WATER RESOURCES

IMPACT

JULY 2019
VOLUME 21 • NUMBER 4

WATER, TEXAS STYLE

AN INTRODUCTION

AMERICAN WATER RESOURCES ASSOCIATION

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Issue Theme: Water, Texas Style
Guest Editor: Todd H. Votteler, Ph.D., Editor-in-Chief of the *Texas Water Journal*

This issue of *Water Resources IMPACT* focuses on Texas and how the state is managing its surface water and groundwater resources, and its plans to slake the thirst of its future population. This issue reflects a number of different perspectives on many of the elements crucial to the future water needs of Texas.

After an introduction by Todd Votteler, Peter Lake examines how Texas plans for, and finances the projects needed for its growing population. Robert Mace then examines how Texas manages its groundwater under the rule of capture modified by local groundwater districts. Sara Thornton addresses the plan for Texas to build 26 new water supply reservoirs by 2070. Kathy Alexander outlines the state's regulatory efforts to encourage conservation and to provide water for the needs of the environment. Suzy Valentine explains the function of Texas' system of interstate compacts for sharing rivers with neighboring states. Gabe Collins dives into the energy/water nexus in Texas, highlighting the energy portion of the state's water demand. John Tracy discusses the extensive effort to research the future water needs of Texas. Finally, Rudy Rosen addresses the need for a growing workforce in Texas water management and how the education system can respond.

VOLUME 21 • NUMBER 4 • ISSN 1522-3175

PUBLISHED FOR:

AMERICAN WATER RESOURCES ASSOCIATION

Water Resources IMPACT is owned and published bi-monthly by the American Water Resources Association, PO BOX 2663, Woodbridge, VA 22195, USA. The single copy digital purchase rate is $17.00 (USD).

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SUBSCRIPTION RATES

Water Resources IMPACT

SINGLE DIGITAL
COPIES AVAILABLE

$17.00 (USD)

PUBLISHED BY:

The MPX Group, 7105 Medicine Lake Road,
Golden Valley, MN 55427 • 763-553-1630

PUBLISHED July 2019/AWRA

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PRESIDENT'S MESSAGE

Improving through Resilient Adaptation

Lisa Beutler, President

WE JUST WRAPPED UP a wonderful Summer Specialty Conference in Sparks, Nevada on Improving Water Infrastructure through Resilient Adaptation. I love all our American Water Resources Association (AWRA) conferences and the great thing about the smaller specialty conferences is the opportunity to meet and have extraordinary conversations. Participants are often the exemplars in their field and exploring the raw edges of their disciplines. They come to the conferences to share their work and engage on topics that bridge across the water sectors. The specialty conferences simultaneously provide information applicable to our day to day work and serve as an R&D lab for interdisciplinary exploration. By the end of these conferences there is a good chance you will have met many of the other attendees and have plans to stay in touch with more than a few.

The AWRA promises Community, Conversation and Connections. This summer's conference delivered just that. The printed conference program set the stage for discussions with a preamble highlighting the challenges we face. Aging infrastructure, climate change and population growth often "act in unison to threaten our abilities to meet ever-growing water demands in this world." It continued by proffering that there are no "one size fits all solutions" and, to quote John F. Kennedy, "There are risks and costs to action, but they are far less than the long-range risks of comfortable inaction."

The conference was ably co-led by **Venki Uddameri** (Texas Tech University and our JAWRA editor), **Tapash Das** (Jacobs Engineering and Future Risk Committee Chair), and long-time AWRA member and noted utility executive **Jay Jasperse** (Sonoma Water). They crafted a program focused on the intersection of demands and the steps water resource professionals are taking to tackle these challenges head on. Their goal was to develop "innovative tools and techniques to characterize future risks and develop <u>both</u> engineered and policy solutions to improve resilience and help communities successfully adapt to the ever-changing landscape of water resources planning, engineering and management."

Several consistent themes emerged over the course of three days. Front and center were the concepts of extremes being the new normal. This was not a new topic for any of the participants. Yet, while we certainly know more than we did just five years ago, and many speakers shared their very latest research, our need for more and better data was equally apparent.

The second theme revolved around the limitations of engineered solutions in the face of stacked, complex problems. These types of problems require a suite of responses including reintroduction of watersheds to their natural footprints, incorporation of multi-disciplinary skill sets, decision support systems that allow tradeoffs to be better evaluated, and robust governance to guide adaptive management as conditions change.

A third, and in some ways more daunting theme, was the need for changes in societal responses. This extends well beyond asking people to just act "greener." It requires rethinking risk and what it means to stay out of harms' way. It also means moving past denial to action.

Keynote speaker **Tony Willardson**, economist and Western States Water Council CEO, provided a summation of the themes, noting "Resilient adaptation requires investments in more than grey or green infrastructure, but also in science, technology, observations, data analysis and visualization for decision support, as well as innovative institutional, legal and political governance. There is a growing and increasingly serious need for collaboration and leadership at all levels, both public and private, academic and operational, corporate and regulatory."

The need for improving through resilient adaptation extends beyond the water profession. Organizations, like infrastructure, have life cycles and must be responsive to stressors and changing needs. Our fifty-plus year-old AWRA is no exception. You may have already noticed changes in the works, including a transition to virtual management systems. We are committed to improving our environmental footprint, finding ways to be more efficient and to adding value for our members.

During the coming months we will be asking for your help in shaping AWRA to be all it can be. Resilient adaptive management is dependent on an effective feedback cycle. That means we need to hear from you. We want to know more about you, what issues you are facing, and how AWRA can better serve you. Please consider participating in surveys and other outreach we will be conducting during the rest of the year. We also love hearing from you for any reason. Please feel free to drop a note to president@awra.org with any ideas or suggestions you might have. We want to be your association home for Community, Conversation, and Connections. ■

CONTRIBUTIONS TO
COMMUNITY | CONVERSATION | CONNECTIONS

AWRA thanks our Summer Specialty Conference Opening Reception Sponsor – **Stantec**, and our in-kind sponsors **Argonne National Laboratory**, Lemont, IL, Bureau of Reclamation, Research and Development Office, **Denver Federal Center**, Denver, CO, **Bureau of Reclamation**, Upper Colorado Region, University of Colorado, Boulder CO, **Denver Water**, Denver, CO, **Desert Research Institute**, Reno, NV, **Indian Institute of Technology Kharagpur**, Kharagpur, India. **Jacobs Engineering Group Inc.**, San Diego, CA, **Oregon State University**, Corvallis, OR, **Ramboll Environ**, Emeryville, CA, **Sonoma Water**, Santa Rosa, CA, **Southern Nevada Water Authority**, Las Vegas, NV, **Stantec Consulting Services, Inc.**, Sacramento, CA, **Texas Tech University**, Lubbock, TX, **US Geological Survey**, Carson City, NV

AWRA also wishes to congratulate and thank the Conference Planning Committee -

CONFERENCE GENERAL CHAIR - **Venki Uddameri** TECHNICAL PROGRAM CO-CHAIRS **Tapash Das** and **Jay Jasperse**,FINANCE CHAIR - **Yung-Hsin Sun**, FIELD TRIP / WORKSHOP COMMITTEE CHAIR - **Dan McEvoy**, STUDENT ACTIVITIES CHAIR - **Nina S. Oakley**, and MEMBERS - **Michael Dettinger, Ashok Kumar Gupta, Armin Munevar, Colby Pellegrino, May Wu, Ken Nowak,** and **James Prairie.**

CELEBRATING 55 YEARS OF JAWRA – SUSTAINED CONTRIBUTIONS TO IMPROVE WATER RESOURCES

ANOTHER INSTALLMENT of Celebrating 55 Years of JAWRA is presented in the June 2019 issue. The editorial highlights some contributions of JAWRA in the third decade (1985-1994), focusing on a set of trendsetting papers that defined analysis of hydrologic time-series analysis and geographic information systems. To read all the installments of the 55 Years of JAWRA editorials, visit the virtual issue at https://onlinelibrary.wiley.com/doi/toc/10.1111/(ISSN)17521688.JAWRA55.

Featured Collection – The Emerging Science of Aquatic Systems Connectivity Part II

The June issue presents Part II of the featured series *The Emerging Science of Aquatic Systems Connectivity*. The introduction by Smith et al. presents an overview of the papers from the collection featured in Part II. Highlights of the papers published in the second part of the featured collection are:

Ameli and Creed study the role of wetland location and demonstrate wetlands close to the main stream network play a disproportionately important role in attenuating peakflow, while wetland location may not be important for regulating baseflow.

Green *et al*. study the drained upland depressions within the Des Moines Lobe of Iowa and conclude they have insufficient storage capacity to significantly alter regional and local flood events.

Jones *et al*. utilize four case studies to explore recent advances in process-based modeling of non-floodplain wetlands in low-gradient, wetland-rich landscapes.

Beiger *et al*. propose and test a simple concept to incorporate hydrologic connectivity in a watershed model (SWAT+), which improves the simulation of processes controlling the response of watersheds to rainfall events.

Follstad Shah *et al*. suggest mitigation efforts in urban rivers may be better informed by comparing physiochemical patterns (quality) to the relative magnitude of source water inputs (quantity) derived from water isotopes.

Blersch *et al*.propose a new metric called metabolic variance for stream restoration practitioners to assess improved ecosystem services, specifically stream metabolism, and show its utility in post restoration activities.

Caruso *et al*. develop a two-dimensional hydrodynamic model using HEC-RAS 2D and demonstrate its utility for evaluation and design of reconnection of the Green River with floodplain wetlands at Ouray National Wildlife Refuge, Utah.

Zaffaroni *et al*. study the role of wetland connectivity on improving conservation outcomes for threatened amphibian species and state both wetland habitat quality and connectivity act jointly but differently on amphibian population dynamics and should both be considered when managing wetlandscapes.

Featured Series – Optimizing Ogallala Aquifer Water Use to Sustain Food Systems:

The June issue also contains two papers from the featured series Optimizing Ogallala Aquifer Water Use to Sustain Food Systems. These papers focus on economic aspects of managing groundwater.

Shepler *et al*. demonstrate the age and land ownership status of agricultural producers are found to consistently impact a range of groundwater conservation motivations and actions.

Gurrero *et al*. report a study assessing the impacts of dairy industry expansion on water usage, crop mix, and business composition in light of continual depletion of the Ogallala Aquifer.

In addition to the papers from the featured collection and featured series highlighted above, you will find four other technical papers in the June issue and there are a variety of other articles tackling various water resources topics on Early View (online ahead of issue publication), visit https://onlinelibrary.wiley.com/toc/17521688/0/0 to explore these papers.

FEATURE

Water, Texas Style: An Introduction

Todd H. Votteler

NO WATER? NO TEXAS?

BORDERED BY THE GULF OF MEXICO and Rocky Mountains, consisting of high plains, low marshes, dense forests, rolling hills, and numerous other terrains, Texas is a land ready-made for extreme weather events. These indigenous extreme events, now subject to intensification due to climate change, present new challenges that Texans can ignore only at our own peril.

Hurricane Harvey impacts Houston, Texas - August 17, 2017 – September 2, 2017
(Photo credit: Karl Spencer - iStock.com)

Among the greatest of these challenges is the management of water. The lack of water during droughts, the overabundance during floods, and slaking the growing thirst of evermore Texans while leaving enough to meet the needs of the environment present realities that must be anticipated and prepared for now.

Public surface water, privately-owned groundwater, and a slow legal convergence of groundwater law with oil and gas law by Texas courts make the challenges confronting water professionals in Texas ever more difficult to solve.

Yet, while daunting, Texas is responding to these challenges. Since 1997, the state has reconfigured many aspects of water management by creating a bottom up approach to water planning, creating a new suite of funding mechanisms to finance acquiring the additional water supplies it will need, creating dozens of new groundwater conservation districts to locally manage its groundwater, and by taking steps to address the needs of the environment for water. The blueprint for meeting the future water needs of the state relies significantly on the construction and completion of new reservoirs, something the state has not accomplished since the 1980s. Now it is up to the relentless gallop of time, and the next multiyear drought, to determine whether these measures taken as a whole will be adequate.

WHO DOES WHAT IN TEXAS WATER?

As of 2019, the population of Texas is growing by an average of 1,000 people every day. The total population of Texas is now 29 million, with some 4 million added since 2010. The state manages water for all these people via a complex web of entities. At the top is the governor and the legislature that oversee state agencies such as the Texas Commission on Environmental Quality (TCEQ), Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), Bureau of Economic Geology, Texas General Land Office, Texas Railroad Commission, Texas Department of Agriculture, Texas Health and Human Services, and others that have some role in water management. However, the TCEQ, TWDB, and TPWD deserve special mention as their roles are central and determinative to the current and future state of Texas water.

The Texas Commission on Environmental Quality was created in 1993 (although its roots reach back as far as 1913) and is the primary environmental protection agency for the state. It is the fourth largest environmental agency in the United States. TCEQ has three full-time commissioners, who are appointed by the governor. The commissioners establish overall agency direction and policy, and make final determinations on contested permitting and enforcement matters. TCEQ's Office of Water oversees all aspects of planning, permitting, and monitoring to protect the state's water resources.

The TWDB was created in 1957, and is managed by three full-time board members who are appointed by the governor. TWDB's primary responsibilities are supporting the water planning process, approving a State Water Plan, providing loans for a variety of water and wastewater projects, and conducting studies and making data available related to surface water, groundwater, and the freshwater needs of the state's bays and estuaries.

TPWD is the state fish, wildlife, and parks agency. It has roots back to 1895 and is governed by a nine-member commission appointed by the governor. Among other functions TPWD manages and protects fish, wildlife, and thier habitat, which is the foundation for the department's role in water. As part of this function TPWD provides technical and policy expertise for addressing water issues that impact the environment.

In addition to the statewide agencies that have a role in water management there are numerous regional and local entities. Texas has 40 local and regional authorities and districts to manage various aspects of surface water. The abilities of these entities vary. Some may incur debt, levy taxes, charge for services and adopt rules for those services, enter into contracts, obtain easements, and exercise eminent domain. Some of these entities operate across entire river basins. Some river basins are overseen by multiple entities. Most lack regulatory authority and are governed by board members who are appointed by the governor. In 1929, the Texas Legislature created the first river authority in Texas, the Brazos River Authority. Most river authorities are funded by revenue from some combination of water, wastewater, and hydroelectric projects. Another type of special district is the water control and improvement district, or WCID. WCIDs have broad authority to supply and store water for domestic, commercial, and industrial uses. WCIDs can operate wastewater systems, provide irrigation, drainage, and water-quality services.

Many Texas cities have municipal water supply divisions. In addition, Texas has over 1,200 active municipal utility districts, or MUDs. These are political subdivisions of the state that provide water, sewer, and drainage services over a limited area, mostly outside of city limits. MUDs have elected boards and levy taxes to support their operations. There are also numerous special utility districts, or SUDs, that provide water, wastewater, and firefighting services, but that cannot levy taxes. Overall, there are currently 7,017 water utilities in Texas providing drinking water, ranging in scope from the City of Houston's huge system to the smallest mom and pop systems. Some 75% of these utilities supply drinking water using groundwater, but these serve only 25% of the population. Surface water is used by the remaining 25% of these utilities to supply 75% of the state's population. With regard to wastewater there are currently 3,058 facilities permitted and authorized to operate in Texas.

Texas created the first of 100 groundwater conservation districts in 1949 (plus two subsidence districts) that regulate to some degree the majority of the state's groundwater even though the state has retained the rule of capture as an underlying foundation of water management. GCDs, as they are often referred to, have elected boards and collect fees or taxes to fund their operations.

ABOUT THIS ISSUE

Water, Texas Style focuses on how the Lone Star state manages its surface water and groundwater resources, and how it proposes to quench the thirst of its rapidly expanding population. This issue reflects a number of different perspectives on elements crucial to meeting the future water needs of Texas. While not every element of Texas water is covered I have included most of the fundamental topics. Peter Lake examines how Texas plans for, and finances the projects needed for its growing population. Robert Mace then examines how Texas manages and regulates its groundwater under the rule of capture modified by a system of local groundwater districts. Sara Thornton addresses the plan for Texas to build 26 new reservoirs by 2070 for water supply and flood control, despite the lack of any new reservoir projects since the 1980s. Kathy Alexander outlines the state's regulatory efforts to encourage conservation and to provide water for the needs of the environment. Suzy Valentine explains the function of Texas' system of interstate compacts for sharing rivers with neighboring states. Gabe Collins dives into the energy-water nexus in Texas, highlighting the energy portion of our water supply, and the differences between energy sources and their needs for water and the potential vulnerability that could result. John Tracy discusses the extensive efforts to research the future water needs of Texas and how those efforts across multiple institutions are organized. Finally, Rudy Rosen addresses the need for growing a workforce for Texas water management and how education can respond to the accelerating needs for new water professionals in light of the wave of retiring baby boomers.

Together these authors shed light upon how Texas, a state with such extremes of climate and geography, and a state with an array of water institutions is preparing to meet the challenge of a secure water future supplies for its rapidly growing population. ■

Todd H. Votteler, Ph.D. is Editor-in-Chief of the Texas Water Journal and Texas+Water. Votteler is President of Collaborative Water Resolution in Austin, a Partner with Four Worlds Consulting in Corvallis, a Fellow at the Meadows Center for Water and the Environment at Texas State University, and a Mentor at the Austin Technology Incubator at The University of Texas. Contact: todd@texaswaterjournal.org

Planning, Financing and Providing for the Needs of 23 Million More Texans by 2070

Peter Lake

TEXAS IS NO STRANGER to big challenges, and the state has historically met such challenges with big solutions. Not surprisingly, it's no different when it comes to fighting drought and providing adequate water supplies. The fact that the state meteorologist said, "Texas is a land of perennial drought interrupted by the occasional devastating flood," almost 100 years ago shows that this is not a new challenge. The rapid population growth the state is experiencing in the 21st century makes the challenge even more significant.

After the multi-year drought of the 1950s, the state legislature established the Texas Water Development Board (TWDB). The new agency's mission was, in short, to ensure the water security of Texas. Today, we fulfill that mission through three functional areas – water science, water planning, and water finance. Our "water science" efforts measure the water resources in the state. This includes mapping and modeling aquifers, measuring reservoir capacities, monitoring bays and estuaries, etc. At its core, these efforts quantify how much water is currently available in the state. This lays the foundation for the agency's "water planning" effort, which essentially compares the water resources available today to the expected water demands of tomorrow. In the event of an expected deficit between the two, the planning process identifies how to provide new water supply ("water management strategies") to mitigate the anticipated water shortage. These planning efforts are encapsulated in the State Water Plan, which can be viewed in an easy-to-use, interactive interface on the TWDB website. Finally, the agency's "water financing" efforts provide low-cost financing to communities around Texas to help turn the water management strategies in the State Water Plan into projects. All three agency functional areas work in sync to ensure that Texas will have the water it needs for the nearly 23 million more citizens expected to live in the state by 2070.

For over 40 years, water management strategies were determined in a centrally driven process in Austin. Since 1997, however, the State Water Plan has been built at the local and regional level. Today, over 450 volunteers around the state work in 16 regional planning groups to identify the future water management strategies needed in their area. Per state law, each regional planning group must include representatives of 12 interest groups, including agriculture, municipalities, and industry. Starting the planning process at the regional level empowers the local stakeholders – who know their water resources and their water needs the best – to select water management strategies optimal for their area of the state. Only after a regional water plan is approved by the regional planning group does it become integrated into the overall State Water Plan.

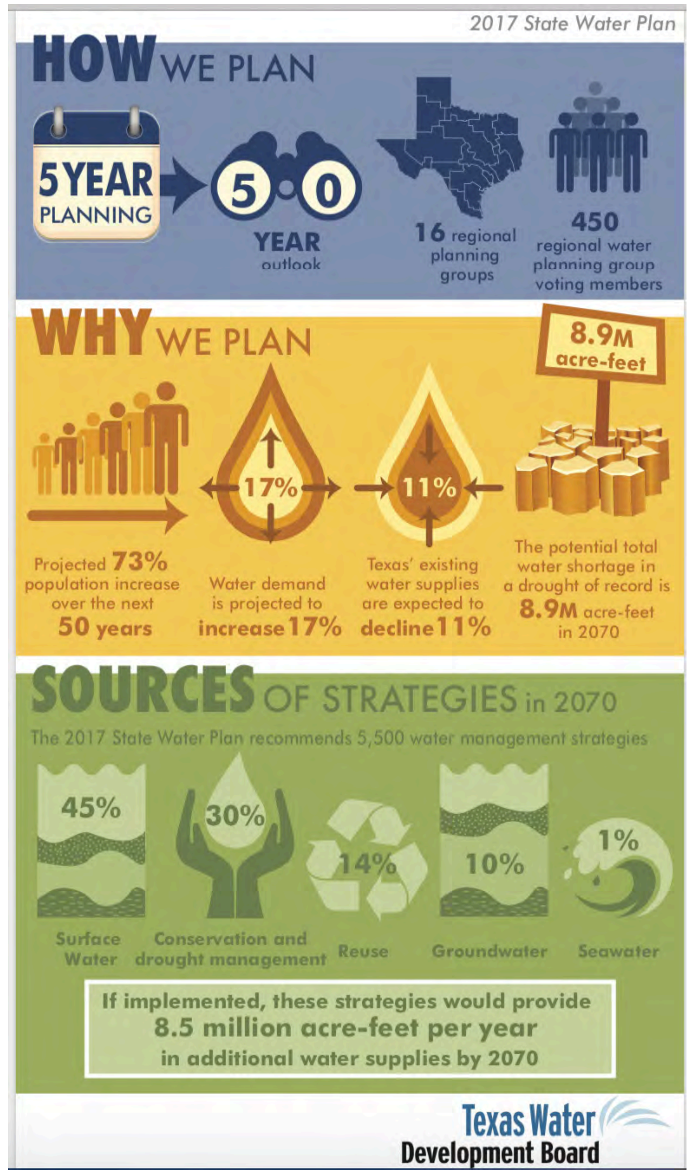
There are some key characteristics of water planning in Texas that ensure the State Water Plan will effectively meet the needs of the state over the long term. First, the State Water Plan is designed around the worst-case scenario. In other words, each regional planning group must identify water management strategies to provide water for an entire year in the worst drought on record (i.e., when water supplies are the lowest and water demand is the highest). Second, the State Water Plan is based on hard science. Regional planning groups must use TWDB-approved demographic information, water supply information, and project evaluation data and tools in their work. Third, every member of the regional planning groups (at a minimum the 12 interest group representatives mentioned above) votes to approve – or not approve – the regional water plan. This mechanism means the array of stakeholders on the regional water planning groups must work together in planning their water future. Finally, the regional water planning groups must plan for 50 years into the future, and every 5 years the planning process begins anew. Texas is continually evaluating its long-term water demand and constantly updating water management strategies to address those future needs.

SWIFT

State Water Implementation Fund for Texas

Planning is important, but plans don't matter much unless they are implemented. To implement the State Water Plan, the Texas Legislature established the State Water Implementation Fund for Texas (SWIFT) in 2013 with a $2 billion capitalization from the state's "Rainy Day" fund. By leveraging that initial capitalization with bond issuances, the TWDB uses SWIFT to provide financial assistance to local entities building the water supply projects identified in the State Water Plan. Since its inception, the SWIFT program has committed over $8 billion of financial assistance spread across 54 State Water Plan projects. That translates into almost 500 billion gallons of new water supply, including the first major reservoir built in Texas in the last quarter century. By participating in the SWIFT program, water providers around the state have saved their citizens almost $850 million dollars. Importantly, the financial benefits of participating in the SWIFT program (~$850 million in just 4 years!) are only available to those building projects in the State Water Plan. This direct link between long-term, regional water planning (the State Water Plan) and the financial assistance program (SWIFT) creates a strong incentive to participate in the planning process and build the water supply today that the state will need tomorrow.

The success of the state's efforts are evident. Since SWIFT was established, participation in the State Water Plan has increased almost 50%. Water providers across the state have partnered on major regional projects: the City of Dallas and Tarrant Regional Water District are working together on the



150-mile Integrated Pipeline, and the City of Houston joined with multiple partners in the greater metropolitan area on the Luce Bayou Interbasin Transfer Project, which will eventually feature the single largest water treatment facility on the planet. Most importantly, these projects and many others are under construction today. Texas recognizes the challenge of drought, and is tackling it head on – the combination of the State Water Plan and the SWIFT program is unique to Texas and plays a major role in securing the state's water future. ■

Peter Lake is Chairman of the Texas Water Development Board. His diverse professional background includes derivatives trader on the Chicago Mercantile Exchange, special operations executive at VantageCap Partners, and business development executive at an upstream energy company. He holds a bachelor's degree from the University of Chicago and an MBA from Stanford. Contact: boardmembers@twdb.texas.gov

FEATURE

Groundwater Governance, Management, Regulation, and Emerging Issues in the Lone Star State

Robert E. Mace

Texas is infamous for being one of the last states in the union to adhere to the Rule of Capture. However, the Rule of Capture expresses itself in several ways, not all of which currently apply to Texas. One way is through ownership: Under the Rule of Capture, the landowner owns groundwater, and so it is in Texas.

Another way is through tort law: if one landowner pumps a well and drains a neighbor's well, there is no legal recourse, which still applies in Texas. And the other way is through management: the Rule of Capture means that a landowner can drill wherever they want on their property and pump as much as they want regardless of the impacts to neighbors, springs, and streams; however, for 80 percent of the groundwater produced in Texas, this no longer applies.

After water providers and state and federal agencies became concerned about declining water levels in the Ogallala Aquifer during the Dust Bowl and after a protracted political fight with irrigators over state control, the Texas Legislature provided for the creation of locally-controlled groundwater conservation districts in 1949. Today, these districts regulate the spacing of wells from property lines and each other as well as the amount of water that people can pump, thus superseding the Rule of Capture where they exist. At present, there are 100 groundwater conservation districts and 2 subsidence districts that cover nearly 70 percent of the state.

Where districts do not exist, the unaltered Rule of Capture (with exceptions for acts of malice and waste) still applies; however, most of the viable groundwater resources of the state are under the regulatory authority of groundwater conservation districts.

Multiple groundwater conservation districts manage eight of the nine state-recognized major aquifers of Texas and many of the 22 minor aquifers. For example, the Ogallala Aquifer currently has 11 districts, and the Edwards-Trinity (Plateau) Aquifer has 28 districts regulating their groundwater. Historically, districts had different management goals—or, more commonly, no goals at all except perhaps preventing state control of groundwater (a rallying cry for district creation I heard well into the early 2000s) or preventing the export of groundwater (even though districts are not allowed to disallow export [but they can sure make it damned difficult!]).

In 2005, the Texas Legislature took a step toward regionalizing groundwater management by requiring groundwater conservation districts inside state-defined groundwater management areas—generally bounded by the nine major aquifers of the state—to establish desired future conditions for their groundwater resources. Desired future conditions represent the collective policy goals of the districts for their relevant aquifers for the next 50 years, coterminous with the state's water planning period. A state agency, the Texas Water Development Board, then uses its groundwater availability models—developed in consultation with stakeholders—to calculate the modeled available groundwater for the aquifers—the estimated amount of water that can be pumped to achieve the desired future condition. Districts are then required to pass and enforce rules to achieve their desired future conditions.

While it's often dangerous to mention "Texas" and "United Nations" in the same sentence around these parts, groundwater

Pecos High Bridge - truss bridge in Val Verde County, Texas (Photo credit: Wanda Jewell - iStock.com) governance in Texas arguably addresses the United Nations' eight core tenets of good governance: (1) responsibility (local voters, board of directors, groundwater conservation district, the legislature); (2) accountability (voters, legislature, courts); (3) transparency (open meetings, posting requirements); (4) efficiency (defined permit processes); (5) legitimacy (the majority of districts are locally created and confirmed); (6) participation (elections, public meetings, comment requirements); (7) equity and inclusiveness (rules and processes apply to all); and (8) rule of law (grounded in legislation subject to court review). However, various interests have emerging concerns about groundwater governance and management in the state.

Of the eight tenets, efficiency is one that would be questioned by some permit applicants. Depending on the district, whether or not someone contests the permit, how much water the applicant wants, and whether or not the applicant will export the water, an applicant may need to wait years to receive a final administrative decision on a permit application and even more years (sometimes more than a decade) for the courts to rule on an appeal. The Texas Legislature has considered putting time limits on permit application processing and introducing some uniformity to district rulemaking because rules often vary from district to district.

Another emerging issue is surface water-groundwater interaction. The Rule of Capture doesn't recognize that groundwater contributes spring flow and base flow to streams and rivers. Yet the Rule allows one property right—the pumping of groundwater—to impact another property right—the permitted use of surface water—and deprive the state of its water (the state owns surface water in Texas). Somewhat famously, groundwater pumping west of Fort Stockton in the 1950s dried up the historic Comanche Springs, a source of water to about 100 irrigators immediately downstream of the spring. State courts invoked the Rule of Capture to resolve the legal arguments.

More recently, groundwater pumping in the alluvium of the San Saba River has caused downstream users with superior rights to complain to the state that upstream groundwater users are pumping the underflow of the river, pumping that would require a surface-water permit under state law and be junior to the downstream rights. However, regional pumping is also impacting many springs and sources of base flow across the state, and there is nothing in state law to prevent this from happening (with one exception in the San Antonio Segment of the Edwards Aquifer where state law requires the protection of endangered species associated with Comal and San Marcos springs). Groundwater conservation districts have the option to choose desired future conditions that are protective of spring and base flow, and some do, mainly in the Edwards Aquifer and parts of the Edwards-Trinity (Plateau) Aquifer.

The protection of spring flows and base flows are generally intertwined with managing aquifers sustainably. With the passage of the Sustainable Groundwater Management Act in California in 2014, several environmental groups and philanthropic organizations have expressed interest in pursuing a similar path in Texas. One concern is that few aquifers are currently managed sustainably in Texas. An extreme example is the Ogallala Aquifer where pumping is estimated to be six times the rate of water recharging the formation. Reducing pumping to achieve sustainability would likely have significant economic impacts on irrigators, drinking-water suppliers, and cities. On the other hand, the long-term viability of the state's water resources is in question without sustainable management.

In a recent case involving regulatory takings, the Texas Supreme Court invoked the words "fair share," a term used in Texas oil and gas law. This invocation resulted in some groundwater interests advocating not only for each landowner to get their fair share of groundwater (in their view, an allocation of the total amount of groundwater in storage), but for landowners to also be compensated when other pumping drains water from beneath their land (thus superseding the expression of the Rule of Capture through tort law). While I don't think that is what the justices meant in their dictum, that is one option for managing groundwater in the state. Gabriel Collins and Hilmar Blumberg describe a different way to incorporate fair share in a 2016 article in the Texas Water Journal where a district proportioned managed available groundwater to every landowner based on the volume of groundwater beneath the land. In this way, each landowner gets a fair share and, if a landowner decides not to pump, the water remains in the aquifer.

Like many things in life, groundwater governance in Texas is more complicated and nuanced than it first appears, especially if all you know is that Texas still has the Rule of Capture. While the Rule continues to express itself through ownership and tort law, the legislature and local voters have substantially superseded it—from a management perspective—for most of the state and for much of the groundwater that is pumped. The long shadow of the Rule still casts itself over surface water-groundwater interaction and sustainable management; however, decisions on how to manage are regional and local. Groundwater conservation districts at least have the option of choosing to manage in a way to protect spring flows and base flows and achieve sustainability. The United Nations would call that good governance. ■

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FEATURE

Surface Water Management: Planning for Feast or Famine

Sara Thornton

AS A RESOURCE CRITICAL to human survival, people often believe water to be a perpetually renewable resource. This belief, however, is confronting the harsh reality of limited water supplies and the need to develop and secure additional water supplies. The drafters of the first Texas Water Plan in 1961 likely never imagined planning for the magnitude of extreme drought and flood conditions that recently plagued Texas. From 2010 to 2015, almost the entire state was suffering from some stage of drought to the point that communities had to truck in their water supplies and requiring the Governor of Texas to declare an ongoing state of emergency due to such extreme drought conditions. Juxtaposed against that, in 2017, Hurricane Harvey dumped up to 60 inches of rain in some parts of Texas. Knowing events like these can and will occur in the future, water supply planners must address how to permit and manage surface water during such events. Whether feast or famine, surface water management must closely consider these extremes and evaluate opportunities to minimize endangerment of the public while optimizing the availability of surface water supplies.

Surface Water Supplies in Texas

Texas is comprised of 15 major river basins with about 191,000 miles of streams and rivers. Surface water is expected to supply approximately 12.4 million acre-feet of water in 2020 with more than half of this available supply in reservoirs. Following the 1950s drought of record, Texas water suppliers constructed over 126 major water supply reservoirs between 1957 and 1980 to maximize use of surface water supplies. Today, Texas relies on 188 major reservoirs (a normal capacity of 5,000 acre-feet or larger) for water supply purposes with a total storage capacity of almost 40 million acre-feet. Most of these reservoirs are located in the northern and eastern portions of the state where rainfall is more abundant (Figure 1). At a time when this water supply strategy is desperately needed to address Texas' booming population growth and potentially control flood events, reservoir development has unfortunately all but halted with the last major reservoir constructed over 30 years ago.

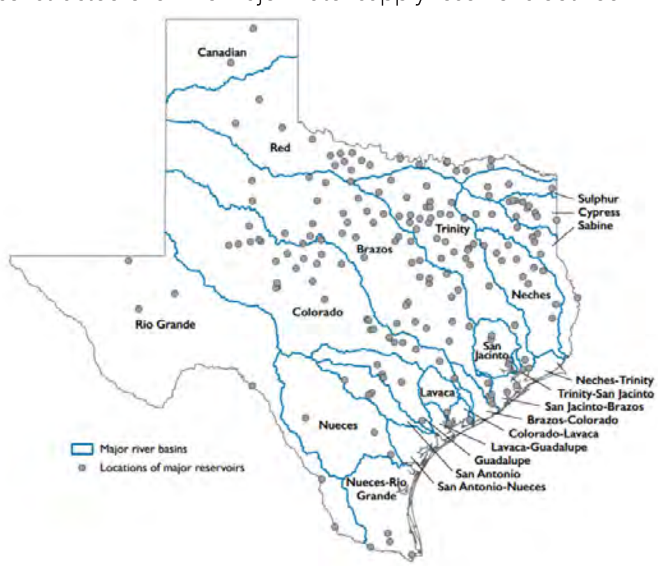

Figure 1. Major Texas reservoirs and river basins.

Water Supplies for Growing Populations

Between 2000 and 2010 Texas experienced a greater population growth than any other state – expanding from 20.8 million to 25.1 million. Our surface water supplies have not kept pace with growth since 1980, as per capita water storage in Texas has decreased by 30 percent. The 2017 State Water Plan predicts that the population will grow approximately 70 percent, from 29.5 million to 51 million, between 2020 and 2070 (Figure 2). Fortunately, this estimated growth is not tied to a corresponding percent increase in demand for water–instead, the water demand is only projected to rise by 22 percent. Even so, given the current inability to reliably meet existing water demands under extreme drought conditions, in order to also meet this increased future demand, new supplies must be

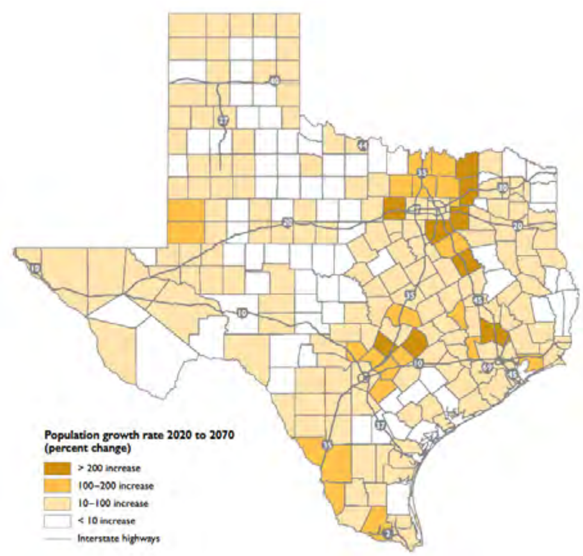

Figure 2. Texas population growth from 2020 to 2070.

developed. Development of these water supplies, however, must be done smartly and should be seen as an opportunity to not only address increasing water demands, but to also minimize potential impacts from flood events that are occurring at an alarming rate, as evidenced by recent extreme flooding across Texas. In addressing the growing need for additional water supplies, water planners should concurrently evaluate ways to ensure that the development of new surface water supplies will reduce, or at least not contribute to, negative impacts as a result of flooding from extreme weather events.

More People, More Development, More Flooding

With the ever-growing population there comes an increasing amount of development—and with that an increasing concern for flooding. Even prior to Hurricane Harvey's landfall in 2017, litigation occurred in the Houston area due to flooding intensified by additional development that increased impervious surfaces while failing to provide sufficient mitigation through flood and drainage areas. A 2014 study evaluating wetlands losses in the Houston area determined a loss of 24,600 of the 447,949 acres of natural wetlands due to development. The filling and development of wetlands, when accompanied by insufficient mitigation, results in the loss of critical wetland values, including flood attenuation, storm surge protections, and erosion control.

Now, in the wake of Hurricane Harvey, it is even clearer that we must take a more proactive approach to mitigate flood hazards. The impacts of Hurricane Harvey were staggering (see Figure 3). However, recent research by Texas A&M University at Galveston seems to indicate that the recovery and rebuilding period after hurricane and flood events could exacerbate future flooding. Research concerning rebuilding after Hurricane Ike reflected that in rebuilding there appeared to be little reduction in the issuance of U.S. Army Corps of Engineers' construction permits for fill of jurisdictional waters of the U.S. (including wetlands), and issuance appeared to increase in some cases. As noted, wetlands are critical to flood retention and attenuation, and their continued piecemeal loss without thoughtful, larger-scale planning and mitigation will only lead to an increase in flood hazards.

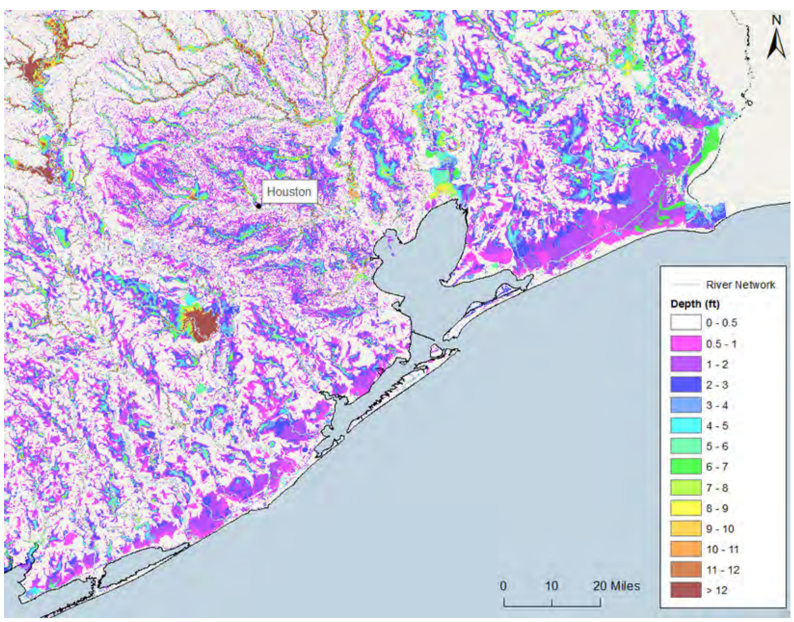

Figure 3. Hurricane Harvey flood map.

Given the wide-reaching effects of this natural disaster, there has not surprisingly been an effort by Texas legislators during the 2019 Legislative Session to introduce legislation to improve preparedness for natural disasters, particularly flood hazard management. These legislative efforts appear to be partly derived from the November 2018 Report of the Governor's Commission to Rebuild Texas, and, unfortunately, focus solely on how to address natural disasters and flooding without considering a water management component. Given the interplay between water supplies and excessive flooding, we should instead strive to collectively address both the need to develop new water supplies and to diminish flooding impacts.

Path Forward: Developing Multipurpose Surface Water Supplies

So, how do we reconcile these times of feast and famine? Given our increasing population and potential for disastrous droughts, there is no doubt we must develop additional supplies. But, are there ways in which to develop those supplies to capture floodwater to prevent loss of life and property damage while enhancing the ability to retain those floodwaters for water supply purposes? The answer is an emphatic "Yes"—and the way those projects are developed, including any mitigation required for those projects, is also critical for water supply and water quality purposes.

In Texas, surface water is generally considered "state water" that is owned and regulated for use by the state, and, like most of the western United States, Texas water rights permitting is governed by the prior appropriation doctrine. Under the prior appropriation doctrine, permits are issued with a priority date with first in time being first in right to water that is permitted. Generally, the Texas Commission on Environmental Quality (TCEQ) permits the authority to use state water—and that use must be for a "beneficial use." Although flood protection is not specifically defined as a "beneficial use," it most certainly qualifies, and permits have been issued for this use. Therefore, in pursuing water supply projects, a project could also include a flood protection purpose. The question then remains—how do we get water planners to also seek a use for flood protection?

Section 16.131 of the Texas Water Code explicitly recognizes TWDB's authority to use funding for the development of projects for both water supply and flood protection. In the 2017 State Water Plan, regional planning groups have recommended 26 new major reservoirs. To the extent these reservoirs are not proposed for flood protection, TWDB should closely review these reservoirs to determine the feasibility of their also providing flood protection in those basins experiencing extreme flood events.

Implementation of mitigation is another component of the development of additional water supplies and reduction of flood hazards. To comply with Clean Water Act Section 404, reservoir projects require significant compensatory mitigation for impacts to wetlands, streams, and open waters. This mitigation provides an opportunity to protect and restore areas within the watershed to mitigate impacts to the aquatic environment and to restore the values provided by these waters. For Hurricane Harvey, restored wetlands could have decreased the record peak flows that were primarily responsible for significant flood damage. Water planners could even collaborate with local flood management agencies to see if there are ways to partner the required mitigation tied to reservoir projects with locally-funded efforts to implement mitigation measures through restoration of natural flood-mitigating features.

The benefits of this collaboration on mitigation could be significant, with watershed restoration and enhancement activities also improving the water quality of water supply sources. It is important to not lose sight of water quality impacts resulting from flood events—the levels of contaminants that eventually discharge into watersheds often contain toxic and hazardous materials negatively affecting water supply sources and impacting aquatic life. Although TCEQ can permit and control direct discharges from point sources pursuant to the Clean Water Act Section 402 and Chapter 26 of the Texas Water Code, extreme storm events often result in unauthorized point source discharges and nonpoint source pollution. Reservoirs can alleviate some of these impacts by directly capturing and holding floodwaters, thereby reducing pollutant loading from urban runoff with the associated mitigation functioning to filter out pollutants.

In the future development of surface water supplies, opportunities clearly exist to not only maximize water supplies and improve water quality but also provide the added benefit of lessening the intensity of the extreme flood events that will continue to plague Texas as populations grow, development occurs, and extreme climatic conditions continue. We must take advantage of these opportunities to proactively address the dichotomous feast and famine conditions Texas faces regarding water supply and flooding to ensure the public health and safety of our communities now and in the future. ■

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2019 Annual Conference Field Trips

Sunday, November 3
8:30am – 3:00pm

Utah Water Research Laboratory (UWRL)

At the UWRL, participants will get an up-close tour of the hydraulics modeling facilities and AggieAir, an innovative unmanned aerial system (UAS) program that is transforming remote sensing and precision agriculture. The AggieAir UAS program, developed at the UWRL, has a 10-year history of providing quality environmental data for water resources management and other scientific applications.

Main Website: https://uwrl.usu.edu/index

AggieAir webpage: https://aggieair.usu.edu/

Earlier UWRL Model for the Orville Dam Spillway:
https://www.youtube.com/watch?v=xgBBOx8gkck&t=35s

Sunday, November 3
1:00pm - 7:00pm

Wasatch Drain Tunnel Tour and Snowbird Resort Tram Ride

The Wasatch Drain Tunnel tour will include traveling underground to learn about a very unique water storage and treatment system for Snowbird and Little Cottonwood Canyon. The tour will include information about the water system, geology, mining history, and the Little Cottonwood watershed. Following the Tunnel tour, attendees can take the Snowbird Tram to the Summit to see the view.

Snowbird Ski Resort: https://www.snowbird.com/

Wasatch Drain Tunnel:
http://www.canyonwater.com/#waterDiv

FEATURE

The Rise of Water Conservation and Efforts to Protect Environmental Flows

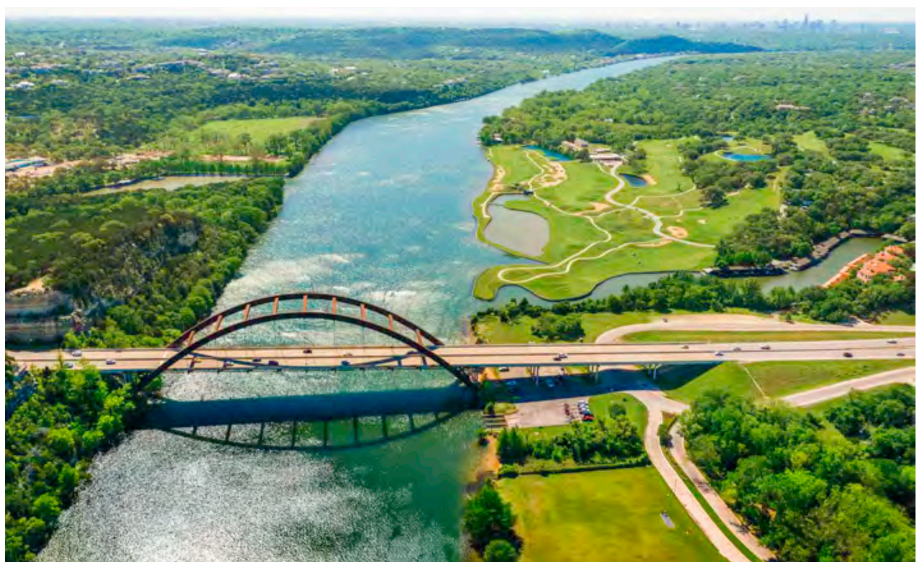
Kathy Alexander

GROWING POPULATION and anticipated shortages of water to meet the demands of all sectors is a recurring theme and a driver of water policy initiatives for water conservation and environmental flow protection in Texas. Water conservation began as a focus on water development and later evolved to legislation incorporating a definition of water conservation in Texas law (Texas Water Code Chapter 11). Later still, consideration of water conservation evolved to coordinated efforts to achieve water conservation in the state. Environmental flow protection has evolved from little to no consideration of the environment, to site specific protection, to basin wide protection through environmental flow standards adopted by the Texas Commission on Environmental Quality (TCEQ), used hereinafter to also include TCEQ's predecessor agencies. What follows is a brief history of the major policy initiatives to address these important aspects of water management.

1985 Legislation

The first comprehensive legislative efforts to address both water conservation and environmental flow protection occurred in 1985. The legislation was in response to the problems associated with anticipated growing populations and the need for water supplies to meet anticipated demands across Texas. These policy initiatives were based on the premise that water shortages could be mitigated by building water projects and practicing water conservation. There was also a recognition that as new projects were developed, there was a need to ensure protection of freshwater inflows to Texas' bays and estuaries and to consider the environmental needs of rivers and streams in regulatory processes.

The 1985 legislation required applicants for state financial assistance to have conservation programs and for the TCEQ to consider water conservation planning in considering whether new water rights could be granted. The 1985 legislation also required TCEQ to consider instream uses, freshwater inflows, water quality, and fish and wildlife habitat impacts for new water rights within 200 river miles of the Texas coast.



Aerial view Pennybacker 360 bridge on Colorado River, Austin, Texas (Photo credit: dszc - iStock.com)

1997 Legislation

In 1997 the Texas legislature passed an omnibus water bill, Senate Bill 1. As with the 1985 legislative efforts, Senate Bill 1 recognized concerns associated with growing populations and projected future water shortages. This legislation made changes across a broad range of planning, management, and regulatory processes in Texas and set up a procedure for locally driven water planning for the state. The new planning process required that Regional Water Plans for the sixteen regions in Texas consider improved conservation as a strategy to help meet future demands. The legislation required any water conservation plans to be consistent with Regional Water Plans. Developing water conservation plans for surface water also became less discretionary and more compulsory by requiring water right permit applicants to submit water conservation plans. In addition, the legislation also required larger water right holders to develop, submit, and implement water conservation plans. Groundwater districts could also require permit applicants to submit water conservation plans and to consider whether new uses would avoid waste and achieve water conservation. Senate Bill 1 also authorized the TCEQ to include requirements in reuse permits to protect instream uses and freshwater inflows to bays and estuaries and recognized the importance of environmental protection for rivers and streams by establishing the Texas Water Trust to hold water rights dedicated to environmental water needs.

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NIGHT AT THE MUSEUM

Join us for a night at the Natural History Museum of Utah, an evening of networking! A great opportunity to meet fellow conference attendees and visit the world-class museum, located near the University of Utah. The event will include beer, wine and heavy hors d'oeuvres.

Attendees can explore:

- The Native Voices Exhibit, a history and contemporary culture of Utah's native peoples.
- The Dark Sky Exhibit, immersive and interactive exhibit that displays our changing night sky.
- The sweeping Sky Terrace view of the Salt Lake Valley below.

Presenter:

As a young girl, Eileen Quintana lived on a Navajo reservation without running water and electricity. She will discuss the importance of water in the culture and history of Native Americans.

2001 and 2003 Legislation

In 2001, the legislature enacted Senate Bill 2 which enhanced consideration of the environment by requiring an instream flow data collection and evaluation program and studies aimed at determining flow conditions in the state's rivers and streams necessary to support a sound ecological environment. The TCEQ would then consider the results of these studies in permitting new water rights. The studies are very detailed and time intensive. Studies for the San Antonio River and the Brazos River were completed in 2017 and 2018, respectively.

In 2003, the legislature also created the Water Conservation Implementation Task Force to further conservation initiatives and to recognize the full potential of water conservation in meeting future water needs in Texas. The Task Force developed a set of Best Management Practices for all sectors of water use to provide an integrated set of water conservation efforts and actions across Texas. In addition, the legislature required water conservation plans to include specified five- and ten-year targets for water use reduction and required an ongoing review of water conservation plans. TCEQ adopted rules requiring updated water conservation plans to be submitted every five years, in conjunction with the Regional Water Planning cycle.

2007 Legislation

In 2007, the Texas legislature passed Senate Bill 3, which further enhanced water conservation and environmental flow protection. For water conservation, Senate Bill 3 addressed public awareness of water conservation by requiring a statewide program to educate Texans about water conservation. The bill also established a Water Conservation Advisory Council composed of 23 members across a broad range of interests. The Council is a resource that provides expertise in water conservation by monitoring trends and new technologies in water conservation. The Council submits a report to the Legislature and the Governor in even-numbered years on progress made in state water conservation.

Environmental flow protection was completely overhauled in 2007 with the passage of Senate Bill 3. Previous efforts to protect environmental flows focused on site specific, case-by-case consideration. In addition, in the early 2000s several entities applied for new instream water rights, which further illuminated the need for the state to address this important issue. In response to the applications for new instream water rights, legislation was passed prohibiting the granting of these types of permits. At the same time, the legislation began a public process, led by a study commission, to look at balancing growing water use demands with environmental protection. The study commission, in a 2004 Interim Report to the legislature, recommended a locally-driven scientific approach that included adaptive management, based on protection of the whole river system. In 2005, Texas Governor Rick Perry created an Environmental Flows Advisory Committee to develop and recommend a specific process to balance the needs of the environment with human water needs using the 2004 study commission report as a starting point. The committee considered information from a wide variety of stakeholders and scientists and issued a report in 2006 recommending a locally driven structure, like that used in the water planning process.

Senate Bill 3 incorporated these recommendations by establishing a framework for protecting instream flows and freshwater inflows to bays and estuaries. Under the new framework, local scientists would consider available scientific data and studies and recommend an environmental flow regime, defined as a variable schedule of flow quantities throughout the river system. Local stakeholders would then consider the science and the need for future water supplies and provide a recommendation. Finally, the TCEQ would consider both recommendations and adopt, through rulemaking, a set of environmental flow standards for the river basin. Rules for environmental flow standards have been adopted for the following: the Sabine and Neches Rivers and Sabine Lake Bay; the Trinity and San Jacinto Rivers and Galveston Bay; the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays; the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays; the Nueces River and Corpus Christi and Baffin Bays; the Brazos River and its associated bay and estuary system; and the Rio Grande, the Rio Grande estuary, and the Lower Laguna Madre.

The river basins with adopted environmental flow standards are shown in Figure 1. The rules for each basin establish a set of streamflow standards at defined measurement points, typically United States Geological Survey (USGS) gaging stations, within each basin. Figure

FIGURE 1. RIVER BASINS WITH ADOPTED ENVIRONMENTAL FLOW STANDARDS

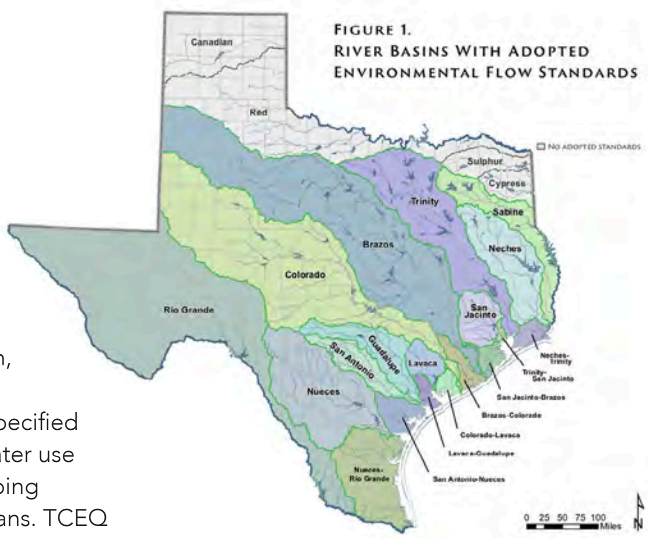
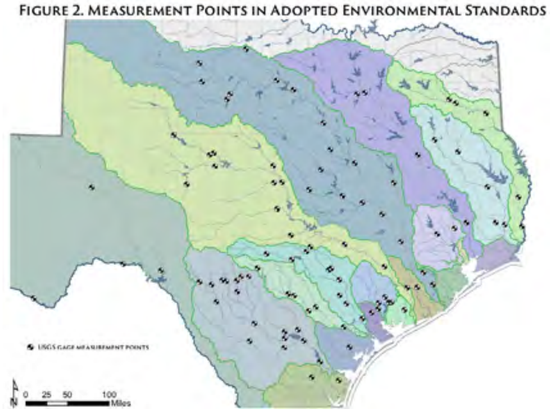


FIGURE 2. MEASUREMENT POINTS IN ADOPTED ENVIRONMENTAL STANDARDS



2 Shows the locations for measurement points across the state and illustrates the geographic extent of the adopted standards. There is no statutory deadline for adoption of environmental flow standards for the state's remaining basins.

In addition to the new framework, Senate Bill 3 recognized the importance of adaptive management, and included requirements for an ongoing review and potential refinement of the adopted environmental flow standards. The stakeholder committees prepared work plans with timelines for specific studies the groups felt were important to fill gaps in the science. Based on new scientific information, the groups could recommend potential refinements to the adopted environmental flow standards. As studies are completed, adaptive management efforts are ongoing across the state to address both instream needs and freshwater inflows to the bays.

Conclusion

The progression of major initiatives outlined in this article led to a 2017 Texas State Water Plan that is the first state plan to include a significant share of capital costs associated with municipal water conservation and to directly consider the adopted environmental flow standards in the evaluation of future water development strategies. In addition, the Texas Living Waters Project found that water conservation efforts in Texas contributed to a 20% reduction in water use in the municipal sector from 2000 to 2017. Average municipal per capita water use dropped from 175 gallons per day in 2000 to 138 gallons per day in 2015. Concerns for the future in both water conservation and environmental flow protections revolve around continued and/or increased funding and data collection. As Texas continues to grow in population, water conservation efforts and protection of environmental flows will remain at the forefront of the discussion on meeting future water supply needs. ■

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FEATURE

Hands Across the Waters: How Texas Works with River Compacts

Suzy Valentine

Natural watershed boundaries for major rivers do not usually conform to the political boundaries that define states, territories, or even nations. In the United States, these shared watersheds present unique challenges about how their water resources can be divided fairly. The development of interstate compacts has provided opportunities for multistate cooperation to address the associated policy issues, while supporting each state's sovereignty and avoiding federal interference.

As a contract between two or more states, interstate river compacts establish a formal, legal relationship between the states which can be a conduit to promote comity and settle interstate disputes. Typically, this has included agreements on the equitable distribution and accounting of water resources, as well as cooperation between the member states to protect and develop future resources.

Interstate river compacts also allow individual states to maintain control over how their water supplies are regulated and administered internally to meet the requirements of compact agreements between the member states. By creating independent, interstate commissions, compacts can often address mutual issues more directly and effectively than individual agencies between states. In addition, they enable the states to have the flexibility to adapt over time to meet future challenges.

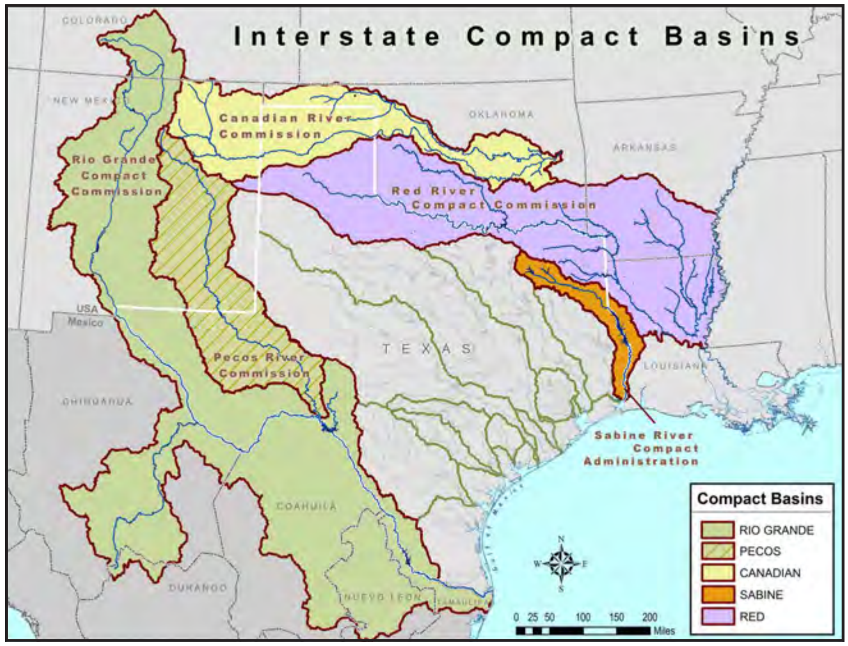

Figure 1. Interstate compact basins of Texas.

The State of Texas has entered into agreements with neighboring states to establish interstate river compacts for its five shared river basins covering the Rio Grande, Pecos, Canadian, Sabine, and Red rivers (Figure 1). Each river compact was approved by state legislatures, as well as the U.S. Congress and the President. Thus, the compacts represent both state and federal law. Unique among the member states, Texas has also established corresponding internal state agencies with governor-appointed commissioners who represent Texas on their corresponding interstate river compact commissions.

Each Texas compact has addressed the distinct issues and priorities of its basin through negotiating compliance requirements. As a result, Texas has used a variety of approaches in dealing with neighboring states to ensure that it receives an equitable distribution of the shared water resources. This includes developing and nurturing good working relationships with its compact partners as much as possible.

Rio Grande Compact

Approved in 1939, the Rio Grande Compact with New Mexico and Colorado is Texas' oldest river compact agreement, covering the Rio Grande from its headwaters to Fort Quitman, Texas. It is unique among Texas' compacts since it incorporates not only interstate water deliveries, but also deliveries to Mexico, which are required under an international treaty, the Convention of 1906.

Each state had different motivations, but ultimately, the states were able to find a way to forge an agreement for the Compact. The upstream states' delivery obligations would be counted at Elephant Butte Reservoir (Figure 2) located about 100 miles above the Texas-New Mexico state line, and Texas would receive an annual release

Figure 2. Elephant Butte Reservoir on the Rio Grande, New Mexico.

of 790,000 acre-feet from the reservoir with accrued debits and credits (Texas Water Code, chapter 41.009, Rio Grande Compact, article VIII, 1938).

While delivering water to an existing upstream reservoir is convenient, this situation has become a major concern for Texas, especially since the demand for water below the reservoir has exponentially increased over time. The result has been a significant increase in groundwater pumping from wells which are hydrologically connected to the Rio Grande.

In 2008, Elephant Butte Irrigation District in New Mexico, El Paso County Water Improvement District No. 1 in Texas and the United States entered into an Operating Agreement relating to the operation of the Rio Grande Project. In 2011, New Mexico sued the irrigation districts and the United States in the United States District Court of New Mexico (New Mexico v. United States, et al., 11-CV-691) claiming, among other things, that the Operating Agreement violated New Mexico state law.

As New Mexico challenged the 2008 Operating Agreement, in 2013, Texas filed a lawsuit against New Mexico and Colorado in the U.S. Supreme Court (No. 141, Original, Texas v. New Mexico and Colorado) based on the Compact to protect its current and future water supplies. Since the initial filing, New Mexico's District Court case was stayed, and the Supreme Court case has been progressing through the various court actions. The appointed special master issued a report in 2017 which was favorable to Texas and recommended that New Mexico's motion to dismiss be denied along with the motions to intervene by the irrigation districts. In March 2018, the Supreme Court unanimously approved the special master's recommendation and reports.

Currently, discovery is ongoing and ends in 2020, with the trial scheduled for early 2021.

Pecos River Compact

The Pecos River originates in north-central New Mexico and flows southward, where it joins the Rio Grande in the backwaters of Amistad Reservoir (Figure 3). It was once a major river, fordable at only a few places by settlers and cattle drivers heading west. Early attempts to provide water for irrigation and settlements failed due to the unpredictability of seasonal flows, damaging floods, poor water quality and a lack of supporting infrastructure. Both New Mexico and Texas hoped to construct water supply reservoirs, and after several efforts to negotiate a compact for this purpose, in 1935, they signed an agreement allowing construction of Alamogordo (Sumner) Dam in New Mexico and Red Bluff Dam in Texas.

Figure 3. Amistad Reservoir, where the Pecos River flows into the Rio Grande.

The Pecos River Compact was eventually approved in 1949. While the primary purpose of the Compact was for the equitable division and apportionment of the use of the Pecos River, promoting interstate comity and removing future controversies were prominent features. Due to the unpredictable flows of the Pecos, the Compact does not specify the amount of water, but it does require New Mexico to deliver water to Texas using complex calculations based on "1947 conditions" in New Mexico (TWC, chapter 42.010, Pecos River Compact, article VI, 1948).

For years, Texas considered New Mexico to be deficient in fulfilling the terms of the contract, and in 1974, Texas filed suit in the U.S. Supreme Court. In 1988, the Court ruled against New Mexico and appointed a river master to oversee the accounting (Texas v. New Mexico, No. 65, Orig., 485 U.S. 388, 1988). After the litigation, New Mexico has taken significant measures to ensure compliance, including retiring water rights, augmentation pumping, and signing delivery agreements with irrigation districts. New Mexico has also collaborated with Texas on several projects to improve the water quality in the basin that would enhance the amount of usable water. These efforts include co-sponsoring the U.S. Army Corps of Engineers' Pecos Watershed Assessment Study and supporting the Malaga Bend project to reduce the salinity of the waters which flow downstream to Texas (Figure 4).

Canadian River Compact

The longest tributary of the Arkansas River, the Canadian River flows from northeastern New Mexico across the Texas Panhandle into Oklahoma. In the

Figure 4. Malaga Bend, Pecos River, New Mexico.

1940s, Texas farmers and cities lobbied for the construction of Lake Meredith on the Canadian River to augment the declining Ogallala Aquifer. During this time, New Mexico was concerned that construction of such a large project could affect the future use of Canadian River water in New Mexico, and Oklahoma wanted to ensure that it would have enough water for future projects in the Canadian basin.

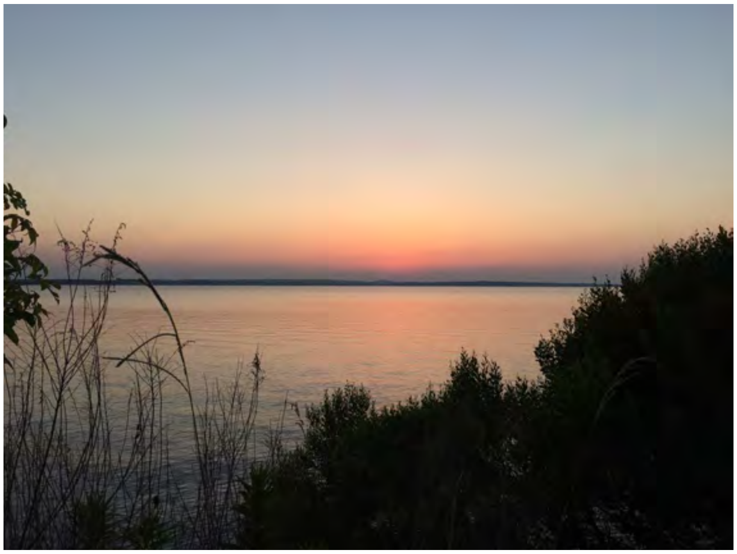

Figure 5. Toledo Bend Reservoir, Sabine River, Texas-Louisiana.

As a result, the Canadian River Compact was approved in 1952 to expedite the construction of Lake Meredith, while protecting the basin storage rights in New Mexico and Oklahoma. The Canadian River and its tributaries only have significant flows during high runoff events. Therefore, the Compact is based on the amount of conservation storage that each upstream state is allowed to impound. New Mexico has unrestricted use of all waters originating in the drainage basin above Conchas Dam, but is limited to 200,000 acre-feet of storage below the dam. Downstream, Texas can store up to 500,000 acre-feet of water, depending on the amount of conservation storage in Oklahoma. (TWC, chapter 43.006, Canadian River Compact, art. V, 1950) These Compact requirements were later reaffirmed in 1987, after Texas and Oklahoma filed suit in the U.S. Supreme Court against New Mexico (Texas and Oklahoma v. New Mexico, No. 109, Orig., 501 U.S. 221, 1991) over its plans to enlarge the capacity of Ute Reservoir.

Since then, the member states have worked together and with federal and state agencies to maintain the flows in the river, protect endangered species, and control periodic flooding.

Sabine River Compact

Flowing from its headwaters in northeast Texas into Louisiana, the Sabine River forms the state boundary as it flows into Toledo Bend Reservoir and downstream into the Gulf of Mexico. The impetus for the Sabine River Compact arose from competing claims to the river by the states and local water users. After the states agreed on the need to compromise, in 1954, the Compact was approved to allocate the waters of the Sabine River between the states. The Sabine River Compact Administration (SRCA) was also established to oversee the process.

The Sabine Compact has several unique features, including a minimum flow requirement of 36 cubic feet per second at the "Stateline" (the point where the Sabine River first touches both Louisiana and Texas). Post-Compact reservoirs in Texas are required to release a pro-rata share of water based on their drainage area to provide the minimum flow requirement. Any new projects or diversions approved by either state in the Stateline reach also require approval from the SRCA. Additionally, the states are required to use the water flows as they occur with no accumulation of credits or debits (TWC, chapter 44.010, Sabine River Compact, art. V, VI, 1953).

So far, disputes between the states have been resolved through negotiations and agreements. Notably, the commissioners for both states were able to work together to construct and share the stored waters of Toledo Bend Reservoir, which was completed in 1966 without federal funding (Figure 5).

Red River Compact

The Red River flows across the Texas Panhandle and forms the Texas-Oklahoma boundary until it reaches the Texas-Arkansas state line. The river continues through Arkansas and Louisiana into the Atchafalaya River. Therefore, the Red River covers a large and diverse region, with the western areas undergoing water shortages, while the eastern areas often suffer flooding conditions. Approved in 1980, the Red River Compact is Texas' most recent river compact. Therefore, it has not experienced many of the controversies which develop over time with shared water resources.

The primary purposes of the Compact were to "promote interstate comity and remove causes of controversy" by governing the use, control and

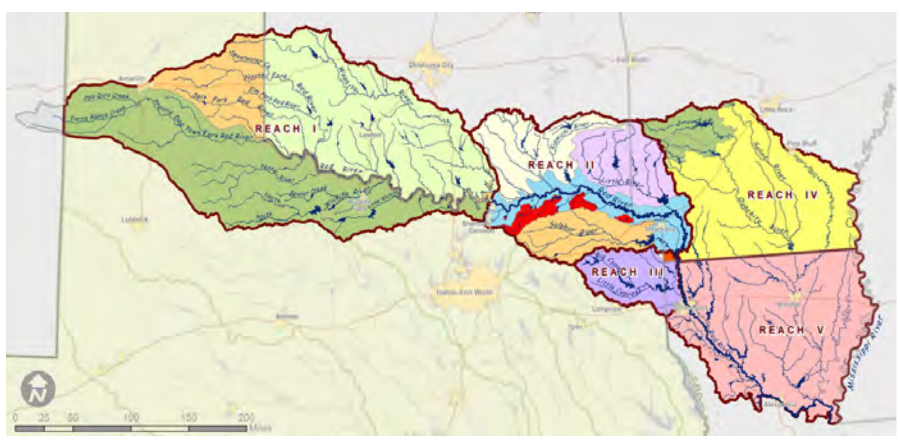

Figure 6. Five reaches of the Red River basin, Texas-Oklahoma-Arkansas-Louisiana.

distribution of the waters of the Red River and its tributaries. For compliance determinations, the Compact uses five separate reaches due to the size of the basin (Figure 6). Other purposes of the Compact included promoting programs for water quality control and alleviation of pollution, both natural and man-made, as well as programs for conservation, flood protection, navigation development, and joint-state planning and actions (TWC, chapter 46.013, art. I, 1978).

Conclusion

Texas is the downstream state for the Rio Grande and Pecos river basins, the upstream state for the Sabine River basin, and both for the Canadian and Red river basins. Under these competing circumstances, Texas' interstate river compacts were developed to resolve disputes or concerns between the states over how to share their water resources. With legal action as a last resort, Texas has sought to find ways to work toward common goals with neighboring states, with varying degrees of success. These efforts have included cooperating on a wide variety of projects and mutually beneficial activities which have provided the opportunity to establish strong working relationships and trust between Compact commissioners and stakeholders of the different states. These relationships are the foundation on which agreements are built to work out differences and develop solutions into the future. ■

Suzy Valentine, P.E., serves as the Engineer Adviser for the Rio Grande Compact Commission of Texas. She has been an adviser for Texas' interstate river compacts for the Pecos, Canadian, Red and Sabine river basins. Ms. Valentine has over 30 years of experience in water resources engineering, project management, and program management. Contact: suzyvmc@gmail.com

American Water Resources Association
Washington Section

AWRA-WS Organizes Dinner Meeting and AWRA-Central Washington University Student Networking Mixer in Ellensburg on April 11, 2019

By Jason McCormick,
AWRA-WA Past Board President

THE AWRA-WASHINGTON SECTION Ellensburg Dinner Meeting was organized on April 11, and featured a talk from Urban Eberhart, Manager, Kittitas Reclamation District (KRD) and Yakima Basin Integrated Plan Workgroup Member. We also leveraged the opportunity to provide professional networking opportunities for AWRA-Central Washington University (AWRA-CWU) Student Chapter members and recognize the student chapter in its fourth year. The event was held at [the Pub] operated by Ironhorse Brewery in downtown Ellensburg, and was attended by 15 professionals and 21 students. Urban's talk focused on the Yakima Basin Integrated Plan (YBIP) and the Cle Elum Fish Passage Project, the largest and most successful integrated water resources planning efforts in the United States. We are fortunate to have a national and world-wide model for integrated water resources planning in Central Washington State. As our Washington presence east of the Cascades continues to grow, we welcome professionals east and west of the Cascades to capitalize on education and social opportunities offered through the AWRA-WA Dinner Meetings. ■

Urban Eberhart, KRD, YBIP

Presentation

FEATURE

The Texas Energy and Water Nexus

Gabe Collins

WATER AND ENERGY are intimately connected. Every time someone turns on the lights or fills their car's tank with gasoline, they are using water that helped cool a coal-fired plant or refine crude oil.

At least three primary energy-water nexus points can be readily identified: (1) the use of electricity and thermal energy to produce and move water for human consumption; (2) the use of water to support electricity production; and (3) the use of water to support the production of coal, crude oil, and natural gas. All three exist in ample measure across Texas.

To help quantify the energy-water nexus, Figure 1 displays the estimated amount of water embedded in key energy commodities. To create an "apples to apples" comparison, I have converted each commodity to barrels of oil equivalent, equal to 5.8 million British Thermal Units (BTU).

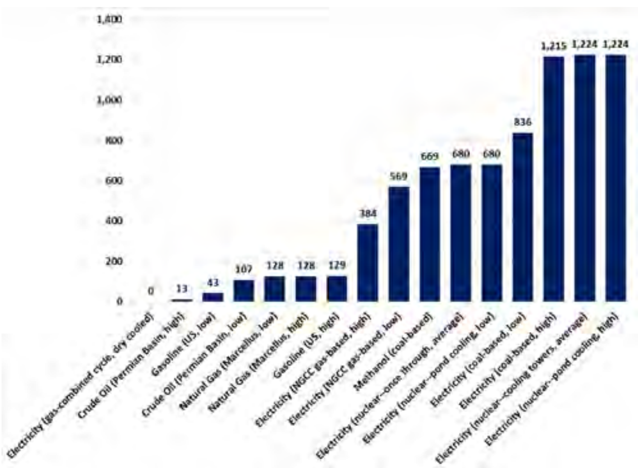

Figure 1. Estimated Water Usage to Produce Key Energy Commodities, Gallons Per Barrel of Oil Equivalent

Source: Collins, Energy Information Administration (EIA), Electric Power Research Institute (EPRI), FracFocus, Gerbens-Leenes and Hoekstra, Range Resources, Author's Estimate

Water Production and Movement

Sourcing, transporting and treating water requires significant energy inputs, and is among the world's largest—and most underappreciated uses of energy. The International Energy Agency estimates that in 2014 supplying water and removing and treating the resulting wastewater required an estimated 4% of all electricity consumed worldwide—more than three times the power used by the data centers that allow you to post reams of photos on Facebook and Instagram, binge watch shows on Netflix, and otherwise use the internet.

Figure 2 shows the estimated amount of energy—primarily electricity – embedded in every 1,000 gallons of water delivered to customers in two large Central Texas cities over its "wellhead to sewer plant" lifetime. The case examples are San Antonio (groundwater) and Austin (surface water). Note that a kilowatt-hour (kWh) is about as much energy as a toaster would use if it ran for an hour non-stop.

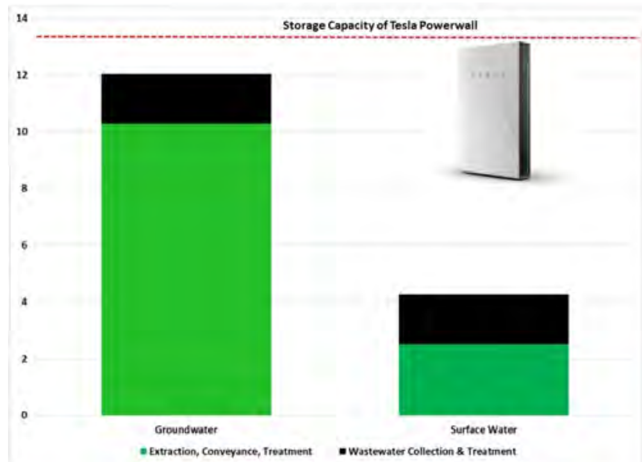

Figure 2. Estimated Lifecycle Energy "Embedded" in Groundwater and Surface Water delivered to Urban Consumers in Central Texas, kilowatt-hours (kWh) per 1,000 Gallons

Source: Collins (2019), Austin Water, EV Insider

The estimated energy embedded in every 1,000 gallons of groundwater supplies used by San Antonio (12 kWh) approaches the energy storage capacity of a Tesla Powerwall (14 kWh). Austin's water distribution system is gravity-based and relies upon surface water, which helps make its water conveyance less energy-intensive than San Antonio's. If the energy used by a consumer to heat water for use in their home were included in the embedded figure, the total could rise to as much as 200 kWh per 1,000 gallons.

The water a West Texas farmer would use to grow the cotton that might be in your blue jeans at this very moment also requires lots of energy to obtain. Water is heavy--weighing about 8.3 lbs per gallon—and often must be pumped for hundreds of vertical feet from deep aquifers to irrigate crops. A 1,000-acre cotton farm in the Texas South Plains would likely use as much electricity in a growing season as 50 homes do in a year, and a corn farm of that size in the Panhandle would use as much power as more than 90 average Texas homes do in a year.

Water Use in Electricity Production in Texas

Texans also use water each time they turn on the lights. The Texas power sector consumed about 465,000 acre-feet of water in 2016—roughly equal to the municipal water use that year of Dallas County, home to nearly 10% of Texas's entire population. Over the past decade, the water-intensity of electricity production fluctuated between 275 and 400 gallons per megawatt-hour generated. This is commensurate with the estimated water needs of gas-fired power plants, which have steadily accounted for about half of the electricity generated in

Texas each year since 1990.

Data for 2011 from Carey King and Margaret Cook at the University of Texas suggest that coal-fired power stations in Texas consume approximately 525 gallons of water for each megawatt-hour of electricity produced, while the state's two nuclear energy complexes use approximately 600 gallons/MWh and the 83 gas-fired plants in the dataset consume 309 gallons/MWh. Those data are now nearly a decade old, but the basic thermodynamics of power plant cooling systems have not significantly shifted during the intervening period.

Texas remains heavily reliant on thermal power plants, with coal, natural gas, and nuclear-fueled facilities accounting for 83% of electricity generated in 2017, according to the Energy Information Administration (EIA). The state's thermal-centric fuel structure ties electricity security and water security closely together, since virtually all of Texas's nuclear and coal power plants, as well as a meaningful portion of its gas-fired generators, require steady access to cooling water in order to operate.

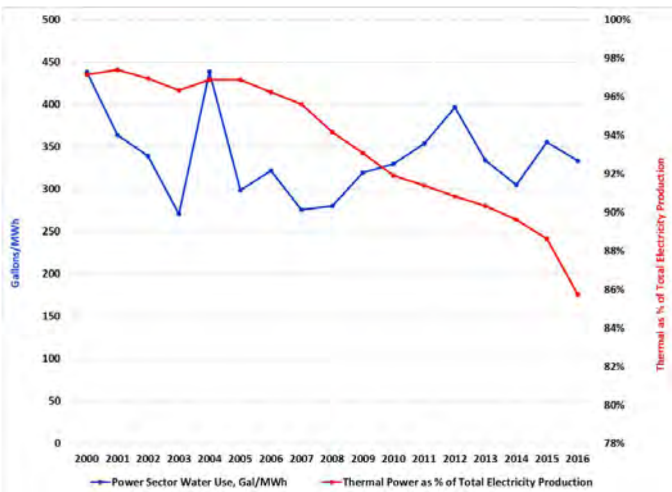

Figure 3. Texas Power Sector Water Use, Gallons/MWh Generated

Source: EIA, Texas Water Development Board, Author's Analysis

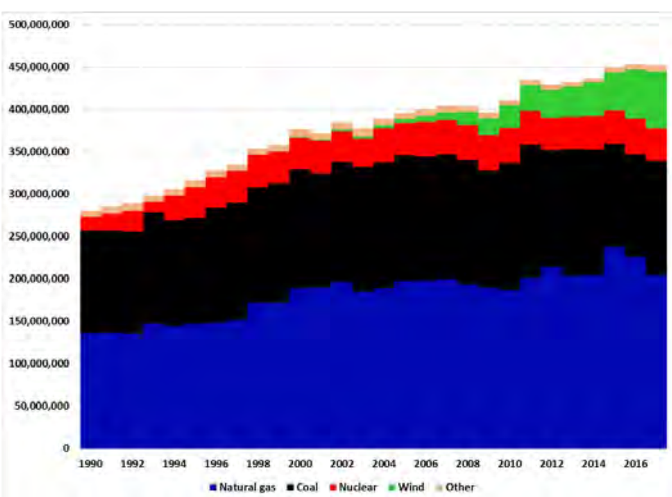

Figure 4. Electricity Generation By Fuel Type in Texas, 1990-2017 (MWh)

Source: EIA

The relationship between electricity production and water usage potentially creates mutually re-enforcing risks. Grid outages precipitated by water availability issues could rapidly reverberate into the municipal water and wastewater sectors, which depend heavily on ample and reliable electricity supplies to function. Venezuela offers a contemporary example of how quickly an electricity problem can become a water security issue. Widespread blackouts—caused in this case by political mismanagement—knocked out municipal water service and have rapidly reduced some residents of the capital Caracas to drawing water from streams by hand (Bermúdez, 2019).

Hotter summers and scarcer water could lead to power outages. A dataset compiled by the National Renewable Energy Laboratory shows water-related power plant shutdowns and curtailments nationwide peaking during the "dog days" of late summer, when drought and heat are generally at their annual apogee.

If–or more appropriately when–Texas suffers another serious drought, power supplies would be at risk. Water-intensive coal and water-dependent gas-fired facilities reach their highest utilization rates in late summer as utilities work to ensure supplies during peak air conditioning periods. And so a power plant located along a river shared by rice irrigators who also need late summer water supplies could find itself in a position where, water levels could potentially fall below plant intake levels and force curtailments or shutdowns, with adverse consequences for electricity customers.

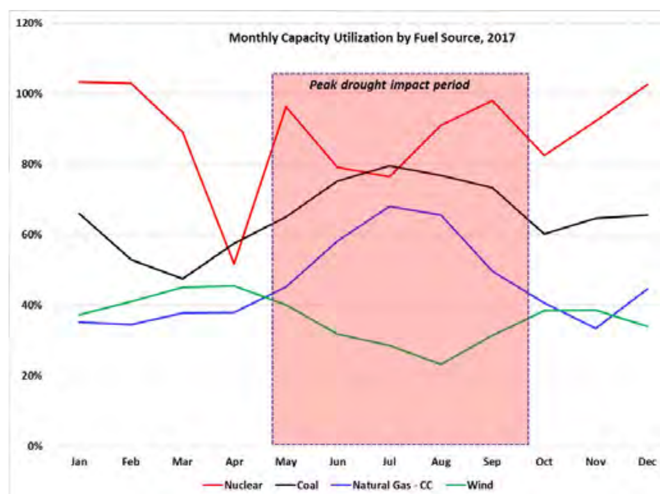

Figure 5. Thermal Power's Balancing Role in Texas Electricity Supply Exacerbates Water Security Risks

Source: EIA, Author's Analysis

A. Water Use in Fossil Fuel and Chemical Production in Texas

The hydraulic fracturing revolution that helped propel Texas to become the world's fourth-largest standalone oil producer after Russia, Saudi Arabia, and the rest of the US uses large amounts of water. Completing oil wells with 2-mile horizontal laterals in the Permian Basin can use enough water per well to submerge a football field 80 feet deep. The entire Permian–including New Mexico—uses approximately as much water per day for fracking as the City of San Antonio consumes for all purposes on an annual basis.

Downstream energy operations in Texas also use significant amounts of water. Valero—the largest independent U.S. refiner and operator of one of the world's most complex set of refining assets—reports that processing a barrel of crude oil requires 0.4 to 1.2 barrels of water, depending on refinery complexity and the level on-site hydrogen production activity.

The burgeoning petrochemical industry on the Texas Gulf Coast also uses large volumes of water to support its operations. For instance, Dow Chemical's massive Freeport operations make it one of the Brazos River Basin's biggest industrial water users. Dow also holds some of the most senior water rights on the river and has had to make several "priority calls" in recent years in order to force junior rights holders upstream to reduce their water use and preserve river flows. Among other things, these priority calls helped spark litigation that upheld the use rights of senior water holders versus more junior municipal water holders, even when public welfare concerns were at stake.

Conclusion

The energy-water nexus is a global challenge but also an opportunity for Texas. The North China Plain, northern India, Mexico, much of central Asia and the Middle East, Mediterranean Europe, and major swaths of North and Sub-Saharan Africa all feature climates that approximate that of various parts of Texas. This reality, combined with Texas's large agricultural sector, industrial heft, and solutions-oriented business and political culture, positions the state to play a global leadership role in ameliorating a set of challenges that affects a substantial portion of the world's population. In certain other arid locales—notably Iran—political dysfunction has allowed water crises to escalate to the point that they threaten human wellbeing and economic growth. Proactive engagement with the energy-water nexus can help Texas preempt such problems and offer a positive global example of how to maintain robust demographic, economic, and industrial growth while positively managing water-related challenges. ■

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Dinner Meeting

American Water Resources Association-Washington Section Holds Dinner Meeting on April 29, 2019 in Seattle

Julie Vano

The American Water Resources Association-Washington Section hosted its April Dinner Meeting on April 29, 2019 at the Pyramid Alehouse Restaurant in Seattle. Dr. Julie Vano from the National Center for Atmospheric Research gave a presentation on "Supporting Better Water Management and Planning in a Changing Climate." She talked about bridging the gap between scientists and the community, and how to make decisions that are based on the best available information which adequately evaluates vulnerabilities and risks posed by both our natural and human systems. She discussed the newly released guidance on the Dos and Don'ts for using climate information for water resources planning and management. The event was attended by 28 engineers, scientists, and representatives from different government agencies. ■

American Water Resources Association Washington Section

FEATURE

Water Research in Texas: An Ever Evolving Topic and a Highly Engaged Community

John Tracy

Great Egret, (Ardea alba) hunting in Texas - iStock.com

Wetlands Marsh Delta near Texas Louisiana Border (Photo credit: RoschetzkyIstockPhoto - iStock.com)

It has been fewer than three and half years since I came to Texas as Director of the Texas Water Resources Institute, and began my learning process as to the depth and breadth of water research that is ongoing across the state. This learning process is obviously an ongoing activity, and as is the case with most good research programs, answering one question creates ten more. So, describing and understanding water resources research in Texas is not only a constantly evolving subject, it is an ever expanding subject that will never be able to be adequately described or cataloged.

With this caveat, I think the best way to start discussing water research in Texas is to first provide some basic information on the higher education and research institutions across Texas. Texas currently has 35 distinct publicly supported universities, of which 31 are organized under six university systems, these being the University of Texas System; the Texas A&M University System; the University of Houston System, the University of North Texas System, the Texas State University System; and the Texas Tech University System. In addition, Texas is home to a large number of private universities, with the larger doctoral degree granting private universities being Rice University, Baylor University, Southern Methodist University, and Texas Christian University. Overall, nine Texas universities (both public and private) are classified as Carnegie Tier 1 Universities (R1: Doctoral Universities – Very high research activity), and an additional eight universities are classified as Carnegie Tier 2 Universities. All of the Texas universities categorized as Carnegie Tier 1 and Tier 2 universities have active research programs focusing on one or more areas related to water resources. In addition, the USGS Water Science Center headquartered in Austin engages in a wide range of water research activities, as well as the Southwest Research Institute in San Antonio.

With so many institutions involved, how does one go about understanding, let alone describing, the water resource research activities across Texas in both a concise and understandable manner? The range of water research being undertaken by faculty and researchers within these institutions is quite broad, and just a brief list of some of the ongoing research activities are:

- Water management in arid regions that receive fewer than 6 inches of precipitation a year;
- Management of nonrenewable groundwater resources that are the limiting resource for agricultural production in the panhandle of Texas;
- Treatment and management of waters produced in the extraction of oil and gas, particularly from fracking operations;
- Development of watershed scale plans to restore Texas watersheds and waterways that do not meet acceptable water quality standards;
- Assessing the impacts of climate change on surface water and groundwater resources from humid to arid climates across the state;
- Understanding the dynamic risks of flooding, and developing rapid response mechanisms to protect life and property in both the coastal regions of the state, where flooding is due to tropical storms, and inland regions, where flash flooding is drive by convective storm activity;
- Increasing the resilience of water supplies for all water use sectors through the use of advanced technologies, management practices and adaptive governance processes; and
- Management of transboundary surface water and groundwater resources under both water quality and quantity concerns.

Addressing just one of these topics would well exceed the word limit for this article, and more likely require the development of a special issue of *JAWRA, the Journal of the American Water Resources Association.* Thus, I do not think it is productive to describe the water research programs and activities in Texas in any detail. Rather, I think it is more productive to focus on what I believe to be the common thread that ties most of the research efforts together, which is: *the vast majority of water research in Texas is focused on enhancing the ability of water users, managers and policy setters to get the most out of Texas' water resources.* That is, the water research agenda in Texas is tightly tied to the water planning and management challenges that are constantly evolving in Texas. The most recent example of this is that after the years of drought Texas faced at the start of this decade, with 2011 being the drought of record across many areas of Texas, there was a concerted effort focused on increasing Texas' access to water across all use sectors, and to make these water supplies more resilient and adaptive to drought conditions. This included research and development of innovative technologies to treat marginal and waste waters for use as municipal and industrial water supplies; development of novel sensor systems and information management technology to better understand water use patterns; identification of the availability of brackish groundwater resources across the state for use in oil and gas exploration; reuse of produced water from fracking operations as potential waters supplies; and development of more energy and cost effective coastal desalination systems. While these research activities are still on going, many of the technological and management innovations are already being used to increase the resilience, or extend the life, of water supplies across Texas. In addition, the knowledge generated through this research has already found its way into the updates to the State Water Plan for Texas, which occur on a five year cycle.

Having a water research agenda that is this responsive and adaptable to water resource challenges that the state faces requires a significant connection between the water research community and the water users, managers, and policy makers to help direct an ever evolving research agenda, and ensure that the knowledge created through research is actionable. Within Texas, the connection between the water research and water resources communities is not done in an ad hoc manner, rather it is facilitated through the creation of institutional mechanisms that formalize the role that the water research community has in advancing Texas water policies and practices. The two clearest examples of these institutional mechanisms are the role that the water research community has in the Texas Groundwater Protection Committee (TGPC) and the Water Conservation Advisory Committee (WCAC).

The TGPC was created by Texas House Bill 1458 in 1989, and its purpose is to bridge the gap between state groundwater programs administered by a variety of agencies, improve coordination between the agencies that comprise the TGPC, and work to protect Texas groundwater as a vital resource. The Texas Water Code sets the development of non-degradation standards for the state's groundwater and asserts that all groundwater be kept reasonably free of contaminants that interfere with the present and potential future use of groundwater, and defines the TGPC mission to aid in informing the development of these standards and addressing contamination concerns. When formed, both the University of Texas Bureau of Economic Geology, and Texas A&M AgriLife Research were given seats on the TGPC, primarily to serve as a link to the knowledge base that exists within the groundwater research community in Texas to help the committee in their discussion and developing recommendations to the Texas legislature.

The Water Conservation Advisory Council (WCAC) was created as part of Texas Senate Bill 3 and House bill 4 in 2007 by the 80th Texas Legislature. The mission of the WCAC is *to establish a professional forum for the continuing development of water conservation resources, expertise, and progress evaluation of the highest quality for the benefit of Texas - its state leadership, regional and local governments, and the general public* (see 'About' at savetexaswater.org). The Texas legislature bills that created the WCAC directed the Texas Water Development Board to appoint members on the WCAC using rules set out in Chapter 10 of the Texas Water Code, which defines 23 entities and groups that represent the wide range of interests in water use and management across Texas. One specifically designated member group is reserved for Higher Education, which is reappointed on a regular basis through the nomination of faculty and researchers associated with Texas universities to serve as a committee member.

While the main missions of the TGPC and the WCAC are not focused on advancing water research programs in Texas, the inclusion of the academic research community as an institutional partner has clearly aided the water research community in developing its research agenda. These committees have created institutional links between the Texas water research community, and the agencies that plan for, regulate, and finance water resource systems across Texas, as well as the water users themselves. In addition to helping form the Texas water research agenda, this linkage provides an effective mechanism to transfer knowledge generated by these programs to aid agencies in achieving their missions, and assessing both the validity and efficacy of our research findings in as they say "the real world." There are many other examples of less formal institutional linkages between the water research and water resource communities across Texas, but the general impact is similar. That is, the Texas water research community is highly responsive to the changing water resource challenges within the state, because it is institutionally engaged with the water resources community. ■

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Water Education Leadership in Texas: Pathway for Students from Middle School to University Degree

Rudolph Rosen

ANTICIPATED HIGH NUMBERS of retirements and current difficulties attracting job-ready workers to fill job openings have created concerns in the water industry. Sufficient numbers of properly trained workers are needed to avoid water pollution incidents and to ensure safe drinking water and the long-term sustainability of water systems. But the challenge recruiting new water workers may start early. Work in Texas and elsewhere indicates that understanding about water is low among students and that many teachers feel deficient in their own knowledge about water and how to integrate water education into their own classroom activities.

In response to concern about inadequate water education in Texas, educators have developed a comprehensive curriculum for water science that seeks to connect students to water. The addition of flexible postsecondary education options is creating a pathway that starts in middle school and continues on through high school and beyond to a career in water. The curriculum provides for place-based and experiential classroom and outdoors educational opportunities to learn about water, with resources for teachers and students that follow Texas' extensive K-12 educational standards. Beyond high school a new model has been proposed for post-secondary training that envisions multiple routes for a high school graduate or practicing professional to combine technical training, competency-based credit and additional educational accomplishments to complete a Bachelor of Science (B.S.) or Bachelor of Applied Arts and Sciences (B.A.A.S.) degree in water.

Middle and High School Education

Texas middle and high school science teachers have requirements to teach students about water. These requirements are contained in the Texas Essential Knowledge and Skills, generally referred to as TEKS. The TEKS impose requirements for education about water, but teachers had no comprehensive textbook or even a teacher's guide on the subject. This lack of instructional resources departed markedly from the more typical circumstances encountered by teachers of other science subjects, such as math, chemistry and physics where comprehensive textbooks and teaching guides are available to address relevant TEKS.

To provide the context for teaching students about water, including about working in the water industry, Texas university and state agency educators collaborated with educators at the Missouri Department of Conservation to create a curriculum called *Texas Aquatic Science* for middle through high school students. Why use the term "aquatic science" instead of water in Texas? Middle school water education requirements are contained in general science TEKS, while high school TEKS for water are mainly listed under categories named Aquatic Science and Environmental Systems. The curriculum's name comes from its alignment with TEKS, many of which are found in the category Aquatic Science.

Released in 2015, *Texas Aquatic Science* includes a suite of learning materials entirely available on-line that take science students through the world of water, from headwaters to oceans and molecules to ecosystems.

Instruction is anchored by the peer-reviewed textbook *Texas Aquatic Science* published by Texas A&M University Press. The textbook is available at any major bookseller and on-line free of charge (texasaquaticscience.org). Also free and available on-line are an 800-page teachers guide, teaching supplements and over 125 specially produced videos for home school and classroom learning.

The curriculum uses place-based materials and real-life Texas examples to illustrate principles of water science and emphasizes experiential activities. A network of over 65 certified learning centers throughout Texas enables teachers to take entire classes outdoors to complete investigations linked to the curriculum.

The textbook features a series of career summaries and images intended to help students picture themselves working in water. The curriculum and associated materials are now top internet results for searches on "aquatic science," including "aquatic science curriculum-book-videos-careers-images" making this resource valuable to students interested in water who live outside of Texas.

Educated Workforce for Water Security

Texas water industry leaders meeting in a series of planning sessions in 2015 and 2016 identified a general failure of postsecondary degree-granting institutions to deliver job-ready graduates to meet future water industry needs. Their findings, reported in an article published in 2017 by the *Texas Water Journal*, add to nationwide concern over high rates of retirement eligibility and difficulties finding and attracting trained workers to fill job openings. Industry fears were confirmed by a U.S. Government Accountability Office report released in January 2018 on water workforce readiness and by a bill introduced in the U.S. Senate in the same month to establish a water infrastructure workforce development program to help maintain water security nationwide.

Post-Secondary Education Model

University educational models are not ones that bend easily to disruptive change. Current incentives are driving universities to focus on theoretical training. A new model proposed for water education in Texas would buck that trend for the sake of helping ensure Texas' water security. Details were listed in a paper published in November 2018 by the *Texas Water Journal* titled, "Water security for Texas: A post-secondary education pathway for water workforce readiness." The model pathway will equip graduates with practical scientific and operational training along with relevant post-secondary degrees that will position them for the jobs of today and tomorrow.

The model envisions multiple routes for a high school graduate or practicing professional to combine options for training and education to complete a B.S. or B.A.A.S. degree. (Figure 1).

Access to a combination of distance education, extension education, mobile laboratories, competency-based education credits, industry training, community colleges and regional universities will ensure local opportunities for training and degrees for students throughout Texas. The model also addresses requirements for licensing and long-term employment of graduates. It includes an option for the first two years of academic work to be completed at a community college and the last two years at a four-year degree granting regional university. Practicing industry professionals who have completed certifications and training through industry, government, or university extension programs will be able to earn competency-based credit toward a degree at a participating community college or university. Internships or work-study arrangements in water-related industries will be compulsory for students without prior relevant experience.

Conclusion

Connecting students to water while they are in middle and high school is thought to be a key to making a connection to the importance of water and possibly stimulating high school graduates to consider technical training or a post-secondary degree in water. To take these students forward,

Texas leaders in water education have advocated better alignment of existing technical training and degree programs. This alignment is considered an essential ingredient to building a pathway to careers in water. (Figure 2)

The post-secondary model relies on a mix of rigorous science and practical applied industry readiness training. Promoters of this model hope that early introduction to careers in water provided by *Texas Aquatic Science* will help students take this pathway to future employment in the water industry. It should be attractive to students seeking a clear path for a position in the water industry and long-term professional growth potential. It should also be attractive to practicing water professionals seeking a relevant university degree to enhance their own professional advancement opportunities. ■

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Figure 1. Options to obtain a B.S. or B.A.A.S. water degree. (Illustration from the article 'Water Security for Texas: A Post-Secondary Education Pathway for the Water Workforce' published in the *Texas Water Journal*.)

Figure 2. A water worker from careers in the textbook *Texas Aquatic Science*.

GUEST ARTICLE

Predictive and Observational Flood Mapping

David R. Maidment, Xing Zheng, Harry Evans, David Arctur, Paola Passalacqua, Christine Thies

IF YOU HEAR THE PHRASE "flood map" in the United States, what usually springs to mind are regulatory maps constructed by the Federal Emergency Management Agency (FEMA) to identify the 100-year and 500-year floodplains in American communities. These are static maps developed from statistically defined precipitation and streamflow events. However, inundation during an actual flood event is dynamic with flow in the stream network rising and falling in response to the local storm precipitation, which itself is highly variable in space and time.

Flood inundation based on the Height Above Nearest Drainage (HAND) principle relies on defining for each point in the landscape the vertical height of the land surface relative to the elevation of the streambed to which it drains. This enables the creation of contour map of relative elevation of the landscape above the streambed, as shown in Figure 1. This provides a very effective flood mapping approach, supporting both predictive flood mapping using forecast models for flood discharge, and observational flood mapping based on the current location of the water's edge.

To create these flood maps, the stream network is broken into a set of mapping reaches, generally drawn from confluence to confluence where tributaries join the main stem, and further subdivided where necessary to achieve mapping reaches of the order of 1-2 km in length. At any point in time, the water flow within this reach is assumed to be uniform, such as the blue zone in Figure 1, which has a single HAND value of water level above the streambed throughout the reach length.

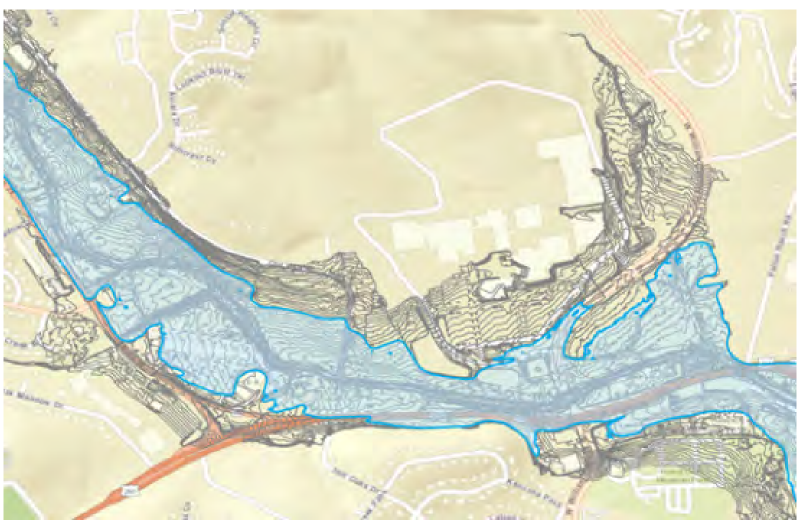

Figure 1. Flood inundation based on 1-ft contours of elevation above the streambed.

A rating curve connecting the discharge to the water level can be constructed using Manning's equation, where the geometrical properties of the channel reach are defined from the HAND map information. For example, for a given water level, the volume of water and wetted bed area in the stream reach can be computed, and when divided by the reach length, these yield the average cross-sectional area and wetted perimeter length needed for Manning's equation. Assuming a Manning's "n" value for roughness, and computing the longitudinal slope of the stream bed from the digital elevation model, the remainder of the quantities needed for Manning's equation are determined.

There are situations where structures such as bridges and dams lie along streams, and Manning's equation is not an appropriate method for constructing a rating curve – in this instance an engineering model such as HEC-RAS can be used, where the rating curve for the HAND mapping reach is determined by averaging the rating curves for the cross-sections lying within that reach. The HAND method is less useful where there are substantial areas of two-dimensional flow, such as within the street system of cities.

Using the Medium Resolution National Hydrography Dataset Plus (NHDPlus) for streamflow lines, and the 10m National Elevation Dataset raster for land surface topography, a corresponding 10m resolution HAND raster has been calculated by Liu et al. (2018) for the continental United States, and rating curves computed for each stream reach in the 5.2 million km of the stream network. This dataset is accessible at: https://web.corral.tacc.utexas.edu/nfiedata/. A comparable methodology has been used by the National Weather Service (NWS) at the National Water Center in Tuscaloosa, AL, to derive HAND-based flood inundation contour maps for the streams and rivers draining most of Texas from the new NHDPlus High Resolution data. These data are being used in planning exercises with local flood emergency responders conducted by the NWS West Gulf River Forecast Center for the Houston area and for the Blanco River in Texas. The results of these exercises show that the first response community welcomes the prospect of receiving flood forecast briefings using forecast inundation maps along rivers, rather than forecast hydrographs at particular locations on the rivers, as is the case for the NWS regional flood forecasting system at present.

Esri and the Center for Water and Environment of the University of Texas at Austin have developed a prototype cell-phone app called Pin2Flood that enables the first responders to drawn their own flood inundation maps as a flood occurs.

The first responder stands at the water's edge of the flooded area, clicks on the phone to define a "Pin" (a point with latitude and longitude coordinates), and the Pin location identifies the HAND contour elevation just enclosing that location and thus defines a local flood inundation map, such as the blue inundation area shown in Figure 1. This nearby inundation zone can be seen both by the first responder and by the Emergency Operations Center coordinating response over the flooded region, thus enabling portions of an overall map of flood inundation to be compiled as the flood occurs. This set of time-referenced Pins marking current flood extent can be stored and referenced to assist in assessing the extent of flood damage, such as by overlaying the inundation maps with information about address points for individual homes and businesses, or by using land parcels or structure footprints to assess flood impact after the flood is over.

First responders speak of trying to respond to floods occurring during bad weather and often at night as being "in a dark closet" – they can sense dimly only their immediate surroundings, and other first responders elsewhere in the area are similarly standing in their own "dark closets". In the Emergency Operations Center, the coordination staff is trying to grasp the magnitude of the flood through verbal descriptions communicated from the first responders by telephone or radio. Pin2Flood shines a light into these dark closets, enabling the local first responders to assess the extent of the problem they have to address locally, and also regionally as a composite picture is compiled at the Emergency Operations Center as Pins are dropped by first responders in different locations in the area.

There is thus created a rather unique combination – predictive flood mapping being derived from the regional and national forecasting efforts of the National Weather Service or local forecasting systems such as the Flood Early Warning System of the City of Austin, complemented by observational flood mapping carried by the local first responders conducting flood emergency response in cities and counties. Flood extent observations compiled using Pin2Flood complement water depths at gages measured using Flood Alert networks in communities that have such systems, and provide a unique approach to gathering flood extent data in rural areas which have few or no flood gages. With a properly coordinated national effort using a common flood inundation library of contour maps of relative elevation based on best available information, the predictive and observational flood mapping could be brought together and lead to greater forecast accuracy and better situational awareness of current flood conditions.

Accurate flood inundation mapping at local scale requires Light Detection and Ranging (LiDAR) data for land surface topography – such data using a 1m Digital Elevation Model cell resolution have been completed for central Texas, and are being used in Travis County to define HAND-based flood inundation maps to replace those developed earlier using the 10m National Elevation Dataset. The LiDAR data are thus 100 times more dense, which turns out to be quite sufficient to define good inundation contour maps. However, LiDAR data contain many embedded drainage structures, such as culverts and bridges, which complicate the mapping process, and require a more elaborate process for identifying the line of minimum channel elevation and constructing the HAND maps (Zheng et al., 2018).

Both the predictive and observational mapping processes for flood emergency response are in the prototyping phase and being tested with first responders in flood mapping exercises in Texas being conducted in 2019. While there is still significant work to be done before these methods are fully developed, the process is advanced sufficiently far to indicate that the pathway is sound. This indicates that a new kind of flood inundation mapping method has been created, designed specifically to support flood emergency response, which complements the existing FEMA methodology for inundation mapping for flood mitigation and insurance. ■

ACKNOWLEDGEMENTS

The authors express their appreciation to Fernando Salas, Dean Djokic, David Tarboton, Yan Liu and Shaowen Wang, and to Esri and Kisters for their collaboration in this research. This research was supported by the Texas Division of Emergency Management.

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Asteroids and Climate Change

Eric J. Fitch

"Save yourself little mammals. We Tyrannosaurus rexes will save you from the Asteroid!" said no T-rex ever.

APPROXIMATELY 65 MILLION years ago, an event occurred which modern analysis of the fossil record indicates obliterated 70-80% of all plant and animal species on Earth. It is most often referred to as either the Cretaceous–Paleogene (K–Pg) or the Cretaceous–Tertiary (K–T) extinction event. It is considered to be one of five major mass extinction events which have taken place in Earth's biosphere in the last half-billion years. Science uncovered evidence in the fossil record and debate ensued in the 1930s regarding the cause and duration of the K-Pg event. In 1980, research published by the multidisciplinary team of Luis Alvarez, Walter Alvarez, Frank Asaro and Helen Michel presented evidence indicating the triggering event was the collision between an asteroid or similar celestial body of significant mass and Earth. The collision shrouded the planet's surface from the sun and disrupted the planet's primary food webs as well as other physical processes. The scientists' primary argument was the presence of much higher concentration of iridium in the rocks marking the K-Pg boundary. Iridium is relatively rare in Earth's crust but far more abundant in asteroids and other "space rocks".

At first met with healthy skepticism, the theory gained much broader acceptance when other geoscientists confirmed not only the global distribution of elevated iridium levels in K-Pg boundary deposits but also the presence of shocked quartz which is an indicator of high energy impacts like that found in meteorite impact craters. Evidence of giant ancient tsunamis around the Gulf Coast and Caribbean at the same time frame seemed to narrow the location for the event At roughly the same time as the Alvarezes, Asaro and Michel were presenting their hypothesis, a pair of geophysicists, Antonio Camargo-Zanoguera and Glen Penfield, were doing deep surveys of Yucatan Peninsula and adjacent areas of the Gulf of Mexico for the Mexican national oil company PEMEX. Over the next two-plus decades, work by these geophysicists in collaboration with other scientists uncovered the presence of an impact crater deep within Earth, at the same level as the K-Pg event was identified as a likely source. It is called the Chicxulub crater because its center is located near the town of Chicxulub, Mexico. Subsequent research has indicated that the impact was caused either by an asteroid or comet with a range of 6.8 to 50.3 miles in diameter. Most recently, and in response to continued skepticism in some circles that this one impact could have precipitated the entire extinction event, studies have indicated that the impact occurred in an area that was ideal for causing maximum environmental disruption.

As the science the asteroid impact cause of the K-Pg event reached the mass media and pop culture, there was an explosion in public awareness fueled by popular culture (see the movies Deep Impact and Armageddon). Film themes revolved around the arrogant premise that: (1) this is awful, but (2) we aren't "dumb dinosaurs" and (3) we can use our brains and technology to "save the planet". Cue the heroics of Bruce Willis, Ben Affleck, Robert Duvall, Mary McCormack, et al. Scientists, engineers, and other knowledgeable individuals pointed out that there was greater probability that humanity would go the way of the dinosaurs. Even with the advances humankind has put in place to detect and respond to such threats, it is highly likely that we would not be able to protect the planet from the impact and its consequences. Conversely, the global community is facing a more slowly evolving set of global impacts that are producing similar results with regard to biodiversity and the vitality of the biosphere, especially for our own species.

Climate change caused by greatly increased concentrations of greenhouse gases in the atmosphere, overwhelmingly as the result of anthropogenic activity, is resulting in increasing retention of heat in the atmosphere and oceans that would otherwise radiate out into space. The mean temperature of the atmosphere and the oceans are rising and this excess energy is driving massive changes in both media. Sixty-five million years later, our species and Earth's biosphere are being threatened by a large scale event taking place, from the perspective of geologic time, nearly as rapidly as the K-Pg/K-T event. Unlike that event we can take action to reduce the impact and respond to/mitigate its effects.

From a scientific standpoint, the debate is functionally over. The one area where the analysis of the reality of anthropogenic climate change seems to be wrong is that many of the thresholds and impacts are occurring sooner than "originally" projected. Global atmospheric CO2 levels have passed the 415 ppm (parts per million) level; levels have not been this high for over 800,000 years, before the emergence of the species *Homo sapiens*. Records for global mean atmospheric temperature seem to fall every year. The global models for ocean warming are proving wrong; the oceans are warming at four times the projected rate and 2018 was the warmest global mean ocean temperature on record. Ocean acidification is also a mounting problem. Storms, flooding and other effects associated with a warming planet are causing/contributing to death, property destruction and displacement of peoples around the world. The "cherry on the top" is a recent United Nations report projecting the near term extinction of over a million species as a result of anthropogenic activities including climate change.

So far, however, humankind is being less than heroic or even effective in our response despite the fact that we have knowledge, foresight and the means to do all of this. Why? It boils down to the fact that political and economic power is concentrated in the hands of people whose short term interests favor the status quo: continuing to burn fossil fuels and release other greenhouse gases is central to short term economic gain and retention of political control. These forces have moved the current leadership of the wealthiest and most powerful nation on the planet, which is also the greatest per capita emitter of greenhouse gases, to turn its back on efforts to curtail GHG generation and to respond to systemic environmental changes.

There are some bright spots in an otherwise bleak tapestry, and they often emanate from places where the negative impacts are happening the fastest and hardest. A prime example is Louisiana. If there is a poster child in the United States for climate change driven negative impact it is the Pelican State. On top of being ground zero for some of the most destructive hurricanes of the last hundred years, it is literally disappearing into the sea. Louisiana losing a football (American) field of land an hour; it is losing land to the sea faster than any other region in the world. Sea level rise is occurring more rapidly in the Gulf of Mexico than in most of the rest of the world. Sea levels are rising because of increasing input of water from the melting of glaciers and ice caps and thermal expansion of water. Add to the rise are three other key factors that have strong impacts in coastal Louisiana. Coastal Louisiana is experiencing rapid rates of erosion, exacerbated by historic human activities especially channelization for navigation which cut through marsh structures exposing them to erosive forces. Sediment deposition from the Mississippi River which built up the coastal marshlands over centuries has been greatly reduced due to locking the river into a channelized flow. Finally, extraction of oil, natural gas and minerals from beneath coastal seabed has caused subsidence of these lands; so as the water rises the land sinks - exacerbated by the pumping of groundwater by land-based industrial facilities. On top of already significant coastal losses, using the newest numbers it is projected that Louisiana could loses another 2,800 square miles of land in the next forty years and would need to be floodproofed, elevated or bought out and abandoned or demolished.

Despite having an economy heavily dependent upon the fossil fuel industry, despite being a politically conservative Republican leaning state, despite numerous factors, the enormity of the threat to their state has led leaders in the public, private and nonprofit sectors to demand and implement mitigation measures. Louisiana has developed an advanced coastal monitoring system and is using this information to design an advanced system of coastal protection and restoration. As attributed to Samuel Johnson "Depend upon it, sir, when a man knows he is to be hanged in a fortnight, it concentrates his mind wonderfully", Louisianans do not have the luxury of denial. That is a good thing that should become the position of all of us if we are to avoid the worst karmic impacts from our past and present disregard for Earth and its biosphere. ■

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