Texas Water Markets Review:

HISTORIC TRENDS AND FUTURE POTENTIAL

FEBRUARY 24, 2023

CONTENT

ABSTRACT

Freshwater resources in Texas are facing unprecedented pressures. Increasing competition between water users, coupled with increasingly variable supplies, is giving rise to water scarcity across the state. For the first time in the state's history, municipal water demand will outpace agriculture by 2060. Although the first half of the 20th century was dominated by reservoir construction and groundwater production to buffer against shocks, the end of the century saw a diversification of tools for managing water scarcity, including water markets. Water markets were seen as a promising tool for managing water demands in Texas because of the favorable enabling conditions and propensity for decentralized, locally governed intervention. Looking back on more than 30 years of experimentation across the state, what have we learned about water markets in Texas? And what role could water markets play in future water management to improve sustainability? In this report, we analyze the status and trends of the broadening set of water markets across Texas. We take a comprehensive perspective of water markets and include various types of market-based reallocation programs, such as, water banks, water trusts and spot markets, and how they fulfill different purposes (e.g., consumptive use, environmental flows). This review provides the first statewide analysis of trends, diversity and pathways for future work to improve the public benefits and equity of different water markets. We construct a transactions database and locate over 2,350 individual surface water transactions between 1987 and 2022 spanning 13 major basins across the state, which reallocated over 4 million acre-feet (AF) of water at a total cost of $1.3 billion USD. We illustrate how different basins have different signatures of transactions, suggesting that comparing water markets within basins is more instructive for policy makers than comparing across basins. We pay particular attention to what the evidence says about the ability of water markets to reallocate water to the environment and where we see the most opportunity for improving their enabling conditions. We conclude with seven recommendations focused on incremental changes in existing water management practices to improve conditions for water markets and their contributions toward a water-secure future for the people of Texas and their environment.

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This analysis was made possible with the support of the Mitchell Foundation. Review and feedback were provided by National Wildlife Foundation and a TNC-Oxford Water Partnership. Data for analysis was provided by Texas Water Development Board and WestWater Research.

INTRODUCTION

Water markets have been a decentralized tool for reallocating water and water rights in Texas for more than 100 years. The economic theory of water markets predicts that water markets can provide incentives to improve water use efficiency and encourage reallocation to higher value uses, thereby decreasing water scarcity (Bjornlund, 2003). Water markets rely on three regulatory elements: a cap on extractions, the allocation of water rights on a legal basis and the creation of trading rules to facilitate reallocation (Easter et al., 1999). Economists have promoted water markets for decades as a tool for alleviating water scarcity by incentivizing gains in efficiency (Rosegrant and Binswanger, 1994) and economic gains from trade (Hearne, 1997). However, international experiments (Grafton et al., 2011; Libecap, 2009) demonstrate that the three regulatory elements are necessary but insufficient enabling conditions for water markets to reduce scarcity at the scale that economists envisioned (Garrick et al., 2020; Meinzen-Dick, 2007).

Texas' experience with water markets has been built on the backdrop of hydrological conditions and political landscapes that favor markets for reallocating water. Water scarcity in Texas is driven by dynamics between competing water demands (e.g., within agriculture and between urban and rural users) (Wight et al., 2021) and increasingly variable water supplies (Nielsen-Gammon et al., 2020). Texas' political propensity for decentralized, locally governed interventions has helped incentivize legislative priorities to create the necessary legal frameworks for water trading. Figure 1 represents a select number of Texas water laws that promoted water markets in the state.[1] Major droughts in the late 1800s, the drought of record in the 1950s and the 2011 drought provided motivation to usher in legislative changes to improve conditions for reallocating water via markets. Figure 1 also helps illustrate that the current enabling conditions that

1 For a more detailed summary of Texas water law over time, see Timothy Brown, "A primer for Understanding Texas Water Law": https://lrl.texas.gov/legis/water_Primer.pdf

promote water markets in Texas have been decades in the making. The institutional infrastructure and legal frameworks required to set up water markets in Texas were not granted in Texas' original constitution but rather kindled by a series of legislative priorities that followed on the backs of droughts that severely crippled the state. However, it was not until the mid 1980s that Texas established environmental flow protections, which meant that few of the several thousand allocated water rights considered environmental flows (Wurbs, 2017). Even in the wake of landmark legislation like Senate Bill 3 (SB3), which established environmental flow standards in 2007, environmental water demands still go unmet (Anchor and Hoffpauir, 2021).

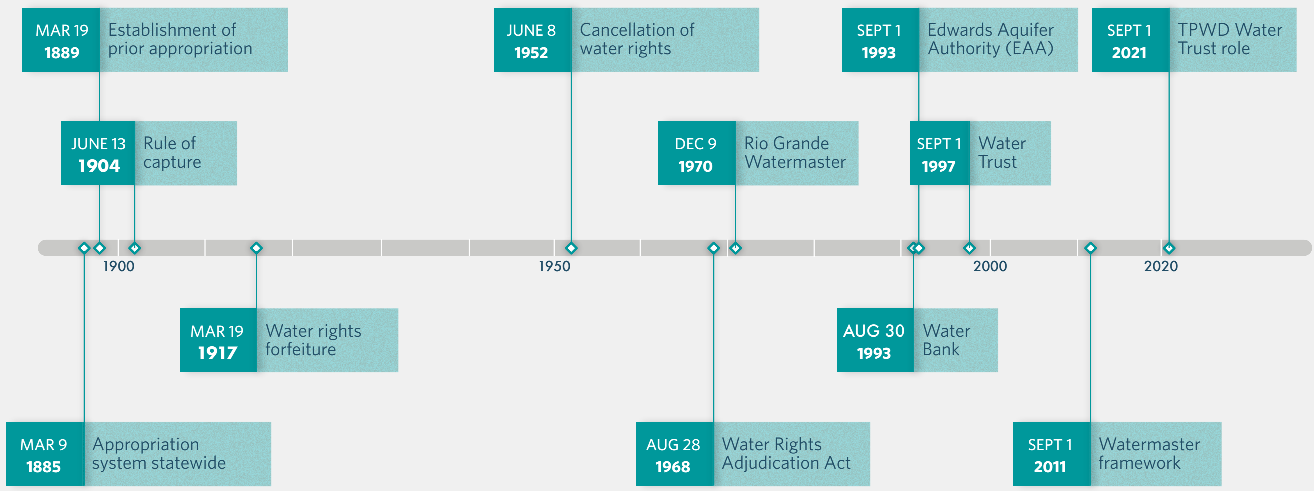

Figure 1: A select number of influential Texas water laws that contributed to enabling water markets in the state.

As of this writing, the state of Texas is at a pivotal moment in terms of managing water resources. According to the Texas Water Development Board (TWDB), projected water demand will rise over 18 million AF (MAF) by 2030 (TWDB, 2021), and for the first time in the state's history, demand for municipal uses is projected to exceed water demand for irrigation by 2060 (TWDB, 2021). Although there are areas that could be served by additional infrastructure projects (e.g., reservoirs) and technological solutions (e.g., desalination or aquifer storage and recharge [ASR]), which focus on augmenting supplies, they can be considerably more expensive (per volume) than water conservation or demand management strategies. For example, to provide an additional 5,000 AF, brackish groundwater desalination can cost $2,690/AF/year and conventional groundwater $1,119/AF/year, whereas smart water meters, a tool for demand management, can provide the same amount of water with an annual savings of $2,800/AF. As a result, there is a renewed interest to review demand-management strategies, including water markets and related incentives.

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18MAF
by 2030

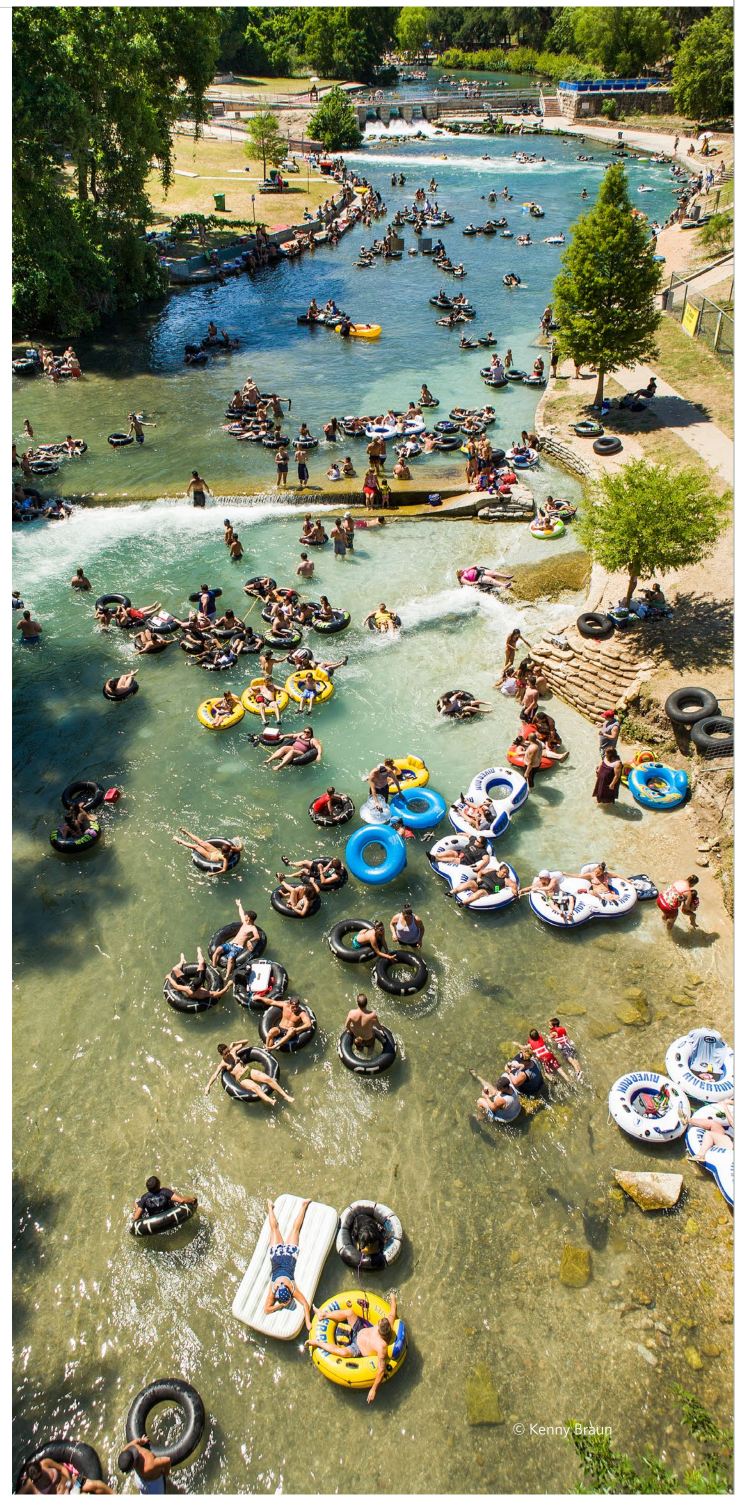
Our report makes its contribution by providing a bridge between historic market performance and future market potential. We focus on the questions: What have we learned about water markets in Texas over the last 30 years? And what role could water markets play in sustainable water management in the future?

Our objectives are to:

1
Provide information on the status and trends of water markets across Texas

2
Offer a definition of water markets that (a) reflects their diversity and (b) improves future efforts in science, communication and policy between governments, NGOs, water managers and academic institutions

3
Provide policy recommendations for designing and operating markets to improve public and private benefits



The next section describes our mixed-methods approach for scoping literature, our semi-structured interview process and the development of our statewide surface water transactions database. Next, we share results that demonstrate the diversity of markets across the state based on different metrics. We follow with a discussion section that elaborates on key findings like the recent acceleration of environmental water transactions. Finally, we offer a list of seven policy recommendations that are informed by this work and offer promising potential to improve water market efficiency across the state—both for people and nature.

METHODS

We employed a mixed-methods approach designed to collect and analyze information on water markets from three sources: (1) academic literature, (2) transactions data and (3) expert opinions. We were explicit in our methodology to embrace perspectives from multiple disciplines and draw synergies between hydrology, economics and governance to continue to challenge the historical perspective of water markets as a panacea (Meinzen-Dick, 2007; Ostrom and Cox, 2010).

We combined surface water transactions data from the Water Transfer Database (WTD), WestWater, and The Nature Conservancy. The WTD was developed by the University of California Santa Barbara (Bren School) and drew all its data from the *Water Strategist* from 1987 to 2010. This dataset contains information on volumes, prices, year, type and direction of transaction of 335 transactions for Texas between 1987 and 2009. WestWater provided data for 147 sales and 1,836 leases from 2009 to 2022. The Nature Conservancy provided 34 transactions since 2015, 10 of which provided water to the environment. We recognize our database is not an exhaustive list of all surface water transactions in Texas because (a) data on water transactions are historically difficult to obtain and (b) any informal transactions are not recorded. However, we believe 2,352 individual transactions to be an appropriate sample size given its temporal (1987-2022) and spatial (13 basins) coverage, and we are unaware of any database with a higher count of transactions for Texas.

To provide supplemental perspectives to the literature and transactions database, we interviewed 12 people, including lawyers, engineers and hydrologists, in senior positions at state agencies, private practices and academic institutions. We employed a semi-structured interview approach that focused on information gathering (e.g., "Are trends in our transactions database consistent with your perception of transactions?") yet provided the opportunity to hear opinions on institutional

perspectives of the interviewees' choice (Carr et al., 2011). After sampling questions with practitioners, we focused on three primary questions to guide the conversations:

1
What is working well with water markets in Texas?

2
What is not working?

3
How could science and policy improve the public and private benefits of water markets?

We consolidated feedback from each interview and looked for patterns of agreement and disagreement between interviewees (O'Keeffe et al., 2016).
This information provided additional historical and political contexts in which to understand the transactions data as well as the literature.

BACKGROUND

Academic literature on water markets in Texas has steadily increased over the past 30 years (see figure 2 below) fueled by increased attention to water scarcity (Griffin, 2012; Nielsen, Gammon et al., 2020) and favorable legal enabling conditions (Gervais, 2015; Griffin, 1998). However, most studies focus on only two water markets in Texas: the Rio Grande (Booker et al., 2005; Debaere and Li, 2020; Ward et al., 2007; Yoskowitz, 1999) and the Edwards Aquifer (Gillig et al., 2004; Griffin, 2021; Votteler, 1998).

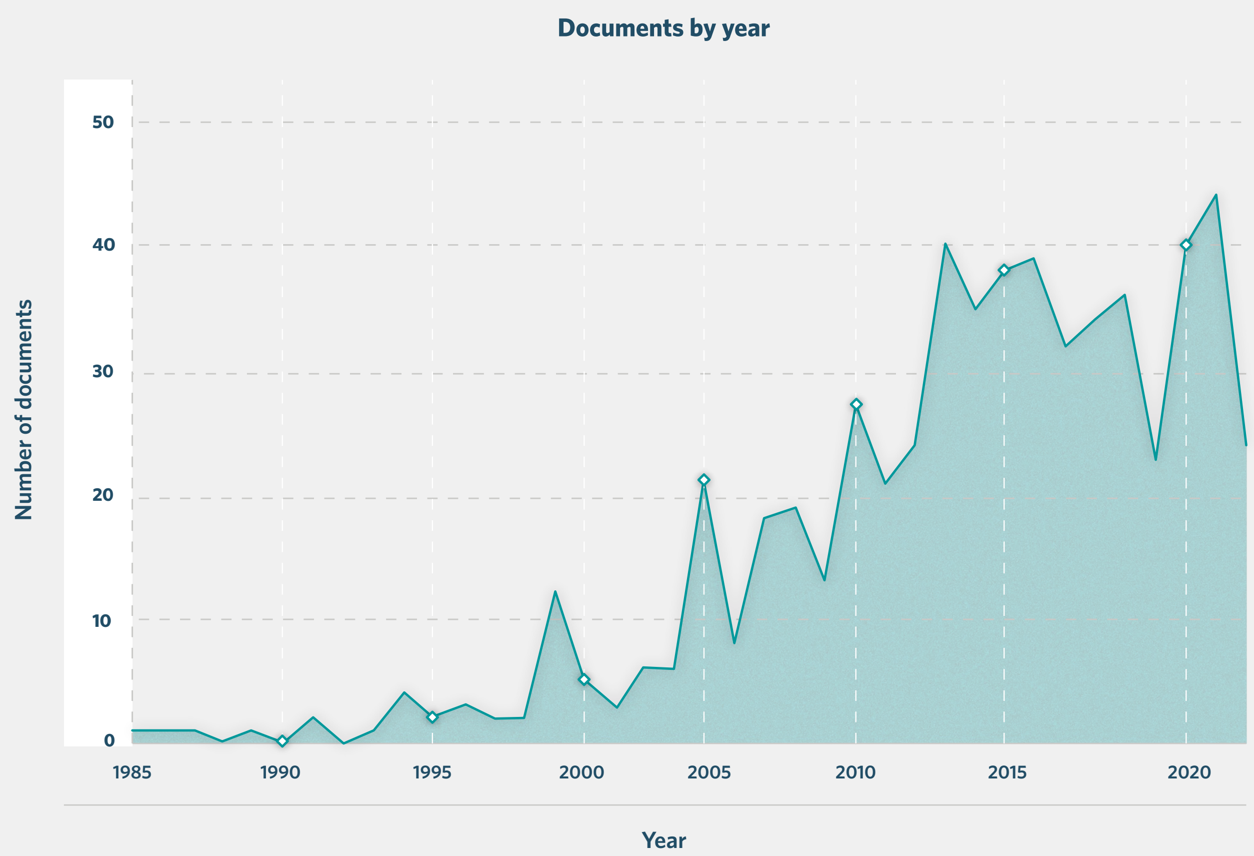


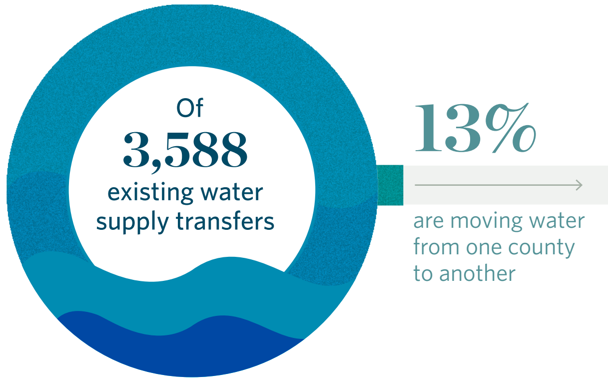
Figure 2: Analytics from Scopus searching ("Texas" or "TX" and "water markets"); n=518.

The Rio Grande water market is the most active water market in Texas and exemplifies many of the enabling conditions that economic theory predicts facilitate water trading: a well-defined cap, rules for trading, scarcity and ability to move water effectively (Garrick et al., 2020). After a 15-year adjudication process ending in 1971, the Rio Grande market design offered several unique (from a statewide standpoint) attributes, including an amendment procedure, absence of seniority, water contracts and watermaster operations (Chang and Griffin, 1992). Although there are areas for improvement in terms of conserving water, including water transfer restrictions, insecure rights to conserved water, and land ownership and arrangements (Ward et al., 2007), recent studies demonstrate that the market has been effective in shifting producers to higher valued and less-water-intensive crops, especially in times of drought (Debaere and Li, 2020).

The Edwards Aquifer water market is also unique for Texas in that it was designed to protect endangered species (Kaiser and Phillips, 1998; Ward et al., 2008). The aquifer itself boasts unique characteristics that have enabled trading in a state where rule of capture persists (Drummond et al., 2004): (a) an incentive to conserve endangered species at the state level mandated by a federal law (Votteler, 1998), (b) a well-funded groundwater management district (Springs and District, 2004) and (c) an aquifer that is well modeled (Scanlon et al., 2003; Smith et al., 2005).

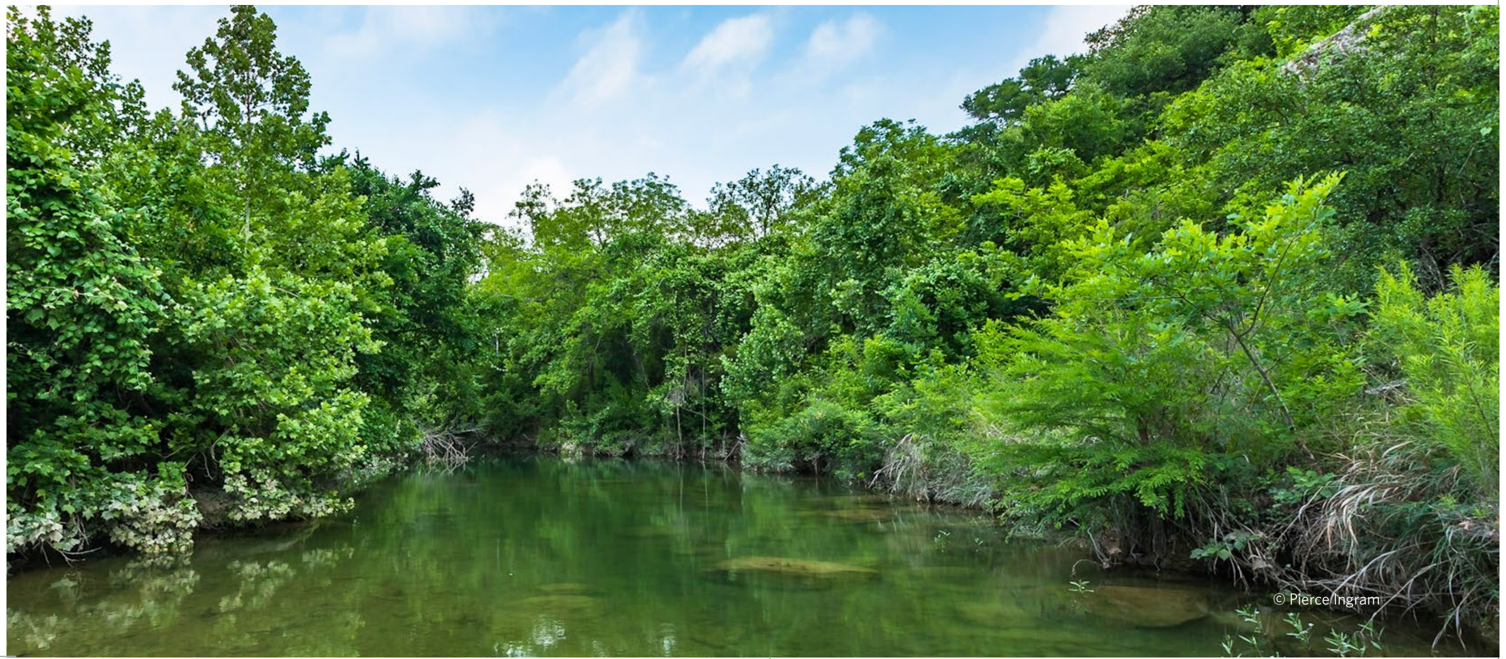
Additionally, the karst geology in the Edwards Aquifer provides very high porosity, permeability and transmissivity (Painter et al., 2007). High transmissivity provides flexibility for pumping, which means there is one market encompassing two pools with low transaction costs and third-party effects (Griffin, 2021). Management of the Edwards also includes some pumping caps as well as cutbacks on some permits in times of drought. As a result of favorable enabling conditions, decreased water supplies from recent dry conditions and increasing municipal demands in central Texas, there were over 2,400 short-term lease transactions (which are not included in our database) between 2005 and 2016 in the Edwards Aquifer water market (Griffin, 2021).

Although the Edwards Aquifer is unique in terms of its enabling conditions and hydrogeology that facilitate this level of trading, there are indications



that conditions for more groundwater markets are improving. Historically, incentivizing groundwater markets in Texas was challenged by the rule of capture (Drummond et al., 2004), which precludes the regulatory "cap" required for markets. Likewise, Texas water law treats groundwater and surface water differently, although there are several examples of rivers whose hydrogeological characteristics blur the lines between groundwater and surface water (A. Smith et al., 2015). Exploratory analysis suggests a growing demand for groundwater leasing, which could have important implications for groundwater trading in future. Data on groundwater transfers from TWDB show that of the 3,588 existing water supply transfers, only 13% of those transfers are moving water from one county to another (i.e., county to county). In contrast, data on planned future supply transfers show that 53% of planned transfers will be county to county. In terms of volume, today less than 280,000 AF of groundwater are transferred county to county; however, by 2070, that number could be closer to 375,000 AF.

Although the rule of capture may be the most significant limiting factor for unlocking the potential of groundwater markets at a state level, setting sustainable and enforceable pumping limits at the Groundwater Conservation Districts (GCDs) offers a pathway for improving markets under the rule of capture by (a) improving enabling conditions for markets and (b) protecting environmental water



needs. Landmark legislation in the late 1990s (see figure 1 for reference) created institutions that were designed to help facilitate water rights trading, including for the environment. The Texas Water Bank was established in 1993 to "facilitate the transfer, sale, or lease of water and water rights throughout the state" (TWDB Texas Water Bank), and the Texas Water Trust was designed to acquire water rights for environmental purposes. The Texas Water Trust and Texas Water Bank drew inspiration from similar institutions in other western states (Neuman, 2004); however, over the past 30 years, they have had very limited success in guiding water transactions. The Texas Water Trust has only received two donations, and the Texas Water Bank has only facilitated one transaction, which suggests there is an opportunity to revisit their roles and capacities to improve their ability to facilitate more water transactions, especially for the environment.

Despite the robustness of the Rio Grande and Edwards Aquifer water markets, other water markets in Texas have been slower to mature. There have been several factors proposed for explaining the lack of market activity outside of the Rio Grande and Edwards, including that (a) water scarcity is generally a bigger problem in the western half of the state; (b) Texas (compared to states like California) lacks natural and built conveyance for transporting water; (c) water rights enforcement is spotty; and

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(d) river authorities tend to monopolize power and water within basins, which decreases market activity (Griffin and Characklis, 2011). However, despite the increasing number of peer—reviewed studies, most of the literature we reviewed tends to cluster—either geographically (e.g., Rio Grande and Edwards) or by type of water market (e.g., surface water, spot market, groundwater market), and the market activity is analyzed from a specific academic perspective, such as institutional analysis (Chang and Griffin, 1992) or public policy (White et al., 2017). These clusters in the literature create blind spots for improving policy and enabling conditions of water markets because they tend to be focused on accomplishing the goal(s) that each water market is designed for. Our transactions database takes a first step at shedding light on additional markets throughout the state to help quantify the diversity of existing markets that may not resemble either the Rio Grande or the Edwards Aquifer.

RESULTS

Analyzing the transactions database provides insights on several aspects of Texas water markets that have been overlooked:

Formal water market trading has occurred in 13 basins across the state.

Between 1987 and 2022, over $1.3 billion USD and >4 M AF of surface water has been formally transacted. Leases have occurred more often (2,088) than sales (264), and the average price of leases (normalized for volume) is lower than sales. Figure 3 below demonstrates how widespread these transactions are, both in terms of count of transactions (left) and volume (right).

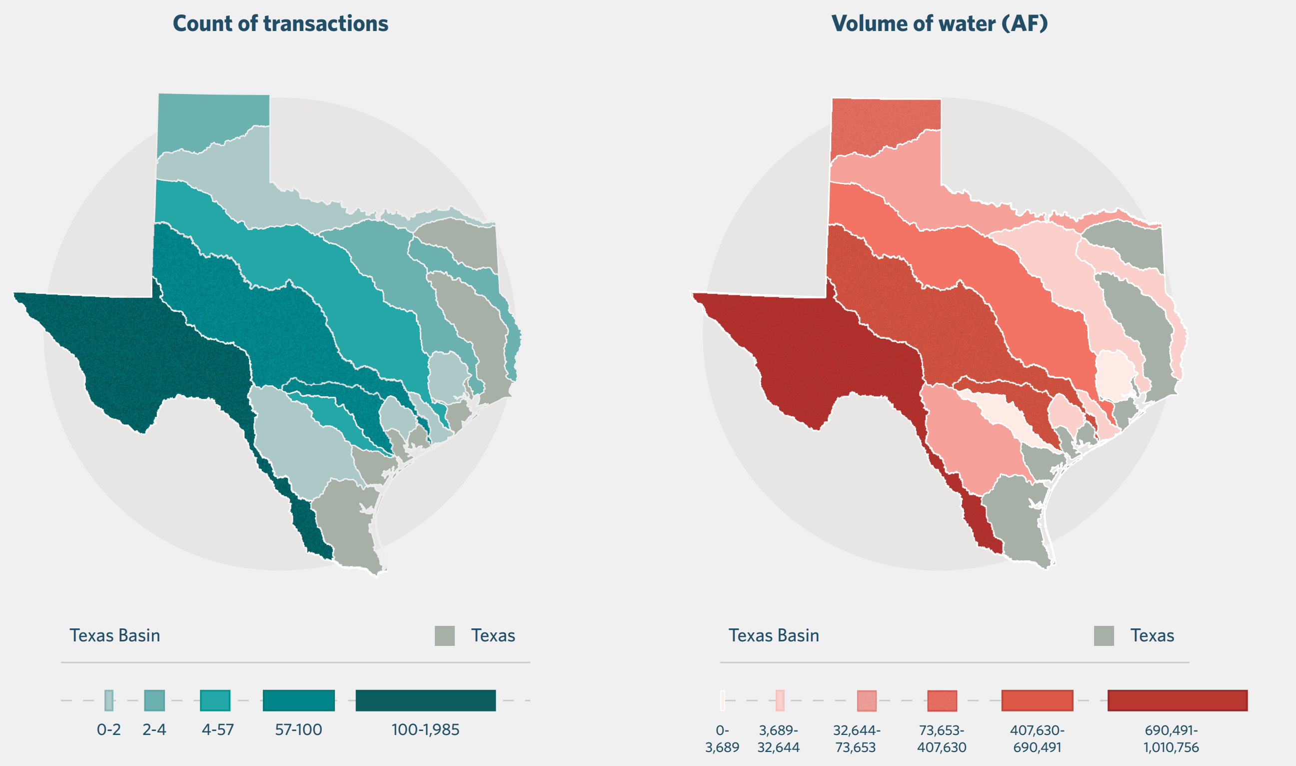

Figure 3: Map of *counts of transactions* (left) and *volume of water* in AF (right), both categorized by natural breaks.

Water market activity is increasing across the state, especially in the last decade.

We see that formal surface water transactions have increased on an annual basis over the past 30 years, with a significant increase in the past 10 years. One subtle trend is that the increase in the number of transactions is driven primarily by leases. Figure 4 illustrates that leases occur more often and are cheaper (by volume) than sales, which is consistent with empirical evidence of transaction costs between these types of markets (Womble and Hanemann, 2020). Leases offer a flexible option for various water users (producers, municipalities, etc.) and can help buffer against acute water scarcity or shortages. We note that sales continue to provide an important tool for water users looking to acquire long-term water rights, such as municipalities or environmental NGOs who are attempting to address chronic water-scarcity challenges.

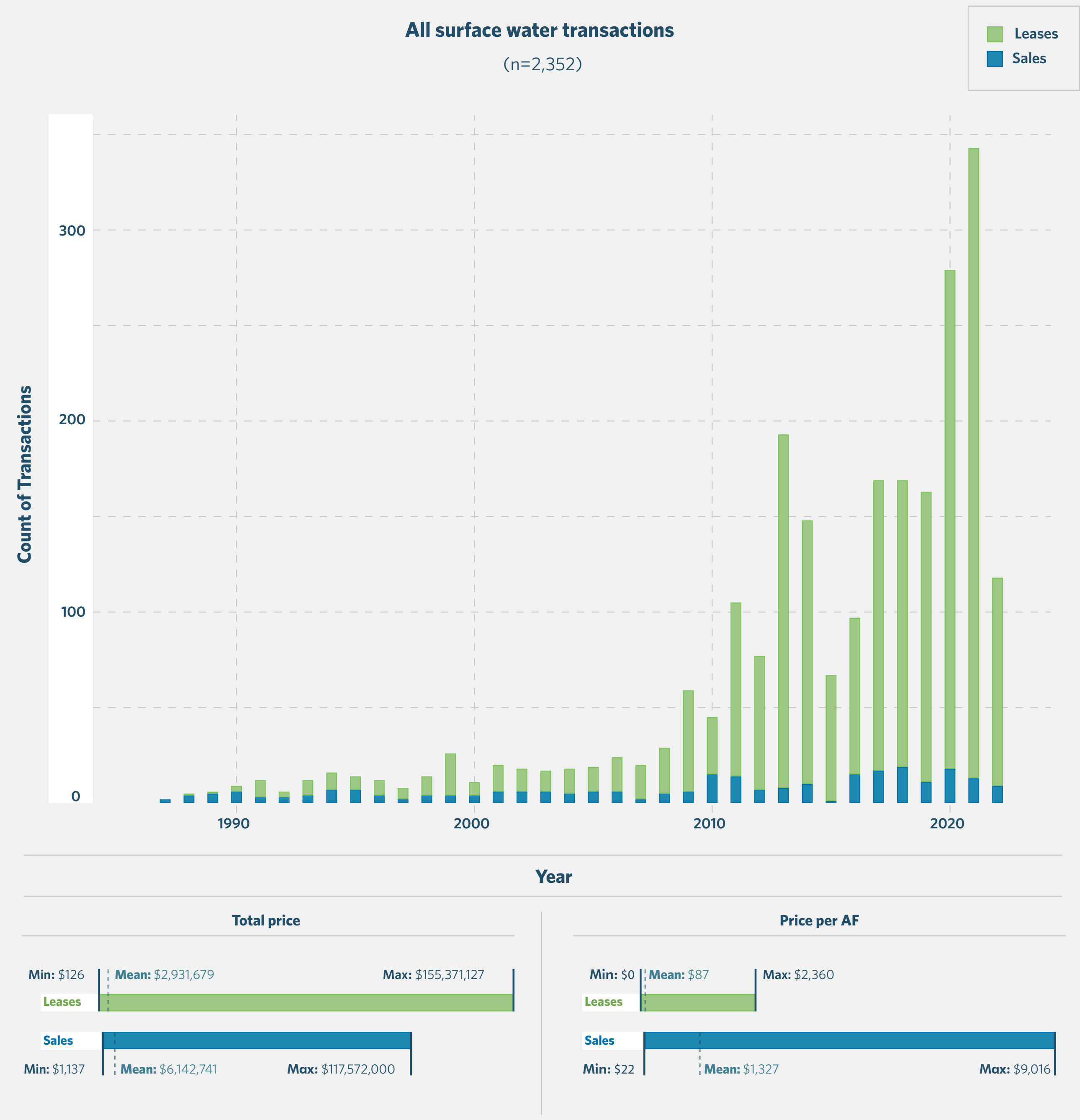

Figure 4: Graphic showing count of transactions (by lease and sales) and a table showing summary statistics for total price and price per AF of transactions.

Water is moving out of agriculture and mostly going to urban use.

Figure 5 below is a graphical representation of two columns of our database: (1) previous use (what the water was used for before the transactions) and (2) new use (what the water is used for after the transactions). The graphic shows how water transactions are moving water from previous uses (left-hand side) to new uses (right-hand side). Understanding how water transactions are shifting water within and between sectors has important implications for water management and policy. Our results confirm that Texas, like many water-scarce geographies, shows a trend in reallocation from rural use to urban use (Garrick et al., 2019).

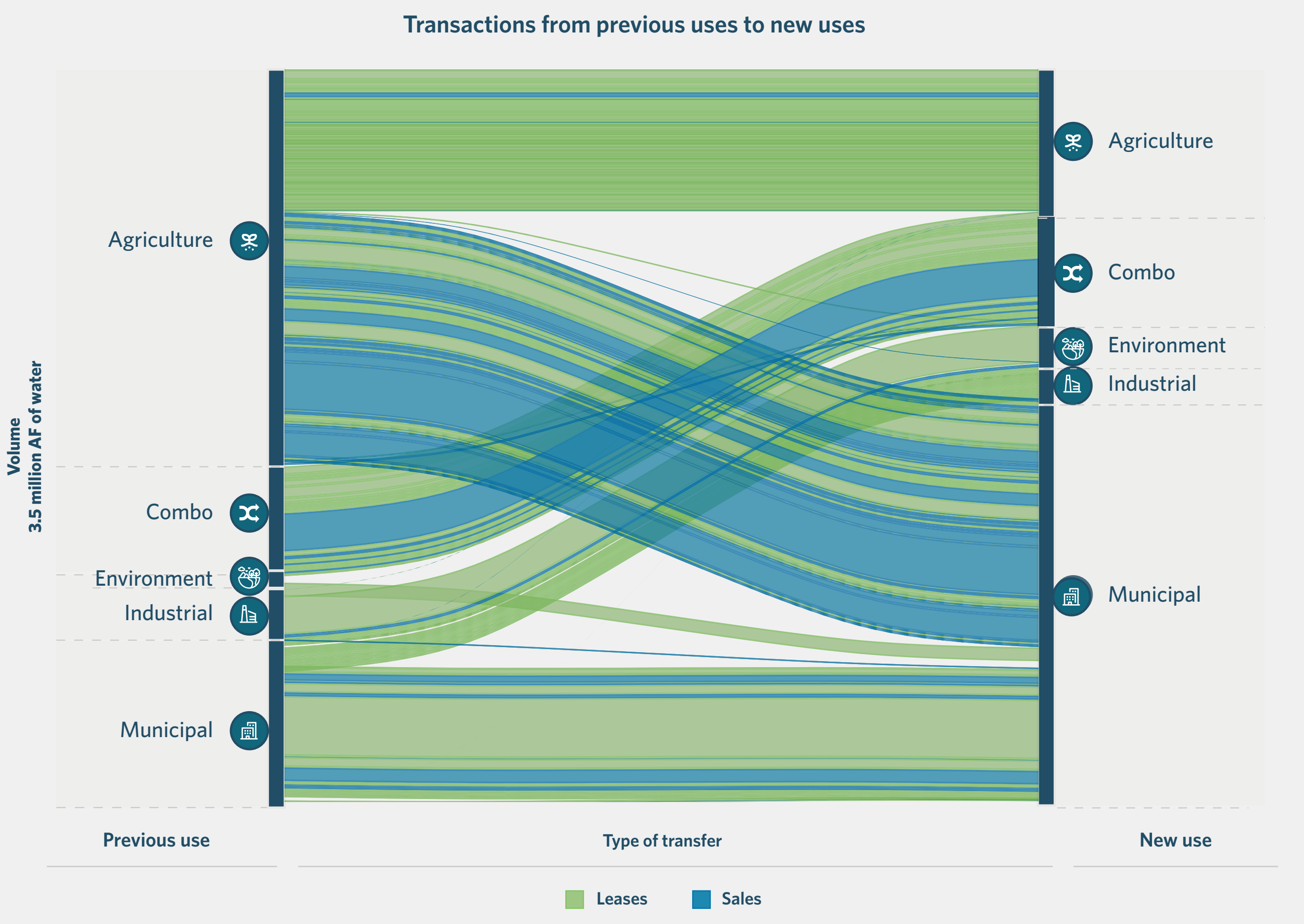

Figure 5: An alluvial plot showing flows of transactions between previous use (left) and new use (right). Flows of transactions are displayed as volume and are proportional in this graphic; e.g., "new" municipal use is over 50% of all new uses.

An increasing amount of water is going to environmental uses.

A significant amount of water (266,000 AF total, with a mean transaction size of 16,000 AF) has been reallocated to environmental uses, although this shift is recent (last 10 years). We notice that the environment is receiving water from all sectors except urban water users. In terms of count, more transactions going to the environment are from agriculture although one large transaction from industrial use skews the graphic in figure 5.

In terms of transactions, different basins have different signatures; therefore, it may be more informative to analyze within basins rather than across them.

Figure 6 displays all 2,352 surface water transactions on a single multivariable plot. Types of transactions are displayed as different shapes: blue circles correspond to sales, and green circles are leases. The size of these circles corresponds to their volume. The y-axis represents total price per AF of water (adjusted for 2020 values) and is log10 scale. This graphic illustrates several lessons:

1
Transactions have been consistent over the past 30 years. There are peaks and valleys in frequency, but every year in the past 35 years, formal surface water trading occurred.

2
Volumes and prices showed significant variability.

3
Sales were more expensive than leases, on average.

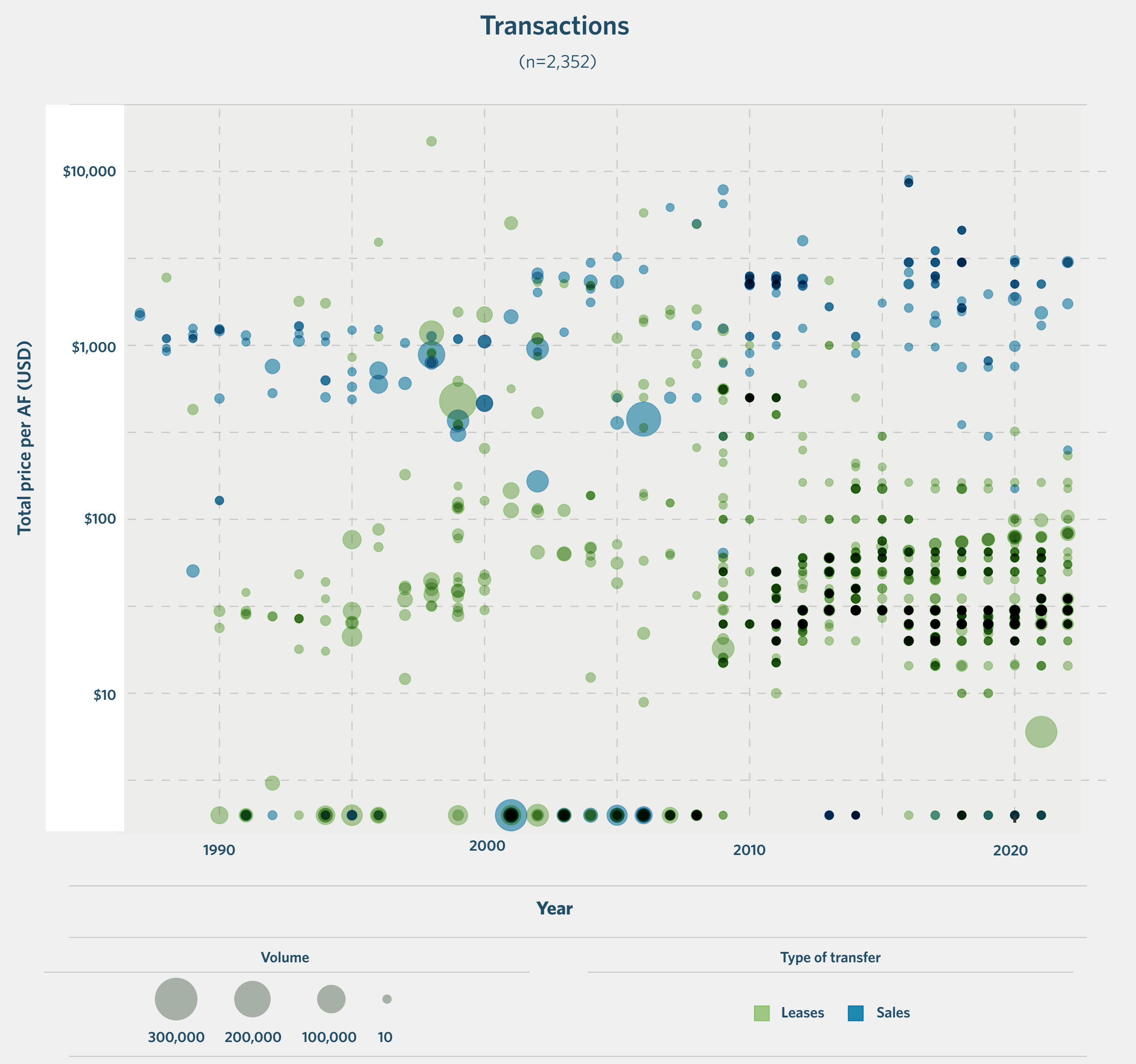

Figure 6: All surface water transactions (n=2,352) shown as individual points of different types (green circles are leases, and blue circles are sales); and size (denoting volumes) over time. Price (adjusted to price per AF in 2020 USD) is displayed as logarithmic on the y-axis. Time is displayed on the x-axis.

While figure 6 is informative and demonstrates the breadth of market activity across the state, we find that displaying individual basins captures the diversity of Texas water markets with more clarity. Figures 7a and 7b show the Colorado River (figure 7a) and the Guadalupe River (figure 7b). Here we can see different signatures of each water market.

The Colorado water market was dominated by several exceptionally large transactions near the turn of the 21st century when the Lower Colorado River Authority (LCRA) purchased downstream senior irrigation water rights to add to their water supply portfolio. By the early 2000s dozens of transactions of similarly moderate volumes (of leases and sales) with highly divergent prices suggest a certain amount of inelastic demand likely driven by rapid urbanization and water utility organizations like LCRA trying to provide new water supplies.

The Guadalupe water market saw the majority of its activity between 1995 and 2005, with an almost even mix of sales and leases that were similar in volume but divergent in price. The largest transaction (volumetrically) was very recent (a lease in 2021) and was not among the most expensive transactions (normalized by volume).

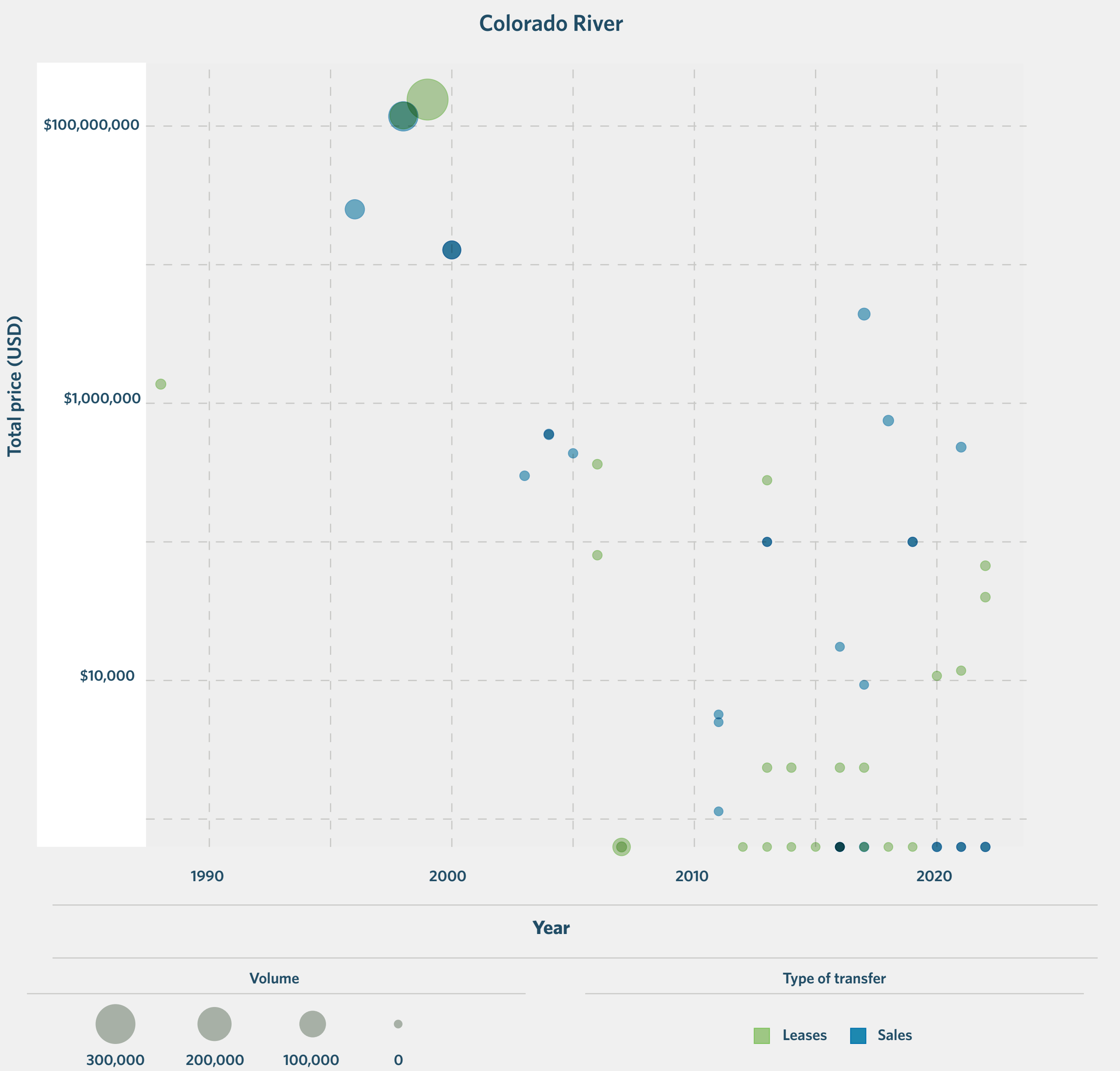

Figure 7a: The Colorado River transactions as individual points of different types (green circles are leases, and blue circles are sales) and size (denoting volumes) over time. Price (adjusted to price per AF in 2020 USD) is displayed as logarithmic on the y-axis. Time is displayed on the x-axis.

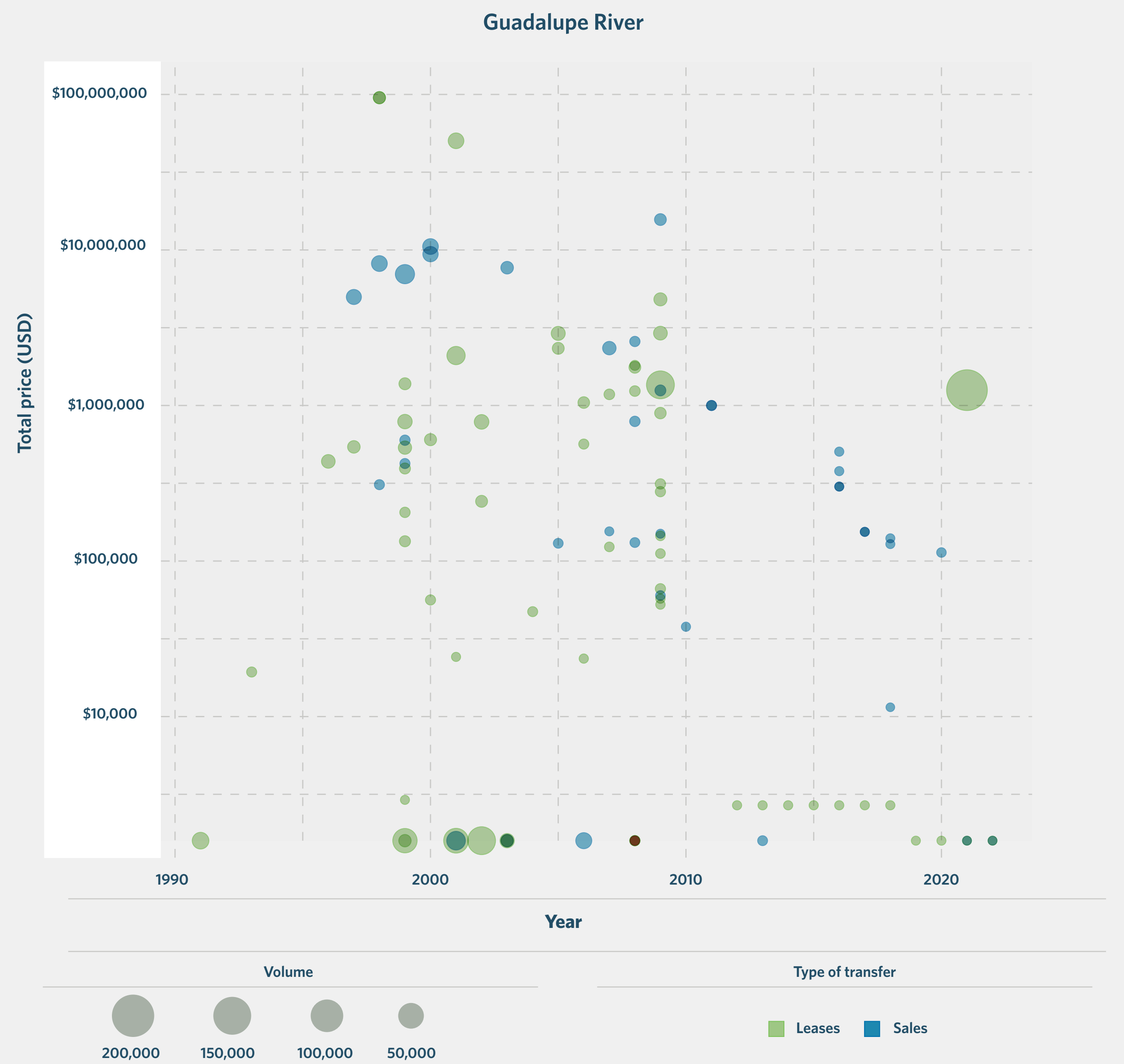

Figure 7b: The Guadalupe River transactions as individual points of different types (green circles are leases, and blue circles are sales) and size (denoting volumes) over time. Price (adjusted to price per AF in 2020 USD) is displayed as logarithmic on the y-axis. Time is displayed on the x-axis.

DISCUSSION

The state of water markets in Texas.

There is broad and deep experience of water markets across Texas, providing an opportunity to unpack how they have contributed to reducing water scarcity—both within agricultural regions (e.g., Rio Grande, Upper Colorado) as well as between sectors (e.g., agriculture and municipal users). In addition to transactions between different sectors, transactions have occurred between different users (e.g., producers trading with producers; producers trading with water districts). How users completed transactions was also variable; sometimes a third-party broker was used, while occasionally a state-run water trading institution (e.g., Texas Water Bank) was employed. As a result of the multiple types of transactions that we see, our research leads us to think of "water markets" as an umbrella term for **voluntary transactions between water users to reallocate water**.

Environmental water transactions serve an increasingly important need.

Our database shows an accelerating trend in water transactions for the environment principally driven by NGO participation in different water markets across the state. Since 2019, 10 different transactions across five basins moved a total of 266,645 AF of water for environmental benefit. We should note that all these transactions were leases, which speaks to the comparative advantage in terms of lower transaction costs compared to sales. Leases also have advantages in terms of flexibility. For example, during a three-year agreement, if there were sufficient flows to reach environmental targets, the NGO leasing the water could lease back to producers. On the other hand, leases can be less desirable for securing long-term environmental water. Nonetheless, these results are encouraging from a conservation perspective because they demonstrate that environmental water transactions (EWTs) offer a tool for NGOs to improve outcomes for producers and the environment. For example, in many river basins across the state, flow requirements for species and habitat are unmet under current conditions. Under a business-as-usual scenario, irrigators can continue to pump in times of drought, which increases the risk of shocks to their production (Grafton et al., 2018) while accelerating negative environmental impacts for the river (Richter et al., 2020). Employing EWTs provides an alternative pathway, which incentivizes producers to leave water in stream for compensation. This voluntary transaction improves farm resilience in times of drought by offering the producer an alternative use for their water – they could lease or sell it to an NGO, providing them with an income and the option to rest some part of their land. In turn, an NGO could use that water to help improve instream habitat. Although scaling these "win-win" scenarios requires complementary investments in governance, data and finance (Garrick et al., 2020), today at the farm-scale, EWTs offer producers and NGOs options for improving resiliency in the face of drought and climate change.

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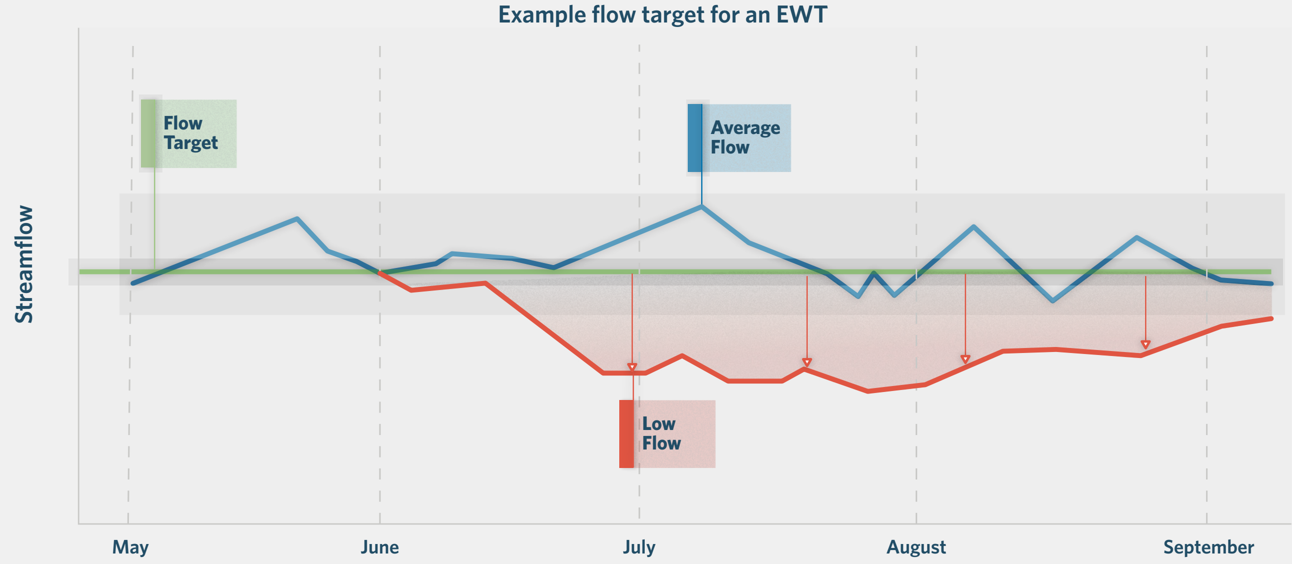
266,645 AF of water for environmental benefit.

These results also demonstrate that using water markets for environmental purposes is fulfilling a role in which regulatory policies have struggled. To further illustrate the mechanics of an EWT, we provide a case study from 2021 in figure 8 below. Here we see how an NGO can target the location, timing and sequencing of incentives within an EWT design to provide targeted environmental benefits.

Example flow target for an EWT



Context

TNC is working to protect streamflow for imperiled aquatic species threatened by prolonged drought periods and increasing water demands in the upper Colorado River Basin.

EWT design

Lease agreements that incentivize producers to reduce irrigation in periods when flows on the San Saba River drop below 10 cubic feet/second (cfs).

Conservation objective

Work with active water rights holders to reduce demand during low-flow periods to protect up to 5 cfs on the San Saba River.

Results

Instream flows and aquatic habitat protected for fish and wildlife for a 4-mile stretch of the San Saba River.

Figure 8: A snapshot of one of the EWTs that The Nature Conservancy has been designing on the San Saba River. This EWT uses a lease agreement to help close the flow deficit during low-flow periods. Flow deficit is the shaded red area with down arrows, which is between the flow target, shown in green, and the low-flow line, shown in red.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Each city utilized a different type of water market to fulfill a similar objective, which is illustrative of the **diversity of water markets.**

Municipalities have a history of using surface water and groundwater markets to satisfy growing water demands.

Increased water scarcity due to population growth and drought has been driving Texas municipalities and regional water managers to develop new and alternative water supplies for decades. Large-scale water transactions by the cities of Corpus Christi, Austin and San Angelo provide examples of how different municipalities dealt with increasing demands and ultimately relied on water markets to help secure needed supplies. However, each city utilized a different type of water market to fulfill a similar objective, which is illustrative of the diversity of water markets.

In 1992, the City of Corpus Christi entered into an option agreement with the Garwood Irrigation Company, which held one of the most senior water rights in the Lower Colorado River Basin. The transaction was finalized in 1999 and transferred 35,000 acre-feet of surface water from agricultural irrigation to municipal use at a cost of $450/AF (Smith, 2004). Subsequent investment in transmission and storage infrastructure has provided supplies for the City of Corpus as well as other communities in the coastal bend region.

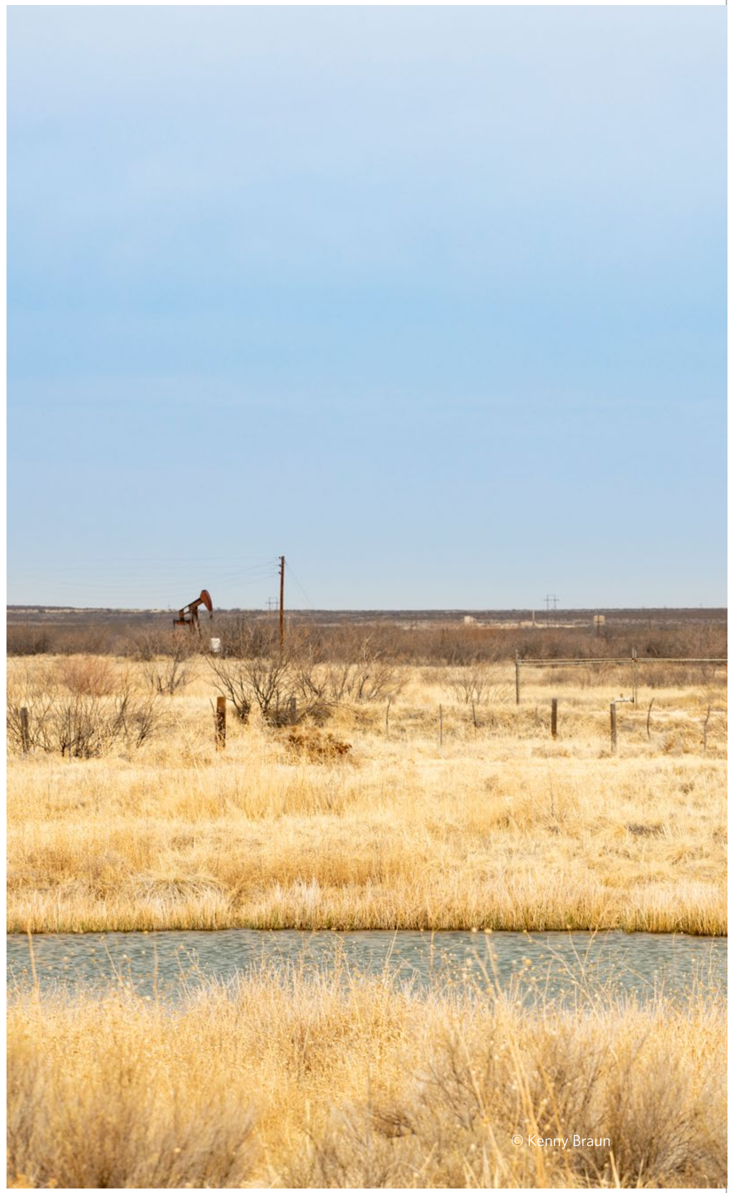
In 1998, the Lower Colorado River Authority (LCRA), the largest river authority and regional water supplier in the Colorado River Basin, purchased the Garwood Irrigation Company and the remaining 133,000 acre-feet of water rights for $75 million (Griffin and Characklis, 2011). Through the purchase, LCRA was able to add 100,000 acre-feet to their existing supplies in the highland lakes reservoir system and market the water to rapidly growing cities in central Texas. Identifying the opportunity to capitalize on the reallocation in the basin, the rapidly growing City of Austin entered into a contract with the LCRA in 1999, providing 201,000 acre-feet/year to the City of Austin through 2050 at a cost of $100 million (Austin Water, 2015; Lavy, 2020).

In a period of severe drought in the early 1970s, the City of San Angelo, which was dependent on dwindling surface water supplies in the upper Colorado River Basin, purchased the groundwater rights on more than 38,000 acres of land 60 miles east of the city over the Hickory aquifer. The transaction cost more than $200,000 (Williams, 1972), but it would take more than 40 years and an additional $120 million before the city received any water from those wells. Despite the challenge, the City of San Angelo has recently purchased more groundwater rights from a landowner over the Edwards-Trinity Aquifer more than 200 miles from the city with no current infrastructure to transport the supply.

Produced water has potential in a circular water market carefully guided by science and policy.

Produced water is "a complex mixture of organic and inorganic compounds and the largest volume of by-product generated during oil and gas recovery operations" (Igunnu and Chen, 2014). In the case of Texas, the current prospects for a market involving produced water are confined by the Permian Basin, but the scale in terms of volume of water is astonishing: 511,000 AF/year is recoverable for beneficial uses, although today only 256,000 AF/year is technically feasible (Texas Produced Water Consortium, 2022). Because the data are sparse, these values represent broad estimates. Today, the economic and environmental implications of reallocating produced water are problematic. From an economic standpoint, cleaning produced water is expensive, with treatment on average costing $2.55/bbl and sometimes as much as $10 per barrel (bbl) (Texas Produced Water Consortium, 2022). Data are still sparse, and there remain significant research gaps for piloting the required treatment technologies, and their limitations. Research gaps notwithstanding, for treatment to be competitive compared to alternatives (e.g., deep well injection) the price per barrel for treatment would need to be less than $1/bbl. Even if cleaning produced water were economically feasible, there are additional costs associated with transporting the produced water to willing buyers without existing water infrastructure.

From an environmental standpoint, produced water, if used outside of the oil and gas industry, carries significant health risks to humans and wildlife. According to published research led by the Environmental Defense Fund (EDF) (Danforth et al., 2020), produced water has more than 1,200 chemical constituents potentially present; less than 25% of those constituents have approved analytical methods for use and regulation, and less than 15% have toxicological data. One interviewee familiar with the consortium and produced water mentioned there was no consensus in the literature for a safe threshold for beneficial reuse of produced water outside oil and gas operations in terms of protecting against adverse impacts to human health or the environment.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Considering the levels of risk and uncertainty associated with marketing produced water in the short term, we encourage future research and investments to focus on market design within the oil and gas industry. This circular market has at least two advantages: (1) using produced water within the oil and gas industry could offset the demand that is currently being placed on native water supplies (e.g., groundwater wells) and (2) it could provide an economic incentive for oil and gas operations to improve cleaning technologies, which could lower the cost of cleaning produced water to an acceptable level for potential future uses.

What's working well in Texas water markets?

Our transactions database, interviews and literature review point to the same conclusion: that despite the need for targeted reform, enabling conditions at the state level are favorable for water markets. Specifically, Texas surface water law and its regulatory system provide the necessary enabling conditions that can support water market activities.

Enabling conditions that promote healthy water markets:

1. Functional caps are in place.

While the state does not have a formal cap, nor has it implemented statutory limitations on the authorization of new permits in any basin, there are limits on granting new water right permits, which protect existing senior water rights holders, imposed by (a) the fact that the state's river basins are fully if not over-allocated and (b) introduced Environmental Flow Standards in basins where applicable.

2. Day-to-day oversight works when in place.

Texas watermaster areas provide regional oversight of surface water administration, on a near real-time basis, by ensuring water users adhere to their priority position and special permit conditions. In cases where water scarcity is creating conflict, watermasters have been used to broker conflict resolution, a design principle for managing common pool resources (Ostrom, 1993).

3. Water markets are fulfilling multiple needs.

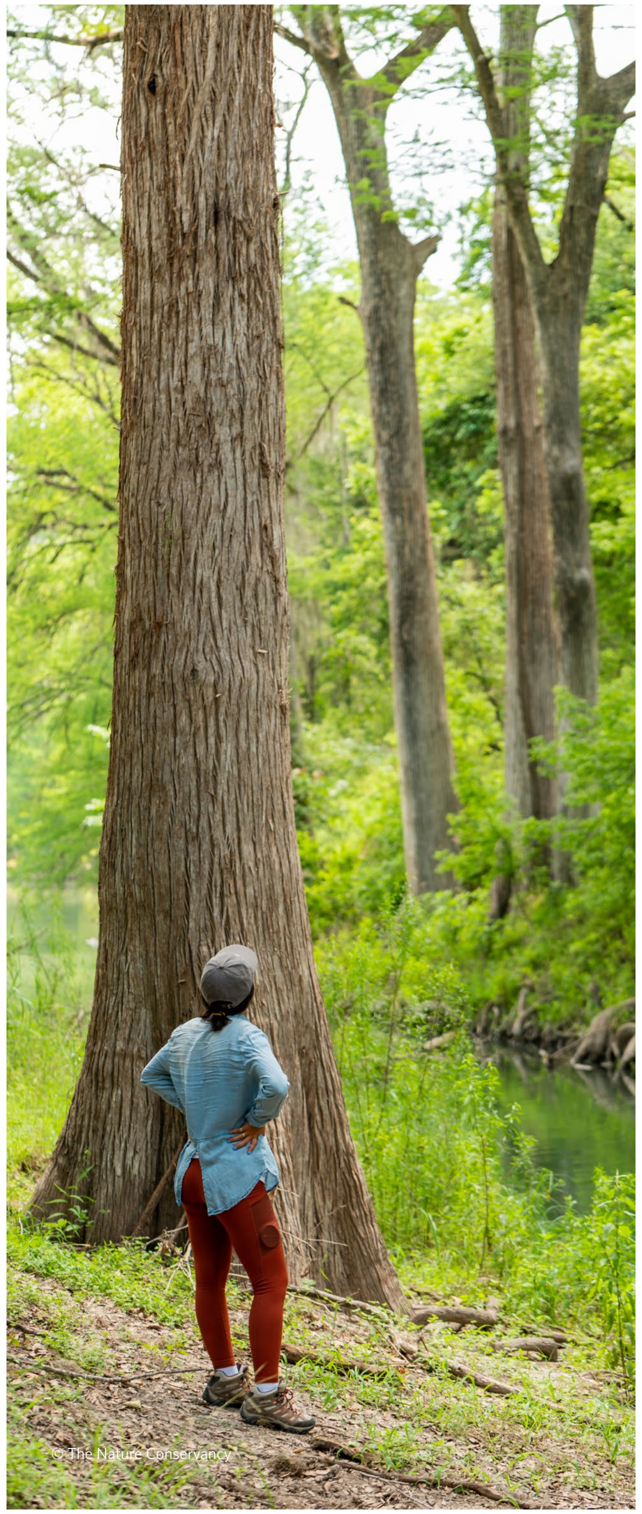
Hundreds of transactions have reallocated water to municipal uses to meet increased urbanization. Transactions that focus on providing water for the environment represent the largest area of water market growth in the state.

4. The Texas legislature has shown support for building water markets.

The creation of different water institutions (see figure 1 in the introduction) provided the necessary governance for water markets to incubate and develop (e.g., Texas Water Bank, 1993, and Texas Water Trust, 1997).

Areas for improvement, with a focus on low-hanging fruit.

Although we find evidence throughout the state of water markets designed and deployed to meet diverse objectives, there are several factors that are limiting their potential.



Factors that limit Texas' potential:

1
At present, permitting timelines, especially for permanent sales, are *restricting trading.*

2
Current application of bed-and-banks permits are limiting water rights holders' ability to market their water rights for all beneficial uses (e.g., instream), which *restrict market "depth."*

3
The current water governance and monitoring of surface water use rests on the honor system in which water users report and manage their own water usage, which, although appropriate 100 years ago, is no longer an effective approach and can *jeopardize market viability, private property rights and the reliability of water rights management.*

4
The bifurcated legal system of appropriated state water (surface water) vs. the private ownership of groundwater creates a challenge for water users and managers and *limits overall confidence in market activity* as compared to other western states.

We have outlined for the Texas Legislature seven recommendations that are evidence based and feasible within the current legal environment and that could improve the benefits of water markets for people and the environment.

Enabling conditions that promote healthy water markets:

1. **Increase funding for the Water Bank and Texas Water Trust and transfer the Water Trust to TPWD.** These institutions require funding and support for designated staff to promote and manage. Oversight by an institution working on environmental issues provides a better institutional "fit" for the Water Trust.

2. **Consider an expedited approval process for permit amendments to implement short-term leases that involve only a change in diversion points, place and purpose of use among users based on regional specific metrics (e.g., river miles) and that would not adversely affect environmental flows or availability for existing rights.** At present, with narrow exceptions, transactions are required to follow the same amendment protocols regardless of whether they involve a change in location of one mile or 50 miles. An expedited permitting system for transactions of a specific type (e.g., leases) within a specified range (e.g., defined for each basin) could promote more trading by lowering transaction times and associated costs.

3. **Revisit restrictions on bed-and-banks permit applications and allow for authorizations of all beneficial uses.** Current interpretation of bed-and-banks authorizations is too narrow and precludes transactions that could provide benefits to different water users. In particular, new authorizations for environmental flow protection should be allowed, without requiring a physical diversion, when existing rights are protected and a new appropriation is not involved.

4. **Expand watermaster programs.** Watermasters have a proven track record of improving management of water rights and water market conditions in Texas. Regional watermaster programs can better serve needs of water users at the basin level by providing near real-time protection of water rights holders that is not available outside of watermaster areas.

5. **Conduct a comprehensive study on non-use of water rights.** Significant opportunities to pursue transactions or dedications to the Texas Water Trust may exist as a result of water rights with extended periods of limited or no use (e.g., >10 years). Identification of such water rights could reveal the potential for transactions, including through placement in the Water Bank or the Texas Water Trust.

6. **Fund studies on groundwater/surface water interaction to quantify the impact of groundwater withdrawals and water management on surface water rights.** Many regions where surface water rights exist are influenced by groundwater pumping, which is not managed conjunctively. Similarly, groundwater supplies can be affected by surface water pumping. Studies to help quantify the relationship between groundwater pumping and surface water withdrawals would provide the potential to improve the management of both water resources and, especially, to improve water planning.

7. **Provide Groundwater Conservation Districts with the resources, including updated and improved groundwater availability models, to identify and manage for sustainable levels of groundwater pumping.** Improved information and management approaches, including consideration of environmental needs, would set the stage for more effective water markets.

CONCLUSION

Texas in 2023 is a different place than Texas in 1923, and projections suggest that by 2060 the state will have gone through a series of additional transformations—including how it manages water. We provide the first state-level analysis of historic trends (1987-2021) in surface water markets by linking literature, transactions data and expert interviews to provide an evidence-based perspective on their performance. We find that water markets of different types have been continuously active and fulfilling multiple demands for multiple types of users across the state. We illustrate using transactions data from 13 basins that water leases occur more frequently and are cheaper than sales and have been used to move significant volumes (>260,000 AF) of water to the environment in recent years. We provide illustrations of different basins' water market activity as well as an example of an environmental water transaction to demonstrate the diversity of Texas water markets. We situate these findings in the context of an evolving institutional landscape—one that has required support by the Texas Legislature for more than 100 years. Further tailored by expert interviews and a scoping review, we provide lists of what is working well with Texas water markets and what can be improved, as well as a set of seven specific recommendations that provide pathways for improving the public and private benefits of water markets. Our review suggests that Texas is at a crossroads in terms of managing its most valuable resource in a time of unprecedented pressures. As evidenced by our transactions database, we believe water markets can play a role in helping Texas manage its water resources, specifically in times of scarcity and as a tool to help reallocate water to different users. Our results are hopeful and demonstrate that the hard lifts like legal enabling conditions are already in place and that investments today should focus on targeted improvements to ensure that future design and use of water markets in Texas are sustainable and inclusive.

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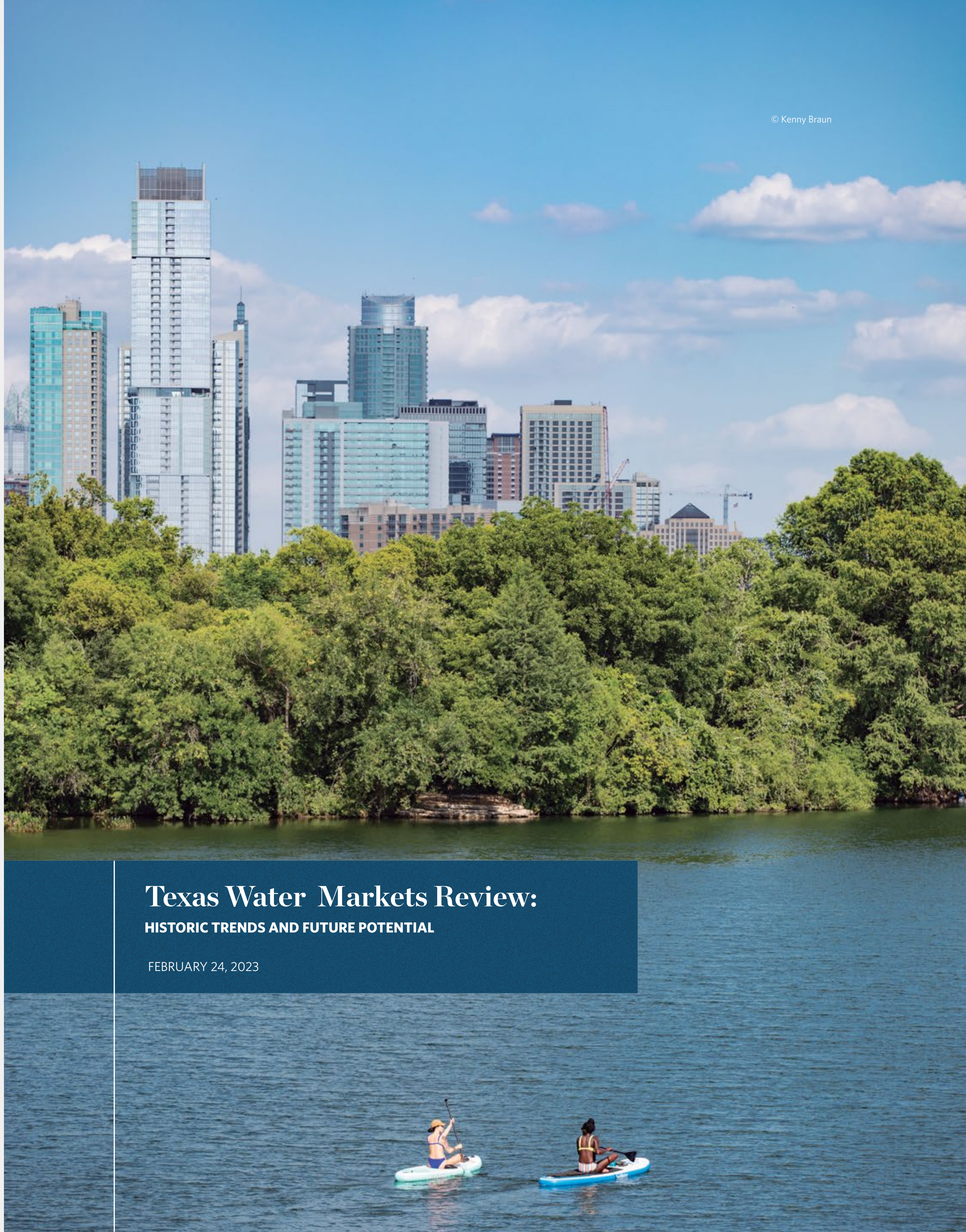

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Texas Water Markets Review:

HISTORIC TRENDS AND FUTURE POTENTIAL

FEBRUARY 24, 2023

The Nature Conservancy Texas

TEXAS LIVING WATERS PROJECT

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