tx H_2O

A Publication of the Texas Water Resources Institute

Summer 2024

UNDER PRESSURE

TEXAS AQUIFERS FACE MODERN CHALLENGES

Inside: Protecting, researching and managing Texas groundwater

Texas A&M AgriLife Research | Texas A&M AgriLife Extension Service | Texas A&M University College of Agriculture and Life Sciences

Working to make every drop count

Making the invisible, visible.

That was the slogan of the United Nations two years ago when groundwater was declared the water topic of the year. This issue of *txH$_2$O* is also focused on this finite resource.

Did you know that about 70% of groundwater withdrawn globally and in the United States is used for agriculture? Did you know that groundwater provides close to 40% of all drinking water in the United States and almost half of all drinking water worldwide? Meanwhile, in many regions, current climate impacts have reduced the reliability of surface water for supporting growing populations' drinking water needs, and therefore, groundwater has become the water supply backup plan.

Groundwater, in contrast with surface water, is more challenging to manage, assess and understand. And of course, since we do not see it, we tend to assume it is infinite. A lack of data, research and expertise clouds our understanding. Management approaches that do not recognize the links between surface water and groundwater are some of the most critical challenges facing Texas, the country and the world.

Because groundwater is being used as a strategic resource to build resilience capacity towards the future, it is imperative to invest in education and research while prioritizing our efforts to protect groundwater for future generations.

In this edition of *txH$_2$O,* we highlight approaches to groundwater law and management around the United States, the basics of Texas' aquifers and groundwater use, the Texas Well Owner Network's service to groundwater users, researchers at Texas A&M using satellite data to study soil moisture and groundwater, and case studies of some of the most infamous Texas groundwater legal disputes. This issue also features two groups moving groundwater stewardship forward in Texas — the Transboundary Aquifer Assessment Program, which I lead, and the Texas Groundwater Protection Committee.

I hope you enjoy reading and help us spread the word to make the invisible a lot more visible.

And as always, please join us in making every drop count.

Rosario Sanchez, Ph.D.
TWRI Senior Research Scientist and Associate Graduate Faculty of the Water Management and Hydrological Sciences Program, Texas A&M University

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Published by
Texas Water Resources Institute

Editor
Leslie Lee
Texas Water Resources Institute

Art Direction
Sarah Richardson
Texas Water Resources Institute

Assistant Editors
Cameron Castilaw
Danielle Kalisek
Sarah Richardson
Texas Water Resources Institute

Student Writer
Madison Pigg
Texas Water Resources Institute

On the Cover
Karst waters in the Natural Bridge Caverns in San Antonio, Texas. Photo by Marisa Collura, TWRI.

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Texas Water Resources Institute
make every drop count

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Comal Springs, part of the Edwards Aquifer system, in New Braunfels. Photo by Leslie Lee, TWRI.

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WATER RESEARCH AND NEWS

Recent water science news from around the state and nation

Shaylynn Postma, TWRI research associate, conducting water quality monitoring in the Little Brazos watershed. Photo by Ed Rhodes, TWRI.

NIWR celebrates 60th anniversary

Around the United States, 54 institutes are part of the National Institutes for Water Resources (NIWR), as authorized by the Water Resources Research Act of 1964 and 1984.

The Texas Water Resources Institute joins the other 53 institutes in celebrating NIWR during its 60th anniversary. The original legislation stated that, subject to the approval of the Secretary of the Interior, "one water resources research and technology institute, center, or equivalent agency," may be established in each state and territory, at a college or university, as designated by its governor. The institutes receive funding through the U.S. Geological Survey, to support, coordinate and facilitate research through the annual base grants, national competitive grants, coordination grants, and student internships.
Read more ⇨ tx.ag/water24

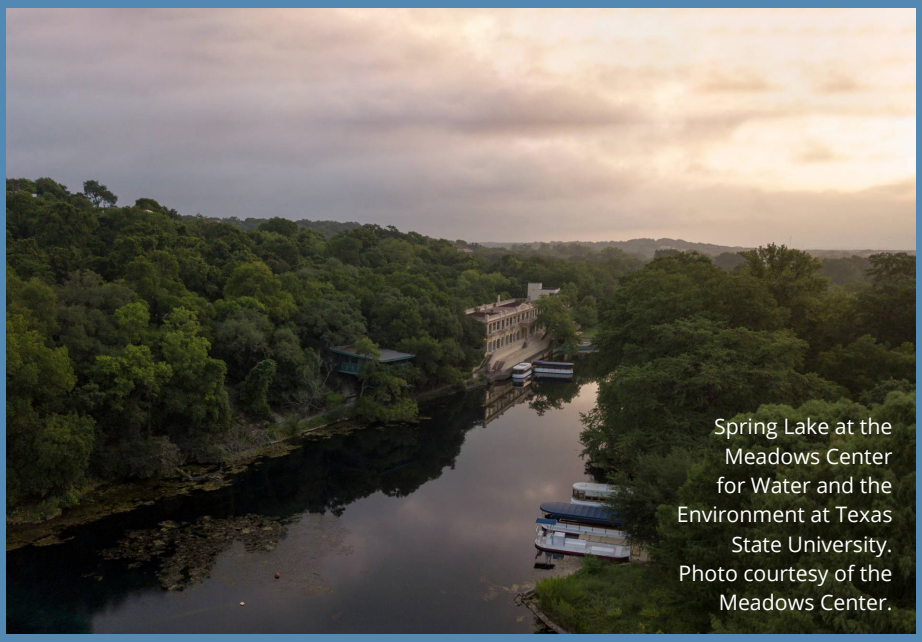
Most Americans are oblivious to 'forever chemicals'

A first-of-its-kind study published by Texas Water Resources Institute (TWRI) scientists last November measured U.S. adults' knowledge of perfluoroalkyl and polyfluoroalkyl substances, or PFAS chemicals. TWRI conducted the first generalized U.S. study on public awareness of PFAS and found most Americans do not know what the substances are or understand potential associated risks.

PFAS are a category of thousands of manufactured chemicals and an emerging concern to environmental and human health. PFAS are called "forever chemicals" because their bonds between carbon and fluorine molecules, one of the strongest chemical bonds possible, make PFAS removal and breakdown very difficult.

45.1% of respondents had never heard of PFAS, and 31.6% had heard of PFAS but did not know what they are. 11.5% knew their community had been exposed to PFAS. 97.4% did not believe their drinking water had been impacted by PFAS.

In contrast, in July 2023 the U.S. Geological Survey published research showing that at least 45% of the nation's tap water was estimated to contain one or more types of PFAS chemicals. **Read more ⇨ tx.ag/water24**



Spring Lake at the Meadows Center for Water and the Environment at Texas State University. Photo courtesy of the Meadows Center.

Texas springs in crisis

The number of dry springs in Texas has nearly tripled since the early 1980s, according to research published by scientists at the Meadows Center for Water and the Environment at Texas State University.

In the article, the authors began with Gunnar Brune's 1975 report, "Major and Historical Springs of Texas," and his 1981 book, "The Springs of Texas, Volume 1," then used a range of methods, including satellite imagery, historical maps and fieldwork, to identify and assess springs common to both texts.

The resulting analysis revealed that 30% of the springs examined by Brune are now dry, compared to 11% in 1981, representing a 173% increase or 2.7 times more failed springs. **Read more ⇨ tx.ag/water24**

What is the state of Texas' wetlands?

With roughly 3.9 million acres of wetlands, 2.3% of its total land area, Texas has the fifth largest wetland acreage in the United States. As of 1990, there was an estimated 52% reduction in the state's original wetland acreage, but there has been no recent assessment of statewide wetland loss or gain since then.

Recent analysis published in the *Texas Water Journal* explained that Texas wetlands face intensifying challenges in the coming decades.

The authors discussed actions that could anticipate effects of climate change, sea level rise and urban expansion to help address complex wetlands challenges. They recommended incorporating new technologies to allow for more timely and cost-efficient large-scale monitoring of wetland loss and gain. **Read more ⇨ tx.ag/water24**

John Bunker Sands Wetland Center in Combine, Texas. Photo by Cameron Castilaw, TWRI.

Lake watch: new algorithm tracks daily reservoir evaporation rates

Texas A&M University College of Engineering researchers have developed a more accurate method for estimating daily reservoir evaporation rates. The recent study highlighted the efforts of Texas A&M researchers Huilin Gao, Ph.D. and Bingjie Zhao, Ph.D., with coauthors from multiple institutions and agencies.

"This method will enhance decision-making processes related to reservoir operations, water rights allocation, and long-term water planning in Texas and beyond," said Nelun Fernando, Ph.D., manager of the Texas Water Development Board's water availability department.

Researchers said the daily evaporation algorithm has only been applied to Texas lakes. The results reveal a clear geographic distribution and strong seasonality of evaporation throughout Texas, with the highest average losses occurring in July. The data also shows a significant upward trend in evaporation rates, increasing about 1.1 inches per decade. **Read more ⇨ tx.ag/water24**

Keep reading about these important research advances at tx.ag/water24

Where Does Your **Groundwater** Come From?

Get acquainted with Texas' aquifers and the educators advocating for groundwater conservation

On any given day, Sarah Valdez could be teaching 2nd-graders that their drinking water comes from deep underground, showing high schoolers how to examine an endangered aquifer-dwelling beetle with a microscope, or demonstrating for families how fast pollutants can seep through a limestone aquifer into groundwater.

Valdez serves as senior outreach coordinator at the Edwards Aquifer Authority Education Outreach Center (EAA-EOC) in San Antonio, where she helps people learn groundwater basics and take steps towards conserving water in their daily lives.

"We try to make it exciting because groundwater is intangible — you cannot see what lies beneath you, and that can be hard to teach," she said.

Throughout the state, many Texans are unsure whether their drinking water source is surface water or groundwater, although 55% of all water used in Texas is groundwater, according to the Texas Water Development Board.

Could in-person groundwater education help individuals eventually protect and conserve groundwater in their daily lives?

Aquifer basics

Water educators like Valdez communicate these basics every day: aquifers are underground formations of rock and sediment that hold water, Texas has nine major and 22 minor aquifers, and those aquifers' geological features vary widely.

Some aquifers recharge over a long period of time, while others can recharge quickly. Some are confined between two layers of impermeable rock, while others are unconfined aquifers, topped by permeable layers of sediment. Some hold brackish or salty water, others naturally fresh water.

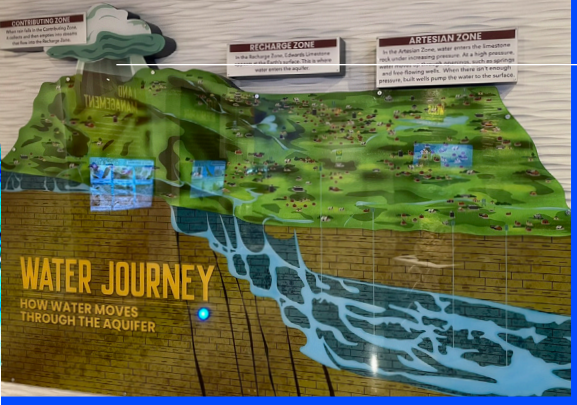
Many cities in Texas depend on groundwater. If you live in Amarillo, a portion of drinking water supplies comes from the Ogallala Aquifer. In Bryan-College Station, it comes from the Carrizo-Wilcox Aquifer.

The city of San Antonio is largely dependent on the Edwards Aquifer, a large geologic system that can be understood in three zones of land area. The contributing zone catches rain, and that rainfall flows into the recharge zone, which has geological features permeable enough for the water to seep down into the aquifer. The artesian zone of the system has geological and hydrological conditions most suitable for drilling productive water wells.

"It's not one uniform piece of rock," Valdez said. "Rain in our region does not equal rising aquifer levels if that rain was not in the recharge zone. The center's water journey exhibit display helps visitors gain that understanding."

Helping the next generation protect groundwater

Open since 2022, EAA-EOC is free for groups and visitors of all ages and provides transportation grants for many school groups. Most field trip groups are grades 4-8, and the exhibits align with Texas Essential Knowledge and Skills classroom concepts, Valdez explained. Being "ultra-accessible" is a core philosophy for the center, which is accessible to wheelchair users throughout and was designed for bilingual audiences with a wide range of ages and abilities.



Exhibits include a threatened and endangered species aquarium, a real karst touchstone, an interactive cloud caster where students can make vapor clouds, an LED globe showing live weather data and a cave theater.

The center is in the Edwards Aquifer recharge zone inside Morgan's Wonderland Camp, an accessible camp providing people with physical and developmental disabilities camp experiences alongside campers without special needs, and EAA leases the center in partnership with Morgan's. Near the center, students can hike and learn in EAA's Field Research Park.

"For many of these children from urban areas, this is one of their first times exploring wild spaces and open landscapes," Valdez said. "So, it's a lot of fun to be part of their initial experience outdoors."

For younger students, "your water comes from underground" is the main concept her team instills. Helping students get enthusiastic about water can be challenging.

"We try to make that connection: this is your groundwater, this is water that you drink, your decisions affect all of us, and the best way to make good decisions about your groundwater is to understand it," she said. "I always say, over and over, people won't take care of something unless they understand it." ⇨

(Top) The EOC prioritizes experiential learning, accessible and bilingual language, and displays designed with many different ages in mind. (Bottom) Valdez explains the different zones in the Edwards Aquifer region. Photos courtesy of EAA-EOC and Leslie Lee, TWRI.

Texas State student interpreters give glass bottom boat tours to visitors and field trip groups at the Edwards Aquifer-fed Spring Lake. Photos courtesy of The Meadows Center for Water and the Environment.

One-of-a-kind experiences spur learning

Travel about 60 miles north on Interstate 35, and you'll find another groundwater educational experience unlike any other: Spring Lake.

Located in San Marcos, Spring Lake is owned by Texas State University. The Meadows Center for Water and the Environment is the key university research center overseeing the operations and stewardship of the lake and its surrounding habitat.

Texas currently has about 190 flowing natural springs, according to Meadows Center research. A spring results when an aquifer is filled to the point where groundwater overflows onto the land surface.

Visitors and field trip groups at Spring Lake gaze at the Edwards Aquifer-fed lake through the unique perspective of glass-bottom boats.

"It's a magical place," said Rob Dussler, Ph.D., chief education officer at the center. "Many kids who visit Spring Lake do not have safe, equitable access to nature, and so they arrive at our site with high excitement and energy."

Texas State students work for the Meadows Center as "interpreters" of Spring Lake, he said, leading tours as visitors get up close with the lake and learn how to help protect it.

"The experiences are novel for many visitors, including close encounters with clear spring water, the flora and fauna in and around the lake and the compelling ride on a historic glass-bottom boat," Dussler said.

Spring Lake has been a major attraction in San Marcos for more than a century. Today, Dussler said it hosts over 120,000 visitors annually, with 30,000 of those being school children, half of which are from under-resourced areas.

"I'm so proud that the Meadows Center at Texas State University is the key steward of this most magical and important place," he said.

"One of our chief conservation strategies is that if children can have a formative experience in nature when growing up, the likelihood they will exhibit pro-environmental behavior as they grow up is higher."

Research published in the *Journal of Environmental Psychology* in 2022 analyzed 50 years of environmental educational programming and showed that such programming does result in real behavior change, Dussler said.

"So, we believe that our programs can make a difference in groundwater conservation and pro-environmental behavior, and that's also supported by the research," he said.

"Every day, we work to empower children and adults to understand what groundwater is, where their groundwater comes from, and then personalize it for them — how does my behavior affect the groundwater?"

Story by **Madison Pigg**

14 Years of the Texas Well Owner Network

Thousands of Texans have access to well water quality testing because of the TWON team's tireless educational work

Hilltop in Hemphill County, Texas. Photo by Sam Craft, Texas A&M AgriLife Marketing and Communications.

The Texas Well Owner Network began serving Texans in 2011, aiming to monitor and maintain water quality while also educating new or established private water well owners.

The Texas A&M AgriLife Extension Service professionals who now deliver TWON programs have the same goals today and have worked extensively over the last 14 years curating and perfecting their approach to education for the public. TWON provides two educational programs: a one-hour program called Well Informed, and a four-hour program called Well Educated. Both begin with residents bringing in well water samples for analysis.

"When was the last time you had your well water tested?" is TWON Coordinator Joel Pigg's favorite question to ask attendees. He said the response is nearly always "never."

An AgriLife Extension Specialist in College Station, Pigg said that is either because the individual has no idea that well water is not regularly tested like city water is, or because the landowners have lived on the property for years and say the water "tastes completely fine." But, even water that tastes, smells or looks fine should be tested once a year, he said.

How TWON water testing works

The collected water samples are tested by TWON personnel (utilizing portable laboratory equipment) in the local extension or groundwater conservation district (GCD) office for nitrate levels, absence or presence of coliform bacteria or E. coli bacteria, and in some parts of the state, arsenic levels. Pigg said that testing water wells is vital because even if the water tastes fine, there could be harmful bacteria, chemicals or naturally occurring pollutants that can harm humans in it.

The next day or later that week, residents return to receive their water quality results and attend an educational program.

Pigg helps residents interpret and understand the results of their water screening and connects them to resources needed to remediate any water quality issues.

First-time landowners learn well basics

Although this program has been around for 14 years, the TWON team is constantly changing their practices to better align their goals with the needs of Texas well owners. TWON can now help connect well owners to well-health-monitoring tools and services to keep them informed about the availability of water in their well.

There are over one million private water wells in Texas, which provide water to 2,230,000 citizens — equal to the population of Houston.

TWON has seen a steady increase in wells over the past decade and a significant increase in first-time well owners. This trend is growing, Pigg said, and TWON is helping fill the resulting educational gaps — teaching landowners about water conservation, what a water well is and the responsibilities of a well owner.

According to Pigg, in recent years, many people have moved from larger cities to rural areas, and many are unaware that their water is not provided by the city. He has seen individuals come to the program not ⇨

knowing that they have a well house, see a photo in his presentation and, “it is like a light comes on and they realize what this shed is on their land,” he said.

“It is fun for us to see the educational and safety benefits we are providing to these excited new landowners.”

Pigg emphasized that TWON is not a regulatory group, but solely an educational tool. TWON strives to not make individuals feel bad for not knowing certain things, but rather equip them with proper well management knowledge.

Drought impacts on groundwater

Challenges to well health have changed over time. Due to the increase in droughts in Texas, well depth is getting deeper, he said, and bacteria is known to occur more frequently in wells where less water is moving in the aquifer.

E. coli numbers tend to rise with the longevity of a drought. Pigg explained that this is typically because there is not enough water to flush out the harmful bacteria. Bacteria like this can cause moderate to severe illnesses in those who consume the water.

Local community leaders and AgriLife Extension agents look forward to TWON coming to their county, because of the long-lasting benefits it provides to local residents.

“At the TWON program, citizens and landowners learned the importance of regularly testing water for water quality, septic safety, rainwater collection, riparian areas and water conservation,” said Kelly Tarla, a Burnet County extension agent. “I feel like having these programs in 2023 changed the trajectory of the way our citizens think about water.”

TWON serves Texans even in the most remote counties.

As Luke Hendryx, Brewster-Jeff Davis county extension agent, said, “the water testing that the TWON program provided to stakeholders in Far West Texas helped to fill a void for a vital service that is difficult for most citizens to receive due to the remoteness of our area.

"Stakeholders consistently make requests for TWON to return to the area," he said.

John Smith, an AgriLife Extension program specialist in College Station, worked with water well screening in the early days of the program. TWON began as a water quality testing idea by Monty Dozier, Ph.D., now director of AgriLife Extension's Disaster Assessment and Recovery Unit, Smith said. It evolved into a program that included septic systems and surface pollution, in collaboration with Diane Boellstorff, Ph.D., professor and extension specialist emerita. Drew Gholson, Ph.D., who now leads the National Center for Alluvial Aquifer Research at Mississippi State University, was the first TWON coordinator. He served Texans in that role for years and helped establish the program and its curriculum.

“I believe when we walk into Texas county AgriLife Extension offices with TWON, what we are doing is one of the most relevant education programs that they will have in that county office," Smith said. "The addition of Joel Pigg to the staff has enhanced our work with GCDs across the state with his background as a GCD manager before coming into our water quality program.”

As Texas continues to grow and change, TWON will continue working to ensure that each and every resident dependent on a well has the chance to have safe drinking water.

Texas Well Owner Network workshop in Austin County, Texas. Photo courtesy of Joel Pigg, TWON.

Story by **Cameron Castilaw**

UNDERSTANDING GROUNDWATER LAW

Legal statutes and precedents governing groundwater vary among states and can be challenging for residents to navigate

Illustrations by Freepik.com.

Groundwater does not usually conform to property lines. It flows through layers of soil, rock, springs and caves and obeys hydrological and geological principles, not human laws or boundary lines. Establishing and understanding laws around groundwater ownership and management can become very confusing very quickly.

As increased water demand and pressure on surface water supplies raise the value of groundwater resources, understanding groundwater laws and precedents matters even more.

In Texas, groundwater law has largely been decided by the judicial system, and the Texas Legislature has passed few groundwater-related bills. The resulting myriad of precedents presents challenges to groundwater users.

"They came to be through a mix of case law and legislation that have evolved over time, which makes it even harder to wrap your head around," said Amy Hardberger, J.D., a professor of water law and director of the Center for Water Law and Policy at Texas Tech University. "Then the presence of groundwater conservation districts adds another layer of regional variability. So, when somebody says, well, what is the groundwater law of Texas? It's like, how much time do you have?"

The current systems

Federal guidelines leave groundwater law and management up to each state. While the U.S. government can sometimes weigh in on issues involving multiple states, international boundaries or endangered species, groundwater law is largely at each state's discretion.

"It's important to know that all water law is basically a state issue and highly regionalized," Hardberger said.

There are four general approaches to groundwater ownership that states follow. While some states use a combination of approaches, these are the most helpful to learn when it comes to understanding groundwater law.

Rule of capture

Absolute dominion, or rule of capture, is how Texas has decided groundwater ownership for more than a century. (See the East decision on page 18.)

"The Texas approach is: if you own the land, then you own the groundwater that's underneath your feet," said Gabriel Eckstein, J.D., a professor in the Texas A&M University School of Law and director of the Energy, Environmental and Natural Resource Systems Law Program.

Reasonable use

Reasonable use, sometimes called the American rule, is similar to absolute dominion, with a few limitations. In this approach, either the state owns the groundwater, or the groundwater is "unowned" until captured, Eckstein said, but landowners have the sole right to access the groundwater below their land. This approach is the most common in the United States, used by 17 states.

Hardberger said this doctrine provides clarity in disputes between water users.

"We now have a little bit of a relationship that we pay attention to between these two users," Hardberger said. "So, you can't use an unreasonable amount or amount that unreasonably interferes with somebody else's use of their water."

Prior appropriation

Prior appropriation is used mostly in western states, and it involves more management of groundwater sources than the previous two laws.

"It's basically first in time, first in right," Eckstein said. "Meaning, if you have a list of who got their water first, the first person on the list is going to get 100% of their water right.

"So long as there is enough water in the river (or aquifer), every prior appropriation holder will get 100% of the right they claimed through the process," he said. "However, when you have a shortage, e.g., due to over-allocation or during a drought, all of the rights holders who have the earliest rights get 100% of their right. Eventually, as you work your way down the list based on the priority date, you run out of water. When you run out of water, everyone from that point on the list and everyone with a younger right gets 0% of their right."

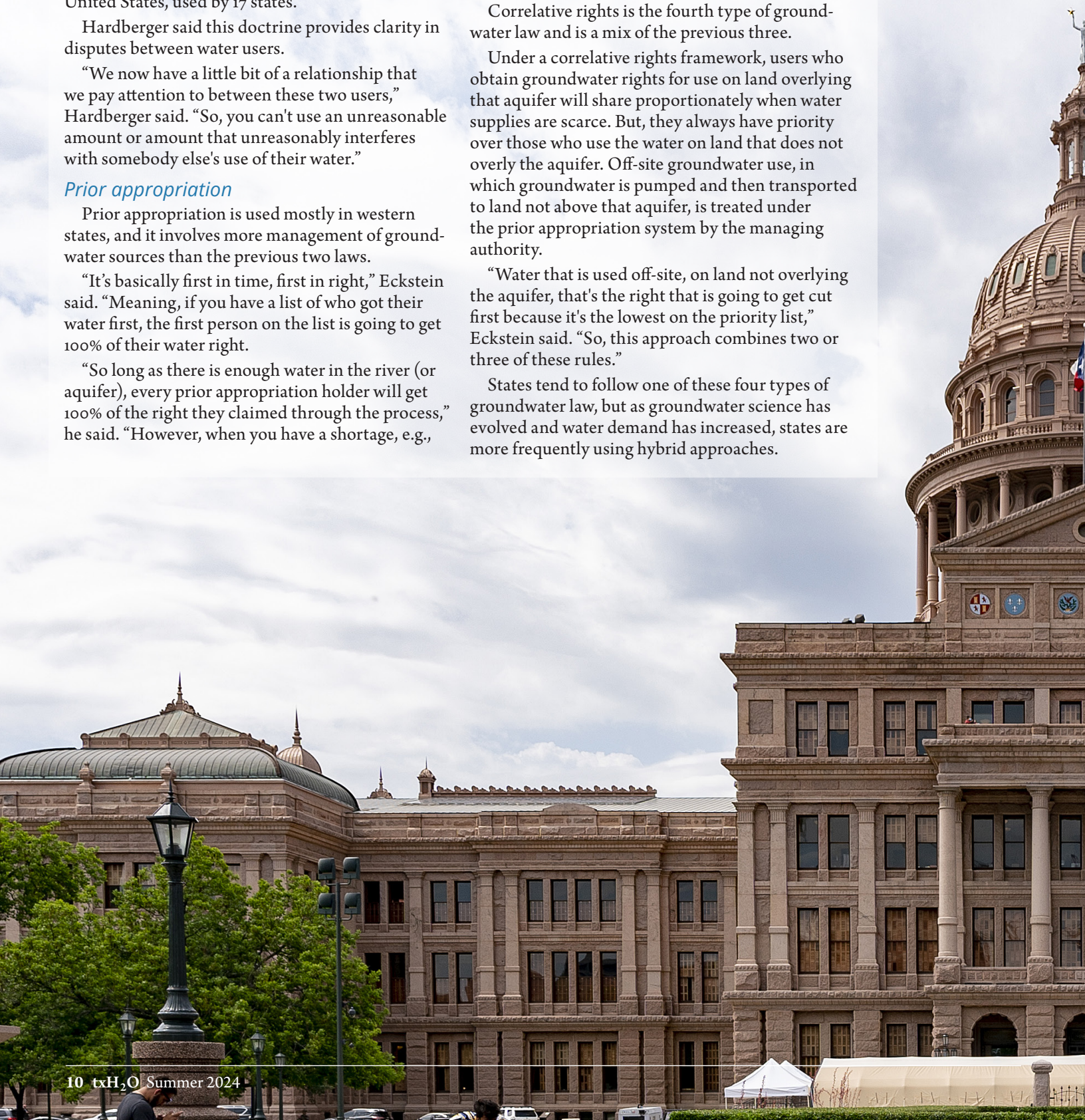
Correlative rights

Correlative rights is the fourth type of groundwater law and is a mix of the previous three.

Under a correlative rights framework, users who obtain groundwater rights for use on land overlying that aquifer will share proportionately when water supplies are scarce. But, they always have priority over those who use the water on land that does not overly the aquifer. Off-site groundwater use, in which groundwater is pumped and then transported to land not above that aquifer, is treated under the prior appropriation system by the managing authority.

"Water that is used off-site, on land not overlying the aquifer, that's the right that is going to get cut first because it's the lowest on the priority list," Eckstein said. "So, this approach combines two or three of these rules."

States tend to follow one of these four types of groundwater law, but as groundwater science has evolved and water demand has increased, states are more frequently using hybrid approaches.



How state groundwater laws evolve

Each state handles its own groundwater law and management systems. But how do those decisions come to be?

"Most of the states started with absolute dominion because it's part of English common law, which they adopted when they joined the United States," Eckstein explained. "Common law is what some people tend to call judge-made law. It happens when the courts develop their own legal system in the absence of legislated rules. And since the rule of capture for groundwater was part of the law in England, we borrowed it and applied it here."

Since then, most states have moved away from the rule of capture. Only a small handful have kept it in place.

"Some of them still use it. They think `Why should we change?'" Eckstein said. "Some states have so much surface water, that groundwater is not a big issue for them."

States with higher groundwater demand have adjusted laws to address disputes and interference between neighbors.

"When you move further south and west, a lot of the states have changed to the reasonable use rule because they started to get disputes. They wanted to come up with a way to still respect ownership, because this is the United States and property is important, but give some kind of reasonableness test to the use," Eckstein said.

Economics also affect states' groundwater approaches, he said.

"Moving further west, you have less and less water, and some states, again, mostly in the west, wanted to promote economics, but also wanted to apply a reasonableness or beneficial test to the use," Eckstein said. "And that's how they came up with prior appropriation."

Correlative rights is another way of looking at the same water problems that prior appropriation addresses.

"These states had the same justification, not a lot of water and the desire to develop," Eckstein said. "They also wanted to be able to use water off-site. As a result, it created all sorts of complicated variations."

While groundwater managers face droughts, weather variability, population increases and higher water demand, these realities have mostly not yet affected groundwater law, Eckstein said, because enacting any major changes is difficult and slow.

"Trying to tweak these laws now is really hard," he said. "And this is where some states are."

Crossing state lines

Groundwater does not follow state lines, and many states face interstate aquifer challenges.

"We have dozens of interstate compacts on surface water — Texas has a compact with Oklahoma on the Red River, with New Mexico

The Texas Capitol in Austin. Photo by Laura McKenzie, Texas A&M AgriLife Marketing and Communications.

Inside the Texas Capitol in Austin. Photos by Laura McKenzie, Texas A&M AgriLife Marketing and Communications.

on the Pecos River, and with New Mexico and Colorado on the Rio Grande," Eckstein said. "But there's never been a compact for groundwater in the United States."

This is in part because there have never been legal disputes between states when it comes to groundwater until recently. In 2014, the state of Mississippi sued the state of Tennessee for allegedly pulling more groundwater from Mississippi than they should have. This case found its way to the U.S. Supreme Court, where in 2021 it was ruled that the law applied to interstate groundwater should be the same as to interstate surface water.

"That rule is called equitable apportionment. We apportion the water equitably, in a fair manner. How you determine what is fair is mostly based on economics — who's making the best use of the water, producing the most economic benefits, or has the highest economic value," Eckstein said. "This is the first time it's ever been applied to groundwater. It's the first time a case like this has ever gone to the Supreme Court."

Why understanding groundwater law matters

Court cases continue to shape states' groundwater law and management.

One such recent case is *Texas v. New Mexico and Colorado*, ruled on by the U.S. Supreme Court in June. The Court rejected the states' proposed settlement for shared water in the Rio Grande Basin and set precedent for the federal government's potential involvement in future multistate groundwater disputes.

Ordinary Texans seeking to steward their groundwater resources while also sustaining profitable working lands may find it challenging to understand Texas' groundwater laws.

"I think this is one of the biggest challenges we have in Texas, because our groundwater rules are complicated," Hardberger said.

Hardberger explained that at its core, groundwater law can be boiled down to one thing for Texans.

"It's just property rights," she said. "It defines who gets access to water, how much, what can they do with it? What are the limits of that? That is the guiding principle."

Knowing even the general rules of Texas water law can help Texans avoid difficult situations.

"Texans need to understand the rule of capture and that, generally, allows a tremendous amount of pumping legally, which can cause problems," Hardberger said. "And then, understand that there might be regional regulation that may change that. If every Texan even understood that very, very basic thing, we would be better off. Unfortunately, a lot of times, people don't realize how we regulate groundwater until it hurts them."

Story by **Madison Pigg**

Partnering with NASA, Texas A&M's Binayak Mohanty uses out-of-this-world tech to answer under-our-feet questions

Using technology in orbit, scientists are examining Earth's soil moisture and water resources.

Soil moisture data is a key indicator for drought and flood forecasting, agricultural monitoring, forest fire prediction, water supply management and other natural resources activities.

Binayak Mohanty, Ph.D., a Regents Professor at Texas A&M University, has been a leading soil moisture researcher for decades. Partnering with NASA-funded satellite technology, he has led soil moisture multi-scale data collection and analyses at Texas A&M for years.

Mohanty serves on the Department of Biological and Agricultural Engineering faculty, is the Texas A&M College of Agriculture and Life Sciences Chair in Hydrological Engineering and Sciences and leads a team of scientists and graduate students in Texas A&M's Vadose Zone Research Group (VZRG).

Meet the vadose zone

The vadose zone is the layer of earth that lies between topsoil and groundwater, located above the water table. Also known as the critical or unsaturated zone, the vadose zone is always changing and shifting; it is intrinsically dynamic because it's unsaturated.

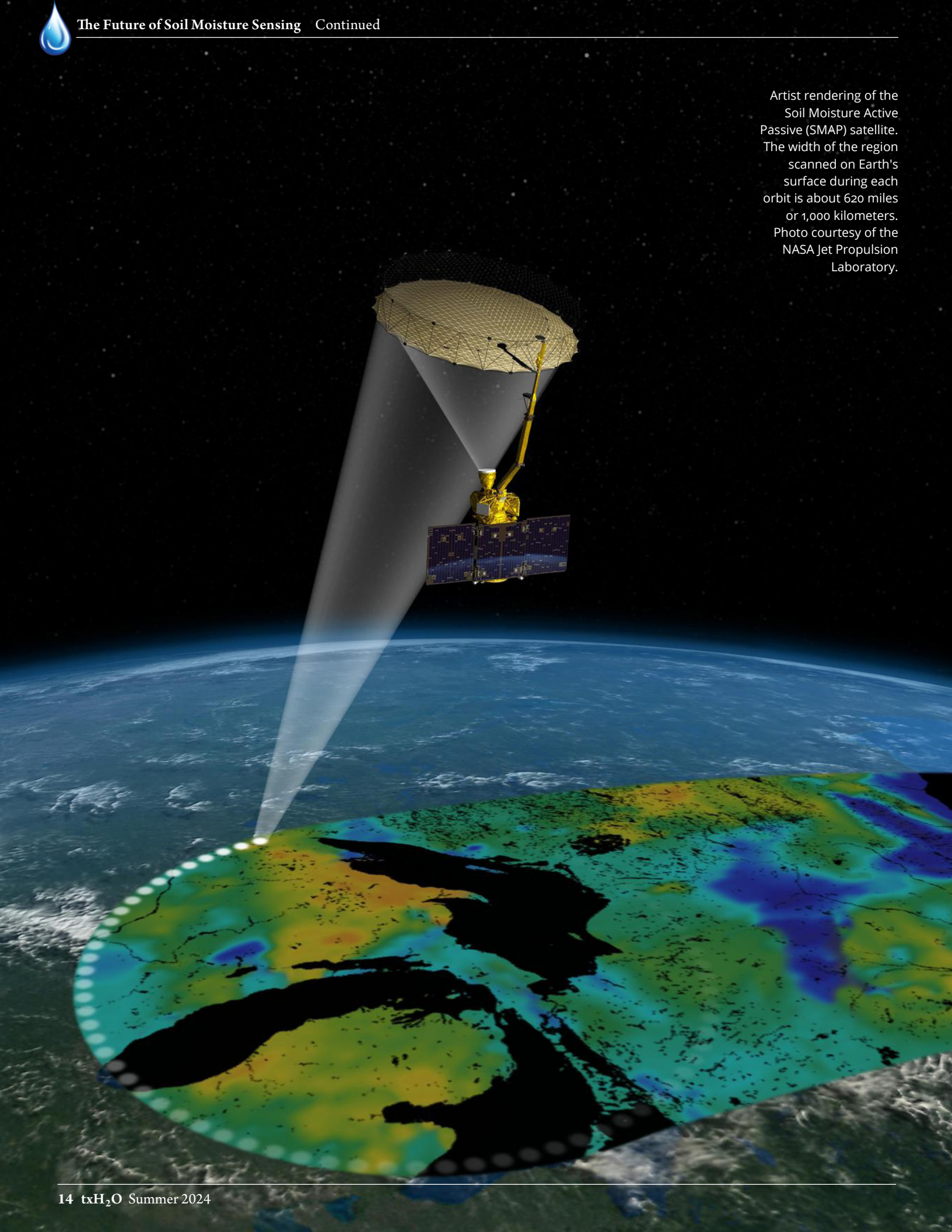
Accurately measuring vadose zone moisture on a fine scale is key to scientists improving water conservation technology, mitigating drought impacts, understanding how water contaminants move, predicting floods, and making sustainable advances in agriculture.

Tackling this dynamic environment, VZRG began using NASA satellite data in 2002 to study the numerical modeling of hydrological processes, soil bio-geo-chemistry, scaling issues in hydrology and multi-scale observations and measurements.

Mohanty said the group's current primary focus is remote-sensing soil moisture data, made possible by imagery from state-of-the-art NASA satellites, such as the Soil Moisture Active Passive (SMAP) satellite. ⇨

Artist's concept depicts the NISAR satellite in orbit over central and Northern California. Photo courtesy of the NASA Jet Propulsion Laboratory.

Title badge illustration created with assets from Freepik.com by Sarah Richardson, TWRI.



Artist rendering of the Soil Moisture Active Passive (SMAP) satellite. The width of the region scanned on Earth's surface during each orbit is about 620 miles or 1,000 kilometers. Photo courtesy of the NASA Jet Propulsion Laboratory.

Launched in 2015, SMAP provides global updates on soil moisture every 2-3 days and helps create predictions for future droughts, floods, ecosystem health and weather patterns. Other Earth-observing satellites provide additional groundwater, surface water and evapotranspiration estimations, such as Gravity Recovery and Climate Experiment (GRACE) and Surface Water and Ocean Topography (SWOT), as well as the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the Terra satellite.

Assimilating the data from these satellites, the researchers then calculate regional water budgets and their spatio-temporal variabilities and uncertainties for various hydrologic, agronomic, and environmental applications, Mohanty said.

New satellite opens doors for innovative groundwater research

NASA is partnering with the Indian Space Research Organization (ISRO) to launch a new satellite: the NASA-ISRO Synthetic Aperture Radar Mission, or NISAR, scheduled to launch in October 2024.

This satellite will be used to measure Earth's changing ecosystems, dynamic surfaces and ice masses, providing information about biomass, natural hazards, sea level rise and groundwater, and it will support many other applications, Mohanty said. High-resolution spatial data measured at two frequencies by the radar will not only help track groundwater availability but also aquifer recharge rates, or how fast rainfall moves through sediment and rock layers into the aquifer pool.

Using NISAR, scientists will be able to track groundwater movement and changes. Decision-makers could use this data to manage groundwater supplies, avert overdrawn aquifers and prevent subsidence, or the gradual sinking of land surface over time.

This insightful new data can help city officials and scientists plan urban development that won't cause subsidence. NISAR data will also benefit coastal populations, helping researchers map shoreline changes, ocean currents, wind velocities, ship locations and oil spills.

NISAR and Texas A&M

VZRG will be using NISAR soil moisture data to study agricultural water management, ecosystem health, hydrologic predictions including flash floods and flash droughts, and feedback between land and atmosphere for a better understanding of global water, energy and carbon cycles at multiple space and time scales.

Mohanty said that the satellite will scan nearly all of Earth's land and ice twice every 12 days, and new data will be available each time it makes an orbit around the Earth.

This will provide high-resolution data about surface water and groundwater for even the most remote places, helping scientists detect problems, such as subsidence, without traveling or relying on sparse well data. It will also centralize the measurements, enabling more accurate and accessible information sharing.

It is immensely important to document these changes over time, he said. The groundwater and surface water data can help predict future weather patterns and natural hazard potentials. NISAR will also track and detect floods even when vegetation makes floodwaters difficult to view. Flood damage is a multi-billion-dollar problem around the United States and globally, and NISAR could enable greater flood detection and preparedness, protecting lives and economies.

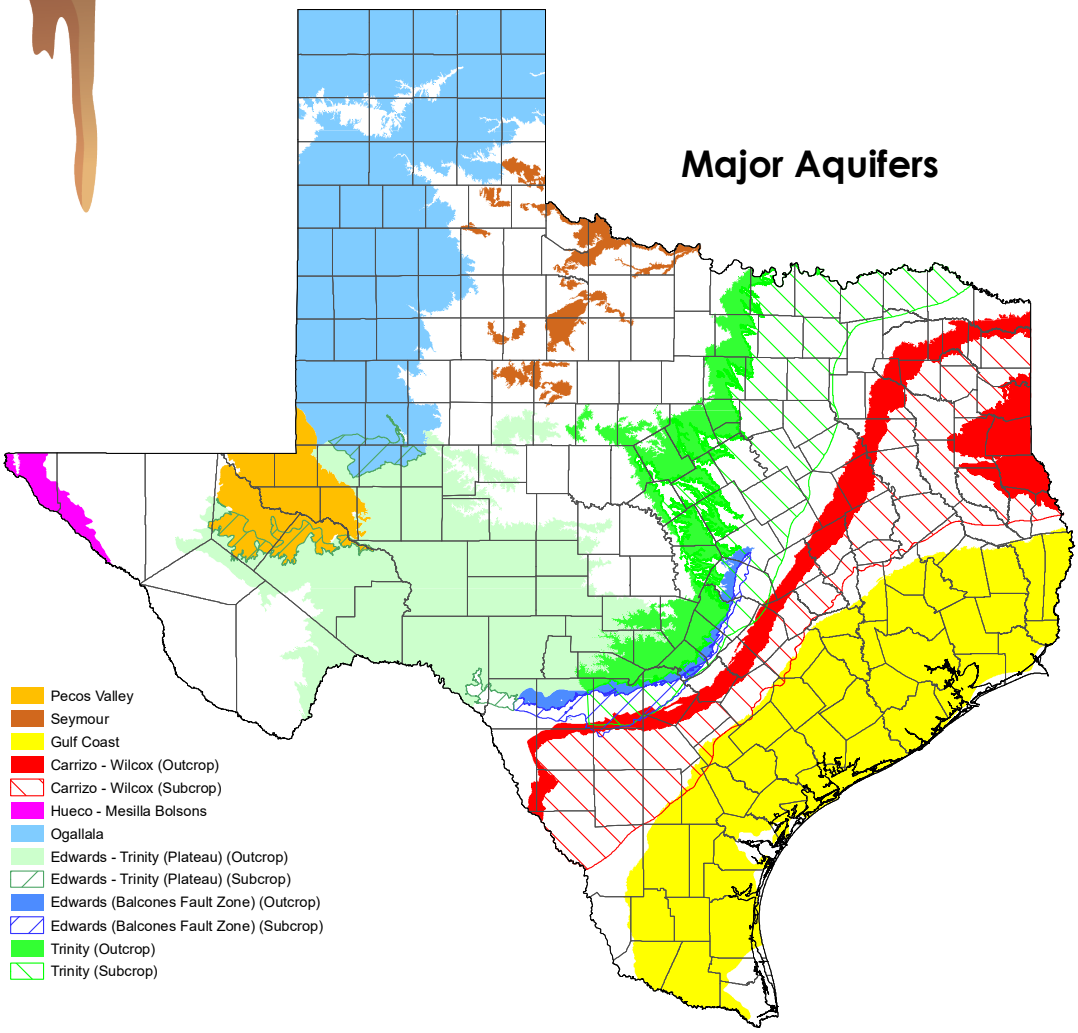
"Our goal for this research is not only to account for Earth's water resources while the NISAR mission will be in orbit, but also to develop a foundational understanding of water cycle processes to help formulate long-term solutions to global water-related challenges," Mohanty said.

Photo from Freepik.com edited by Sarah Richardson, TWRI.

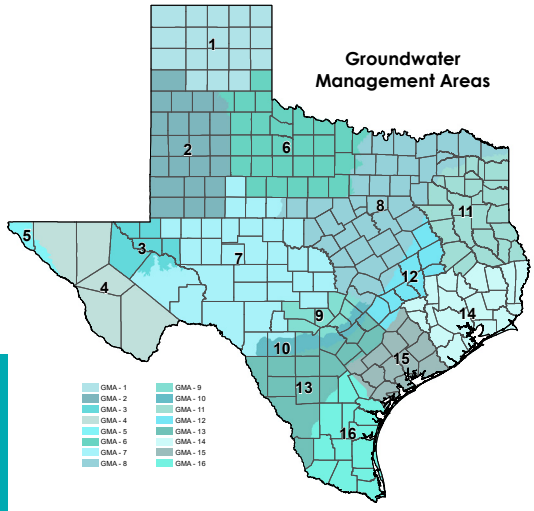
Water for Texas

Map Collection

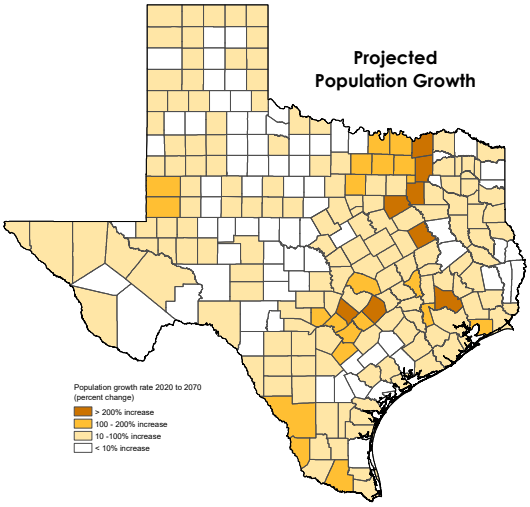
Major Aquifers



Groundwater Management Areas

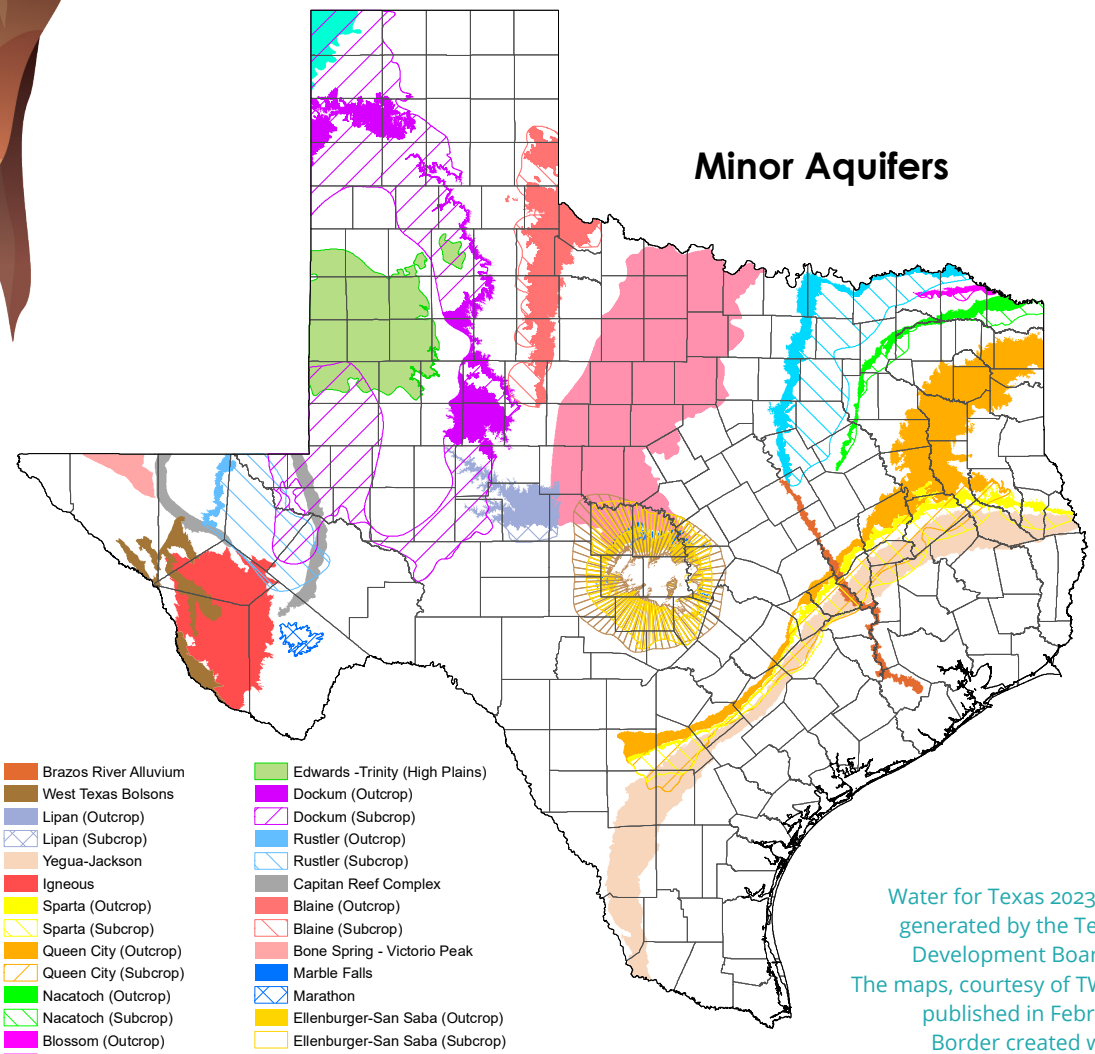


Projected Population Growth



Scan for a PDF map poster

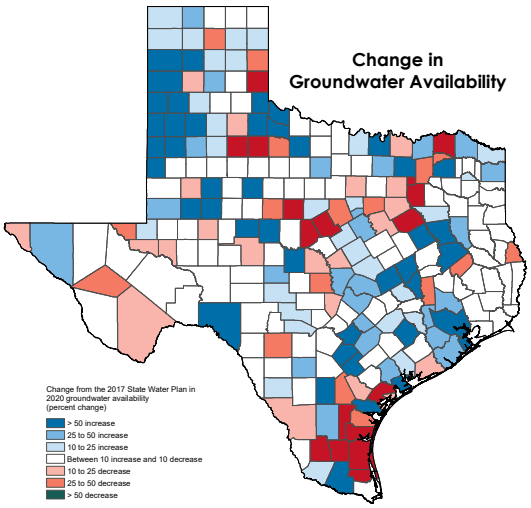
Minor Aquifers



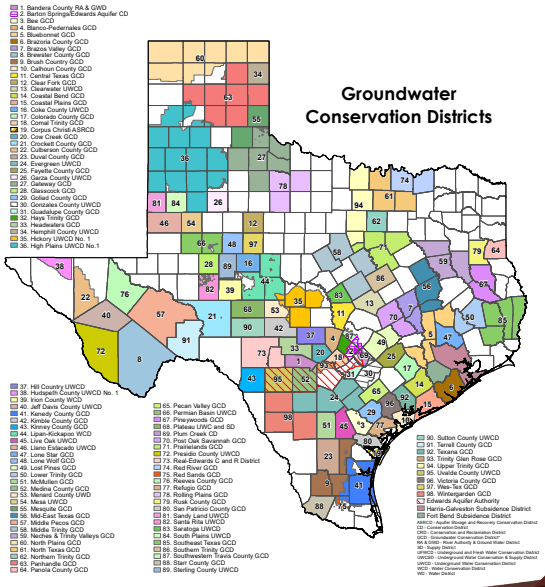
- Brazos River Alluvium
- West Texas Bolsons
- Lipan (Outcrop)
- Lipan (Subcrop)
- Yegua-Jackson
- Igneous
- Sparta (Outcrop)
- Sparta (Subcrop)
- Queen City (Outcrop)
- Queen City (Subcrop)
- Nacatoch (Outcrop)
- Nacatoch (Subcrop)
- Blossom (Outcrop)
- Blossom (Subcrop)
- Woodbine (Outcrop)
- Woodbine (Subcrop)
- Rita Blanca
- Edwards -Trinity (High Plains)
- Dockum (Outcrop)
- Dockum (Subcrop)
- Rustler (Outcrop)
- Rustler (Subcrop)
- Capitan Reef Complex
- Blaine (Outcrop)
- Blaine (Subcrop)
- Bone Spring - Victorio Peak
- Marble Falls
- Marathon
- Ellenburger-San Saba (Outcrop)
- Ellenburger-San Saba (Subcrop)
- Hickory (Outcrop)
- Hickory (Subcrop)
- Cross Timbers

Water for Texas 2023 map data generated by the Texas Water Development Board (TWDB). The maps, courtesy of TWDB, were published in February 2023. Border created with assets from Freepik.com by Sarah Richardson, TWRI.

Change in Groundwater Availability



Groundwater Conservation Districts



Texas' MOST INFAMOUS Groundwater Lawsuits

These court cases set today's Texas groundwater law precedents

Have you ever wondered why groundwater is legally considered private property in Texas but state property in other states in the United States? Or why the Edwards Aquifer is managed differently than the rest of Texas' groundwater? And how much legal authority do groundwater districts have? These particulars of Texas groundwater law and management were decided by key lawsuits and court rulings across the past 120 years, resulting in a complicated patchwork of precedents and guidelines.

"To understand how groundwater law works in Texas, you have to start with the unique history here and the timeline of these major decisions that changed how groundwater is used and managed," said Gabriel Eckstein, J.D., a professor in the Texas A&M University School of Law and director of the Energy, Environmental and Natural Resource Systems Law Program. "The state's history as both the 'wild west' and an agricultural and economic powerhouse in American history really sets the stage for how groundwater law evolved in the state."

These are some of the most influential groundwater court cases in Texas history, decisions that have shaped the Lone Star State's legal stances on groundwater rights, management and access.

The first major precedent was set over a century ago in the small town of Denison, where a landowner named W.A. East would soon become forever synonymous with the rule of capture and Texas groundwater.

(Top) West Texas skyline near Fort Stockton, Texas. Photo by Sam Craft, Texas A&M AgriLife Marketing and Communications.
(Bottom) Comal Springs. Photo by Leslie Lee, TWRI.

East v. Houston and Texas Central Railroad Company

Who: W. A. East, a landowner, versus the Houston and Texas Central Railroad Company

When: 1904

Where: Denison, Texas

What: The Houston and Texas Central Railroad Company decided to build a maintenance yard for their steam-powered locomotives in Denison and needed to drill a well. East owned property near the railway's land, and the company asked him about the wells on the property and the underground source. After seeing the wells on East's property, the company dug its well, with one major difference: it was much larger and deeper.

Why: After the rail company started pumping water, East's and many of his neighbors' wells started to run dry within months. East decided to sue the Houston and Texas Central Railroad Company for taking water from under his property. He asked the court to apply the reasonable use doctrine, claiming that the company was taking more than its fair share of water and not using it to better the land it was coming from.

Outcome and precedents: East eventually lost his case against the company. While the judge did agree that the railroad company was taking more than its fair share of water and that East and his neighbors were negatively affected by this, it was his ruling that no one party involved had sole rights to the water underground and as such, the railroad owed nothing to East or any other neighbors.

Following two years of appeals and overrulings, in 1904 the Texas Supreme Court weighed in on the issue, agreed with the original decision, and by doing so, officially set the rule of capture as the groundwater law of Texas.

"Essentially, the Texas Supreme Court borrowed language from an 1861 ruling by the Ohio Supreme Court that groundwater was so 'secret, occult and concealed,' that applying any set of legal rules to regulate groundwater would be a hopeless endeavor," said Todd Votteler, Ph.D., principal at Collaborative Water Resolution, LLC and editor-in-chief of the *Texas Water Journal*. "That Ohio Supreme Court ruling was actually based on an 1843 case decided in England, *Acton v. Blundell.*

"So the rule of capture is really a tort law concept and essentially says, 'you can't sue your neighbor if your well dries up, or the local spring or something like that.'"

There was little scientific understanding of groundwaters' origins at this time, and by adhering to the rule of capture, Texas chose to intertwine property rights and groundwater.

"They blatantly said, 'Hey, the economy would fall apart if we didn't allow the water to be used and pumped out,' and that's the priority; any attempt to regulate it would be impossible," Eckstein said. "So, Texas went full-blown absolute ownership, rule of capture, and just has been reluctant to move away from it. And it's become like a property right for landowners."

Sierra Club et al. v. Babbitt et al.

Who: Sierra Club, an environmental organization, versus the Secretary of the Interior, Bruce Babbitt (the case was originally filed as Sierra Club versus Lujan, but the name changed when the secretary changed)

When: 1993

Where: Midland, Texas

What: The Edwards Aquifer has provided water for the land above it for centuries, while also being home to many endangered aquatic species that can only be found in the aquifer and its associated habitats, such as Comal and San Marcos springs. As Texas' population grew, especially in the San Antonio and Austin areas over the aquifer, more and more water was pumped from it. Before this court case, there was no real regulation on aquifer pumping or efforts to conserve the aquifer's water levels. Lower water levels put the endangered species associated with the aquifer in danger of extinction.

Why: The Sierra Club filed a lawsuit against Babbitt, claiming that the U.S. Fish and Wildlife Service (USFWS) had not done enough to protect the endangered species living in Comal and San Marcos springs in allowing too much groundwater pumping, therefore violating the Endangered Species Act (ESA). The Sierra Club wanted USFWS to regulate pumping from the aquifer to maintain a healthy level of spring flow for wildlife.

Outcome and precedents: The court agreed with the Sierra Club that USFWS had failed to uphold the ESA by not doing more to inform people about preserving spring flows for the endangered species, and by not taking action to reduce aquifer pumping during dry periods to ensure the springs would continue to flow.

In the ruling, the judge gave the Texas Legislature until the end of the 1993 legislative session to pass a bill to regulate aquifer pumping and protect the springs. In response to the legal threat of a federal takeover of the aquifer under the ESA, the Edwards Aquifer Authority (EAA) Act was adopted.

"The case was really critical because that led to the creation of the Edwards Aquifer Authority and created this specialized groundwater district," said Amy Hardberger, J.D., a professor of water law and director of the Center for Water Law and Policy at Texas Tech University.

EAA is a political subdivision of the State of Texas that was created to manage, enhance and protect the Edwards Aquifer system, according to EAA's website.

This also marked the first time in Texas water law that groundwater was lawfully regulated.

"What's really significant about that, is that many people were convinced at that time that it was unconstitutional, under the state constitution, to regulate groundwater pumping," Votteler said. "And they would cite the East case, among other things, to support that argument. And so, the legislature created the Edwards Aquifer Authority in response to the judgment from a federal court." ⇨

Guitar Holding Company v. Hudspeth County Underground Water Conservation District No. 1

Who: Guitar Holding Company, a local landowner, versus Hudspeth County Underground Water Conservation District No. 1

When: 2008

Where: Hudspeth County, Texas

What: The Bone Spring-Victorio Peak Aquifer provides groundwater in northeast Hudspeth County, which was primarily cattle ranches until 1947, when irrigated agriculture industry developed in the region. This increased water usage at some points in the following decades exceeded recharge rates of the aquifer. In 1990, the Hudspeth County Underground Water Conservation District created a system to help manage water pumping and had strict rules for transporting water out of the district. While they amended the new system in 1998 pursuant to Chapter 36 of the Texas Water Code, an audit of the system in 2000 determined that the district's system violated the code.

In 2002 the groundwater district created a new system for water permits, and had three permit types: validation, operating and transfer. Validation permits were approved for well owners who had historically pulled groundwater from an aquifer prior to the new system. It guaranteed their right to pump, as long as they proved historic use; and, that historic use amount was considered when determining how much water they were entitled to. Those without historic use applied for operating permits, which only allowed pumping if the aquifer's water level was high enough. Any permit holder could apply for a transfer permit, which allowed for the capture and transfer of groundwater outside the district. This new system benefited historic users with a validation permit more because they could pump more groundwater and transfer all of their permitted water.

Guitar Holding Company was created in 2002 to manage the Guitar family's land, they had owned in the district since 1924, which was 38,296 acres in 2002. In the 1940s - 1960s, much of it was used for irrigated farming, but had been used for cattle ranching since. They applied for a validation permit for their 15 wells, permission to drill 52 new wells and the ability to transfer water outside the district, just before the new system went into effect, requesting that their application be processed in the old system. It was processed under the 2002 system, and Guitar received a validation permit, but was unhappy that despite their land area being larger than their neighbors, they had access to less water. This was due to neighbors showing a historic use of more groundwater on irrigated farmland, not ranchland.

Why: Guitar challenged the new system in court, arguing that the district overstepped and by giving more water to those with proven historical use, it created an unbalanced system. Guitar also argued that it was unfair that even those without historical evidence of transferring water were able to do so.

Outcome and precedents: The District Court of Hudspeth County and the El Paso Court of Appeals originally sided with the groundwater district, but the Texas Supreme Court did not. It sided with Guitar, ruling that the district needed to consider the water's purpose, in addition to the amount of water used, when looking at historical use. They also ruled that the transfer permit did not protect district users since it allowed permit holders to change their water use and created unfair benefits for validation permits.

This case created precedents for water transfers and how much historic use could be considered by groundwater districts.

"This was a really important case in discussing how groundwater districts can regulate historic use," Hardberger said. "Particularly when somebody wanted to apply for transfer permits for exporting for groundwater projects."

Windmill and stock tank near Fort Stockton, Texas. Photo by Sam Craft, Texas A&M AgriLife Marketing and Communications.

McDaniel and Day v. Edwards Aquifer Authority

Who: Joel McDaniel and Burrell Day, landowners, versus the EAA

When: 2012

Where: Von Ormy, Texas, a part of the San Antonio metropolitan area

What: McDaniel and Day purchased 381 acres of land to grow crops and graze cattle on in 1994 in Von Ormy, Texas. They pumped water from the Edwards Aquifer, and there was a collapsed well on the property that was used for irrigation decades before. The well still had water flowing out of it but it mostly fed a lake on the property used for irrigation and recreation.

To fix the well or drill a replacement, a permit would be required from EAA, which had been created by the Texas Legislature the previous year. In 1994, Day put in an application to pump 700 acre-feet of water annually for farming. Ultimately, the permit application was denied in 2000, with the authority claiming that based on historical information, the water being pumped from the aquifer was not being "placed to a beneficial use."

Why: Day protested the decision and in a subsequent hearing by the State Office of Administrative Hearings, the judge decided water being used from the lake, although it initially came from well water, it was considered surface water once it left the ground and merged with the lake water and could not be used in Day's application. This, along with historical information, led to the judge's ruling that Day was allowed 14 acre-feet of water. Day appealed the decision and sued EAA for taking his property without compensation.

Outcome and precedents: For over a decade, the case went through multiple appeals and courts. Eventually, a district court decided that EAA's permitting system based on historical use was a "departure" from the Texas Water Code. The Texas Supreme Court later affirmed that ruling and used oil and gas ownership laws in Texas as a basis to decide in favor of Day. They also declared groundwater as a vested property right, meaning too much regulation by an agency like EAA could become a regulatory takings argument.

In light of the East case establishing Texas as a rule of capture state over a century earlier, many experts viewed this ruling as a modern reaffirmation of that doctrine, Votteler said. It set limits on how much control EAA had when it came to water being pumped from the aquifer by private landowners. The ruling moved groundwater law and regulation closer to how oil and gas are regulated in the state, he said.

"The Texas Supreme Court said, 'Hey, groundwater kind of looks like oil and gas," Votteler said. "It flows. It's fluidic. And the rule in oil and gas is absolute ownership, under your property, you own it, like you own the land and the trees on your property."

Bragg v. Edwards Aquifer Authority

Who: Glenn and JoLynn Bragg, orchard owners, versus EAA

When: 2008

Where: Medina County, Texas

What: Glenn and JoLynn Bragg owned and operated two pecan orchards in Medina County since 1979 and 1983, and both properties were above the Edwards Aquifer. The Braggs submitted applications to the EAA to continue using water from the aquifer at their orchards after the authority was created. One of their applications was for twice the amount of water the orchard historically used, and the second requested using aquifer water at a location that did not use groundwater until 1995.

In 1998, EAA recommended partial denial of the first application, granting a permit for around half of what the Braggs applied for, and complete denial for the second application due to the lack of historic use.

Why: In response, the Braggs sued EAA, claiming that denial of the permits was essentially taking their private property and that EAA had to compensate them for it. The courts found in favor of the Braggs and awarded them over $700,000 in damages. Both parties appealed the decision, the Braggs because they felt that the calculations had been incorrect and that they were owed more, and EAA because they claimed that nothing had been taken from the Braggs and that the amount of money was incorrectly high.

Outcome and precedents: After years of delays, rulings and appeals in 2013 the San Antonio Court of Appeals decided that when the authority awarded the Braggs less water than they had claimed, those actions were an overreach and resulted in a regulatory taking. The court also laid out how to calculate the damages entitled to the Braggs.

This case answered the question as to how much authority groundwater authorities have over the water. The Braggs' successful argument — that the limited and rejected permits were takings of their private property and deserved compensation — resulted in limiting the regulatory scope of entities such as EAA on private property.

"This ruling has raised questions about groundwater management in Texas," Votteler said, "because it's not always clear with the regulation of groundwater when the regulation results in a taking and when it doesn't."

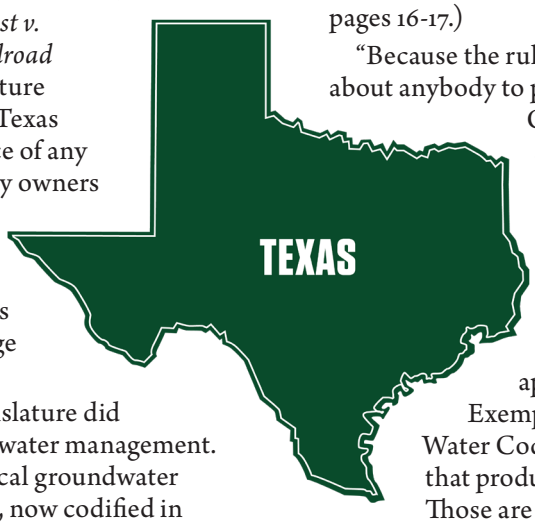
Different States, Different Management Strategies

Texas, Kansas and Arizona, three states representative of increasingly stressed U.S. groundwater supplies, work to prevent aquifer depletion

For most of the 20th century, organized management of groundwater pumping in Texas was largely nonexistent. The rule of capture was the law, and how to steward groundwater resources was left up to landowners.

"When tracing the roots of groundwater law and management in Texas, all roads lead east, and more specifically, to the East decision," said Trey Gerfers, general manager of the Presidio County Underground Water Conservation District (PCUWCD).

That 1904 court decision, *East v. Houston and Texas Central Railroad Company,* made the rule of capture the foundational precedent of Texas groundwater law, in the absence of any state legislation. Texas property owners owned all groundwater under their land and could pump as much as they saw fit. (Learn more in "Texas' Most Infamous Groundwater Lawsuits" on page 18.)



In 1949, the Texas State Legislature did eventually weigh in on groundwater management. It authorized the creation of local groundwater conservation districts (GCDs), now codified in Chapter 36 of the Texas Water Code, granting districts limited powers and requiring GCDs to work to manage, conserve and protect groundwater through rule-making and well-permitting.

Texas' first GCD, High Plains Underground Water Conservation District Number 1, was created in 1951.

Texas groundwater management evolves

Over 70 years later, Texas groundwater law and management is a patchwork of precedents and local GCDs, which remain the state's preferred groundwater management tool.

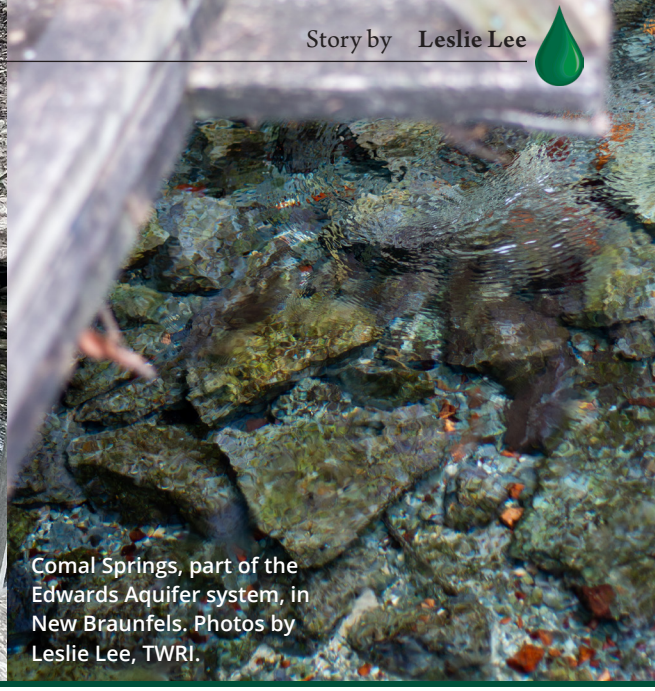
GCDs must receive local voter approval to be established and enact rules. Districts can manage groundwater through well spacing and production limitations, and can place requirements on the drilling, equipping, operating, completing and substantially modifying of wells. Currently, there are 98 GCDs and two subsidence districts in Texas. (See Water for Texas Map Collection on pages 16-17.)

"Because the rule of capture essentially allows just about anybody to pump as much water as they want, GCDs are the most effective means available to protect landowners and their rights in groundwater," Gerfers said. "In fact, GCDs are typically created by landowners and other concerned parties, often in the face of a perceived threat."

GCDs also consider and permit all applications for non-exempt water wells. Exempt water wells are defined by the Texas Water Code as all domestic and livestock wells that produce less than 25,000 gallons per day. Those are exempt from permitting, metering or fee requirements. All other industrial and agricultural wells are non-exempt.

GCDs maintain records of all non-exempt wells in the district and can enact permitting, spacing, metering or fee rules for those wells. Today, the state also requires that all newly drilled wells submit a drilling log to the local GCD.

One exception to this framework is all land under the jurisdiction of the Edwards Aquifer Authority, a south-central Texas entity created in 1993 to regulate and manage the aquifer's levels in compliance with the federal Endangered Species Act. (See page 19.)



Comal Springs, part of the Edwards Aquifer system, in New Braunfels. Photos by Leslie Lee, TWRI.

For groundwater supply planning, Texas uses another tool: groundwater management areas (GMAs). Delineated by the Texas Water Development Board (TWDB), GMAs are made of multiple GCDs and must meet jointly to develop cooperative management goals and desired future conditions (DFCs) for the area. "In setting DFCs, GCDs balance groundwater production with conservation and protection of the aquifer and then manage that production on a long-term basis to achieve and maintain the DFC's," according to the Texas Alliance of Groundwater Districts.

Modern-day Texas faces a triple threat of major population growth demanding more water, rapid urban and suburban development changing the landscape, and climate impacts changing the environment and weather. As surface water supplies face these pressures, and more providers turn to groundwater for supply. With those demands looming, some groundwater stakeholders have helped GCDs grow and become more effective at water measurement and management.

In Far West Texas, PCUWCD was created in 1999 to proactively protect local aquifers when municipal water pumping and industrial impacts began concerning landowners. Their aquifers are currently used at a sustainable rate, Gerfers said. "But the balance is delicate; just one user or one city could disrupt that balance, and it's the task of GCDs to negotiate this fine line," he said.

In 2023, Presidio County voters passed a proposition that dedicated funding to the GCD by allowing it to assess an ad valorem tax without raising net property taxes. With that funding increase and grants from government agencies and organizations, PCUWCD has increased its number of monitoring wells and improved data collection.

"We communicate to our stakeholders that the district has a legal obligation to understand how much water is being pumped," Gerfers said. "And, the well owner will ultimately benefit by having a better picture of how much water is being pulled out of the aquifer. Because if someone's not following those rules, then that's going to hurt everybody."

One challenge to groundwater management improvements in Texas is that people are generally resistant to change, said Lucas Gregory, Ph.D., Texas Water Resources Institute associate director.

"And, unless there is a real incentive to do so, changing groundwater management at any level in Texas is very difficult," Gregory said. "Those incentives could be economic, drought-based, or even availability-based — but these often result in pumping simply stopping rather than changing its management.

"Because of the way water law is set up here, groundwater users have to weigh the long-term benefits of conservation-minded management with the risk of their neighbor continuing to pump like they always do and potentially negating whatever positive conservation gains are made. Essentially, this can be a disincentive to use water more conservatively."

Ag producers in Kansas do more with less

In Kansas, groundwater is a state-managed resource, and agricultural producers' approaches to conserving the Ogallala Aquifer have evolved over time.

"The water in western Kansas is a limited, finite resource that supports our food and agriculture industry," said Susan Metzger, Ph.D., director of the Kansas Water Institute and Kansas Center for Agricultural Resources and the Environment, at Kansas State University. "And that industry is the largest economic contributor to the state of Kansas. So, we're really invested in finding ways to make that a stable future for our economy."

Bill Golden, Ph.D., Kansas State University research assistant professor, has collaborated with Kansas farmers on water conservation strategies for decades.

"When I first started, oftentimes a producer's perspective was 'we can't live with less water, and we're already as

efficient as we can be. This is the way my dad did it. This is the way I want to do it,'" he said. He remembers when perspectives began to shift: around the time aquifer levels began rapidly declining in northwest Kansas. If families wanted to continue passing down irrigated cropland to the next generation, something had to change, he said.

Around 2010, after years of meeting and discussing solutions to majorly declining Ogallala Aquifer levels, a group of producers in the Sheridan County area in northwest Kansas were ready to change the status quo, said Shannon Kenyon, district manager of Kansas' Groundwater Management District 4, which includes the county.

At the time, the only tool available was delegating an Intensive Groundwater Use Control Area, or IGUCA, which cedes control of pumping limits to the Kansas Division of Water Resources.

"These producers wanted to conserve water and coordinate with each other, while also controlling their own destiny; but we didn't have a legal way of doing that," Kenyon said. "So, in 2012 Locally Enhanced Management Areas, or LEMAs, were officially added as a provision to the Kansas Groundwater Management District Act."

LEMA plans are based on stakeholder input, then written by the groundwater management districts and submitted to the Kansas Division of Water Resources for approval. LEMAs allow districts to set goals and control measures to conserve water. There are currently four LEMAs in Kansas.

"I'm a firm believer that the best long-term solutions come from the ground up," Metzger said. "Locally driven solutions have the highest probability for long-term success. And LEMAs are a locally driven solution."

The first LEMA became official in 2013 when the Sheridan County producers agreed to a 20% reduction in groundwater pumping, and the state approved it, Kenyon said. This original LEMA is called the Sheridan Six because it was the sixth high-priority area designated by District 4. The Sheridan Six farmers used various irrigation management strategies and technologies to pump less water.

And it all paid off.

"At the end of the day, they've achieved closer to a 35% reduction," she said. "It has been monumental."

"We can monitor the soil moisture data, monitor rainfall, use new irrigation technology — there are all sorts of things that we can do to use less water," Golden said.

He completed the first economic analysis of the agricultural operations in the Sheridan LEMA, a study funded by the Ogallala Aquifer Program (OAP). It found that with a 20% reduction in groundwater pumping, crop yields remained the same, and profits increased because fewer inputs such as fertilizer and seed were needed.

Around this time, most producers in Kansas believed they were operating at around 95% water efficiency, Golden said. But, success stories like the Sheridan Six showed that water use efficiency could be improved more than 5%. By being better water managers, he said, producers have not only extended the aquifer life in that region, but also made their land more valuable.

"Within that region, just within that first five-year period of 2013–18, they doubled the life of their aquifer," Kenyon said. "One of the most powerful things that's come out of this is that the Sheridan Six producers go out often and talk about what's worked for them, and how many bushels per inches of water they produce, instead of bushels per acre. Instead of 'whoever has the highest yield wins,' now it's 'whoever has the largest yield on the least amount of water wins'."

Arizona seeks solutions

Thousands of miles from the High Plains, groundwater stakeholders in Arizona are also looking for new groundwater management policies and tools.

Groundwater serves as 41% of Arizona's water supply, according to the Arizona Department of Water Resources. Arizona has three categories of groundwater use regulations: active management areas (AMAs), Irrigation Non-expansion Areas (INAs), and the rest of the state, which is not subject to any groundwater regulation but must submit a notice of intent to drill a well, said Sharon B. Megdal, Ph.D., director of the University of Arizona Water Resources Research Center. The state of Arizona does not follow the rule of capture; residents and landowners do not own groundwater, but instead have the right to use it.

Population growth and suburban and rural development have stretched-thin some Arizona groundwater supplies in recent years, and in January of 2023 Arizona Governor Katie Hobbs issued an Executive Order to establish the Governor's Water Policy Council. It was tasked with modernizing the Arizona Groundwater Management Act. Megdal was an appointed

Mobile drip irrigation in a wheat field in Kansas. Photo courtesy of the Kansas Center for Agricultural Resources and the Environment.

member, along with water professionals, tribal community leaders, water users and legislators.

"There is a lot of pressure and stress on our aquifers in our rural regions right now," she said. "Most people agree that something needs to change. The work is finding common ground. The question always is, can the decision-makers come together and find common ground on groundwater management?"

After months of input and collaboration, the council's recommendations charted a path forward.

"Many communities are facing aquifer depletion with limited access to renewable water supplies and no regulatory tools to manage the groundwater declines," its January 2024 report said. "There is a lack of data points due to no requirements for metering and reporting groundwater use outside AMAs and INAs."

Ultimately, the council recommended to the governor a "Rural Groundwater Management Area" (RGMA) framework proposal as a foundation for a new groundwater management program for rural Arizona.

The resulting legislation, Arizona House Bill 2857, was introduced in February but did not receive a hearing; it proposed amending existing laws to allow the creation and management of RGMAs. Other groundwater bills were introduced and debated, but no statewide agreement was reached. June 18, after the legislative session concluded, the council met and state officials presented ongoing rural groundwater legislation discussions and a detailed analysis of an "ag to urban" groundwater-management proposal. Discussions are ongoing.

"Arizona has a long and successful history of groundwater management in the AMAs," Megdal said. "However, even for the AMAs, opportunities for improvement exist. For the rural areas where no groundwater management framework exists, decision-makers and water users are actively focusing on how to manage groundwater in a way that is tailored to the local communities and supportive of their vitality."

Managing groundwater for future generations

"Our ultimate goal is to understand the health of our aquifer and how pumping is affecting that aquifer, so that we're not depleting it and not robbing future generations of water just because we're not managing it properly," Gerfers said.

"Simply pumping a well until it runs dry isn't the only option — nor should it be," Gregory said. "That water resource is the lifeblood of Texas and we need to think about how to extend the viability of these supplies. Not only do Texans need water to drink, that water drives the economy. From agriculture to industry, water is a must and adds billions of dollars to the Texas economy.

"Technology advancements will continue helping us improve water management just as it has in the last 75 years. It will certainly come at a cost, but that cost is likely much less than not having those current sources of water."

As new policies and strategies move forward, states and regions will continue to take different approaches to groundwater management.

"There's not one right way to do things when it comes to groundwater," Gregory said. "There are of course pros and cons to certain approaches. Ultimately, the decisions we make today will impact us now and into the future. Today, we must envision that future and adjust planning and management to get us there."

Aquifers Along the Border

Transboundary Aquifer Assessment Program scientists identify vulnerable borderland aquifers

When it comes to shared surface water, the United States and Mexico are lawfully obligated to abide by binational treaties and the International Boundary and Water Commission (IBWC). But what about governance of the groundwater that both countries have access to, in aquifers underlying the nearly 2,000-mile border?

Not only does no such groundwater treaty or governance exist, but in recent decades, heavily strained river systems have decreased surface water reliability in border states, resulting in more demand for groundwater extraction and treaty compliance issues, particularly in the Rio Grande basin.

For 15 years, the Transboundary Aquifer Assessment Program (TAAP) has been studying these borderland aquifers. TAAP conducts the foundational research needed to help communities and governments if binational groundwater governance cooperation ever becomes a reality at a federal, regional or local level.

TAAP was authorized under the U.S.-Mexico Transboundary Aquifer Assessment Act of 2006 on the U.S. side, and formally became a binational effort in 2009, led by the United States Geological Survey (USGS) and IBWC, to conduct binational scientific research to systematically assess priority transboundary aquifers.

A complete count or map of the aquifers along the U.S.-Mexico border did not exist until 2023.

Thanks to the leadership of Rosario Sanchez, Ph.D., Texas Water Resources Institute (TWRI) senior research scientist and TAAP lead, that map of all 72 shared borderland aquifers is now publicly available. (See map on right.) Of those shared aquifers, 32 are along the Texas-Mexico border.

In 2024, Sanchez and collaborators in Texas, New Mexico and Arizona continue pushing this work forward for the millions of people depending on these aquifers.

Identifying hot spots

The original TAAP authorization bill instructed the program to focus on four priority aquifers: the San Pedro and Santa Cruz aquifers between Arizona and Sonora, and the Hueco-Bolson and Conejos Medanos Aquifer/Mesilla Bolson aquifers between Texas, New Mexico and Chihuahua. The program has made great strides in those areas, and Sanchez also studies many other stressed aquifers along the border.

"It's nobody's water," Sanchez said. "So, everybody uses it, regardless of their neighbors or their shared natural systems."

A few years ago, the TAAP research team at TWRI developed a new approach to finding "hot spots" called Effective Transboundary Aquifer Areas (ETAAs), a process used to identify priority areas of an aquifer. ETAAs are identified by a high density of water wells and groundwater extraction.

Sanchez said that decision-makers could use ETAAs to prioritize groundwater-stressed regions or communities that could need additional funding or resources.

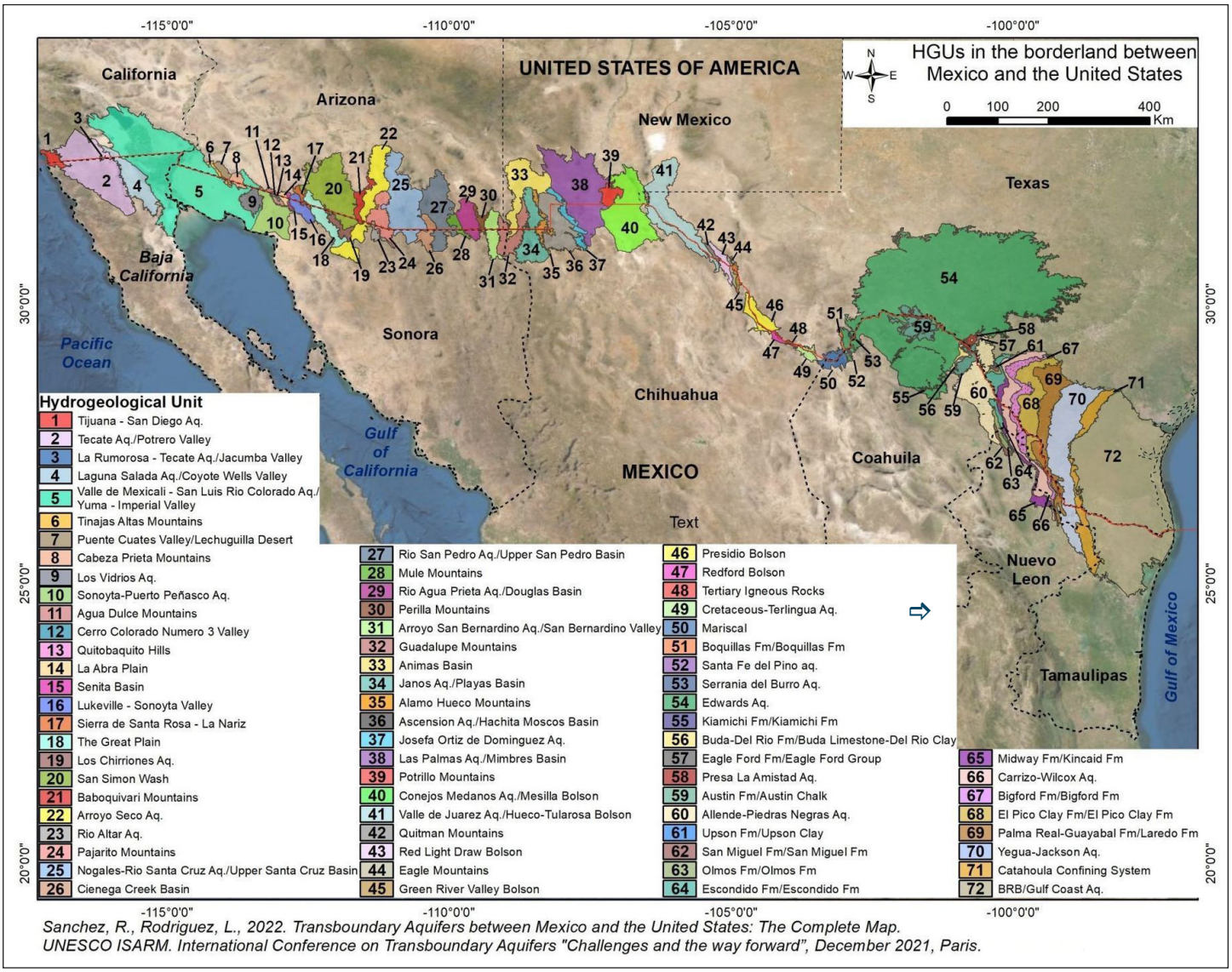
"We are looking for hot spots of groundwater extraction, movement and potential impacts — not just for over-drafting, but also contamination and vulnerability to contamination," Sanchez said.

"We look for areas of land with more than one well per 100 square kilometers," she said. The group first published research on the ETAA approach in 2020, and has since further refined it.

One important hot spot that they've continued to study further is the Conejos Medanos Aquifer, or Mesilla Bolson, near El Paso. Equally important is the Valle de Juarez Aquifer or Hueco-Tularosa Bolson, which is shared between El Paso and Juarez, she said. The Allende Piedras Negras/Maverick Aquifer is also a significant ETAA.

Within TAAP, Sanchez said there are working groups studying these hot spots, including scientists from the New Mexico Water Resources Institute, University of Arizona Water Resources Research Center (UAWRRC) and the Universidad de Sonora, guided by the coordination of USGS.

"Prioritizing aquifers has to be a binational effort," said Sharon B. Megdal, Ph.D., UAWRRC director. "We have to consider many factors when prioritizing aquifers, including hydrological and sociological impacts."



Sanchez, R., Rodriguez, L., 2022. Transboundary Aquifers between Mexico and the United States: The Complete Map. UNESCO ISARM. International Conference on Transboundary Aquifers "Challenges and the way forward", December 2021, Paris.

Hydrogeological units (HGUs) in the borderland between Mexico and the United States. Map developed by Rosario Sanchez, TWRI. Left: Sanchez speaking at the National Science Summit in Chihuahua, Mexico, in 2023.

In southern Arizona, the Santa Cruz, San Pedro and Douglas aquifers stretch under the border into the Mexican state of Sonora and are important hot spots of groundwater extraction in that region, Sanchez said. Big Bend and the springs in Big Bend are another Texas area that is sensitive to groundwater overuse.

"There are very vulnerable systems out there," Megdal said. "These ecosystems are very, very dependent on groundwater flow — groundwater flow that nobody is regulating."

Studying successful binational agreements

In research published by Sanchez, Megdal and collaborators in January, they discussed how two countries can craft groundwater system frameworks that are mutually beneficial and conserve water.

The researchers concluded that a "framework agreement" would serve the region's groundwater challenges well. In international diplomacy, a framework agreement commits two or more parties to recognize and address an issue of shared concern within certain generally agreed upon parameters. It would provide agreement on specific elements of the aquifers at a local level, with substantive and/or procedural elements to be resolved by future negotiations, thus allowing the parties to advance as needed on a more regional basis.

"A framework agreement is needed, timely, achievable and essential to meeting the region's water security needs in the foreseeable future," the binational team said.

Surface water supplies in the Rio Grande Valley continue to decrease and become unreliable, which means more users will turn to groundwater, and aquifers will continue to show more stress, Sanchez said.

"These systems are going to speak eventually, and we're not ready," she said. "We don't have the luxury to keep ignoring groundwater."

Texas Groundwater Protection Committee

TGPC brings together members from different agencies and organizations to help protect Texas groundwater

Illustration created with assets from Freepik.com by Sarah Richardson, TWRI.

The Texas Groundwater Protection Committee (TGPC) has worked for more than 30 years to steward groundwater across the state. While Texas' population has grown and urbanized in those decades, TGPC has continually worked to understand and address Texas' groundwater quality issues.

"Membership has evolved over the years, but our mission has always pretty much been the same," said TGPC Designated Chairman Kelly Mills. "We coordinate groundwater protection programs within the state of Texas, which has different agencies implementing them through federal and state laws."

The history of TGPC

A bill passed by the 71st Texas State Legislature in 1989 created TGPC in Chapter 26 of the Texas Water Code. It was originally composed of seven members: the chief executives of the Texas Water Commission (now the Texas Commission on Environmental Quality, TCEQ), the Texas Water Development Board, the Railroad Commission of Texas, the Texas Department of Health (now the Texas Department of State Health Services), and the Texas State Soil and Water Conservation Board, as well as the Deputy Commissioner of the Department of Agriculture, and a representative of the Texas Groundwater Conservation Districts Association (now the Texas Alliance of Groundwater Districts).

In 1993, TGPC saw the 73rd Texas State Legislature amend the Texas Water Code to extend committee membership to the Texas Agricultural Experiment Station (now Texas A&M AgriLife Research) and the Bureau of Economic Geology at the University of Texas at Austin (the Bureau).

The legislature set TGPC's duties as: coordinating groundwater protection activities of the agencies represented on the committee; developing and updating a comprehensive groundwater protection strategy for the state; studying and recommending to the legislature groundwater protection programs for areas where groundwater is not protected by current regulation; filing a report on the committee's activities and recommendations with the governor and the legislature; and publishing a joint groundwater monitoring and contamination report.

"Many of our programs and a lot of our efforts are geared towards prioritizing and helping private water well owners protect our groundwater resources," Mills said.

TGPC accomplishes most of its work through its three subcommittees (groundwater issues, public outreach and education, and legislative report), made up of agency and organization members and the general public. The subcommittees address specific groundwater issues or areas of program development and keep TGPC apprised of ongoing issues and projects. The subcommittees report and provide recommendations to TGPC at its regularly scheduled meetings. At its meetings, TGPC considers the findings and recommendations of the subcommittees, and after holding discussion, takes action as it finds appropriate for each issue. The public can also participate in the subcommittee process.

TGPC today

As of January 2024, TGPC has produced various reports and educational materials for the state, including:

- 17 reports to the legislature with recommendations.
- 34 *Joint Groundwater Monitoring and Contamination Reports,* tracking 22,534 cases of groundwater contamination.
- Numerous brochures, fact sheets and white papers on groundwater-related subjects.
- Three Pesticide Management Plans.
- Three groundwater protection strategies for the state.

TGPC membership has grown, with the most recent addition being in 1999, when House Bill 1848 amended TGPC's enabling law to provide that a representative of the Water Well Drillers and Pump Installers Program of the Texas Department of Licensing and Regulation selected by their executive director serve as a member of TGPC.

While much of the committee's mission has not changed, improvements in online resources for reports and public outreach and education efforts have helped TGPC reach a wider audience. TGPC's funding for its activities comes from TCEQ, which receives this money through a U.S. Environmental Protection Agency Clean Water Act grant.

"We have small amounts of money that we use to contract with the Bureau to study certain naturally occurring constituents (e.g., arsenic, fluoride, and nitrate)," said Abiy Berehe, TCEQ groundwater planning and assessment team leader. "We also have a contract with the Texas A&M AgriLife Extension Service to develop fact sheets about drinking water supplied by private water wells to help with outreach and education activities throughout the state."

Another long-term outreach effort of the committee is addressing abandoned and deteriorated private water wells, Mills mentioned.

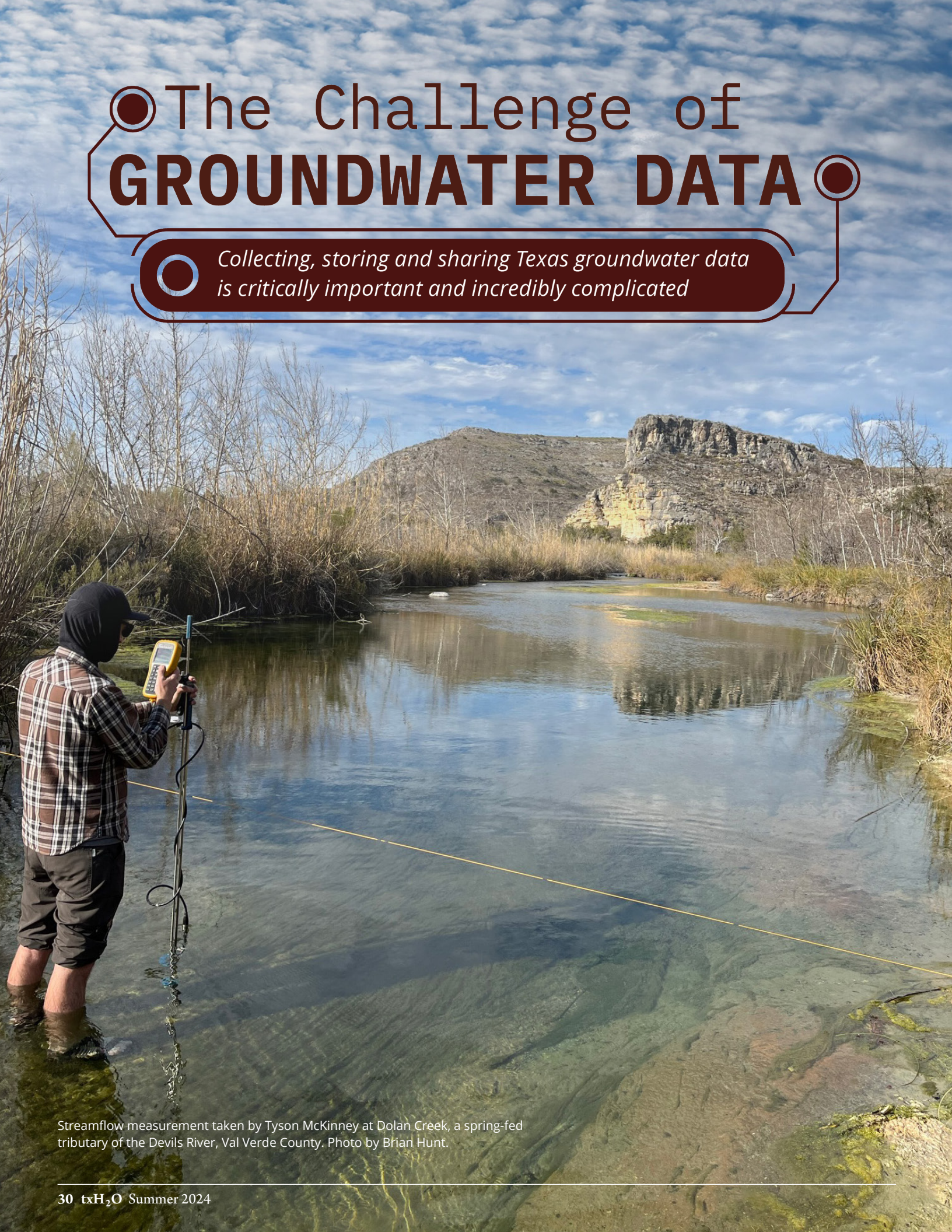
"Abandoned wells are a conduit for contamination and a public health risk," Mills said. "TCEQ publications RG-347 and RG-347 especially provide landowners with the options that are available and the details on how to address this hazard."

In its three decades of existence, TGPC has worked to bridge the gap between Texas groundwater agencies and organizations to improve groundwater quality for the state.

"We all share the common goal of protecting groundwater for the state of Texas," Mills said.

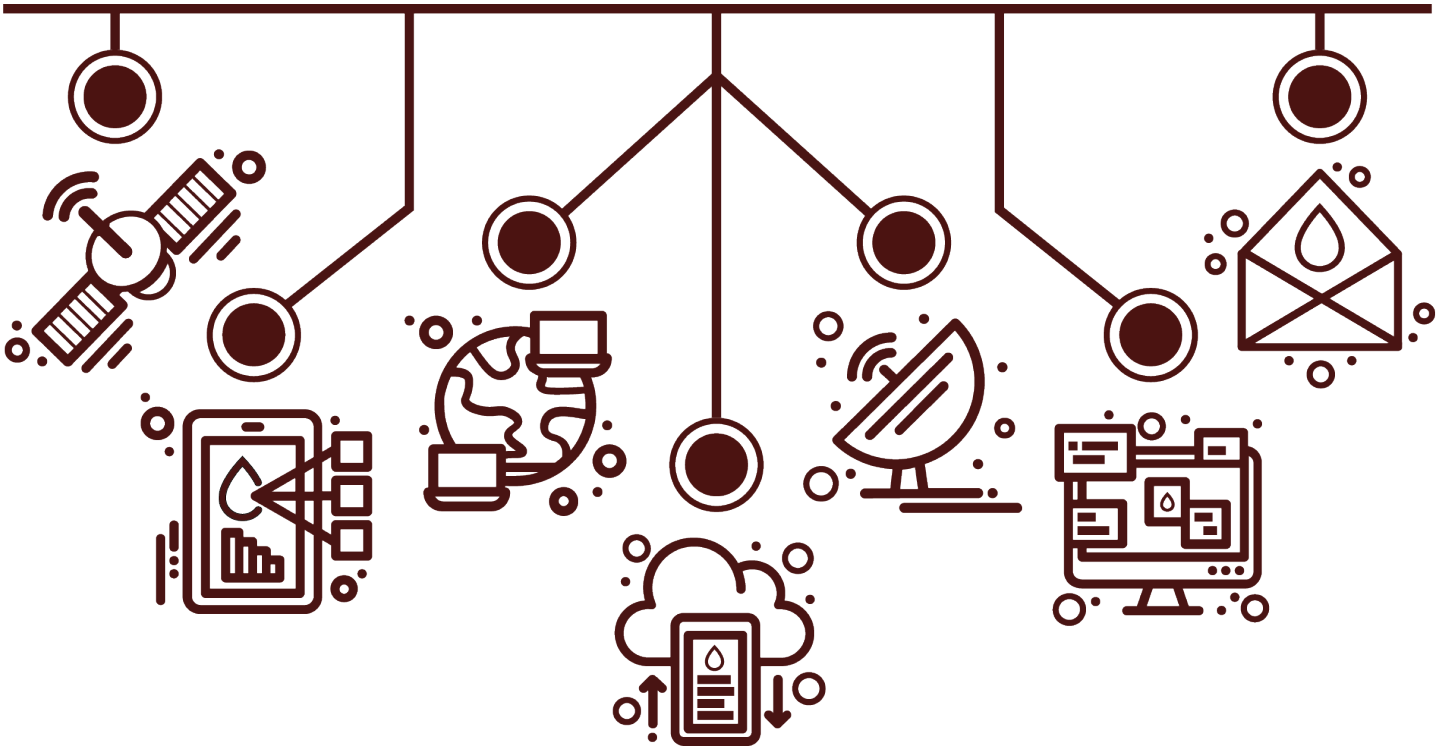
The Challenge of GROUNDWATER DATA

Collecting, storing and sharing Texas groundwater data is critically important and incredibly complicated



Streamflow measurement taken by Tyson McKinney at Dolan Creek, a spring-fed tributary of the Devils River, Val Verde County. Photo by Brian Hunt.

Graphic created using assets from Freepik.com by Sarah Richardson, TWRI.



Texas aquifers have more straws removing water from them today than ever before. Thankfully, decision-makers and landowners also have access to critically important groundwater quality and quantity data more than ever before, because of the federal-, state- and county-based agencies that have been collecting groundwater data for decades.

The U.S. Geological Survey (USGS) is the federal agency responsible for measuring hydrologic and hydrogeologic data across the nation and in Texas. Groundwater level and groundwater quality data can be found on the National Water Dashboard at tx.ag/usgsnwd.

The Texas Water Development Board (TWDB) is the state agency responsible for storing groundwater data in Texas, and TWDB teams also collect groundwater quality and quantity data. At the local level, groundwater conservation districts (GCDs) collect the majority of groundwater level data and submit it to TWDB for inclusion in their Groundwater Data Viewer at tx.ag/TWDBviewer.

"The Texas Water Development Board is an amazing state agency that serves as a clearinghouse for data and a resource for managing the technical side of issues with aquifers, groundwater and surface water," said Brian Hunt, a geologist and hydrogeologist for the Bureau of Economic Geology at the University of Texas at Austin. The TWDB database provides a consistent and accessible platform to obtain groundwater data throughout the state.

"The better the data, the better the science; the better the science, the better the planning," said Heather Dodson, data team lead in TWDB's groundwater technical assistance department. That is what TWDB strives for, and collecting this data, even when difficult, is worthwhile for the health of the state's groundwater resources, she said.

The massive amount of groundwater data collected across Texas can be difficult to work with, Hunt said. Texas groundwater scientists and decision-makers navigate a patchwork of overlapping agencies with different authorities and priorities, all with varied methods of data collection and databases, he explained. Each agency has different methods, tools and protocols to collect the data, which have all evolved. Thus, compiling the data into databases can be a challenge.

Throw in the landscape's widely variable hydrogeology, and the picture of groundwater in Texas can seem about as clear as mud.

How groundwater data is collected

According to Dodson, TWDB groundwater data methods to measure the water level (head) in flowing wells include steel tapes and chalk, electric lines (E-lines), pressure transducers and pressure gauges. TWDB also performs water quality monitoring, sending the collected groundwater samples to a lab for testing.

Many GCDs and TWDB have a recorder program that provides real-time, automatic well readings and sends recurring reports on water levels in various locations. TWDB has a robust network across the state, and these measurements are valuable because they track both short- and long-term trends in water quantity, giving local residents and city and state officials key information for water-related decisions.

For example, GCDs may use this information to make drought declarations or permitting decisions. ⇨

"I encourage landowners that data can be their best friend," said Trey Gerfers, general manager of the Presidio County Underground Water Conservation District in Far West Texas. "It's the best way available to ensure landowners' rights in groundwater. If you don't know when and if your levels are fluctuating and you don't have that data over long periods, then you don't know what's happening with your water supply."

Dodson and TWDB teams share with landowners the benefits of data collection and cooperating with TWDB and local GCD programs. If a landowner has a well that can fill a data gap in TWDB's monitoring network, TWDB may ask to add that well to its network, at no cost to the landowner. TWDB collects groundwater quality samples representative of every region in the state on a four-year cycle, but their current funding level does not support state-wide water quality sampling year-round.

Monitoring natural springs is another groundwater data point that TWDB stewards. "We've been monitoring water quality for springs for many years, but we've started a new initiative for a dedicated Springs Monitoring Program to add spring flow data to our monitoring program," Dodson said. "This initiative is now going on its fourth year."

Data through the decades

Since it was created by the Texas Legislature in 1957, TWDB has been involved in documenting groundwater levels and establishing a central source for that data. The TWDB Groundwater Data Viewer does not contain every water well ever drilled in Texas, because it is a scientific database to assist with regional groundwater planning and provide site specific data for local groundwater management. It contains information on selected water wells, springs, oil/gas tests that were originally intended to be or were converted to water wells, water levels and water quality.

A separate database exists for wells being drilled in Texas, Hunt said. Water well drillers are now required to submit a report for every water well drilled, and that information is accessible using the TWDB Groundwater Data Viewer. This database has every single new well drilled since 2003.

It is important for this inventory process to continue so that scientists can see how well data changes over time from these new wells, Dodson said.

Wells established before 2003 are generally not within the well driller's database and can be more difficult to locate, access and find well information for. This is the challenge for many GCDs trying to account for the pumping within a given area, Hunt explained.

As climate impacts, population growth and land use changes continue to shape Texas, scientists like Dodson and Hunt, and local groundwater experts like Gerfers, will continue putting in the work to build reliable groundwater datasets to help Texans protect groundwater supplies for future generations.

"Out here in Far West Texas, self-reliance and independence is a way of life, but I think that showing folks how it benefits them to have their wells' water level data on hand does make a difference," Gerfers said. "For folks dependent on groundwater, collecting long-term data is really in our best interest."

Drone image of a streamflow measurement taken in the Devils River upstream of the Devils River State Natural Area (Del Norte), in Val Verde County. Photo by Tyson McKinney.

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