the Bureau of Geology who have—you saw today and yesterday—a whole bunch of resources and links. There is a gap right now for our water users on the ground, those parciantes, those irrigators, those small system water operators who are raising grandkids, taking care of aging parents, who work in Los Alamos or Santa Fe, who commute to Sandia. People are commuting to these jobs, and they are still managing that sense of community at home. How do we get them the tools they need to manage water now and into the future? I see the state water plan being that translator of information. All the good work you are doing here today is critical to our water future, we hope to gather so we can compile in a list of resources, so that once that state water plan is complete—which we hope to have done by the end of calendar year 2018—we go out and start telling folks, "Did you know . . . ?"

There is a lot of information we have learned today and throughout this conference that water managers on the ground might not necessarily know a whole lot about, but they have an inclination for managing water. You don't hear about all the conflicts that happen on acequias in times of drought too often because neighbors know how to be neighbors in many of our traditional communities. I think there are lessons to be learned from the grassroots up and from the top down. The state water plan should really be the tool that brings that information into the private sector. That is where we support the work that Sam is doing, and we want to feature the NMDSWB model as a web-based, living component of the state water plan website. As the model changes, as it evolves, as it improves, then we're also able to update it in real time and then be able to get that information back to folks.

We are learning new information outside of the regional water planning process. We had a comparative analysis of planning in seven western states, and New Mexico, compared to our seven western states, barely invests a drop in the bucket in planning or in water resource management. Hopefully, through this planning process, we can bring attention to how important it is to invest in water for our future. We've got new information on public water systems. We've developed a couple white papers in recent months, and we hope to get that information back to you all.

We've had a lot of discussion about what the regional water planning boundaries should look like, and when we took that out to the public, we ended up all over the map. Should we go by hydrologic boundaries, or should we go by political boundaries? Should we go by county boundaries? We are already doing that preliminary work to look at what the boundaries look like and what the most efficient way to plan is, and then also leverage the resources that we have. I am the program manager, and I have one planner in Santa Fe. For us to be in all places at all times is ridiculous. That is where we see the value in partnerships with New Mexico State University and New Mexico Tech and the Bureau of Geology and the other partners we have.

Some new information I thought you would find interesting is on the key collaborative project types. We talk a lot about collaboration, and especially in times when funding is limited. When a project is three-fourths of the way down the road and then funding stops, that is just heartbreaking. That wasn't my funding at the ISC that got cut. It was Sam's. When Sam is not able to finish his program, it hurts all of us because we depend on that data and we are project partners. I think it is really important that we look at these key collaborative project types that came out of the regions and we figure out where we can leverage best practices to finish the implementation of projects already started. There are a lot of projects on the ground.

We saw it in the project list that came out of each of the regional water plans, but I am going to go in reverse from number six to number one of what key collaborative project types folks felt from the region were important.

Water policy came in at number six priority, the need for state and local ordinances and guidelines for voluntary programs to improve water management. I see a direct correlation that has not been overtly expressed in the conference this week: the tie of water management to land use and how much say local land use officials have in how they see their communities grow. Now, communities are statutorily authorized to have zoning codes and to create their land use. Not every community wants an Intel or could house an Intel, and they say that through their comprehensive plans, so making sure that the state water plan complements comprehensive plans and natural resource plans is our goal. We want to see what new policies could come out of our discussions going forward. We are looking to have a statewide town hall, hopefully you'll all be a part of it, to help guide and direct policies into the future for the state to consider. There will be more information coming out on that. Policy development was number six in project types.

Regional water planning implementation was next. Regional water planning has been completed, so what now? You hear everybody saying we don't have the people or we don't have the funding, but we definitely have commonalities across the regions where we can forge partnerships. When we look at watershed management, we can start looking at some of these regions and these towns with water quality and watershed restoration issues and start to pair people up with potential resources. We see the state water plan bringing people together on that front.

The fourth one was water conservation projects. People had projects in the works related to wastewater reuse.

Number three was infrastructure. There are big costs related to infrastructure projects. The delivery and treatment of regional water projects across New Mexico are very expensive. We have a lot of bright minds ready to do the work, but there is no money to get the projects off the ground. There have been many engineering reports and documents that support project development. Not being able to aggregate resources where necessary in a community where you don't have a water operator or a bookkeeper could keep small water systems from getting off the ground. There were a lot of project types coming out of the regions related to water infrastructure and those associated needs.

Number two was watershed management, including forest thinning and restoration, and habitat and riparian wetland restoration. That was a big one. For several months, we all smelled the smoke in the air and definitely had concerns about what makes New Mexico, New Mexico if not the landscape and the need to protect our watershed.

Number one ties us back to today's meeting and this conference. The number one key collaborative project type that came out of all the regions was the need for data collection and monitoring, aquifer mapping, groundwater level monitoring, groundwater modeling, and data collection efforts across the entire state—a better understanding of our groundwater resource. I think we all have gaps in our understanding of that resource, but the need to advocate for more funding, better data collection, and continuity in project funding is a big concern. I'm here to encourage you all to continue to be involved in the development of the policies for the state water plan and to tell you that you can continue to promote the work you are doing through our effort to update the state water plan.

My colleague Myron Armijo is here today. We also have a component regarding consultation with the tribes, nations, and pueblos. We'll be going out to the communities and talking to those leaders, seeing how we can improve their understanding of water resources or how we might leverage projects and opportunities. We're going to be out and about, but I want to invite everybody to the statewide town hall on policy development. That's going to be really important going forward, so that we can start to close that gap between supply and demand by 2060. We are really excited to be a partner with WRRI and see the NMDSWB model continue to evolve and be able to feature it as one of many tools in the state water plan. The people who aren't here today and don't run in our circles don't know about all the great work happening, and I think we could get more support from folks in the community at that grassroots level when they rise up and know what's happening and can tap the information. With that, thank you.

# 62nd Annual New Mexico Water Conference Poster Abstracts

## Legacy Molybdenum Mine Tailings in the Context of the Questa Caldera: Distinguishing Anthropogenic from Background Water Types

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## Poster Abstract 1

Questa is located near the confluence of the Rio Grande and Red River in north central New Mexico. Domestic supply wells in the area access waters collected and transmitted by the watershed in the adjoining Questa caldera, which also hosts an inactive molybdenum mine. Most wells are located in the rift- fill aquifer; a considerable subset monitors groundwater around a mine tailing facility. Some access a volcanic aquifer associated with the Red River spring zone.

We have evaluated three sets of data: (1) from New Mexico Bureau of Geology and Mineral Resources (NMBGMR) sampling during 2015 (2) current tailings facility monitoring data from the New Mexico Environment Department (NMENV), and (3) 2005 USGS mountain block aquifer data.

Regionally, sulfate and calcium are strongly correlated with total dissolved solids (TDS) loads. Constituents of concern at the Questa mine tailings facility superfund site include molybdenum, uranium, and sulfate. Wells completed in the mountain block discharge weathering products with elevated concentrations of trace metals. Alluvial aquifer wells up gradient of the tailings facility generally have low TDS, but may have elevated levels of some metals including uranium, complicating separation and mixing analysis in relation to contaminant loading.

Traditional water source evaluation methods in conjunction with grouped regression led to identification of important chemical tracers for hydrogeological processes and aquifer groups. Incorporation of stable isotopes analysis improves the ability of statistical techniques to distinguish between aquifers and water types.

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# Binational Aquifers of the Mesilla Basin Region—Hydrogeologic Realities and Groundwater-Development Potential

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## Poster Abstract 2

Groundwater-development potential in the context of 2017 hydrogeologic reality is the theme of this overview of binational aquifer systems of the Mesilla Basin region New Mexico, Texas, and Chihuahua-Mexico. The selected maps, cross sections and block diagrams schematically illustrate basic hydrostratigraphic, lithofacies, and structural-boundary components of the region's hydrogeologic framework at a compilation scale of 1:100,000. They are the product of more than five decades of multi-disciplinary/institutional studies coordinated by the NM Water Resources Research Institute; and reflect the work-in-progress nature of all such types of geology-based water-science endeavors.

Thick Rio Grande rift-basin fill of the Upper Cenozoic Santa Fe Group (SFG) and thin alluvial deposits of the Rio Grande's Mesilla Valley form the primary aquifer systems. Past and current groundwater-resource development is sustained by 1) perennial recharge from the Rio Grande and a few higher-mountain watersheds, and 2) mining of the large quantities of fresh to moderately brackish water (<5,000 mg/L tds) stored in SFG basin fill. A conservative estimate of recoverable groundwater reserves of this quality range in basin areas west of the Rio Grande is about 80 $km^3$ ($65x10^6$ ac-ft). However, much of the recharge to the aquifer system occurred during Late Pleistocene- Early Holocene high stands of pluvial-Lake Palomas in Chihuahua's Los Muertos Basin, which is located about 65 km (40 mi) southwest of El Paso. The lake's source watershed was about 70,000 $km^2$ (27,000 $mi^2$); and at its highest level of 1,210 m (3,970 ft) amsl, lake-surface area exceeded 7,000 $km^2$.

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# Isotopic and Geochemical Groundwater Characterization in the Mesilla Basin, New Mexico

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## Poster Abstract 3

Groundwater geochemical and isotopic data have been collected to estimate the age, residence time, sources, and mixing of groundwater at various depths within the Mesilla Basin aquifer system. The objective of the study was to use the aqueous isotopic and geochemical data to characterize the deep groundwater system in the Mesilla Basin. Several groundwater wells were sampled, and the water samples characterized using a number of isotopic and chemical analyses. The age dating results indicate that the Mesilla Basin aquifer system contains groundwater of both relatively young and older ages. The concentrations of the radioisotopes of carbon ($^{14}C$) and tritium results indicate a large range of modeled ages in the groundwater, it suggests that half of the samples have >50% modern water. Noble gas isotope age dating indicated that groundwater at well 310 feet depth (LC-2A) was ~8 years old and groundwater at well 650 feet depth (LC-2F) was ~50-90 years old. There were also significant variabilities within the groundwater geochemistry. Many of the analytical results had standard deviation values that were equal or larger than the mean values. These results suggest significant spatial variability in the aqueous geochemistry of the groundwater within the Mesilla Basin, which has implications for various flow, transport, and geochemical processes. Quantifying these processes and evaluating the groundwater residence time is critical for sustainable management of groundwater.

Keywords: Mesilla, groundwater, geochemistry, isotopes, water quality

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# Nitrogen-Doped Graphene and Aminated Graphene Catalysis of Persulfate Activation and Emerging Contaminant Degradation in Wastewater

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## Poster Abstract 4

We evaluated three types of functionalized, graphene-based materials for activating persulfate (PS) and removing (i.e., sorption and oxidation) sulfamethoxazole (SMX) as a model emerging contaminant. Although advanced oxidative water treatment requires PS activation, activation requires energy or chemical inputs, and toxic substances are contained in many catalysts. Graphene-based materials were examined herein as an alternative to metal-based catalysts. Results show that nitrogen-doped graphene (N-GP) and aminated graphene ($NH_2$-GP) can effectively activate PS. Overall, PS activation by graphene oxide was not observed in this study. N-GP (50 mg $L^{-1}$) can rapidly activate PS (1 mM) to remove >99.9% SMX within 3 hours, and $NH_2$-GP (50 mg $L^{-1}$) activated PS (1 mM) can also remove 50% SMX within 10 hours. SMX sorption and total removal was greater for N-GP, which suggests oxidation was enhanced by increasing proximity to PS activation sites. Increasing pH enhanced the N-GP catalytic ability, and >99.9% SMX removal time decreased from 3 hours to 1 hour when pH increased from 3 to 9. However, the PS catalytic ability was inhibited at pH 9 for $NH_2$-GP. Increases in ionic strength (100 mM NaCl or $Na_2SO_4$) and addition of radical scavengers (500 mM ethanol) both had negligible impacts on SMX removal. With bicarbonate addition (100 mM), while the catalytic ability of N-GP remained unaltered, $NH_2$-GP catalytic ability was inhibited completely. Humic acid (250 mg $L^{-1}$) was partially effective in inhibiting SMX removal in both N-GP and $NH_2$-GP systems. These results have implications for elucidating oxidant catalysis mechanisms, and they quantify the ability of functionalization of graphene with hetero-atom doping to effectively catalyze PS for water treatment of organic pollutants including emerging and recalcitrant contaminants.

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# Numerical Simulation of the Potential for Induced Groundwater Salinization and Land Subsidence upon Extraction of Brackish Water

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## Poster Abstract 5

New Mexico (NM) has been in a long-term drought that could impact sustainability of the agricultural industry as well as drinking water supply, and a desalination plant is proposed (i.e., Santa Teresa) as an alternative (i.e., brackish) water use. Producing "new/alternative" water from unused brackish zones is attractive for augmenting drought and to support water resource development. However, we do not know what impacts this will have on the hydrologic system (e.g., drawing fresh water into saline formations or land subsidence). The potential impacts of the pumping of brackish water have not been thoroughly investigated by prior researchers, although two potential impacts have been commonly examined along coastal areas with significant groundwater production, which include the increased salinization of fresh groundwater (i.e., saltwater intrusion) and the occurrence of land subsidence. We hypothesize the extraction of brackish water could potentially induce land subsidence and impact the salinity of fresh groundwater resources. To examine this hypothesis, a brackish water and fresh water multi-aquifer model has been developed simulation of a wide range of groundwater pumping rate scenarios. The groundwater numerical model solves coupled equations for variable-density groundwater fluid flow, reactive transport, and geomechanical deformation. With the simulation results, this work aims to quantify the potential for induced salinization of groundwater and land subsidence due to increased production of brackish water for nontraditional water uses including desalination.

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# Nonaqueous Phase Liquid Solubilization and Soil Adsorption Behavior of 1,4 Dioxane and Trichloroethylene Mixtures

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## Poster Abstract 6

Groundwater contamination often occurs with mixtures of contaminants, and the interactions of contaminants within multicomponent systems can impact the transport behavior of contaminants in the subsurface. Solvent stabilizer 1,4-Dioxane, an emerging recalcitrant groundwater contaminant, was commonly mixed into multicomponent nonaqueous phase liquids (NAPL) containing chlorinated solvents such as trichloroethylene (TCE), and the impact of co-disposal on contaminant transport processes remains uncertain. Thus, batch equilibrium experiments were conducted with variations in 1,4-dioxane and TCE compositions to evaluate impacts on NAPL component aqueous dissolution and sorption to solid-aquifer sediments. The solubilization results indicated deviations from Raoult's Law. 1,4-Dioxane is miscible with water, but the solubility of TCE increased with increasing amounts of 1,4-dioxane, which suggests that 1,4-dioxane acts as a cosolvent causing solubility enhancement of the co-contaminants. Linear equilibrium sorption partitioning coefficients ($K_d$) were also measured with variations in 1,4-dioxane and TCE compositions, and the findings indicate that both contaminants adsorb to aquifer sediments with sorption coefficients that increased with increasing organic matter content. However, the sorption coefficient for TCE decreased with increases in 1,4-dioxane concentration, which was attributed to the cosolvency impacts on TCE solubility. These findings support our understanding of the mass-transfer processes controlling groundwater plumes containing 1,4-dioxane within the subsurface and also have implications for remediation 1,4-dioxane contamination.

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# Manganese Dioxide Activation of Sodium Persulfate for Contaminant Oxidation

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## Poster Abstract 7

Contaminants in drinking water and groundwater are often a concern for water resources and a cause of environmental impacts. Sodium persulfate is an important oxidant for contaminants, but must be activated to increase its effectiveness for the degradation of recalcitrant organic contaminants. Ferrous iron is one of the most widely used activation agents, and it has been proven effective particularly for above-ground applications. However, its effectiveness is often limited in subsurface applications because of aqueous-availability constraints associated with iron speciation and cycling. This project investigated alternative redox activation agents, permanganate and manganese dioxide, for persulfate activation and transformation of 1,4-dioxane as our model wastewater or groundwater contaminant. Batch reactor experiments were conducted to measure the kinetics and loss of persulfate and 1,4-dioxane, with and without permanganate or manganese dioxide. Our results show that 1,4-dioxane oxidation followed first order kinetics, and the activation of persulfate by manganese was confirmed by comparing rate coefficients for 1,4-dioxane destruction, measured loss of persulfate, and measured increased concentrations of sulfate. It was also observed that as the oxidant-to-contaminant ratio was increased, the 1,4-dioxane decay rate coefficient also increased. The rate coefficient of 1,4-dioxane degradation increased with increases in the amount of manganese. In addition, the magnitude of the increase in the rate coefficient was greater when manganese was in aqueous form (permanganate) rather than as a solid phase ($MnO_2$). These results have implications for applying in situ chemical oxidation in subsurface systems, especially for conditions wherein significant quantities of manganese exist in groundwater and aquifer minerals to support possible natural persulfate activation.

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# Using Contaminant Mass Discharge and Attenuation Rate Analysis to Develop Pump-and-Treat Remediation System Closure Criteria for Transition to Monitored Natural Attenuation

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## Poster Abstract 8

Contaminant mass discharge (CMD) analysis is an effective tool for characterizing groundwater contaminant transport and evaluating pump-and-treat (P&T) remediation system performance. Attenuation rate constant calculations are regularly used to evaluate natural attenuation of groundwater contamination plumes. Combining results from CMD and first-order rate constant attenuation rate analysis can provide the data necessary to optimize P&T system operation or support transition of P&T remediation to monitored natural attenuation.

Trichloroethylene (TCE) concentration data from two P&T systems and the additional site groundwater monitoring network at the NASA White Sands Test Facility (WSTF) were analyzed using CMD, attenuation rate, and whole plume characteristics analysis. Spatial and temporal contaminant attenuation rate coefficients were calculated within different plume areas, and CMD was calculated at the P&T extraction wells for both systems. Temporal CMD results were analyzed, before and after P&T system startup, to assess remediation system performance. Calculated CMD results at plume transects were compared to the amount of TCE removed at each P&T system to assess plume behavior in response to P&T system operation. Average concentration, total plume mass, and weighted mean center of temporal TCE concentrations were examined as whole plume characteristics. P&T closure criteria was developed using results from the analysis. Results indicated that CMD from the source areas was comparable to the natural attenuation rate of the WSTF groundwater plume prior to P&T operation and that the temporal decrease in total mass exceeded mass extracted at the P&T systems.

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# Cyclodextrin Stabilization of Advanced Oxidation of 1,4-Dioxane and Co-Contaminants Using Aqueous Ozone for Contaminated Groundwater Treatment

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## Poster Abstract 9

Recalcitrant emerging contaminants in groundwater, such as 1,4-dioxane, require strong oxidants for complete mineralization, whereas strong oxidant efficacy for in-situ chemical oxidation (ISCO) may be limited by oxidant decay, reactivity, and non-specificity. We examined hydroxypropy-β-cyclodextrin (HPβCD) for aqueous ozone ($O_3$) stabilization, and its impact on $O_3$ reactivity with contaminants was evaluated in well-mixed reactors and soil-column experiments. The degradation kinetics of 1,4-dioxane, trichloroethylene (TCE), and 1,1,1 trichloroethane (TCA) by $O_3$ in single and multiple contaminant systems, with and without HPβCD, were quantified. Experiment results showed that $O_3$ and contaminants all form inclusion complexes with HPβCD. The contaminant decay rate constants for $O_3$ in HPβCD increased compared to the rate constants without HPβCD. This suggests the formation of ternary complexes with HPβCD, oxidant, and contaminant. In presence of chlorinated co-contaminants, the degradation rate constant of 1,4-dioxane was higher than in absence of co-contaminants. Additionally, experiments with increases in ionic strength (50-100 mM NaCl) had increased degradation rate constants of contaminants for both single and multiple contaminant systems. Upon addition of $NaHCO_3$, the degradation rate constants for 1,4-dioxane with HPβCD decreased with increasing pH for TCE and TCA. This is in contrast to 1,4-dioxane where significant changes were not observed. Soil-column and well-mixed reactor experiment results were comparable. These results have implications for both above-ground treatment and ISCO of organic contaminants by $O_3$ especially where hydrophobic contaminants are present. The results suggest that the use of clathrate stabilizers, such as HPβCD, can support the development of a facilitated-transport enabled ISCO for the $O_3$ treatment of groundwater impacted by recalcitrant emerging contaminants.

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# Treatment Technologies for Beneficial Use of Produced Water: State-of-the-Art Review

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## Poster Abstract 10

Produced water is generated during oil and natural gas exploration and production. Underground oil and gas deposits naturally coexist with groundwater in the same formation, and when those hydrocarbons are extracted, formation water is produced to the surface as by-product. In addition, the drilling activities also generate wastewater mainly because of the flowback of fluids employed during hydraulic fracturing.

The composition of produced water could be significantly variable; however, there are certain contaminants such as suspended solids, organic matter, and salts that are consistently present in produced water. The traditional method to dispose produced water involves mainly deep well injection, but this option is becoming more challenging due to high operational cost, limited disposal capacity, and more stringent regulations. Since produced water is commonly generated in arid and semi arid areas where there is scarce of fresh water resources, it has been recently investigated for its potential benefits as a nontraditional source of water; for example, drilling and hydraulic fracturing, irrigation, livestock watering, public water systems, among others. Because of the complex composition of produced water, traditional wastewater treatment trains and facilities are not the most adequate for its treatment. Specific treatment technologies and trains must be developed. Pretreatment is a critical step in order to avoid some contaminants to affect the efficiency of the treatment operations. The objective of this study is to conduct a literature review to investigate the state-of-the-art of treatment processes and technologies for pretreatment and desalination of produced water generated in the Permian Basin.

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# Estimating Recharge of Flood Irrigated Alfalfa by Calculating Evapotranspiration and Soil Moisture in the Mesilla Valley

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## Poster Abstract 11

This poster will present the Objectives, hypothesis, research pictures, and preliminary data of an ongoing field study. The study pertains to quantifying recharge in a water balance method using calculated water inflow, evapotranspiration, and soil moisture in three distinct flood irrigated alfalfa fields. The fields range from 5 to 80 acres, are all located in the Mesilla Valley south of Las Cruces. Each field has a different soil type with varying amounts of small particles (clay and silt).

In addition to the water balance of each individual field, the study aims to find a relationship between recharge rates and silt & clay percentages in the soil. Soil moisture sensors every foot to a total depth of six feet show a percentage of water in the soil at any given moment. This data will be presented in the poster along with preliminary estimated ET rate for the first half of 2017.
Other visuals of for the poster include pictures of instruments and their installation along with triangular and rectangular flumes that were built for the project in order to calculate inflow to the largest field. These flumes put into practice new designs from "Simple Flow Device for Open Channels" Report that was published for New Mexico State University Civil Engineering, funded by the New Mexico Water Resource Institute.

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# Using Remote Sensing to Develop ET Fluxes for the Mesilla Valley Aquifer

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## Poster Abstract 12

Quantifying ET (evapotranspiration- the combination of water losses to the atmosphere from evaporation and transpiration) is necessary for management of water resources and calculating other large processes such as groundwater recharge. The purpose of this study is to improve and validate two models, the Simplified Surface Energy Balance for operational application (SSEBop, Gabriel Senay, USGS) and the Regional ET Estimation Model (REEM, Zohrab Samani, NMSU) for use in the Mesilla Valley of southern New Mexico. Ground measurements of actual ET from 2017 and 2018 produced using eddy covariance methods will be used. Measurements of precipitation, groundwater levels, soil moisture profile, and irrigation applications are also being performed.

The study is approximately halfway through the first growing season of the study. The model algorithms are still being tested, pending ground ET measurements and climate data for the rest of 2017 and 2018. This poster will present data collected in the field, preliminary ET calculations, and remote sensing imagery.

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## The Next Generation of Evaporation Pans

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### Poster Abstract 13

Accurate tracking of open-water evaporative losses, one of the largest consumptive uses of water in the arid Southwest, will become increasingly important in the future with the anticipated climate shifts toward longer, more-severe droughts. The current methods for estimating evaporation on reservoirs are known to have uncertainties ranging from ± 20 to 40 percent. This uncertainty in evaporation rates needs to be reduced in order to give water-resource managers a better understanding of current and future water supplies.

This study will investigate an improved method for determining open-water evaporation rates by developing a Floating Evaporation Pan (FEP) with built-in wave-guard and adjustable freeboard that will measure continuous evaporation rates at a fixed location within a reservoir. The FEP will be semi-submerged to minimize the difference in water temperature between the FEP and the reservoir. In addition, a goal of the FEP design is to have minimal influence on the atmospheric boundary layer overlying the pan relative to the reservoir. Establishing these two conditions will provide a more accurate quantification of evaporation. The accuracy of the FEP will be verified through the use of a hemispherical evaporation chamber, designed to measure the actual evaporation rate adjacent to the FEP.

Through innovative design and extensive field measurements, this study aims to develop a more accurate, robust, automated, and real-time technique for measuring near-actual reservoir or lake evaporation, leading to effective long-term monitoring and management of our Nation's reservoir and lake water resources.

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# Using Temperature Forecasts to Improve Seasonal Streamflow Forecasts in the Colorado and Rio Grande Basins

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## Poster Abstract 14

Recent research documents the influence of increasing temperature on streamflow across the American West, including snow-melt driven rivers such as the Colorado or Rio Grande. At the same time, some basins are reporting decreasing skill in seasonal streamflow forecasts, termed water supply forecasts (WSFs), over the recent decade. While the skill in seasonal precipitation forecasts from dynamical models remains low, their skill in predicting seasonal temperature variations could potentially be harvested for WSFs to account for non-stationarity in regional temperatures. Here, we investigate whether WSF skill can be improved by incorporating seasonal temperature forecasts from dynamical forecasting models (from the North American Multi Model Ensemble and the European Centre for Medium-Range Weather Forecast System 4) into traditional statistical forecast models. We find improved streamflow forecast skill relative to traditional WSF approaches in a majority of headwater locations in the Colorado and Rio Grande basins. Incorporation of temperature into WSFs thus provides a promising avenue to increase the robustness of current forecasting techniques in the face of continued regional warming.

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# Effects of Changing Available Water Regimes on Riparian Vegetation in the Mesilla Valley Basin Aquifer New Mexico, USA

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## Poster Abstract 15

Due to exceeding levels of groundwater pumping as well as continuous drought seasons in the southwest, the Mesilla valley basin aquifer and the Rio Grande are projected to experience declining water levels. These water changes can consequently have an effect in stream ecosystem attributes including riparian vegetation, wildlife habitat areas, and the agriculture surrounding. Riparian vegetation is known to be impacted by both groundwater and surface water and can provide a direct connection in determining the current conditions of both water systems. Studies have shown the importance of riparian areas due to their multiple functions and their diverse ecosystem however, much attention has lacked in the riparian areas along the lower Rio Grande in New Mexico due to the extensive agriculture that dominates the area.

To understand riparian vegetation responses to fluctuating levels of surface/ groundwater interactions from exceeding drought conditions, the use of Aerial photography processed through Geographical Information System (GIS) were utilized to monitor annual changes in riparian vegetation size. These annual vegetation changes alongside the lower Rio Grande were compared to water data from both annual flow and well data in order to identify any trends of vegetation sized linked to decline in water availability. Annual trends specifically before and after drought years were compared to show the effects that drought had on the vegetation. With frequent and longer lasting droughts, riparian zones in New Mexico and in the Southwest are expected to continue to experience an increase in water scarce issues in the future.

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# A Dynamic Statewide Water Budget for New Mexico – Future Scenarios

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## Poster Abstract 16

The New Mexico Dynamic Statewide Water Budget (NMDSWB) is a multiyear effort to account for the origin and fate of New Mexico's water supply. The NMDSWB model aggregates monthly water stocks and fluxes for four mass balance accounting units (MBAUs), which include counties, water planning regions, river basins, and statewide. The model estimates how much water moves through the stocks and fluxes within the MBAUs for a historical period and into the future. The historical period of the model is based on data and modeled estimates from 1975-2011. The future period of the model spans from 2012-2100, where many of the future water stock and flux estimates are calibrated from the historical model. The future period of the model incorporates three scenario options that can be altered by the user to drive the model in place of observed historical data. The three future scenario options are climate change, population growth rate, and water use efficiency. The climate change option consists of four separate Global Circulation Model runs, each of which is associated with future temperature, precipitation, and streamflow estimates. The population growth rate option can be altered from the predicted population changes to determine the effects on public and domestic water use. The water use efficiency option allows for change in agricultural and human water use efficiencies. The implementation of future scenario options within the model allows the user to forecast New Mexico's water budget for a range of potential scenarios.

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# The Warming of the Buckman Municipal Well Field, Santa Fe County, New Mexico

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## Poster Abstract 17

Students attending the Summer of Applied Geophysical Experience (SAGE) field school in Santa Fe have had a unique opportunity to collect temperature profile data in monitoring wells in the Buckman municipal well field (BMWF) between 2013 and 2017. The BMWF is an important source of water for the city of Santa Fe. Geothermal gradients calculated from profile data measured in three monitoring piezometer nests that are located <300 m apart are 46 to 79°C/km; the higher geothermal gradients are associated with two well nests that are within 200 m of a small mapped fault. Temperatures measured in all three monitoring nests showed little to no change between 2013 and 2014. Two of the well nests began flowing in 2015 and temperatures rose in the bottom of these wells by 0.33–0.37 °C (±0.01 °C) between 2014 and 2017, with the most dramatic change occurring between 2014 and 2016.

Repeat measurements of thermal profiles and discharge temperatures in both monitoring and production wells in the BMWF record the complex interplay of cooling in aquifers during times of high production and warming during recovery from overproduction. When the field was in high production before 2003, a significant cone of depression formed, creating horizontal hydraulic gradients that drew in water from the side, thus cooling portions of the aquifer system. As production decreased after 2003, the cone of depression relaxed and vertical hydraulic gradients associated with the regional-scale groundwater flow system began to warm the aquifer after a lag of a decade.

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# Evaluation of Forest Silvicultural Treatment Effects on Runoff and Sediment Yield in Northern New Mexico

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## Poster Abstract 18

Throughout the southwestern US, thinning operations are used to reduce stand density and provide resiliency to the fire landscape. In addition to reducing fire risks, thinning treatments also increase surface runoff, water availability, and sediment yield during monsoonal rainfall events. Quantifying these values is critical to understand watershed health and water resource management for specific forest types and silvicultural prescriptions. This study was established to understand the relationship between specific thinning treatments and the associated overstory/understory conditions on surface runoff and sediment yield. The study site was a mixed conifer forest located in northern New Mexico. The four thinning prescriptions (completed in 2005) included replications of a control (non-thinned), innerspace (between slash piles), lop-scatter (slash was scattered and burned), and pile (slash was piled and burned). Rainfall simulations (~16 cm/hr) as both dry and wet run were used to measure runoff and sediment yield in 2015 and 2017. Ten years after thinning, time to runoff was the only response variable that differed by treatment; whereas, the pile treatment resulted in an increase in time to runoff. By 2017, there were no treatment effects on time to runoff (dry and wet) . However, time to peak runoff for the wet run was found to be greater under the pile treatment. Results from this study, although preliminary, show that thinning prescription, especially pile treatments, have an influence on water movement after rainfall events. Future directions include identification of key microsite characteristics that influence runoff and sediement yield in conjuction with treatment effects.

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# Relationship between Tree Canopy Cover and Discharge of Upper Gallinas Watershed, NM, 1939 - 2015

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## Poster Abstract 19

Climate change results in Land use changes which affects the vegetation-cover patterns. General trend of land use in the US Southwest from 1945 to 1992 indicates decreases in forests and increases in urban areas. The state of New Mexico, in particular, will experience warmer temperatures which will reduce mountain snow packs, and peak spring runoff will shift to earlier in the season. In the northeastern part of the state, the City of Las Vegas has been dealing with the threat of water shortage since the beginning of the 21st century. The Gallinas River, which is the primary source of potable water (95%) for the approximately 14,000 residents of Las Vegas, is a tributary of the Pecos River System, yielding an average of 3,100 acre-feet of water annually. The upper watershed covers approximately 76 mi2, from its headwaters on Elk Mountain (11,600 ft. elevation) to USGS gauging station near Montezuma (4,900 ft.). Land use has transitioned from agriculture, focusing on timber, livestock, and hay production, to primarily full-time and part-time residential use and summer recreation over the past few decades. Aerial photography and object-oriented classification techniques were used to determine the percentage of tree canopy cover from 1939 to 2015. The purpose of this study is to determine if a correlation exists between tree canopy cover, precipitation, and temperature and the Gallinas River discharge from 1939 to 2015. This information can potentially be used by restoration managers and land owners to make environmentally friendly decisions on utilizing the land.

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# Efforts on Calibration and Validation of Modeling Groundwater Recharge in New Mexico

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## Poster Abstract 20

It is crucial to understand the rate and distribution of groundwater recharge in New Mexico because it not only largely defines a limit for water availability in this semi-arid state, but also is the least understood aspect of the state's water budget. With the goal of estimating groundwater recharge statewide, we are developing the Evapotranspiration and Recharge Model (ETRM), which uses existing spatial datasets to model the daily soil water balance over the state at a resolution of 250-m cell.

The current estimated recharge presents diffuse recharge only, not focused recharge as in channels and playas. Four USGS gauged ephemeral streams in NM – Mogollon Creek, Zuni River, the Rio Puerco above Bernardo, and the Rio Puerco above Arroyo Chico – were analyzed in order to link focused recharge with measured basin characteristics. Generalization of these relationships may permit estimation of focused recharge on a watershed scale in the model. While the other three channels produce similar magnitudes and patterns of cumulative runoff estimation, the Mogollon Creek presents a different runoff response and about one order-of-magnitude smaller ETRM modeled runoff amount than USGS gauged data. We attribute this difference to the prevalence of gaining reaches in this watershed. As the sparse instruments in NM help little in improving estimation of recharge, the Walnut Gulch Experimental Watershed, which is one of the most densely gauged and monitored semiarid watershed for hydrology research purposes, is now being modeled with ETRM to compare output with higher spatial resolution field data.

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# AML Project: Inventory and Characterization of Inactive/Abandoned Mine (AML) Features in New Mexico

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## Poster Abstract 21

The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) and Mineral Engineering Department at New Mexico Tech is conducting research on legacy mine features in New Mexico. The objective of our research is to develop a better procedure to inventory and characterize inactive or abandoned mine features in the state. This project will inventory mine features in three mining districts in New Mexico: the Jicarilla Mountains District in Lincoln County and the North Magdalena and Rosedale Districts in Socorro County. Samples are collected to determine whole-rock geochemistry, mineralogical, physical, and engineering properties, acid-base accounting, hydrologic conditions, particle size analyses, soil classification, and hazard ranking. Paste pH is used as a proxy for pH in leachate that might enter the water system after passing through mine waste piles. This allows us to determine if there is any potential for acid mine drainage. On several occasions water has been found in shafts, pits, and springs in mined areas. Once found, water is sampled in the field and tested for trace metals, stable isotopes, and general chemistry. By testing water found in and around mine features, we can assess whether AML features are influencing the watershed in which they are found. This allows us to prioritize which sites need remediation. These mine features are being mapped, evaluated for future mineral-resource potential, and evaluated for slope stability. The results of these studies will help the AML and other organizations better understand and remediate our state's legacy mining issues.

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# Watershed Treatments in the Chama Peak Land Alliance Region

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## Poster Abstract 22

This poster describes the practical application of research and mapping conducted by the Navajo- Blanco Resilience Partnership to prioritize and maximize the effectiveness of forest treatments in the San Juan and Chama watersheds of northwestern New Mexico and southwestern Colorado, including the headwaters above the Bureau of Reclamation's San Juan-Chama Project (SJCP) and the private lands affiliated with the Chama Peak Land Alliance. The Nature Conservancy (TNC) has conducted extensive research and GIS mapping to evaluate fire and debris-flow risks in these forested watersheds, which provide a significant portion of the water supply to Santa Fe, Albuquerque, and the Middle Rio Grande Conservancy District. Anticipated high-severity wildfires and subsequent post-fire flooding threaten these watersheds and the downstream communities that depend on them. Reduced runoff, increased soil erosion, and post-fire debris flows have the potential to degrade water supplies and impact SJCP operations. The Chama Peak Land Alliance, TNC's Rio Grande Water Fund, and other members of the Navajo-Blanco Resilience Partnership, have used TNC's research as a basis for prioritizing forest treatment projects to promote forest health and watershed security in the Navajo and Blanco basins. With partner funding from the Albuquerque-Bernalillo County Water Utility Authority, projects are underway to reduce the threat of high-severity wildfire in these critical watersheds. This poster highlights these implementation projects and this exciting partnership between government agencies, nonprofits, and landowners.

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# An Attached Growth vs Suspended Culture Comparison for the Algal Remediation of Arsenic from Water

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## Poster Abstract 23

Arsenic contamination of water is an important global health concern. Arsenic readily leaches into ground and surface water from soils of high arsenic content as well as through anthropogenic activities, such as mining and agricultural practices. Once introduced into a water system, arsenic can affect a range of mild to detrimental health effects to the human body. Easily applied, low-cost solutions to this issue would be of great benefit, especially in developing, rural, and tribal communities, where resources are limited. To this end, an investigation was conducted into arsenic remediation by algae in suspended growth and attached growth (biofilm) cultures. For comparison, two different materials were provided for algal biofilms to adhere to and arsenic removal by algae was observed. These experiments were performed at bench scale (15L) at UNM, using microalgal cultures that were cultivated at the Santa Fe Community College Biofuels Center of Excellence. Arsenic removal was quantified by monitoring concentration within the synthetic feed using inductively coupled plasma-mass spectrometry (ICP-MS). A locally abundant algal polyculture dominated by Scenedesmus was investigated, and changes to community make up were examined using genetic sequencing. I definite preference for a cotton surface for attachment was detected int both biological growth and arsenic removal. Our hope is that the results of these experiments can carve a path for additional research towards the application of algal populations in the remediation of metals from water.

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# In Situ Soil Moisture Condition of Different Land Uses within Three Acequia Irrigated Valleys in Northern New Mexico

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## Poster Abstract 24

Increasing drought pressures in the southwestern United States create a need for improved gathering of data on environmental hydrological processes. The quantification of surface soil moisture at the field scale is difficult due to its natural variability in time and space. These data are necessary for understanding basic hydrological processes and for improving watershed management aimed at conserving water resources. Many northern New Mexico acequia farming communities possess a distinctive irrigation culture allowing them to fairly allocate irrigation quantities to help preserve water in times of low availability. The objectives of this study were to characterize the volumetric water content (VWC), using time domain reflectometry, of surface soil moisture in three acequia irrigated valleys and compare any differences in VWC degree and variability between three acequia irrigated study valleys and three different land use types found within each valley. The difference in estimated soil VWC between the valleys of El Rito, Valdez/Arroyo Hondo, and Alcalde was found to be negligible. For most of the time periods examined, there was no significant difference ($p \leq 0.05$) in the VWC means between the valleys. Significant differences ($p \leq 0.05$) in estimated VWC means between valleys were found between certain periods which was likely due to increased levels of precipitation in combination with irrigation. Numerous differences in means and variability were shown among the different evaluated land use types. Irrigated pasture and riparian lands, had the highest amount of variability, riparian having the greatest variability and irrigated pasture being the wettest over all periods.

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# Forty-eight Years of Meteorological Data (1969-2016): NMSU Agricultural Science Center at Farmington

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## Poster Abstract 25

Surface water in the semi-arid climate of the Four Corners Region of New Mexico is a crucial life resource. Vigilant monitoring of weather conditions and efficient water-use is necessary for productive life in this water-deficit region, which averages 8 inches of precipitation per year (48year average).

Meteorological data are collected at two weather stations located at the New Mexico State University Agricultural Science Center near Farmington (ASCF). The National Weather Service (NWS) Station is a daily manual data collection station in service since 1969. The New Mexico Climate Center (NMCC) weather station is an automated station with daily and hourly computer online accessible weather data.

Weather station data are summarized in the ASCF Annual Progress Reports. Critical components of these summaries are mean precipitation, maximum/minimum air temperatures, extreme air temperatures, freeze-free days, daily evaporation, wind movement, soil temperatures, humidity, solar radiation, and growing degree days. Summary reports of these data are compiled on a five-year basis.
Historical weather data collected over 48 years at ASCF has been used in many applications, such as identifying plant hardiness zones, crop-management plans, ET calculations for irrigation of crops and landscapes, and weather forecast modeling. Data components from these reports, including air temperatures, wind movement, solar radiation, and relative humidity (among others), are used to calculate reference evapotranspiration (ET) used in irrigation scheduling. Growers, foresters, natural resource managers, municipal planners, weather forecasters and other community members utilize ASCF weather data, demonstrating the importance of long-term weather monitoring to the region.

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# The Effects of Vegetation Regrow on Snow Accumulation and Ablation Post-Wildfire

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## Poster Abstract 26

Wildfires are increasingly prevalent in the southwestern United States due to the region's exceptional dry weather and dense forests. In New Mexico, many people rely on water from mountain river basins for residential, industrial, and irrigation uses. Seasonally snow-covered catchments are one of the primary sources of water in these basins, demonstrating the importance of snow accumulation and melt processes in high elevation areas. Such areas have faced innumerable effects from wildfires in recent years. The Las Conchas fire in 2011, burned over 156k acres over the course of 38 days, resulting in extensive damage throughout the Valles Caldera and burning much of Rabbit Mountain. Just two years later, the Thompson Ridge Fire burned a large portion of Redondo, the caldera's largest, most-elevated mountain. Little is known about the ramifications of vegetation regrowth on snow processes following these wildfires.

In this study, we analyzed the influence of vegetation reestablishment on snow accumulation and ablation post-wildfire to identify how snowpack conditions are temporally effected. To accomplish this, we evaluated the snow-water equivalent (SWE) in the 2017 water-year on Rabbit Mountain and Redondo in severely burned areas with no vegetation regrowth, low severity burned areas, and severely burned areas experiencing aspen regeneration. Initial results indicated that aspen regeneration increases the quantity of SWE relative to areas with no vegetation regrowth.

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# Managing for Climate Change: Improving Community Resilience through Education and Outreach

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## Poster Abstract 27

Strategies to reduce impacts of global warming through adaptive capacity building and climate mitigation initiatives are common global goals. However not all climate initiatives have been successful. The need to understand the motivation, willingness and socio-economic characteristics that drives resilient communities is crucial for climate literate society. This study present a review of literature on best climate adaptation, mitigation, education and outreach practices as well socio-economic factors that enhance community preparedness and response to climate change. The result is expected to develop a model program that utilizes a volunteer culture to increase climate literacy. It is also expected to reveal the connection between climate knowledge and community resilience in addition to socio-economic factors that can lead to climate resilient decisions.

Key words: climate change, resilience, community preparedness, climate education

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# Novel Spectroscopic Solution for Heavy Metal Ion Detection: Silicate Coated Gold Nanoparticles

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## Poster Abstract 28

Certain heavy metals can cause severe problems if they accumulate in the environment and enter human body through food chain. Fast detection of low concentration heavy metal ions in aqueous solution is a critical problem around the world. In this research, 5,10,15,20-Tetrakis(4-aminophenyl)-21H,23H-porphyrin (TAPP) functionalized silicate coated gold nanoparticles were synthesized and applied to detect $Zn^{2+}$, $Cu^{2+}$, and $Cd^{2+}$ in aqueous solutions. Gold nanoparticles are good substrate for fluorescence and SERS. A silicate coating can prevent them from aggregating and contaminating the analyte. Furthermore, functional groups can be attached to silicate shell which can further react with heavy metals. Porphyrin is a highly sensitive chromogenic reagent. Porphyrins and their metal chelates have very strong and characteristic absorption bands in the region from 400 to 500 nm, the Soret band. TAPP attached silicate coated gold NPs exhibited signal changes when reacted with heavy metal ions. By applying principle component analysis (PCA) to the resulted spectra, different metal ion complexes were separated. The result shows the Raman signal of TAPP attached to coated Au NPs is 5.7 times to the intensity of TAPP mixed with coated Au NPs and this conjugated system can detect $Zn^{2+}$, $Cu^{2+}$, and $Cd^{2+}$ in aqueous solution at concentration of $1.5 \times 10^{-5}$ M by using fluorescence spectra separately.

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# Climate Change Impacts on Acequia Water Resources: In Upland Watershed of El Rito

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## Poster Abstract 29

Under the challenge of climate change the development of traditional irrigation valley is risky, the acequia, El Rito is typical example in New Mexico. The main water resource to supply to El Rito is from the upland watershed where is designated as wildness district. Further water management is necessary to exploit the ecological value and keep sustainability. One hydrology model is built on a system dynamics platform, Powersim Studio 10 Expert, with monthly time step. The upland watershed is divided into hydrologic response units with geology properties, soil texture and land cover classification. Evapotranspiration, interception, infiltration, deep percolation, and runoff routing are calculated in the model, and the hydrology model runs from 1950 to 2099 continuously. The calibration of model is from 2010 to 2015 with runoff of modeling and gage measurement. The scenarios are climate changes combining temperatures and precipitation patterns. Multiple analysis are conducted on stream flow to show the surface flow behavior in long term. This El Rito upland watershed model is fundamental to water assessment, development, and management as basic work of Acequias study.

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# Structure and Preliminary Santa Fe Group Stratigraphy under the Eastern San Agustin Plains—Implications for Groundwater Flow

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## Poster Abstract 30

We use very limited borehole data together with Bouguer gravity data, previous resistivity sounding data, and previous geologic mapping to characterize the geologic structure and stratigraphy under the eastern San Agustin Plains (ESAP). Home to the Very Large Array (VLA), the ESAP are located east of Datil and separated from the western plains by a SSW trending bedrock high, underlying low hills, east of the topographic embayment hosting a modern playa called C-N lake. Under the ESAP, a NE-trending bedrock high separates the North graben to the north from the C-N graben to the south. The North graben is an east-tilted half-graben filled by at least 3500 ft of Santa Fe Group basin fill. The C-N graben underlies the northern C-N embayment and is interpreted as a northeast-elongated, fully-fault bounded graben of comparable depth as the North graben.

An important question, with implications for aquifer storage and ground water flow, is whether sizeable playa deposits underlie the ESAP. Subsurface stratigraphic correlation of three wells (max depth of 400 ft) near C-N playa indicates playa deposits extend downward 200 ft, but whether they exist below 400 ft is unknown. The 700 ft-thick basin fill encountered in a VLA well consists wholly of sandy gravel. There is no evidence of fine-grained playa deposits in a 3500 ft-deep well drilled in the southern North graben. These stratigraphic and structural observations are consistent with southerly groundwater flow in the North graben and northern C-N graben that is apparently unimpeded by fine-grained playa deposits.

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# Investigation of Soil Composition from Burned Areas Affecting Water Quality Changes Following Wildfire

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## Poster Abstract 31

Long-term effects of soil chemistry changes post wildfire are not well documented. The aim of this research is twofold: 1) to characterize the effects of fire on the metal and anion composition in soil by burn severity following the 2011 Las Conchas wildfire and 2) assess the potential contamination of these soil components to the East Fork Jemez River. The river is an important water source to the surrounding Pueblos and villages. Periodically the river systems in this watershed have not met certain water quality standards as determined by the New Mexico Environment Department. Eight samples were collected and bagged from the Sierra de los Valles dome, the headwaters of the East Fork Jemez River, from the high, moderate, low and unburned categories. The concentrations for twenty-two metals where obtained using inductively coupled plasma emissions spectrometry. One-way analysis of variance showed seventeen of the twenty-two metals had statistically significant differences for group means per burn severity: Al, As, Ba, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Si, Sr, and V. Tukey Kramer post hoc method determined that most of the variance occurred between the high/moderate and low/unburned severities. Ion chromatography determined the concentrations of seven anions: F, Br, Cl, NO2, NO3, PO4 and SO4. The moderate and low burn severities showed the highest anion concentrations but Br and NO2 were the only anions to have statistically significant differences. The impacts of specific metals and anions leaching effects are being investigated as a source of stream impairment.

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# Evaluating the Sustainability of Desalination Implementation and Management in the Bi-National Santa Teresa, NM Community

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## Poster Abstract 32

Burgeoning industrial growth in the bi-national Santa Teresa, NM community – coupled with realities of drought and limited freshwater supply – challenge the region's long-term ability to meet its water demands. Desalination of brackish water serves as a potential solution to these water supply constraints, but the effects of establishing an inland desalination plant remain unknown. This study will develop a system dynamics model to account for interdependent environmental, social, and economic factors that dynamically affect the sustainability of inland desalination implementation and management for the region. Results will likely reveal the need to revise the current water management structure to better facilitate community involvement and outside funding opportunities, such as public-private partnerships. This research will serve to inform nascent policy decision-making efforts in Santa Teresa regarding the future of the community's alternative water supply management.

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# Soil Water and Nutrient Dynamics Under Grassland and Crop Systems in the Eastern New Mexico

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## Poster Abstract 33

Improved understanding of soil water and nutrient dynamics under different land management can lead to the development of sustainable farming systems that maintain soil fertility and improve soil water storage. A study was conducted near Clovis NM to estimate soil water, soil organic carbon (SOC), and nitrogen (N) dynamics as influenced by different land management systems: conventional tillage (CT), strip tillage (ST), and no-tillage (NT) crop systems with winter wheat-corn/sorghum rotation, and grazed (GP) and ungrazed (UGP) grass systems. The CT, GP, and UGP have been on the respective management practices for more than 40 years, and ST and NT have been on these practices for at least four years. Soil samples were collected from 0-20, 20-40, 40-60, and 60- 80 cm depths in June 2017 and analyzed for soil bulk density (Db), volumetric soil water content (VWC), water-filled pore space (WFPS), available soil nitrogen (ASN), SOC, and total N. These samples are also analyzed for soil microbial components and their connection to soil health and water conservation. The Db was not significantly different between land management systems. The VWC and WFPS were significantly greater in ST and NT than in other treatments. Similarly, WFPS was significantly greater in UGP and CT than in GP. The ASN followed a trend of NT>CT>ST>UGP>GP in the surface 0-20 cm, and it was significantly greater in CT than other treatments in 40-60 and 60-80 cm depths. Reducing tillage and grazing intensity has potential to conserve water and improve sustainability of dryland agroecosystems.

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# A Community Approach to Groundwater Monitoring in New Mexico

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## Poster Abstract 34

In the southwest U.S., we face a future of warmer annual average temperatures, with increasing variability in precipitation, reduced groundwater recharge, and increasing demand on groundwater. However, because of limited funding, groundwater level monitoring programs in New Mexico have been shrinking over the past several years. Many of the groundwater users in New Mexico know the importance of groundwater level monitoring and its applications in research and modeling. The Aquifer Mapping Program at the New Mexico Bureau of Geology and Mineral Resources is tapping into the willingness of water-interested New Mexicans to share data and resources to develop the Collaborative Groundwater Monitoring Network. This collaboration is achieved by collecting data from groups or well owners that are monitoring water levels, equipping or manually measuring wells, and providing education and outreach. With these partnerships, the Network is able to fill spatial and temporal gaps in the current groundwater level monitoring networks while promoting increased awareness of groundwater issues and providing an important dataset for making informed water management decisions.

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# Photocatalytic Treatment of Desalination Concentrate Using Optical Fibers Coated with Nanostructured Thin Films: Impact of Water Chemistry and Seasonal Climate Variations

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## Poster Abstract 35

Treatment of desalination concentrate can reduce concentrate volume for disposal, increase water recovery, and convert waste to resource. However, concentrate treatment is costly and energy intensive due to high concentrations of salt and recalcitrant organic matter in concentrate. Photocatalytic oxidation provides a novel energy neutral technology for concentrate treatment by degrading organic contaminants. Polymer assisted hydrothermal deposition method was used to synthesize innovative pure and Fe-doped TiO2 mixed-phase nanocomposite thin films on side-glowing optical fibers (SOFs). The properties of the photocatalysts coated SOF were characterized by surface morphology, nanostructure, crystallite size and phase, and zeta potential. Photodegradation efficiency and durability of the photocatalysts treating different types of desalination concentrate was studied under natural sunlight. Synthetic solutions and reverse osmosis (RO) concentrates from brackish water and municipal wastewater desalination facilities were tested to elucidate the impact of water chemistry, operating conditions, and seasonal climate variations (solar irradiation intensity and temperature) on photocatalytic efficiency. High ionic strength and divalent electrolyte ions in RO concentrate accelerated photocatalytic process while the presence of carbonate species and organic matter hindered photodegradation. Outdoor testing of immobilized continuous-flow photoreactors suggested that the catalyst-coated SOFs can utilize a wide spectrum of natural sunlight and achieved durable photocatalytic performance. This type of photoreactor will be suitable for arid and semi-arid regions because the solar resources are abundant, and the closed compact reactor developed in this project is particularly appealing for reducing water loss that occurs in an open system.

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# An Integrated Algal-Membrane System for Wastewater Treatment and Reuse

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## Poster Abstract 36

An integrated algal- and membrane-based system was designed for wastewater treatment and potable water recovery. The membrane processes were applied for algae harvesting and contaminants removal. Forward osmosis (FO) is an emerging alternative for microalgae harvesting. It is a passive process that uses osmotic pressure gradient to drive the permeation of water across the hydrophilic membrane from feed water (low osmotic pressure) to draw solution (high osmotic pressure). The results demonstrated that FO was effective for harvesting algae and extracting water from algae-treated wastewater effluent. FO coupled with reverse osmosis (RO) was implemented for potable water recovery, and the system produced a high quality water from municipal wastewater. The water quality parameters, including pH, conductivity, total organic carbon, biochemical oxygen demand, major cations and anions, trace heavy metals, were analyzed for treated water. Fluorescence excitation-emission matrix spectroscopy and liquid chromatography mass spectroscopy were also used to examine the removal of organic substance and trace organic pollutants. The concentrations of all constituents found in the feed water were reduced by the FO-RO process to levels lower than the EPA primary drinking water standards-making the process capable of treating algal effluent for potable reuse.

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# Monitoring Water Quality Parameters within a Known Range of Western River Cooter (*Pseudemys gorzugi*) within Black River Drainage

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## Poster Abstract 37

Understanding the effects water quality has on wildlife is an important part of ecosystem management. Over the past century, Pecos River and its tributaries have been a subject to continuous anthropogenic alterations. We compared water quality parameters along the upper and lower stretches of Black River, a tributary of Pecos River located in Eddy County, New Mexico, within a range of the state threatened turtle species- Western River Cooter (Pseudemys gorzugi). We investigated nitrogen compounds (ammonium and nitrate), dissolved oxygen, salinity, pH, turbidity, visibility, and temperature, as well as conductivity, oxidation reduction potential (ORP), and water depth. We collected parameters once a month from September 2016 to June 2017 at 14 sampling points along two 1500m stretches of the river. Our analyses show slight differences between upstream and downstream sites. Specifically, dissolved oxygen appeared higher at the downstream site while conductivity, salinity, and visibility were higher at the upper stretch. pH was higher at the upper stretch while ammonium was generally higher at the lower stretch. ORP and nitrate concentrations varied between sites depending on the month of survey. A side-by-side comparison of mean dissolved oxygen, salinity, temperature, and pH between historic (1997) and current data show similarities, indicating no significant long term shift. Our research will help further the understanding of water quality along Black River and create opportunities for collaboration with other studies.

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# Modification of Ion-Exchange membranes to Improve Anti-Biofouling Properties in Electrodialysis

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## Poster Abstract 38

Advanced technologies have been utilized to treat alternative water sources to meet freshwater demand in many areas of the world. Consequently, membrane processes such as reverse osmosis (RO), nanofiltration (NF), and electrodialysis (ED) gain increasing importance to produce high-quality water from seawater, brackish water, and wastewater. ED is favored for its higher energy efficiency and water recovery as compared to pressure-driven membrane technologies. Like other membrane processes, the main obstacle to ED is biofouling of ion-exchange membranes, resulting in reduced membrane performance, shortened membrane lifetime, and subsequently increased operational & maintenance cost. Membrane fouling is a dynamic process initiated from microbial colonization and growth on membrane surface. Prevention or reduction of undesired interactions between foulants and membrane surface is an imperative method to control the adhesion of foulants. This could be achieved through surface modification of membranes with the aim to increase membrane surface hydrophilicity, modify membrane surface charge, and incorporation of biocidal organic polymer or inorganic particles on the membrane surface. This study aims to improve anti-biofouling properties of ion-exchange membranes in ED process by modifying membrane surface with polymers such as polyethyleneimine (PEI) and nano-particles such as titanium dioxide ($TiO_2$) and graphene oxide (GO).

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# Hysteresis Loops in the Snowpack-streamflow Relationship of Western U.S. Watersheds: Gila vs. Yellowstone

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## Poster Abstract 39

Mountain snowpack provides essential water for socio-economic systems in the Western U.S., yet in-situ knowledge is limited by the financial and logistical constraints of snowpack monitoring systems like the Snow Telemetry (SNOTEL) program. Satellite-based metrics, such as snow cover extent (SCE), allow researchers to study greater spatial extents to gain new insight into snowpack-streamflow dynamics.

A statistical analysis of SCE and streamflow from 2000 to 2016 across 154 natural watersheds revealed distinct hysteresis loops that can be attributed to the fundamental hydrological differences between the accumulation and ablation phases of the snow cycle. Although this behavior is not surprising, these loops provide a new conceptual framework for studying the factors influencing the snowpack-streamflow connection within and between watersheds using limited in-situ data.

This phenomenon is studied by examining two watersheds with opposing hysteresis loop responses: the Gila River watershed in southeastern New Mexico and the Yellowstone River watershed in northeastern Montana. The Yellowstone watershed experiences a deep, persistent snowpack with a consistent snow season. Accordingly, it displays a classic loop structure that exhibits the expected rise and fall of streamflow with changes in SCE. The Gila watershed, in contrast, has an ephemeral snowpack with high interannual variation in extent and timing. The Gila watershed displays no loop structure, implying that it does not have a well-defined snowpack-streamflow relationship between or even within water years.

Future research will explore the characteristics of these loops and their relationships to various hydro-climatological variables to determine the potential for satellite-derived SCE in watershed analysis.

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# Short-term Response of Soil Water Content to Forest Canopy Conditions in the Valles Caldera National Preserve, NM

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## Poster Abstract 40

In arid environments, resource managers are particularly interested in how water yield can be increased from forests while protecting upland watershed ecosystems and downstream communities. Forests play a critical role in the partitioning of water. Trees intercept, redistribute, and transpire water. The number of trees in an area impacts how much evapotranspiration occurs in addition to the water availability and potential evapotranspiration. The relationship between soil moisture and runoff as a function of canopy density are evolving topics in the understanding of hydrologic processes. Generally speaking however, soil conditions are heavily dependent on climate conditions and interact with vegetation in a continuous feedback loop. Furthermore, studies of runoff generation mechanisms in northern New Mexico's ponderosa pine forests indicate that runoff is transported by either overland flow or lateral subsurface flow, particularly in years with above average snowpack conditions, making soil moisture conditions particularly relevant to the topic of increasing water yield. Soil and canopy property data were collected at 21 sites in the Valles Caldera to evaluate the relationship between canopy density, leaf area index (LAI), soil type, volumetric water content and gravimetric water content immediately following the onset of snowmelt during the 2017 water year. While soil water processes are highly non-linear, initial results show that linear regression paired with soil, meteorological, and canopy data can be used to determine increases in soil water content and availability.

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## Restoring Ranching by Restoring a Watershed

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## Poster Abstract 41

In the northern Chihuahuan desert, climate changes combined with historic over-grazing has pushed ecological sites from grasslands to shrub-dominant states challenging ranchers in these areas. In 2015 the State of New Mexico Department of Agriculture estimated the amount of cattle in New Mexico was 1.34 million head, down from over 1.5 million in 2007. This study is a part of a collaboration with the South Central NM Stormwater Coalition, which includes different stakeholders, to design and conduct restoration efforts on Rincon Arroyo, a 85,770-acre watershed, most of which is used as grazing land for many ranchers. Our hypothesis is that by increasing grass-like vegetation, we can help the restoration in this watershed. The methods include the installation of debris dams in the arroyo to guide water onto floodplains to rebuild pastures, good grazing practices and reseeding methods. We need to understand the movement of water in the arroyo so we can slow it down and it can infiltrate. Our water monitoring equipment includes soil moisture vertical profiles, infiltration vertical profiles, flow stage monitoring wells, and wild life cameras with flow stage staff gauges. With these monitoring methods, we expect to know the characteristics of the arroyos in the watershed including flow, infiltration, and stage. Ranching is a profession that passes from generation to generation. With the restoration of Rincon Arroyo, we hope to keep not only this noble tradition alive but also have a richer ecosystem, which will benefit all individuals who live here.

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# Method for Estimating Groundwater Storage Change in Variably Confined Aquifers in New Mexico

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## Poster Abstract 42

In response to increasing needs to understand the water budget of New Mexico as part of the WRRI statewide water assessment, we developed a method to estimate historical groundwater storage changes. Building on previous methods for estimating changes in groundwater storage in unconfined aquifers (Rinehart et al., 2015 and 2016) our new method adds several steps to address variably confined aquifers. The major adaption to the original unconfined method is the mapping of the top of the confined aquifer. This is required to determine where the aquifer is either confined or unconfined. Variably confined aquifers in NM can have up to four orders of magnitude variations in storage coefficients (specific storage vs. specific yield) dependent on where the aquifer is confined or unconfined, the distribution of rock types, and aquifer thicknesses. To test the new method, we applied it in two variably confined aquifer systems: the confined Permian aquifer system in the Sacramento Mountains and the Roswell Artesian Basin, and a section of variably confined Jurassic sandstone aquifers underlying the southwestern San Juan Basin. The disparity of data quality, quantity, and density served to further test the method's effectiveness in aquifers with dense data coverage (Roswell Artesian Basin) and sparse data coverage (San Juan Basin). The method worked best in the Roswell Artesian Basin, though outlier wells in regions with sparse data may have skewed the estimates. The analysis done in the San Juan Basin did not have a dense enough well coverage (spatially and temporally) for meaningful conclusions to be drawn.

Rinehart, A.J., Timmons, S., Felix, B., and Pokorny, C., 2015, Groundwater level and storage changes—Regions of New Mexico: Technical Completion Report, NM Water Resources Research Institute.

Rinehart, A.J., Mamer, E., Kludt, T., Felix, B., Pokorny, C., and Timmons, S., 2016, Groundwater level and storage changes in alluvial Basins in the Rio Grande, New Mexico: Technical Completion Report, NM Water Resources Research Institute.

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# Monitoring the Water Quality Impacts of a Prescribed Burn: Pre-Burn Results, Santa Fe Municipal Watershed

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## Poster Abstract 43

A planned project to thin a portion of the forest in the upper Santa Fe Municipal Watershed involves prescribed fire by aerial ignition in the absence of mechanical treatments. These burn treatments are an attempt to decrease fuel loads that could lead to dangerous wildfires and also to increase soil water availability per tree. Careful study of the impacts of these burn treatments on water quality and quantity will enable adaptive management over the course of the treatment and will inform managers in other regions of the effects of this cost-effective technique.

We report baseline water quality data collected ahead of the prescribed burn treatments, as no burns have yet occurred upstream of our sample site, the Santa Fe River directly above McClure Reservoir. Water samples collected at roughly two week intervals between March 2016 and June 2017 via an ISCO automated sampler were analyzed for dissolved organic carbon (DOC), particulate organic carbon (POC), anions, dissolved metals, total dissolved solids, and hardness. In addition, we report a continuous record of parameters collected by a water quality sonde.

No measured parameters exceed their Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs), and the general water chemistry is reflective of the dominant lithology in the watershed, a biotite rich granite. Seasonal snowmelt dilutes most constituent concentrations in the spring, however DOC and POC are flushed into the river during the snowmelt phase. Daily cycles of DOC and POC are observed and are associated with the daily rise and fall of stream stage.

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# Effects of NRCS and BLM Conservation Practices on Hydrologic Processes in the Rio Puerco Watershed

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## Poster Abstract 44

The Rio Puerco Watershed (RPW) is a highly dynamic and diverse ecological system that has a long history of anthropogenic alterations. Historic overutilization, exacerbated by periods of prolonged drought, has resulted in considerable degradation. The BLM and NRCS use conservation practices, namely prescribed grazing and brush control via herbicide application, on private and public lands throughout the region to improve ecological stability and ecosystem health. Their goal is to decrease sagebrush cover while allowing for an increase in herbaceous cover and a decrease in erosion risk. The objectives of this project are to investigate the effects of the herbicide application on hydrological processes in the RPW. To examine the impacts of the treatments on hydrological processes, six runoff monitoring plots and associated weather stations were established in two treatment areas and two reference areas. We used Upwelling Bernoulli Tubes to measure surface flow and will link this data directly to local precipitation quantities. All field measurements will then be used to calibrate a Gridded Surface Subsurface Hydrologic Analysis model for the RPW to illustrate the potential impacts at a larger scale. Expanding the plot-level measurements to the watershed-scale will provide a solid understanding of how this system reacts hydrologically to the conservation practice and serve as a basis for future range management decisions. If conservation practices on rangelands within the RPW can decrease potential runoff and sediment load, the improvement of the hydrological stability would provide valuable water resources across the region.

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# Groundwater Saturated Thickness and Storage Changes in the New Mexican Southern High Plains Aquifer

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## Poster Abstract 45

The unconfined aquifers in the fluvial Ogallala Formation and younger sediments of the New Mexican Southern High Plains are the primary and increasingly limited freshwater source, making it vital to understand changing of groundwater storage patterns. We used historical water level measurements to estimate the changing saturated thickness and groundwater storage in two regions: the Quay-Roosevelt-Curry County region (QRC) and the Lea County region. Our study, part of the WRRI statewide water assessment, uses USGS water level measurements, and USGS maps of historically saturated regions of the aquifer, aquifer bottom elevations and specific yields. Our workflow consisted of data review and spatial correlations, polynomial de-trending and kriging interpolation of water elevations, estimating saturated thickness, and then mapping and summarizing groundwater storage changes.

For both regions, the saturated thickness of the aquifer has decreased through time, unsurprisingly for a region with extensive large-scale irrigation, with no recharge or surface water resources. The saturated thickness declines in the QRC region have large areas that have either reached no remaining saturated thickness or have less than 30 ft of saturated thickness remaining (the typical thickness needed to support irrigation). In the Lea County region, thicker saturated thicknesses remain, with far fewer areas with no remaining or thin saturated thickness. The difference in remaining saturated thickness between the QRC and Lea County regions is thought to be caused both by differing initial saturated thickness and differing water use rates.

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# Improvement of Ion Selectivity in Electrodialysis through Surface Modification of Ion Exchange Membranes

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## Poster Abstract 46

Development of alternative water sources is critical to augment local water supplies. Selective removal of certain contaminants and partial desalination of impaired waters can be a cost-effective method to meet specific water quality requirement. For example, agricultural irrigation requires removal of only certain ions such as sodium from water while cooling water requires the removal of hardness. Current membrane desalination technologies are energy intensive and less flexible to produce water for certain purpose and with certain ionic composition. Selective removal of ions using electrodialysis (ED) is an attractive approach to produce water with specific quality requirements with less energy consumption. . This study aims to improve the selective removal of mono-valent and di-valent ions using ED through surface modification of commercially available cation exchange membranes (CEM) with polymers such as polyethyleneimine (PEI). The performance of normal grade and selective membranes is evaluated by treating different source waters with different salinity levels and ionic compositions under different operating conditions.

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# Agriculture as a System for Managed Aquifer Recharge for Deserts by Restoring Hydrologic Connectivity to Floodplains and Aquifers

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## Poster Abstract 47

In the American Southwest, what underlies both drought and increased flooding as social crises is a water storage problem. Less winter precipitation has diminished snowpacks and the resulting spring runoff. Reduced soil water holding capacity in these drylands, arid and semi-arid lands, coupled with increased precipitation intensity has increased catastrophic flooding. Communities are seeking solutions to watersheds "leaking" their resources of water and soil. Historically, floods along the Rio Grande River network in New Mexico were more connected to more richly vegetated floodplains, which resulted in watersheds retaining more their water and soil resources. Agriculture supported that natural dynamic by spreading flood flow onto floodplains (floodplain connectivity), which resulted in infiltration into shallow (aquifer connectivity). Connectivity has been recognized as a key driver in dryland ecosystems, in particular the strong feedbacks between hydrologic processes and vegetation density and patterns. This research hypothesizes that restoring hydrologic connectivity to floodplains and aquifers supports ecological resource health and social goals of watersheds optimizing available water and retaining soils. This study is in collaboration with the South Central New Mexico Stormwater Management Coalition, which has recognized the "needs of the region would best be served by a regional watershed management approach" and chose the Rincon Arroyo watershed in the Hatch Valley / Rincon as a priority project for restoration. The study methods aim to answer the question how much connectivity does it take to control floods and downstream sediment deposition? Geospatial analysis, land manager collaboration, and ground-truthing will identify the existing and potential flow connectivities. A system dynamics model will estimate the connectivity patterns that could support vegetation and minimize watershed leakiness. Anticipated results are quantifying the extent of a watershed's leakiness to the degree of floodplain connectivity, within states that differ per slope, aspect, and soils. Nearly forty percent of the global land surface is managed in agriculture, revealing the potential power of linking ecological resource health with the goals of agricultural managers and their downstream communities.

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# Gila National Forest Stream Temperature and Intermittency Monitoring Network for Gila Trout and other Fish Species of Conservation Need

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## Poster Abstract 48

Management of imperiled fishes of greatest conservation need in the arid Southwest requires an understanding of their habitat. The importance of stream temperature is well recognized especially in light of a changing climate where there will be a major shift in temperature and precipitation in the 21st century. To this end, the 2016 WRRI Student Grant funded deployment of a stream temperature and intermittency-monitoring network in Willow Creek, Gila National Forest, New Mexico. Willow Creek is home to a population of Gila trout (Oncorhynchus gilae) that were once extirpated in the 2012 Whitewater-Baldy Wildfire. Preliminary data Willow Creek from May 23 to June 27, 2017 revealed a maximum seven-day weekly average temperature of 15.6°C. The maximum daily range increased from 11.28°C to 20.87°C. The maximum 2-hour average was 20.85°C. From the literature, the 7-day chronic sub-lethal temperature for Gila trout is 28.25°C. Thus, these temperatures throughout Willow Creek were not an immediate threat to Gila trout persistence in Willow Creek. Temperature data continues to be collected through the summer months when lowest flows occur. I will present the results of the 2017 summer stream temperatures and describe whether these will have a n effect on the long term persistence of Gila trout and other imperiled fish within the community. The implementation of this monitoring network will allow for further data collection and analysis of Willow Creek as a long-term recovery stream.

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