The Academy of Medicine, Engineering & Science of Texas

2014 TEXAS WATER SUMMIT REPORT

Securing Our Economic Future

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In May of 2012, The Academy of Medicine, Engineering & Science of Texas (TAMEST) held the 2012 Texas Water Summit: Securing Water for Texas' Future, with a program focused on the major challenges of ensuring future water resources. On May 19, 2014, TAMEST held a second water summit to gain a better understanding of the issues surrounding water use in the agricultural, industrial, commercial, and ecological sectors.

This report includes summaries of the presentations and panel discussions from the 2014 Texas Water Summit: Securing Our Economic Future, where over 250 scientists, engineers, policymakers, agency officials, and other stakeholders gathered to discuss the challenges and opportunities Texas faces in providing water to sustain the state's economic growth and stability.

Video footage and slides from both the 2012 and 2014 summits as well as digital versions of the reports can be viewed at www.tamest.org. Copies of the printed reports are available upon request.

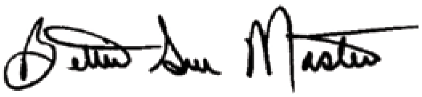
Introduction

Water security is one of the most urgent challenges of the 21st century. Globally, many areas are experiencing water stress, and a significant portion of the world's population lacks access to fresh water. In the U.S., although there is no argument that adequate water is critical to meet the needs of a growing population and to promote a healthy economy, water is often taken for granted despite declining supplies due to rising demands, climate change, and ecosystem degradation.

There is a considerable amount of research devoted to advancing our understanding of the science of water resources to address agricultural, industrial, municipal, and ecological needs. We are making progress in the application of this research across all sectors, but it is important to continue to develop technologies and conservation initiatives to help alleviate the social, economic, and political impacts of water stress.

On May 19, 2014, TAMEST was pleased to organize and present the 2014 Texas Water Summit: Securing Our Economic Future. This event served to engage individuals from various economic sectors to identify and explore solutions to our water needs for economic development, and hopefully will promote a continuing role for the application of science and technology to address water issues that face the state.

The 2014 Texas Water Summit is an example of TAMEST's commitment to promote interaction and collaboration among all stakeholders on issues of critical importance to the state of Texas. We wish to thank all of our sponsors for making this event possible.



Bettie Sue Masters, Ph.D., D.Sc. (IOM)
2014 TAMEST President

ABOUT TAMEST

The Academy of Medicine, Engineering & Science of Texas (TAMEST) was established in 2004 to provide broader recognition of the state's top achievers in medicine, engineering, and science, and to build a stronger identity for Texas as an important destination and center of achievement in these fields. With 270+ members, TAMEST is composed of the Texas-based members of the three National Academies (Institute of Medicine, National Academy of Engineering, and National Academy of Sciences) and the state's 10 Nobel Laureates.

TAMEST members have been elected by their peers to one or more of the National Academies in recognition of their contributions to their respective fields. They serve in an advisory role to the nation and are a valuable resource to the State of Texas.

Since 2011, the worst single-year drought in Texas' recorded history, there has been growing public awareness about the impact of an expanding population on the state's water supplies. With our traditional water sources finite at best, the increase in water needed to support agriculture, industry, energy production, and basic human needs is already taxing the state's infrastructure.

The 2012 State Water Plan estimated that regional and local entities would need $53 billion to fund water infrastructure projects by 2060, but this is only a fraction of the $231 billion projected cost of addressing all of the state's water needs. Although recent legislation has established funding mechanisms to help finance water strategies identified in the 2012 State Water Plan, rising water costs are inevitable across all sectors. Currently, 85 percent of the state's water demand is for agricultural and municipal use and only 15 percent is devoted to key sectors of our economy such as oil and gas, power generation, and manufacturing. With roughly two-thirds of the state in continuing drought conditions and a population predicted to double in size over the next 50 years, the implications for Texas are clear: meet the critical water needs of all sectors of the economy or face a future of severely constrained growth.

The 2014 Texas Water Summit was designed to give stakeholders a better understanding of a number of critical issues around sustaining our economy as our population grows: the potential of the 2012 State Water Plan to address our future water needs; projections for future availability; the economics of water; and the promise of technology for conservation and reuse applications in the agricultural, commercial, and industrial sectors. By identifying the key issues as well as possible solutions, we hope the summit helps build consensus on a path forward toward sustaining our remarkable economic growth into the future.

Danny D. Reible, Ph.D. (NAE)
2014 Texas Water Summit Program Chair

2014 TEXAS WATER SUMMIT PROGRAM COMMITTEE

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Michael H. Young, Ph.D. Senior Research Scientist and Associate Director for Environment Division, Bureau of Economic Geology, The University of Texas at Austin

Kent Zammit Senior Program Manager, Electric Power Research Institute (EPRI)

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State Climatologist Dr. John Nielsen-Gammon provides an update on drought conditions in Texas.

Potential for Texas Water Plan to Address Future Water Needs

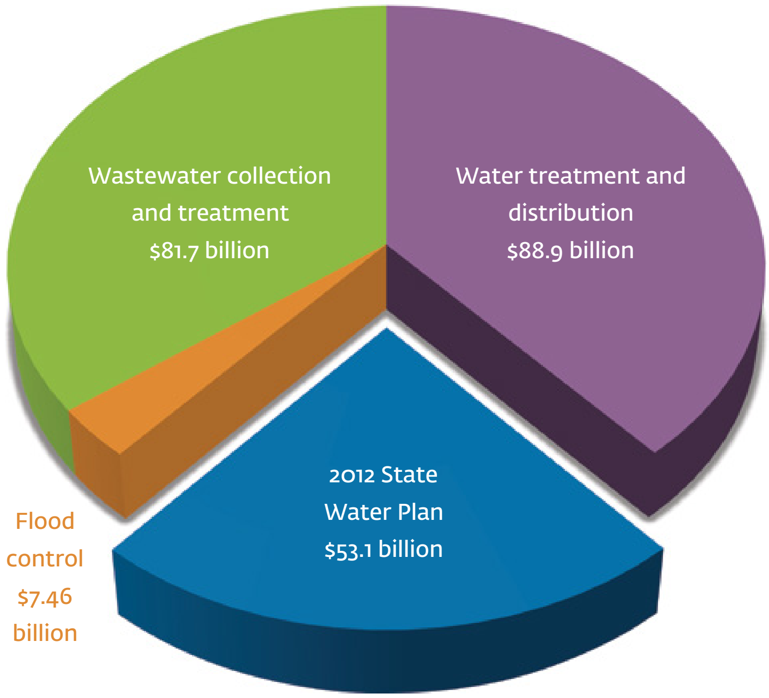
Carlos Rubinstein
Chairman
Texas Water Development Board

Carlos Rubinstein served four years as a commissioner for the Texas Commission on Environmental Quality prior to his appointment as chair of the Texas Water Development Board. He is the Texas representative to the Western States Water Council; the Border Governors' Conference Sustainable Development worktable; the Governmental Advisory Committee advising the EPA Administrator on environmental concerns regarding NAFTA; the North American Agreement on Environmental Cooperation; and the Commission for Environmental Cooperation.

Elizabeth Fazio, J.D., LL.M.
Committee Director
Committee on Natural Resources
Texas House of Representatives

Elizabeth Fazio provides strategic planning for the development of the state's natural resources and water rights at the Texas legislature. She is an accomplished leader in the formulation and execution of public policy, demonstrating financial and legal expertise to drive sustainable change in the preservation and conservation of water resources.

TOTAL CAPITAL COSTS = $231 BILLION



Texas' Water Needs

Source: Texas Water Development Board

Texas Water Needs

With the population of Texas projected to increase 82 percent between 2010 and 2060, annual water demand is expected to rise from about 18 million acre-feet to approximately 22 million acre-feet in the same time period. The 2012 State Water Plan provides details on 562 water management strategies that are a summary of 3,000 projects with the potential to generate 9 million acre-feet of water.

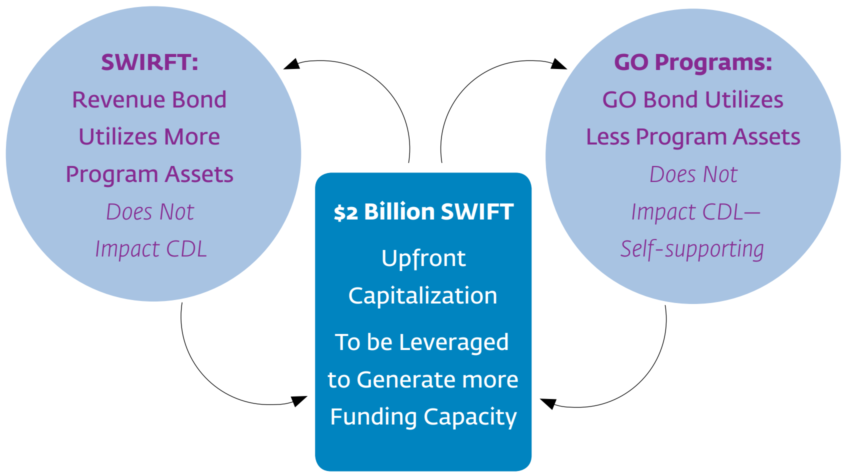
The total estimated capital costs of implementing all of the recommended strategies in the 2012 State Water Plan is $53 billion, representing less than a quarter of the $231 billion projected cost of developing water supplies, water treatment collection and distribution, wastewater infrastructure, and flood control required to meet the needs of Texas in the next 50 years.

The estimated 9 million acre-feet of water that could be generated by the strategies in the 2012 State Water Plan can be divided into three roughly equivalent categories. The most cost-efficient way to obtain water is through conservation and reuse, accounting for one-third of the volume of water created through state water plan strategies for 12 percent of the total capital costs. Another third could come from developing new infrastructure and methods to further the use of existing supplies, including transporting water, accounting for 45 percent of the capital costs. The development of new water supplies could provide the final third, including new reservoirs and groundwater wells, aquifer recovery and storage, and desalination of seawater

"The 2012 State Water Plan provides details on 562 water management strategies that are a summary of 3,000 projects with the potential to generate 9 million acre-feet of water."

Financing the 2012 State Water Plan
(CDL = Constitutional Debt Limit)

Source: Texas Water Development Board



"Financing the 2012 State Water Plan will require leveraging funds from GO Bonds, the SWIFT, and the SWIRFT."

and brackish groundwater. This category accounts for 43 percent of the capital costs.

Financing the 2012 State Water Plan

In November 2011, voters approved Proposition 2, allowing the Texas Water Development Board (TWDB) to issue general obligation (GO) bonds at its determination and on a continuing basis for the Texas Water Development Fund II (Dfund), as long as no more than $6 billion worth of bonds are outstanding at any one time.

In 2013, the Texas Legislature enacted House Bill 4, Senate Joint Resolution 1, and House Bill 1025 to create two funds—the State Water Implementation Fund for Texas (SWIFT) and the State Water Implementation Revenue Fund for Texas (SWIRFT)—to help finance projects in the 2012 State Water Plan. As a result of the legislation and the subsequent passing of Proposition 6, $2 billion was transferred from the state's Economic Stabilization ("Rainy Day") Fund into the SWIFT, creating a water infrastructure bank to enhance the TWDB's financing capabilities with constitutionally created programs. In tandem, the SWIRFT will allow the TWDB to issue revenue bonds for projects. Financing the 2012 State Water Plan will require leveraging funds from GO Bonds, the SWIFT, and the SWIRFT.

In addition to creating the SWIFT and the SWIRFT, the legislation included directives to ensure active management, transparency, and oversight of the SWIFT. As a result of these directives, the TWDB was restructured and an advisory board was created; guidelines were set for use of the fund; a process was defined for prioritization of the use of the fund; and technical aspects of the legislation were outlined.

What Will the SWIFT Fund?

The goals for managing the financing of water projects include increasing and protecting Texas' water supply; leveraging a one-time capitalization with bonding capacity; protecting the corpus of the SWIFT by spending it as carefully as possible; and providing support and incentives to local and regional communities through reduced interest rates and repayment terms that meet their needs.

Funding eligibility is limited to public entities and nonprofit water supply corporations, but these entities can enter into public/private partnerships. At least 10 percent of funded projects must be in rural areas, and at least 20 percent must be conservation or reuse projects. Since the SWIFT was specifically intended to fund the 2012 State Water Plan, only projects in the plan will be considered. However, since changing conditions in Texas can justify the inclusion of new projects, the regional planning groups can amend their plans and submit new projects to the TWDB for consideration.

How Will Projects Be Prioritized?

Prioritization criteria are being developed to evaluate projects at both the regional and agency levels. The TWDB solicited input from citizens and experts across the state to develop a prioritization system, and a stakeholders committee with representation from the regional planning groups developed uniform standards to prioritize projects at the regional level.

As directed by statute, the regional planning groups must evaluate projects on the following: 1) the decade in which the project is needed; 2) feasibility; 3) viability; 4) sustainability; and 5) cost-effectiveness. At the agency level, again as directed by statute, top priorities must include the following: 1) serving a large population; 2) assisting a diverse urban and rural population; 3) providing regionalization; and 4) meeting a high percentage of water supply needs.

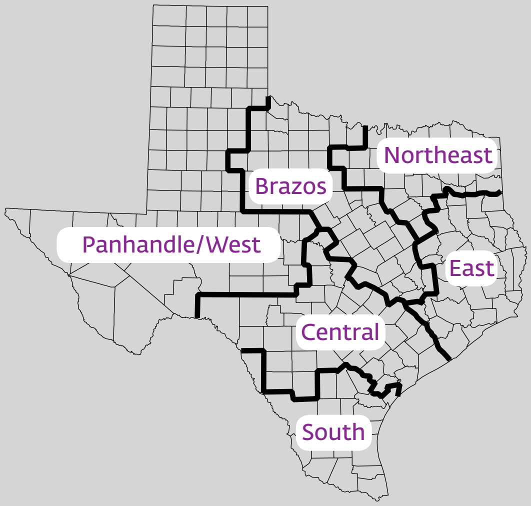
A website for submitting comments on prioritization rules was made available in April 2014. The TWDB is hosting formal and informal meetings around the state in addition to board work sessions to solicit input. The deadline for adopting the prioritization rules is March 2015, but the goal is to complete this process by December 2014.

TWDB Support

The TWDB has established six planning and development teams by geographic area to provide customers access to staff with an understanding of regional needs and the best programs to meet those needs. New scientific platforms have been added to TWDB data sets and an interactive state water plan website has been launched. An agricultural and rural ombudsman has been appointed to assist communities with planning for their future water needs.

Geographic Areas for Regional Water Planning and Development Teams

Source: Texas Water Development Board



"The TWDB has established six planning and development teams by geographic area to provide customers access to staff with an understanding of regional needs and the best programs to meet those needs."

Water for Ecological Needs

Laura Huffman
Texas State Director
The Nature Conservancy

Laura Huffman heads a team of more than 80 scientists, conservation experts, and support staff at The Nature Conservancy, which operates in all 50 states and 35 countries outside of the U.S. She is one of The Nature Conservancy's most trusted national voices and speaks regularly on an array of topics, including freshwater protection, the Gulf of Mexico, conservation easements, and current pressing environmental issues.

"Growing cities, agriculture, industry, and energy have to understand the needs of all sectors and be interested in solving water issues in a holistic fashion."

For The Nature Conservancy, freshwater is and has been emerging as the number one natural resource issue of the day. Freshwater is the centerpiece for culture, community, and economy, and the quality of the conversation about water will dictate whether the problem is solved or reaches a choke point.

Texas is the crucible of all major global dynamics that drive freshwater projections. Global population is projected to reach 9 billion by 2060, and the population of Texas will nearly double to 50 million during this period. A megatrend sitting below population growth is urbanization. Texas is already 86 percent urbanites, and the state can expect to see some breakneck population growth as people continue to move to cities. All over the world, coastal cities are growing the fastest, and with Houston expected to double in size, Texas is following that trend. With predictions of sea level rise and extreme coastal weather events, more people and assets are moving into harm's way than ever before. Ironically, the federal disaster recovery system currently in place allows rebuilding over and over again in the same locations.

Access to fresh water is critical to four major categorical users: growing cities; agriculture to feed growing populations; energy and industry to provide goods and services; and last but certainly not least, the environment. Water quality and adequate flows reflect the health of rivers, streams, and aquifers. A decline in the quality and quantity of water systems is an important indicator of failure to make sure this resource is viable and available for the future. In other words, healthy and biodiverse waterways are a strong indication that current needs are being met while stewarding this resource for future generations.

The Highland Lakes in the Colorado River Basin are a case in point. The fundamental hydrology of this system has been compromised, bringing inflows to an all-time low. Something is happening to prevent this system from recharging itself, and with the realization of projected population stress, the situation could become untenable.

There is no question that the biodiversity supported by water systems is critical to the state. Natural resources are vitally tied to the health of the Texas economy. Consider the importance of freshwater inflows to the Gulf of Mexico, where state and global economies converge.

"...healthy and biodiverse waterways are a strong indication that current needs are being met while stewarding this resource for future generations."

Around the world, the conversation about water gets divisive quickly. Each sector tends to look at their categorical use of water and declare it to be superior to others. Growing cities, agriculture, industry, and energy have to understand the needs of all sectors and be interested in solving water issues in a holistic fashion.

In Texas, the passage of HB 4 by a significant margin signals a higher level of public concern and understanding about water. It is a national best practice that a minimum of 20 percent of the funding authorized by the state must be earmarked for conservation, and together with the 10 percent set aside for rural/agricultural conservation, Texas is sending a strong signal about how the state will prioritize strategies.

The 2012 State Water Plan is not perfect, but it is a way of expressing needs and a game plan to ensure that Texas has water into the future. Water conservation should be first, as it will always be the most cost-effective source of new water supplies, and conservation measures can be implemented across all sectors. Success will require building effective value propositions. Cities can support conservation through rate

"Texas has the opportunity to stand out as a state that recognizes a bad water conversation and turns it into a better conversation about how to secure fresh water for the future."

structures and repairing old infrastructure. In the agricultural sector, work is needed to make it economical for farmers to replace irrigation equipment or adopt new systems. In the oil and gas industry, introducing brackish water into the hydraulic fracturing process and increasing the number of times it can be reused will help conserve fresh water. The energy and industry sectors will need to address the cycling time of water and energy and expand on their brackish and reuse programs.

Building new infrastructure has to be part of the solution. There is considerable debate about the potential for various supply strategies, and more research is needed in areas such as aquifer storage and brackish desalination. Establishing an environmental commissioning for new water supply projects would improve understanding of the expense and consequences of various strategies.

Creative solutions to providing adequate water supplies will require a comprehensive conversation. Texas has the opportunity to stand out as a state that recognizes a bad water conversation and turns it into a better conversation about how to secure fresh water for the future.

Future Water Availability

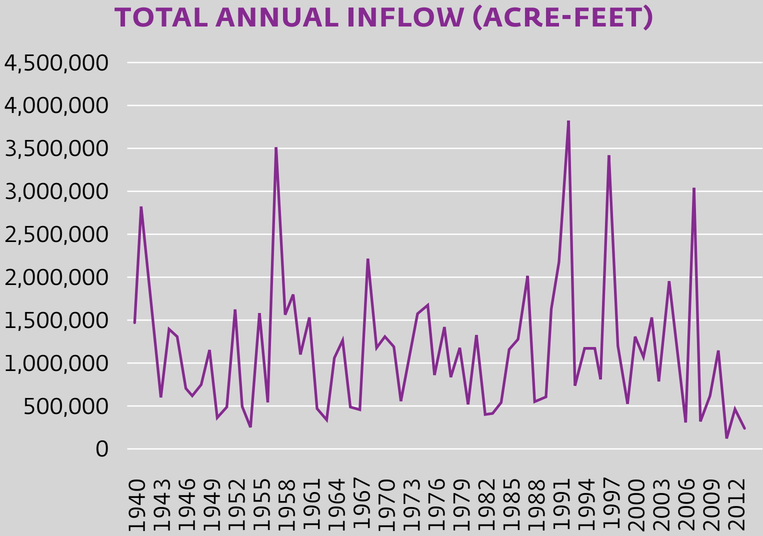
Bradfield Lyon, Ph.D.
Research Scientist
International Research Institute for Climate and Society
The Earth Institute at Columbia University

Dr. Bradfield Lyon's research has focused on climate variations on time scales ranging from subseasonal to multi-decadal to long-term climate change, with a particular interest in drought, its physical causes, seasonal prediction, and impacts. Dr. Lyon is working with the Lower Colorado River Authority to develop seasonal forecasts for inflows to the Lower Colorado River Basin system.

"The potential impacts of long-term climate change on water availability are of considerable concern."

Lower Colorado River Basin Inflows: 1940–2013

Source: Lower Colorado River Authority



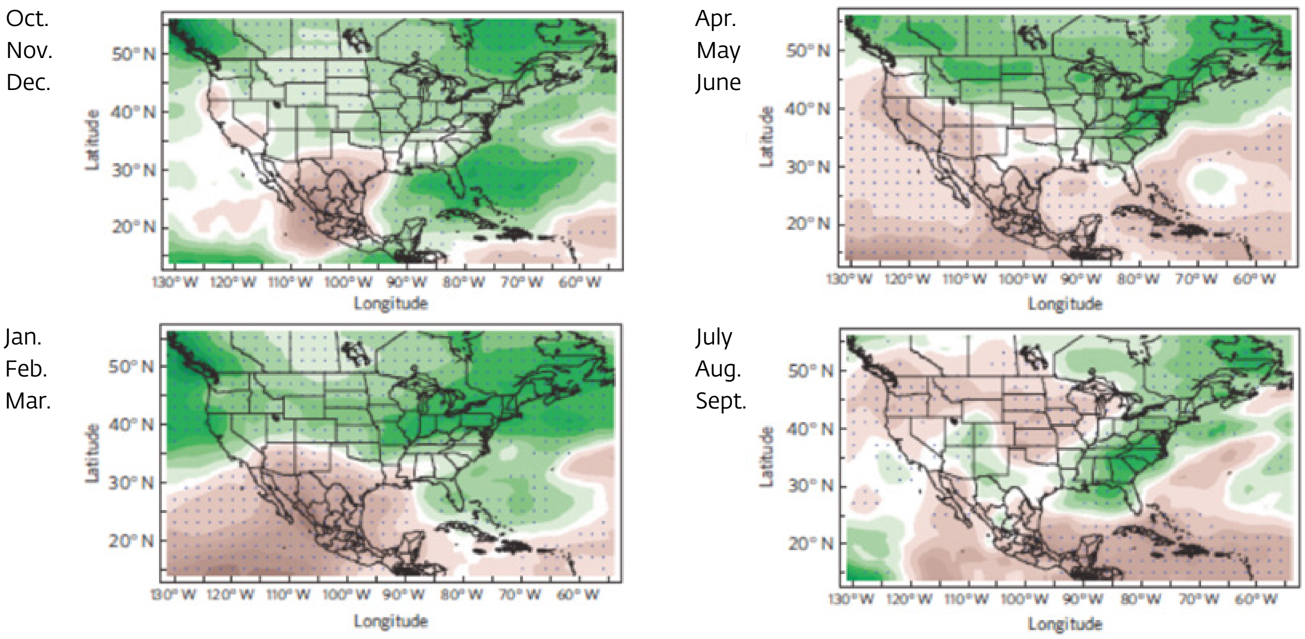
Challenges to meeting the growing demand for water in Texas during periods of severe drought underscore the critical role climate variations play in affecting water supply. From a climate perspective, water supply comes in the form of precipitation and water demand arises from the atmosphere's capacity to hold water, met by evaporation from the surface. The warmer the atmosphere, the greater its water demand. In the coming 30–40 years, water availability will depend on changes in the character of precipitation and changes in temperature. This is complicated by the fact that climate varies on multiple timescales: from one season and one year to the next, from decade to decade, and under long-term climate change. Climate variations in all of these areas will come into play in efforts to meet water demands.

The Lower Colorado River Basin (LCRB) system includes the Highland Lakes of Central Texas created by six dams on the Colorado River. Data from 1940–2013 reflects considerable variability of inflows into the system as well as extremely low inflows over the past several years. In addition to precipitation amounts, higher inflows in the LCRB are associated with extreme weather events producing substantial rainfall and surface runoff. Over the past several years, a reduction in the frequency of extreme weather events (and precipitation in general) has contributed to low inflow to the LCRB while higher temperatures have resulted in increased evaporation rates. Future changes in both precipitation extremes and temperature will impact inflows to the system.

"...a reduction in the frequency of extreme weather events (and precipitation in general) has contributed to low inflow to the LCRB while higher temperatures have resulted in increased evaporation rates."

Multi-model Projections for Changes in Seasonal Precipitation Relative to Current Climate: 2021–2041*

Brown areas indicate drying, green indicates wetter conditions, and a pattern reflects consensus among 16 climate models.



On seasonal to interannual time scales, low inflows to the LCRB system show some association with La Niña weather conditions, characterized by cooler than average temperatures in the tropical Pacific. On decadal timescales, the combination of a cooler Pacific and a warmer Atlantic favors multi-year periods of drought. Although these are the conditions that Texas is currently facing, this is not a prediction that the current drought will last a decade, only that there is an increase in the odds of it occurring. Climate variations from one year or one season to the next are expected, and climatologists are predicting a 70 percent chance of an El Niño developing in the fall of 2014 favoring an increase in rainfall, particularly in southern Texas. Although existing sea surface temperature patterns correlate with lower rainfall and inflows, there is little skill in predicting when decadal shifts in ocean temperatures will occur. Nonetheless, tree ring records indicate that there have been periods of multi-year drought in Texas over the past several hundred years, and a reoccurrence

**Seager, R., M. Ting, C. Li, N. Naik, B. Cook, J. Nakamura, and H. Liu, 2012: Projections of declining surface-water availability for the southwestern United States. Nature Climate Change, doi:10.1038/NCLIMATE1787.*

would not be a surprise.

The potential impacts of long-term climate change on water availability are of considerable concern. On short time scales (e.g., 20–30 years), natural climate variability can mask or enhance the more slowly changing climate change signal. For example, although observed trends indicate Texas is getting slightly wetter, the cause of this is not clear, and studies suggest many subtropical regions will become drier as the planet warms. If natural climate variations are masking the climate change signal, this would suggest a future decrease in rainfall. Rising temperature trends across the country are generally more uniform as shown in the recent 2014 U.S. National Climate Assessment.

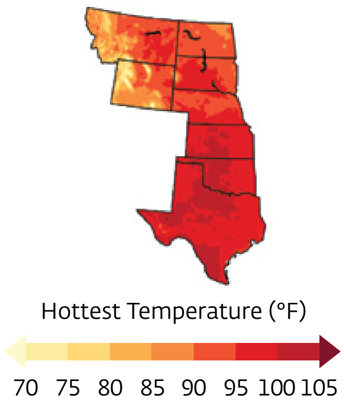
Researchers use multiple models to generate climate change projections. There can be considerable variation in these projections for a specific region, particularly at the level of an individual state, due to differences in model formulation and the effect of natural climate variations generated within the models. A recent study examining several of the most recent climate model projections over North America finds seasonally varying influence of increasing greenhouse gases. In the vicinity of Texas, changes in spring and summer precipitation are less certain, with the models indicating a decrease in rainfall in other seasons. While the models are an imperfect representation of the actual climate, the model consensus for drying in the region is a real concern. Put another way, in no season is there consensus for an increase in precipitation.

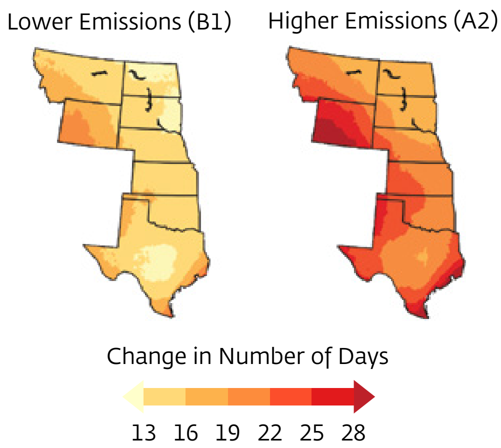
There is very strong agreement across climate models for a projected increase in surface air temperature in the coming decades as a result of increasing greenhouse gases. As reported in the U.S. National Climate Assessment, between 2041 and 2071, this will also increase the number of extreme temperature days. The higher temperatures will increase evaporation from lakes, ponds, and the soil, reducing water availability and intensifying droughts that develop naturally.

In conclusion, while natural variations in the climate system will likely be the dominant source of variability in water availability over the next 30–40 years, it is very likely that average temperatures and extreme high temperatures will continue to increase. There is a strong consensus among climate models for intensification of heat waves that will exacerbate droughts and accelerate surface water loss. Natural climate variations will also dominate precipitation variability in Texas over this period. While there is more uncertainty about future changes in precipitation versus temperature, climate models favor drying in Texas. Overall, future climate change will push water supply systems in the direction of increasing water stress.

Projected Changes in Extreme Temperatures By 2041–2071

Source: U.S. National Climate Assessment, 2014





"There is strong consensus among climate models for intensification of heat waves that will exacerbate droughts and accelerate surface water loss."

Panel on the

Economics of Water

Ari M. Michelsen, Ph.D.
Regents Fellow
Professor and Center Director
Texas A&M AgriLife Research and Extension Center at El Paso
The Texas A&M University System

Dr. Ari Michelsen's research focuses on Integrated Water Resources Management, water resources valuation, conservation, markets, and policy analysis.

Sheila M. Olmstead, Ph.D.
Associate Professor
Lyndon B. Johnson School of Public Affairs
The University of Texas at Austin

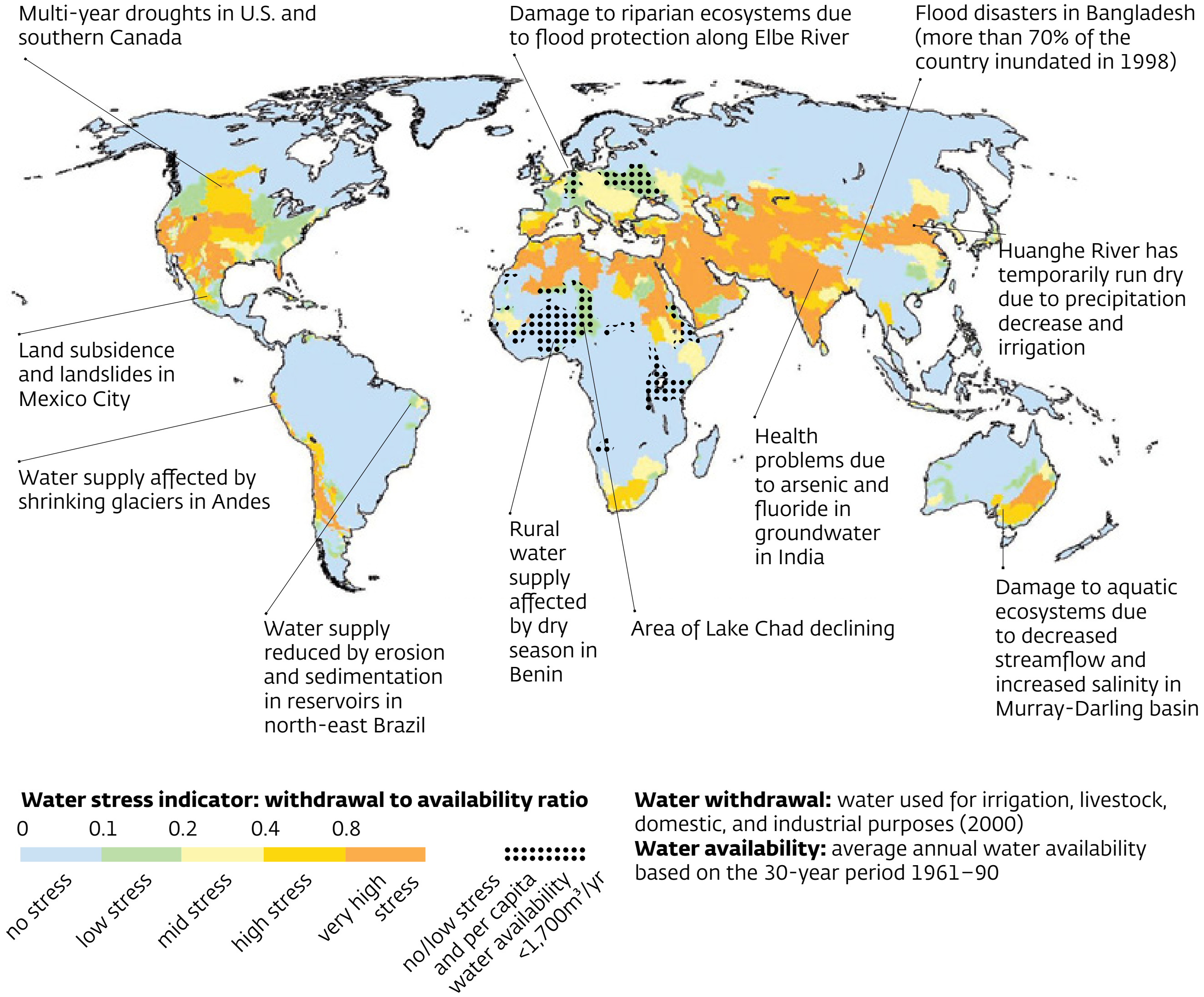
Dr. Sheila Olmstead is an environmental economist who has worked extensively on the economices of water resource management.

Keith R. Phillips, Ph.D.
Senior Economist and Research Officer
Federal Reserve Bank of Dallas

Keith Phillips' areas of concentration include regional economics and economic forecasting.

Vulnerabilities of Global Water Resources

Source: Alcamo, J., P. Döll, T. Henrichs, F. Kaspar, B. Lehner, T. Rösch and S. Siebert, 2003a: Development and testing of the WaterGAP 2 global model of water use and availability. Hydrol. Sci. J., 48, 317–338



Water withdrawal: water used for irrigation, livestock, domestic, and industrial purposes (2000)
Water availability: average annual water availability based on the 30-year period 1961–90

Water supplies in many areas of the world are being threatened by political conflict, drought, declining aquifers, groundwater contamination, erosion, and sedimentation. Adequate water supplies are critical to the production of food, energy, goods and services, transportation, and health. Failure to effectively manage this resource will have devastating economic, social, and political impacts on a global scale.

> *"Water resource economics is a valuable tool in understanding water pricing, water markets, and benefit-cost analysis, and can be used to navigate the complexities of managing water efficiently."*

Water resource economics is the intersection of physical, cultural, and social conditions, scientific information, policy, law, and institutions. Water resource economics is a valuable tool in understanding water pricing, water markets, and benefit-cost analysis, and can be used to navigate the complexities of managing water efficiently.

WATER PRICING AND WATER MARKETS

Most goods and services are purchased in markets where costs reflect scarcity or abundance, but water allocation and prices are often not based on supply and demand. In Texas, access to water is determined by the allocation of water rights, and water is almost always priced below its value due to water rights ownership issues, and laws, regulations, and policies that restrict water markets and dictate the price of water.

Most consumers purchase water from public entities such as cities or water authorities. Prices are generally moderate as they are based on the cost of treatment and delivery, and scarcity is often managed by rationing water among users.

In the U.S., as in most countries, the price of water in the agricultural sector is significantly lower than for industry or municipal use, resulting in pressure for the reallocation of water, particularly in times of scarcity. The application of market principles in Texas would allow a more efficient allocation of water resources, but there are challenges to implementing market practices with both surface water and groundwater.

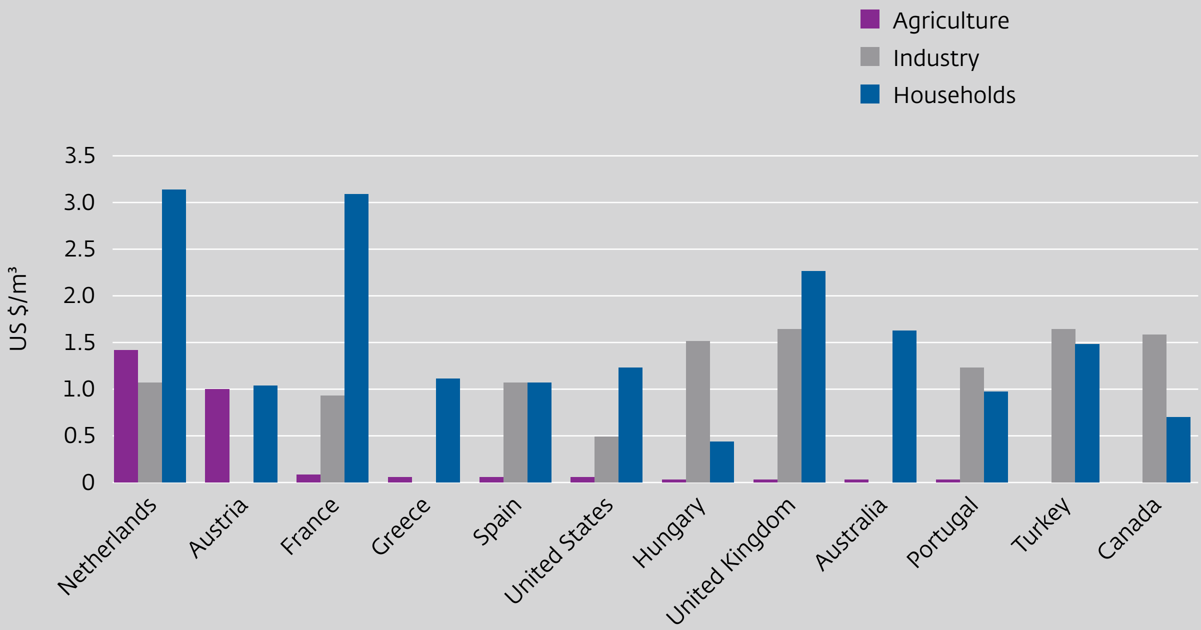
Surface water levels are falling in all regions of Texas, but this is not evenly distributed across the state. Surface water rights are issued by the state, and most basins are fully allocated. Although the legal framework exists to accommodate interbasin water transfers, in practice there are many restrictions including the no-injury rule and the junior rights rule.

Under the current system, 70 percent of surface water rights in Texas are held by public entities and water authorities. Although this may be beneficial for planning purposes, markets work best when there are a higher number of buyers and sellers. Market practices are also hindered by inflexible take-or-pay contracts and prohibiting river authority customers from reselling water. Market principles would allow customers to benefit from sales to each other, and the benefits of these transactions would likely increase in times of scarcity.

Groundwater supplies are predicted to fall over the next 10–50 years, and West Texas will be heavily impacted. Most major Texas aquifers have already declined, including the Trinity Aquifer in North Texas that has fallen more than 1,000 feet in areas around Dallas, and large swaths of the Ogallala Aquifer are down by hundreds of feet. Predictions show some areas of the Ogallala Aquifer depleted as early as 2025.

Comparative Water Prices by Country and Sector: Late 1990s

Source: Organization for Economic Cooperation and Development. 2001.



Groundwater rights have historically been dictated by the rule of capture, stipulating that water is not owned until it is pumped out of the ground, and that groundwater is essentially the private property of overlying landowners. This practice is inefficient and leads to the tragedy of the commons where one person's actions leave less for everyone else. The state's Groundwater Conservation Districts (GCD) have been given the authority to regulate groundwater and are trying to establish property rights to water. The Texas Supreme Court has upheld property owners' rights to water, and the rule of capture will continue to be a challenge as long as it is intact.

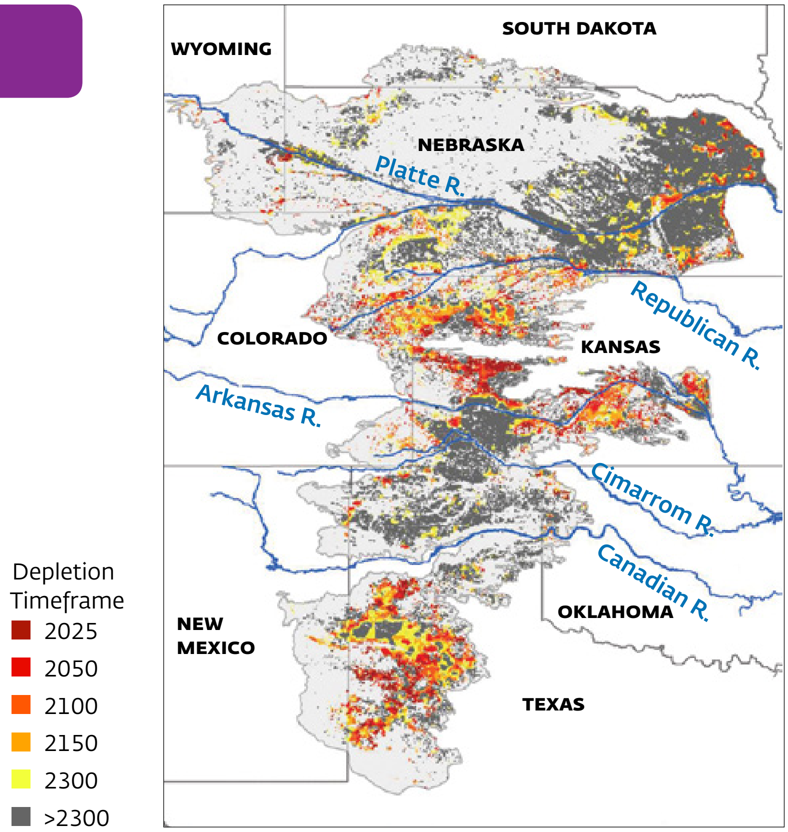
From a market perspective, if an individual has no legal right to a fixed amount of water, there is no way to provide guarantees to buyers. In addition, GCDs have imposed export limits and fees. The application of market principles would allow more efficient allocation of groundwater resources. The system should protect property rights but also encourage marketing so water prices reflect supply and demand.

There is growing awareness of the efficiency of market principles in the management of water resources. Sales of

"...the price of water in the agricultural sector is significantly lower than for industry or municipal use, resulting in pressure for the reallocation of water, particularly in times of scarcity."

Ogallala Aquifer Depletion Timeframe Predictions

Source: Michigan State University Hydrogeology Lab



"Predictions show some areas of the Ogallala Aquifer depleted as early as 2025."

water from the agricultural sector to municipalities and industry are occurring and are likely to increase. Regional water plans under Senate Bill 1 (1997) have embraced water transfers and markets. More water planners, farmers, and municipalities are realizing that market principles are part of the solution for effectively managing water resources.

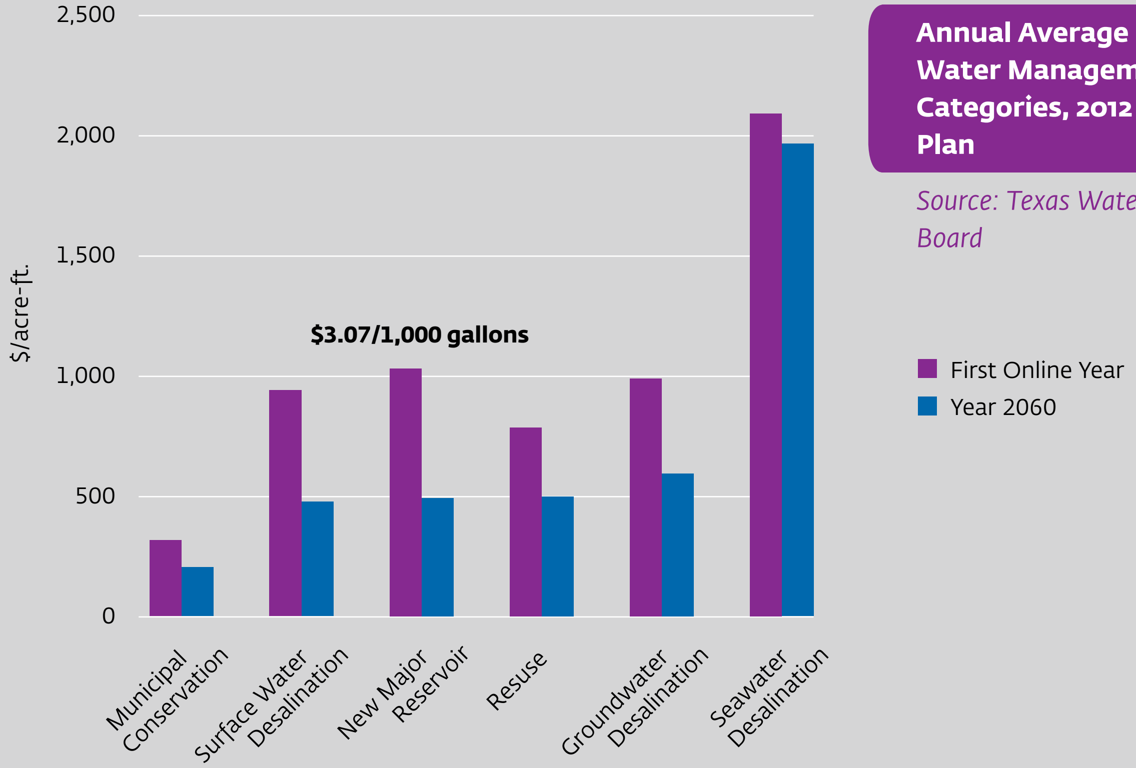
BENEFIT-COST ANALYSIS

Conservation is often the most cost-effective way to extend water supplies. Allowing the price of water to reflect scarcity promotes conservation as it allows households, firms, and farms with different costs and benefits of water use to decide how to reduce consumption and by how much. Conservation incentives and public education programs have proven to be successful but should be used in conjunction with market prices.

Water supply investments should have economic benefits that outweigh their costs. In identifying SWIFT and SWIRFT projects, a rigorous benefit-cost analysis will help Texas avoid some of the pitfalls of western and southwestern water projects. Large water infrastructure projects tend to have costs that exceed their benefits, subsidizing use in one location at the greater expense of others. Reduced instream

Annual Average Unit Costs of Water Management Strategy Categories, 2012 State Water Plan

Source: Texas Water Development Board



flows and/or reduced groundwater levels should be on the cost side of the ledger during the benefit-cost analysis of a large infrastructure project.

The total capital costs for meeting Texas' water supply and infrastructure needs are estimated at $231 billion, including the $53.1 billion required to implement the 2012 State Water Plan. With respect to the $53.1 billion, the state legislature has determined that $26.9 billion in financial assistance will be needed to fund the strategies in the 2012 plan, leaving $26.2 billion in funding to be obtained from other sources.

As municipalities and communities are challenged to find ways to fund projects, water resource economics can play a role in developing sound management decisions. Opportunities include the following: 1) assessing user willingness and ability to pay for new projects; 2) developing new technologies for municipal and agricultural water use; 3) assistance in water market development; 4) multidisciplinary modeling and evaluation; 5) economic, policy, and institutional analyses; and 6) the application of Integrated Water Resource Management (IWRM) methods, the approach internationally accepted as the way forward for efficient, equitable, and sustainable development and management of the world's limited water resources.

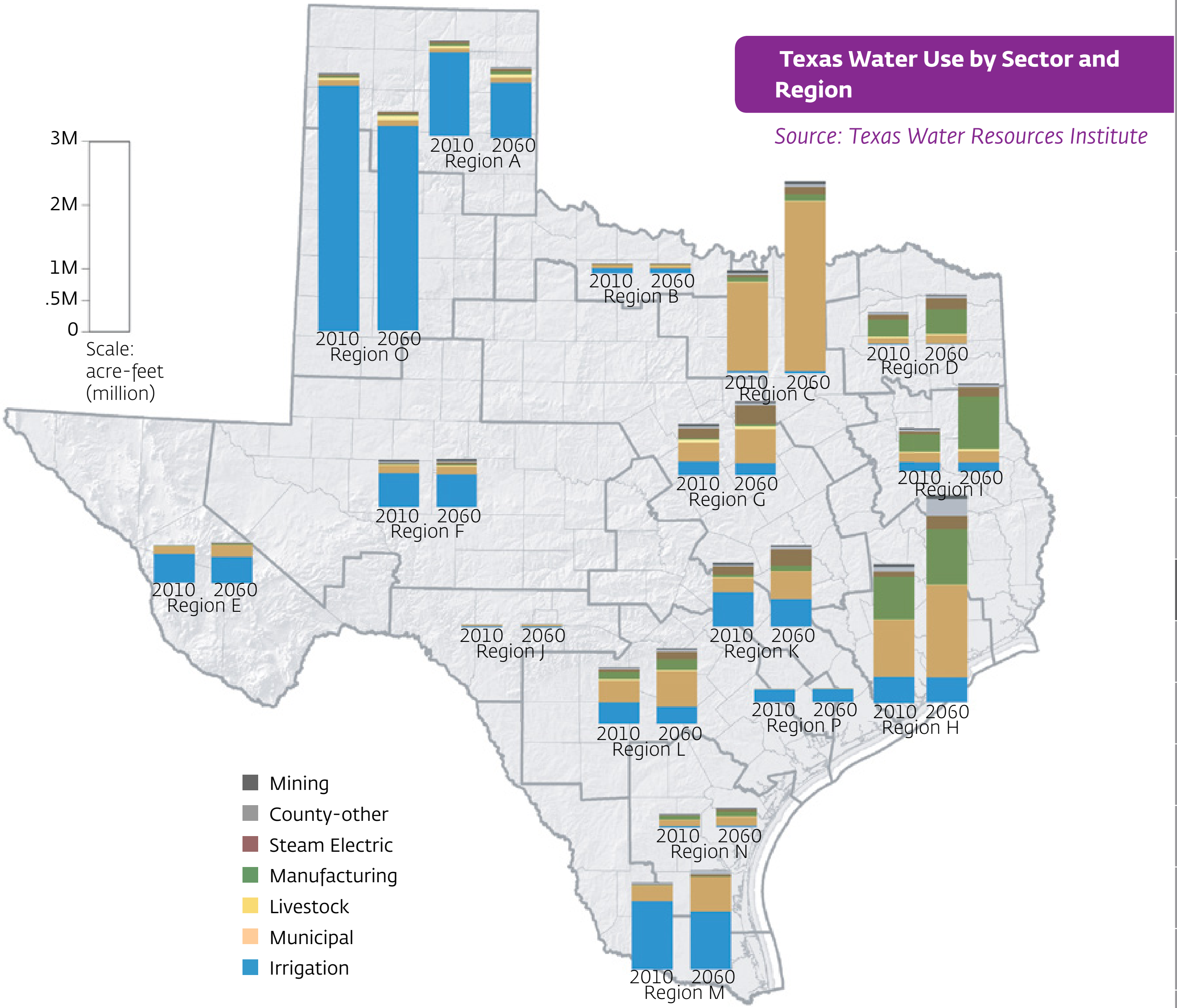
"Large water infrastructure projects tend to have costs that exceed their benefits, subsidizing use in one location at the greater expense of others."

Agricultural Water Requirements and Conservation Technologies

Jay Bragg
Associate Director
Commodity and Regulatory Activities
Texas Farm Bureau

In addition to serving as a liaison between farmers and ranchers and state and federal agencies, Jay Bragg educates agency staff on farm and ranch practices, assesses the possible impacts of proposed rules and regulations, and communicates those impacts back to Farm Bureau members and staff on matters related to air quality, water quality, and water planning as well as a host of other issues ranging from food safety to farm labor.

"Over the past decade, Texas farmers have invested hundreds of millions of dollars to improve irrigation efficiencies."



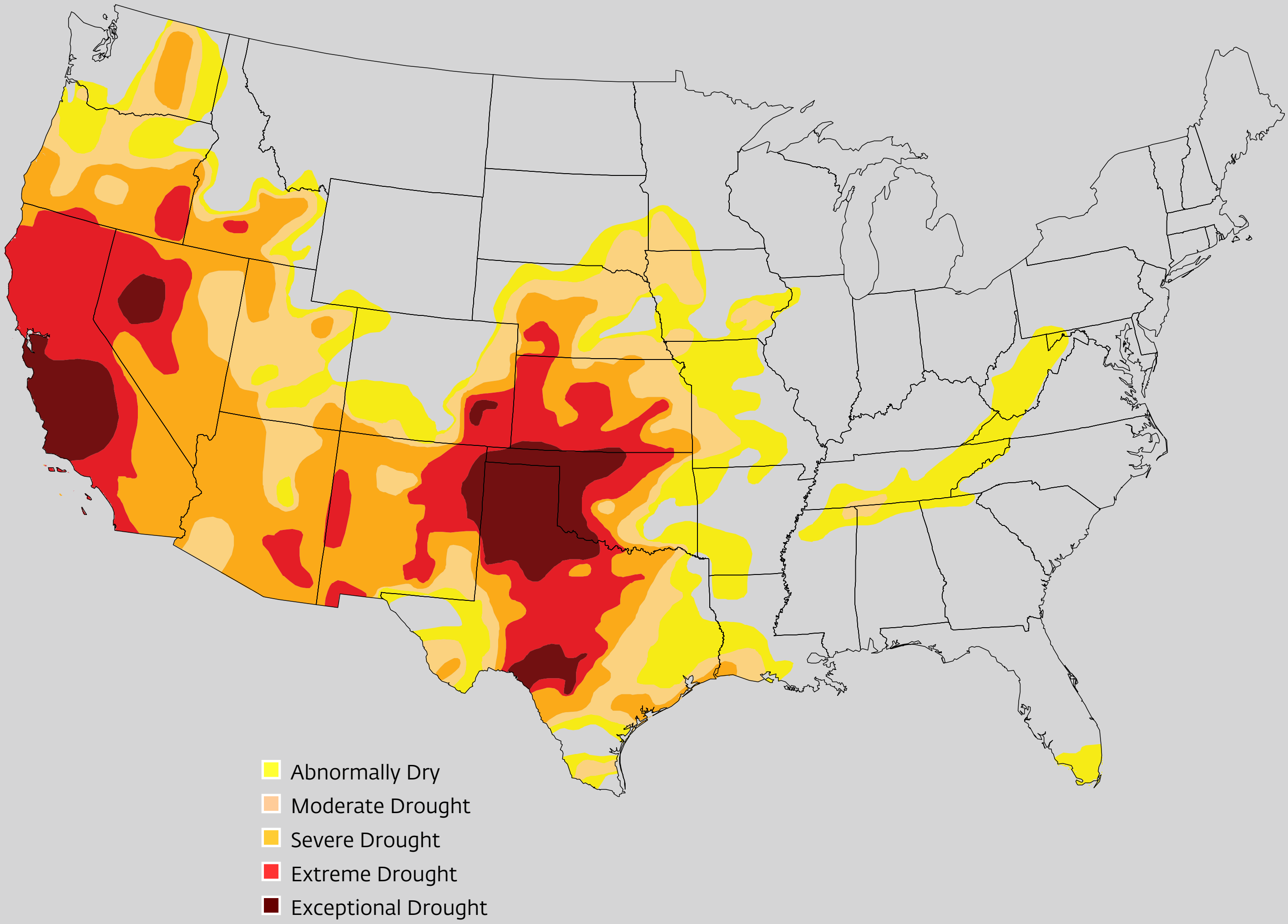
Irrigation accounts for 40 percent of the total value of crops in the U.S. It helps provide stability in production, preventing total losses during a drought. Irrigation can double or triple crop yields and allows crops to be grown where they otherwise could not.

Agricultural irrigation accounts for roughly 56 percent of total water use in Texas, and of that total, 86 percent comes from groundwater, 11.6 percent from surface water, and 2.4 percent from a combination of surface and groundwater. Today Texas farmers use the same amount of water for irrigation as in the 1970s, yet produce an average of 62 percent more in commodities on fewer acres.

Over the past decade, Texas farmers have invested hundreds

"Today Texas farmers use the same amount of water for irrigation as in the 1970s, yet produce an average of 62 percent more in commodities on fewer acres."

U.S. Drought Monitor, May 13, 2014



of millions of dollars to improve irrigation efficiencies. Roughly 80 percent of all irrigated acres in Texas now utilizes center pivot irrigation systems as compared to less than 40 percent in 1990, improving efficiency from 60 to 95 percent. In areas where pivot irrigation isn't feasible due to geography or canal systems, precision laser leveling, irrigation scheduling, and other new techniques have greatly improved on-farm efficiencies in furrow or flood irrigation systems. Drip, subsurface drip, or trickle irrigation systems are 98 percent efficient, but in most cases are cost prohibitive, rendering this method practical only for higher value crops or in areas where pumping costs are extremely high.

By 2060, Texas is projected to add more than 20 million new citizens. During the same time period, the population of the U.S. will grow by 100–200 million, and the world by 2 billion, exceeding a total global population of 10 billion. In order to meet global demands, food production must increase by more than 50 percent in this time frame. Population growth will compete for productive farmland, resulting in fewer acres to grow crops. Between 1982 and 2007, the U.S. lost 40 million acres of farm and ranch land to development, with Texas losing 1.5 million acres of prime farmland.

The frequency and duration of drought appears to be worsening. Since 2011, the worst 12-month drought on record, conditions have not improved, and 2014 was the driest start to spring on record. This problem is not isolated to Texas, with similar conditions plaguing the Pacific Coast, the Southwest, and parts of the Midwest.

Looking toward the future, farmers are turning to precision farming and irrigation techniques, using advanced technology to track production based on irrigation, fertilizer, and crop selection. Improved crop varieties developed through selective breeding and biotechnology are being introduced to boost yields and improve water efficiency.

Moving forward, better utilization of available acres will be critical. In addition, farmers will need to maintain or increase the number of irrigated acres because of global demands for food, fuel, fiber, and the pressure to increase yields on irrigated lands. At the same time, water scarcity and cost will necessitate reductions in per acre water usage.

"Between 1982 and 2007, the U.S. lost 40 million acres of farm and ranch land to development, with Texas losing 1.5 million acres of prime farmland."

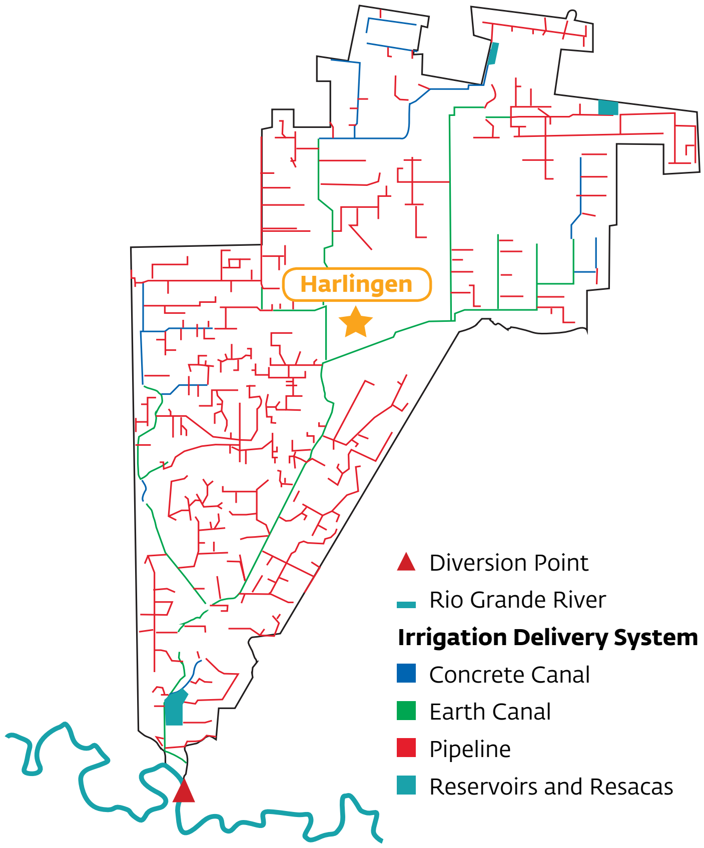
Regional Opportunities and Challenges:

Rio Grande Valley

Wayne Halbert
General Manager
Harlingen Irrigation District

In addition to serving as the general manager of Harlingen Irrigation District since 1989, Wayne Halbert is legislative director of the Texas Irrigation Council, governor's appointee to the Rio Grande Regional Water Authority, and chairman of the Rio Grande Watermaster Advisory Committee. He farms 600 acres of sugarcane, grains, and cotton in the Rangerville area.

"Giving water providers and farmers the tools they need to be good stewards results in significant gains in water conservation."



Finding ways to do more with less water is critical to the future of agriculture. Surface water irrigation providers are challenged to make 100+ year-old facilities more efficient through infrastructure, automation, interconnectivity, and quality management. The resulting system optimization will minimize district water losses and enable precise delivery of irrigation water.

In the Harlingen Irrigation District (HID), the Texas Project for Ag Water Efficiency (Texas AWE) operates a large-scale project demonstrating cost-effective technologies to maximize surface water use efficiency from the point of diversion at the Rio Grande River to on-site consumption by crops. With 40 miles of canals, 200 miles of pipeline, 37 automated gates, and 36 re-lift pump houses, HID's system integrates state-of-the-art irrigation water distribution network control and management with on-farm irrigation technology and management systems. The system is networked by telemetry, controlled by SCADA, and remotely accessible, allowing canal riders to monitor and regulate water levels throughout the district with internet access from smart phones, tablets, and laptops. The system

"...HID's system integrates state-of-the-art irrigation water distribution network control and management with on-farm irrigation technology and management systems."

Benefits of Surge vs. Furrow Irrigation

Crop (Year)	Volume of Water Used/Acre (in acre-inches)		Savings with Surge
	Furrow	Surge	
Sugarcane (2005)	30.68	14.64	54%
Cotton (2005)	19.53	13.48	31%
Seed Corn (2007)	23.95	17.31	28%
Cotton (2010)	18	14	22%

"The Texas AWE program demonstrated the economic advantages and water conservation benefits of surge irrigation over furrow irrigation for sugarcane, cotton, and seed corn."

components were designed and built with off-the-shelf, low-cost technology, and plans are replicable across the state.

The original focus of the Texas AWE project was the implementation of new irrigation technologies and tools, but this is often cost prohibitive for farmers given the low price of water. The focus of the project shifted to providing district operations with advanced tools to better serve the farmers, and to helping farmers improve water use efficiency and get better returns with the technologies they were already using.

The Surge Valve Cooperative was the outcome of one of Texas AWE's on-farm demonstration projects. Surge irrigation, where water is intermittently applied to the irrigation furrow, is a method that has not been widely used, partially due to the cost of installing a surge valve system. The Texas AWE program demonstrated the economic advantages and water conservation benefits of surge irrigation over furrow irrigation for sugarcane, cotton, and seed corn. A subsequent grant from the Bureau of Reclamation provided funds for the Surge Valve Cooperative to give farmers access to system components at highly

Large Pan Flood vs. Narrow Border Flood Irrigation

reduced costs.

Another on-farm demonstration project showed the benefits of narrow border flood vs. large pan flood irrigation, the most common method used for the area's citrus crop. For a minimum investment, a narrow border flood system irrigating directly under the trees was shown to increase cash income by as much as 50 percent, increase yields an average of 18.5 percent, and produce better quality fruit.

As part of the Texas AWE project, a meter calibration facility was built to demonstrate new technologies including various types of metering devices for pipe systems and open-flow channels. The only one of its kind in Texas, this facility is also used for training in meter calibration and open channel irrigation techniques.

Giving water providers and farmers the tools they need to be good stewards results in significant gains in water conservation. Demonstrations and training in innovative technologies enhance delivery systems and promote informed and timely management decisions. The Texas AWE website (www.texasawe.org) provides project data and reports, related news reports, videos, and other resources.

"Demonstrations and training in innovative technologies enhance delivery systems and promote informed and timely management decisions."

Regional Opportunities and Challenges:

High Plains

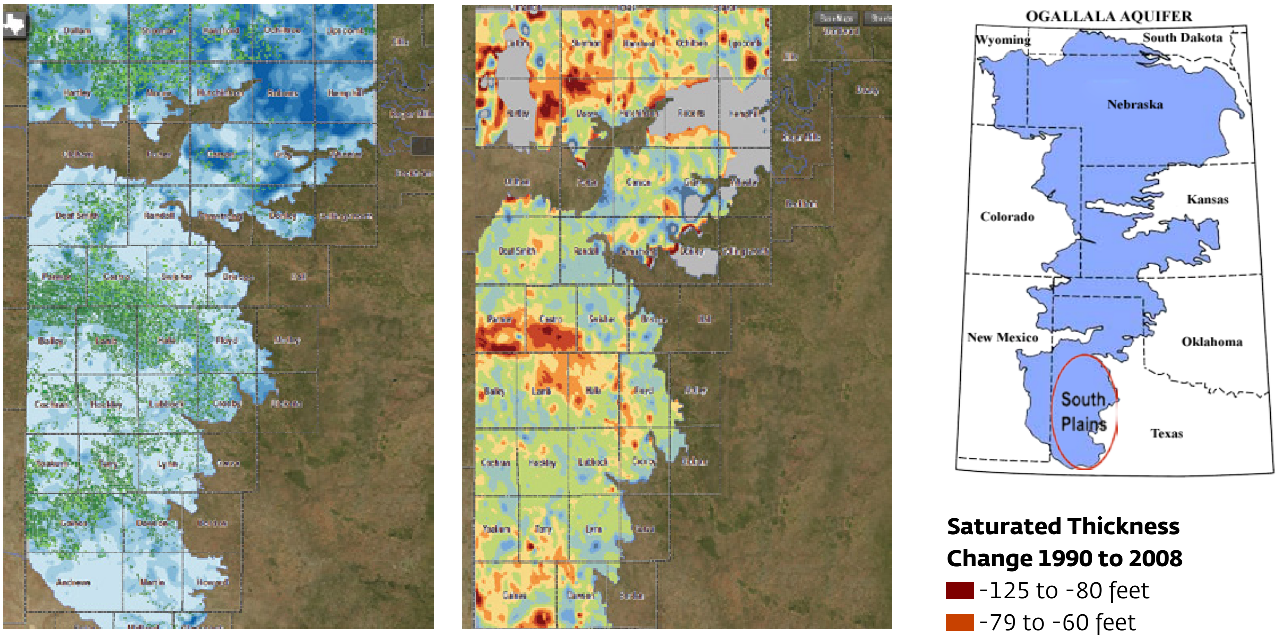
Charles West, Ph.D.
Thornton Distinguished Chair of Plant and Soil Science
Interim Director of the CASNR Water Center
Texas Alliance for Water Conservation
Texas Tech University

Dr. Charles West is the project leader for the Texas Alliance for Water Conservation (TAWC) at Texas Tech University. His research focuses on quantifying the water use of forage crops and pastures as affected by grazing management in an effort to integrate forages into row-crop systems as a way to reduce the use of irrigation water while sustaining profitability.

"Reductions in the saturated thickness across the Ogallala Aquifer pose a threat to future water supplies for all users."

Declines in Saturated Thickness in Areas of the Ogallala Aquifer in the High Plains Region of Texas

Left: green areas show wells tapping the aquifer in 2008. Middle: change in thickness from 1990 to 2008. Right: oval indicates TAWC project area. GIS Maps Courtesy of TTU Center for Geospatial Technology.



Saturated Thickness Change 1990 to 2008

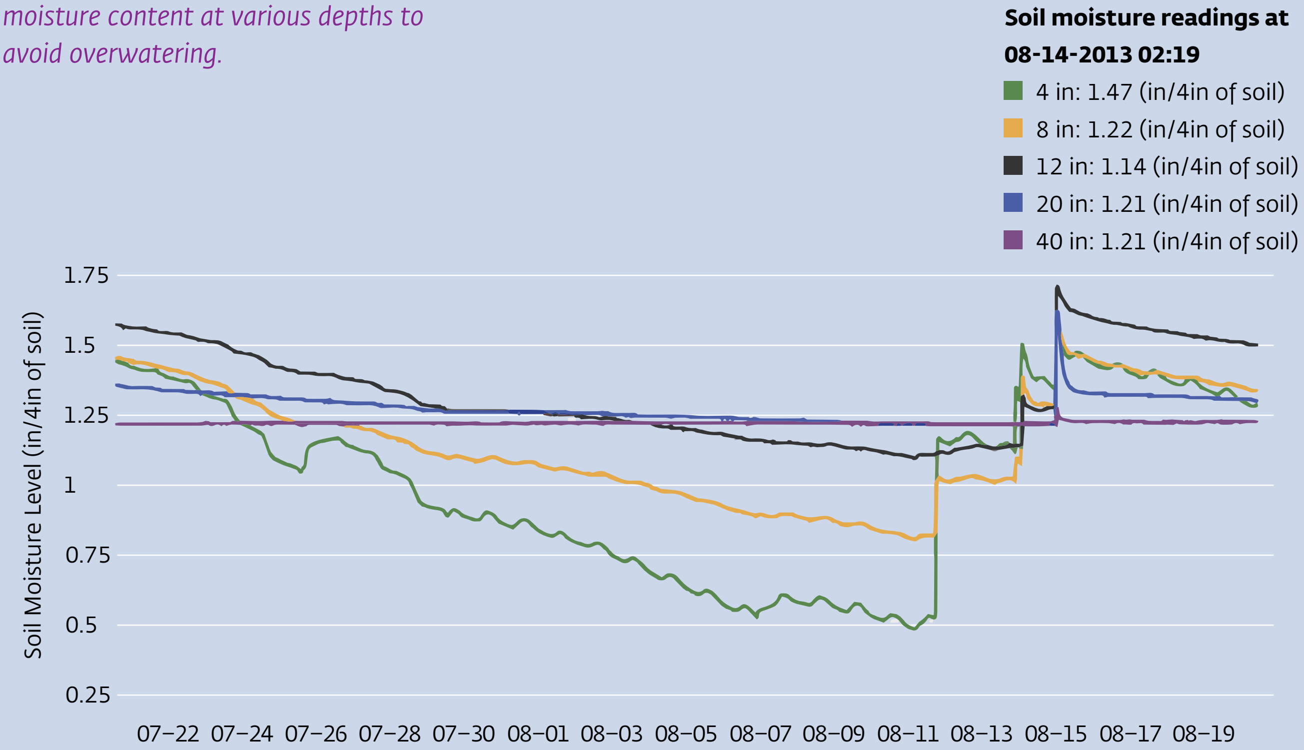
- -125 to -80 feet
- -79 to -60 feet
- -59 to -40 feet
- -39 to -20 feet
- -19 to 0 feet
- 1 to 20 feet

Groundwater from the southern portion of the Ogallala Aquifer is the primary source of water for agricultural irrigation in the High Plains Region of West Texas. Reductions in the saturated thickness across the Ogallala Aquifer pose a threat to future water supplies for all users.

The Texas Alliance for Water Conservation (TAWC) is conducting a project in the High Plains Region to identify effective crop and irrigation systems that reduce water use and enhance profitability. Phase I of the TAWC project (2005–2013) included on-farm demonstrations in 2 southern plains counties using various crops and irrigation methods. The project area consisted of 30 fields covering over 4,700 acres with center pivot, furrow, and subsurface drip irrigation systems represented. Phase II of the project, spanning 2014–2018, adds 8 sites in 6 more counties corresponding to areas with high rates of aquifer decline northwest of Lubbock. At the completion of Phase II, TAWC

Data from Multi-level Soil Moisture Sensors

Multi-level soil moisture sensors demonstrated the importance of tracking moisture content at various depths to avoid overwatering.



will have accumulated data from 14 growing seasons.

The TAWC project collects extensive data on each site related to weather, water use, and soil conditions using different tools such as irrigation monitors and soil capacitance probes, allowing producers to determine what tools work best for them.

The TAWC website (TAWC.us) provides online access to advanced planning tools. The Resource Allocation Analyzer is a strategic planning tool that allows producers to develop scenarios and predict returns for the upcoming growing season by matching crops with available water. The Irrigation Scheduler, developed specifically for the High Plains Region, is a tactical, in-season planning tool used to track and plan daily and weekly water use with data on soil water, crop water demand, and crop water use based on an evapotranspiration model.

Barriers to adoption of the tools and techniques demonstrated include prohibitive implementation costs and the time investment to learn complex new technologies. The most influential factor in a producer's decision to

"Barriers to adoption of the tools and techniques demonstrated include prohibitive implementation costs and the time investment to learn complex new technologies."

make changes is knowing other producers who have been successful. The role of crop consultants in data acquisition and advising producers is becoming more important with the adoption of new technologies.

In addition to the online support tools provided to producers through the website, Phase I of the TAWC project established best management practices using more efficient equipment and methods to reduce evaporative loss. Expensive field-testing of emerging technologies, including soil water sensors and irrigation types, delivers valuable information for producers, and the transmission of data via radio telemetry provides easy access by computer, tablet, or smart phone. Thorough economic evaluations are conducted on both the site and regional levels to document inputs and returns. Outreach to producers and the public includes talks at meetings, informational booths at conferences, radio interviews of project participants, and in-field demonstrations of crop water management.

In Phase II, in addition to expanding producer sites and enhancing online tools, intensive crop consultant workshops will be conducted. Another goal for the project is to demonstrate how TAWC can be a model for use across Texas and surrounding semi-arid regions.

Regional Opportunities and Challenges:

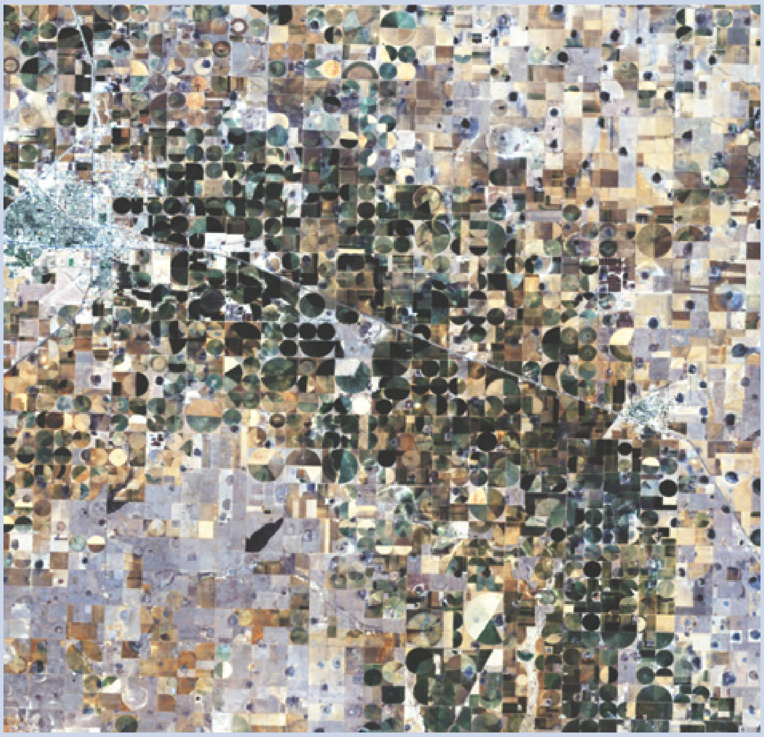
Advanced Irrigation Technologies

Stephan Maas, Ph.D.
Professor of Agricultural Microclimatology with a joint appointment with Texas A&M AgriLife Research
Texas Tech University

Dr. Stephan Maas specializes in the interactions of crop plants with their environment. His research focuses on environmental effects on crop growth, crop simulation modeling, and agricultural applications of remote sensing.

"In order to maximize the adoption of objective irrigation scheduling methods, field-specific tools that are easy to use and available at little or no cost are needed."

Landsat Satellite Image from TAWC Project Area



Commercial irrigation monitoring tools allow increased system efficiency and avoid overwatering, but the required investment can be prohibitive for producers. In order to maximize the adoption of objective irrigation scheduling methods, field-specific tools that are easy to use and available at little or no cost are needed.

The most common freely available irrigation scheduling tools are based on the **standard crop coefficient** approach, where a crop's daily water use (WU) is estimated by multiplying a value for reference evapotranspiration (ET_0) derived from weather data by an empirically determined crop coefficient (K_c).

Daily WU = ET_0 x K_c

A number of operational versions of this irrigation scheduling tool are available to producers and crop consultants through Internet websites and smart phone applications. But standard crop coefficients are designed to estimate WU under "standard conditions" with no limitations to growth or evapotranspiration, and this method is ineffective in determining how much water the crops in a particular field are actually using.

The Texas Alliance of Water Conservation (TAWC) is developing a field-specific irrigation tool based on the **spectral crop coefficient** approach using data from satellite observations to evaluate ground cover and soil moisture.

Satellite Remote Sensing Images Illustrating Soil Moisture Levels in TAWC Project Area

Top: green shows higher moisture levels in irrigated fields in August. Bottom: same area showing reduction in moisture levels after irrigation systems are shut down.

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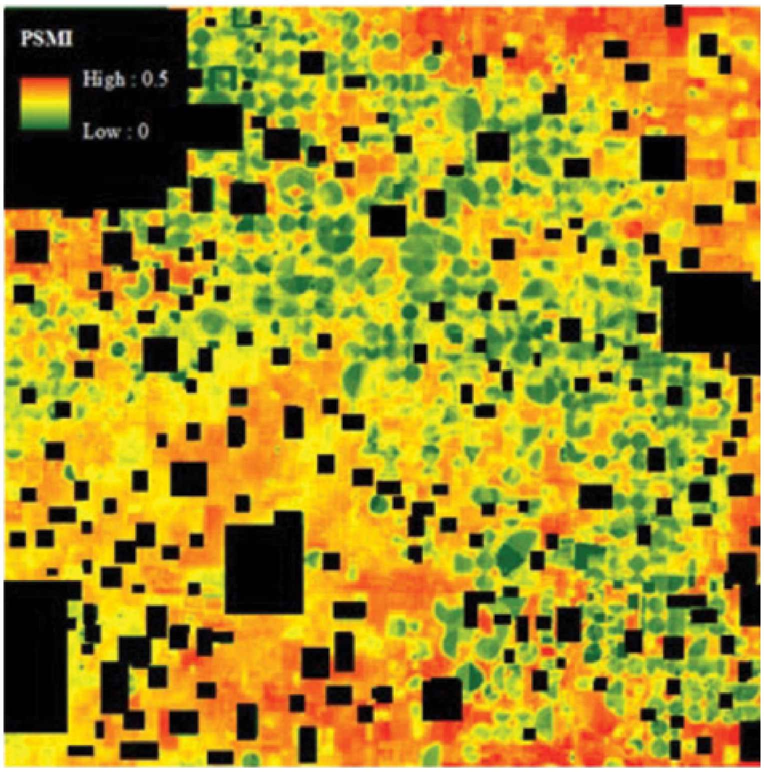

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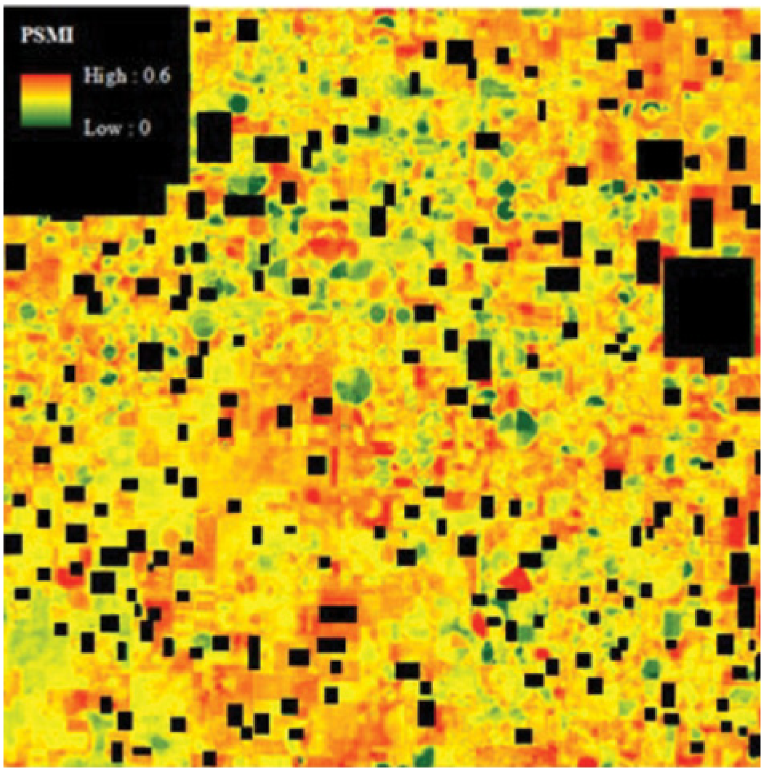


Daily WU = K_{sp} x PET_{fc} x F_{stress}

K_{sp} is the spectral crop coefficient (value of 0–1) equivalent to the vegetation ground cover and can be estimated from readily available multispectral remote sensing imagery. PET_{fc} is the potential evapotranspiration rate calculated from weather data obtained from standard observing stations, including air temperature, humidity, solar irradiance, and wind speed. F_{stress} is a stress factor valued from 0–1.

Satellite imaging information covers the entire U.S. and other parts of the world, has adequate spatial resolution to see individual fields, and is available at no cost the day after it is acquired. The development of this tool holds great potential for enhancing the adoption of objective irrigation scheduling methods to conserve agricultural water resources.

Many irrigation scheduling tools also keep track of soil moisture using a simple soil moisture budget.

SW_{today} = $SW_{yesterday}$ - ET + Rain + Irrigation.

Soil moisture can also be estimated using satellite remote sensing image data in the red, near-infrared, and thermal infrared spectral bands. Texas Tech University has developed a new technique called the Perpendicular Soil Moisture Index which is highly correlated with the soil moisture in a field.

The development of tools based on satellite remote sensing data will provide producers and crop consultants with affordable options for adopting objective, field-specific irrigation scheduling methods to reduce over-irrigation and conserve agricultural water resources.

"The development of tools based on satellite remote sensing data will provide producers and crop consultants with affordable options for adopting objective, field-specific irrigation scheduling methods to reduce over-irrigation and conserve agricultural water resources."

Industrial, Commercial & Institutional Opportunities

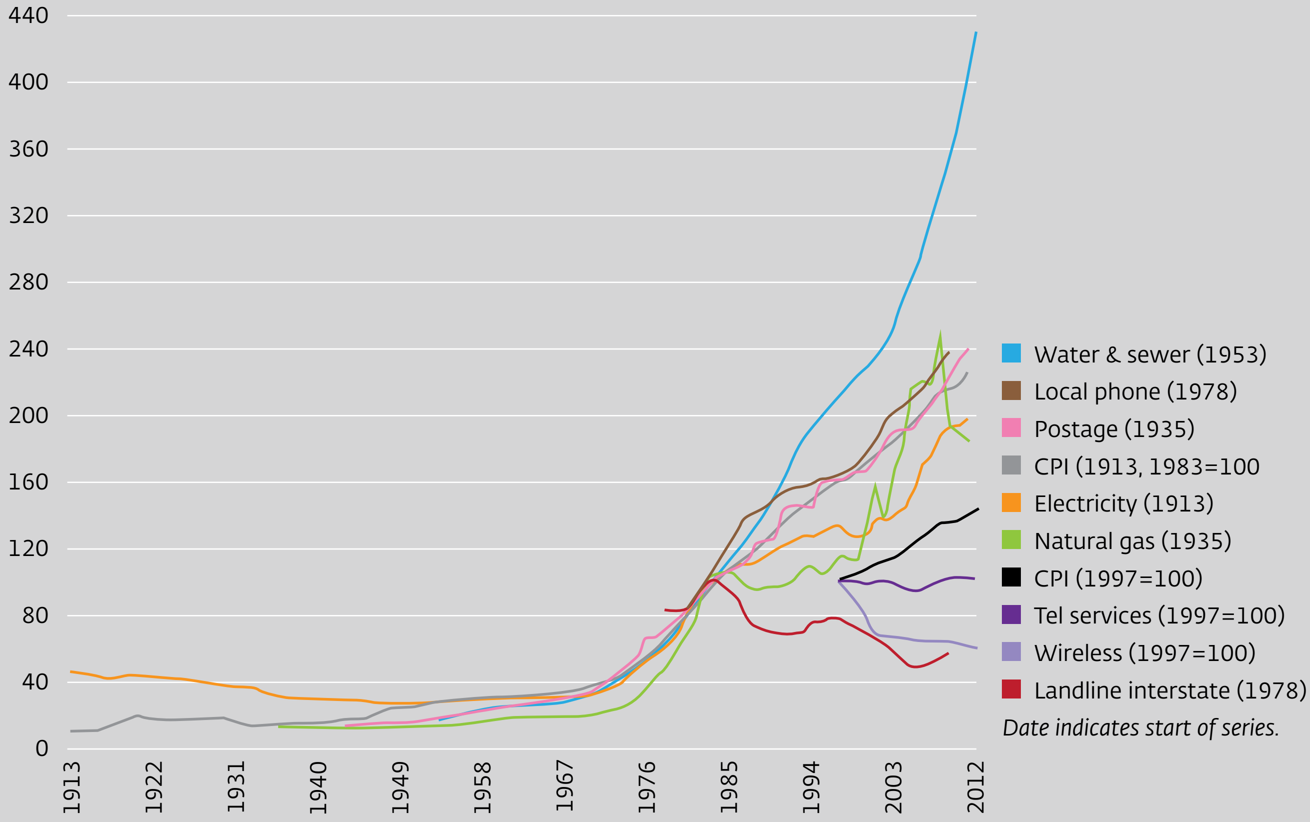
H.W. (Bill) Hoffman, P.E.
Senior Technical Adviser
Water Management, Inc.

Bill Hoffman is the former Assistant Director of Planning for the Texas Water Development Board and has authored a number of publications, papers, and chapters in books on water conservation. He has over 45 years of experience in matters related to water use and conservation.

"On the horizon, the life cycle of much of the nation's large water pipe system is coming to an end, requiring substantial investments to replace aging infrastructure."

Long-term Trends in Consumer Price Index for Utilities

*Source: Institute of Public Utilities, Michigan State University**



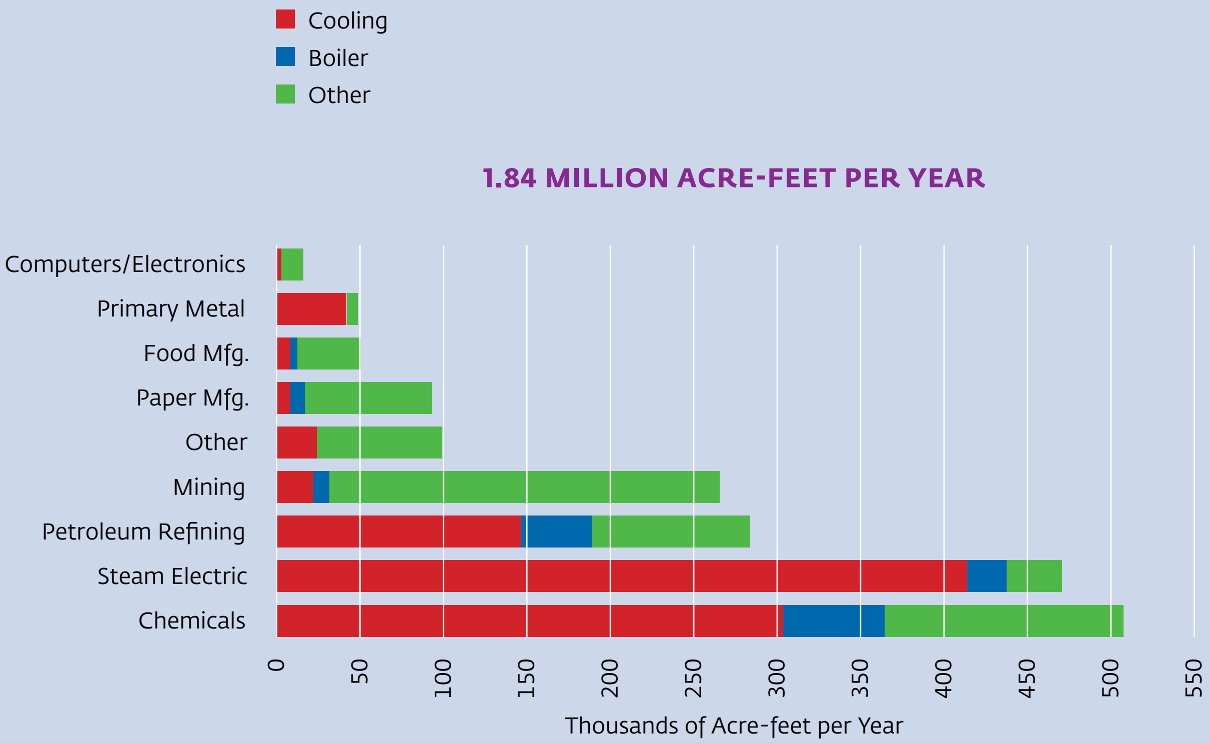
The price of water and wastewater services is growing much faster than the price of other utilities. Even in areas where water supply is plentiful, related costs such as energy, treatment, solid waste disposal, capital equipment, and labor are driving prices upward. On the horizon, the life cycle of much of the nation's large water pipe system is coming to an end, requiring substantial investments to replace aging infrastructure.

Overall, industrial, commercial, and institutional (ICI) applications use approximately 55 percent of non-agricultural water in Texas. Although a significant portion of ICI water is self-supplied, about half comes from municipal systems. With rising costs and the growing emphasis on sustainability, it is important

*http://ipu.msu.edu/research/pdfs/IPU%20Consumer%20Price%20Index%20for%20Utilities%202013%20(2014).pdf

Industrial Water Use in Texas: 2011

Source: Texas Water Development Board



"Although cooling towers provide significant savings in energy costs, they will become less cost-effective as water rates increase."

"More research and education is needed in the area of urban and industrial water use and conservation beyond landscape irrigation."

to look for opportunities to improve ICI water use efficiency.

Initiating conservation measures in areas such as outdoor water use and system leaks will result in substantial water savings. A recent study by the Texas Water Development Board (TWDB) found that between 2004 and 2008, outdoor residential use averaged 31 percent of total residential water use, ranging from a low of 14 percent to a high of 62 percent. The 2009 Texas Water Development Board study of distribution system leak loss found that on average, leaks account for 14 percent of the water distributed by Texas cities.

Cooling towers used for air conditioning, manufacturing, and electrical power generation use large volumes of water in the ICI sector. Although cooling towers provide significant savings in energy costs, they will become less cost-effective as water rates increase.

Water conservation initiatives in the ICI sector include on-site sourcing and reuse applications such as rainwater and stormwater harvesting, wastewater and gray water systems, and reuse of air conditioner condensate, swimming pool backwash, foundation drain water, and reject water from reverse osmosis and nanofiltration processes. The implementation of these technologies will require updating current Texas gray water rules that do not address anything beyond gray water.

Texas is a leader in water conservation initiatives, including new municipal water use reporting requirements, financial aid programs, and new codes and standards. Texas is also a national leader in rainwater harvesting. From a research and educational standpoint, much of the focus is on landscape and agricultural conservation. More research and education are needed in the areas of urban and industrial water use and conservation beyond landscape irrigation.

Panel on

Sector Based Use and Conservation

UNCONVENTIONALS AND WATER USE IN TEXAS

Jean-Philippe Nicot, Ph.D.
Research Scientist
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Dr. JP Nicot's recent research efforts include the intersection of water resources with hydraulic fracturing, carbon storage, and nuclear waste disposal.

UNCONVENTIONAL OIL AND GAS WATER RECYCLING AND REUSE

Todd Langford
Senior Sales Professional
GE Power & Water
Water & Process Technologies

Todd Langford's focus is on business development for water issues surrounding the unconventional oil and gas market.

POWER GENERATION

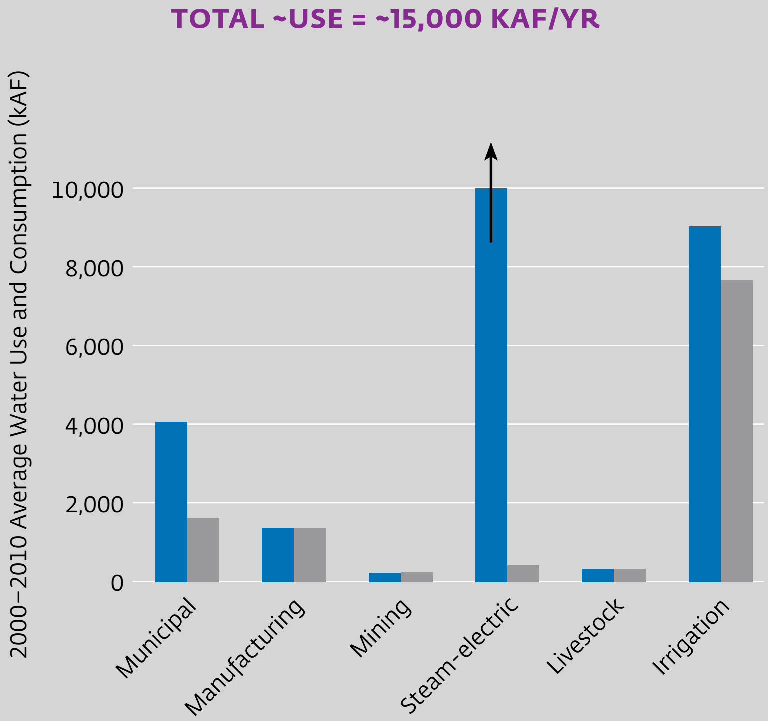
Carey King, Ph.D.
Assistant Director
Energy Institute
The University of Texas at Austin

Dr. Carey King performs interdisciplinary research related to energy systems' interactions within the economy and environment.

THE PETROCHEMICAL INDUSTRY

Tim Finley
Global Water Technology Leader
The Dow Chemical Company

Tim Finley leads technical aspects of water rights, water scouring strategy, and water conservation efforts at Dow's Freeport site.



Average Annual Water Use vs. Consumption by Sector: 2001–2010

Source: Bureau of Economic Geology, UT Austin

Use
Consumption

2011 Mining consumption

Oil and Gas =~120 kAF water use (HF, drilling, waterflooding)

HF =~81.5 kAF water use

HF =~65 kAF water consumption

All other mining uses =~100 kAF

Total consumption =~190 kAF

UNCONVENTIONALS AND WATER USE IN TEXAS

The shale revolution started in Texas in the 1990s, and the state accounts for a significant portion of the nation's oil and gas production from shales and tight formations using hydraulic fracturing (HF). The amount of water used by the oil and gas industry has continued to increase but has also become more diversified over time, introducing the use of brackish water and recycling in varying amounts across the state.

Water use by the mining sector accounts for about 0.5 percent of the state's total, and oil and gas production accounts for about 60 percent of the water used by the mining sector. Water used (vs. consumed) in HF operations in 2013 has been estimated at approximately 100,000 acre-feet. Although HF operations account for a small fraction of the total water use statewide, the percentages are significantly higher in sparsely populated counties.

Opportunities for reducing the use of freshwater in HF operations include increasing the use of brackish groundwater, the development of less water-intensive technologies and more salt-tolerant additives, and the reuse/recyling of conventional produced water or flowback/produced water.

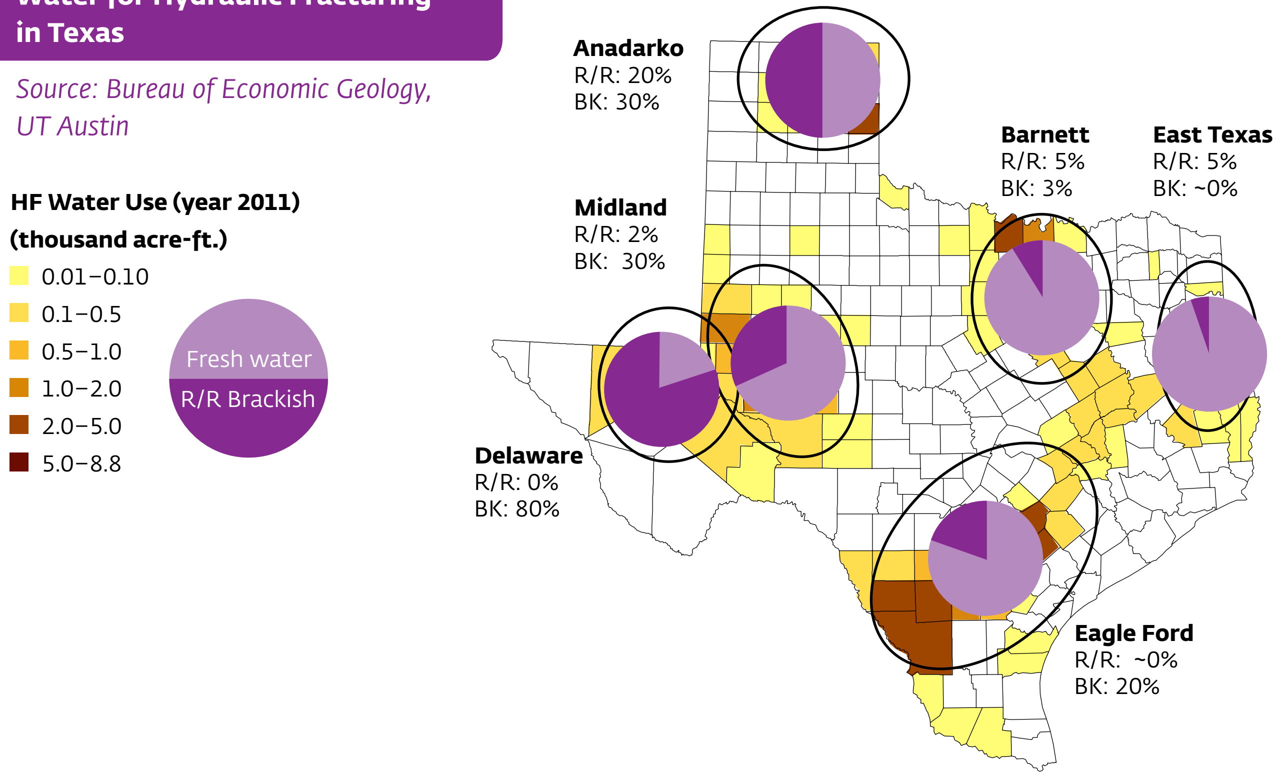
Brackish aquifers are becoming an important source of water for HF operations, particularly in areas of the state where freshwater is scarce. Access to brackish groundwater supplies can be expensive, as they are usually deeper than freshwater supplies, and in many cases the well yields are not as high. Unlike freshwater, brackish water resources are not

"Water use by the mining sector accounts for about 0.5 percent of the state's total, and oil and gas production accounts for about 60 percent of the water used by the mining sector."

Reuse, Recycling, and Brackish Water for Hydraulic Fracturing in Texas

Source: Bureau of Economic Geology, UT Austin

FRACTION FROM RECYCLING/REUSE (R/R) AND BRACKISH WATER (BK) *Based on ~30% of water use*



"As freshwater supplies decline, the HF industry will be in competition with other sectors, including municipal use, for brackish groundwater resources."

yet well understood, and research is ongoing to determine how much will be available and the long-term impacts of its use. As freshwater supplies decline, the HF industry will be in competition with other sectors, including municipal use, for brackish groundwater resources.

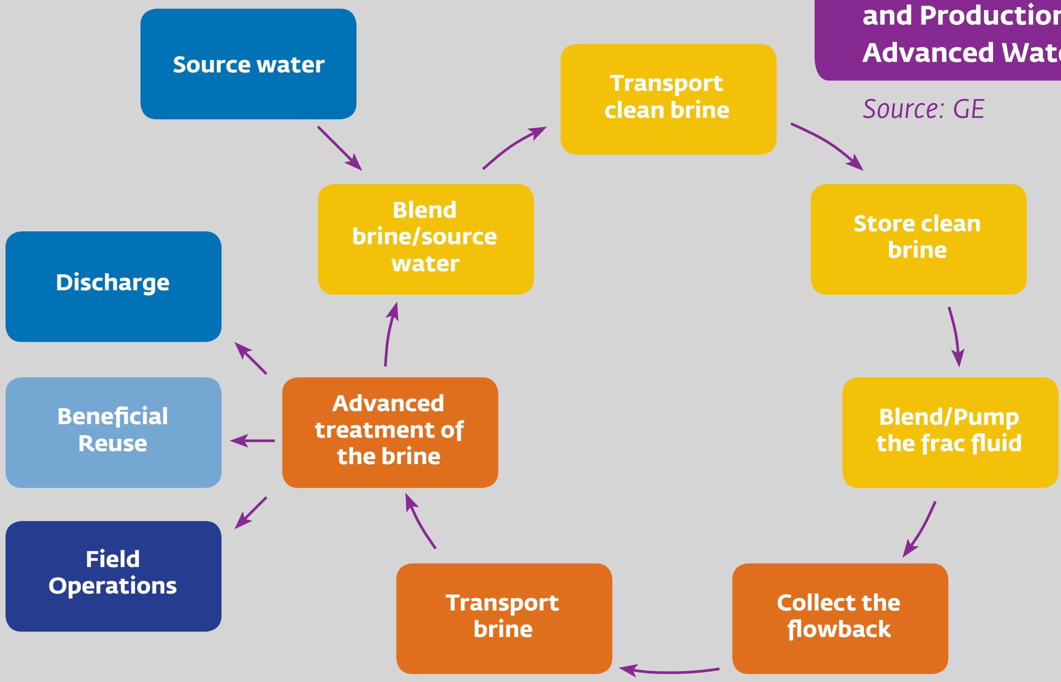
The least expensive way to dispose of flowback and produced water is through injection wells, but the growing scarcity of water will increase incentives for reuse in the future. The overall rate of reuse and recycling across the state was less than 5 percent in 2011, but this varies by area and is based on the volumes, salinity, and contamination levels of flowback and produced water. Flowback for shale formations is usually 20–30 percent of the injected amount with rates approaching or higher than 100 percent in tight formations.

UNCONVENTIONAL OIL AND GAS WATER RECYCLING AND REUSE

On a global scale, unconventional oil and gas development is one of the mega trends impacting localized water scarcity and energy demand/supply discussions. The historical cost of water management for HF includes the costs of source water, transportation and storage at the HF site, blending it to produce HF fluid, using it in the HF process, and the collection, transportation, and ultimate disposal of produced

Hydraulic Fracturing Drilling and Production Life Cycle with Advanced Water Treatment

Source: GE



water. The oil and gas industry's primary needs related to water sustainability are cost-effective reuse technologies, resource recovery, and viable alternative non-potable sources for HF water.

Technology exists to treat flowback and produced water for reuse either directly or by blending it with fresh water, thereby reducing the amount of new source water needed for future HF jobs. Further, advanced treatment options are available to capture byproducts that can be converted to useable forms such as valuable salts, or even to treat produced water to a standard where it can be beneficially reused in other applications.

Water-related risks to the continued growth of unconventional oil and gas production vary by region but could include sourcing the water needed for HF operations, growing concerns about seismic activity possibly associated with salt water disposal wells, and storage and transportation of produced water.

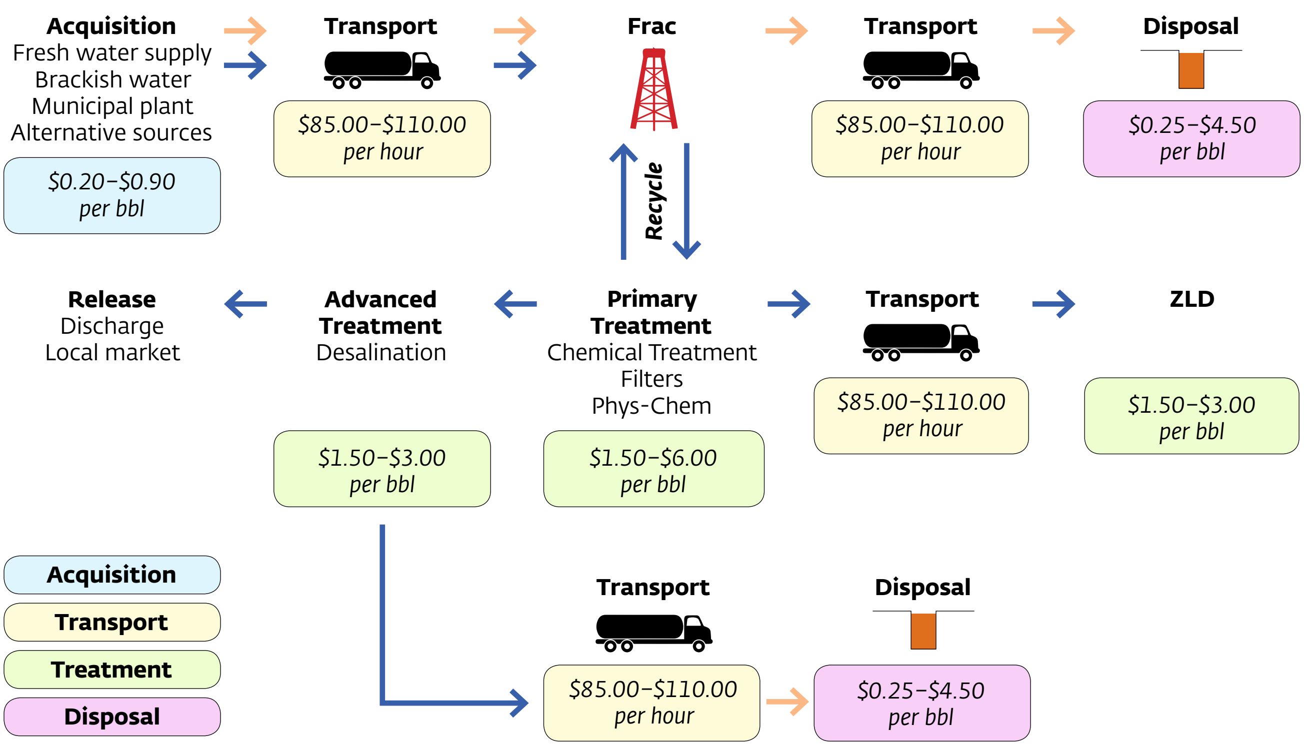
With current technologies, treating water for reuse and recycling in the HF process can raise costs in some areas while reducing costs in others. Sourced water can range from $.20–$.90 per barrel, and on the high end the total cost to bring flowback and produced water to zero liquid discharge can reach up to $9.00 per barrel of water treated.

Disposal wells currently offer the most cost-effective way to manage produced water, but from a sustainability perspective, this water is essentially removed from the

"The oil and gas industry's primary needs related to water sustainability are cost effective reuse technologies, resource recovery, and viable alternative non-potable sources for HF water."

Economics of Water Reuse and Recycling in Hydraulic Fracturing

Source: GE



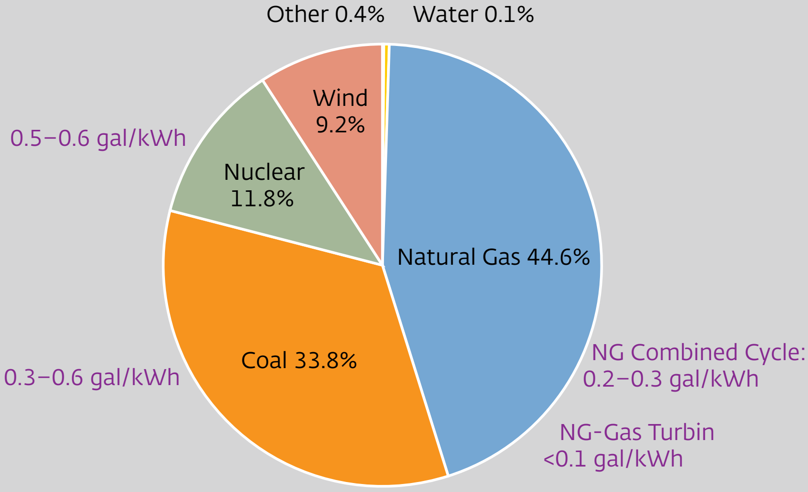
"Disposal wells currently offer the most cost-effective way to manage the produced water, but from a sustainability perspective, this water is essentially removed from the water cycle."

water cycle. Exploration and production companies are now, more than ever, exploring options to minimize their water footprint. Incentives to reuse and recycle should be considered to encourage producers to implement available technologies. In Pennsylvania, around 89 percent of the water produced in the HF process is reused or recycled. This is accomplished primarily because the cost to treat and reuse produced water is economically viable, made possible by technology advancements that allow for use of produced water with higher salinity levels in the HF process.

There is no single silver bullet technology to resolve all the issues surrounding water use, reuse, and recycling in unconventional oil and gas operations. Each project is unique, as the quantity and quality of available and produced water vary by location along with the associated economics. Developing technologies, the rising cost of water, and regulators working with industry will determine the future of reuse and recycling in the unconventional oil and gas sector.

POWER GENERATION

Power generation plants in Texas consume less than 4 percent of the state's water for cooling steam cycles in nuclear, coal,



Water Cooling Use for Texas Power Generation: 2012

Source: Energy Institute, UT Austin

430 terawatt-hours
Cooling Water Consumption:
~0.4–0.5 million acre-ft/yr
(<4% Texas total consumption per TWDB demand)

Chart percentages based on ERCOT generation

and natural gas plants. Combined-cycle technology in natural gas plants results in lower water use because about two-thirds of the power generated comes from gas turbines. Texas also has two dry cooled combined-cycle power plants.

Water consumption by Texas power plants came under scrutiny during the 2011 drought when water rights were being called in the Brazos River Basin. The Texas Commission on Environmental Quality determined that public health and safety concerns justified continuing water access to cities and power plants, effectively overriding the seniority of agricultural water rights.

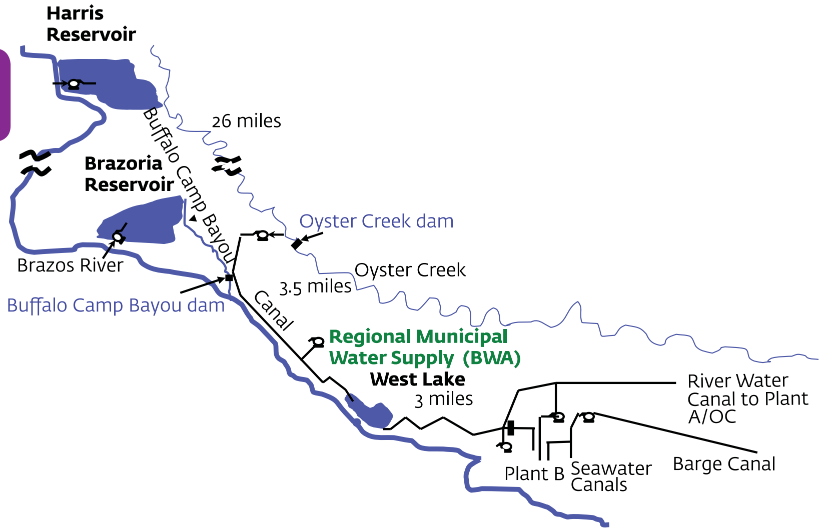
This intervention into the ERCOT market raises questions about the amount of water and electricity needed to ensure public health and safety. The answers to these questions can essentially change some of the dynamics of the ERCOT market:

- Should the electricity needs of commercial and manufacturing operations take priority over agricultural irrigation?
- With the revenue/water ratio for Texas agriculture at $2,000/acre-foot and ERCOT wholesale market sales at $20,000–$40,000/acre-foot, does the decision come down to economics? The industrial sector also generally has a high value of revenue per acre-foot of water consumption compared to agriculture.
- In the future, is Texas going to assure legal access to water for existing power plants in drought conditions?
- Can new thermal power plants assume the same assurance, or do they have to find more expensive water or install dry cooled plant technology?
- Will legacy facilities with water rights have a market advantage in ERCOT?

If Texas has a drought plan but it is not put into effect, it

"If Texas has a drought plan but it is not put into effect, it raises questions about the value and validity of the plan."

Dow Freeport Water Infrastructure



raises questions about the value and validity of the plan. Management of river basins such as the Brazos may need to be less ordered by water rights and consider small water markets that allow the leasing of water rights during drought conditions.

Several competitive new technology applications for power generation, including wind, solar, and dry cooled combined-cycle plants do not consume water. Although it is cost prohibitive to retrofit wet cooled to dry cooled systems, the capital investment required to build dry cooled plants will be justifiable as water gets more expensive and continues to be scarce.

THE PETROCHEMICAL INDUSTRY

Texas has a large number of coastal petrochemical facilities that supply raw materials for downstream product manufacturing nationwide. Dow's Freeport site is the largest petrochemical facility in the Western Hemisphere, with more than 65 production plants on more than 5,000 acres. This site produces in excess of 32 billion pounds of product annually, representing approximately 40 percent of Dow's U.S. production and 20 percent of Dow's global production.

"Through various strategies, including reuse and recycling, Dow achieved a 5–10 percent reduction in water use in the 4th quarter of 2011 followed by another 5–10 percent reduction in 2012."

Dow's Freeport site was established in 1940 and is located at the mouth of the Brazos River. Dow holds relatively senior water rights on the Brazos and owns two off-channel reservoirs that store a limited 45-day reserve of water when full. When natural flow is insufficient, in addition to local storage, Dow relies on contracts with the Brazos River Authority (BRA) for releases of interruptible water and long-term contract supplies from BRA's reservoirs.

Water demand in the Lower Brazos River Basin below the flood gage at Hempstead is approximately 400,000 gallons per minute (gpm). The demand at Dow's intake pumps, which supply local communities and industry, is approximately 100,000 gpm or an estimated 8 percent of the water supply coming out of the Brazos. As with other

Texas river basins over the past decade, available water from the Brazos River has been adversely affected by lack of rainfall, water capture, pumping, and evaporation.

In September of 2011, the majority of Texas was in exceptional drought. Reservoirs across the state were severely depleted, and the only water coming down to Dow's part of the Brazos River was water purchased from BRA reservoirs by Dow, the Gulf Coast Water Authority, and NRG Energy. Due to BRA's prediction that there would be no interruptible/excess water available in 2012 if the drought continued into a second summer, Dow conducted a comprehensive review and assessment of water use on the entire 5,000-acre Freeport site.

Dow's process to develop a long-term strategy was based on the understanding that 1) a secure water supply is essential for business success, and 2) conservation should be viewed as a way to generate new water driven at a price point aligned with the future cost of new water supplies. Through various strategies, including reuse and recycling, Dow achieved a 5–10 percent reduction in water use in the 4th quarter of 2011 followed by another 5–10 percent reduction in 2012. The total estimated permanent demand reduction was 12,000 gpm with additional drought response reductions of 4,200 gpm or 25 million gallons per day. Dow's water conservation efforts were recognized by the Texas Commission on Environmental Quality with a Texas Environmental Excellence Award.

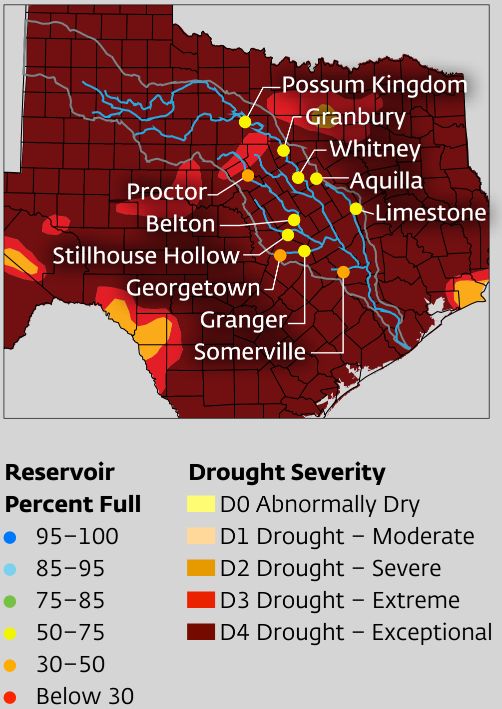
Advanced planning is essential to avoid potential economic consequences of water shortages. It is not uncommon for the lower portion of river basins to experience excess flows at certain times of the year creating a false perception about water stress. Over the past five years, all major Texas river basins have shown evidence of inflow deterioration, and at many locations historically low base flows suggest groundwater depletion may be contributing to the severity of observed effects.

In 2014, water regulators have come close to initiating water rights calls on multiple occasions. Although lower basin flows improve with precipitation, significant rainfall events have primarily occurred nearer to the coast and below major basin reservoirs which are still at or near all-time lows.

In April of 2014, the Texas Commission on Environmental Quality created the office of lower Brazos watermaster to oversee water allocations for the central and lower portions of the Brazos River Basin. Proponents believe this will create transparency and promote a clearer understanding of risk to help drive needed investments in water security. It is also perceived by some as a way to provide the transparency and framework needed to allow market principles to play a more significant role in water allocation.

Brazos River Basin, September 13, 2011

Source: Brazos River Authority



Brazos River in June of 2009 Upstream of Dow's Intake

Opportunities for New Industrial Waters:

Brackish/Salt Water Resources

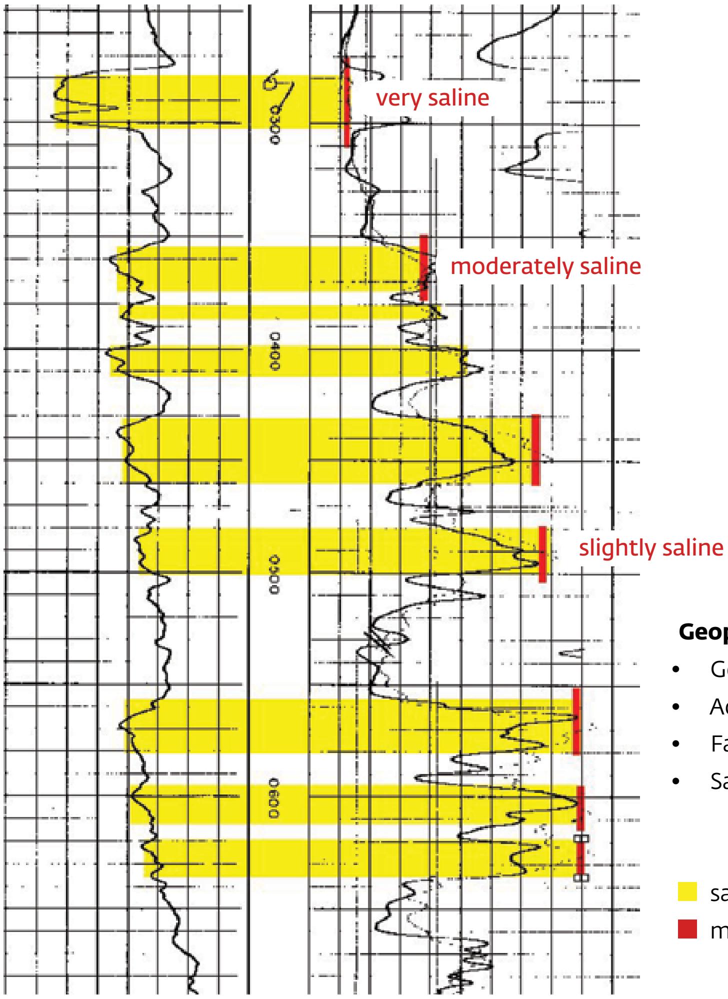
John Meyer, P.G.
Geologist
Texas Water Development Board

John Meyer's work at the Texas Water Development Board focuses on brackish groundwater resources. He is a certified Professional Geoscientist in Texas with over 29 years of experience and B.S. and M.S. degrees in geology from the University of Wyoming.

"Desalination of brackish groundwater accounts for approximately 2 percent of the water management strategies outlined in the 2012 State Water Plan, and some areas of Texas are depending on it as the primary source of new supplies."

Geophysical Well Logs Data Use

Source: Lower Rio Grande Valley BRACS Study, TWDB



Geophysical Well Logs used for:

- Geology (sand, clay, ...depositional environment)
- Aquifer extent (top and bottom depths)
- Fault identification
- Salinity zone (top and bottom depths)

sands

maximum deep resistivity

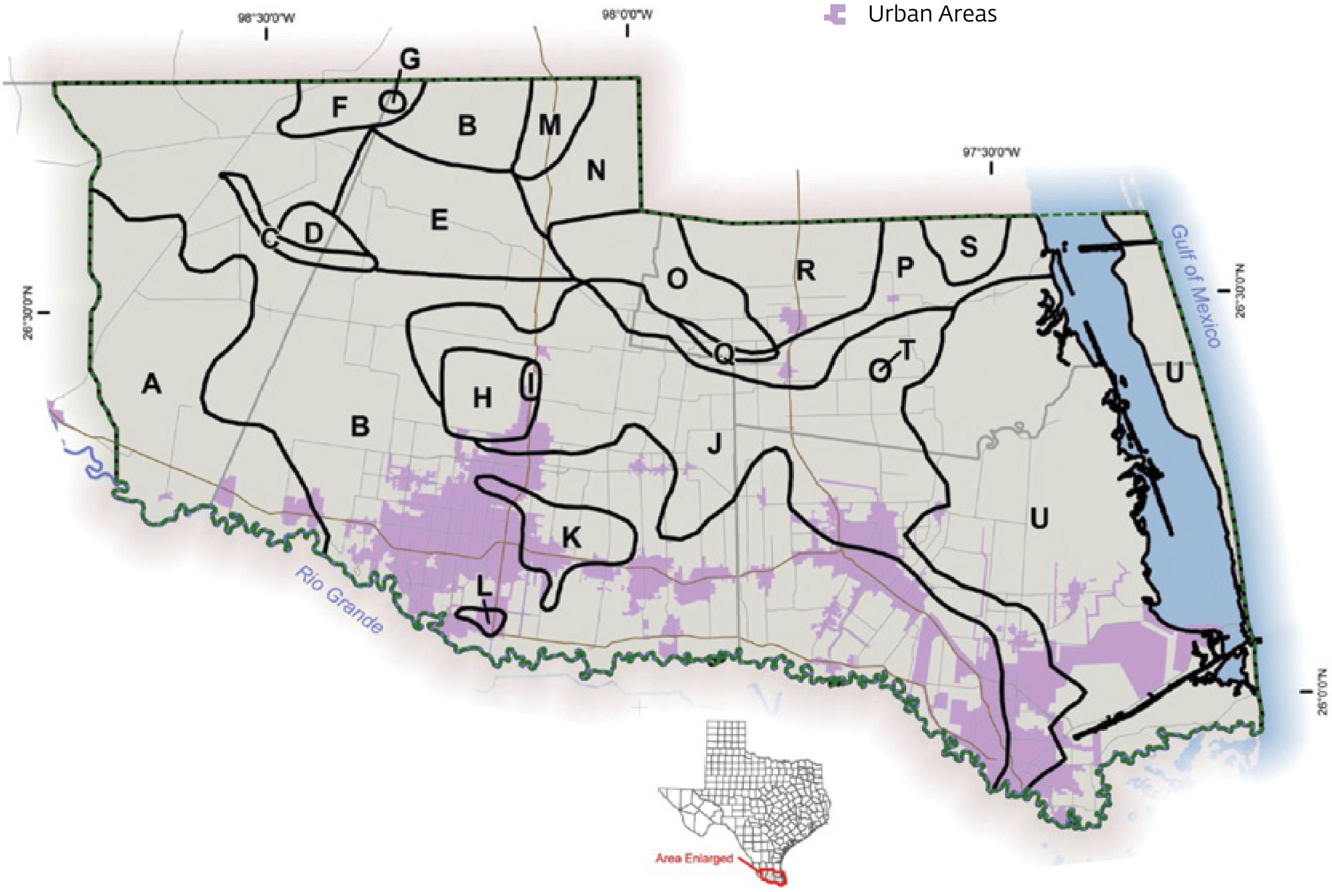
Water salinity ranges from 1,000–35,000 milligrams per liter of total dissolved solids (mg/ltr TDS) with seawater at the upper end of this range. Most of the water from wells drilled in Texas is in the fresh to slightly saline range of 0–3,000 mg/ltr TDS, and there is considerable information available on these resources. The state's brackish groundwater resources with 1,000–10,000 mg/ltr TDS, the zone most cost-effective to treat for municipal use, are estimated at 2.7 billion acre-feet.

Desalination of brackish groundwater accounts for approximately 2 percent of the water management strategies outlined in the 2012 State Water Plan, and some areas of Texas are depending on it as the primary source of new supplies. The Texas Water Development Board's (TWDB) Brackish Resources Aquifer Characterization System (BRACS) conducts multi-county studies in parts of the state interested in desalination for water supply. The resulting data is being used to map and characterize brackish portions of aquifers in order to provide useful information to regional planning groups and other entities.

An 11-county pilot study over the Pecos Valley Aquifer

Salinity Zones in Lower Rio Grande Valley Gulf Coast Aquifer

Source: Lower Rio Grande Valley BRACS Study, TWDB



Groundwater Salinity Classification	Total Dissolved Solids Concentration (units: milligrams per liter)
Fresh	0 to 1,000
Slightly Saline	1,000 to 3,000
Moderately Saline	3,000 to 10,000
Very Saline	10,000 to 35,000
Brine	Greater than 35,000

A	B	C	D	E	F	G	H	I	J
				SS Shallow 2		VS Shallow 1		VS Shallow 3	
		MS Shallow 5		MS Intermediate 1	MS Shallow 4	MS Shallow 4	MS Shallow 2	MS S hallow 2	
	SS Deep	SS Deep		SS Deep	SS Deep	SS Deep	SS Intermediate	SS Intermediate	
MS Deep	MS Deep	MS Deep	MS Deep	MS Deep	MS Deep	MS Deep	MS Deep	MS Deep	MS Deep
VS Deep	VS Deep	VS Deep	VS Deep	VS Deep	VS Deep	VS Deep	VS Deep	VS Deep	VS Deep
BR Deep	BR Deep	BR Deep	BR Deep	BR Deep	BR Deep	BR Deep	BR Deep	BR Deep	BR Deep

"...maps indicating the depth and thickness of various salinity zones can help to identify the most promising areas to develop water resources."

was conducted to test the BRACS methodology. The study used about 5,000 data points evenly distributed between water wells and oil and gas wells to help define the three-dimensional aspects of the aquifer and map out different water quality zones. The results of the Pecos Valley Aquifer study were published in June 2012 as TWDB Report 382. Three more studies will be completed in 2014: on the Gulf Coast Aquifer in the Lower Rio Grande Valley, the Carrizo-Wilcox Aquifer in Central Texas, and the Queen City-Sparta Aquifers in McMullen and Atascosa Counties.

Expanding knowledge of brackish water resources requires extensive data collection and development, and each aquifer will require unique analysis based on data availability and local hydrogeology. The deliverables associated with each study include a peer-reviewed report, geographic information system (GIS) datasets, access to the BRACS database and the database dictionary, and access to all geophysical well logs and water well reports used in the study.

The existing TWDB Groundwater Database includes data on over 138,000 wells and is used to characterize the major/minor aquifers around the state. The BRACS database expands on the current TWDB database, incorporating raw data from the studies into new tables. It contains all of the collected well data and interpretations with hyperlinks to thousands of digital geophysical well logs and water reports, and also provides links to additional databases through key fields.

Where data from water wells typically ends at the base of fresh to slightly saline water zones, the geophysical well logs from BRACS studies are used to interpret water salinity levels at different depths. The Gulf Coast Aquifer study in the Lower Rio Grande Valley identified 21 zones, each with a different salinity profile. With this information, maps indicating the depth and thickness of various salinity zones can be produced to help identify the most promising areas to develop water resources. The detailed characterization of the aquifers produced with this data will also be valuable in supporting aquifer storage and recovery evaluations.

Opportunities for New Industrial Waters:

Upgrading Technologies

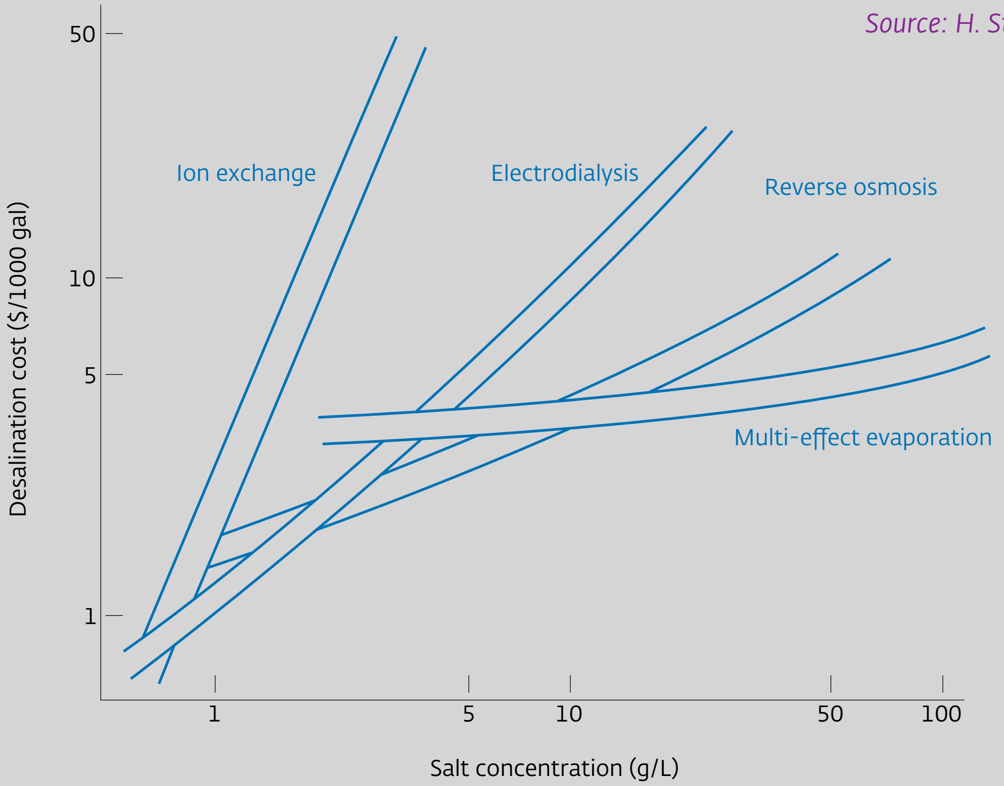
Benny D. Freeman, Ph.D.
Richard B. Curran Centennial Chair in Engineering
Cockrell School of Engineering
The University of Texas at Austin

Dr. Freeman's research group focuses on structure/property correlation development for desalination and gas separation membrane materials. His group also studies reactive barrier packaging materials and new materials for improving fouling resistance and permeation performance of liquid separation membranes.

"Over the past decade, research advancements have significantly reduced the energy costs of desalination."

Comparative Costs of Desalination Technologies at Various Salinity Levels

Source: H. Strathman, Ph.D.: 1991



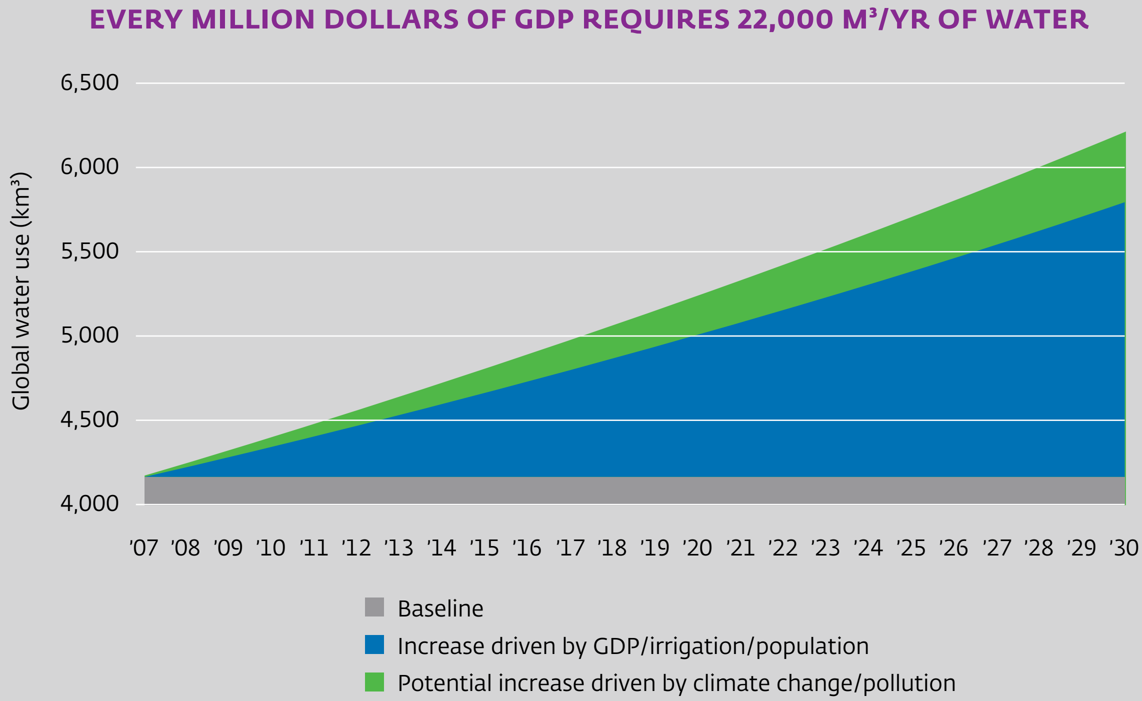
Opportunities for upgrading water include desalination and the removal of organics and particulates. Over the past decade, research advancements have significantly reduced the energy costs of desalination. Reverse osmosis energy requirements are now around 3–4 kilowatt hours per cubic meter (kWh/m³), making it the least expensive method for the desalination of seawater. This technology has been used for many years in large-scale facilities to produce potable water from seawater.

Water salinity levels dictate the technology used for desalination. Ion exchange and electrodialysis are used at the lowest salinity levels, such as for manufacturing ultra-pure water. Reverse osmosis is used in mid-range salinity levels, including brackish groundwater and seawater. At very high salinity levels, where reverse osmosis becomes infeasible due to osmotic water pressure limitations, thermal techniques are the most cost-effective.

Tremendous amounts of energy are required to produce clean water, and conversely, clean water is required to produce electricity. Thermal electric power generation

Drivers for Increased Water Use

Source: Jeff McCutcheon, Ph.D., University of Connecticut School of Engineering



> *"Economic growth is closely tied to increased water use because of he corresponding demand for more electricity."*

represents the largest category of water use in the U.S. Economic growth is closely tied to increased water use because of the corresponding demand for more electricity.

Unconventional oil and gas resources, and shale gas in particular, are now recognized as one of the largest economic drivers in the world. Hydraulic fracturing (HF) and horizontal drilling processes have provided access to immense reserves, and natural gas has become an important fuel for power generation.

The HF process uses vast amounts of water, often in areas with limited supplies. Using brackish groundwater and/or reusing flowback and produced water in the HF process can reduce the demand for freshwater, but these options require the application of water purification membrane technologies.

A major challenge in the use of water purification membranes is fouling, where contaminants accumulate and clog the surface of the filter membranes, resulting in increased operating costs for cleaning and/or replacing membranes as well as higher energy costs. New technologies

Mobile Frackwater Purification Unit

to alter the properties of the membrane surface include using polydopamine, the product of the oxidation of dopamine, which adheres to membrane surfaces rendering them hydrophillic, making them resistant to fouling.

A pilot project in the Barnett Shale area was conducted to compare the performance of modified vs. unmodified membranes in both an ultrafiltration process to remove particulates followed by reverse osmosis. Although the test results verified that modified membranes improve resistance to fouling in the treatment of flowback and produced water, this technology cannot compete with the low cost of injection well disposal. The same technology is being used to desalinate water extracted from brackish aquifers to complement the use of freshwater in the HF process.

This research has generated portable, small-scale desalination systems that are currently under evaluation by the U.S. Bureau of Reclamation for rural applications. New research is focused on exploring dopamine alternatives, other emulsions such as crude oil, other membranes, and the effect of operating conditions on fouling properties.

"This research has generated portable, small-scale desalination systems that are currently under evaluation by the U.S. Bureau of Reclamation for rural applications."

Opportunities for New Industrial Waters:

Industrial Water Reuse

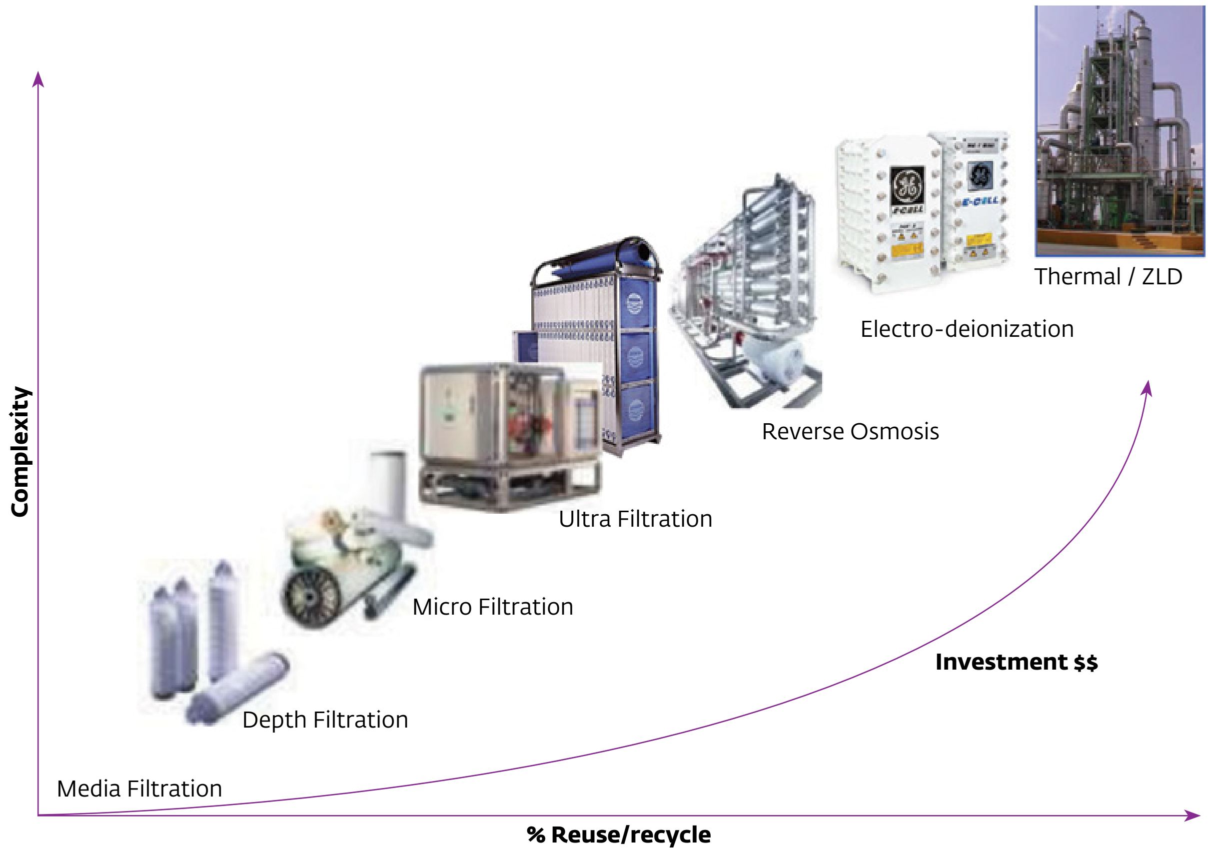
Bob Holt
Corporate Account Executive
GE Power & Water
Water & Process Technologies

Bob Holt has 35 years of experience in developing sustainable integrated water treatment solutions for multiple industries including power, upstream and downstream hydrocarbon processing, chemical processing, biotech, semiconductor, food processing, and mining.

"Key stakeholders in the industrial sector are actively pursuing ways to optimize their water usage and evaluate economically viable and sustainable reuse options."

Water Reuse Technology Spectrum

Source: GE



On a global scale, agriculture accounts for 70 percent of water withdrawals, but in advanced economies, industry leads with 44 percent, and developing countries are moving in this direction. Both municipal and industrial wastewater can be effectively treated for reuse to help augment fresh water supplies and meet demands for irrigation and industrial process water.

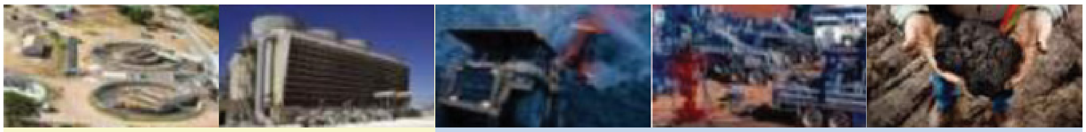
Conventional water treatment technologies are typically used to remove contaminants from industrial and municipal wastewater before discharge into natural water systems. In treating water for reuse or recycling, advanced technology is used to remove particulate, organic, and inorganic constituents prior to beneficial use options including aquifer recharge, direct or indirect potable water production, or process and cooling water. In some applications, the inorganic salts can be converted to useful byproducts and the solid and/or organic content to methane as an alternate energy source.

Water treatment processes can be used as stand-alone technologies or in combination with others, depending on

"Water treatment processes can be used as stand-alone technologies or in combination with others, depending on the end use."

Key Water Reuse Areas

Source: GE



Segment	Muni waste	Cooling Tower	Mines Blowdown	Unconventional Gas	Heavy Oil/ Refineries
Technical challenge	Low	Medium	High	High	High
Customers	Municipal	Utilities	Industrial	Oil & Gas	Oil & Gas
Drivers	Availability	Efficiency	Environmental	Environmental	Environmental

Less challenging ⟷ **More challenging**

Technologies exist to meet the challenge

> *"Municipal water reuse is common due to the proximity of the source water to reuse demand, its predictability, availability, and relative ease of treatment."*

the end use. The technologies in the reuse spectrum come with distinct capital and operational costs that must be evaluated against alternatives to determine their economic feasibility for each application.

Municipal water reuse is common due to the proximity of the source water to reuse demand, its predictability, availability, and relative ease of treatment. The majority of municipal water reused by industry is for irrigation, cooling water makeup in power generation, and oil refining.

Treating industrial water for reuse is typically more costly than treating municipal water due to higher levels of particulates, organic, and inorganic constituents contained within required removal levels. Key stakeholders in the industrial sector are actively pursuing ways to optimize their water usage and evaluate economically viable and sustainable reuse options.

Food and beverage producers are leaders in water reuse, conducting comprehensive evaluations of their water balance and production processes, and using multiple technologies to maximize water reuse and recovery and minimize the impact on the local watershed and stakeholders.

In the upstream oil and gas sector, there are systems using multiple technologies to treat water for reuse and/or discharge including thermal evaporators treating produced water from the steam assisted gravity drain process. The oil and gas downstream industry operates facilities using multiple technologies including advanced membrane biological, filtration, and desalination processes to treat refinery effluent for water reuse and/or direct discharge.

Other sectors using water reuse/recycling technologies include the automotive, semiconductor, pharmaceutical, and mining industries. The effective application of advanced technologies for industrial water reuse represents an important value creation opportunity and a call for regional integrated resource and infrastructure coordination and development.

"The effective application of advanced tehnologies for industrial water reuse represents an important value creation opportunity and a call for regional integrated resource and infrastructure coordination and development."

Open Discussion:

Where Do We Go from Here?

TAMEST Vice President Ken Arnold participates in the closing discussion.

Texas faces daunting challenges in meeting the needs and expectations of the future economy, and it will require concerted effort and sacrifice from all sectors to meet those needs. The state's ability to ensure a sustainable supply of water for all users will be exacerbated by population growth, long-term climatic changes, and the continued growth of a water-intensive but high value-added industrial economy.

The current historic levels of low inflow into major Texas river basins can be attributed to a combination of factors: lack of rainfall, low soil moisture that reduces runoff and increases retention in upstream watersheds, increased evaporation rates, increased consumption, and changes in land use patterns such as the conversion of grassland to shrubland. According to the latest report from the Intergovernmental Panel and Climate Change, climate models are predicting Texas will continue to experience decreased soil moisture and runoff even under normal rainfall conditions. The extreme decline in soil saturation and runoff levels in West Texas may be illustrations of the validity of these predictions.

As with the state's energy future, there is no single solution to Texas' water challenges. In the face of increased demand and potentially reduced supply, a combination of approaches will be required, including:

- water conservation in the agricultural, municipal, and industrial/commercial sectors;
- exploitation of brackish and produced water for both industrial and municipal use;
- advances in water treatment technologies to allow direct recycling of municipal water and reuse of industrial water; and
- increased recognition of the shared nature of our water resources and a legal and property rights structure that balances the natural tensions for that resource.

Agriculture has made significant progress in improving the efficiency of irrigation systems, but the low cost of water will continue to be a barrier to the implementation of conservation initiatives and the adoption of new technologies. Projects utilizing on-site demonstrations, advanced planning tools, and training programs have proven to be successful in supporting increased water use efficiency. The use of satellite imagery and other remote sensing tools (e.g., UAVs) to gather data on soil moisture and vegetation is proving to be useful in the development of cost-effective irrigation scheduling tools.

Municipalities and the commercial and institutional sectors they support continue to provide opportunities for expanding water conservation efforts. Institutional consumers such as large commercial entities, universities, and government agencies represent large-volume users with the potential to increase water use efficiency through uniform, mandated conservation practices. On-site sourcing and reuse applications will become more cost effective with rising energy and water costs, including rainwater and stormwater harvesting, wastewater and gray water systems, and the reuse of air conditioner condensate, swimming pool backwash, foundation drain water, and reject water from reverse osmosis and nanofiltration processes. It is imperative that the state's regulatory environment supports the expansion of these applications and encourages a functioning market for both poor quality and high quality waters.

Industrial users have the opportunity to maximize the use of alternative water sourcing, as the monetary value of their products can support investment in water-related infrastructure and treatment. Oil and gas production consumes high volumes of water, generates significant

"The state's ability to ensure a sustainable supply of water for all users will be exacerbated by population growth, long-term climatic changes, and the continued growth of a water-intensive but high value-added industrial economy."

"The low cost of water and the low value of produced goods, particularly in the agricultural sector, are the primary barriers to the commercialization of technologies that support the treatment, conservation, reuse, and recycling of water."

quantities of produced water, and has relatively flexible water quality requirements. Increased coupling of water producing wells with drilling and hydraulic fracturing activities can support infrastructure investments to allow more efficient water management across this sector.

The application of advanced water treatment technologies will become increasingly important as groundwater and surface water supplies decline. Significant reductions in the energy needed for desalination through advanced membrane efficiency have lowered the cost of using brackish groundwater and seawater resources for water supplies. Texas has an abundance of relatively low-cost sources of energy including off-peak wind power and waste gas that could be used for advanced water treatment.

Advances in the effectiveness of contaminant removal technologies are evident in the introduction of new municipal water supply sources. For example, Wichita Falls and Big Spring are treating their wastewater for direct potable reuse, and San Angelo is blending water from the Hickory Aquifer with its current surface water supply after treating it to remove radium.

CHALLENGES

The extreme drought conditions experienced throughout Texas in 2011 were the driving force behind legislative action to provide financial assistance for the strategies outlined in the 2012 State Water Plan. Although the available funding represents a fraction of the estimated cost of meeting Texas' water needs over the next 50 years, it provides significant opportunities for unique public-private partnerships that can effectively leverage public funds with other sources.

Funding is also needed for research and support services. Continued research is critical for the advancement and application of new technologies, yet federal research funding at the academic level has declined 25–50 percent in recent years. In the agricultural sector, the reduction in funding for extension services is causing the U.S. to fall behind other countries in promoting technological advances.

The low cost of water and the low value of produced goods, particularly in the agricultural sector, are the primary barriers to the commercialization of technologies that support the treatment, conservation, reuse, and recycling of water. Water continues to be priced below its value due to water rights ownership issues, and laws, regulations, and policies that restrict water markets and dictate the price of water. The application of sound economic practices and changes in the state's regulatory structure will be needed to move Texas forward.

Program Chair Dr. Danny Reible gives a summary of the day's presentations and discussions.

Meeting the challenges of ensuring adequate water supplies will require growing cities, agriculture, industry, and energy understand the needs of all sectors and have an interest in a collaborative approach to solving water issues. The 2014 Texas Water Summit served to encourage cross-sector dialogue in an effort to identify and allow the implementation of integrated solutions to the state's water needs. It is hoped that in the coming years, the pressing need for water to drive the economy will continue to advance such solutions.

Highlights of Texas Water Legislation

This summary provides highlights of Texas legislation related to funding for the state's water needs. A comprehensive timeline can be found at **www.lrl.state.tx.us/legis/watertimeline.cfm**

1957

HB 161: Created the Texas Water Development Board (TWDB) and prescribed its composition, powers, and duties. Authorized the TWDB to issue $100 million in state bonds to create the Texas Water Development Fund.

HJR 3: Constitutional amendment authorized the issuance and sale of $200 million in bonds to create the Texas Water Development Fund to provide financial assistance in the conservation and development of the state's water resources.

SB 1 Water Planning Act of 1957 mandated a formal process for developing a plan to meet the state's future water needs. (State water plans have been adopted in 1961, 1968, 1984, 1990, 1992, 1997, 2002, 2007, and 2012.)

1985

HJR 6 Constitutional amendment authorized the issuance of an additional $980 million of Texas Water Development Bonds; created special water funds for water conservation, water development, water quality enhancement, flood control, drainage, subsidence control, recharge, chloride control, agricultural soil and water conservation, and desalinization; authorized a bond insurance program; and clarified the purposes for which Texas Water Development Bonds may be issued.

1987

SJR 54 Constitutional amendment authorized the issuance of an additional $400 million of Texas Water Development Bonds for water supply, water quality, and flood control purposes.

1989

SJR 5 Constitutional amendment authorized the issuance of an additional $500 million of Texas water development bonds for water supply, water quality, and flood control purposes.

1997

SB 1 Created 16 regional water planning groups, outlining a process tasking local and regional stakeholders with developing consensus-based regional plans on meeting water needs in times of drought.

SJR 17 Constitutional amendment created the Texas Water Development Fund II, authorizing the TWDB to administer the fund and issue general obligation (GO) bonds.

2001

SB 2 Clarified the role of groundwater conservation districts in managing and safeguarding groundwater within their jurisdictions. Established the Rural Water Assistance Fund and the Water Infrastructure Fund. Provided for detailed studies and determinations of the instream flow needs for priority river basins.

HJR 81 Provided for the issuance of up to $2 billion in additional GO bonds by the Texas Water Development Board.

2007

SB 3 Created a process designed to use existing information and the best available science to establish environmental flow recommendations and standards for all Texas river basins and estuaries.

2011

SJR 4 Constitutional amendment provided for the issuance of additional GO bonds by the Texas Water Development Board in an amount not to exceed $6 billion outstanding at any one time.

Prop 2 Proposition 2 approved by voters, allowing the TWDB to issue GO bonds as provided for in SJR 4.

2013

SJR 1 Constitutional amendment provided for the creation of the State Water Implementation Fund for Texas (SWIFT) and the State Water Implementation Revenue Fund for Texas (SWIRFT) to assist in the financing of priority projects in the 2012 State Water Plan.

HB 1025 Supplemental appropriations bill authorized the allocation of $2 billion from the State's Economic Stabilization Fund for the SWIFT pending voter approval.

HB 4 Provided for governance changes to the Texas Water Development Board, created a SWIFT advisory committee, set guidelines for use of the funds, and defined a process for prioritization of projects.

Prop 6 Proposition 6 approved by voters, allowing the transfer of $2 billion into the SWIFT as provided for in HB 1025.

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