WATER MARKETS FOR TEXAS

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TABLE OF TERMS

Short Name or Acronym	Descriptive Name
acft	acre-foot
AR	aquifer recharge
ASR	aquifer storage and recovery
BBEST	Basin and Bay Expert Science Team
BMWD	Bexar Metropolitan Water District
BRA	Brazos River Authority
DFC	desired future condition
EAA	Edwards Aquifer Authority
EAHCP	Edwards Aquifer Habitat Conservation Plan
GBRA	Guadalupe-Blanco River Authority
GCD	groundwater conservation district
GDP	gross domestic product
GMA	groundwater management area
gpcd	gallons per capita per day
HB	house bill
MAG	modeled available groundwater
MUD	municipal utility district
PGMA	priority groundwater management area
RWRDG	Regional Water Resource Development Group
SARA	San Antonio River Authority
SAWS	San Antonio Water System
SB	senate bill
TCEQ	Texas Commission on Environmental Quality
TDWR	Texas Department of Water Resources
TWDB	Texas Water Development Board
VISPO	Voluntary Irrigation Suspension Program Option
WCID	water control and improvement district

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INTRODUCTION

In 1997, the Texas Legislature established a preference for the voluntary transfer of water through markets in Senate Bill (SB) 1. Since then, little has been done to encourage or facilitate voluntary transfers through water markets. This report substantiates that water markets are effective tools for encouraging and facilitating the voluntary transfer of water, and regional water markets are an essential water management strategy. They foster more efficient and effective water use, reduce conflicts over water supplies, and in some cases reduce the amount of water use by assigning a needed value to water.

This report will examine existing water markets in Texas and elsewhere that enable voluntary water transfers that result in more efficient and effective use of existing water resources. Moreover, this report includes two case studies of established Texas water markets that are changing water use, in the Lower and Middle Rio Grande Valley and the Edwards Aquifer. This report will also describe how policy frameworks and characteristics enable those water markets to operate and how those water markets in turn benefit their regions.

This report will also characterize the barriers to establishing new Texas water markets and identify potential statewide or local policy interventions to encourage regional water market creation and development. Finally, this report will describe strategies for thoughtfully creating new regional water markets in Texas.

CHAPTER 1. WATER MARKETS

A. Water as a Commodity

Water is a commodity that is bought and sold. For most of us, we demonstrate this when we purchase bottled water or pay our utility bills. However, water has unique characteristics that set it apart from assets such as land and commodities that can be traded in a market. Water moves in a journey from the sky to the sea and back again, while land generally is stationary.

Water is a complex commodity, with attributes like those of public and private goods (Western Governors' Association, 2012, p. ix). For private commodities, such as crops or hydrocarbons, markets generally set prices where supply and demand intersect. Public commodities, such as water, are more difficult to value and apportion using the supply and demand framework because the current water-appraising mechanisms do not necessarily reflect water's intrinsic value as a scarce resource. Misconceptions about water transactions occur partly due to misunderstanding water's unique characteristics (Hanemann, 2022, p. 5). For example, water, oil, and electricity can all be supplied by utilities and corporations—but while oil and electricity are beneficial, only water is indispensable for human life. The electricity supply is manufactured, while oil and water supplies are provided by nature. Water infrastructure collects, cleans, and distributes water but does not generate it. Electricity is hard to store but easy to transport, while oil and water are relatively easy to store, but difficult to transport. Water distribution systems are typically not built for open market distribution but are instead created for specific users, limiting who can trade water. Electricity and oil are exchanged within daily or hourly markets that are impractical for water (Hanemann, 2022, p. 5).

When water is priced as a commodity, that price sends a signal to sellers, buyers, and users regarding the water's ultimate treatment. The lower the price, the more freely the water will be used. The higher the value, the more conservatively the water will be used. Like most commodities, the price of water is influenced by its scarcity. However, water's price is dictated more by the cost of the infrastructure network that cleans and distributes it than by water's availability. Water infrastructure networks last a long time and modifying their capacity is excessively expensive. Water projects are heavily subsidized, and large amounts of public water are held by private entities. Decisions concerning the water's extraction, use, and reuse can affect other users dependent upon the same water resource, including parties who are not involved in the decision-making process. Water extraction and transport out of its area of origin can be seen as a threat to that area's future, unlike with electricity, oil, and natural gas. These are major reasons why unregulated markets for surface water transfers do not exist (and are rare for groundwater) and transfers are controlled by state regulatory agendas (Kaiser & Phillips, 1998, p. 429).

Water's value as a commodity can vary enormously depending on location, use, and other factors, as can its value in terms of economic return. Today in Texas, the value of water is generally highest for hydraulic fracturing (fracking) for oil and gas resources and lowest for agricultural water. In Texas's 2002 State Water Plan, the Texas Water Development Board (TWDB) calculated the economic benefits of using 1 acre-foot (acft)[1] of water among different sectors within the regional water planning groups (Table 1). For example, in Region L—which includes San Antonio and the Edwards Aquifer—TWDB found that the benefit of 1 acft of commercial water use was $335,305. In contrast, the 1-acft benefit of residential water use was $39,514, and the 1-acft benefit of water used for irrigation was $121 (TWDB, 2002, p. 120).

Table 1. Direct economic benefit per acre-foot of water for different water uses in the regions (based on 1995 economic benefits and shown in 1999 dollars).

Region	Residential	Commercial	Steam-Electric	Mining	Irrigation	Livestock
A	34,946	122,096	65,348	12,698	298	33,748
B	55,738	160,682	7,650	14,919	338	10,913
C	47,900	148,779	35,012	21,029	467	1,950
D	50,653	176,674	8,867	35,447	111	16,503
E	25,228	218,148	61,636	12,144	161	1,627
F	34,437	193,356	15,459	10,643	187	16,734
G	41,856	240,578	11,358	9,109	317	11,907
H	46,852	246,079	36,670	24,352	115	11,905
I	47,079	162,198	16,407	44,021	116	1,737
J	41,308	141,557	0	9,613	186	13,379
K	41,328	207,736	1,456	8,311	160	1,927
L	39,514	335,305	6,501	5,786	121	8,839
M	28,414	153,365	28,535	3,666	283	8,839
N	51,988	123,361	64,854	10,673	90	1,109
O	34,771	208,509	11,744	18,792	169	31,986
P	54,258	188,221	0	33,665	179	9,268

Source: Water for Texas 2002, Texas Water Development Board (2002), Table 12-1, page 120.

[1] 1 acre-foot of water equals 325,851 gallons.

B. What is a Water Market?

Given the unique properties of water as a commodity, water markets differ from other commodities markets. In general, a market is a platform for transactions in which something of value may be exchanged or traded; water markets apply this framework to water. However, the term "water market" has been used in so many different water-related circumstances that it has been diluted to include any trading of water or water rights. **Here are some examples of how "water market" has been defined in academic and professional literature:**

- "[A] "water market" can be described as a stock market for water. Instead of offering financial products like stocks and bonds, sellers in water markets can offer short- or long-term leases on their water rights and even sell them outright" (Kumar, 2019, para. 3).
- "A water market is an institutional structure designed to facilitate the transfer of rights and titles to ownership in water or rights or in rights to use water" (Kaiser & Phillips, 1998, p. 414).
- "A water market is a complex interaction of individuals and institutions — the product of a large number of people, structures, operational mechanisms and rules" (Head et al., 2021, p. 1).
- "Water markets – the rights to use water are traded among water users, government agencies, water utilities or non-governmental organizations; this trading is facilitated by governance conditions including formally defined water rights with associated monitoring and enforcement, and a fixed cap on total water use. … A water market brings together willing buyers and sellers wanting to exchange water rights. Buyers are looking for the right to use more water. Sellers are willing to trade some of their water rights for monetary compensation" (Richter, 2016, pp. 42, 81).
- "Water markets are considered to be voluntary mechanisms that stimulate the flexible transfer of water, more efficiently use water within a system, and if well designed, can also have environmental benefits. Generally, water market strategies can range from water banking, short-term water leases, fallowing agreements, non-diversion agreements, acquisition of rights (either permanent or leased), and other demand reduction and water management strategies. The key is that an agreement about water use between a willing seller and a willing buyer" (Lieberknecht, 2018, p. 1).

While these definitions cover many aspects of what this report considers to be a water market, none of them contain every key element of a water market. Therefore, to properly orient the discussion, this report defines a "water market" as an organized and regulated system that facilitates temporary and/or permanent exchanges of water usage rights from any source, among voluntary participants, within a specific geographic area.

Water markets can be created for the exchange and transfer of water from any source. Existing water markets facilitate the exchange of surface water or groundwater. Surface water and groundwater volumes are not interchangeable generally: surface water transactions generally occur between surface water users, and groundwater transactions generally occur between groundwater users. In each market context, one water user sells or leases a portion of their predetermined water allotment to another user, who uses the agreed-upon amount of water.

Successful water markets require water scarcity as an initial condition and water availability through voluntary transfers as the potential solution. If there is a substantial difference between the water's value where it is located and the value where it is demanded, then there is an opportunity to convey water through a market transaction. As with other natural resource commodity markets, such as those for oil and gas, there is a long history of government-subsidized support and substantial quantities of public water—being controlled by private entities.

Water markets are an attractive management strategy for areas where more frequent and intense droughts are exacerbating water scarcity. However, why water markets emerge in certain situations rather than others is not well understood (Breviglieri et al., 2018, p. 1087). Where water markets develop economic, legal, institutional, technical, and hydrological elements coalesce. In these instances, and as evidenced within the Edwards Aquifer and Lower and Middle Rio Grande water markets that will be discussed later, buyers may obtain water supplies and sellers may accrue greater benefits by transferring their water instead of using it for their own enterprises (Kaiser & Phillips, 1998, pp. 427–432).

"What is a water market? Regions within which water can be traded. Geographic areas within which water rights can be traded within the existing regulatory and physical system."

- Water rights broker

Water markets can be defined geographically, such as within a single watershed or aquifer, multiple surface watersheds or aquifers, or a combination of surface watersheds and aquifers. The physical nature and hydrological boundaries of the water resource serve as key elements in defining the contours of a given local water market. Water markets generally rely upon natural conduits to deliver water, such rivers and aquifers. However, water markets can be created for a variety of systems, including reservoirs, conveyance infrastructure, aquifer storage and recovery (ASR) facilities, and combinations of these options.

C. What are Water Transactions Versus Water Markets?

It is important to draw a distinction between water transactions that occur inside and outside of a water market. The term "water transactions" is frequently used without context in discussions of water markets in the literature, in the media, among decision-makers, and even within the community of water professionals. The resulting confusion has impeded water markets' adoption as a powerful solution to growing water resource challenges. While water transactions outside of a water market can be useful, their usefulness within a water market is potentially much greater. Water transactions' existence does not necessarily indicate the presence of a water market as previously defined. Water transactions can occur inside and outside of water markets, but the transactions are different. Transactions outside of water markets are often referred to as "water marketing." Water transactions, also referred to as water transfers, can move water between any uses or users. The National Research Council has defined a water transfer as "any change in the point of or a change in the type or location of use" of water (Chong & Sunding, 2006, p. 246). The Western Governors' Association defines a water transfer as follows:

- "A water transfer is a voluntary agreement that results in a temporary or permanent change in the type, time, or place of use of water and/or a water right. Water transfers can be local or distant; they can be a sale, lease, or donation; and they can move water among agricultural, municipal, industrial and environmental uses" (Western Governors' Association, 2012, p. 8).

Water marketing transactions typically involve a fixed price and may include the conveyance of water from one region to another. This is why many water marketing transactions are treated with suspicion. Further, water marketing transactions may not involve public participation as genuine markets do, largely due to their asymmetrical nature. Water transactions can occur in established, organized, and readily accessible surface water or groundwater markets with well-defined structures. Alternatively, they can occur sporadically outside of true water markets. We often ignore the distinctions between water exchanges with and without a formal agreement or contract, and refer to them interchangeably as water trades, transfers, and exchanges (Hanemann, 2022, p. 4).

D. What are the Different Types of Water Transactions within a Water Market?

Generally, water markets rely on transactions where quantities of water are sold by a willing seller to a willing buyer. Many types of transactions occur within a water market—but they often do not fit the traditional economic definition of a market and sometimes do not involve monetary compensation (Western Governors' Association, 2012, p. 42). Still, water transactions generally vary in four major ways:

1. **Type:** Transactions within water markets come in a variety of forms, explained in detail on the following pages.
2. **Scale:** Transactions can involve volumes of water ranging from well over 100,000 acft to under 1 acft of water.
3. **Duration:** The time scales of transactions range from permanent transfers such as water right sales to temporary transfers such as leases.
4. **Water-sharing arrangements after the initial transaction:** In addition to straightforward sales and leases, other agreements exist that allow for continued water use by the original right holder.

Several sources have examined the range of water transactions being deployed (Chang & Griffin, 1992, p. 879; Chong & Sunding, 2006, pp. 252, 254; Fazeli et al., 2021, p. 83; Montilla-López et al., 2016, p. 466; TWDB, 2003, p. 24; Western Governors' Association, 2012, pp. 48–51). Types of transactions within water markets include:

- **Water sales:** Volumes of or rights to surface water, groundwater, reclaimed water, or conserved water rights[2] are transferred through a permanent agreement or contract.
- **Water leases:** Surface water, groundwater, reclaimed water, or conserved water rights are leased for annual or multi-year terms. Short-term or annual leases can also be referred to as "spot market" transactions.
- **Water sale/leasebacks:** The seller of a water right reserves the option to lease the water associated with that right from the buyer at little or no cost. These transactions may include options agreements where water is leased by the seller as requested by the buyer.
- **Options contracts:** Options contracts and forbearance agreements for surface or groundwater involve one party paying a water right holder to not use their permitted water under certain circumstances. These include dry-year options where a party may pay an agricultural user not to irrigate during drought or other low-flow years. Options contracts may be used as water supply strategies and for other uses such as to reserve

[2] Conserved water is the amount of water saved by water right holder through practices, techniques, and technologies that would otherwise be irretrievably lost to all consumptive beneficial uses arising from storage, transportation, distribution, or use.

water for environmental flows[3] for the health of bays and estuaries, such as described in McColly et al. (2021).

- **Water rights trades and institutional transfers:** These transactions involve the trading of existing surface or groundwater rights for other surface or groundwater rights within the same watershed or aquifer, or occasionally between different water sources in different states. This can include institutional transfers where one government agency exchanges a water right with another agency, such as in the western United States, where a federal agency can own surface water rights.
- **Water rights donations:** An existing water right holder may donate all or a portion of their water right towards another user or specified beneficial purpose. For example, Texas surface water rights may be dedicated to the Texas Water Trust to ensure the maintenance of water rights for environmental flows.
- **Water rights retirements:** A water right, or portions of a right, are retired in exchange for funding for water conservation measures that result in an equal or greater benefit to users. One common example includes paying to install advanced irrigation technology for agricultural purposes that reduces net water use, allowing the associated water right to be retired.
- **Subordination agreements:** Under these agreements, a senior water right holder consents (usually with compensation) to subordinate their senior right to a junior water right, meaning the junior water right is treated as if it were the senior right. These agreements work within water bodies governed under the prior appropriation system, like Texas's surface water resources, where water rights granted earlier in time are more senior than those subsequently granted.
- **Water banks:** These are water market mechanisms through which public or private entities act as intermediaries in the trading of rights, matching buyers to sellers via a set of rules that are designed to reduce transaction costs and risks. Water banks can potentially serve as a type of water market.
- **Groundwater banking:** This water market strategy involves storing surface or groundwater within aquifers for subsequent use. The aquifer storage facilities work as literal banks that during wet years, store surface water or groundwater—often from imported sources—that can be used during dry years. Groundwater banks should not be confused with water banks.
- **Groundwater ranching:** Typically conducted by cities, groundwater ranching involves purchasing land (often irrigated) overlying groundwater resources that the buyer can develop (or pump). Another term for this type of transaction is "buy and dry." One example of this type of transaction occurred in the Texas Panhandle, when T. Boone Pickens purchased the groundwater right associated with 211,000 acres of land for $130 million. Pickens ultimately sold those rights to the Canadian River Municipal Water Authority to provide municipal water supplies to Amarillo and Lubbock (Texas House Committee on Natural Resources, 2018, pp. 95-96).

[3] An environmental flow is defined by TCEQ as "an amount of water that should remain in a stream or river for the benefit of the environment of the river, bay, and estuary, while balancing human needs" (TCEQ, n.d.a, para. 3).

- **Internal leasing of stored water:** In this form of leasing, the purchaser of stored water within a surface water project (such as a reservoir) leases water that they have reserved for their future needs, but do not need in the immediate future. Typically, this is controlled by the water districts that own the right to the stored water.

Most transactions involve water that is used for agricultural irrigation since agriculture is the largest category of water use. One strategy for making irrigation water available for a water market is to fallow farmland. Short-term fallowing gives the lessee the option to take water during some seasons instead of the obligation to accept water delivery for every year of the lease. Long-term fallowing through long-term leasing allows on-farm water conservation, system conservation, or the substitution of local water supplies to make water available. The farm then releases the water available through its underlying water right to complete the transfer.

Within most water markets, the sale or lease of water rights are the two most common transactions. Moreover, and as evidenced within the Edwards Aquifer and Rio Grande water markets that will be discussed later, these transactions reallocate water from lower value uses to higher value uses.

E. What are the Benefits of Water Markets?

Traditional command and control systems for water management are often inflexible, provide little incentive for innovation, and rarely implement effective and efficient water solutions (Cantin et al., 2005, p. 2). However, when water is exchanged or traded, there are two different types of potential benefits. The first is flexibility, which is typically a short-term benefit allowing water users to satisfy their demands (Hanemann, 2022, p. 3). Water supplies and water demands fluctuate based on many factors, e.g., weather, changes in demand for agricultural commodities, home construction, and new industrial needs. The second potential benefit is reallocation of water, which is typically a long-term benefit (Hanemann, 2022, p. 3). Reallocation is fueled by long-term movements, such as urban population growth requiring water supplies to move from agricultural to municipal use and water supply changes resulting from climate change. Dealing with these long-term changes requires a reallocation of water among different uses or users. Flexibility and reallocation are economically beneficial and lead to more efficient uses of water by promoting economic efficiency in different ways and on different time scales (Hanemann, 2022, p. 3). While leasing transactions within water markets produce less reallocation of lower valued uses to higher valued uses, the flexibility they provide is critical for reducing conflict among users.

Water markets offer several advantages as a water supply strategy. Allowing water to be traded—on a temporary or long-term basis, or through a permanent sale of a water right—can significantly lower the cost of managing water demand (Bardeen, 2021). For example, voluntary transfers through water markets have obviated the need for several water supply projects recommended in multiple editions of the State Water Plan. Water markets can enhance and amplify existing water supply systems by facilitating voluntary transfers of available water quantities that are appraised and exchanged at a price that better reflects their values.

Water's value in terms of economic return varies for different uses. In Texas, the value is generally higher for municipal uses than it is for agriculture. Well-designed water markets can reallocate water from lower value uses to higher value uses while simultaneously minimizing the impacts to communities dependent on low-value water uses. Moving water from lower value uses to higher value uses can have substantial benefits for the economy.

Beyond providing new water sources for higher value water users—such as municipalities—water markets offer other benefits. Several sources have identified a range of these benefits, detailed below (Breviglieri, 2018, pp. 1076, 1077; Texas House Committee on Natural Resources, 2016, 2018; Filatova, 2014, p. 227; Kaiser, 1994, p. I; Kaiser & McFarland, 1997, p. 822; Kaiser & Phillips, 1998, pp. 427–429; Oregon Institute for Water and Watersheds, 2012; Richter, 2016, p. 44; Western Governors' Association, 2012, p. ix; U.S. Environmental Protection Agency, n.d.).

1. **Adaptive water management:** Adaptive management provides flexibility and tools to move water to accommodate new and emerging uses over time and during droughts, rather than locking water into a single use in perpetuity. Markets offer a mechanism for real-time adaptive management for water needs, enhancing allocation flexibility and allowing communities to quickly adapt to changing conditions and personal preferences by enabling water transfers.
2. **Agricultural water conservation:** Conservation is promoted by providing an incentive for agricultural water users—the largest water users in Texas and the United States—to shift to crops that use less water, invest in improved irrigation technology, and implement other water-saving practices.
3. **Rural and agricultural revenue opportunities:** Agricultural users receive new revenue-generating opportunities and options for averting irrigation shortages during droughts.
4. **Voluntary water transfers:** Water is allocated to new uses to meet emerging water demands through a voluntary market framework rather than through regulations and mandates, because all transactions are voluntary and occur between willing sellers and buyers. This approach helps avoid governmental intervention by facilitating resource decisions between resource users and decentralizing decision-making regarding water, ensuring better accommodation of local conditions and unique circumstances. Market mechanisms to allocate and reallocate water between competing uses can be more successful in achieving water efficiency than a rigid, centrally controlled process that does not rely on a price signals.
5. **Greater investment in water:** Investment in water increases as the price of water rises with increased demand. Higher market prices will support investment in water conservation, improved water resource management, and new infrastructure required to facilitate water transfers.
6. **Reduction in net water use:** Water markets assign a price for water, which in turn informs users of its relative value, especially within water-scarce areas. Water markets therefore provide strong stimulus for reducing consumptive water use because a water-saving entity can be rewarded financially by selling or leasing the unneeded portion of its water right. Appropriate water pricing also discourages waste.

7. **Alternative water management strategy:** Users can increase their supplies by obtaining water through a market. This can reduce the need for additional water supplies that may be more expensive and time-consuming to develop, and which may have significant environmental impacts.
8. **Improving water productivity and allocation efficiency:** Water markets discourage wasteful or low-value water uses which represent unrealized financial gains for the water right holder. Trading water facilitates the reallocation of water rights to more productive uses, usually resulting in more revenue generation in local economies, and maximizing the benefits for both water buyers and sellers, when water markets are efficient and based on the laws of supply and demand.
9. **Environmental protection flexibility:** Purchasing water in a market and dedicating its use to environmental purposes creates opportunities to restore water flows in depleted freshwater and estuarine ecosystems, also known as in-stream and environmental flows. Water markets can internalize the costs of protecting environmental flows, thereby reducing or eliminating the need for external funding.
10. **Recreational opportunities:** Water markets can provide water for a range of recreational water needs, including fisheries and outdoor activities. For example, Trout Unlimited and the Nature Conservancy have leased and purchased water rights to supplement flows in recreational fish habitats. In Central Texas, companies that depend on specific flows for kayaking and tubing have paid for storage releases from Canyon Lake to enhance flows on the Guadalupe River.
11. **Improving water quality:** Water markets can quantify the water quality benefits of rivers, streams, lakes, ponds, wetlands, and aquifers and translate them into credits through water quality trading. For example, wastewater treatment plants faced with substantial costs to upgrade treatment technologies can pay for nutrient reduction at other wastewater treatment facilities, farms, or other nutrient sources to achieve the same or better water quality outcome at a lower cost.
12. **Reducing flood impacts:** Market based instruments can quantify the flood attenuation benefits of rivers, streams, lakes, ponds, wetlands, and aquifers and translate them into credits that can be bought and sold.
13. **Better water use data:** When water is appropriately priced, water use accounting improves, because water providers and users are more willing to participate in practices such as metering.
14. **Private property rights protection:** Markets can protect the private property rights of sellers and third parties by making water rights universal, exclusive, transferable, and enforceable.

A critical but often overlooked result of water markets is that they can change not only water management systems, but also human behavior related to water use. Water markets' ability to change the water users' behavior is examined in Chapter 2.

F. What are the Requirements for a Successful Water Market?

Successful water markets require certain key elements that have been described by a number of sources including Ayres et al., 2021; Texas House Committee on Natural Resources, 2016; Kumar, 2019; Richter, 2016; Schumacher, 2020). These key elements include:

1. Water scarcity and rising demand for water within the area served by the water market;
2. A fixed allocation of water (limit or cap) on the total allowable or permitted water use or consumptive use of water within the water market;
3. Legally defined, enforceable, and secure water rights or entitlements;
4. The ability and flexibility to efficiently transfer water rights between users or sectors;
5. The existence of significant volumes of inefficiently used water within the watershed or aquifer, providing the liquidity necessary for the water market to function[4];
6. Local community stakeholder participation in and support for the water market's creation;
7. The ability to monetize and/or trade conserved or available water;
8. A central exchange for transfers so buyers and sellers have a venue for transactions;
9. A registry of rights and a common understanding of the rules governing transfers, so water rights or entitlements are understood by all parties involved in a transaction;
10. Reliable measurement, monitoring, and enforcement systems to ensure compliance with rules and regulations and for verification of transactions;
11. A sound basis in hydrology, ecology, and engineering for the structure of the market to inform management, environmental, and social outcomes;
12. An approval process that protects third party interests, while being efficient enough to not add significant costs or delays, because excessive transaction costs and time requirements will discourage transactions;
13. A method to convey water from its original point of diversion to the new place of use;[5] and
14. A trusted entity that oversees the water market and enforces limits and other rules that protect participants' property rights.

[4] Because agriculture is the largest category of water use globally, agricultural water use typically provides this component of the required volume of water.

[5] Transfers can be authorized to use natural channels, with protection for other right holders, depending upon the circumstances. In practice, water transfers almost always take advantage of unused capacity in existing infrastructure rather than new construction.

Of the elements listed above that are necessary for a functional water market, the first—fixed allocations—is the most important. Water markets are not created according to one rigid template, and developing and implementing appropriate water market structure and rules can require significant time. Periodic adjustments may be needed to match changing hydrologic, economic, and political circumstances. This means that expertise in water market design is beneficial when creating a water market with a structure that balances the complexities of operations, management, and oversight.

Most water markets in the western United States do not meet the conditions listed above, primarily due to a lack of clear water rights, which are difficult to trade (Kumar, 2019). Exceptions to this exist in Oregon, Washington, and Colorado, where examples of well-structured water markets are managed by the Deschutes River Conservancy, the Washington Department of Ecology, and the Northern Colorado Water Conservancy District (Northern Water). In Texas, the Rio Grande and Edwards Aquifer water markets are well-structured, as discussed in Chapter 2. The successful elements described above are evident in both of these Texas water markets.

CHAPTER 2. EXISTING WATER MARKETS AND THEIR IMPACTS

A. The Rio Grande Water Market

1. Background

The Rio Grande has four main tributaries: the Rio Conchos and the Rio San Juan in Mexico, and the Pecos and Devils rivers in the United States (Figure 1). Two major main-stem reservoirs have been constructed on the river in Texas. Falcon Reservoir, which is between Laredo and McAllen, was completed in 1954, and Amistad Reservoir, which is upstream of Falcon Reservoir, northwest of Del Rio, was completed in 1969. Of Falcon Reservoir's conservation capacity, 58.6% (1,551,007 acft) was allocated to the United States, and 41.4% (1,095,810 acft) was allocated to Mexico (Water Data for Texas, n.d.b). Of Amistad Reservoir's conservation capacity, 56.2% (1,840,849 acft) was allocated to the United States, and 43.8%, (1,434,683 acft) was allocated to Mexico (Water Data for Texas, n.d.a).

Groundwater supplies are minimal in the Rio Grande's lower and middle segments, making surface water the primary water source. For purposes of management, the Rio Grande is divided into three segments:

1. The Upper Rio Grande, from Fort Quitman south to the confluence with Amistad Reservoir;
2. The Middle Rio Grande, from Amistad Reservoir south to the confluence with Falcon Reservoir; and
3. The Lower Rio Grande, from Falcon Reservoir south to the confluence with the Gulf of Mexico.

Figure 1. Rio Grande Basin with major reservoirs.

Source: Encyclopedia Britannica, 2011.

During Texas's drought of record—the 1950–1957 statewide drought—there were more claims for water in the Rio Grande than available water. Consequently, during the peak and final full year of the drought in 1956, the State of Texas filed a suit against 40 water districts and hundreds of corporations and individuals. The suit was filed so a court could determine which water rights were valid and then determine the nature and extent of each valid water right. The case, *State of Texas v. Hidalgo County Water Control and Improvement District 18* (also known as the Valley Water Case), was decided in 1969 by Special Judge J. H. Starley (Chang & Griffin, 1992, p. 879).[6] At that time, the Rio Grande, like all Texas rivers at one time, had numerous users with unrecorded water rights claims. The State's case requested that a state district court adjudicate the surface water rights in the Lower Rio Grande segment. Adjudication is a judicial process where a water right is clarified, and the location, amount, use, timing, and priority date for the water right is permanently established through a court decree. Pursuant to the ruling in the Valley Water Case, a court-ordered water management plan for the Rio Grande system was developed and operational by 1971.

Judge Starley's plan required that the two main channel reservoirs on the Rio Grande, Amistad and Falcon, operate as one system (Jarvis, 2009, p. 4). Similar conjunctive management arrangements requiring coordinated reservoir use exist elsewhere, including lakes Powell and Mead on the Colorado River and lakes Buchanan and Travis on the Colorado River of Texas. The court's plan first prioritized water rights based on use instead of when they were issued. This change prioritized municipal, industrial, and domestic uses above certain other water rights, including those for agriculture, which constituted the vast majority of rights in the system. The second priority was the system, or operating reserve, that bears all conveyance and evaporative losses of the system. Irrigated agriculture, which accounts for most permitted water in the Middle and Lower Rio Grande, and mining were established as lower priorities.

This contrasts with the prior appropriation scheme for surface water in the Upper Rio Grande and other Texas river basins, where water rights are managed according to the "first in time, first in right" priority system. Middle and Lower Rio Grande surface water rights became correlative as the result of the permanent court injunction against seniority in water rights found in the Valley Water Case's final judgment (*State v. Hidalgo County Water Control & Improvement District No. 18*, 1969). Under this correlative regime, periodic shortages or excesses of surface water are shared equally by all surface water right holders within each priority of use through proportional allocations or reductions.

Because seniority is absent in the Middle and Lower Rio Grande, there is no seniority-based value of water. In the Middle and Lower Rio Grande, irrigated agriculture rights are reduced by 50% or 40% when they are converted to municipal, industrial, or domestic rights, which are more likely to be used every year (Rio Grande Regional Water Authority. 2005, p. 2). Converting irrigation rights to municipal, industrial, or domestic rights results in a first-priority right,

[6] Judge Starley was appointed by the Texas Chief Justice after attempts to find another judge were unsuccessful, even though Judge Starley had a potential conflict of interest.

therefore increasing the value of the right. These reductions of permitted water through the conversion process work to reduce water overallocation within the Rio Grande.

The final judgment in the Valley Water Case also adjudicated 135,980 acft of municipal, industrial, and domestic use rights in the Lower Rio Grande (Jarvis, 2007, p. 14). The Rio Grande water market expanded from the Lower Rio Grande to include the Middle Rio Grande water market in 1984, after water rights in that segment were adjudicated (Chang & Griffin, 1992, p. 880). In the Middle Rio Grande, 43,290 acft of municipal, industrial, and domestic use rights were adjudicated (Jarvis, 2007, p. 14).

Both the management plan and the adjudication of water rights within the Middle and Lower Rio Grande were essential prerequisites for development of the region's water market. The next step came with the Legislature's creation of the Rio Grande Watermaster.

2. Rio Grande Wastermaster Program

When the court's water management plan for the Rio Grande system was introduced in 1971, the Legislature directed the Texas Water Rights Commission (now the Texas Commission on Environmental Quality [TCEQ]) to implement Judge Starley's plan and oversee it through the Rio Grande Watermaster's office. The first Rio Grande Watermaster Program began in the 1950s as a voluntary program known locally as the "Falcon Compact" (Stubbs et al., 2004, p. 4). The Rio Grande Watermaster's office controls the surface water use in the Rio Grande Basin water market from Fort Quitman to the Gulf Coast and closely monitors all diversions within its jurisdiction. Meters are required at every authorized diversion point in the Middle and Lower Rio Grande. All water right holders pay nominal fees (transaction costs) to reimburse the watermaster for expenses involved in the administration of the watermaster program.

There are 29 irrigation districts in the Lower Rio Grande that divert water from the river and distribute it through a system of canals. These districts contact the watermaster to request river diversions, and the watermaster then contacts the International Boundary and Water Commission to request releases from Falcon and Amistad reservoirs (Stubbs et al., 2004, p. 7). As much as 40% of the water delivered via canal is lost to seepage and evaporation (Naishadham, 2021), and when less water is moving through the canals, the amount of evaporation can increase. Many canals in the Lower Rio Grande are over 100 years old and originally delivered large amounts of water infrequently for irrigation. With more frequent, smaller deliveries for municipalities, water loss via these canals will likely increase unless they are replaced with pipelines (Naishadham, 2021). The Cameron County Irrigation District #2 in San Benito, Texas replaced 50 miles of their 250 miles of open canals with a pipeline that ranged in cost from $250,000 to $1 million/mile (Naishadham, 2021).

Because flows in the Middle and Lower Rio Grande are minimal without releases from Amistad and Falcon reservoirs, the lowermost reservoir, Falcon, is considered the diversion point for all downstream diversions. Given that reservoir releases travel across the same stretch of the river and diverters are concentrated close to the Gulf of Mexico, the movement of water within the market is considered inconsequential for return flows or instream flows, meaning that the "no injury" rule[7] is satisfied regarding surface water right holders (Griffin & Boadu, 1992, p. 275).

Water below Amistad Reservoir is allocated on an account basis, similar to a bank account where there is a constantly changing balance. Priority is given to accounts with municipal rights, and at the beginning of each year, the account balance for each municipal water right resets to its full authorization. Municipal water right priorities are guaranteed through the monthly reestablishment of a municipal water reserve in the Middle and Lower Rio Grande system totaling 225,000 acft, an amount equivalent to 1 year of average diversions for all Texas municipal demands below Amistad Reservoir to the Gulf of Mexico (TCEQ, n.d.b). Rio Grande water for irrigation below Amistad Reservoir is allocated according to an irrigation water right holder's total acreage and is based on two classes of rights. Class A irrigation rights were statutory water rights prior to adjudication. These rights were allocated more water per acre of irrigated land than class B irrigation rights, which were based upon riparian use or unrecorded water right claims.[8]

Unlike the allocations for municipal, industrial, and domestic uses, which reset to their full amount at the beginning of each year, irrigation water rights are not reset at the beginning of the year and rely on balances that are carried forward each year (TCEQ, n.d.b). As noted above, when irrigated agriculture rights are converted to municipal, industrial, or domestic rights, they are reduced by 40% when they are class A rights and 50% when they are class B rights. Every month, the Rio Grande watermaster determines how much of the unallocated water assigned to the United States is available in Amistad and Falcon reservoirs. Once surplus water quantities are identified, they are allocated to the irrigation accounts. When irrigators use their water, those amounts are subtracted from their respective irrigation account by type of use from the account's usable balance.

3. The Rio Grande Water Market

The Middle and Lower Rio Grande feature a thriving water market. The Rio Grande watermaster acts as a clearinghouse for contract water sales and provides information on which water rights holders have contract water for sale. As of 2024, most of the transactions do not involve the sale of water rights but are instead short-term leases of discrete amounts of water for a specific period through a contract, also known as contract water or "wet water." Contract water can only be sold between the same types of water rights holders. For example, irrigation contract water can only be sold between users with irrigation rights, and municipal contract water can only be sold to between users with municipal water rights (Rio Grande Regional Water Authority, 2005, p. 2).[9]

[7] Under what is generally referred to as the "no injury" rule an application for a new surface water right or an amended surface water right shall not be granted by the Texas Commission on Environmental Quality if granting the application will cause an adverse impact to an existing water right or the environment as provided under Texas Water Code § 11.122 and 30 Tex. Admin. Code §297.45 (1999).

[8] Mining rights are also classified as class A or B rights.

[9] This requirement also reduces water speculation.

Collectively, Rio Grande water rights sales and leases and contract water sales reveal the value of water based on the type of authorized use. The Rio Grande water market works efficiently because the owner of a Middle and Lower Rio Grande water right—in perpetuity or for a defined term—may sell or lease all or part of their water right or contract water to another party who will put the water to beneficial use. The Rio Grande Watermaster's office acts as a clearinghouse of water prices and availability, which facilitates the market's smooth operation. Though the Rio Grande Watermaster's office is not a party to these transactions, it makes available offers to sell or lease water rights and sell contract water both online and over the phone. Unlike other Texas surface water transactions that involve a change in the place of use, transactions within the Rio Grande water market do not require a public notice because TCEQ allows water within the market to move upstream and downstream without impacting other water rights' reliability.

The efficiency of the Middle and Lower Rio Grande water market is also enhanced by the watermaster's authority to use river baseflows to meet water demands without having to initiate an equivalent release from Falcon Reservoir. This active approach to water management is unique in Texas, augmenting the potential of available water stored by water right holders to be used in the future or support future market transactions. TCEQ's rules allow the Middle and Lower Rio Grande water market to function as if a bed and banks permit[10] existed for all water right holders in the system.

Municipal and irrigation water districts in the Lower Rio Grande are typically lessors and lessees of surface water within the water market, rarely selling their surface water rights (S. Lambert, personal communication, April 11, 2023). This is similar to river authorities that consider surface water rights as their primary assets. Irrigation districts lease water to municipalities but generally do not lease to other irrigation districts (S. Lambert, personal communication, April 11, 2023). Lower Rio Grande municipalities and industries have acquired water by financing the irrigation system modernization in exchange for the right to use all or part of the water those systems conserved (TWDB, 2003, p. 12). This innovative approach works to conserve water and improve canal distribution efficiencies within the irrigation districts.

4. Environmental Flows in the Middle and Lower Rio Grande

Through SB 3, the 80th Texas Legislature created the environmental flows process which led to the creation of the Rio Grande Basin and Bay Expert Science Team (BBEST). The Rio Grande BBEST was charged with developing flow regimes "adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies" (Texas Water Code § 11.002(16); DeYoe et al., 2012, pp. 1-5). However, maintaining a sound ecological environment in the Middle and Lower Rio Grande faces unique hurdles. The authorized annual diversion from Amistad and Falcon reservoirs for Middle and Lower Rio Grande water rights is approximately twice the combined firm annual yield of Amistad and Falcon reservoirs (DeYoe et al., 2012, pp. 1-3, 1-4). This indicates a substantial

[10] Under Texas Water Code § 11.042 certain circumstances a person "may use the bank and bed of any flowing natural stream in the state to convey the water from the place of storage to the place of use or to the diversion point of the appropriator."

over-appropriation in the Middle and Lower Rio Grande system, which will likely result in periodic shortages for the lower priority irrigation and mining water rights (DeYoe et al., 2012, pp. 1-2, 1-4). However, the environmental flow standards TCEQ adopted under the authority of SB 3 only apply to “new permits or certain water rights amendments issued by the TCEQ on or after September 1, 2007” (DeYoe et al., 2012, p. 1-4). The Lower Rio Grande BBEST (a subdivision of the Rio Grande BBEST) therefore found that the over-appropriated state of the Rio Grande resulted in “little or no need for specific environmental flow regime recommendations from the BBEST or environmental flow standards from the TCEQ solely for new appropriations of water within the Texas Rio Grande system” (DeYoe et al., 2012, pp. 1-2, 1-4).

During deliberations in 2012, the Lower Rio Grande BBEST defined sound ecological environment as an environment that “Maintains native species, Is sustainable, and Is a current condition” (DeYoe et al., 2012, p. 1-6). The Lower Rio Grande BBEST applied this definition to its Lower Rio Grande study area, which was divided into six geographical regions: the Lower Laguna Madre, the tidal portion of the Rio Grande, the above-tidal portion of the Rio Grande up to Anzalduas Dam, the Arroyo Colorado, resacas, and coastal basins between the Lower Laguna Madre and the Rio Grande tidal (DeYoe et al., 2012, p. 1-7). In 2012, only the Lower Laguna Madre was found to be “relatively sound” with “qualified exceptions,” but it was trending “toward a more unsound (or disturbed) environmental condition” (DeYoe et al., 2012, pp. 1-8–1-11).5.

5. Rio Grande Water Plans Projected Municipal Shortages that Never Materialized

In 1962, reported surface water and groundwater supplied for municipal, industrial, and domestic water uses in the Lower Rio Grande counties of Starr, Hidalgo, Cameron, and Willacy was 73,192 acft (Carr et al., 1965, p. 81). Of this total amount, 66,859 acft was for municipal and domestic supplies, and 6,333 acft was for industrial uses. Future water demands projected by Carr et al. (1965) for municipal, industrial, and domestic water requirements in the Lower Rio Grande Valley were to decrease to 68,404 acft in 1975 but then increase to 126,516 acft in 2000.

In 1968, just a few years before the Lower Rio Grande water market began to function in 1971, TWDB (1968) published a new state water plan. It provided more detail regarding the projected future needs of the Lower Rio Grande, projecting that by 2020, annual water deliveries for municipal and industrial uses would reach 150,000 acft/year, and irrigation deliveries would reach 1,090,000 acft/year (TWDB, 1968a, p. I-13). The 1968 Texas Water Plan’s recommended project for delivering over 1 million acft of water for irrigation was exceptionally ambitious for the time. The plan included a coastal canal as part of a larger, proposed Texas Water System that would divert 12–13 million acft from the Mississippi River (TWDB, 1968b, pp. 9, 35). The coastal canal was to convey 1,090,000 acft/year to the Rio Grande Valley for irrigation (TWDB, 1968a, p. I-24). Of the projected irrigation deliveries, 385,000 acft/year was intended for existing irrigation and 315,000 acft/year was intended for new irrigation (TWDB, 1968a, p. I-14). The remaining 390,000 acft/year would replace irrigation releases from Amistad Reservoir in the Rio Grande Valley. However, the 390,000 acft/year returned to Amistad Reservoir would instead be diverted to the Winter Garden area (an agricultural area located north of Laredo and southwest of San Antonio) for irrigation in the amount of 200,000 acft/year while the remaining 190,000 acft/year would be diverted to Webb and Maverick counties for irrigated agriculture (Table 2; TWDB, 1968a, pp. I-8, I-14). Of course, neither the canal nor the proposed Texas Water System were built.

The 1984 Texas Water Plan (1984 Plan) was much less ambitious than the one published in 1968. The 1984 Plan notes that all Lower Rio Grande surface water supplies were practically committed by 1980 (Texas Department of Water Resources [TDWR], 1984a, p. 51). The 1984 Plan identified the following water supply limitations and challenges for the Lower Rio Grande Valley: 1) existing groundwater supplies were beginning to be depleted; 2) demands were beginning to exceed current surface water supplies; 3) no supplemental supplies were available, except from great distances; 4) there was limited availability and poor characteristics for additional dam and reservoir sites; and 5) supplemental surface or groundwater supplies transported from great distances might be the only option to meet future demands (TDWR, 1984a, p. 9).

Table 2. The 1968 Texas Water Plan projected Lower Rio Grande surface water supplies and use in 2020.

Projected Supplies	Municipal and industrial surface water demand (acre-feet [acft])	Mining surface water demand (acft)	Irrigation surface water demand (acft)	Total
Local surface water supplies				1,500,000
Imported surface water supplies			700,000 (385,000 existing; 315,000 new)	700,000
Total in-basin supplies (surface water, groundwater and return flows)				2,298,500
Projected in-basin surface water demands	202,300	21,000	1,026,200	1,249,700
Out-of-basin requirement (Rio Grande and Nueces Coastal Basin)				848,800
Export under Texas Water System to Winter Garden			200,000	
Export to Webb and Maverick counties			190,000	

Source: TWDB, 1968a, pp. III-12, IV-73.

In the 1984 Plan, municipal use by Lower Rio Grande cities was estimated at approximately 79,500 acft, and industrial use was estimated at 5,000 acft (TDWR, 1984b, pp. III-22-1, III-22-2). The 1984 Plan estimated that the South Texas and Lower Gulf Coast region would experience significant municipal and industrial water shortages, the "large majority" of which would occur in the Lower Rio Grande Valley (TDWR, 1984a, p. 52). These significant shortages were predicted to begin prior to 1990 for the Lower Rio Grande, with the magnitude of shortages then increasing through 2030 (TDWR, 1984a, p. 51). Even with the additional major reservoirs proposed for the 1980–2030 period, the Lower Rio Grande Valley was projected to have significant shortages of municipal, industrial, and irrigation water within the next 50 years (TDWR, 1984a, p. 42). These municipal and industrial shortages were estimated to be 131,700 acft by 2000 and 437,400 acft by 2030 (TDWR, 1984a, pp. 51, 52). The high-growth population projections associated with these municipal and industrial shortages were substantially higher than reality. The 1984 Plan projected that Brownsville's population would reach 170,834 under the low-growth scenario, and 189,493 in 2000 under the high-growth scenario. By comparison, the 2000 U.S. Census estimated that the city's population was 139,400 (TDWR, 1984b, p. A-45; World Population Review, n.d.).

6. The Changing Allocation of Water Uses within the Rio Grande Water Market: Municipal Demands Met Through the Water Market

No major new water supplies have been developed in the Rio Grande region since the water market began operation in 1971. The lack of new water supply development did not endanger municipal needs within the region—instead, the regional water market worked to furnish water towards growing municipal demands. After adjudication, 155,000 acft of water rights were designated for domestic, municipal, and industrial use in the Middle and Lower Rio Grande (Jarvis, 2011, p. 10). Since 1971, irrigation rights conversion through voluntary market-based sales, transfers, or leases has increased the total water rights authorized for municipal and industrial use (Jarvis, 2011, p. 10). Jarvis (1991, p. 15) reported that by 1989, municipal rights in the Lower Rio Grande had increased to a total of 185,499 acft because of the conversion of irrigation rights. Chang and Griffin (1992, p. 885) report that from 1971 to 1989, 152 transactions changing the use were recorded for the Middle and Lower Rio Grande. Almost all the transactions transferred water from irrigation to nonagricultural use, resulting in a 75,000 acft increase in total municipal rights. By 2007, Jarvis (2007, p. 14) reported that 106,224 acft of irrigation rights had been converted to municipal rights in the Lower Rio Grande. By 2011, Jarvis (2011, p. 10) reported that there were approximately 390,000 acft of municipal and industrial use rights in the Middle and Lower Rio Grande. All told, approximately 235,000 acft of irrigation rights were converted to municipal and industrial use rights over the 40-year period of water market operation from 1971 to 2011 (Jarvis, 2011, pp. 10–11). By 2000, the vast majority of Middle and Lower Rio Grande water rights were held by 27 irrigation districts (TWDB, 2003, p. 19). As of 2023, most surface water rights in the Middle and Lower Rio Grande were held by municipalities, water supply corporations, and irrigation districts (S. Lambert, personal communication, April 11, 2023).

Table 3 describes the water usage, by use category, within the Lower Rio Grande between 1971 and 2018.[11] Although overall water availability declined slightly within the Lower Rio Grande Basin, the amount of water reallocated towards municipal use increased. In 1971, when the Lower Rio Grande water market was first formed (the Middle Rio Grande water market was created in 1984), there were 1,995,607 acft of water permitted within the Lower Rio Grande Basin. By 2018, there were 1,806,545 acft of water permitted reflecting the 40% and 50% reductions when water rights permitted for agricultural use are converted to municipal, industrial, or domestic rights. Throughout this nearly half-century period, water permitted for irrigation gradually shifted towards other purposes, including domestic, industrial, mining, and municipal water rights. Except for mining, these uses were classified as multiple-use rights in the Rio Grande Basin by 2018.

Table 4 shows that between 1971 when the Lower Rio Grande water market was created and 2018, surface water rights decreased by 9.5% from the initial total of authorized rights. Irrigation water rights declined by 16.7% over that period. In contrast, non-irrigation water rights—including municipal, industrial, and mining uses—increased by 84.2% during that period.

The reduction in total surface water rights over time is mostly due to irrigation rights being converted to non-irrigation rights, including rights more recently classified as multiple-use rights. These trends are illustrated in Figures 2 and 3. Figure 2 shows that as the overall volume of permitted water declined between 1971 and 2018, so did the total amount used for irrigation purposes. In the meantime, the volumes associated with non-irrigation and multiple-use permits increased. As depicted in Figure 3, as of 2018, total authorized irrigation rights have been reduced by 16.7% since 1971. Although it seems that a large volume of irrigation rights have been converted to municipal and industrial rights, irrigation rights accounted for 92.8% of the total of all permitted rights in the Lower Rio Grande market in 1971, and in 2018 they still accounted for the majority at 85.4%.

The character of Rio Grande water rights changed with the passage of SB 1 in 1997, which amended the Texas Water Code to allow multiple-use permits within all basins, including the Middle and Lower Rio Grande (Issuance of permit, 2017, (b)(5)). Shortly after SB 1's passage, many Middle and Lower Rio Grande permits became multiple-use permits authorized for specific purposes, with each permit "limiting the total amount of water that may actually be diverted for all of the purposes to the amount of water appropriated" (Issuance of permit, 2017, (b)(5)).

[11] The authors made multiple attempts, including public information requests, to obtain transaction data from TCEQ and the Rio Grande Watermaster's office. Ultimately, they were unable to obtain data similar to the transaction data provided by the EAA that was used for the Edwards Aquifer water market analysis in the next chapter. Transparency and the ready availability of data are critical for markets to function efficiently.

*Table 3. Changes in Lower Rio Grande permitted consumptive surface water rights totals 1971–2018, in acre-feet.**

	1971[1]	1990[2]	2001[3]	2003[4]	2006[5]	2018[6]
Irrigation	1,852,417	1,766,980	1,689,709	1,629,969	1,631,451	1,542,732
Municipal	143,190**	167,481		243,916		
Domestic		25,484		22,064		
Municipal, domestic, and livestock			227,439		235,745	
Industrial		46,707[7]	11,834	7,635	11,301	
Mining			957	605	593	6,097
Multiple use[8]						257,716
Total	1,995,607	2,006,649	1,929,939	1,904,188	1,879,090	1,806,545

[1] Data taken from the Table 1 to 5 of "Lower Rio Grande Valley Water Documents," Texas Water Rights Commission and Texas Attorney General, June 1971.

[2] Chang & Griffin, 1992, data taken from Table 4, p. 885.

[3] Rio Grande Regional Water Planning Group (Region M), 2001, Table 3.5, p. 3-37.

[4] TCEQ, Rio Grande Water Division, Lower Totals Report, March 12, 2003.

[5] Rio Grande Regional Water Planning Group, 2006, Table 3.5, p. 3-37.

[6] Rio Grande Regional Water Planning Group, 2020, p. 3-9.

[7] The total acre-feet for industrial permits in Chang and Griffin (1992) most likely includes permits that were outside of the Lower Rio Grande water market.

[8] Multiple-use permits were authorized by the Texas Legislature in 1997 through Senate Bill (SB) 1. These permits could include a combination of any of the other listed uses as well as recreational use.

* The reported numbers show some variation in 1990 and 2006, most likely due to how the water rights were sorted at the time, but otherwise, the reallocation has been relatively steady during the 47-year period.

** The state court in 1971 lumped the following uses under the municipal category; municipal, domestic, industrial, livestock, and government agency uses.

Table 4. Comparison of 1971 and 2018 Lower Rio Grande permitted consumptive surface water rights, in acre-feet (acft).

	1971 acft (percent of total)	2018 acft (percent of total)	Change in acft	Change by percent
Irrigation	1,852,417 (92.8%)	1,542,732 (85.4%)	–309,685	–16.7%
Non-irrigation	143,190 (7.2%)	263,813 (14.6%)	+120,623	+84.2%
Total	1,995,607	1,806,545	–189,062	–9.5%

Sources: Texas Water Rights Commission, Texas Attorney General, 1971, Tables I, II, III, IV, V; Rio Grande Regional Water Planning Group, 2020, p. 3-9.

Figure 2. Changes in Lower Rio Grande surface water rights by acre-feet in 1971 and 2018.

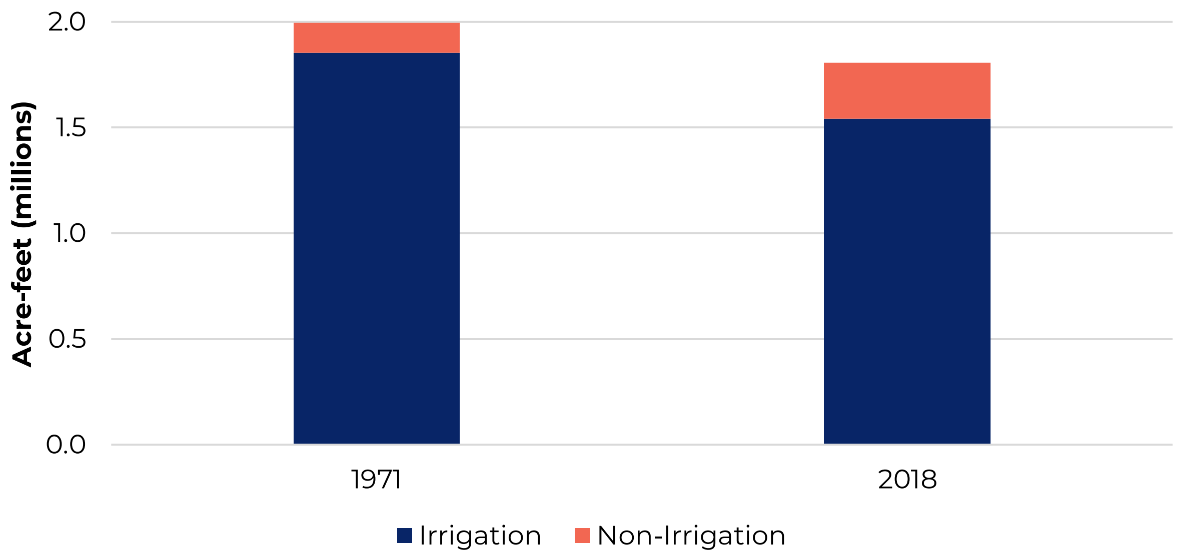
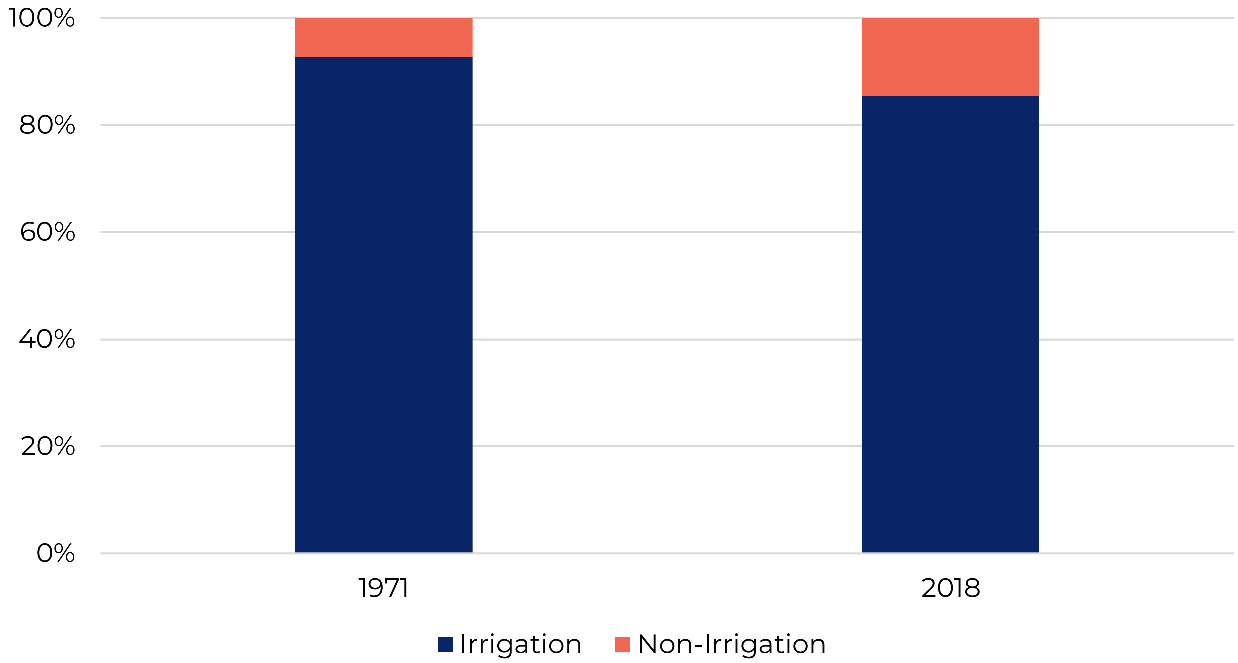


Figure 3. Changes in Lower Rio Grande surface water rights by percentage in 1971 and 2018.



7. The Water Market's Influence on Regional Agriculture

Interestingly, the conversion of irrigation rights to municipal and industrial rights has not reduced the output of agriculture irrigated by deliveries from the Lower Rio Grande water market. But agricultural practices dependent upon the Lower Rio Grande water market have evolved. Debaere and Li (2020) compared crop production in adjacent counties with and without access to Rio Grande water market surface water. They found that after the Lower Rio Grande water market began in 1971, regional crop production shifted from lower value to higher value crops—or from less-productive crops that were generating fewer average dollars per unit of water to more productive crops. This indicates that some farmers with low-value crops were leasing their water rights to farmers with high-value crops. During drought, these reallocations were much more frequent, and more high-value crops were grown as a percent of overall crop production relative to non-drought years (Debaere & Li, 2020). In contrast, adjacent counties without Lower Rio Grande water market access did not experience a similar shift in crop production, and low-value crops maintained their share of overall crop production during drought (Debaere & Li, 2020). Debaere and Li (2020) suggest that their results may also demonstrate the relative inflexibility of the prior appropriation water rights system found in the neighboring South Texas counties, and that more water rights tend to be concentrated in lower value crops under prior appropriation than is justified by their productivity (Debaere & Li, 2020). In 1992, Chang and Griffin (1992, p. 889) found that the benefits accrued to a municipality that buys and converts irrigation rights to municipal rights clearly exceed agricultural opportunity costs. Moreover, irrigation right holders benefit by monetizing their unused rights and creating future income streams by converting their unused irrigation rights to municipal rights that can be leased to municipal users and suppliers. Further, Chang and Griffin (1992) found that the estimated municipal benefits from water market activity far exceeded the agricultural costs of the transfer. Lower Rio Grande water market had a substantially positive influence upon the economy of the region (Griffin & Boadu, 1992, p. 288).[12]

8. Conclusions

Several characteristics contribute to the Middle and Lower Rio Grande water market's success. These include a firm cap on the amount of potential allocated water, regulatory enforcement through the Rio Grande Watermaster Program, and a clearinghouse for transactional data. Other characteristics that contribute to this market's function include: the absence of an alternative groundwater supply; the use of correlative rights instead of seniority-based prior appropriation rights; a large number of water rights holders, as opposed to some areas of Texas, where there is a virtual monopoly on supplies; strong growth in urban water demand; a lack of return flow conflicts because most return flows discharge into the Arroyo Colorado and the Brownsville ship channel; an extensive canal system that facilitates the conveyance of water; and the fact that the Rio Grande itself is the major conduit of water transportation (TWDB, 2003, pp. 18–19). An additional factor is that like in the Edwards Aquifer water market, which is discussed in the next section, water cannot be imported from other sources into the Middle and Lower Rio Grande. Further, water cannot be exported from the Middle and Lower Rio Grande due provisions in the 1994 treaty between the United States and Mexico, which governs international management of the Rio Grande (United States, Mexico, 1944). Lastly, the monthly allocation process discourages the importation of water into the system by making that water available for all users rather than a single individual purchaser (Texas House Committee on Natural Resources, 2018, p. 92).

As noted above, the 1984 Plan projected that municipal and industrial shortages in the Lower Rio Grande Valley would reach 131,700 acft by 2000 and 437,400 acft by 2030 (TDWR, 1984a, pp. 51, 52). The 2020 U.S. Census reported Brownsville's population at 189,382, almost the exact number projected by the high-growth scenario of the 1984 Plan. Despite this, analysis of the data reveals that the anticipated municipal and industrial shortages projected for the Lower Rio Grande Valley have only materialized during the recent drought. By 2006, the total acre-feet of municipal, industrial, and domestic water rights in the Lower Rio Grande had increased by 85,000 acft since 1971, as a result of the gradual conversion of irrigation rights through voluntary transactions within the water market (Rio Grande Regional Water Planning Group, 2006, p. 1-40). This suggests that the water market has been able to accommodate municipal, industrial, and domestic needs as they develop by reallocating water from lower value uses to higher value uses. It is important to remember that the last major water supply project developed for the Middle and Lower Rio Grande was Amistad Reservoir in 1969. In the absence

[12] There may be additional opportunities for the Middle and Lower Rio Grande water market. McColly et al. (2021) concluded that the Lower Rio Grande may also be a good candidate for trading water options. A water option is a financial product that provides a vehicle to interested buyers and sellers to create a contract formalizing the terms of the possible future water deliveries.

of new supplies, it is the operations of the water market that have allowed the region to accommodate the water needs of its burgeoning population and economy. As noted by Griffin and Boadu (1992), reallocation in the Lower Rio Grande “has occurred steadily and without fanfare” (p. 276), which is a key advantage of the development of well-structured water markets.

B. Edwards Aquifer Water Market

1. Background: The Creation of the Edwards Aquifer Authority and the Beginning of the Edwards Aquifer Water Market

The groundwater within the Edwards Aquifer was once essentially the sole source of water for the region in South-Central Texas that includes San Antonio. The Edwards Aquifer also contributes surface water flow to the Guadalupe River Basin, primarily through the discharge of Comal and San Marcos springs, both of which are home to endangered aquatic species. In 1956, during the Texas's multiyear drought of record, Comal Springs did not flow for almost 5 months (Votteler, 2000, p. 1). The 1950s drought, coupled with emerging regional competition over the groundwater of the Edwards Aquifer, initiated a multi-decade dispute. Urban interests in San Antonio (Bexar County) were pitted against agricultural interests to the west (primarily in Medina and Uvalde counties) and communities dependent on Comal and San Marcos springs to the east (primarily in Comal and Hays counties) (Votteler, 2023, p. 1).

In 1991, the Sierra Club filed an Endangered Species Act lawsuit in U.S. District Court alleging that the U.S. Secretary of the Interior and the U.S. Fish and Wildlife Service had allowed takings of endangered species by not ensuring an aquifer water level sufficient to maintain the flow of Comal and San Marcos springs needed for endangered species' aquatic habitat. The Sierra Club's motivation was to protect the threatened and endangered species and their associated habitats. The Guadalupe-Blanco River Authority (GBRA), which had initiated the original threat to sue under the Endangered Species Act, and which ultimately financed the litigation, was acting to protect the water resources of the Guadalupe River Basin. These resources included surface water rights issued by the State of Texas and held by GBRA and Union Carbide Corporation (J. Specht, unpublished interview, July 26, 1999). In 1993, Senior Federal District Court Judge Lucius Bunton ruled in *Sierra Club et al. v. Babbitt et al.* that adequate flows from Comal and San Marcos springs had to be guaranteed to provide for the needs of the endangered species found in those ecosystems (*Sierra Club v. Babbitt*, 1993). The Legislature responded to Judge Bunton's ruling by passing the Edwards Aquifer Authority Act (EAA Act), SB 1477, on May 30, 1993. The EAA Act became effective on September 1, 1993.

The EAA Act created the Edwards Aquifer Authority (EAA), a conservation and reclamation district for the purpose of regulating Edwards Aquifer groundwater withdrawals. The EAA Act required that EAA permit groundwater withdrawals based on groundwater use between June 1, 1972, and May 31, 1993 (Edwards Aquifer Authority Enabling Act (EAA Act), 1993, § 1.169(a)). Irrigators were given a minimum of 2 acft/year per acre irrigated EAA Act, 1991, § 1.16(c)). In addition, the EAA Act initially capped groundwater withdrawals at 450,000 acft/year. Withdrawals after January 1, 2008—15 years after the EAA Act's passage—were to be limited to 400,000 acft/year (EAA Act, 1991, § 1.14(later repealed). The EAA Act authorized the EAA to achieve the required limits on withdrawals by issuing permits and potentially by purchasing and retiring permitted groundwater rights.

The EAA eventually received and processed 1,084 permit applications requesting groundwater rights totaling 846,180 acft/year (EAA, 2005, p. 1). In 2000, after a lengthy review and hearing process, the EAA proposed issuing 818 regular permits totaling 532,275 acft/year (EAA, 2000, pp. 2, 4). In 2007, the Legislature passed SB 3, raising the aquifer-pumping cap to its current level of 572,000 acft/year. This action settled several lingering disputes over aquifer permits.

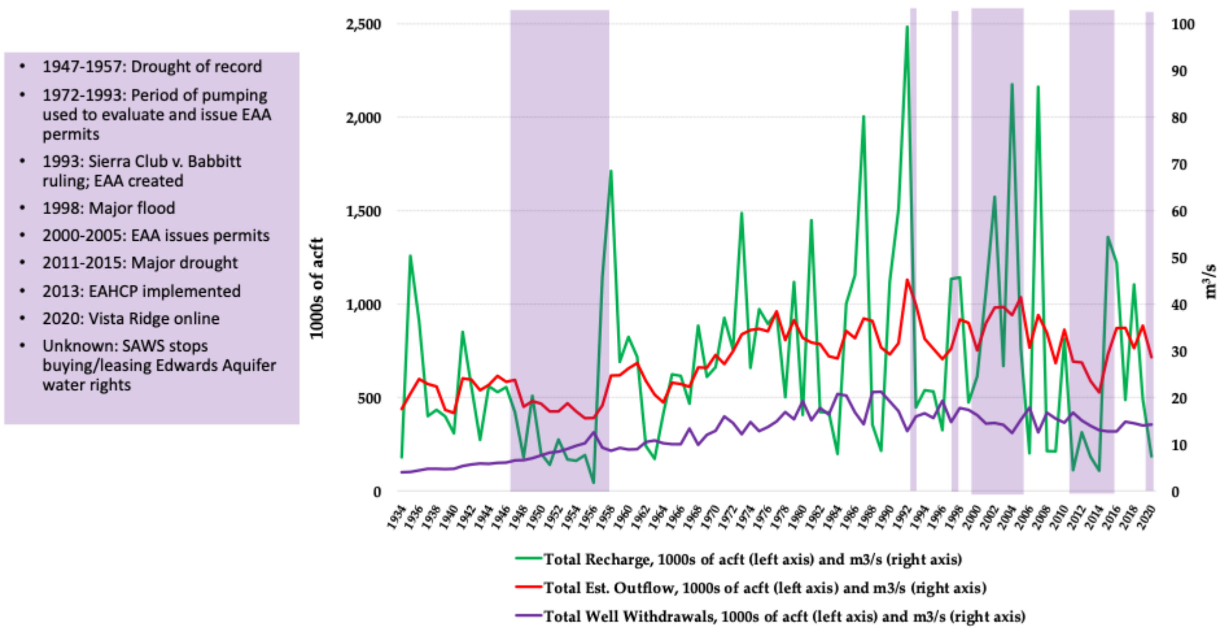
Unlike in other regulated aquifers, the Edwards Aquifer's unique karst characteristics allow pumping to be transferred relatively easily from one location overlying the aquifer to another location through a permit sale or lease. Water moves comparatively quickly through the aquifer and recharges more like a lake than most aquifers. Because the Edwards Aquifer is a confined aquifer, pumping-caused reductions in hydrostatic pressure result in a relatively consistent drawdown across the artesian zone of the aquifer. This means that one well generally cannot pump another dry by locally depleting the aquifer. Aquifer pumping can therefore be managed regionally, creating unique opportunities for water transactions (Texas House Committee on Natural Resources, 2018).

Figure 4 shows Edwards Aquifer recharge, outflow (withdrawals and springflow), and withdrawals from 1934 to 2020. The figure overlays key events related to aquifer use, such as droughts, floods, withdrawal regulations, and groundwater availability from the Vista Ridge pipeline, SAWS' major water supply alternative. This figure illustrates some of the major influences affecting the Edwards Aquifer water market during the period of the water market analysis from 1997 to 2020.

Investors made some of the first Edwards Aquifer water purchases prior to 1997 when the EAA began the process of reviewing permit applications. For example, U.S. Filter, a water services company, purchased land and water rights in the Edwards Aquifer prior to 1997 (Rick, 1997). In an attempt to organize the process of purchasing rights once the EAA started to issue permits the San Antonio Water System (SAWS) and the San Antonio River Authority (SARA) created a joint buying group of water purveyors, called the Regional Water Resource Development Group (RWRDG) in 1997. An initial interlocal agreement was drafted and adopted by 13 members organizations (Young, 2001). SARA served as the RWRDG administrator, apportioning water sales and leases and managing RWRDG's finances. SAWS served as RWRDG's first agent, arranging for all transfers of water through sales and leases within price limits set by RWRDG members. The agent's duties also included developing "the water market within which Edwards Aquifer groundwater rights will be traded" (RWRDG, 2006, p. 6).

SAWS had a strong incentive to participate in the emerging water market. SAWS (2005, p. 6) anticipated that its final permits from the EAA would total around 159,040 acft/year in base permits. Under drought reductions, this amount might only provide 135,000 acft/year, well below both the 178,000 acft/year SAWS pumped in 1998 and the record 193,944 acft it pumped in 1984 (Arce, 2003, p. 1; SAWS, 1998, p. 55). The Edwards Aquifer water market allowed SAWS to address this potential shortage through water right purchases and leases. Through the water market, buyers were able to contact permit holders and propose a transaction, which are completed through private conveyance using a warranty deed.

Figure 4. Edwards Aquifer flow balance vs. key events.



2. Edwards Aquifer Water Market Transactions and Trends

a. Aggregate Data

Between 1997 and 2020, over 1 million acft of Edwards Aquifer water was sold or leased in 8,832 transactions (Table 5). Most that water was part of 5,844 lease transactions totaling 824,827 acft, with a median volume of 65 acft per lease transaction. Water right sales accounted for 190,141 acft, which occurred in 2,244 transactions, with a median volume of 25 acft.

In the early years of the Edwards Aquifer water market, between 1998 and 2005, most volumes were traded to municipal users (Figure 5). Starting in 2006, other market participants, including irrigation and mining users, transacted greater water volumes within the market. Upticks in trading coincided with regional droughts in 2006, 2008, 2009, and 2011–2015 as water scarcity drove participation in the market. Every year, more water was exchanged through leases than through sales (Figure 6).

*Table 5. Edwards Aquifer water market: Key figures, 1997–2020.**

Total number of water transactions (sales and leases)	8,832 reported

Total sale transactions	2,244
Total lease transactions	5,844
Median volume of sale transactions	25 acre-feet (acft)
Median volume of lease transactions	65 acft
Volume of water in transactions (sales and leases)	1,014,968 acft
Volume of water in sales transactions	190,141 acft
Volume of water in lease transactions	824,827 acft
Volume of water right sales by municipal users	70,343 acft
Volume of water right sales by industrial users	14,641 acft
Volume of water right sales by agricultural users	106,085 acft
Water right leases by municipal users	374,444 acft
Water right leases by industrial users	98,825 acft
Water right leases by agricultural users	351,196 acft
Total volume of water rights sold from agricultural to municipal users	49,708 acft
Volume of water rights sold from agricultural to industrial users	6,364 acft
Volume of water rights sold from agricultural to agricultural users	100,226 acft
Volume of water rights sold from municipal to municipal users	15,330 acft
Volume of water rights leased from agricultural to municipal users	236,693 acft
Volume of water rights leased from agricultural to industrial users	44,416 acft
Volume of water rights leased from agricultural to agricultural users	325,718 acft
Volume of water rights leased from municipal to municipal users	117,895 acft

* San Antonio City code prohibits industrial water users in Bexar County from drilling groundwater supply wells within the City of San Antonio (San Antonio, Texas Ordinance Number 80574, 1994; San Antonio, Texas Ordinance Number 86747, 1997). As a result, most industrial water users in Bexar County are supplied directly by San Antonio Water System.

Figure 5. Traded water volumes in leases and sales by transferee use, acre-feet.

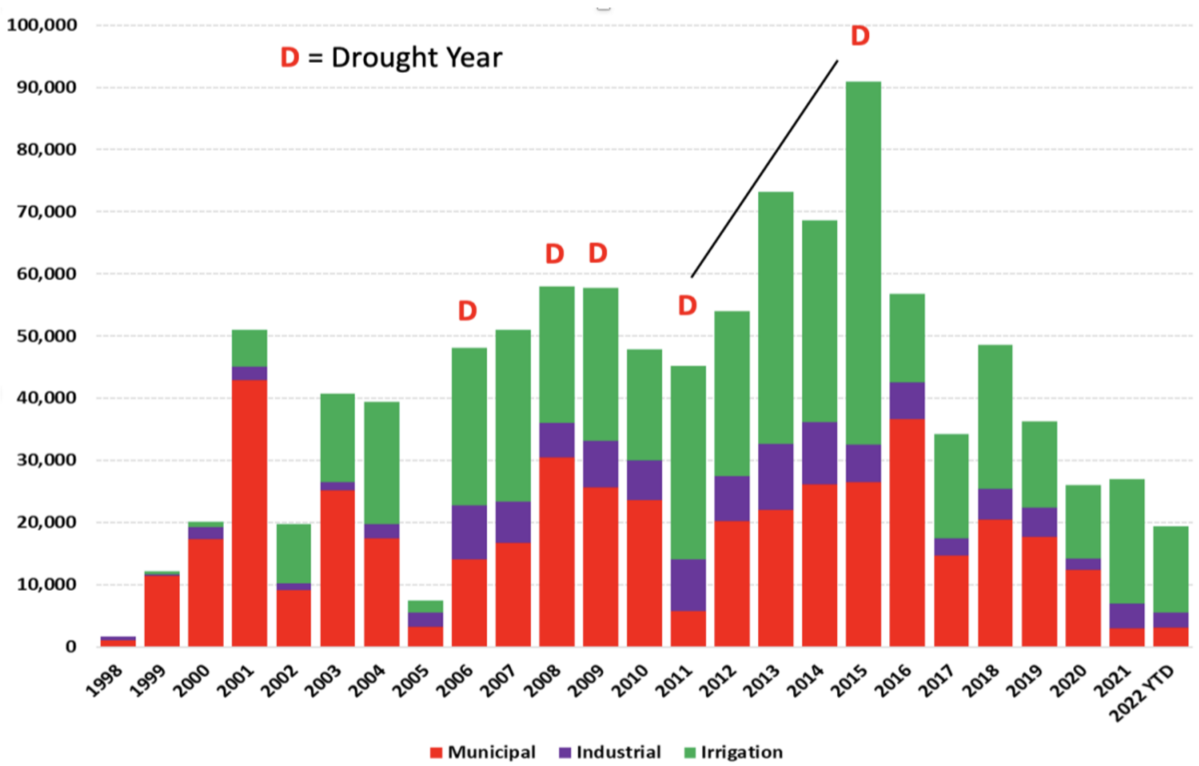
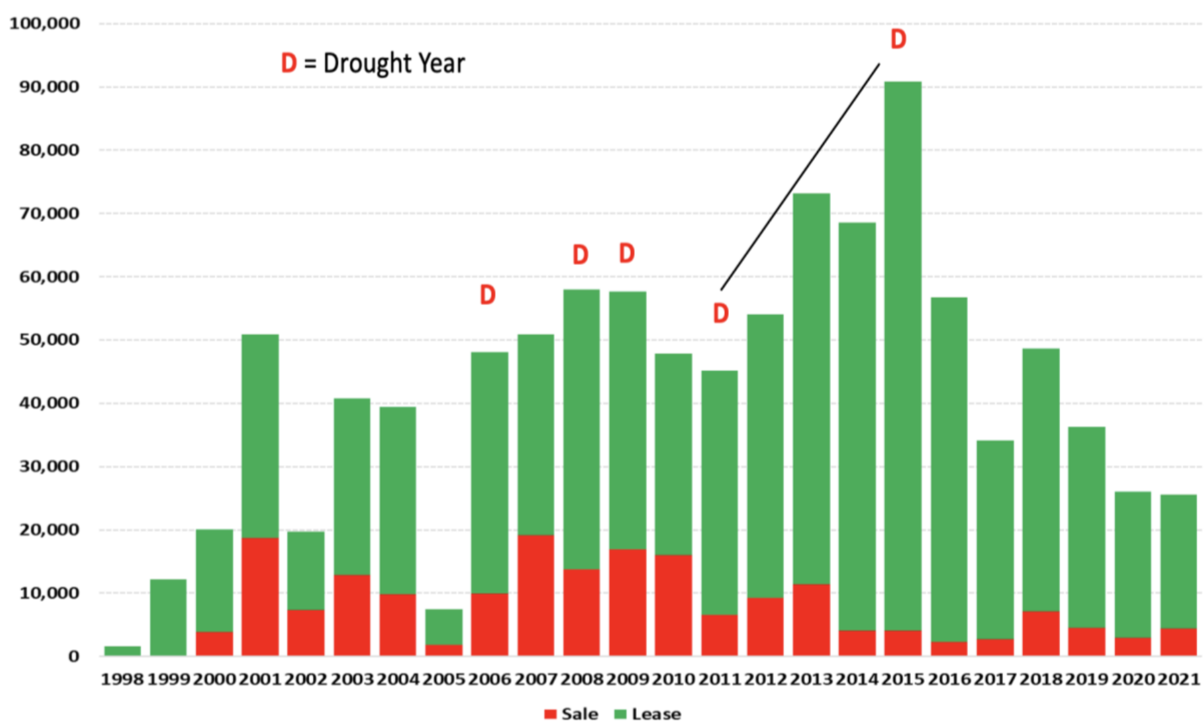


Figure 6. Traded water volumes, leases vs. sales, acre-feet.



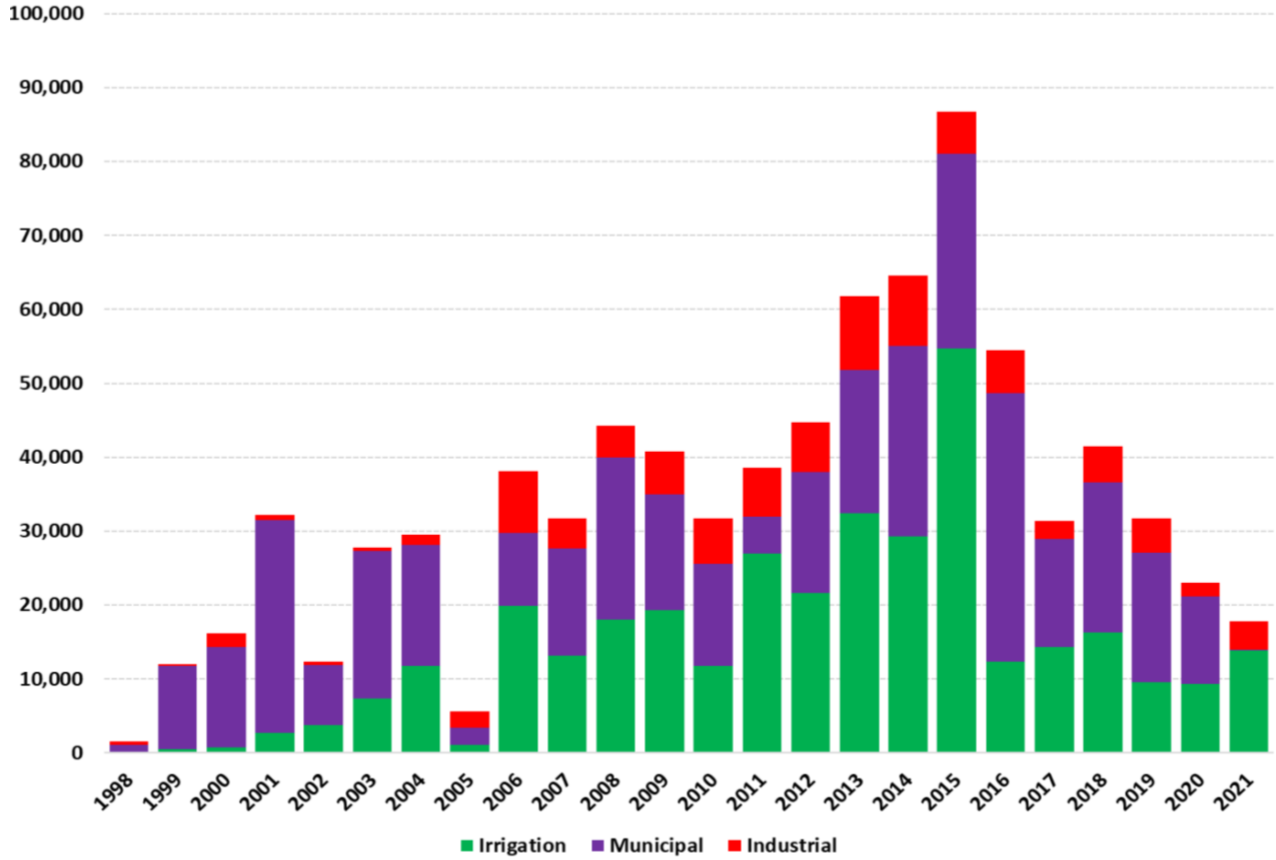
b. Water Rights Leases Data

From 1997 to 2020, most of the water rights leased in the Edwards Aquifer water market went to municipal and industrial users, for a combined 473,269 acft, or 57% of the total leased (Table 6). Figure 7 shows that during the initial years of the market, municipal needs drove the leasing market, while agricultural needs dominated the market during the 2011–2015 drought. Leases to municipal users totaled 374,444 acft. Leases to agricultural users totaled 351,196 acft. Most water leased to agricultural users was leased from other agricultural users.

Table 6. Edwards Aquifer water market: Water right leases, 1997–2020.

Total number of water transactions (sales and leases)	8,832 reported
Total lease transactions	5,844
Total volume of water in lease transactions	824,827 acre-feet (acft)
Water right leases to municipal users	374,444 acft
Water right leases to industrial users	98,825 acft
Water right leases to agricultural users	351,196 acft
Median volume of lease transactions	65 acft
Total volume of water rights leased from agricultural to municipal users	236,693 acft
Total volume of water rights leased from agricultural to industrial users	44,416 acft
Total volume of water rights leased from agricultural to agricultural users	325,718 acft
Total volume of water rights leased from municipal to municipal users	117,895 acft
Total volume of water rights leased from municipal to industrial users	19,305 acft
Total volume of water rights leased from municipal to agricultural users	17,202 acft
Total volume of water rights leased from industrial to municipal users	16,933 acft
Total volume of water rights leased from industrial to industrial users	34,603 acft
Total volume of water rights leased from industrial to agricultural users	5,225 acft

Figure 7. Leases by transferee/buyer type, in acre-feet.



c. Water Rights Sales Data

As with leasing activity, sales activity was driven by municipal and agricultural users from 1997 to 2020 (Table 7; Figure 8). Most of the water rights sold were agricultural rights, and most water rights sold by agricultural users went to other agricultural users. Agricultural users purchased 106,085 acft of Edwards Aquifer water rights, while municipal users bought 70,343 acft, and industrial users bought 14,651 acft. Therefore, a total of 84,984 acft of rights shifted from lower valued agricultural uses to higher valued municipal and industrial uses from 1997 to 2020. Figure 8 shows that municipal purchases accounted for most of the activity at the beginning of the period and during the middle of the period. This was the result of SAWS acquiring additional water rights to bring its available rights above its maximum pumping in 1984 (discussed in detail below).

Table 7. Edwards Aquifer water market: Water right sales, 1997–2020.

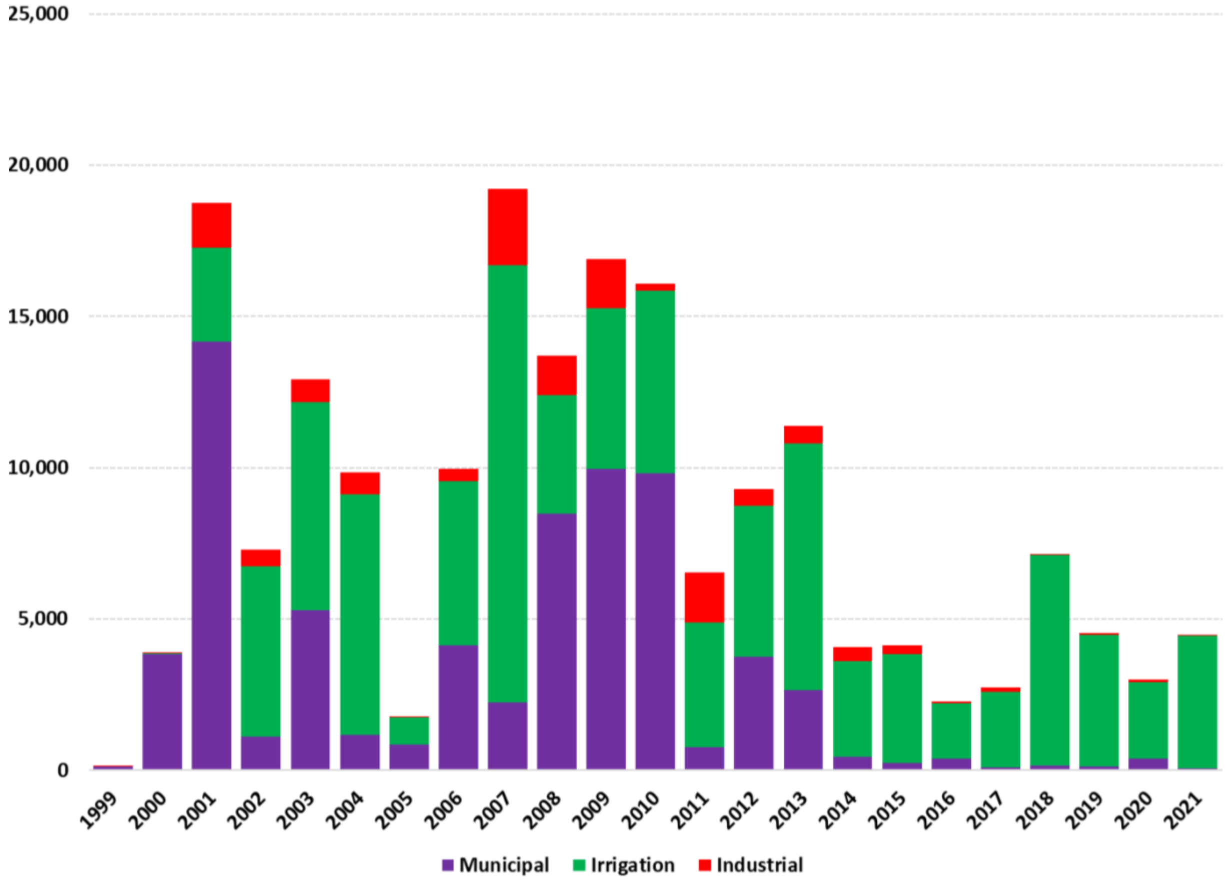
Total number of water transactions (sales and leases)	8,832 reported
Total sale transactions	2,244
Total volume of water in sales transactions	190,141 acre-feet (acft)
Total volume of water right sales to municipal users	70,343 acft
Total volume of water right sales to industrial users	14,641 acft
Total volume of water right sales to agricultural users	106,085 acft
Median volume of sale transactions	25 acft
Total volume of water rights sold from agricultural to municipal users	49,708 acft
Total volume of water rights sold from agricultural to industrial users	6,364 acft
Total volume of water rights sold from agricultural to agricultural users	100,226 acft
Total volume of water rights sold from municipal to municipal users	15,330 acft
Total volume of water rights sold from municipal to industrial users	486 acft
Total volume of water rights sold from municipal to agricultural users	423 acft
Total volume of water rights sold from industrial to municipal users	5,305 acft
Total volume of water rights sold from industrial to industrial users	6,790 acft
Total volume of water rights sold from industrial to agricultural users	5,421 acft

Overall, water rights buying and leasing activity in the Edwards Aquifer has occurred primarily west of Cibolo Creek in Bexar, Medina, and Uvalde counties.[13] A rule limiting transfers of groundwater rights from west to east of Cibolo Creek was adopted because more pumping in the east from wells closer to Comal and San Marcos springs could significantly impact spring discharge, and the endangered species. This limitation on Cibolo Creek transfers has created a

[13] Geographical metadata are insufficient to delineate transactions occurring east of Cibolo Creek versus west of Cibolo Creek, which is the geographic dividing line between Bexar County and Comal and Hayes counties where right transfers from Bexar County and west into Comal and Hays Counties are restricted.

market within the Edwards Aquifer water market where water east of Cibolo Creek is often twice the price of water west of Cibolo Creek. There is not a similar limitation on transferring water from east to west of Cibolo Creek (LBG-Guyton Associates, 2008; Texas House Committee on Natural Resources, 2018).

Figure 8. Sales by transferee/buyer type, acre-feet.



d. Water Demands Met Through the Edwards Aquifer Water Market

Municipal and irrigation uses in Bexar, Medina, and Uvalde counties drive the Edwards Aquifer water market (Figure 7, 8, and 9). Between 1997 and 2010, SAWS was able to purchase water rights to meet the potential shortfall created when it received less water during the permitting process than would be needed to provide the same amount of water under drought restrictions as was used during the 1984 drought year. After 2013, SAWS water right purchases were substantially less in each year. Also, agricultural water users were able to lease rights when needed, giving them better flexibility with their water management. As illustrated in Figure 9, most of the transactions occurred in Bexar (primarily municipal use), Medina (primarily agricultural use), and Uvalde (primarily agricultural use) counties.

From 1997 to 2020, SAWS accounted for the largest quantity of water in the accumulated water right purchase and lease transactions (Figure 10). SAWS' accumulated lease transactions exceeded the volume of its accumulated purchase transactions in every year except 2010, and its lease transactions exceeded its purchases overall (Figure 11).

Figure 9. Where are the transactions taking place?

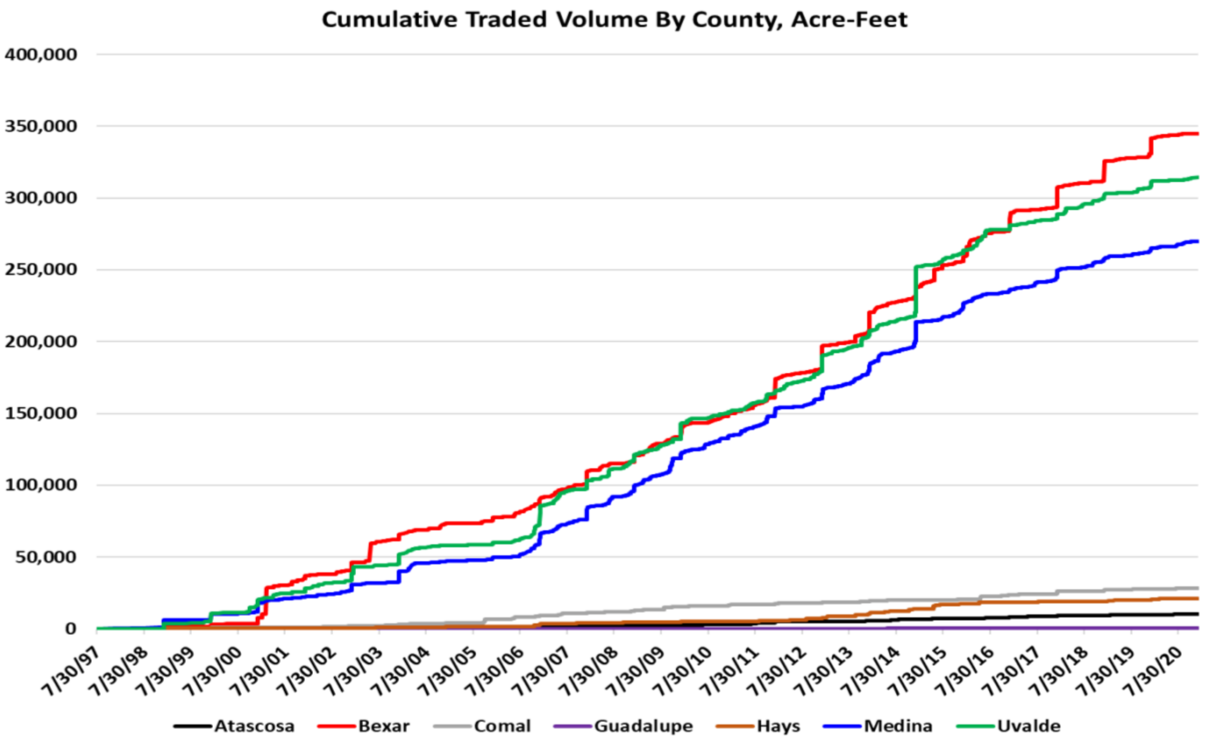


Figure 10. Top 50 transacting parties.

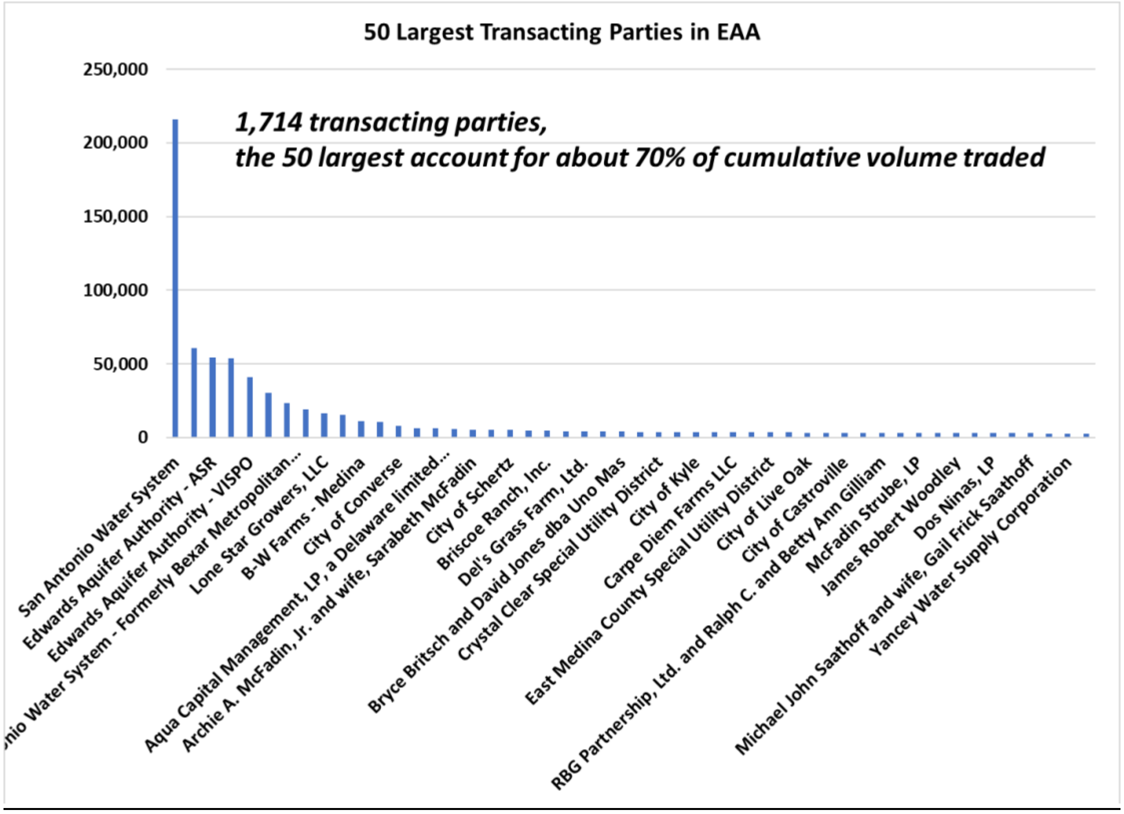
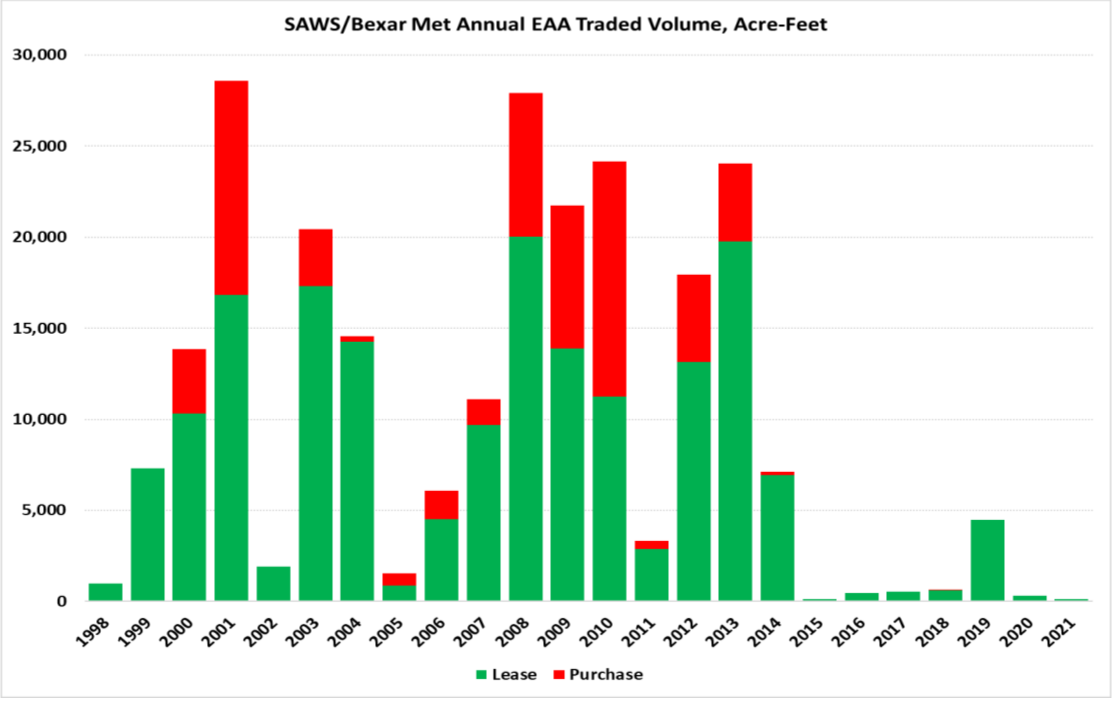
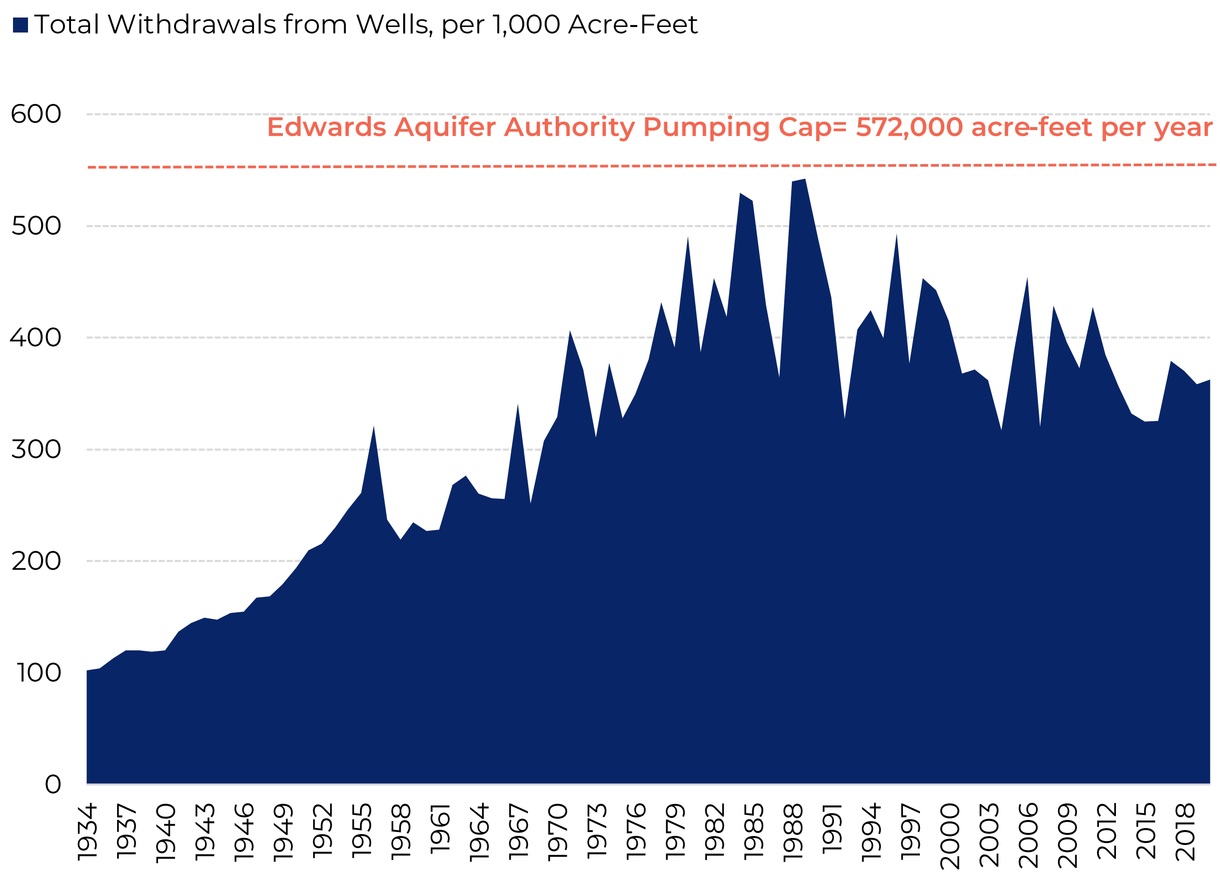


Figure 11. Key parties behind transactions.



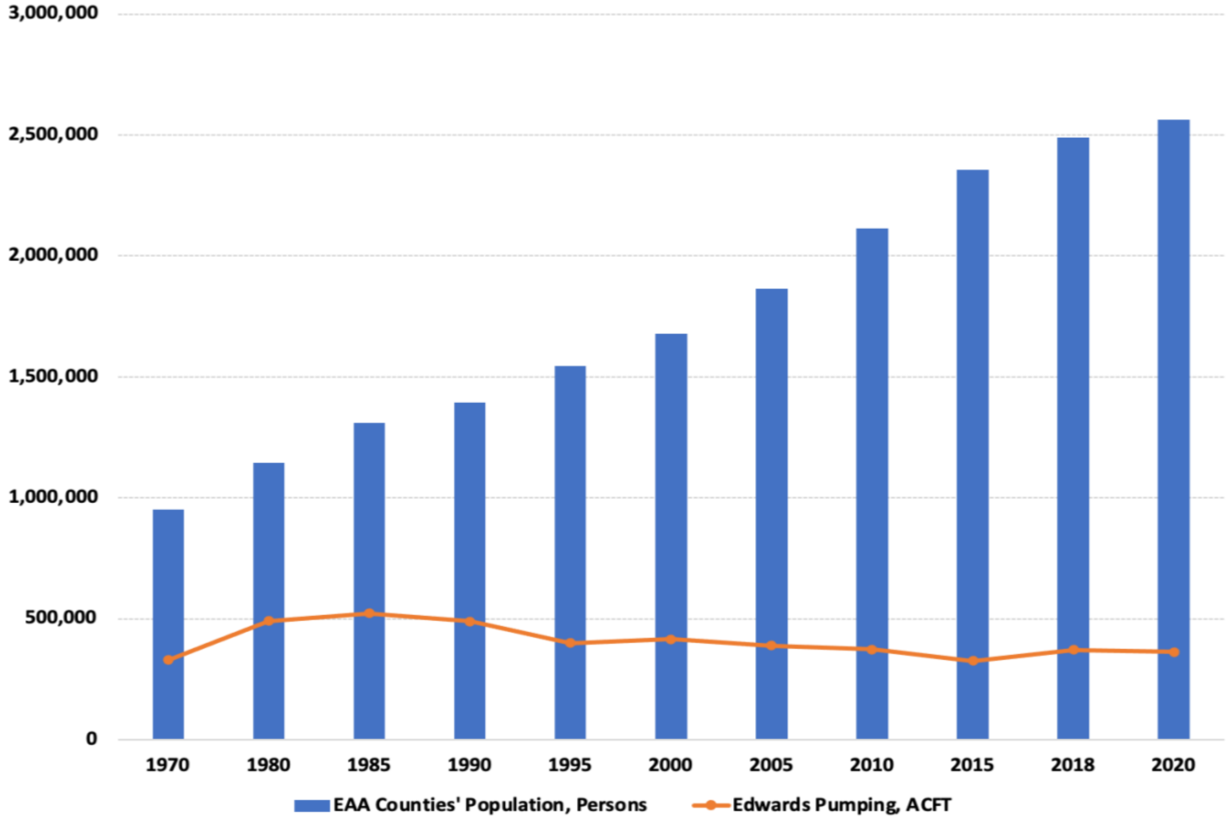
Before the EAA was created, Edwards Aquifer pumping averaged 425,000 acft/year from 1973 to 1992 (Figure 12). Edwards Aquifer pumping reached its peak during drought conditions in 1989, at 542,500 acft. As a result of the regulation of the Edwards Aquifer and the creation of the water market, annual pumping since 1989 has never again reached 500,000 acft/year. From 2001 to 2020, pumping and averaged 370,000 acft/year.[14] Overall, aquifer pumping has declined over the past 45 years, despite substantial growth of the population of the counties that are served by the Edwards Aquifer water market (Figure 13).

Figure 12. Edwards Aquifer pumping vs. cap: 1934-2020, acre-feet.



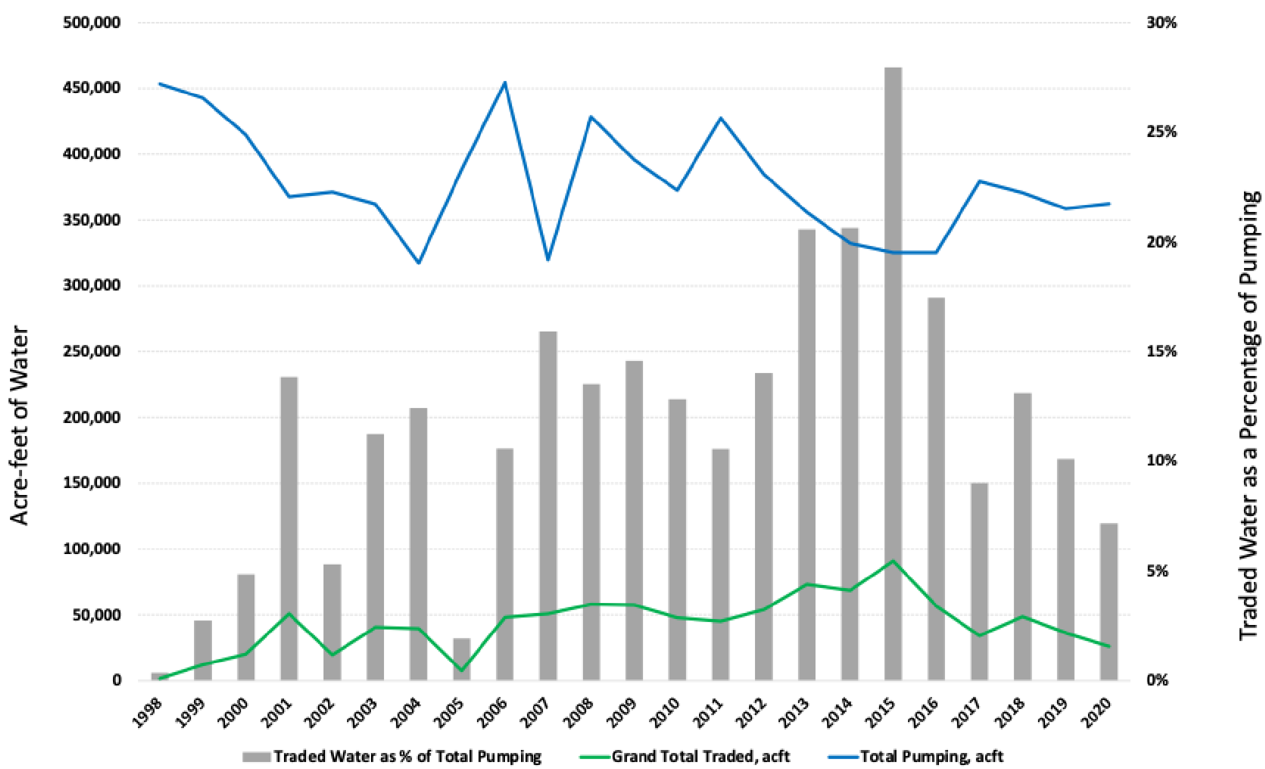
[14] The Vista Ridge Project was completed and began delivering its full amount in August 2020. The project transfers 50,000 acft/year of groundwater from the Carrizo-Wilcox Aquifer in Burleson County via a pipeline to Bexar County.

Figure 13. EAA counties' population vs. Edwards Aquifer pumping, 1970 - 2020.



The decline in pumping is associated with greater volumes of water being traded in the Edwards Aquifer water market—by sale or lease, which correlate with lower total pumping from the Edwards Aquifer (Figure 14). This suggests that water transactions, which assign a value to the water being traded, contribute to the more efficient use of water. As water trading within the water market increases due to rising demand, the perceived value of water also increases. The price signal of increasing water value provides an incentive for suppliers and users to use water more efficiently by preventing leaks, employing more efficient irrigation systems, and implementing other resource stewardship changes.

Figure 14. Total water pumped, total water traded, and traded water as a percentage of pumping, acre-feet.



3. Prices for Sales and Leases of Edwards Aquifer Water

While the EAA has detailed data on sales and leases of Edwards Aquifer rights, these data do not include the prices associated with these sales and leases, as the EAA does not require transaction prices to be reported although it does request voluntary reporting. However, most participants choose not disclose transaction prices (Texas House Committee on Natural Resources, 2018). As a result, only 9% of the 2,244 sales transactions include a price per acre-foot. However, data provided by SAWS, the single largest buyer in the water market, provides a proxy for prices. In 1999, SAWS leased Edwards Aquifer water for $75 per acre-foot and bought permanent water rights for $700 per acre-foot (M. Thuss, unpublished interview, 1999). In 2000, SAWS data indicate that it paid $762 per acre-foot for purchases, increasing to a peak of $5,500 per acre-foot in 2009 (B. Payne, personal communication, September 13, 2022). Other sources report that some participants in the market for Edwards Aquifer rights (most likely east of Cibolo Creek) paid as much as $10,000 per acre-foot to purchase rights (Texas House Committee on Natural Resources, 2018, p. 96).

Because SAWS received less water in its permits from the EAA than it used in the 1984 drought prior to the Edwards Aquifer's regulation, SAWS had to acquire water rights from other permit holders to meet its needs during similar droughts in the future. This resulted in a seller's market initially developing in the Edwards Aquifer water market, where SAWS was compelled to pay higher prices for additional permitted amounts of water. By 2014, however, SAWS relaxed its focused effort to purchase Edwards Aquifer water rights in anticipation of the Vista Ridge Project and other projects delivering groundwater from the Carrizo-Wilcox Aquifer beginning in 2020.

The prices SAWS paid to lease Edwards Aquifer water have generally increased over time, rising from \$70–\$75 per acre-foot in 2000 to \$100–\$140 per acre-foot in 2022 (B. Payne, personal communication, September 13, 2022). However, during the 2010–2015 drought, the price range SAWS paid for leases spiked to \$77–\$185 per acre-foot in 2010, peaking at \$82–\$185 in 2011 and 2012 (B. Payne, personal communication, September 13, 2022).

By 2024, the Edwards Aquifer water market was more of a buyer's market. In 2022, SAWS resumed purchasing smaller amounts of water when opportunities emerged. The additional supply provided by the Vista Ridge Project has, for the time being, eroded SAWS' incentive to purchase additional rights. SAWS is currently offering a much lower price per acre-foot of \$3,500, compared to the \$5,500 per acre-foot offered in 2009 (B. Payne, personal communication, September 13, 2022). While the demand for purchasing Edwards Aquifer rights has eased for now, the demand—and therefore the price of purchasing Edwards Aquifer rights—will likely rise again once San Antonio starts to outgrow the additional supply provided by Vista Ridge Project and other projects.

4. Water Market Provides Flexibility for Water Management

The Edwards Aquifer Habitat Conservation Plan (EAHCP) was created to protect federally listed species that live in the Edwards Aquifer and Comal and San Marcos springs, ending the regional dispute over aquifer management (RECON Environmental, Inc, et al, 2012). The EAHCP contains measures to ensure continuous minimum springflow from Comal and San Marcos springs during a repeat of the drought of record. These flow protection measures include the Voluntary Irrigation Suspension Program Option (VISPO), which pays irrigators to forbear groundwater use during severe droughts. The measures also include the use of SAWS' H_2Oaks Center, an ASR facility, to store water in the Carrizo-Wilcox Aquifer to offset Edwards Aquifer pumping during severe drought. The water stored in SAWS ASR facility comes primarily from the Edwards Aquifer. Both programs are effective because of the presence of the Edwards Aquifer water market.

VISPO and ASR transactions are water market transactions, but they pay participating pumpers to not use their enrolled water rights. VISPO participants enroll for 5 years and receive \$54 per acre-foot in years when their water is not needed, plus an additional \$160 per acre-foot in forbearance years when they cannot use their enrolled rights, for a total of \$214 per acre-foot. By 2020, 41,795 acft had been enrolled in VISPO (Yablonski, 2020, p. 22). Participants in the ASR program enroll for 9 years and receive a flat fee of \$100 per acre-foot per year in both standby years and forbearance years. By 2020, the ASR program had 50,000 acft enrolled (Yablonski, 2020, p. 25). By 2020, approximately 89,000 acft of the 179,901 acft of irrigation permits were enrolled in VISPO or ASR (Yablonski, 2020, p. 25). Both of these programs allow participants to lease their water to other water market users while their permitted water is enrolled in these programs. Some participants, who are primarily irrigation permit holders, therefore receive $100 per acre-foot from the ASR program and $140 per acre-foot or more from another party that is leasing their water, for a combined $240 per acre-foot.[15]

To the degree that the VISPO and ASR measures have allowed the Edwards Aquifer region to avoid developing alternative water supplies that would have otherwise been required to meet regional needs during droughts, the costs of the VISPO and ASR programs could be compared to the costs of additional water supplies. The existence of both programs promotes flexible water management, especially during drought times, and potentially mitigate the need for new water supplies to satisfy demands during critical periods.

Transactions within the Edwards Aquifer water market have provided the flexibility needed by aquifer water users for a variety of short-term needs. The median size of the 5,844 transactions—65 acft—also supports the idea that these transactions enabled a variety of water users to satisfy short-term needs for relatively modest amounts of water (Table 5). However, many of these leases that transferred water to SAWS are optimizing Edwards Aquifer groundwater use and serving long-term regional needs through ASR storage in SAWS' H_2Oaks Center, primarily for use during droughts. Unlike the karst Edwards Aquifer, water injected into the sands of the Carrizo Aquifer at the SAWS H_2Oaks Center tends to remain in place and is not subject to evaporative losses. ASR allows SAWS to procure water through the Edwards Aquifer market and bank it for use during a period of higher demand, such as a drought. ASR also allowed SAWS to maximize the beneficial characteristics of both aquifers by creating an underground storage facility without the considerable costs and conflicts associated with creating a surface water reservoir.

5. How Water Use Changed After the Edwards Aquifer was Regulated and the Water Market was Created

Water markets provide a mechanism for the voluntary reallocation of water resources. This function is an essential water management strategy for regions where water demands continue to increase along with the costs for developing viable alternative supplies. Between 1997 and 2020, the Edwards Aquifer water market facilitated the transfer of 85,000 acft of rights from lower valued agricultural uses to higher valued municipal and industrial uses.[16] Table 8 compares the allocation of Edwards Aquifer rights among uses throughout the process of applicants applying for permits beginning in 1997 to the final permits approved by the EAA in 2005, to the allocation of permits among uses in 2020. Figure 15 demonstrates how water has shifted between the categories of uses from 1997 to 2020. The final permit amount total was

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[15] The ASR program has been recently modified to become a forbearance program similar to VISPO.

[16] Determining the actual amount of water reallocated through the Edwards Aquifer water market is a little tricky in the early years because trades began before permits were issued. However, it is likely that the initial amount of water allocated to irrigation actually underestimates the volume of water that has moved from agriculture to municipal and industrial uses since 1997. In addition, the EAA issued permits totaling 549,000 acft/year in batches from 2001 to 2005 as hearings were held contesting the amount of water that some applicants would receive. Finally, the Legislature raised the statutory limit on pumping in 2007 to 572,000 acft/year to accommodate some users who believed they were entitled to additional water.

established in November 2005 by the EAA at 549,000 acft/yr effective January 1, 2006 (EAA, 2005, p. 1), only to be tinkered with by the Texas Legislature when it increased the total to 572,000 acft/yr in 2007. Beginning in 2006, municipal rights increased from 296,686 acft to 354,244 acft or 19%, while industrial rights decreased from 45,554 acft to 42,560 acft or 7%, and agricultural rights decreased from 205,623 acft to 174,465 acft or 15%. As of November 2022, SAWS' 96 permits totaled 268,141 acft, accounting for 73% of all municipal use (G. Eckhardt, personal communication, November 28, 2022). The changes in water permitted for industrial use can be misleading because industrial water users in Bexar County are now supplied directly by SAWS due to San Antonio City code, which prohibits the drilling of groundwater supply wells within the City of San Antonio or SAWS service area without the approval of SAWS (San Antonio, Texas Ordinance Number 80574, 1994; San Antonio, Texas Ordinance Number 86747, 1997). As a result of this ordinance some of the water that has shifted from industrial use to municipal use is still being used by industrial users. As Figure 15 shows after final permits were issued in 2006 more water shifted from agriculture to municipal use as would be expected given the shortfall for permitted municipal water during recent droughts and the initial overallocation of water to agricultural use in access of demand for that category due to the statutory minimums.

Table 9 compares two periods of Edwards Aquifer pumping. The first is the period between 1972 and 1993. This was the period before the aquifer was regulated and the water market was created. The second period is between 1999 and 2020. This was a dryer period, which included multiple severe to exceptional regional droughts. Compared to the first period, pumping during the second period was 46,400 acft/year less on average, while aquifer recharge (AR) during the second period was 183,000 acft/year less on average. This is significant, given the larger population relying on the aquifer during the dryer second period.

Figure 16 depicts the initial permitting regime approved by the EAA in the early 2000s. At that time, 46% of permits were approved for agricultural irrigation, 12% for industrial use, and 42% for municipal use. These proportions changed over the following two decades as more water permits were transferred from agricultural users to municipal users. As shown in Figure 17, by 2021, municipal users accounted for 61% of Edwards Aquifer withdrawals, agricultural users consumed 31%, and industrial users pumped the remaining 7%. This shift was made possible by the Edwards Aquifer water market.

Table 8. Change in Edwards Aquifer rights and allocations, 1997 to 2020.

Year	Total acft / overall % / number of permits	Municipal acft / overall % / number of permits	Industrial acft / Overall % / number of permits	Agricultural acft / overall % / number of permits
1997	778,425 / 100% / 856	355,909 / 46% / 100	75,406 / 10% / 178	344,807 / 44% / 577
1998	778,425 / 100% / 864	356,952 / 46% / 104	75,948 / 10% / 182	343,222 / 44% / 577
1999	778,950 / 100% / 932	368,138 / 47% / 157	76,144 / 10% / 194	333,365 / 43% / 580
2000	779,107 / 100% / 996	381,531 / 49% / 202	77,510 / 10% / 206	317,764 / 41% / 587
2001	779,385 / 100% / 1,174	391,659 / 50% / 330	77,074 / 10% / 229	309,352 / 40% / 614
2002	730,473 / 100% / 1,315	382,621 / 52% / 385	70,539 / 10% / 254	276,013 / 38% / 675
2003	688,784 / 100% / 1,387	358,530 / 52% / 412	61,293 / 9% / 272	266,657 / 39% / 702
2004	628,295 / 100% / 1,491	319,309 / 51% / 487	58,592 / 9% / 286	248,191 / 40% / 717
2005	577,255 / 100% / 1,569	301,999 / 52% / 515	47,658 / 8% / 304	226,395 / 39% / 749
2006[1]	549,066 / 100% / 1,861	296,686 / 54% / 571	45,554 / 8% / 384	205,623 / 37% / 905
2007	549,066 / 100% / 1,808	298,584 / 54% / 590	44,119 / 8% / 354	205,212 / 37% / 863
2008[2]	571,600 / 100% / 2,012	329,174 / 58% / 675	49,565 / 9% / 376	191,609 / 34% / 959
2009	571,600 / 100% / 2,131	341,755 / 60% / 736	47,702 / 8% / 421	180,992 / 32% / 973
2010	571,600 / 100% / 2,049	353,190 / 62% / 697	47,153 / 8% / 402	170,115 / 30% / 949
2011	571,600 / 100% / 2,310	350,536 / 61% / 717	48,330 / 8% / 444	171,582 / 30% / 1,148
2012	571,600 / 100% / 2,082	353,755 / 62% / 625	47,188 / 8% / 428	170,502 / 30% / 1,026
2013	571,600 / 100% / 2,164	350,374 / 61% / 677	48,346 / 8% / 441	172,925 / 30% / 1,045
2014	571,600 / 100% / 2,221	363,266 / 64% / 712	46,492 / 8% / 437	161,842 / 28% / 1,072
2015	571,600 / 100% / 2,253	364,684 / 64% / 732	46,508 / 8% / 420	160,407 / 28% / 1,101
2016	571,600 / 100% / 2,175	382,125 / 67% / 814	41,038 / 7% / 410	148,437 / 26% / 951
2017	571,600 / 100% / 2,214	380,506 / 67% / 790	40,424 / 7% / 401	150,669 / 26% / 1,023
2018	571,600 / 100% / 2,226	378,563 / 66% / 780	40,851 / 7% / 392	151,856 / 27% / 1,053
2019	571,600 / 100% / 2,113	355,977 / 62% / 629	41,271 / 7% / 403	174,021 / 30% / 1,080
2020	571,600 / 100% / 2,166	354,244 / 62% / 607	42,560 / 7% / 409	174,465 / 31% / 1,149
2006-2020 Change*	Total acft: No change. Total permits: +305	Municipal acft: 57,558, or 19% increase. Total permits: +36	Industrial acft: 2,994, or 7% decrease. Total permits: +25	Agricultural acft: 31,158, or 15% decrease. Total permits: +244

[1] EAA order issuing final initial regular permits was November 30, 2005.

[2] Texas Legislature increases permit totals to 572,000 acft/yr in 2007.

* Calculated by author.

Source: Friberg, 2024.

Figure 15. Shifting Edwards Aquifer rights and allocations, 1997 to 2020.

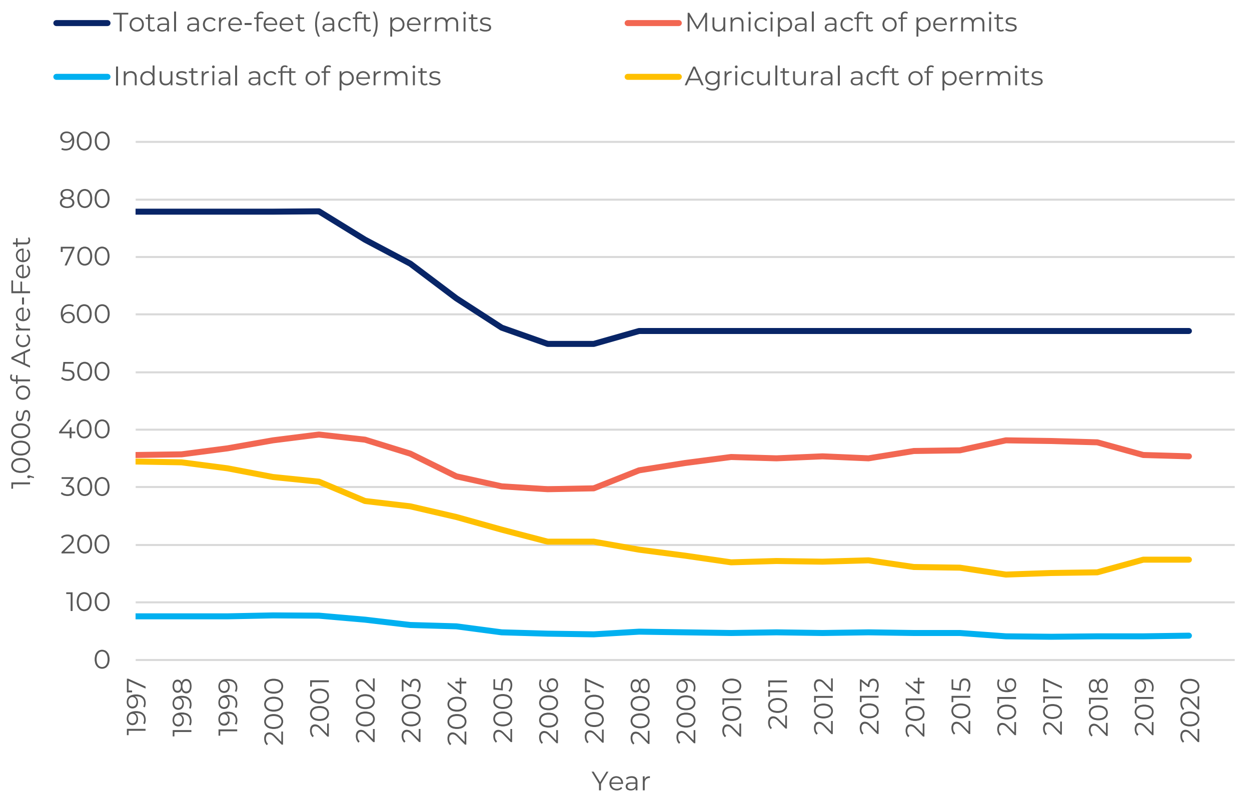


Table 9. Comparing periods with and without regulation and the water market.

	Acre-feet		Acre-feet
Average annual recharge (1972–1993)	933,100	Average annual pumping (1972–1993)	421,700
Average annual recharge (1999–2020)	750,100	Average annual pumping (1999–2020)	375,300
Difference	Decrease of 183,000	Difference	Decrease of 46,400

Figure 16. Proposed groundwater permits by Edwards Aquifer Authority in 2003.

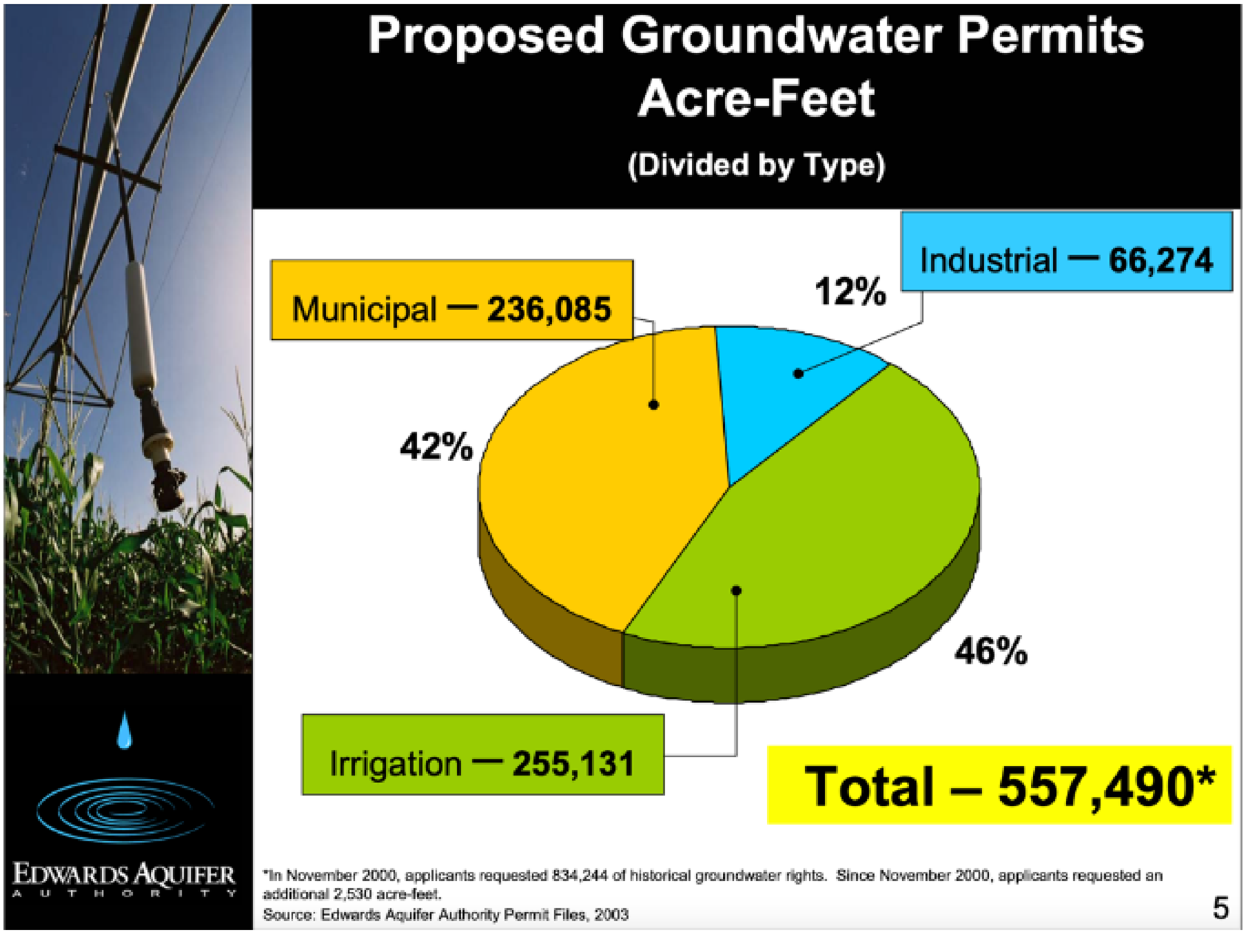
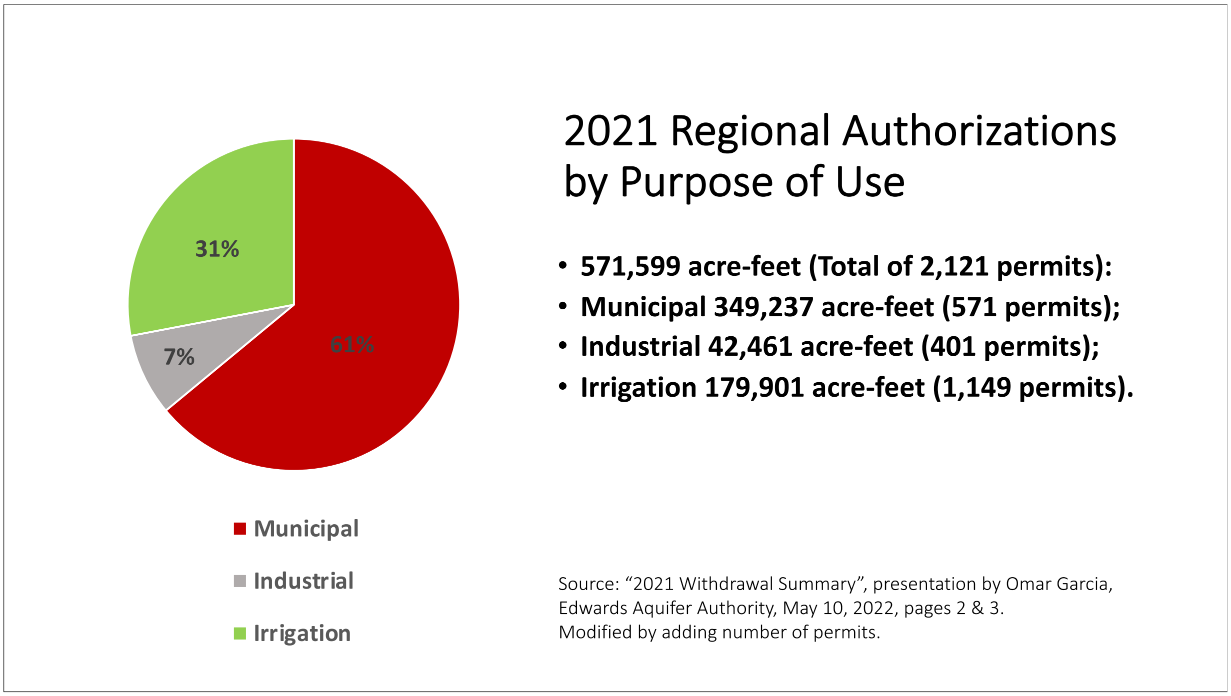


Figure 17. 2021 Regional authorizations by purpose of use.



6. How the Edwards Aquifer Water Market Has Altered the Relationship Between Population Growth and Water Demand

Both the creation of the EAA and the establishment of the Edwards Aquifer water market had a profound effect on SAWS. As discussed in the previous section, over the course of nearly two decades, a substantial portion of Edwards Aquifer water rights transferred from agricultural users to municipal users. SAWS is the major player in, and beneficiary of this market. SAWS secures additional Edwards Aquifer groundwater through multiple methods that include leasing, purchasing, trading, and water conservation (TWDB, 2003, p. 19).

Behavioral changes in Edwards Aquifer water use have led to more efficient use over time. Other major metropolitan areas in the United States and abroad have been able to accommodate population increases while simultaneously reducing their volume of water use. As a result, these cities have decoupled population growth from water use, primarily through reducing per-capita residential water use (Richter et al., 2020, p. 1). When cities' water demand continues to track population growth, there is likely inefficient and/or unsustainable water use—and possible opportunities for creating new water markets. Regarding the Edwards Aquifer region, population growth and water demand clearly decoupled when the EAA was created in 1993 and accelerated when the aquifer was ultimately regulated and as the water market began to function.

The Legislature's creation of the Edwards Aquifer pumping cap inaugurated a series of policy changes that changed water use behavior, decoupling San Antonio's water demand from its population growth. SAWS recognized this in 1993 when the EAA Act (SB 1477) was passed, saying the act would "have a profound effect on the SAWS water resource planning, particularly water conservation and reuse" (SAWS, 1993, p. 8).

In the years following the EAA Act's passage, San Antonio adopted water conservation measures in response to the approaching limits on aquifer use. These measures included rebates for incentivizing plumbing fixture replacements, resulting in an estimated 13,800 acft of water savings from 1994 to 2013 (Joseph, 2013). Additional measures were approved in 1998, when the San Antonio City Council adopted a 50-year water supply plan. Altogether, SAWS water conservation program which was considered to be very aggressive at the time, consisted of some 30 measures. These measures include rebates for water conserving practices and technologies, landscape conversion programs, public education campaigns, and changes to SAWS rate structure, worked in tandem with the water market to decouple population growth from water use in the San Antonio region since 1994 (Richter et al., 2020).

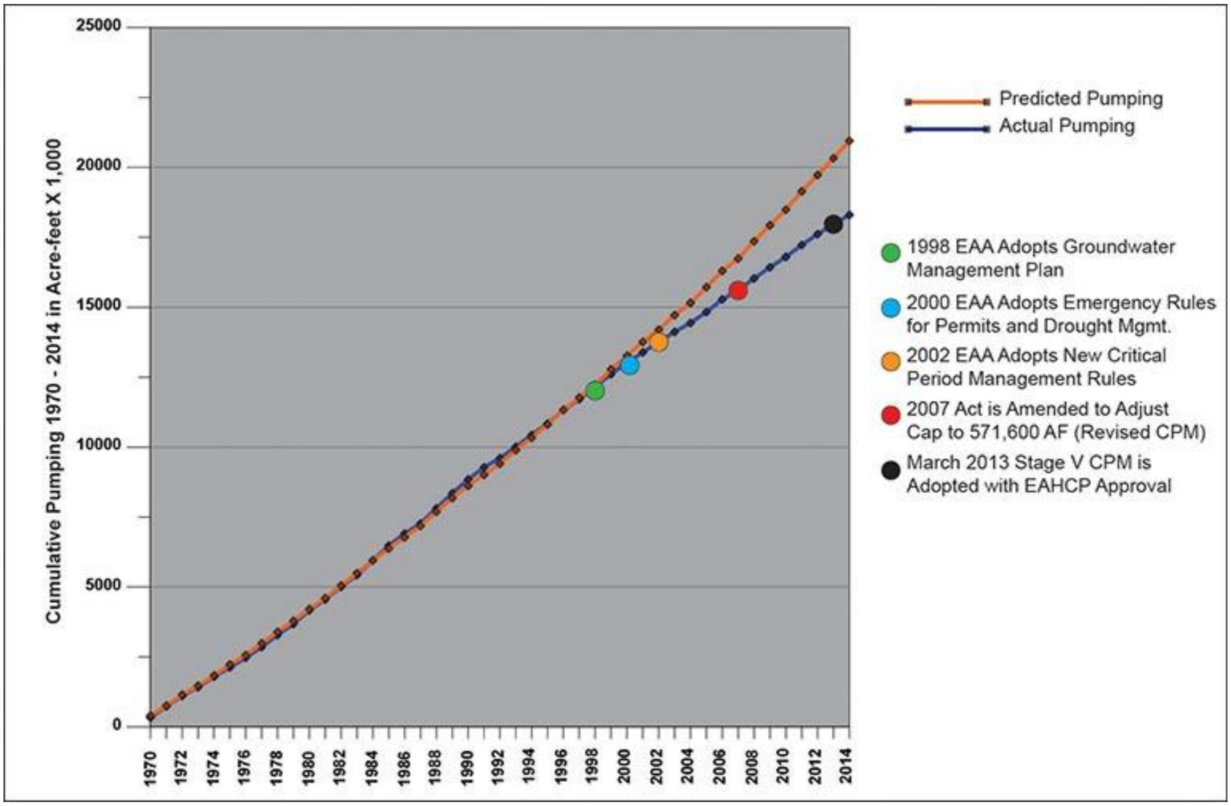
In 1982, SAWS' municipal water use per capita per day was at least 225 gallons per capita per day (gpcd). SAWS' 1998 plan sought to reduce water use to 140 gpcd by 2013 (Arce, 2003, p. 3). By 2016, SAWS' total per capita water consumption had decreased to 117 GPCD, resulting in an estimate 3.2 million acft of cumulative water savings (SAWS, 2017, p. 5). In 2022, SAWS' municipal water consumption had decreased to 111 gpcd (R. Puente, unpublished interview, September 8, 2022).

In 2014, the EAA examined the impacts of regulating the aquifer and creating the water market. These considerable impacts are shown in Figures 17 and 18. Excerpts from the report support the thesis that water use was decoupled from population growth due to both aquifer pumping limits and the water market:

- "The pumping limitations of a permitting system, the value assigned to Edwards [Aquifer] water by the creation of the Edwards [Aquifer] water market and the introduction of improved technologies are all factors that help sustain our main water source while also giving rise to a great, regional conservation ethic" (EAA, n.d., para. 3).
- "Case in point: A long and sustained growth trend in pumping from the aquifer that tracks back to the 1940s suddenly began to flatten in 1997 and has remained flat since. In other words, because of the EAA Act, pumping growth was stopped" (EAA, n.d., para. 4).
- "Since 1997 when the EAA began its initial review of permit requests, the annual growth rate in pumping has stopped, despite a population increase of 670,000 residents in the primary five-county EAA region (Uvalde, Medina, Bexar, Comal and Hays) during the same period" (EAA, n.d., para. 14).
- "Summer peak pumping rates have stabilized since the EAA enacted initial regular permits in 2001 and implemented Critical Period Management strategies in 2002" (EAA, n.d., para. 15).

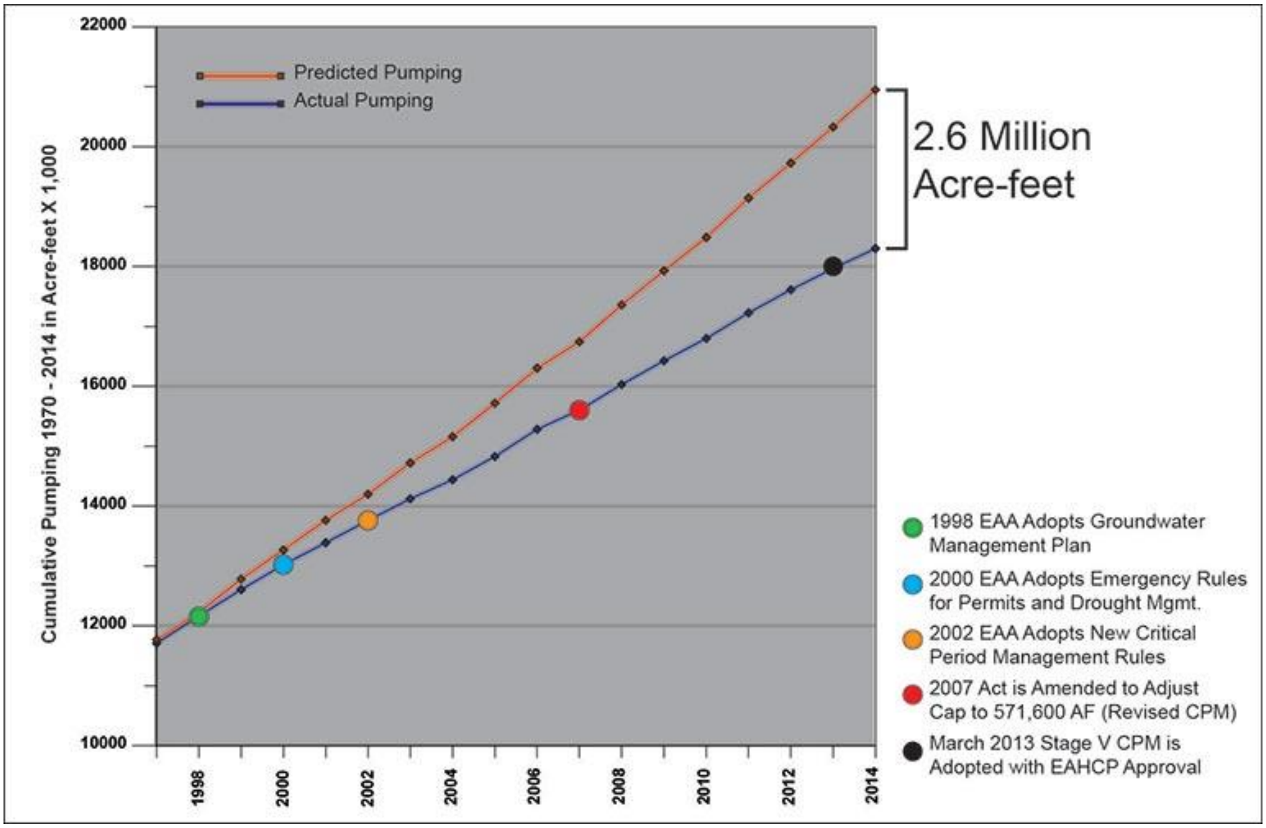
- "By the end of 2014, actual permitted pumping from the Edwards was 2.6 million acre-feet less than predicted by a population growth model for the period 1997 through 2014" (EAA, n.d., para. 13).

Figure 18. Edwards Aquifer predicted versus actual pumping, 1970–2014.



Source: EAA, n.d.

Figure 19. Edwards Aquifer predicted versus actual pumping, 1997–2014.



Source: EAA, n.d.

The Edwards Aquifer water market has also influenced water use in other ways. Each Edwards Aquifer groundwater permit holder has a permit with a specific amount that can be used over the year, subject to critical-period restrictions. Those that use more than their permitted amounts are subject to fines by the EAA. Each permit holder pays a fee to the EAA for every acre-foot of their permitted total that they use (this fee funds the operation of the EAA, which manages the water market, among many other operations). This fee structure also motivates some users to use less water so they can lease or sell their water rights to other users that need it, providing an additional source of income. In addition, permit holders get a refund from the EAA at the end of the year for the water they did not use. This is another incentive for users to conserve their water. These factors motivate users to monitor their water use to ensure they have enough for their anticipated yearly uses and to limit the fees they pay to the EAA. In addition, each permit holder must pay to lease water or buy additional pumping rights if they need more water. This encourages users to maximize their permitted water use to avoid paying for more water through leasing water or purchasing additional water rights. This is all in contrast to the time before the Edwards Aquifer was regulated and the market was created, when additional pumping was free.

7. Impact of the Edwards Aquifer Water Market on Agriculture

Between 2001 and 2020, EAA counties' total gross domestic product (GDP) increased by about 70% in constant dollar terms (Figure 20). However, agricultural output from the Edwards Aquifer region has dropped since 2007 (Figure 21). Hay—the proxy for low-value crops—became a larger portion of the total of agricultural output, rising from about 40% in 1997 to 77% in 2007. As of 2017, hay production remained at about 60% of output. Even though a significant drought occurred from 2011 to 2015, agricultural production appears to have fallen in absolute terms between 2001 and 2020. Unlike in the Lower Rio Grande water market, there has not been a shift toward higher value crops during periods of water scarcity. Farming may be a more vital sector in the Rio Grande Valley economy where 85% of water is held in irrigation rights, whereas water use in the Edwards Aquifer region is dominated by municipal and industrial uses, as well as drought and environmental needs.

Since 2000, it appears that approximately 25% of Edwards Aquifer rights sales classified as 'irrigator to irrigator' may have been sales to water investors, which include true speculators, cities, and water utilities. This may help explain both the decline in farm output and the slow pace of water reallocation between lower value and higher valued crops. If the water rights are not dedicated to agriculture but are instead reserved as a drought cushion through the VISPO and ASR programs, then there may be less incentive to invest in water efficiency measures and/or undertake the risk of switching to more water-efficient crops. The shift to perennial crops such as hay may indicate that some irrigation water rights holders are motivated to maintain their water in state that allows them to maximize their ability to maximize gains for lease or sale during a future drought.

Figure 20. Real gross domestic product (GDP) and total annual Edwards Aquifer pumping in Edwards Aquifer Authority counties, 2001-2020.

Source: U.S. Bureau of Economic Analysis, Real Gross Domestic Product: All Industries in Edwards Aquifer counties [REALGDPALL48055], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/REALGDPALL48055, July 11, 2022.

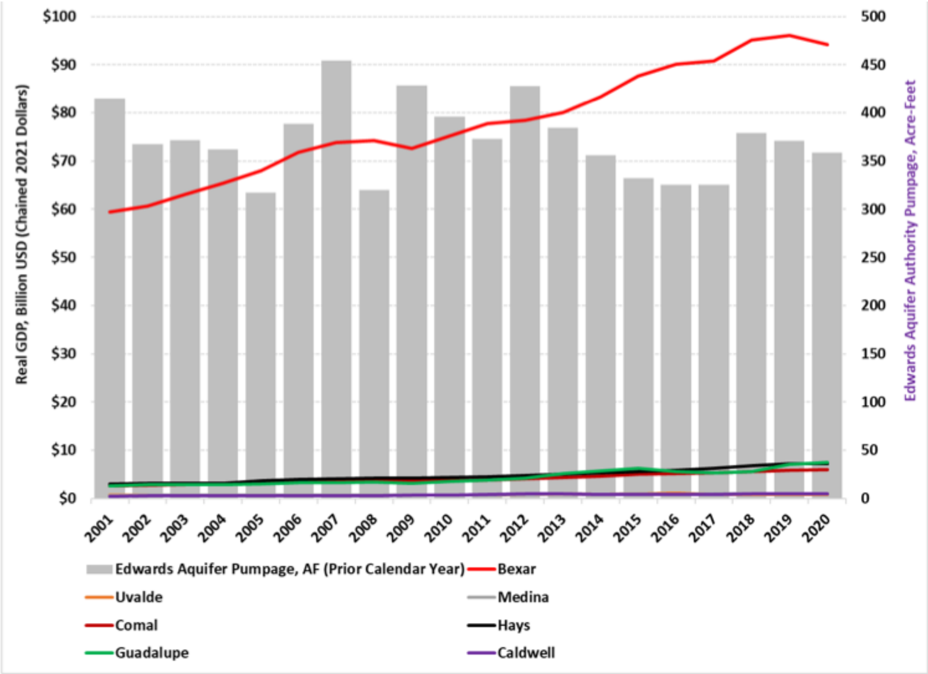
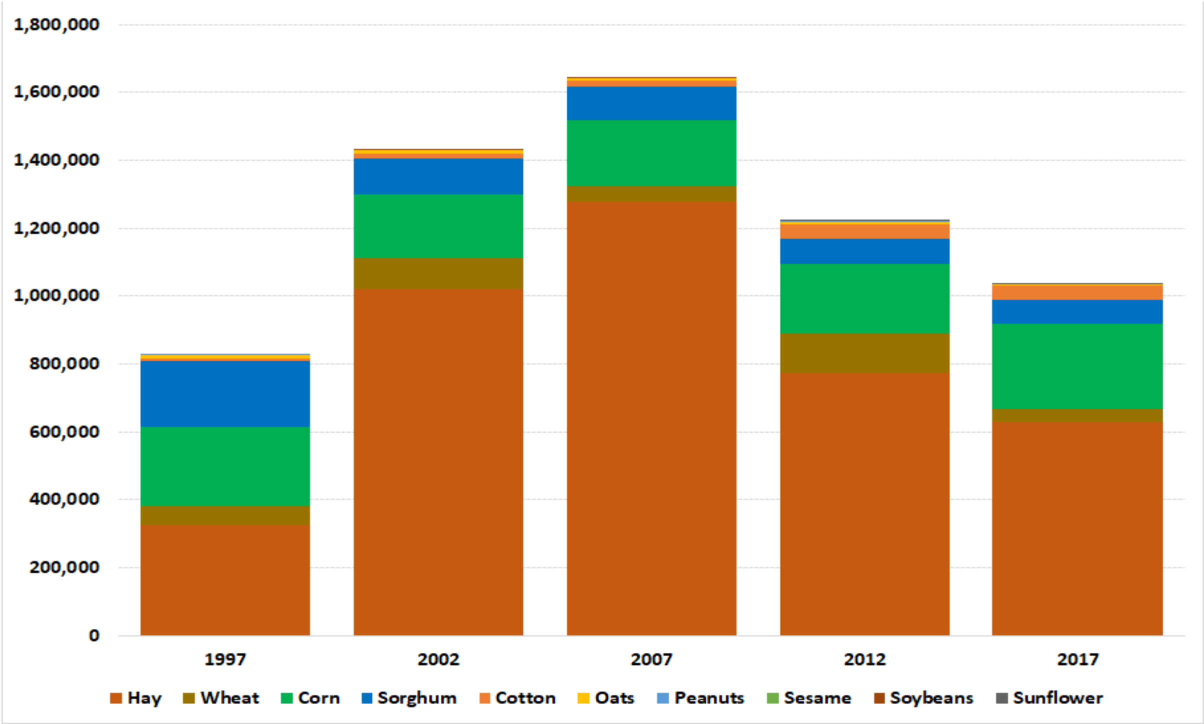


Figure 21. Crop production in Bexar, Caldwell, Comal, Guadalupe, Hays, Medina, and Uvalde counties in tonnes.



8. The Edwards Aquifer Water Market Works as a Water Supply Strategy

Water planners have struggled to accurately project water needs and use in the Edwards Aquifer region, as demonstrated by Table 10's comparisons of demand projections and actual use. The differences between water planners' projected water demands and actual use indicate that the water market and the associated regional conservation efforts profoundly impacted water use in ways that were not anticipated during the water planning process.

For example, SAWS' 1998 Water Resources Plan significantly overestimated water demand between 2000 and 2004. While that plan anticipated a demand of 197,375 acft by 2004, the actual water use was nearly 35,000 acft less. TWDB's 2002 state water plan also forecasted significant SAWS and Bexar Metropolitan Water District (BMWD) water demands in 2010 and 2020 that failed to materialize. That plan anticipated that the combined utilities would need 289,909 acft of water by 2010 and 326,728 acft in 2020. In reality, the actual use of all municipal users within the EAA—which includes SAWS and BMWD—was substantially lower, with 259,900 acft being used in 2010 and 223,400 consumed in 2020. These findings are consistent with those described in Figures 17 and 18, where the actual pumping volumes from the Edwards Aquifer fall below predicted pumping levels.

State water plans from 1990, 1992, and 1997 also projected water demands that did not materialize. The 1990 state water plan projected that if Edwards Aquifer pumping was limited to 424,000 acft annually, by 2000, San Antonio would need an additional 111,184 acft/yr. The sources for this water would be 19,000 acft/yr from Medina Reservoir and 7,900 acft/yr from the proposed Applewhite Reservoir, both in the San Antonio River Basin, and 84,284 acft/yr from the proposed Lindenau and Cuero reservoirs in the Guadalupe River Basin (TWDB, 1990, pp. 3-12, 3-16, 3-42, 3-45, 3-88; TWDB, 1992, p. 94). In addition, 148,400 acft would be needed from the proposed Goliad Reservoir by 2020 or 2030 (TWDB, 1990, p. 3-12). The 1997 state water plan—the first one produced after the EAA was created[17]—projected that San Antonio's water use would reach 220,405 acft/year in 2000, and that the Cibolo Reservoir (122,000 acft/year) on the San Antonio River would need to be developed before 2010 to meet San Antonio's water needs (TWDB, 1997, pp. 3-82, 3-174). The Edwards Aquifer water market, coupled with SAWS' ASR and conservation programs, obviated the need for these additional reservoirs.

[17]The 1997 state water plan was the last one produced before the implementation of the new bottom-up regional water planning process—created through SB 1 in 1996—was implemented. The EAA was created in 1993 but was in limbo until after the Legislature modified EAA Act in 1995 to address federal voting rights objections to the EAA, and the Texas Supreme Court ruled that the EAA was constitutional in *Barshop v. Medina County Underground Water Conservation Dist.*, No. 95-0881 (Tex. Aug. 22, 1996).

Table 10. Edwards Aquifer municipal water demand projections compared to actual use, in acre-feet (acft).

Plan	1984 max use year	1993	2000	2001	2002	2003	2004	2010	2020
1997 state water plan, SAWS, and BMWD	-	EAA Act	220,405	-	-	-	-	-	-
1998 SAWS	-	EAA Act	188,555	189,658	191,986	194,872	197,375	213,380	245,256[1]
2001 Region L Plan, SAWS	-	EAA Act	220,405	-	-	-	-	242,339	272,507[1]
2002 state water plan	-	EAA Act	228,728 (SAWS)	-	-	-	-	289,909 (SAWS+ BMWD)	326,728 (SAWS+ BMWD)
2005 SAWS	-	EAA Act	-	-	-	-	-	176,118-220,588	187,472 - 239,392[1]
TWDB projected use Bexar County		EAA Act	240,256	240,355	222,830			306,852	340,750
TWDB estimated use Bexar County	252,584	EAA Act	240,247 (3,940 surface water)	240,286 (9,892 surface water)	222,729 (9,431 surface water)	231,103 (10,463 surface water)	221,388 (10,566 surface water)	252,345 (21,242 was surface water)	292,408 (8,448 was surface water, 48,342 reuse)
Actual use by SAWS	191,430[2]	EAA Act	180,564	178,385	161,758	168,969	162,716	176,796[3]	217,991
EAA district estimated municipal use	287,200	EAA Act	261,300	245,900	228,400	237,200	220,300	259,900	223,400

Definitions of terms: Aquifer storage and recovery (ASR); Bexar Metropolitan Water District (BMWD); Edwards Aquifer Authority (EAA); San Antonio Water System (SAWS); Texas Water Development Board (TWDB).

[1] Projections did not include demand for future BMWD service area served by SAWS beginning in 2012. SAWS received Bexar Metropolitan Water Districts (BMWD) permits totaling at least 24,000 acft when it absorbed BMWD.

[2] Other sources document SAWS' peak Edwards Aquifer pumping at 193,944 acft in 1984 (SAWS, 1998, p. 55).

[3] SAWS net pumping was 200,640 acft of Edwards Aquifer water, 25,532 acft of which was stored in ASR. This left 175,108 acft for distribution, plus another 1,688 acft of Edwards Aquifer water brought back from ASR for distribution. The net total of Edwards Aquifer water distributed in 2010 was therefore 176,796 acft. The SAWS 2010 value does not include the use of all the separate systems that made up BMWD. The SAWS 2020 number *does* include most of what was BMWD, and it's actually lower than 2010. This means that even with the population growth in SAWS' service area and the addition of the demand from the BMWD system, SAWS pumping in 2020 was similar to use in 2000.

Sources: EAA, 2021a, Table 4, pp. 9, 10; EAA, 2022 p. 6; SAWS, 1998, p. 16; SAWS, 2005, pp. 10, 11, 18; South Central Texas Regional Water Planning Group, 2001, Table 4-2, p. 4-8; TWDB, 1997, p. 3-82; TWDB, 2021.

Because of the water market, those who relied upon the aquifer were able to meet their needs under the cap on aquifer pumping. As a result, the environmental impacts from habitat loss and reductions in environmental flows associated with the massive main channel dams planned for the Guadalupe and San Antonio rivers were avoided, along with the enormous costs that would have been required to build these projects.

9. Why Were the Short-Term Projections for Water Demands in Region L and for San Antonio So Much Higher Than Actual Demand?

The planners at TWDB, SAWS, and the Region L Water Planning Group knew that the 450,000 acft/year aquifer pumping limit decided in 1993 was much lower than EAA's actual permitted pumping amount by 2003, 549,000 acft/year (Table 10). After years of disagreement about the limit, the Legislature ultimately raised it to 572,000 acft/year in 2007. The TWDB, SAWS and Region L planners are among the best in the world, so why did they significantly overestimate how much water would be pumped from the aquifer less than 5 years later? There were drought years, but they were mixed with years with floods. Population trends do not explain the difference as the region's population continued to grow. The most likely reasons for the overestimations are that the impact of the Edwards Aquifer water market and the limits on aquifer pumping had profound impacts on water use that were truly an unknown for the planners

A well-structured water market requires a cap or limit, such as the one that exists for the Edwards Aquifer water market. However, a cap and perceived threats of penalties do not necessarily result in greater demands being met by less water. If there was no trading in the market, pumping would have stabilized at the pre-market level or started to rise to meet the cap. This is the opposite of what happened in the Edwards Aquifer, as shown in Figure 12. Pumping peaked in the 1989 drought year and has been substantially below the 572,000 acft cap and the 542,500 acft pumped in 1989. Beginning in 1997, the Edwards Aquifer water had an actual value attached to it, determined by supply and demand within the market, it could be traded. That was the signal to permit holders that there was an incentive to conserve water so they could trade excess water on the market. It was also a signal to water right holders who did not plan to trade their rights through the market—but who were concerned about their current or future needs—to reduce their water use to avoid the expense of securing more water through the market. Once trading within the market began to function and the potential for gain became apparent, permit holders reassessed their water use.

Recall that in 1993 the EAA Act allocated irrigators an annual minimum of 2 acft of water per irrigated acre of land. Overall, this allocation was greater than what irrigators were generally using at the time, as irrigation use peaked in 1985 at 203,100 acft, but irrigators nevertheless received 255,131 acft in permitted groundwater (Table 11). Because of this the reallocation of permitted rights from irrigation to municipal permits is greater than the actual irrigation and municipal pumping changes (Table 8 and 11). However, the permitted groundwater surplus fueled activity within the water market. From 1997 to 2020, sales and leases of irrigation rights have dominated activity in the Edwards Aquifer water market (Tables 6 and 7). During that same period irrigation pumping was under 100,000 acft in most years. The 10-year mean from 2011 to 2020 was 79,400 acft (EAA, 2020). This shift away from irrigation water use is a direct response to the creation of the water market. The exchange of water has increased the water's value, encouraging irrigators to sell their water, or to use less and conserve more water so that it can traded to other irrigators or can be traded for higher valued municipal and industrial uses. This is how the market has facilitated the reallocation of permitted Edwards Aquifer groundwater from the initial uses shown in 2003 to 2020 in Table 11.

Table 11. Comparison of estimated withdrawals from the Edwards Aquifer and permitted use for selected key years, in acre-feet (acft).

Year / event	Irrigation withdrawals / permitted irrigation	Municipal withdrawals / permitted municipal	Domestic and livestock withdrawals / permitted domestic and livestock	Industrial and commercial withdrawals / permitted domestic and livestock	Total withdrawals / total permitted
1989 / maximum year of pumping	196,200* / Pre-Edwards Aquifer Authority (EAA)	285,200 / pre-EAA	38,200 / not permitted	22,900 / pre-EAA	542,500 / pre-EAA
2003 / permits issued by EAA	79,600 / 255,131	237,200 / 236,085	13,700 / not permitted	31,700 / 66,274	362,200 / 557,490
2020 / final year in comparison	97,700 / 174,765	223,400 / 354,278	14,600 / not permitted	26,800 / 42,556	342,457 / 571,999

Sources: Edwards Aquifer Authority, 2021, Table 4; Proposed Groundwater Permits Acre-Feet, 2003, Edwards Aquifer Authority Permit Files, 2003; 2020 Withdrawal Summary, Chuck Ahrens, Edwards Aquifer Authority, May 25, 2021.

*Irrigation withdrawals peaked in 1985 at 203,100 acft.

During drought years, it is not possible to pump close to the 572,000 acft permitted under the cap because of the critical period drought restrictions - during the most extreme conditions, pumping from the entire aquifer could be restricted by 44%. During wet years, the maximum amount is available, but demand is substantially less. However, from 1997 to 2020, SAWS' very large ASR facility, the H_2Oaks Center, was being filled, which created additional demand for Edwards Aquifer pumping during wet years beyond the normal aquifer pumping to satisfy immediate uses.

The increase in SAWS's total groundwater rights over the 1999-2020 period clearly demonstrate the value of the Edwards Aquifer water market. By 2020, SAWS total permitted Edwards Aquifer supply had increased to 271,146 acft/year from the 159,040 acft/year it initially started with in 2004 (SAWS, 2020, p. 5; SAWS, 2005, p. 6).[18] Overall, the Edwards Aquifer water market facilitated over 1 million acft of sales and leases in the region between 1997 and 2020. During that time, regional water conservation efforts substantially reduced water use, incentivized by SAWS, the single largest groundwater user. The Edwards Aquifer water market, coupled with SAWS' ASR facility, provided an alternative water supply, reducing SAWS' need for additional surface water reservoirs on the Guadalupe and San Antonio rivers. Aquifer regulation and the water market reduced aquifer pumping to levels that have sustained adequate minimum flows from Comal and San Marcos springs. All of these efforts contributed to assigning a value to Edwards Aquifer water, resulting in behavioral changes among users.

10. Conclusions

The Edwards Aquifer water market was created as an indirect result of the use of the federal Endangered Species Act to place a limit upon on aquifer pumping. The transition period from a pumping free-for-all to a regulated water market was a fraught period marked by uncertainty, but the resulting water use changes provide lessons—and benefits—for other regions concerned about their groundwater supplies.

The Texas House Committee on Natural Resources (2018) interim report summed up why the Edwards Aquifer water market has been a success:

> "The Edwards [Aquifer] water market has been the most successful Texas groundwater market to date for several reasons. First and foremost, the aquifer is managed closely by a regulatory agency and there is a limited amount of water permits available. Although initial permits were essentially free, over time the value has increased because no new permits will be issued while demand for the water continues to increase. Unlike in other GCDs [groundwater conservation districts], where it is often easier to purchase land and apply for a new permit, all the Edwards permits have already been issued. Second, there are fewer impediments to transfers in the Edwards meaning fewer opportunities for a transfer application to be denied – particularly for a change in withdrawal location. In practice, permits will only be denied if the water is not present due to a previous transfer of the same water or other title inconsistencies" (Texas House Committee on Natural Resources, 2018, p. 96).

[18] SAWS also received Bexar Metropolitan Water Districts (BMWD) permits totaling at least 24,000 acft when it absorbed BMWD in 2012.

CHAPTER 3. BARRIERS TO NEW WATER MARKETS IN TEXAS

A. Background

For decades, water markets have received periodic consideration by researchers, water management professionals, regulators, and lawmakers. While many factors have influenced the evolution of water management in Texas, there is little evidence that the general structure of Texas water policies, laws, and institutions have been crafted with the creation and widespread adoption of water markets in mind. Notable exceptions to this led to the creation of the Middle and Lower Rio Grande and the Edwards Aquifer water markets, which trace their origins to water crises that occurred during the drought of record in 1956. The litigation that occurred over the decades that followed in those regions resulted in the only structured water markets in Texas. Both markets exist as isolated pockets within the fabric of Texas water management.

Despite the success of the Edwards Aquifer and Middle and Lower Rio Grande water markets, similar water markets have not been created elsewhere in Texas. This chapter will identify consistent barriers to Texas water market development. In addition to analyzing factors related to Texas water institutions, law, public policy, and management strategies, this analysis includes excerpts from over 30 interviews with key Texas water experts and other water market practitioners from the western United States and Australia. Because many of the interview subjects requested anonymity in exchange for their candid opinions, all interview subjects' identities have been withheld.

B. Barriers to Both Surface Water and Groundwater Markets

1. Insufficient Water Scarcity to Justify Creating a Water Market

Water scarcity is the key driver for water market creation. However, not all of Texas experiences sufficiently motivating water scarcity. Parts of Texas's eastern half, for example, have surplus supplies and have traditionally been seen as regions that could provide water to water-scarce regions to the west. These water-rich areas are unlikely candidates for regional water markets in the immediate future. Elsewhere in the state, inexpensive water supply options no longer exist and water scarcity is now rising to the necessary threshold for water markets to be established and succeed.

2. The Absence of Available Water for Trading

There are two ways in which there can be too little available water for establishing a water market. There can be insufficient amounts of water physically present, or there can be water that is available but largely withheld from exchange. The latter situation generally occurs where a substantial proportion of water right holders in a given watershed maintain a large inventory of water rights, or water contracts, for future needs, without the current need or ability to use that water.

This situation also arises when users contract for limited water supplies to meet their future needs, reserving the water before other users with competing needs can do the same. This scenario is relatively common with "take or pay"[19] contracts for water, which are often used to finance reservoir projects in Texas. During the period before the water is needed, which can be decades, the water could be available for short-term or mid-term leases. While not a structured water market, these endogenous markets can provide water management flexibility and offset the cost of reserving water far in advance of when it will be needed. While these types of lease transactions do occur in Texas, there is a potential for more such transactions that would benefit those who have reserved water and are paying for it but not using it yet, as well as those who have short- or mid-term water needs that are difficult to satisfy.

Increasing the number of these types of endogenous water market transactions would require support from the project sponsors that have the water rights, and in the case of a reservoir, potentially other entities, such as the U.S. Army Corps of Engineer and the U.S. Bureau of Reclamation. A major obstacle to these types of markets has been the reluctance of entities that have reserved water in this manner to consider short- and mid-term leasing because they are concerned about not being able to get water back when they eventually need it. There is also a concern that these types of leases send a message to the water ratepayers and elected representatives that the entity that originally contracted for water did not need the water in the first place.

"Municipal water providers are risk-averse, so when they look at their water supply portfolio, they are concerned that if they participate in a water market by making their unused supplies that they are holding to meet future needs available for lease in a water market, it could result in them not being able to get the water back when they need it. They aren't comfortable with markets because they are concerned that they are signaling that they don't need their water and that could encourage a change in rules by the state or the Legislature, such that they don't have that water in the future. There are also few opportunities for them to market their excess supplies."

– Water right broker

[19] A "take or pay" water supply contract requires a user to pay for a fixed amount of water every year, even in years when they don't use their full allocation. This ensures that the water supplier can cover their fixed costs, such the cost of bonds used to finance a reservoir project, regardless of how much water is used.

3. The Absence of Either an Artificial or Natural Conveyance

A major issue for potential Texas water markets is the absence of options to convey the water to where it is needed. Unlike electricity, natural gas, and oil, Texas lacks sufficient infrastructure for water conveyance (Johnson et al., 2014). Potential groundwater sellers have no or limited access to systems to transport groundwater to areas of need (Texas House Committee on Natural Resources, 2016). Pipelines also offer conveyance mechanisms for both surface water and groundwater markets. One example is the Colorado-Big Thompson Project, which collects West Slope mountain water in Colorado from the headwaters of the Colorado River and diverts it to the East Slope (U.S. Bureau of Reclamation, n.d.). The Colorado-Big Thompson Project is a self-contained water market consisting of shares of surface water within a regional pipeline that can be traded in acre-feet units to parties within project's service area. Texas may need to study similar projects and develop additional conveyance and storage facilities, both large and small, which would benefit from public and the private sector support (TWDB, 2003, p. 23).

The Edwards Aquifer and the Middle and Lower Rio Grande water markets benefit from natural water distribution systems. The Edwards Aquifer's highly transmissive karst groundwater formation allows water rights that are sold or leased to be withdrawn through existing wells substantial distances from where the rights were originally granted. In the Middle and Lower Rio Grande water market, surface water is stored in Falcon Reservoir and released as needed and transported by the Rio Grande to the intended diversion point as if a bed and banks permit existed for all water right holders in the system. While the bed and banks of rivers offer can readily convey surface water and even groundwater downstream to users, moving water upstream requires expensive infrastructure and a significant amount of energy. The need for storage is also critical for both surface and groundwater markets.

4. Absent or Insufficient Mechanisms to Address the Impacts of Transfers on Third Parties and the Environment

"In Australia's Murray-Darling Basin water market, water for the environment comes off the top."

– Resource economist

"[There is a] need to address impacts to wells in districts outside of the market."

"Mitigation of impacts of the market to the environment and third parties [are necessary]."

"Impacts to surface water by groundwater markets, and groundwater by surface water markets [should be accounted for]."

– Environmental organization staff

With surface water rights, there is also the issue of return flows. More than half of all water diverted from rivers in the western United States is discharged back into the rivers for downstream diversions (Hanemann, 2022, p. 5). Additional consumption of existing rights due to water reuse, additional off-channel diversions, interbasin transfers, and diminished return flows affect the total amount of water available within rivers, reservoirs, and eventually bays and estuaries. Water market transactions can potentially result in impacts to third parties or the environment, which is why surface water right changes must go through a lengthy process in Texas with public objection opportunities before they can be approved. Regulations designed to minimize or eliminate potential impacts to third parties are necessary for the water market to function without conflict (White et al., 2017, pp. 10–11).

5. Public and/or Political Opposition within the Area of Origin

Water, like food, clothing, energy, building materials, and practically everything else used within cities, must be obtained from outside of cities. However, when it comes to moving water from rural areas to cities, the reaction is often emotional in a way that does not occur with the exchange of other commodities. With water resources, however, the oft-articulated concern is that urban interests will benefit at the expense of rural interests (Chong & Sunding, 2006, p. 256). As Hanemann (2022) observes, "the opposition to markets from people/communities that are worried that the water will be transported out of the area of origin is also a major impediment to creating water markets" (p. 9).

"Most farmers have their own water that they own underneath their property. Their water costs are the electricity to pump the water out of the aquifer and then the water lines, etc. They don't pay a commodity price for water. The local community may feel differently about the water sales, but they don't own the water."

– GCD staff

[Regarding water markets] "local use doesn't draw the same concerns that use outside of the area draws."

– Water attorney

The regulation, restrictions, and limits on surface water and groundwater transfers to protect local interests are major obstacles to moving water long distances, oftentimes generating conflict between different regions and economic interests (Johnson et al., 2014). Concerns about the impacts of moving water great distances transcend cultures and can be found across the world where water transfer projects occur (Biswas et al., 1983). Even when third-party effects are addressed, there are still political and social barriers to water markets. However, stakeholder consensus on water market operation is often necessary to create a market if it requires the passage of legislation or another form of administrative approval. A comprehensive valuation of the economic and environmental impacts for both the area of origin and receiving area is an important component before a water market is created to determine the potential impacts on local economies, tax bases, and environmental flows (White et al., 2017).

6. The Lack of Adequate Water Data

Making better water decisions, including the creation and management of water markets, requires sufficient high-quality data that is accessible through open and transparent systems and available in formats that are useful to decision-makers and the public (Rosen et al., 2019). Accurate and reliable water data are a key underlying foundation of a water market. A potential purchaser or lessor will want to know if the water right is quantifiable, reliable, and capable of being used in perpetuity for a sale, or for a specific term for a lease, and what potential conditions could reduce deliveries of the water in question (Johnson et al., 2014, pp. 1–3).

> "Need more data. Need better data."
>
> "Open water data legislation is needed."
>
> **– Environmental organization staff**

Texas's two existing water markets provide users with actionable data and information. The EAA has an online portal that allows willing buyers to find willing sellers that list their water rights that are for sale or lease. The Rio Grande Watermaster's office acts as a clearinghouse for available water so that sellers and buyers can find each other. TWDB also maintains the Texas Water Bank, which also allows sellers and buyers to find each other, however that forum has only seen a small number of users since it was established in 1993.

Although there are informal information networks that operate within certain water markets, the absence of centralized information sources could impede the establishment of additional water markets, because potential buyers and sellers must be able to find each other (Texas House Committee on Natural Resources, 2018; TWDB, 2008). In addition, market managers—whether they are GCDs, TCEQ, or another entity—will need to track transactions to manage the available water and maintain the integrity of the water market.

> [What is required to purchase water rights] "Hire a consultant or lobbyist who knows all the players in an area. There are people in the know, who have a database of rights. That is the person ... people who have ready access to information on the resource."
>
> **– Water attorney**

7. Fragmented State Water Management

In addition to the state agencies that have a role in Texas water management, there are numerous regional and local entities. Texas has 40 local and regional surface water authorities and districts, including river authorities that manage various aspects of surface water. These organizations' powers differ. Some may incur debt, levy taxes, charge for services and adopt rules for those services, enter into contracts, obtain easements, and exercise eminent domain. Some operate across entire river basins, while other river basins are overseen by multiple entities. Most of these entities lack regulatory authority regarding water use and are governed by board members who are appointed by the governor, although a few have elected boards. Texas also has water control and improvement districts (WCIDs), which are special districts that have broad authority to supply and store surface water for domestic, commercial, and industrial uses. WCIDs can operate wastewater systems and provide irrigation, drainage, and water-quality services. Irrigation districts, another type of special district, primarily deliver untreated water for irrigation and to provide land drainage. Irrigation districts are another example. Region M, which is covered by the Rio Grande Regional Water Planning Group, contains 23 separate irrigation districts.

Texas has 100 GCDs and two subsidence districts that regulate, to varying degrees, most of the state's groundwater. GCDs have elected boards and collect fees or taxes to fund their operations. Many GCDs are limited to single county boundaries, which disregard the boundaries of the aquifer or aquifers they overlie.

Regarding municipal water supply, many Texas cities have municipal water supply divisions. There are also over 1,200 active municipal utility districts (MUDs), which are political subdivisions of the state that provide water, sewer, and drainage services over a limited area, mostly outside of city limits. MUDs have elected boards and levy taxes to support their operations. There are also numerous special utility districts that provide water, wastewater, and firefighting services but cannot levy taxes.

In total, Texas had 7,108 public water systems as of 2022, providing drinking water. These systems ranged in size from the City of Houston's huge system to small "mom and pop" systems (TCEQ, 2022, p. 3). A mere 42 of those public water systems serve almost half (47%) the state's 30 million residents (TCEQ, 2022, p. 7). Of those drinking water utilities, 75% use groundwater to supply drinking water, but they serve only 25% of the population. The remaining 25% of drinking water utilities provide water to 75% of the state's population using surface water obtained from rivers, lakes, and reservoirs.

Most of the various types of Texas water supply and management entities have unique sets of rules and policies. This can present many challenges when creating water markets in areas with overlapping jurisdictions or where multiple entities manage the same river basin or hydrologically connected aquifer. This is particularly true for GCDs because their regulatory role and jurisdictions, which are defined by county lines instead of aquifer contours.

Most water planning is conducted at the regional level in Texas, but conflicting planning goals can limit its effectiveness. Numerous interests work within the regional planning process to ensure their projects are included in the state water plan so that may qualify for TWDB loans. This strongly incentivizes including as many competing projects as possible while resisting the regional cooperation that could downgrade a particular project in the TWDB funding competition (Texas House Committee on Natural Resources, 2016). This is symptomatic of the lack of regional cooperation, which has been called the most difficult obstacle to securing the water supply needs of a growing economy and a growing population (Texas House Committee on Natural Resources, 2016).

When water organizations share a common source of water, but operate in silos, management of the resource is incongruent. In Texas, groundwater and surface water are legally distinct, even when hydrologically connected. Such fragmentation, on numerous levels, creates barriers to the establishment of a well-structured water markets.

Barriers to both surface water and groundwater markets, summarized:

- Insufficient water scarcity to justify water market creation
- The absence of available water for trading
- The absence of either a natural or humanmade system for conveyance
- Public and/or political opposition within the area of origin
- Absent or insufficient mechanisms to address the impacts of transfers on third parties and the environment
- The lack of adequate water data
- Fragmented water management

C. Barriers to Groundwater Markets

1. The Absence of a GCD

Groundwater pumping outside of the jurisdiction of a GCD is essentially unrestricted. These areas are known as "rule of capture" areas, where the only law governing groundwater use is the legal tort protecting the pumping by one landowner from injury claims from another landowner. The absence of a mechanism restricting how much groundwater may be pumped from these areas contributes to substantial uncertainty regarding a groundwater source's reliability (TWDB, 2003, p. 15). One landowner's surplus water use may contribute to another's water scarcity. More critically, if groundwater can be pumped without any volume restriction other than the prohibition against waste, then a market value cannot be assigned to the commodity. Absent literal liquidity restrictions, an unregulated aquifer undermines any potential for groundwater market (Texas House Committee on Natural Resources, 2016).

In these unregulated rule of capture areas, buying and selling usually results when a surface estate holder separates the water rights from the surface estate and sells the water rights to a buyer who intends to move and sell the water to third party. This practice is commonly known as "buy and dry," where the purchased groundwater rights are subsequently pumped and exported out of the region of origin (Texas House Committee on Natural Resources, 2018). Within these areas users, have a perverse incentive to both pump first and pump more in order to maximize the return on investment, which results in the unsustainable resource use. Absent regulatory controls, such as pumping caps, that may be imposed through a GCD, prospective purchasers may elect to eschew transactions because there is no guarantee the water, they invest in obtaining will be available over the long term (Texas House Committee on Natural Resources, 2018).

This same problem applies to areas within a GCD that are adjacent to areas that do not have a GCD and are subject only to the rule of capture. Here, within-GCD users who access an aquifer that is also available to an unregulated neighboring area have little to no certainty regarding their groundwater availability (Texas House Committee on Natural Resources, 2018).

The problems associated with the absence of GCDs underscore the relative importance of GCDs for creating water markets for groundwater. GCDs offer regulatory certainty in the form of pumping limits and well spacing requirements. More critically, these requirements generally preclude unbridled pumping from an aquifer—or aquifers—within a GCD's jurisdiction while establishing meaningful limits on how much water can be produced.

2. The Absence of a Groundwater Production Limits

The single most-often mentioned barrier to creating additional Texas groundwater markets is the absence of groundwater extraction or pumping limits, also known as caps. Chapter 36 of the Texas Water Code gives GCDs the power to regulate and limit production, meaning they can limit or cap groundwater production in place. This is a defining feature of the Edwards Aquifer Act. A sustainable limit on groundwater withdrawals is critical to protecting the aquifer, water users dependent upon the aquifer, water market participants, and water market integrity. A sustainable production limit also helps to set a value for water, an essential prerequisite for water market development. The cap makes annual pumping finite, which provides regulatory certainty on how much can be pumped. More critically, this limitation is the necessary precondition for efficiently managing groundwater as a commodity. Potential buyers and lessors in a water market are less likely to engage in transactions to obtain the water if there are no limits on groundwater use that would otherwise ensure they receive the water they purchased (Johnson et al., 2014).

"There will not be any additional groundwater markets unless there are annual limits on aquifer pumping. Period."

"A cap is needed on pumping, and there must be equal/fair shares."

– GCD staff

"A cap is necessary for a market."

– Municipal water district leader

"The key impediment to creating new water markets is putting a cap on water use, whether it is surface or groundwater."

"[GCDs] should have the authority to restrict water use."

– Resource economist

3. Inadequate Data on Domestic, Livestock, and Other Exempt Well Withdrawals

Most GCDs do not require metering or reporting of water use by exempt wells, such as domestic and livestock wells, which can pump up to 25,000 gallons a day. Exempt wells may result in cumulative aquifer pumping that is not well understood because of the lack of data. This lack of data from exempt wells can undermine the value of existing permits because of the uncertainty about a permit's yield during its terms (Texas House Committee on Natural Resources, 2018, p. 98). Furthermore, without metering exempt uses, groundwater regulators and users—including potential market participants—lack sufficient data on actual groundwater availability, which undermines the effectiveness of a pumping cap. It is likely that as groundwater supplies continue to diminish in the future, potential customers will be reluctant to engage in market transactions where significant uncertainty exists about groundwater reliability, reducing the value of the permit holders' water.

4. Impediments within GCD Policies and Rules

For most Texas aquifers, multiple GCDs manage the same aquifer. Texas's 100 GCDs each have rules governing the operations and management of each section of an aquifer within their jurisdiction. The regulatory framework for groundwater transactions depends upon each GCD's existence, powers, and rules. An important factor in the success of the Edwards Aquifer water market is that transactions are easy and predictable within the EAA's multicounty jurisdiction, other aquifers are governed by multiple independent GCDs.

Permitting rules can vary considerably between GCDs managing interconnected portions of aquifers (Johnson et al., 2014, pp. 1–3). The differences in permitting rules can create obstacles to creating effective groundwater markets. For example, some GCDs' are issuing permits for more groundwater use than is sustainable in the long-run (Texas House Committee on Natural Resources, 2018, p. 97). These practices undermine the potential to establish new groundwater markets in Texas. While one district may attempt to limit groundwater

"The lack of reasonable regulations are a major obstacle to the establishment of new Texas groundwater markets. See Justice Hecht's comments in Sipriano."

– GCD staff

"Transactions must be easy and certain."

– Municipal water district leader

"In the Edwards [Aquifer], there are really two markets, one in each pool of the aquifer: Bexar, Median, and Uvalde [western pool]; and Hays and Comal, where the rights [are] three or four times the value of the rights in the western pool. Within these zones [pools], trades are ministerial, meaning the trades do not go through a regulatory review with public comment, etc. The key is the predictability of trades."

– Water attorney

production to a sustainable rate, a neighboring district may take a very different approach. Another issue can be the length of time for which permits are effective. Market transactions can be impeded when the infrastructure required to allow potential customers to obtain the water requires more time to finance than the period for which the groundwater is guaranteed to be available. Therefore, the transfer of groundwater within and from GCDs depends on their specific rules being compatible. Most GCDs, however, have adopted unique rules addressing the requirements for transfers from wells specifically within their boundaries (TWDB, 2003, p. 15). Incompatible rules are a primary challenge to potential new groundwater market development (Texas House Committee on Natural Resources, 2018).

5. Certain Legal Precedents Regarding Private Property Rights and Groundwater

The evolving legal landscape for Texas groundwater is frequently cited as a barrier to creating new groundwater markets. This regulatory uncertainty results from three decisions by the Texas Supreme Court: 1) *EAA v. Day and McDaniel*; 2) *EAA v. Glenn and JoLynn Bragg*; and 3) *Guitar Holding Company v. Hudspeth County Underground Water Conservation District Number 1*.

Before the Texas Supreme Court's decision in *EAA v. Day and McDaniel*, many GCDs were advised that regulations restricting groundwater access were protected from taking claims.[20] After the *EAA v. Day and McDaniel* decision, GCDs had to consider the goals of regulation compared to the economic impact on landowners within their jurisdiction. Specifically, GCDs must consider the impact on investment-backed expectations of subsequent regulation and the economic impact to landowners of pumping limits, a critical element in establishing future groundwater markets. They must also be able to justify the need for these limits to avoid successful takings claims (Johnson & Ellis, 2013). It remains unknown whether a prospective groundwater user could sue a GCD for allowing pumping by historical users that results in a take of water they own in place under their property because they cannot get a permit under a cap that is already

"No additional groundwater markets are likely in Texas. There are two primary reasons for this. No other aquifer [other than the Edwards Aquifer] has a strict limit on the amount of groundwater that can be pumped annually, and [the ruling in] *EAA v. Day and McDaniel*, and *EAA v. JoLynn Bragg* make it impossible to place the limits on permits necessary to create a market."

– Water attorney

"So, how is [it] possible to establish correlative rights districts in Texas under the rule of capture, Day and McDaniel, etc.? Investment-backed expectations are not forever. There will be more groundwater markets."

– Water professor

[20] A physical or regulatory action by government without payment of just compensation under the Fifth Amendment of the U.S. Constitution and, or Article I, section 17 of the Texas Constitution.

above the sustainable pumping level determined by a desired future condition (DFC). It also remains to be seen whether a GCD can be sued for refusing to allow additional pumping to offset the impact of pumping in an adjacent unrestricted rule of capture area or in an adjacent GCD with far less restrictive pumping rules.

In *EAA v. Glenn and JoLynn Bragg*, a Texas court of appeals found that the EAA's limitation of the Braggs' ability to pump groundwater underneath their property resulted in a taking of the Braggs' property rights under the Texas Constitution. Initially, there was some concern that this ruling would preclude any further groundwater regulation in Texas. There is still lingering concern among GCDs that if they adopt pumping limits, which are the critical component to any new groundwater markets, they will be vulnerable to takings litigation by district landowners.

In *Guitar Holding Company v. Hudspeth County Underground Water Conservation District No. 1*, the Texas Supreme Court found that there were limits on the ability of a groundwater permit holder to change the use of a permit based on historic or existing use to another use, which could include export uses. The court found that both the amount of groundwater used and its beneficial purpose are components of historic or existing use (*Guitar Holding Company v. Hudspeth County*, 2008). Potentially, if a landowner seeks to sell groundwater for a use different from the existing permitted use, the new use may require the permit holder to apply for a new permit, depending on the specific GCD's rules (Texas House Committee on Natural Resources, 2018). Such a restriction could impede groundwater trading within a new groundwater market and therefore the functioning of market itself.

Barriers to groundwater markets, summarized:

- The absence of a GCD
- The absence of groundwater pumping limits
- Inadequate data on domestic, livestock, and other exempt well withdrawals
- Impediments within GCD policies and rules and inconsistent policies and rules among districts
- Certain legal precedents regarding private property rights and groundwater

D. Barriers to Surface Water Markets

1. Impediments within the Texas Water Code's Surface Water Regulations

As with groundwater transfers, the legal and regulatory framework required for a surface water transfer is critical for determining whether a trade can be completed. To successfully develop a surface water market, transactions need to occur seamlessly. As one municipal water district leader observed, "transactions must be easy and certain." There are three prerequisites for this: water must be easily conveyed from the seller to the buyer; the seller's property right to transfer the water to the buyer is clear, unencumbered, and well-accepted; and there are no financial issues associated with the water transfer (Hanemann, 2022, p. 9). When these conditions are hindered, exchanges are limited.

> "[I]f the Texas surface water market is to truly develop, the state will need to move toward a system where economic decisions about surface water guide the interactions of buyers and sellers with little government intervention or central planning."
>
> **– Texas House Committee on Natural Resources, 2016**

Moving a water right under the prior appropriation system is inherently complex. Transactions have been compared to "a diplomatic negotiation with a number of parties"—including third parties— "each with important and legitimate interests that need to be accommodated, but without clearly defined rights" (Sax, 2008, p. 3).

Transactions are complex because these "legitimate interests", or third parties, must be protected. There are many ways to mitigate impacts to third parties, such as monetary compensation or access to new or existing supplies to name just a few. When third party interests are protected and the physical restraints associated with a transaction are relaxed or can be addressed through surface or underground storage, it generally results in an increase in water market activity (Hanemann, 2022, p. 9). The uncertainty, time, and cost of completing the process under the current regulatory framework established in the Texas Water Code can make every proposed surface water transaction requiring a surface water rights amendment unique and unpredictable (Johnson et al., 2014).

> "The amendment process would need to be simplified to change the use of and location of water rights. Under current law, there can be no impairment of senior rights as a result of an amendment."
>
> **– Water attorney**

Because surface water is owned by the state, TCEQ must review and approve any transaction that requires changing the purpose, amount, or place of use of a surface water right. This applies to most surface water right transactions, which often involve a change in location or use, such as irrigation to municipal use (TWDB, 2003, p. 11). This process requires public notice, so potentially affected water right holders can object and/or seek alterations to the requested permit changes (TWDB, 2003, p. 11). The lengthy time required to complete this process is an impediment to surface water markets (White et al., 2017, pp. 10-11).

"[Surface water right] transactions must be easy and certain."

– Municipal water district leader

"There is also a lack of a central clearinghouse, no third-party administrator, takes too long to amend [surface water] permits at TCEQ in part because of the requirement for public notice and the potential for protests."

– GCD staff

"People are missing out on economic opportunities because the regulatory framework [for surface water] moves too slow. A water market can address this."

– Water consultant

2. Limitations of the Prior Appropriation System for Surface Water

After SB 1 inaugurated the regional water planning process in 1997, there were attempts to create new Texas surface water markets (White et al., 2017, p. 9). Similar hopes followed the passage of SB 3 in 2007, which established the statewide environmental flows program (Votteler, 2022). As of 2024, these attempts have been unsuccessful in creating any new structured water markets, largely because of the continued legal uncertainty regarding the scope of surface water rights.

"It is widely held that, in the long run, there needs to be significant reallocation of water use in the U.S. West. So far, water marketing in the U.S. West is not producing long-run reallocation on the scale expected. The chief impediment is the complexities in existing water rights."

– Hanemann, 2022, p. 11.

Water rights are considered "real property" in the United States.[21] Most western U.S. states declare in their constitutions that their waters belong to the people of the state through what is known as the public trust doctrine. In Texas, surface water rights are owned by the state and held in trust for the people of Texas. While this does not prevent private use of surface water, it does grant the state an interest in how the water is used and also transferred. This is fundamentally different from how land is regulated. The state has a role in determining the way in which Texas water should be developed for the greatest public benefit.

[21] This is different from other countries that have established water markets, such as Australia.

As real property, economists argue that defined and enforceable property rights in water are a critical factor for effective water markets (Kaiser & Phillips, 1998, p. 432). A system of property rights that can efficiently allocate water has the following characteristics:

- Universality, so all resources are owned, and all entitlements are completely specified;
- Exclusivity, so all benefits and costs accrued as a result of owning and using the resources accrue to the owner, and only to the owner, either directly or indirectly by sale to others;
- Transferability, so property rights can be voluntarily transferred from one owner to another; and
- Enforceability, so all property rights are secure from involuntary seizure or encroachment by others (Votteler, 1998; Tietenberg, 1992).

The Middle and Lower Rio Grande and Edwards Aquifer water markets have all four of these characteristics. The creation of both the Middle and Lower Rio Grande and Edwards Aquifer water markets only occurred after changes to the fundamental nature of their property rights regime embodied the four characteristics of an efficient property rights system. For the Middle and Lower Rio Grande, prior appropriation was replaced with correlative rights paving the way for the water market to be established. For the Edwards Aquifer, the rule of capture was superseded by a permit system. The problems with surface water allocation under the prior appropriation system are frequently cited as a roadblock for creating new surface water markets because of use of priority dates and specific locations for diverting surface water rights (Hanemann, 2022, p. 9). In contrast, Australia's Murray-Darling Basin water market—like the Middle and Lower Rio Grande water market—is correlative in nature and has a priority of water uses. Water markets developed in Australia only after fundamental changes were made regarding the property rights associated with water (Hanemann & Young, 2020). For water markets to flourish in more of the river basins of Texas, some changes to surface water rights regulation under prior appropriation will be needed.

Fundamental changes have been made to the property rights associated with water in Texas in the past. Before 1997, Texas surface water use was prioritized according to the Wagstaff Act, in descending order among domestic and municipal, industrial, irrigation, mining, hydroelectric, navigation, recreation and leisure, and other beneficial uses. The Wagstaff Act's priority of uses meant that higher priority users, such as municipal and industrial users, relied on the state's ability to cut off lower priority users during a drought. This put lower priority users, such as agricultural users, at greater risk. The Wagstaff Act also incentivized underinvestment in water conservation and new water supplies, until it was repealed by SB 1 in 1997.

When necessary, Texas has altered the property rights associated with surface water rights, as was the case with the Middle and Lower Rio Grande water market. Creating new Texas water markets may also require modifying associated property right systems.

3. The Vast Majority of Unused Senior Surface Water is Held by a Small Number of Organizations

The rights for large amounts of Texas's surface water were distributed for beneficial uses at little or no cost, to achieve economic development goals. Most of these surface water rights are held by a small number of organizations. Furthermore, approximately 20 million of the Texas's 23 million acft of permitted surface water was permitted prior to 1985, when environmental flow protections were first applied to permits issued by TCEQ and its predecessors (Rubinstein et al., 2022).

Most of those surface water rights are committed to water supply projects across the state. However, there are still substantial amounts of surface water held in rights that are not currently or completely used. These rights are instead being held for potential future uses. This arrangement—a small number of entities holding a large volume of senior rights in perpetuity—results in significant costs and environmental impacts when users without those rights have more immediate needs. These users may need to develop alternative projects that might otherwise be unnecessary with more water sharing agreements. Sidelining this water also holds back development of additional Texas surface water markets. The reluctance of entities holding large amounts of surface water to make that water available for short to mid-term leasing has already been discussed, but the concentration of the state's unused surface water rights in so few entities is an associated issue.

"Water markets are definitely part of the mix of tools that are needed to address environmental flows. There was significant optimism after SB3 was passed in 2007 that there would be large water deals for freshwater inflows. However, they have not materialized, even though there has been considerable effort to create them."

– Former agency leader

4. The Absence of a Watermaster

Third party noncompliance with water-sharing agreements, such as river compacts and treaties, is also an impediment to water markets (White et al., 2017, pp. 10-11). Surface water users not complying with existing surface water regulations or the limitations set out in their permits is also an issue. Watermaster programs—where they exist in Texas—ensure users' compliance with water right terms and conditions. As discussed, the regulatory certainty provided by the Rio Grande Watermaster Program serves as a key condition for the successful Middle and Lower Rio Grande water market.

In addition to the Rio Grande Watermaster Program, there are three other watermaster programs in Texas. These programs allocate water between users and ensure water right compliance within the Guadalupe, San Antonio, and Nueces rivers, as well as portions of the Brazos and Colorado (Concho) rivers. The remaining river basins in Texas, including several within drought-prone areas in West and South Texas, do not currently have watermaster programs.

The presence of a watermaster program offers several administrative and enforcement mechanisms that facilitate water markets' development and function. These include:

- Monitoring streamflows, reservoir levels, and water use;
- Identifying and stopping illegal diversions;
- Determining if a water right holder can divert water;
- Preventing water right holders that are out of compliance with their water rights or TCEQ's rules from diverting, taking, or storing water;
- Monitoring downstream usage to ensure that upstream releases of stored water reach downstream customers;
- Facilitating communication and cooperation among water users; and
- Providing technical assistance (TCEQ, n.d.c).

Given these and other benefits, creating watermaster programs for other river basins in Texas could open the door to surface water market development.

5. Inadequate Data on Domestic and Livestock Diversions and Other Uncertainties About Third Party Water Uses

As with groundwater, cumulative use of surface water for domestic and livestock uses may substantially reduce surface water availability, especially during droughts. The cumulative impact of these exempt uses are not well understood because of the lack of data. For example, surface water diversions for domestic and livestock purposes are not required to be metered.

To provide a more accurate picture of a river basin's true water availability, more data is needed on the scale of impacts from direct diversions and on numerous small impoundments in watersheds for domestic and livestock uses. This is particularly important during droughts when water may be acutely scarce. Moreover, as water availability fluctuates with increased climate variability in the future, more accurate data regarding true surface water availability, including evaporative losses due to warmer temperatures, will be needed when assigning a value to water. As water becomes more scarce, potential surface water market customers will be reluctant to invest where there is significant uncertainty about the surface water reliability, potentially resulting in a loss of value for surface water right permit holders.

Barriers to surface water markets, summarized:

- Impediments within the Texas Water Code's surface water rules;
- Limitations of the prior appropriation system for surface water;
- Concentration of unused senior surface water in a small number of organizations;
- The absence of a watermaster; and
- Inadequate data on domestic and livestock diversions and other uncertainties about third party water uses.

CHAPTER 4. CREATING NEW WATER MARKETS IN TEXAS

> "Lowering existing levels of consumptive water use while increasing water's productivity will require both strong governmental leadership and game-changing innovation in the private sector. The establishment of high-functioning, well-governed water markets - in which a cap on total consumptive use is set, rights to use water are legally defined, and in which rights can be exchanged among water users within the limit of the cap - can provide a powerful integration of public and private efforts to alleviate water scarcity. A well-functioning water market can provide the institutional framework for those willing to consume less water to be rewarded by those needing more water, or wanting to return water to the environment. By so doing, water markets open up pathways for entities wanting to access more water to do so in a highly cost-effective manner that is far less environmentally damaging than building new infrastructure" (Richter, 2016, p. 41).

There are many regions in the western United States where there are few, if any, water transactions due to the difficulty of completing transactions. The presence of structured water markets is rarer still. Texas's 1990 state water plan highlighted this in Texas, noting the lack of formal or effective mechanisms for promoting water transfers and reallocating water from lower to higher value uses (Kaiser, 1994, p. i). Little has changed since, other than the creation of the Edwards Aquifer water market. Water transactions are common in areas where water assets and the rules for trading them are uniform and easy to understand, such as in the Middle and Lower Rio Grande and the Edwards Aquifer. This chapter describes potential opportunities to increase surface water and groundwater transactions by creating new water markets and by encouraging more transactions outside of formal water markets.

A. Ethical Guidelines for Water Markets

> "[U]nlike almost every other form of property, which we allow to be entirely privatized, water has always been viewed as something in which the community has a stake and which no one can fully own" (Sax, 2008, p. 33).

People clearly feel differently about water than they do about other commodities. In Texas, discussions about water are frequently passionate. The prospect of managing water through markets can generate genuine reservations. Will my community's water be sold to someone else? Will my community end up without water? What will happen to my well? These are reasonable concerns.

Rather than uphold a laissez-faire approach to managing water through markets, this chapter draws upon examples from thoughtfully constructed water markets with proven success. The solutions offered here can address the range of needs associated with managing water under conditions of scarcity.

First, it is important to examine and address the potential negative outcomes of water markets before they are adopted more widely. It must also be acknowledged that not all efforts to create water markets have resulted in sustainable water management (Breviglieri et al., 2018, p. 1087). There is also a common perception that water markets are only created to reallocate water from agricultural to municipal uses, though the evidence of this is mixed (Chong & Sunding, 2006, pp. 256–257). In the case studies of the Edwards Aquifer and the Middle and Lower Rio Grande water markets, significant amounts of water were reallocated from irrigation to municipal uses—but the water markets also facilitated transfers between irrigators, particularly within the Lower Rio Grande, where water has moved from lower valued crop production to higher value crop production.

> "With groundwater, there is a concern among rural interests that water markets mean groundwater export outside of the districts to the cities. Some additional groundwater export to cities will occur with markets, but it won't necessarily ruin the economies of the areas where the water is being exported."
>
> **– Former agency director**

Water transfers from agricultural regions to urban regions are much less common than transfers within the agricultural sector. There are multiple reasons for this, including the lack of conveyance infrastructure and high costs of moving water to urban areas. Also, surface water transfers between agricultural users generally do not require a lengthy approval process and therefore are much easier to complete than high-profile interbasin transfers, or agricultural-to-municipal transfers (Chong & Sunding, 2006, p. 257).

Third-party impacts are also a concern for agriculture-to-municipal surface water transfers. Surface water and groundwater transfers in the United States are generally subject to some form of state approval and must comply with "no injury" rules that were created to protect parties that are not part of the transaction. However, the effectiveness of "no injury" rules vary. Transactions involving surface water rights outside of the water market typically require a permit amendment through a state agency, such as TCEQ. The most common methods of protecting third parties is through direct payments, efficiency improvements, substitution of other water supplies, releases from storage, and alternative transfer methods, such as land fallowing and water banking. Alternative transfer methods attempt to avoid permanently drying up agricultural land and causing economic and environmental impacts resulting from land being permanently taken out of irrigated agriculture (Western Governors' Association, 2012, p. x). A well-designed system should identify and address significant third-party impacts.

As noted in Chapter 3, Texas allows groundwater rights to be severed from the land and made available for sale through the "buy and dry" practice. Historically, it has been easier for groundwater users to purchase land and then mine available groundwater than to purchase the groundwater from an existing landowner (TWDB, 2003, p. 11). The Edwards Aquifer is an exception, at least regarding irrigation rights, because of the requirement that 1 acft of water remain with each acre of land with an irrigation right. In the western half of Texas, separation of the surface estate from underlying groundwater resources limits the future potential of that land. Unchecked, the "buy and dry" practice could have serious repercussions for the future of regions where it is common.

> "Australia is attracting speculators. To combat speculation, you could limit participation in the market to water users and specify that the water must be used within a certain period."
>
> **– Australian water market specialist**

Another practice that could undermine public confidence in water markets is speculation. Speculating in water rights garnered substantial attention during the western megadrought in 2021 related to the purchase of water rights in the western Colorado River in Arizona, Colorado, and Utah (Howe, 2021). In truth, water speculation has been an issue in the West for decades. For example, the Colorado Supreme Court issued an opinion regarding water speculation in 1979 (*Colorado River Water Conservation District v. Vidler Water County*, 1979). More recently, Colorado has considering classifying water speculation as either "traditional" or "investment" (SB 20-048 Work Group, 2021). Traditional speculation is defined as "seeking to appropriate, change, or continue a water right without a specific plan and intent to put the water right to its claimed beneficial use, or without a vested interest in the facilities or place to be served by the water" (SB 20-048 Work Group, 2021, p. 30). Investment speculation is defined as "the appropriation or purchase of water rights followed by the use of those water rights, where the appropriator or purchaser's primary purpose is profiting from increased value of the water in a subsequent transaction such as sale, lease, or payment for non-diversion" (SB 20-048 Work Group, 2021, p. 30).

Water speculation also exists in Texas. The case of the Living Waters Artesian Springs catfish farm is often provided as a notable example of water speculation in the Edwards Aquifer (Votteler, 1998, p. 855)[22]. In addition to this famous example, some ranches with substantial historical Edwards Aquifer water use were purchased prior to the application filing deadline for groundwater rights only to be sold after permits were issued.[23] Given the potential for speculation to undermine public confidence in water markets, measures such as those contemplated by Colorado should be considered in Texas or incorporated into individual water markets' design to discourage or prevent this practice.

Given these accumulated concerns, building the public's confidence in water markets before their widespread adoption will take effort. In the words of Breviglieri et al. (2018), water markets "are not created solely for achieving economic goals; they are socio-political institutions and aim at broader societal objectives" (p. 1076). Water markets are meant to improve the economic efficiency of water use; the gains from the transition should be sufficient and result in all parties being no worse off than before the market was created (Pareto Optimality). Moreover—

[22] In 1991, Living Waters Artesian Springs began withdrawing as much as 40 million gallons/day from the Edwards Aquifer to raise catfish. At the time this equaled about 25% of San Antonio's daily water use. The water was discharged into the Medina River after one use raising concerns that the ultimate goal of the project might be to obtain a large surface water right that could be sold as a water supply (Votteler, 1998, p. 855).

[23] U.S. Filter, a water services company, purchased land and water rights in the Edwards Aquifer (Rick, 1997).

and in contrast to the laissez-faire market approach—water markets require effective regulatory institutions to succeed (Bitran, 2014, 859).

Recognizing that the place water holds in any community's collective psychology is unique, water markets should be established in accordance with principles that ensure market activities benefit local communities and improve stewardship of associated watersheds and aquifers. Adhering to a set of ethical principles for establishing new water markets will increase the likelihood that new water markets will be created and ultimately succeed in advancing efficient and sustainable water use. The recommended principles, or ethical guidelines for water markets are:

1. Water markets should maintain and restore the chemical, physical, and biological integrity of their associated watershed(s) and aquifer(s) and therefore not diminish the aquatic ecology and long-term hydrologic integrity of their associated watershed(s) and aquifer(s);
2. Water markets should provide benefits to the communities within the associated watershed(s) and aquifer(s) that exceed the detriments to the communities within the associated watershed(s) and aquifer(s);[24]
3. Water markets should improve the equitable distribution and availability of water for human health and safety within their associated watershed(s) and aquifer(s);
4. Water markets should explicitly prohibit "buy and dry" transactions that permanently separate all groundwater from its original land, and a minimum per-acre quantity of groundwater that is sufficient to provide for domestic and livestock needs should remain with each acre of land in perpetuity; and
5. Water markets should be transparent to all interests.

[24] Water markets should be Pareto-optimal, which is a situation that exists where there is no alternative that would make some people better off without making anyone worse off.

B. Creating Additional Water Markets in Texas

1. Elements of Well-Structured Water Markets

The unique judicial origins of the Middle and Lower Rio Grande and Edwards Aquifer water markets are unlikely to be repeated with sufficient frequency to effectively transform Texas water use. Both the Edwards Aquifer and Middle and Lower Rio Grande water markets were created as indirect results of court rulings based upon conflicts over water use and availability during water crises that were intensified by drought conditions. Neither system was intentionally established with the goal of being a water market, but instead the specific elements adopted to manage each system facilitated water market development. However, these two water markets provide flexibility for water managers and users, enable the reallocation of water from lower value to higher value uses, and have changed user behavior regarding water. These markets function within Texas's existing systems of surface water and groundwater regulation, although each has a unique set of rules that resulted from judicial rulings and state policies. Therefore, what follows are alternative strategies for creating new water markets informed by the Middle and Lower Rio Grande and Edwards Aquifer water market examples.

The Middle and Lower Rio Grande and Edwards Aquifer water markets have common elements that can inform the framework for creating new, well-structured Texas water markets. Some are practical elements for new water markets, while others suggest alternative features for new water markets. The common elements include:

1. Both water markets are limited to a single aquifer or river basin;
2. The total amount of water available for use within each market is specifically limited or capped;
3. Exports from these water markets are prohibited;
4. Imports into these water markets are prohibited;
5. The water rights of individuals participating in the water market are well-defined;
6. Market transactions are predictable, ministerial, and routine, avoiding a lengthy legal, technical, and administrative review and approval process;
7. Market transactions occur under, are recognized by, and are recorded by a unit of government to maintain the integrity of the process by providing oversight and accountability;
8. During critical low-flow periods when water shortages occur, the oversight authority can restrict the use/availability of water within these markets;
9. The value of water right transactions are known to participants within the water market through formal and informal networks;
10. Market transactions include the ability for buyers to change the point of use within each water market subject to some restrictions; and

11. Both water markets benefited from the initial availability of a substantial volume of lower value agricultural rights, which provided the initial liquidity for the water market.

2. Water Markets as a Regional Water Planning Strategy

Throughout most aspects of Texas water management, one obvious need continually rises to the surface: the need for more regional cooperation among the 7,108 water utilities, 100 GCDs, and 24 river authorities and other special districts that manage Texas water. Such regional cooperation would make managing shared water resources more effective and less expensive and would likely increase water use efficiency.

The regional water planning process could facilitate greater regional cooperation by prioritizing the creation of new water markets. In 2016, the Texas House Committee on Natural Resources (2016) recommended that regional planning groups work together across regions to consider water markets when developing new water sources, finding that "the State could encourage development of markets within river basins and planning regions, by providing guidance to river authorities and other local agencies" (p. 18).

If properly structured, new regional water markets can fundamentally reshape the foundation of regional water management by making regional water use more efficient by changing the behavior of water users. By increasing regional water use efficiency, regional water markets could reduce demand for additional water supplies from new sources inside and outside of their regions and increase cooperation between and reducing fragmentation and competition among local, regional, and statewide water institutions. This would, in turn, reduce expenditures for new supplies and curb current and future disputes over the limited remaining affordable water resources.

In some regions, water markets are likely to be a cost-effective alternative to developing new water supply projects. As Chapter 2 discusses, numerous water projects were originally planned for the Middle and Lower Rio Grande and Edwards Aquifer regions, based on anticipated municipal and industrial demands. But those projects were not built, partly because water use efficiency increased and water was reallocated from agricultural to municipal and industrial uses, thanks to the water markets. New water supply projects require substantial funding from local ratepayers, the state, and the federal government. For projects that receive state or federal funding, the costs are externalized to parties that may see little, if any, direct benefit from these expenditures. In contrast, water markets internalize costs among participants, which could save substantial sums of capital needed to create new water supplies. This money could instead be invested to maintain and expand Texas water infrastructure and to acquire water for uses and purposes that otherwise have fewer options, such as instream flows and freshwater inflows to bays and estuaries.

Therefore, the regional water planning process should examine and identify opportunities to develop new water markets and allow for the creation of water markets to be included as recommended strategies in regional plans to meet each regions' 50-year planning needs. State law governing the regional water planning process should be amended to examine opportunities for developing local or regional water markets as regional water supply strategies. During the 88th regular session of the Legislature, House Bill (HB) 4623 (2023) was filed by Representative Craig Goldman. The bill would have allowed the regional water planning process to consider water markets as water management strategies in the state water plan, by allowing the regional water planning groups to identify opportunities for creating and establishing local or regional water markets. HB 4623 was unanimously approved by the House of Representatives but failed to move in the Senate in the closing weeks of the 88th regular session.

3. Regional Water Banks

Water banks offer a unique foundation for creating new regional water markets that can provide liquidity—literally and figuratively—for a water market. Water banks are permanent institutions that can facilitate and manage water transfers with flexibility and ease in a water market (Szeptycki et al., 2015). The currency deposited into these institutions is water. Excesses within a given region, particularly during wet years, may be transferred or deposited within a water bank. Water right holders can store their water in a bank, and the banked water may be made available to other users, within a designated area, for essentially any water use authorized by the bank. Water banks are efficient at facilitating the division of individual water rights among multiple users in multiple transactions.

Fortunately, as the result of the passage of SB1, TWDB already has the legal infrastructure for creating water banks:

> "The board may establish regional water banks, as necessary, to fulfill the requirements of the Texas Water Code, Chapter 15, Subchapter K. The board, by contract or agreement, may designate state agencies, political subdivisions, or other entities or persons it may deem appropriate to act as regional banks." (31 Texas Admin. Code § 359.13, 1994)

Both state law and TWDB's rules allow water banks to be operated by another entity, such as a GCD with TWDB oversight or a river authority under a TCEQ watermaster's supervision, as established by § 15.703 (a)(7) and § 15.708 of the Texas Water Code.

The Texas Water Bank program authorizes TWDB to do the following regarding regional water banks:

1. Establish regional water banks;
2. Serve as a negotiator;
3. Maintain a registry and serve as an information resource;
4. Encourage conservation through deposits of conserved water;
5. Establish requirements for deposits;
6. Purchase, sell, hold, and/or transfer water or water rights;
7. Act as a clearinghouse for water marketing information;
8. Prepare and publish a manual on structuring water transactions;
9. Accept and hold donations of water rights in trust for environmental purposes;
10. Contract to pay for feasibility studies or the preparation of plans and specifications relating to water conservation efforts or to estimate the amount of water to be saved through conservation efforts; and
11. Perform other actions to facilitate water transactions (TWDB, n.d.b).

"New surface water markets could be established in Texas by creating water banks where people who have water available can park it, where an irrigator can sell their water. These clearinghouses would be part of a new chapter of the Texas Water Code and would be funded by surface water right fees."

– Water attorney

"New groundwater markets could be established in Texas similar to the way new surface water markets could be established. Groundwater right holders would all pay a fee to fund administration of the water market."

– Water attorney

"The bank creation stage is significant work, but once it is done then you get easy and predictable transactions."

– Water consultant

Other important elements of the Texas Water Bank program that can apply to regional water banks include:

1. Water rights or contractual rights to use water, which may include surface water, groundwater, or water from any source to the extent authorized by law, may be deposited in the bank;
2. All or a portion of a water right may be deposited in the bank;
3. Surface water rights placed in the bank are protected from cancellation for 10 years while on deposit in the bank; and
4. TWDB may charge as much as 1% of the value of the water or water right received into or transferred from the water bank to cover its administrative expenses (TWDB, n.d.b).

Though the ability to create water banks in Texas has been in place since 1997, this section of the Texas Water Code has not drawn much attention. That may be due partly to the idea that water banks would all be managed by TWDB, as the Texas Water Trust is managed. However, if water banks are created in association with water markets that are identified through the regional water planning process, and the new water banks are managed directly by regional entities, there may be increased interest in this option.

4. ASR Facilities as Components of Regional Water Banks in Regional Water Markets

As discussed in Chapter 2, since 2004, SAWS' H2Oaks Center has played a critical role in the Edwards Aquifer water market by allowing groundwater to be withdrawn from the Edwards Aquifer during favorable (i.e., wet) conditions and stored within the underground storage facility with the Carrizo-Wilcox Aquifer until it is needed. Others have since recognized the role that ASR projects could play in the establishment of new water markets. As noted by White et al. (2017), reservoirs "typically provide the most effective mechanism to market surface water," meaning that in a similar fashion ASR projects "could also incentivize market transactions" (p. 17).

In 2020, TWDB published a report exploring the potential for additional ASR and aquifer recharge (AR) projects in Texas. TWDB and HDR Engineers concluded that "[t]he survey results show that Texas has numerous areas suitable for ASR or AR" (Shaw et al., 2020, p. 112). The report identified suitable areas near every major population center in Texas. The results of the TWDB survey show the potential for ASR projects to serve as the foundation of new groundwater markets in many of Texas's key demand areas by providing the storage component for new regional water markets. These regional ASR-based water banks could, under certain circumstances, receive both groundwater deposits and surface water right deposits to be stored for sale, resulting in the conjunctive management of water.[25]

There are significant advantages associated with storing surface water within an ASR-based regional water bank. First, the stored water would no longer carry a priority date or other restrictions associated with surface water because the stored surface water would be considered groundwater (2 Tex. Water Code § 11.023, 2019, (a)(9)). Second, water stored in the ASR would not be subject to evaporation losses like stored surface water. The use of the water would not necessarily require TCEQ review in every case if it is stored in the ASR. Water stored in the water bank could be pumped out and delivered to the customer via pipeline or through an existing watercourse using a bed and banks permit.

However, the major limitation for this option is that if surface water is diverted from a different point than authorized, at a different rate, for a different purpose of use, or for use at a different place of use, an amendment to the surface water right would be required. Amendments to § 11.122(b) and 11.122(b-3) of the Texas Water Code have simplified the review process for

[25] Conjunctive management is the combined use of surface water and groundwater in a manner that optimizes the beneficial characteristics of each source (Definitions, 1995, (21)).

amending surface water rights. However, the remaining limitations could be improved by the Legislature by creating a new class of bed and banks permits for regional water markets. This class of permits would authorize approved surface water participants to deliver their water downstream for diversion into an ASR facility serving as a regional water bank. The stored groundwater would then be delivered downstream to the customer using the bed and banks or through a pipeline. One possible way to accomplish this is by creating a new type of permit for bed and banks deliveries similar to the nationwide permits under the federal Clean Water Act, which are designed to streamline the authorization of certain actions with minimal impacts to the nation's aquatic environments (U.S. Army Corps of Engineers, n.d.).

The Legislature has already made some incremental but beneficial changes to the Texas Water Code regarding ASR use in recent sessions. In 2015, legislation allowed a surface water right permit holder or a surface water contract holder to store their water in an ASR as long as the permit or contract does not prohibit such storage (Projects for storage, 2015). Under limited circumstances, a new permit or permit amendment is not needed from TCEQ (Projects for storage, 2015, (b)). In 2019, the Legislature streamlined permitting for surface water right applications regarding new water appropriations and amendments to existing surface water rights for reservoir storage for ASR or AR (Water for use, 2019; Amendment to convert, 2019). New surface water right applications for excess surface water flows to be stored in an ASR (above what is needed for instream and bay and estuary freshwater inflows) are to be processed by TCEQ with 180 days (Amendment to convert, 2019, (h)). A bed and banks permit from TCEQ would allow stored surface water, conserved water, groundwater, and wastewater to be delivered to the extraction point for storage and injection into the ASR (Interbasin transfers, 2014; Multiple ownership, 1986; Storage in another's reservoir, 1986). However, if the amount, purpose of use, or place of use are different than what is authorized in the existing permit, a surface water right amendment would be needed (Projects for storage, 2015, (b)(2)). Relaxing these requirements would encourage more water to be stored in ASR projects and therefore encourage more ASR projects to be initiated.

Off-channel storage could also be used to store surface water rights and to divert high flows above what are required for instream, bay, and estuary health for a sound ecological environment. This surface water could then be stored without treatment or treated using a wetland or via conventional treatment and then be stored in the regional water market's ASR facility.

An ASR project could also serve as the storage facility for groundwater in a regional water bank within a regional water market. Participating GCDs could collaborate to fund groundwater market ASR projects. The state could even consider funding groundwater market ASR projects if participating GCDs adopt consistent rules and sustainable limits on pumping as part of creating a regional water market. The regional water planning process and the DFC process could assist in determining what would constitute a sustainable pumping cap.

Regional water markets could charge a fee for all transactions to fund the market administrative costs and ASR facility operation, and support groundwater markets through projects such as managed recharge to maintain the aquifer's long-term sustainability and therefore the water market's viability. These fees could also help fund fee-based GCDs that are struggling financially to fulfill their missions. During the 88th Legislature, GCDs were given greater latitude regarding export fees. HB 3059 (2023) increased the export fee cap for tax and fee-based GCDs to $00.20 per 1,000 gallons exported. The bill also allows a special law district to charge an export fee, or surcharge, and authorizes a GCD to use fees to maintain wells significantly affected by groundwater development by funding projects such as managed AR (Kirkle et al., 2023, p. 109).

To address some of the concerns related to groundwater exports outside of the jurisdiction of a GCD, exports could be limited to water that is stored in the regional water market's ASR facility. For example, exports of groundwater from the ASR could be limited to a volume that exceeds current regional needs, or exports could be limited to periods when the ASR facility is above 50% of its targeted capacity or some similar restriction. These, or similar limits, would provide an incentive for management entities or potential water exporters to invest transaction fees in projects that firm up the available supply and support the market's operation.

5. Changes that Would Allow for Additional Surface Water Market Creation

In 2016, the Texas House Committee on Natural Resources described the challenges and opportunities for the creation of new surface water markets:

"[I]n terms of a market economy, where the economic decisions and pricing of a good or service is guided by a willing buyer and a willing seller, the Texas surface water market remains less than optimal. The TCEQ has a role in managing those markets because of its supervision over waters of the state. River authorities have even more of a significant role because of their ownership of large water rights, storage, conveyance infrastructure, and wholesale water contracts. The TWDB has a role because of the central planning aspects of the state water plan for projects approval and potential for funding. Finally, for the Texas surface water market to be effective, the decision in question must be supported by a consensus of water stakeholders in each basin" (Texas House Committee on Natural Resources, 2016, pp. 17, 18).

The following sections examine areas of surface water management that could be enhanced or amended to facilitate both the creation of new surface water markets and more water right transactions where the creation of structured water markets is impractical.

A. Surface Water Rights

Water markets are advocated as a solution for water scarcity, but like in the past, some changes to surface water rights laws may be required to expand the use of surface water markets. In Texas and most western states surface water rights are owned by the state and held in trust for its citizens. Therefore, the property right in surface water is a usufructuary right, or a right to use, but not to own. However, the seemingly permanent nature of surface water rights raises a question. When does a private franchise of a public resource granted in perpetuity, effectively convert the public resource into a private resource?

While lawmakers have generally resisted making major changes to the prior appropriation system, it can in fact be changed. In Texas, the hydrologic conditions associated with the drought of record of the 1950s eventually led to the adjudication of the surface water rights of the Middle and Lower Rio Grande and the replacement of the prior appropriation surface water rights system with a correlative rights system. Similar problems in other major Texas river basins during the drought of record resulted in the creation of the Water Rights Adjudication Act of 1967. By 1967, there were numerous unrecorded riparian water rights and unrecorded certified filings in all major Texas river basins. Both the total amount of these claims and the amount of water they were diverting annually were unknown. This unquantified water use made the administration and management of the state's surface-water difficult, if not impossible (Templer, 1952). Over 11,600 unrecorded applications were filed, primarily by riparian landowners, claiming rights to over seven million acft/yr (Templer, 1952).

Prior to this act, the use of unrecorded surface water right claims in all of the major river basins made it impossible to know how much water was being diverted annually. The growing demand for water in Texas—and the uncertainty of its availability due to the changing climate—will eventually force another reevaluation of the current surface water rights framework.

Water market creation and water-related property rights systems are intertwined in the United States and beyond (Hanemann, 2022, pp. 1–3). In Australia, for example, the evolution of water markets over the past 30 years came about only after a fundamental change in the property right to water a century earlier (Hanemann, 2022, pp. 1–3). In the 1880s, Australia began to develop irrigation-based communities and, through that process, shifted from entitlements based on fixed volumes under English riparian law to surface water entitlements based on a proportion of available river flows (Australian Government National Water Commission, 2011, pp. 22, 33). This led to the creation of the Murray-Darling Basin water market, the most prolific water market in the world, but only after the Australian government moved away from financing new water supplies and the options for new supplies were diminishing.

> "[A]s has been noted in other western states, increased awareness and proper valuation of water promotes conservation and movement of water to higher end uses. River segments and ecosystems benefit from such activities."
>
> **– Texas House Committee on Natural Resources, 2018**

Back in the United States, the recent western megadrought once again demonstrated that surface water rights are not immutable to alteration. Some western states, such as Nevada, are reevaluating the nature of their surface water rights. In January of 2024, the Nevada State Supreme Court found that the state "has authority to conjunctively manage surface waters and groundwater," meaning that state regulators can consider surface water and groundwater as a single source (Rothberg, 2024). The justices said the State of Nevada has the authority to prevent groundwater pumping from conflicting with "vested" river rights issued under the prior appropriation doctrine (Rothberg, 2024). Oregon and Washington have made changes to their property rights that are allowing water markets to become a central element for meeting their future water needs. Other states, such as

California, have not made the necessary property rights system changes that would allow more trading and the long-term reallocation of water (Hanemann, 2022, pp. 1–3). However, Chaudhry and Fairbanks (2022) found that California could achieve significant economic gains by simply easing the barriers to trading water across sectors based on the differences in the marginal values of water used for agriculture and water used for municipal or environmental uses.

Most surface water transferred in the United States is either contract water moving within supply system boundaries or short-term leases of appropriative rights, due to the inherent constraints of the prior appropriation system as practiced in most states (Hanemann, 2022, pp. 1–3). Contract transfers and short-term leases provide flexibility for water users, but do not permanently reallocate water from lower to higher value uses. Significant water reallocation to higher value uses requires modifying how states administer and allow for the modification of property rights in surface water. Finding a politically acceptable way to modify these property rights is the ultimate challenge for surface water markets (Hanemann, 2022, pp. 1–3).

In Texas, there are no surface water markets that meet the definition established at the beginning of this report except the Middle and Lower Rio Grande water market. This is due to the complexities and impediments of the current surface water regulation system, and the difficult and lengthy process for modifying most surface water rights. For water markets to flourish in Texas, there are several elements of the current surface water management system that should be reexamined. Changes to these elements could substantially benefit surface water markets by making transactions within the market faster, easier, and less expensive for the parties.

These elements include:

1. **The perpetuity of surface water rights:** Once granted, a surface water right in Texas exists for perpetuity, without a process to review how much they are used or the purposes for which they are used. However, if surface water rights were subject to periodic review, such as every 20 years, the state could determine whether permitted rights are being used, and if not, whether they should be subject to cancellation and reallocation to other uses in some basins. Such a review could also examine whether permitted surface water rights are being used efficiently, and if not, how more efficient use could be incentivized and whether permitted rights could be incentivized to transition to higher value uses.
2. **Incentives for senior water right holders:** Under the prior appropriation system, there is little incentive for senior water right holders to conserve water as opposed to relying on the state to curtail junior water rights holders. This is particularly significant when senior water right holders continue to divert water for lower value uses during significant droughts. The reallocation of water from lower valued uses to higher valued uses is a key outcome of water markets.
3. **Conversion of agricultural water rights to other purposes:** As discussed in Chapter 2, agricultural surface water rights in the Middle and Lower Rio Grande that are converted to domestic, municipal, or industrial rights are reduced in volume by either 40% or 50%. Despite the reduction in water volumes associated with the original water right, this change increases the value of that right as the water is repurposed for higher value uses. If

applied throughout the state, such a policy might eventually make a difference where rivers are over-appropriated.

4. **Annual fees for surface water right holders:** Increasing the annual fees that surface water right holders pay to TCEQ could provide an incentive for surface water right holders to better use their water rights, abandon dormant water rights, sell water rights, or participate in a water market, all while providing additional TCEQ funding through user fees. As of 2024, the fee rates are $0.385/acft authorized for consumptive uses and $0.021/acft authorized for non-consumptive uses (hydroelectric). In 2016, these rates generated only $1.2 million from 218 of the over 6,000 water rights (TCEQ, 2016b, pp. 15, 21). The rates for the aforementioned fees were set in 1985 and have not been adjusted since for inflation or population growth (TCEQ, 2016b, p. 15). These water fees are significantly less than air and waste permit fees, and they do not cover the total cost of administering the water program (TCEQ, 2016b, p. 21). There are a number of permit holders that are exempt from paying these fees, including irrigation water rights. Wholesale water providers are often exempt from paying the water use fee and only pay a minimal water quality fee (TCEQ, 2016b, p. 21). If every surface water right holder pays an annual fee based on the priority date, volume of the right, and type of use of the right, rather than paying a fee based on how much they use annually, it could encourage some unused or underutilized water rights to be sold, leased, abandoned, or traded.
5. **Minimal impacts to senior water rights:** Allowing some de minimis (minimal) impact to senior water rights to avoid the amendment process, and also allowing applicants for amendments to mitigate potential impacts to other water rights, would encourage more surface water transactions by making the amendment process faster and less expensive.

B. Watermasters

Regulatory certainty and enforcement are key preconditions for creating a water market. Toward that end, additional watermaster programs could ensure the integrity of new surface water markets. Watermasters ensure that water rights holders use only the amounts of water they are authorized to use under their water right. To accomplish this, watermaster programs require water use metering to measure the actual amounts withdrawn and include inspections that ensure compliance with the permitted amounts. These activities provide for regulatory certainty. In addition, as in the Middle and Lower Rio Grande, watermasters could administer a clearinghouse of water rights available within basins with water markets for various types of transactions. The Texas Water Code (§ 11.326, 2011) allows TCEQ's executive director to establish watermasters in river basins where they do not exist yet.

The surface water right fees that every surface water holder would pay, other than for those dedicated to environmental flows, could fund these watermaster programs. Creating additional watermaster programs was the most frequent recommendation for improving trades of surface water made by the individuals interviewed for this study. As of 2024, watermasters are present in a limited number of Texas rivers (Figure 22), but a watermaster should be considered for rivers where new surface water markets are created in Texas.

"There is a real need for watermasters. Their absence is a real problem."

– Environmental organization staff

"In the Rio Grande there is no priority system. Watermasters in basins outside of the Rio Grande could be helpful if there is a framework through which a watermaster can approve transactions."

– Water attorney

"Watermasters know how much water is being used. Watermaster protect the usufructuary rights of water right holders in the system."

– Water attorney

"Trading might be managed by the RAs or a watermaster. Watermaster would bring in all water right holders."

– Water rights broker

"A watermaster would be the best overseer of surface water markets in other basins."

– Former agency leader

"TCEQ can create a watermaster if there are problems on a river. Maybe every Texas river will have a watermaster after the next drought of record."

– Former agency leader

Figure 22. Texas watermaster areas.

(TCEQ, n.d.).

6. Changes that Would Allow for the Creation of Additional Groundwater Markets

“Despite existing legal challenges to their implementation, groundwater markets have promise for sustainable management of groundwater in Texas. GCDs with appropriate legal authority and a desire to manage declining groundwater levels may use well-structured water markets as the primary method to reallocate groundwater entitlements from one party to another” (Texas House Committee on Natural Resources, 2018, p. 98).

The following sections examine reforms regarding groundwater management that would open the door for the creation of new groundwater markets. To begin with, all aquifers have their own unique characteristics. Water markets for aquifers that can recharge rapidly, like the Edwards Aquifer, will differ from aquifers that recharge very slowly, like the Ogallala Aquifer. Under certain rainfall conditions, a karst aquifer like the Edwards Aquifer can be replenished within a few days, if the precipitation amounts are large enough and occur at the right places over the contributing and recharge zones. For the Ogallala Aquifer, however, flood events do not translate into significant aquifer recharge. Droughts can have greater impacts on the level of karst aquifers like the Edwards Aquifer than on the level of aquifers like the Ogallala Aquifer. These unique aquifer characteristics should define the limits of and shape the structure of the associated groundwater markets, meaning that different aquifers will have different rules and guidelines for operating a groundwater market.

"GWCDs are slowly migrating toward what the EAA does."

– Environmental organization staff

"After the EAA was created San Antonio only lost one military base. Since then the missions at the other bases have expanded. Toyota would not be there if the regulation of the Edwards Aquifer and creation of the water market had not occurred."

– GCD staff

To start looking for opportunities for new groundwater markets, Texas's 16 regional water planning groups should first examine the priority groundwater management areas (PGMAs) within their boundaries. PGMAs are already experiencing critical groundwater problems or may experience critical groundwater problems within 50 years. These problems include shortages of surface water or groundwater, land subsidence resulting from groundwater withdrawal, or contamination of groundwater supplies.

Creating new Texas groundwater markets would, at a minimum, require several basic elements. These elements include:

1. **Pumping caps:** Limits to groundwater withdrawals are an essential precondition for water market development. If several GCDs elect to participate within a groundwater-based water market, then aquifer pumping would need to be capped within the participating GCDs.

2. **District collaboration:** A logical grouping of GCDs would need to participate in the groundwater market based on each aquifer's unique hydrology, such that hydrologically connected districts would have to participate in the market. If a district opts to not participate in the water market, then it should be required to take measures to prevent resident wells from undermining the groundwater market. In turn, districts that join the water market should have a process to mitigate impacts to wells in districts outside of the water market.

3. **Consistent regulations:** A shared set of rules would be required for the participating districts regarding groundwater management and participation in the market.

> "[O]ne-county fiefdoms [are] terrible. Guitar Holding? Terrible. Have we gone so far with these unfortunate designs that we can't go back? Remember that the most important water trades for a society are intersectoral, especially ag to urban/indust/environ. Intrasectoral transfers are much less valuable, usually, because of the homogeneous nature of water use there. The Lower Rio Grande Valley is clearly an exception because the extended growing season gives rise to lots of cropping alternatives. Desirable intersectoral trades are often across county boundaries (witness surface water trades), so how will in-county yield much increase in social welfare?"
>
> **– Water economist**

4. **Sufficient information:** Water markets require information so the buyers, sellers, and lessors can make informed judgments about the value of the water at the heart of any transaction.

5. **Rule of capture area monitoring:** Pumping in unregulated areas (rule of capture only) near the potential market would need to be evaluated for potential impacts to the proposed market. If impacts appear likely from pumping in the unregulated areas, a new GCD would need to be created, or the unregulated area would need to be annexed by one or more of the districts in the groundwater market.

a) Pumping Limits, or Caps

- "In the absence of a groundwater district, a rule of capture right is theoretically unlimited. The right is also not quantifiable and worse, cannot be protected from actions by adjoining landowners" (Johnson et al., 2014, pp. 1–3).

Water markets, like most markets, should be designed to operate in perpetuity. Groundwater markets that are not based on sustainable pumping limits or caps, will not be perpetual and are likely to eventually fail. More critically, markets without pumping limits invite exploitation and potential depletion of the resource. Prospective groundwater purchasers in a new groundwater market will be more likely to engage in transactions provided they are participating in a sustainable water market. Pumping limits, or caps, are the key to a groundwater market's success.

- "The implementation of a legally imposed limit, or 'cap', on the total volume of consumptive use in a water basin is highly desirable in a water market setting. Once the volume of available water available is fixed, the right to use that water takes on a firm value driven by transparent supply-demand dynamics. That value motivates both efficient use as well as trading in water-scarce settings.

A cap on water use can also be highly beneficial in protecting reserves of water to meet basic human needs, while supporting freshwater and estuarine ecosystems. Arguably, a cap on consumptive water rights provides a more effective and more easily implemented strategy for protecting basic human and ecosystem needs, as compared to the set-aside of a water reserve or environmental flow allocation, because regulatory limits on water rights can be more easily enforced" (Richter, 2016, p. 44).

Typically, the neoclassical economic approach—a free-market approach focusing on the relationships between supplies and demands—to solving the problem of overexploitation of common property resources, such as groundwater, has been to define and enforce property rights through institutional intervention. Here, a governmental institution protects property rights and manages the resource under goals that promote the public interest. Under a pure rule of capture system for groundwater, property rights, in the economic sense, are illusory. Existing users are not protected from the installation of a well on adjacent property and the withdrawal of water volumes injurious to existing well owners. Any claim to a property right to groundwater in these rule of capture areas is entirely contingent on neighboring parties not accessing it first. Indeed, it was this type of unrestricted extraction that ended the rule of capture for oil and gas in Texas, resulting in pooling of underground oil and gas resources.

"The Ogallala and the Guadalupe County GCD are both correlative rights districts. Post Oak Savannah is also correlative rights and has some water marketing."

– Water professor

"Post Oak Savanah Groundwater Conservation District's system is a model. Post Oak's system is essentially a correlative rights system with high user fees and mitigation-like payments to assist with local adverse impacts."

– Water attorney

The regulation and allocation of Edwards Aquifer water within a regulatory framework, centered on a pumping cap, created well-defined property rights in that aquifer. Until permits to withdraw specific amounts of water were issued by EAA, property rights, from a free-market perspective, did not exist in Edwards Aquifer groundwater (Votteler, 1998, p. 875). This is because the fundamental characteristics of property rights—universality, exclusivity, transferability, and enforceability—were absent.

> "Comanche Springs is one of the few current opportunities for creating a new groundwater market. There has been a tremendous amount of effort to find some way to preserve enough groundwater to keep the springs flowing. Putting in a cap is the biggest obstacle."
>
> **– Former agency leader**

> "Comanche Springs, Middle Pecos GCD could be a water market. Middle Pecos GCD has a practical cap instead of a defined cap. A cap is probably necessary to have a groundwater market."
>
> **– Water professor**

None of these characteristics were present in the Edwards Aquifer prior to regulation under the EAA Act. There was no universality because entitlements could not be specified under a system where a pumper's use of water was vulnerable to extraction by a neighbor. Exclusivity did not exist: Well owners did not have a meaningful option of leasing or selling the water to which they had access. Transferability also did not exist: Even if a well owner was paid by a third party to not pump water, nothing prevented another landowner from drilling a new well into the aquifer to begin pumping. Thus, a water transfer through a pipeline, for example, would be rendered meaningless because the purchaser was not protected from the impacts of excessive pumping by other users. Finally, enforceability of a property right was not possible because there was no effective way to prevent a pumper from impacting their neighbor's well level.

An owner with a well-defined property right—possessing the four characteristics mentioned above—has a strong incentive to use that resource judiciously, because a decline in the value of that resource represents a financial loss. When well-defined property rights are exchanged through a market transaction, that exchange can facilitate efficiency as water moves from lower value uses to higher value uses, as evidenced within the Edwards Aquifer water market.

Institutional intervention will be necessary to create sustainable groundwater markets and to sustain the aquifers they are based on. That intervention could come from the GCDs and subsidence districts. The best opportunity for these districts to encourage the creation of new groundwater markets in Texas might be through changing the DFC process to require establishing an annual ceiling on aggregate pumping from each aquifer within a given GCD. A DFC is "the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times as defined by participating groundwater conservation districts within a groundwater

> "DFC MAGs when they first came out were to be withdrawal caps. The DFCs could be a route to creating a groundwater market."
>
> **– Water professor**

management area as part of the joint planning process" (Texas Admin. Code, § 356.10 (9), (2021)). Currently, DFCs vary widely between groundwater management areas (GMAs) and GCDs. However, DFCs and modeled available groundwater (MAG) could serve as groundwater withdrawal caps that are revisited every 5 years.

To make the DFC process more useful for this purpose, DFCs would need to be described volumetrically. In addition, and for the purpose of supporting new groundwater market creation, DFC reports should include the sustainable amount that can be pumped from each aquifer under each GCD's jurisdiction. A sustainable pumping amount would equal the amount of water that may be pumped per year without causing a reduction in the given aquifer's stored volume. This would inform groundwater market participants of groundwater quantities that would be available in perpetuity. In addition, a DFC report should include how much was pumped in the most recent year and how much groundwater was permitted as of the most recent year. These data would provide market participants with improved information regarding overall groundwater usage and better inform them of the value of the water in a groundwater rights lease or sale transaction. A precedent already exists for the disclosure of this information within the Edwards Aquifer water market.

While a limit on pumping equal to median recharge may make sense, it may not be practical or feasible for every Texas aquifer. Market-based transactions could make up the difference between authorized pumping and recharge, providing greater flexibility towards achieving sustainable groundwater pumping. These transactions could include creating managed AR projects, or purchasing and retiring existing groundwater rights:

- "[A] GCD may itself create a fund to purchase groundwater entitlements, in order to reduce the quantity of outstanding permits and thereby discontinue unsustainable extractions on a voluntary basis, so that the cost of doing so is fairly borne by all groundwater users and stakeholders rather than certain individuals" (Texas House Committee on Natural Resources, 2018, p. 98).

Finally, it should not be overlooked that groundwater contributes an average of 30%, or 9.3 million acft/yr, of the surface water in Texas rivers (Bruun et al., 2016, p. iv). Therefore, groundwater pumping limits are also an important supporting factor for surface water markets as well.

b) Policies and Rules Must be Consistent Among GCDs

- "In general, the transfer of groundwater within each groundwater conservation district is dependent on the particular rules of each District. In most, but not all, rules have been adopted that address transfer requirements for water produced from wells located within a district's boundaries. Most of these transactions happen on a routine basis with little fanfare or controversy and create a situation for localized water markets to develop very effectively" (Texas House Committee on Natural Resources, 2016, p. 18).

Another key to a successful groundwater market is ensuring that transactions are predictable and ministerial in nature. Currently, each of the 102 GCDs and subsidence districts has its own unique rules and regulations in place. There is therefore a lack of uniformity in how these districts regulate groundwater, which in many cases could present a challenge for the creation and functioning of groundwater markets that conform to hydrologically connected portions of aquifers containing multiple GCDs. Uniformity—at least regarding how a shared market is managed and how transactions occur and are monitored—would be critical where multiple districts come together to form a groundwater market.

"Two factors make the Rio Grande and the Edwards markets unique. Both have defined limits and a predictable process for transferring water rights. The Rio Grande has a process for converting agricultural water rights into municipal or industrial rights. In the Edwards there are really two markets one in each pool of the aquifer: Bexar, Median and Uvalde; and Hays and Comal where the rights 3 or 4 times the value of the rights in the western pool. Within these zones trades are ministerial, meaning the trades do not go through a regulatory review with public comment, etc. The key is the predictability of trades."

– Water attorney

c) The Need for Sufficient Information through Well Metering

As groundwater supplies continue to diminish in some aquifers, it becomes more critical to accurately measure withdrawals. Water managers, users, and market participants need accurate data in sufficient quantities to make the best short-term management decisions during droughts and the best long-term decisions regarding the availability of groundwater as a finite commodity. Well meters provide the most accurate measure of the groundwater volume being withdrawn from any aquifer. If more groundwater markets are created, market participants will need greater certainty about the available groundwater to maintain market integrity. Successful and sustainable water markets are designed so that the buyer is assured of receiving what they are purchasing under identifiable conditions. This means that in the long-term, groundwater rights within areas without sufficient data on how much water is actually being used are less reliable and, consequently, less valuable than they would be otherwise.

The Edwards Aquifer is an excellent example of how regulation and a market have created defensible groundwater rights. In the Edwards Aquifer, metering is required for all municipal, industrial, and irrigation water wells. However, even in the Edwards Aquifer, where there is a cap on annual pumping and a robust water market, wells that produce 25,000 gallons of water a day or less for domestic or livestock use are exempt from metering. In 2010, metered Edwards Aquifer pumping totaled 372,800 acft, while unmetered aquifer pumping was estimated at 13,600 acft/year (RECON Environmental, Inc., et al., 2012, pp. 2-4, 4-47). The amount of groundwater being pumped by exempt wells from other Texas aquifers is unknown. When studying the rules of 96 GCDs and subsidence districts, McCathran et al. (2015) found that only 31 districts had rules that mentioned a metering requirement for certain well types. However, most of those 31 districts allowed exemptions beyond those authorized within Chapter 36 of the Texas Water Code (McCathran et al., 2015).

Measuring water use supports the seller's ability to provide the water volumes or quantities associated with a water trade, increasing the potential trade value. In turn, these data can assure the buyer that the water they are purchasing will be available when they need it. Further, well metering provides all aquifer users within a GCD with greater confidence that the amount of available groundwater is accurately known. Without this information, property rights in groundwater are less reliable. Well metering also provides the data required to develop the best available science, which enables decision-makers to develop the most effective and least onerous management policies. This is supported by § 36.0015 of the Texas Water Code (2015), which states that:

- "Groundwater conservation districts created as provided by this chapter are the state's preferred method of groundwater management in order to ***protect property rights***, balance the conservation and development of groundwater to meet the needs of this state, and **use the best available science** in the conservation and development of groundwater through rules developed, adopted, and promulgated by a district in accordance with the provisions of this chapter." [emphasis added]

Fortunately, the cost of the equipment necessary for groundwater well monitoring is declining. Given these cost declines, state water policy should encourage metering all non-exempt wells. To that end, the state could establish a cost-share program to assist GCDs and well owners with well-metering costs. This would be a substantial investment, but it would pay great dividends in the future in the form of more accurate information about true groundwater use. GCDs need the resources to identify all domestic and livestock wells within their districts so that the collective impacts of pumping from these wells can at least be reliably estimated. Chapter 36 of the Texas Water Code already requires every well owner to register their well(s) with their district, if they are within district boundaries, but that requirement is far from fulfilled (Tex. Water Code, § 36.117(h)(1), 2007).

7. Enabling More Water Transactions Outside of Water Markets in Texas

Water transactions outside of water markets do not appear to change water use behavior to the degree that transactions within water markets do. However, water transactions outside of markets can help to achieve important goals, such as preserving environmental flows and providing water management flexibility. Therefore, finding ways to enable more water transactions outside

> "If the experience in other western states holds true for Texas, much of the future water marketing will come by way of contract sales of currently unused water stored in large water supply projects. To a large extent, these transfers can be accomplished with minimal state administrative oversight."
>
> **– TWDB, 2003, p. 23**

of water markets would be beneficial for the state. The following sections discuss options for increasing surface water transactions.

A. Endogenous Surface Water Markets

> "Since most of Texas' surface water is already appropriated through water rights held in perpetuity, market-driven water transfers could offer an effective tool for optimal allocation of scarce water resources. Many of the water rights are currently underutilized. Thus, the opportunity exists for voluntary market transfers that could provide both temporary and permanent supplies of water to meet Texas' needs."
>
> **– Texas House Committee on Natural Resources, 2018**

In Texas, the institutional characteristics necessary to efficiently trade surface water are generally inconsistent or absent outside of the Lower Rio Grande region (McColly et al., 2021). Still, much of the water sold in Texas is transacted through wholesale contracts for surface water. These sales do not involve the transfer of water rights but occur when the entities that own the water right(s) create a water supply and then sell the available water to whomever is willing to pay for it. A common example is the creation of a reservoir by a river authority that leases the water to a municipal water system, who then distributes the water to their customers. River authorities are usually the nonfederal project sponsors for reservoirs, and as subdivisions of the state, they can create internal markets. These markets rely on internal water transfers through contracts, which are common among Texas's major water districts and river authorities (Chang & Griffin, 1992). The original surface water right remains with the river authority.

As discussed in Chapter 3, there are many situations in Texas where water is available but withheld from exchange because the purchaser maintains an inventory of water contracts for future needs without a current need or ability to use this water. This situation also happens when water users contract for water for future needs primarily to reserve water while it still available through a "take or pay" contract, a common arrangement used to finance reservoir projects using bonds. Stored water in reservoirs, which is reserved through a contract but may not be needed for decades, could be part of a robust leasing market until the purchaser needs it. Within these endogenous markets, those who have reserved and are paying for water—but are not yet using it—could lease it to those with short- or mid-term water needs.

Though these endogenous markets are not true water markets as defined in this report, they can provide water management flexibility and offset the cost of reserving water far in advance of it being needed. As discussed in Chapter 3, there are several potential obstacles to these endogenous market transactions, such as the concern that transactions could trigger a lengthy TCEQ review.

Another major obstacle to this type of short- and mid-term leasing has been the concern that the entities who have contracted for the water might not be able to use it when they eventually need to. There is also a political concern that these types of leases signal to ratepayers and elected representatives that the purchasing entity did not need the water. The solution to these problems would be to provide legal assurance to contracting entities that water leased under these arrangements will be available for their original contracted use once the demand develops. This would facilitate the provision of a supply of water—literal liquidity—for short- or medium-term transactions within several river basins. The adoption of a formal policy and creation of a database of contracted water that is available for these types of leases would be an important step for creating more opportunities for these transactions.

The Brazos River Authority (BRA) provides one example of how these endogenous markets could operate. BRA's System Operation Permit represents a unique program for managing current and future water supply needs throughout the Brazos River basin in a cost-effective manner that avoids the requirement of TCEQ review for individual transactions. Through Water Use Permit No. 5851 and its required water management plan, the System Operation Permit authorizes BRA: to appropriate state water for multiple uses; to appropriate current and future return flows; 3) an exemption from interbasin transfer rules for the water covered by the permit; 4) flexibility in their water supply and management operations; and 5) the use of the bed and banks of the Brazos River, its tributaries, and BRA's reservoirs for the storage, conveyance and subsequent diversion of state water covered under the permit (TCEQ, 2016a, pp. 3-4). TCEQ approved Permit No. 5851 on November 30, 2016, and the TCEQ Executive Director approved the water management plan on April 2, 2018 (TCEQ, 2016a, p. 1; Alexander, 2018, p. 1). One example of water management flexibility under the Systems Operation Permit is BRA's program for one-year interruptible water agreements for short-term supplies in years when there is water available. Through similar system operation permits through TCEQ other river authorities could evolve into formal managers of these endogenous water markets.

B. Options

An option allows a buyer to purchase a contract for a cash payment that entitles the buyer to make a future purchase of a specified amount of something—in this case water—at a specified price within an agreed-upon timeline at a specific location (McColly et al., 2021). A water options market could provide flexibility in planning for future water needs by allowing buyers to adapt to changing conditions affecting both supply and demand and to mitigate some of the risk associated with future uncertainty. Protecting water for the environment has been difficult in Texas, but option contracts are a viable solution for improving the reliability of environmental and instream flows, just as they are for municipal, industrial, and agricultural users or any other user faced with water reliability risks (McColly et al., 2021).

For example, currently river authorities and major industries hold permits for millions of acre-feet of surface water. These permits represent an opportunity to sell water options (McColly et al., 2021). Large downstream industrial water right holders have an opportunity to collectively develop marine desalination for their own use near the coast and then lease their upstream surface rights or sell options on those rights to upstream users. Dry-year option contracts are already in use by municipalities for securing water to supplement their existing supplies during drought (TDWB, 2003, p. 11). As described in Chapter 2 (Edwards Aquifer VISPO), municipalities and other organizations can contract to use irrigation rights during a specified dry-year period or under specific hydrologic conditions. The buyer improves its ability to fulfill its water supply obligations during a drought, and the water right holder receives a payment during droughts but continues to use its rights outside of the contract's trigger conditions.

> "[T]he ability to effectively price water options would allow an additional market-based product to facilitate more flexible transactions. As people from municipalities, agricultural interests, industry, environmental interests, and other groups look for adaptable methods to offset uncertainty surrounding future water needs and supplies, water options would be useful."
>
> **– McColly et al., 2021, p. 91**

An options contract for surface water may, in some instances, require a change in water use. For example, the water associated with an industrial water right would be converted to instream or environmental flow use if the industrial right holder offered an option to another interest. This change in the surface water right use would need TCEQ approval if the new use under the options contract is different than the original use authorized by the permit. The only exception to this requirement is if there is a forbearance agreement where the benefit is received by the buyer as a result of the irrigator or other permit holder simply not exercising their right. Where a change of use or another change to a surface water right requires TCEQ approval through the amendment process, these transactions will be much less attractive to potential buyers (McColly et al., 2021).

CHAPTER 5. CONCLUSIONS: MEETING A CHALLENGING FUTURE WITH WATER MARKETS

- "The opposition to doing anything meaningful cannot be overcome until the system crashes. If you create water markets you address two problems. First, you can avoid running out of water. Second, you can preserve your way of life" (Hanemann, 2022, p. 9).

- "[D]rought conditions will ultimately drive the advancement of water markets in Texas" (Texas House Committee on Natural Resources, 2018, p. 89).

Water use in both the Middle and Lower Rio Grande and the Edwards Aquifer regions encountered critical conditions in 1956, during the height of the drought of record. Homes, communities, and businesses ran short of water. This forced a crisis response to the water use in those systems. These events eventually led to the creation of the Middle and Lower Rio Grande surface water market and the Edwards Aquifer groundwater market. Both markets have functioned successfully for decades.

When Texas experiences another drought similar to the drought of record, there are likely to be additional critical failures in the institutions and systems for surface water and groundwater management. When that happens, Texas policymakers are likely to revisit the foundations of state surface water and groundwater management systems, just as they did after the drought of record. This will provide an opportunity to reorient Texas's system of surface water and groundwater management towards the creation of new water markets as the foundation for regional water management.

"I think water markets can be replicated elsewhere in Texas, but it will be very hard to do. If it happens again, it is because of a serious drought causing a lawsuit."

– Municipal water district leader

However, progress on this could and should start today. Presently, in areas without water markets, disputes are common, reallocation of water from lower value to higher value uses is minimal, and water management is generally inflexible. Without regulation in the form of pumping limits, active enforcement, and metering, opportunities for water markets are limited, and conflict and uncertainty plague water management (Johnson et al., 2014, pp. 1–3). But in places where regulated water markets exist, conflict is minimal or nonexistent, because the inherent conflict in water management happens on the front end during the creation of the water market. Within water markets, the third-party impacts of transactions are commonly settled in advance or are absent altogether (Chong & Sunding, 2006, p. 255). Therefore, while there can be considerable conflict associated with water market creation, once markets are established and functioning, water management and reallocation can occur efficiently with negligible conflict.

In contrast, developing new water sources by constructing reservoirs or developing large groundwater-based projects remains an increasingly difficult option due to the physical, economic, and environmental constraints and changing land use patterns. Fortunately, these headwinds have fostered an era of significant innovation in water management. Alternatives such as water conservation, aquifer storage and recovery, water reuse, brackish groundwater desalination, and water markets are filling the void that major water supply projects once filled.

While regional water markets foster more efficient local water use, surface water interbasin transfers and long-distance groundwater transfers may prolong inefficient water use in the receiving area by delaying or avoiding significant reallocation of local water supplies from lower value uses to higher value uses. Therefore, large-scale water transfers of water from outside regions can delay the process of water realizing its true value in the receiving region.

"Water is not completely amenable to market allocation, but through careful design of both property rights and market limitations, much can be achieved by relying upon market incentives. Price is the embodiment of available information on the scarcity of water and is an effective tool for motivating *appropriate* levels of individual action in response to this scarcity."

– Boadu & Griffin, 1992, pp. 287–288

In contrast, water markets can effectively reduce water demand by changing water use behavior because when water is priced at a value that reflects its true scarcity the result is more efficient water use. Changing water use behavior by valuing water based upon its true scarcity also reduces the need for large-scale water transfers and their associated water conflicts. Water markets are therefore not only an alternative to water transfers but should be an essential prerequisite before importing large quantities of water from elsewhere is attempted.

For the last 150 years, growth and development in the western United States has been subsidized by an over exaggeration of water abundance, whether through rural boosters advertising gushers of fresh groundwater or city-owned utilities enticing new industries using unsustainably low water rates. This has resulted in a fundamental undervaluation of the available water in the western United States, and most water management problems essentially stem from that issue in one way or another. Beyond what is required to meet human health and safety needs, large volumes of inexpensive water devoted to consumptive uses typically lead to poor resource outcomes. The result is usually inefficient, wasteful, and unwise water use, such as urban landscape irrigation and irrigating low value crops with high water demands in semi-arid and arid regions. This results in excessive diversions of surface water, depleted aquifers, and a never-ending cycle of new water supply project development.

The need to create additional water markets in Texas will be driven by growth, rising costs of developing new supplies, unsustainable groundwater supply use, periodic droughts, and long-term climate changes. Meeting Texas's future water needs will be in jeopardy unless there is an exhaustive effort to make the use of current water supplies more efficient by reallocating water from lower value uses to higher value uses. Doing this through regulation alone will be prohibitively time and resource intensive (Western Governors' Association, 2012, p. ix).

Developing new water markets is an efficient, effective, and feasible vehicle for accomplishing this goal. Texas policymakers have expressed support for voluntary water transfers through water markets as one of Texas's key strategies for meeting future water needs since at least the 1990 state water plan, with more recent encouragement by SB 1 in 1997 and through recommendations by the Texas House Committee on Natural Resources in 2016 and 2018 (Texas House Committee on Natural Resources, 2016; Texas House Committee on Natural Resources, 2018; TWDB, 1990). While water markets are not the solution for every water challenge, they are an effective, proven, and underutilized strategy for answering many of Texas' water problems. Recent decades have witnessed a remarkable renaissance regarding water management, characterized by the development and deployment of innovative water technologies and water management strategies. Water markets can provide the foundation for the optimal integration and most effective implementation of this renaissance in the face of our challenging future.

REFERENCES

Alexander, K. (2018, April 2). Re Brazos River Authority WRPERM 5851. https://brazos.org/Portals/0/Documents/WMP/2018/Alexander-04-02-2018.pdf

Amendment to convert use from reservoir storage to aquifer storage and recovery, 2 Tex. Water Code § 11.158 (2019). https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm#11.158

Amendment to Water Rights Required, Tex. Water Code § 11.122(b) and 11.122(b-3) (2019). https://texas.public.law/statutes/tex._water_code_section_11.122

Appointment of Watermaster, Tex. Water Code § 11.326 (2011). https://texas.public.law/statutes/tex._water_code_section_11.326

Arce, A. F. (2003). *San Antonio Water System Water Resources Development Program*. Center for Innovative Grouting Materials and Technology, University of Houston. https://cigmat.cive.uh.edu/sites/cigmat/files/files/conference/presentation/2003/2.pdf

Australian Government National Water Commission. (2011). *Water markets in Australia: A short history*. https://apo.org.au/node/27438

Ayres, A., Hanak, E., Gary, B., Sencan, G., Bruno, E., Escriva-Bou, A., Gartrell, G., & Collins, J. (2021, September). Improving California's water market: How water trading and banking can support groundwater management. Public Policy Institute of California. https://www.ppic.org/publication/improving-californias-water-market/

Bardeen, S. (2021, September 29). *Improving California's water market*. California Ag Network. https://californiaagnet.com/2021/09/29/improving-californias-water-market/

Barshop v. Medina County Underground Water Conservation Dist., 263 S.W.3d 910 (Tex. 1996).

Bitran, E., Rivera, P., & Villena, M. J. (2014). Water management problems in the Copiapó Basin, Chile: markets, severe scarcity and the regulator. *Water Policy*, *16*(5), 844–863. https://doi.org/10.2166/wp.2014.107

Biswas, A., Dakang, Z., Nickum, J., & Ming, L. (1983). Long-Distance Water Transfer: A Chinese Case Study and International Experiences. Water Resources Series, United Nations University. https://digitallibrary.un.org/record/76038

Breviglieri, G. V., Osório, G., & Puppim de Oliveira, J. A. (2018). Understanding the emergence of water market institutions: Learning from functioning water markets in three countries. *Water Policy*, *20*(6), 1075–1091. https://doi.org/10.2166/wp.2018.119

Bruun, B., Jackson, K., Lake, P., & Walker, J. (2016, December 31). *Texas aquifers study*. Texas Water Development Board. https://www.twdb.texas.gov/groundwater/docs/studies/TexasAquifersStudy_2016.pdf

Cantin, B., Shrubsole, D. & Aït-Ouyahia, M. (2005). Using economic instruments for water demand management: introduction. *Canadian Water Resources Journal* 30(1), 1–10. https://www.tandfonline.com/doi/pdf/10.4296/cwrj30011

Carr, J. T., Jr., Janca, I. G., Warzecha, R. L., Hendricks, R. B., Richardson, A. E., Porterfield, H. H., Jr., & Gillett, P. T. (1965, August). *Appendices to Bulletin 6413: Water supply limitations to irrigation from the Rio Grande in Starr, Hidalgo, Cameron, and Willacy counties, Texas*. Texas Water Commission. https://www.twdb.texas.gov/publications/reports/bulletins/doc/B6413a.pdf

Chang, C., & Griffin, R. C. (1992). Water marketing as a reallocative institution in Texas. *Water Resources Research*, *28*(3), 879–890. https://doi.org/10.1029/91WR02677

Chaudhry, A. M., & Fairbanks, D. H. K. (2022). Distributional implications of supply constraints in water markets. *Journal of Water Resources Planning and Management*, *148*(7). https://doi.org/10.1061/(ASCE)WR.1943-5452.0001563

Chong, H., & Sunding, D. (2006). Water markets and trading. *Annual Review of Environment and Resources*, *31*, 239–264. https://doi.org/10.1146/annurev.energy.31.020105.100323

Colo. River Water Conservation Dist. v. Vidler Water Co., 594 P.2d 566, 568 (Colo. 1979).

Debaere, P., & Li, T. (2020). The effects of water markets: Evidence from the Rio Grande. *Advances in Water Resources*, *145*, 103700. https://doi.org/10.1016/j.advwatres.2020.103700

Definitions, 2 Tex. Water Code § 36.001 (1995). https://statutes.capitol.texas.gov/Docs/WA/htm/WA.36.htm#36.001

Definitions, 31 Tex. Admin. Code, § 356.10 (2021). https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=31&pt=10&ch=356&rl=10

DeYoe, H. R., Buzan, D., Benavides, J. A., Marin, C., Edwards, R. J., & Pulich, W., Jr. (2012, July). *Environmental flows recommendation report: Final submission to the Environmental Flows Advisory Group, Rio Grande, Rio Grande Estuary, and Lower Laguna Madre Basin and Bay Stakeholders Committee, and Texas Commission on Environmental Quality*. The University of Texas Rio Grande Valley. https://scholarworks.utrgv.edu/bio_fac/201/

Edwards Aquifer Authority. (n.d.). *The EAA Act: A success story*. Retrieved November 3, 2022, from https://www.edwardsaquifer.org/eaa/legislation-rules/the-eaa-act-a-success-story/

Edwards Aquifer Authority. (2000). *Edwards Aquifer Authority Technical Media Briefing on Proposed Groundwater Permits*.

Edwards Aquifer Authority. (2003). Permit Files: *Proposed groundwater permits, acre-feet*.

Edwards Aquifer Authority. (2005, November 30). *Fact Sheet: Final Groundwater Withdrawal Permit Amounts Established*.

Edwards Aquifer Authority. (2021a). *Hydrologic data fact sheets: 2020 Discharge in the Edwards Aquifer region*. https://www.edwardsaquifer.org/wp-content/uploads/2022/02/2020-Discharge.pdf

Edwards Aquifer Authority. (2021b, May 25). *2020 withdrawal summary*. Presentation by Chuck Ahrens.

Edwards Aquifer Authority. (2022, May 10). *2021 withdrawal summary*. Presentation by Omar Garcia.

Edwards Aquifer Authority Act, Act of May 30, 1993, 73d Leg., R.S., ch. 626, §§ 1.01-4.03, 1993 Tex. Gen. Laws 2350; as amended.

Encyclopedia Britannica. (2011). *Rio Grande Basin with major reservoirs.* https://cdn.britannica.com/22/113522-050-9D42C279.gif

Exemptions; Exceptions; Limitations, 2 Tex. Water Code § 36.117 (2007). https://texas.public.law/statutes/tex._water_code_section_36.117

Fazeli, S., Bozorg-Haddad, O., Randall, M., & Berrens, R. P. (2021). Introducing water banks: principles and importance. In O. Bozorg-Haddad (Ed.), *Economical, political, and social issues in water resources* (pp. 83–102). Elsevier. https://doi.org/10.1016/B978-0-323-90567-1.00009-7

Filatova, T. (2014). Market-based instruments for flood risk management: A review of theory, practice and perspectives for climate adaptation policy, *Environmental Science & Policy*, *37*, 227-242. https://doi.org/10.1016/j.envsci.2013.09.005

Friberg, Marc. (2024, September 20). Edwards Aquifer Research. Personal communication.

Griffin, R. C., & Boadu, F. O. (1992). Water marketing in Texas: Opportunities for reform. *Natural Resources Journal*, *32*(2), 265–288. https://digitalrepository.unm.edu/nrj/vol32/iss2/3

Guitar Holding Co. v. Hudspeth Cty. Underground Water Conservation Dist. No. 1, 263 S.W.3d 910, 912 (Tex. 2008).

Hanemann, M. (2022, July 18). The problem of water markets. *Oxford Research Encyclopedias.* https://doi.org/10.1093/acrefore/9780199389414.013.711

Hanemann, M., & Young, M. (2020). Water rights reform and water marketing: Australia vs the US West. *Oxford Review of Economic Policy*, *36*(1), 108–131. https://doi.org/10.1093/oxrep/grz037

Heard, S., Fienup, M., & Remson, E. J. (2021). The first SGMA groundwater market is trading: The importance of good design and the risks of getting it wrong. *California Agriculture*, *75*(2), 50–56. https://doi.org/10.3733/ca.2021a0010

Howe, B. R. (2021, January 3). Wall Street eyes billions in Colorado's water. *The New York Times.* https://www.nytimes.com/2021/01/03/business/colorado-river-water-rights.html

Interbasin transfers, 30 Tex. Admin. Code § 295.13 (2014). https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=295&rl=13

Issuance of permit, 2 Tex. Water Code § 11.135 (2017). https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm#11.135

Jarvis, G. (1991). *The Rio Grande from Ft. Quitman to the Gulf: Water rights and needs in the Lower Rio Grande*. Laws of the Rio Grande del Norte: An Interstate Seminar, Albuquerque, NM, United States.

Jarvis, G. (2007, February 1–2). *Buying and selling Rio Grande and Rio Grande tributary surface water in Texas* [Conference presentation]. Law of the Rio Grande: New Perspectives in Changing Times, CLE International Law Conference, Santa Fe, NM, United States.

Jarvis, G. (2009, April 2–3). *Conversion of Irrigation Rights to Municipal and Industrial Rights* [Conference presentation]. Law of the Rio Grande: Collaborative Approaches to the River's Biggest Challenges, CLE International Law Conference, Santa Fe, NM, United States.

Jarvis, G. (2011, February 24–25). *Future of irrigated agriculture and the transfer of irrigation use* [Course presentation]. State Bar of Texas, Annual Changing Face of Water Rights Course, San Antonio, TX, United States.

Johnson, R. S., & Ellis, G. M. (2013). A new day? Two interpretations of the Texas Supreme Court's ruling in *Edwards Aquifer Authority v. Day and McDaniel*. *Texas Water Journal*, *4*(1), 35–54. https://doi.org/10.21423/twj.v4i1.6990

Johnson, R. S., Haag, P., & Johnson, M. (2014, October 31). *Water: Marketing and transportation*. Austin, TX, United States.

Joseph, D. (2013, December 1). SAWS ending toilet program. *San Antonio Express-News*. https://www.expressnews.com/news/environment/article/saws-ending-toilet-program-5026370.php

Kaiser, R. (1994, November). *Legal and institutional barriers to water marketing in Texas* (Technical Report No. 167). Texas Water Resources Institute. https://hdl.handle.net/1969.1/191014

Kaiser, R. A., & McFarland, M. (1997). A bibliographic pathfinder on water marketing. *Natural Resources Journal*, *37*, 881–908. https://digitalrepository.unm.edu/nrj/vol37/iss4/5

Kaiser, R. A., & Phillips, L. M. (1998). Dividing the waters: Water marketing as a conflict resolution strategy in the Edwards Aquifer region. *Natural Resources Journal*, *38*, 411–444. https://digitalrepository.unm.edu/nrj/vol38/iss3/2

Kirkle, S. R., Martinsson, L. K., Schlessinger, S. R., Ortiz, A. R., Fowler, P. L., Puig-Williams, V., Mazur, J. B., & Votteler, T. H. (2023). Commentary: 88th Texas State Legislature: Summaries of

Water-Related Legislative Action. *Texas Water Journal*, *14*(1), 105–135. https://doi.org/10.21423/twj.v14i1.7167

Kumar, D. (2019, January 17). *Water for cash – a primer on water markets.* The Water Center at the University of Pennsylvania. https://web.archive.org/web/20230618223713/https://watercenter.sas.upenn.edu/water-for-cash-a-primer-on-water-markets/

LBG-Guyton Associates. (2008). *Simulated impacts associated with the Cibolo Creek transfers using MODFLOW-NR and Senate Bill 3 assumptions*. Edwards Aquifer Authority. https://www.edwardsaquifer.org/science_docs/simulated-impacts-associated-with-the-cibolo-creek-transfers-using-modflow-nr-and-senate-bill-3-assumptions/

Lieberknecht, Chloe (2018, October 16). Oral and Written Testimony at the Public Hearing held by the Texas House of Representatives Committee on Natural Resources, Waco, Texas. https://texasgroundwater.org/wp-content/uploads/2020/12/Natural-Resources-Committee-Interim-Report-2018.pdf

McCathran, M., Anderson, B., & Hermitte, S. M. (2015, December). *Groundwater production monitoring in the state of Texas* (Technical Note 15-06). Texas Water Development Board. https://www.twdb.texas.gov/publications/reports/technical_notes/doc/TechnicalNote15-06.pdf

McColly, Q., Mace, R., Tissot, P., & Yoskowitz, D. (2021). Pricing options on water in Texas. *Texas Water Journal*, *12*(1), 91–108. https://doi.org/10.21423/twj.v12i1.7121

Montilla-López, N. M., Gutiérrez-Martín, C., & Gómez-Limón, J. A. (2016). Water banks: What have we learnt from the international experience? *Water*, *8*(10), 466. https://doi.org/10.3390/w8100466

Multiple ownership of existing reservoir, 30 Tex. Admin. Code § 295.11 (1986). https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=295&rl=11

Naishadham, S. (2021, October 16). *In South Texas, aging water system meets growing population.* The Associated Press. https://apnews.com/article/climate-change-science-business-texas-droughts-6c9ef910eea9adc40df4e4fa5e9d1bcc

“No Injury” Rule, Texas Water Code § 11.122 and 30 Tex. Admin. Code §297.45 (1999). https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=297&rl=45

Operation of the Bank; Rules, Tex. Water Code § 15.703 (1999). https://texas.public.law/statutes/tex._water_code_section_15.703

Oregon Institute for Water and Watersheds. (2012, April). *Oregon’s water markets*. https://water.oregonstate.edu/sites/water.oregonstate.edu/files/oregon_water_markets_v3_0.pdf

Other Transfers, § 15.708 (1993).
https://texas.public.law/statutes/tex._water_code_section_15.708

Payne, Brandon. (August 13, 2022). Edwards Purchase and Lease Information. Personal communication.

Projects for storage of appropriated water in aquifers, 2 Tex. Water Code § 11.153 (2015).
https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm#11.153

Purpose, 2 Tex. Water Code § 36.0015 (2015).
https://texas.public.law/statutes/tex._water_code_section_36.0015

Purposes for which water may be appropriated, 2 Tex. Water Code § 11.023 (2019).
https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm#11.023

RECON Environmental, Inc., Hicks & Company, Zara Environmental LLC, & BIO-WEST. (2012, November). Edwards Aquifer recovery implementation program: Habitat conservation plan. Edwards Aquifer Recovery Implementation Program.
https://www.edwardsaquifer.net/pdf/Final_HCP.pdf

Regional Banks, 31 Texas Admin. Code § 359.13, 1994.
https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=31&pt=10&ch=359&rl=13

Regional Water Resource Development Group. (2006, May 17). *Interlocal Agreement*.

Richter, B. D. (2016). *Water share: Using water markets and impact investment to drive sustainability*. The Nature Conservancy.
https://www.nature.org/content/dam/tnc/nature/en/documents/WaterShareReport.pdf

Richter, B. D., Benoit, K., Dugan, J., Getacho, G., LaRoe, N., Moro, B., Rynne, T., Tahamtani, M., & Townsend, A. (2020). Decoupling urban water use and growth in response to water scarcity. *Water*, *12*(10), 2868. https://doi.org/10.3390/w12102868

Rick, C. (1997, November 2). Billionaire Bass Clan stakes out area water. *San Antonio Express-News*. https://www.expressnews.com/archive/search/subscriber/

Rio Grande Regional Water Authority. (2005, January). *Rio Grande water rights & allocations*.
https://www.rgrwa.org/images/pdfs/waterrights.pdf

Rio Grande Regional Water Planning Group. (2006, January 5). *Rio Grande regional water plan*. Texas Water Development Board.
https://www.twdb.texas.gov/waterplanning/rwp/plans/2006/M/Region_M_2006_RWP.pdf

Rio Grande Regional Water Planning Group. (2020, November 5). *2021 Rio Grande regional water plan.* Texas Water Development Board.
https://www.twdb.texas.gov/waterplanning/rwp/plans/2021/M/RegionM_2021RWP.pdf

Rio Grande Regional Water Planning Group (Region M). (2001, January). *Regional water supply plan for the Rio Grande Regional Water Planning Area (Region M).* Texas Water Development Board. https://www.twdb.texas.gov/waterplanning/rwp/plans/2001/M/Region_M_2001_RWP.pdf

Rosen, R. A., Hermitte, S. M., Pierce, S., Richards, S., & Roberts, S. V. (2019). An internet for water: Connecting Texas water data. *Texas Water Journal*, *10*(1), 24–31. https://doi.org/10.21423/twj.v10i1.7086

Rothberg, D. (2024, January 25). *Nevada Supreme Court issues major water ruling*. Western Water Notes. https://www.westernwaternotes.com/p/nevada-supreme-court-issues-major

Rubinstein, C., Seaton, C., & Mace, R. E. (2022). Beyond Senate Bill 3: How to achieve environmental flows in Texas under prior appropriation. *Texas Water Journal*, *13*(1), 13–26. https://doi.org/10.21423/twj.v13i1.7115

San Antonio, Texas Ord. No. 80574, § 15 (1994).

San Antonio, Texas Ord. No. 86747, §1 (1997).

San Antonio Water System. (1993, November). *Water conservation and reuse plan*.

San Antonio Water System. (1998). *Securing our water future together: Water resource plan*. https://apps.saws.org/your_water/waterresources/docs/WR-Plan-1998.pdf

San Antonio Water System. (2005, June 21). *Water resource plan 2005 update*. https://apps.saws.org/your_water/waterresources/docs/Water%20Resource%20Plan%20Update%20062005%20429PM%20Final.pdf

San Antonio Water System. (2017, November 7). *2017 water management plan*. https://www.saws.org/wp-content/uploads/2019/02/20171107_SAWS-2017-Water-Management-Plan.pdf

San Antonio Water System. (2020). *Water supply fee semiannual report: January-June 2020*. https://www.saws.org/wp-content/uploads/2020/11/WaterSupplySemiannualReport-Jan-June-2020.pdf

Sax, J. L. (2008). Understanding transfers: Community rights and the privatization of water. *Hasting Environmental Law Journal*, *14*(1), 33–40. https://repository.uclawsf.edu/hastings_environmental_law_journal/vol14/iss1/1

SB 20-048 Work Group. (2021, August 13). SB 20-045 - Report of the work group to explore ways to strengthen current water anti-speculation law. State of Colorado. https://watercenter.colostate.edu/wp-content/uploads/sites/33/2021/09/SB20-048-Final-Report.pdf

Shaw, K., Stein, Z., Deeds, N., George, P., Miczarek, M., & Yang, Q. (2020, September 30). *Statewide survey of aquifer suitability for aquifer storage and recovery projects or aquifer recharge projects*. Texas Water Development Board. https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2000012405.pdf

Schumacher, H. (2020, May 8). *The Fox Canyon Water Market: A market-based tool for groundwater conservation goes live*. U.S. Department of Agriculture. https://www.usda.gov/media/blog/2020/05/08/fox-canyon-water-market-market-based-tool-groundwater-conservation-goes-live

Sierra Club v. Babbitt, No. MO-91-CA-069, slip op. at 69 (W.D. Tex. May 26, 1993) (amended findings of fact and conclusions of law).

South Central Texas Regional Water Planning Group. (2001, January). *South Central Texas Regional Water Planning Area: Regional water plan, volume 1*. San Antonio River Authority. https://www.edwardsaquifer.org/science_docs/south-central-texas-regional-water-planning-area-2001-regional-water-plan-volume-i-executive-summary-and-regional-water-plan-part-1/

State v. Hidalgo County Water Control & Improvement District No. Eighteen, 443 S.W.2d 728 (Tex. Civ. App. 1969).

Storage in another's reservoir, 30 Tex. Admin. Code § 295.12 (1986). https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=295&rl=12

Stubbs, M. J., Rister, M. E., Sturdivant, A. W., & Lacewell, R. D. (2004, August). *An overview of the operational characteristics of selected irrigation districts in the Texas Lower Rio Grande Valley: Brownsville Irrigation District* (Technical Report No. 274). Texas Water Resources Institute. https://hdl.handle.net/1969.1/6102

Szeptycki, L. F., Forgie, J., Hook, E., Lorick, K., & Womble, P. (2015, August 31). *Environmental water rights transfers: A review of state laws*. The National Fish and Wildlife Foundation. https://digitalcommons.usu.edu/instream_all/3/

Templer, O. (1952). "Water Law," *Handbook of Texas Online*. Texas State Historical Association. Accessed February 16, 2025, https://www.tshaonline.org/handbook/entries/water-law#:~:text=The%20Water%20Rights%20Adjudication%20Act,with%20the%20TWC%20by%201969

Tex. H.B. 3059, 88th Leg., R.S. (2023). https://capitol.texas.gov/BillLookup/History.aspx?LegSess=88R&Bill=HB3059.

Tex. H.B. 4623, 88th Leg., R.S. (2023). https://capitol.texas.gov/BillLookup/History.aspx?LegSess=88R&Bill=HB4623.

Texas Commission on Environmental Quality. (n.d.). *Environmental flows*. Retrieved January 22, 2024, from https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/eflows

Texas Commission on Environmental Quality. (n.d.). *Rio Grande Watermaster Program*. Retrieved April 1, 2023, from https://www.tceq.texas.gov/permitting/water_rights/wmaster/rgwr

Texas Commission on Environmental Quality. (n.d.). *Watermasters: What they do and how they're created*. Retrieved January 22, 2023, from https://www.tceq.texas.gov/permitting/water_rights/wmaster/about-wm

Texas Commission on Environmental Quality. (n.d.). *Texas Watermaster Areas*. Retrieved August 15, 2024, from https://www.tceq.texas.gov/permitting/water_rights/wmaster

Texas Commission on Environmental Quality. (2016a, November 30). *Water Use Permit No. 5851*. https://brazos.org/Portals/0/Documents/Permits/SysOpsPermit5851-signed20161209.pdf

Texas Commission on Environmental Quality. (2016b, December). *Water study: Review of the Water Resource Management Account*. https://www.tceq.texas.gov/agency/water-study

Texas Commission on Environmental Quality. (2022, July 1). *State of Texas public drinking water program 2021 annual compliance report*. https://www.tceq.texas.gov/downloads/drinking-water/epa-acr-2021.pdf

Texas Department of Water Resources. (1984, November). *Water for Texas: A comprehensive plan for the future, volume 1* (GP-4-1). Texas Water Development Board https://www.twdb.texas.gov/publications/State_Water_Plan/1984/Water%20for%20Texas%20Volume%201.pdf

Texas Department of Water Resources. (1984, November). *Water for Texas: Technical appendix, volume 2* (GP-4-1). Texas Water Development Board https://www.twdb.texas.gov/publications/State_Water_Plan/1984/Water%20for%20Texas%20Volume%202%20Technical%20Appendix.pdf

Texas House Committee on Natural Resources. (2016, December). *Interim Report to the 85th Texas Legislature*. Texas House of Representatives. https://texasgroundwater.org/wp-content/uploads/2020/12/House-Natural-Resources-Committee-Interim-Report-2016.pdf

Texas House Committee on Natural Resources. (2018, December). *Interim Report to the 86th Texas Legislature*. Texas House of Representatives. https://texasgroundwater.org/wp-content/uploads/2020/12/Natural-Resources-Committee-Interim-Report-2018.pdf

Texas Water Development Board. (n.d.). *Desired future conditions*. Retrieved September 8, 2023, from https://www.twdb.texas.gov/groundwater/dfc/index.asp

Texas Water Development Board. (n.d.). *Texas Water Bank*. Retrieved January 25, 2022, from https://www.twdb.texas.gov/waterplanning/waterbank/bank/index.asp

Texas Water Development Board. (1968, November). *The Texas Water Plan*. https://www.twdb.texas.gov/publications/State_Water_Plan/1968/1968_Texas_Water_Plan.pdf

Texas Water Development Board. (1968, November). *The Texas Water Plan Summary*. https://www.twdb.texas.gov/publications/State_Water_Plan/1968/1968_Texas_Water_Plan_summary.pdf

Texas Water Development Board. (1990, December). *Water for Texas: Today and Tomorrow* (GP-5-1). https://www.twdb.texas.gov/waterplanning/swp/1990/index.asp

Texas Water Development Board. (1992, December). *Water for Texas: Today and Tomorrow* (GP-6-1). https://www.twdb.texas.gov/waterplanning/swp/1992/index.asp

Texas Water Development Board. (1997, August). *Water for Texas* (GP-6-2). https://www.twdb.texas.gov/waterplanning/swp/1997/

Texas Water Development Board. (2002, January). *Water for Texas 2002* (GP-7-1). https://www.twdb.texas.gov/waterplanning/swp/2002/index.asp#Vol1

Texas Water Development Board. (2003). *A Texan's guide to water and water rights marketing*. https://www.twdb.texas.gov/publications/reports/infosheets/doc/WaterRightsMarketingBrochure.pdf

Texas Water Development Board. (2021, October 5). *Historical use and projections* [Data set]. https://www.twdb.texas.gov/waterplanning/data/dashboard/sources/historicaluseandprojections.xlsx

Texas Water Rights Commission, Texas Attorney General's Office. (1971, June). *Lower Rio Grande Valley Water Documents*.

Tietenberg, T. H. (1992). *Environmental and natural resources economics* (3rd ed.). Taylor & Francis.

United States of America, United Mexican States. (1944, February). Treaty Series 944: Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande. https://www.ibwc.gov/wp-content/uploads/2022/11/1944Treaty.pdf

U.S. Army Corps of Engineers. (n.d.). Nationwide Permit Program. https://www.mvn.usace.army.mil/Missions/Regulatory/Permits/Nationwide-Permits-Program/

U.S. Bureau of Economic Analysis. (2022, July 11). *Real Gross Domestic Product: All Industries in XXX County, TX [REALGDPALL48055]*. https://fred.stlouisfed.org/series/REALGDPALL48055

U.S. Bureau of Reclamation. (n.d.). *Colorado-Big Thompson Project*. Retrieved August 14, 2024, from https://www.usbr.gov/projects/index.php?id=432

U.S. Environmental Protection Agency. (n.d.). *Water Quality Trading.* Retrieved August 17, 2024, from https://www.epa.gov/npdes/water-quality-trading#:~:text=Water%20quality%20trading%20is%20a,collectively%20impact%20water%20quality%20conditions

Votteler, T. H. (1998). The little fish that roared: The Endangered Species Act, state groundwater law, and private property rights collide over the Texas Edwards Aquifer. *Environmental Law*, *28*(4), 845–879. https://www.jstor.org/stable/43266685

Votteler, T. H. (2000, March 15). Water from a Stone: The Limits of the Sustainable Development of the Texas Edwards Aquifer. Doctoral Dissertation, Texas State University, 1-468. https://www.edwardsaquifer.net/pdf/Water_from_a_Stone.pdf

Votteler, T. H. (2022, October 25). *Talk+Water: Dr. Andrew Sansom*. Texas+Water. https://podcasts.apple.com/us/podcast/talk-water/id1450729314?i=1000583882301

Votteler, T. H. (2023, May 11). Hands across the Water: How the 57-Year Dispute over the Edwards Aquifer Began, Persisted, and Was Resolved**.** *Water* 15**,** 1835**,** 1-20. https://doi.org/10.3390/w15101835

Water Data for Texas. (n.d.). *Amistad Reservoir*. Retrieved July 5, 2023, from https://www.waterdatafortexas.org/reservoirs/individual/amistad

Water Data for Texas. (n.d.). *Falcon Reservoir*. Retrieved July 5, 2023, from https://www.waterdatafortexas.org/reservoirs/individual/falcon

Water for use as aquifer recharge or in an aquifer storage and recovery project, 2 Tex. Water Code § 11.157 (2019). https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm#11.157

Western Governors' Association. (2012, December*). Water transfers in the West: Projects, trends, and leading practices in voluntary water trading*. Western States Water Council. https://www.westernstateswater.org/wp-content/uploads/2012/12/Water_Transfers_in_the_West_2012.pdf

White, K. H., Rubinstein, C., Settemeyer, H. & Ingram, M. (2017, April). *The case for a Texas water market*. Texas Public Policy Foundation. https://www.texaspolicy.com/the-case-for-a-texas-water-market/

World Population Review. (n.d.). Brownsville, Texas population. Retrieved July 14, 2023, from https://worldpopulationreview.com/us-cities/brownsville-tx-population

Yablonski, A. (2020, December 9). *Balancing environmental, municipal, and agricultural needs in the Edwards Aquifer: A farmer's perspective* [Webinar]. Brown Bag Webinar, University of Arizona Water Resources Research Center. https://wrrc.cals.arizona.edu/events/brown-bag-webinar-balancing-environmental-municipal-and-agricultural-needs-edwards-aquifer

Young, L. D. (2001, September 20). *San Antonio Water System: Operating in the new water market* [Symposium presentation]. Edwards Aquifer Symposium, San Antonio, TX, United States.