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Review

Water Markets in the Western United States: Trends and Opportunities

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Abstract: Efforts to address water scarcity have traditionally relied on changing the spatial and temporal availability of water through water importation, storage, and conveyance. More recently, water managers have invested heavily in improving water use efficiency and conservation. Yet as new supply options become harder to find and/or appropriate, and demand hardens, society must consider other options to, if not reduce scarcity, minimize the impacts of such scarcity. This paper explores the role water markets are playing in addressing water scarcity in the American southwest: a water-limited arid and semi-arid region characterized by significant population growth rates relative to the rest of the US. Focusing on three representative southwestern states—Arizona, California, and Texas—we begin by highlighting how trends in water supply allocations from different water sources (e.g., surface water, groundwater, and wastewater) and water demand by different water users (e.g., agricultural, municipal, and environmental) have changed over time within each state. We then present recent data that shows how water trading has changed over time—in terms of value and volume—both at state level and sector level aggregates. We end with a discussion regarding some institutional adjustments that are necessary for water markets to achieve their potential in helping society address water scarcity.

Keywords: drought; water markets; Western US

1. Introduction

One of the most pressing challenges confronting the US in the 21st century is water scarcity. Population growth, which will increase the demand for water throughout the US, has risen by nearly 7%, or approximately 22 million people, since 2010 (Figure 1). Of course, there have been increases in water use efficiency that have somewhat counteracted the impact of population growth on demand. For example, in California, per capita daily use dropped from 244 to 178 gallons from 1995 to 2010 [1]. Yet increased evapotranspiration from a warmer climate suggests a less available supply reaching our municipalities, agricultural lands, and water bodies, likely increasing the level of conflict among water sectors. Furthermore, while most climate change models suggest that the amount of precipitation may not change significantly over the next 50 to 100 years, precipitation events will become much more variable, intense, and infrequent, with more precipitation falling as rain than snow [2–5]. Combined, these characteristics suggest that conflicts over water scarcity will increase as the temporal distribution and form of supply deviates from what our infrastructure was designed to handle.

The objective of this review paper is to shed light on how water scarcity is changing in the Southwestern US, and the role water markets have and might play in addressing this scarcity. In particular, we focus on how the demand and supply of water are trending in representative states in the southwest—Arizona, California, and Texas—and the increasing role of water markets in helping states to address such scarcity. Two of these states—Texas and California—have accounted for nearly 1/3rd of the population growth in the US (Figure 1). Relative to US averages, the southwestern states of Arizona, California, and Texas confront higher population growth (2.45% vs. 1.15% between 1920 and 2018), higher temperature (61.1 °F vs. 52.5 °F), and less precipitation (20.68 in vs. 30.48 in). Such differences increase water demand and decrease the supply of runoff from precipitation events resulting in rising water scarcity.

Since markets depend on differences in the marginal values across users to create incentives to trade, we differentiate between different types of water use (e.g., agricultural, environmental, municipal/city) to better understand which sectors will likely be driving the market, where scarcity might arise within a state, and the role of water markets in potentially assuaging such scarcity. After briefly describing some general climate and population statistics within each state that likely influence water scarcity, we introduce water supply and demand conditions by state, with a brief background of water use trends.

Following each state-level discussion, we provide data on water market trends and transactions within each state and discuss how those trends may relate to water scarcity characteristics within each state. Note that the effectiveness of water markets and growth in water demand, supply, and use is largely influenced by each state's water rights laws and regulations. Given space limitations, we have opted to focus strictly on presenting the most recent data on water demand, supply, and markets but direct the reader to other sources for an in-depth understanding as to how water rights and regulations within each state influence the trends we identify. For example, for California, see Hanak, et al. [6]; for Arizona, see Colby and Isaaks [7]; for Texas, see Kaiser [8].

Data are presented on the overall market size measured in total volume and value during 2009–2018 as well as the distribution of market activity across western states. We also review active sectors buying and selling water and discuss commonly traded types of water entitlements and transaction structures. In this paper, we use water markets data from Waterlitix™, the largest and most comprehensive database of water rights price and sales information in the United States. Waterlitix™ is a proprietary database developed and maintained by WestWater Research. The data are the results of two decades of continuous, primary research of water right trading and leasing. Transaction information is compiled from state and local regulatory filings, public and private transaction documents such as leases and purchase and sale agreements, and through direct interviews with parties involved in transactions. The database is structured to include both water asset/water right details and transaction specific information. Water asset information includes details on the water asset type involved in the transaction such as authorized diversion volume, quantity of water approved for transfer (which may differ from the authorized diversion volume), other information on the water rights or assets such as priority date, authorized use, source and locational characteristics including water basin, administrative districts or water management boundaries such as a water district or ditch company. The database also includes specific transaction details such as buyer and seller information, previous and new use of the water, transaction structure such as single year lease, multi-year lease, permanent purchase or other complex exchanges where financial consideration is paid. Other transaction information includes financial consideration paid, financial and transaction terms, total payment, and unit price payment that has been normalized across all transactions to allow for comparisons of equivalent transactions and water asset types. All of the transactions within Waterlitix™ are geo-referenced within a geospatial searchable data platform. Prior water market studies include comprehensive transactions from 1987 to 2009 in the Western US [7,9–12]. Our analysis provides an update to these prior studies. We end with a discussion of how the role of water markets may be improved in the future to help states, and the US as a whole, better cope with future rising water scarcity.

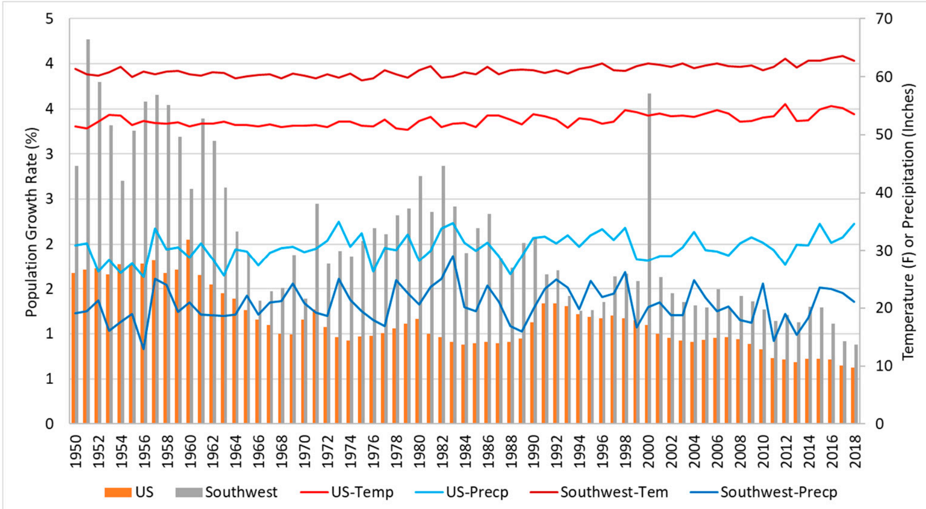


Figure 1. Changes in population over time, average annual temperature, and total precipitation in the US and southwestern states (Arizona, California, and Texas) (1950–2018). Source: Authors calculations, US Census Bureau for the population estimates, and National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information for temperature and precipitation [13]. Notes: Population growth indicates annual population changes in the US and average annual population changes in the three states included in this review. Temperature and total annual precipitation indicate the average annual statistics for the US and the three states.

2. State-Level Water Summaries: Trends and Trades

In this first section, we provide a brief discussion of general water scarcity conditions in each state, and both state and sector water demand, supply, and market trends.

2.1. Arizona

Arizona encompasses a variety of landscapes, ranging from desert to mountain, within an arid to semi-arid climate. Average annual precipitation varies from around 40 inches in mountain areas in the east-central part of the state, down to approximately 3 inches in the southwest region, which is comprised of a hot desert landscape (with temperatures in the summertime between 105 and 115 °F) [14]. Responses to these challenges, though, have led to Arizona having one of the most progressive water management systems' in the southwest. Much of Arizona's water comes from the Colorado River, which meets approximately 32% of the state's surface water withdrawals. With the looming pressure surrounding an over-allocated Colorado River, Arizona must tackle issues of diverting water supplies into rural communities while managing its limited supply. Rural communities, in particular, are more significant in the context of Arizona's water supply issues due to inadequate groundwater and few surface water rights, high population growth rates, in combination with water supplies that often are vulnerable to drought, and limited hydrogeological information from these areas [15–18].

2.1.1. Water Supply and Demand

In 2017, the four primary sources of water in Arizona included groundwater (1.44 million acre-feet, MAF), Colorado River water (1.22 MAF), other in-state surface water supplies (0.84 MAF), and wastewater (0.23 MAF). Using the most recent available data in 2017, groundwater was the leading supplier to the agricultural sector (0.85 MAF) and the industrial sector (0.17 MAF), while the Colorado River was the main supplier to the municipal sector (0.55 MAF). Effluent supplies are allocated to municipal (0.11 MAF), industrial (0.09 MAF), and agricultural (0.03 MAF) sectors. As shown in Figure 2a, Arizona has increasingly been relying on water supplies from the Colorado River and local effluent since 1985, while local surface water supplies are declining.

Over 50% of Arizona's total supply of around 3.75 MAF is allocated to agriculture [19]. In addition to agricultural demand, there is a significant—second only to agriculture—demand by the municipal sector to keep pace with Arizona's growing population. Native American and industrial water demand round out the other two significant categories of demand, the latter of which is largely influenced by the US demand for copper, of which Arizona supplies 65%. Note that Native American water supply and demand in this article refers to Indian reserved water rights. Arizona has many Indian reservations, both on the Colorado River and in central Arizona, close to Phoenix and Tucson [20]. The mining industry, on average, uses about 96,200 acre-feet annually to run its operations and generate power for its plants.

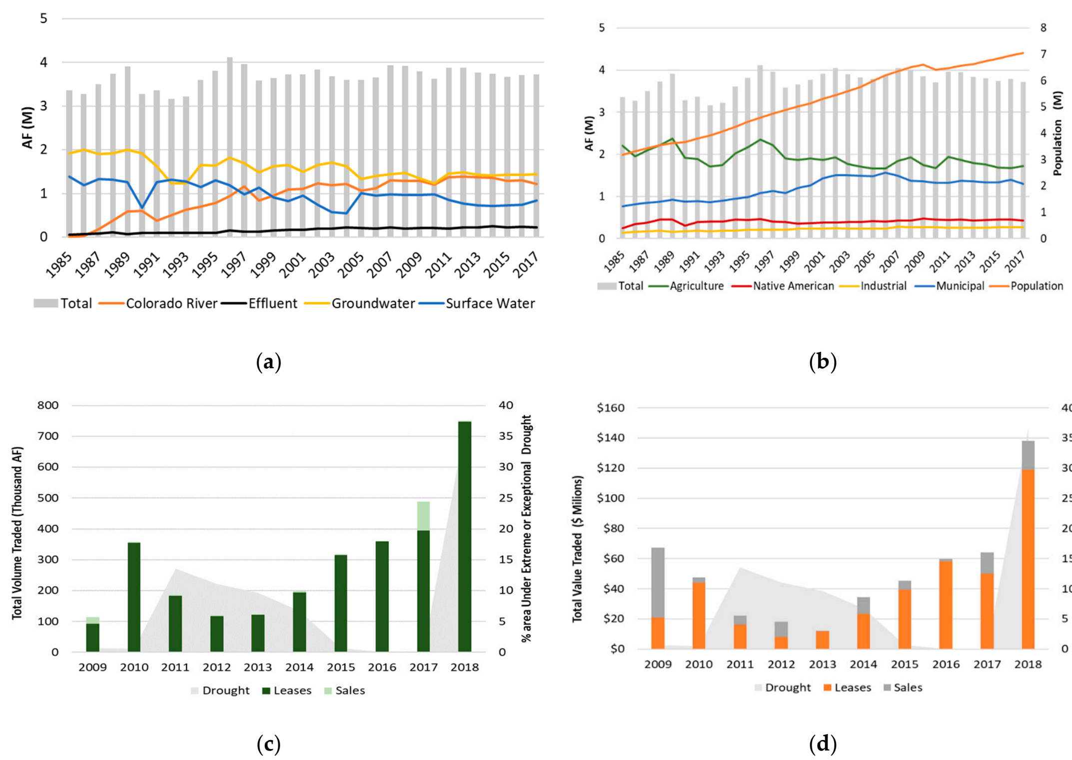


Figure 2. (**a**) Water supply by source, (**b**) water demand by sector, (**c**) total volume traded, and (**d**) total value traded in Arizona. Source: Authors calculations, Arizona Department of Water Resources (DWR), and WestWater Research. Drought data are from the US drought monitor [21]. All prices are in real 2009$ using the Consumer Price Index (CPI)—All Urban Consumers Average from the Bureau of Labor Statistics (BLS).

As mentioned above, demand for water in Arizona primarily comes from the agricultural and municipal sectors, followed by Native Americans and industry. As shown in Figure 2b, we see that while Arizona's population has grown by nearly 100% since 1985, overall water use has increased by only around 10%. Over this period, demand for water by the agricultural sector has been on a slight decline, while the municipal sector, which saw significant increases in water use due to population growth and development in the late 1980s through the early 2000s, has tapered off.

2.1.2. Water Trading

Arizona has an active water trading market. From 2009 to 2018, nearly 151,000 acre-feet (AF) of water was traded annually (Figure 2c), which comprises approximately 4% of its overall consumptive water use annually. There has been a near seven-fold increase in total volume traded since 2009, with a clear trend upwards since 2012. During the extreme or exceptional drought years of 2010 to 2015, traded volume was relatively low compared to 2018, which was also considered an exceptional drought year. In terms of types of trades, 92% of the water trades were in the form of leases, while only a small volume (~8%) was in the form of permanent sales. Noteworthy, in 2018, approximately 20% of the total water supplied was associated with some water trade.

Figure 2d juxtaposes the trade value (in 2009$) over the past ten years across Arizona with the percentage of Arizona under extreme or exceptional drought [21]. In 2018, the over 375,000 acre-feet of water traded through leases and sales had a total market value of $138 M (million) (in 2009$). Market activity has been increasing significantly since 2013, an attribute that may also be related to a healthier US economy, which experienced a significant downturn in 2008, beginning with the housing crises. While it seems apparent that the market is responding to the drought of 2018, both in terms of value and activity, this contrasts with the drought from 2011 to 2014 in which trading activity in the form of a lease or purchase prices did not seem to respond.

Columns 2–4 in Table 1 show the acre-foot price of water leased or sold during the last ten years as well as percentage area within the state under extreme or exceptional drought. As indicated, the price associated with permanently traded water was around $2046/AF, on average, whereas the price associated with a temporary sale registered at approximately $130/AF, on average; consequently, the lease price was about 6% of the sales price. Looking at the change in the three-year moving average over 2009–2018 indicates that the price per acre-foot traded through leases increased slightly by 1.40%.

Table 1. Leases and sales price United States Dollar/acre-feet (US$/AF) by year (2009–2018) and state.

	Arizona			California			Texas		
Year	**Leases**	**Sales**	**D3–D4 [1]**	**Leases**	**Sales**	**D3–D4[1]**	**Leases**	**Sales**	**D3–D4 [1]**
2009	228	2125	1	224	1544	2.08	96	4217	16
2010	125	807	1	197	2498	0.00	122	3293	1
2011	89	2252	14	183	5981	0.00	106	501	68
2012	69	3067	11	224	3692	0.34	115	3016	26
2013	99	1131	10	218	3797	6.64	112	4290	22
2014	121	2032	7	334	9230	75.37	186	1903	17
2015	126	1796	1	446	3700	70.19	159	793	5
2016	162	1294	0	381	4095	48.48	164	1354	0
2017	126	153	0	278	2707	1.84	163	1119	0
2018	159	5806	37	287	5442	2.35	167	3023	6
Average	130	2046	8	277	4268	21	139	2351	16

Notes: All prices are in real dollars in 2009 using the CPI—All Urban Consumers Average from the BLS [22]. [1] Average annual percentage area under extreme (D3) or exceptional drought (D4) [23].

2.2. California

Two characteristics that define California are climate variability within the state and the geographic mismatch between the sources of supply and the bulk of demand. That is, average annual precipitation varies from less than 5 inches in the arid to the semi-arid southern part of the state to more than 100 inches in the more mountainous northern parts [24]. This characteristic also leads to the challenge that over 1/3rd of its water supply comes from northern California, while the bulk of demand, from agriculture to the large urban centers in and around Los Angeles, is from the central and southern parts of the state. As such, water conveyance, storage, and transfer are very much ingrained into California's development path, factors that are critical to changing the spatial and temporal availability of water in California, and the ability of water trading to complement its water portfolio.

2.2.1. Water Supply and Demand

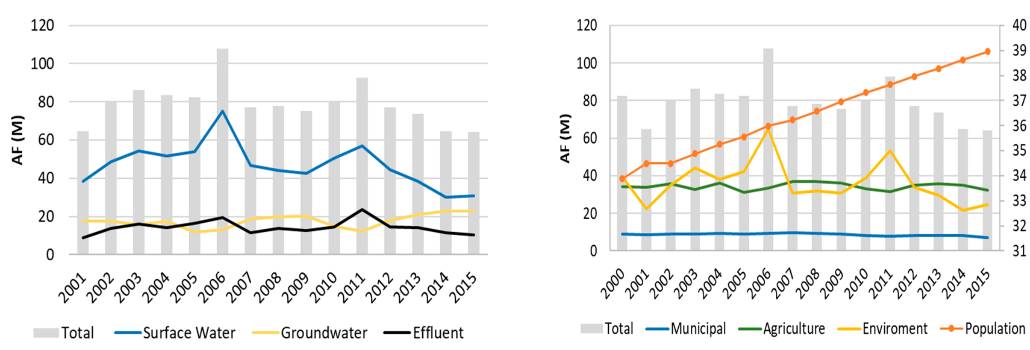
Based on data from 2001 to 2015, the three primary sources that comprise the nearly 61 MAF of water supply in California include surface water (60%), groundwater (22%), and wastewater (18%). Comparing 2015 to 2001, on average, surface water supplies decreased by 1%, groundwater supply increased by 2%, and treated wastewater supplies increased by 1% (Figure 3a). These estimates are largely influenced by the severe and extreme drought California experienced starting around 2013 that resulted in reduced surface flows and aquifer overdraft.

On the demand side, approximately 89% of California's water goes to environmental and agricultural usage and the rest to the urban sector. Environmental water use refers to water in rivers to protect "Wild and Scenic", instream flows to maintain habitat, water to manage wetlands, and water to maintain urban and agricultural water quality (i.e., Delta outflow) [25]. Figure 3b illustrates the trends in water demand by sector as well as population growth in California since the 2000s. Comparisons among sectors indicate that the average annual growth of water demand from 2000 to 2015 in the urban sector was slightly negative (−1%), as was the growth in the agricultural sector (−0.33%). On average, water allocated to the environment was down by approximately 2%. Interestingly, even though the California population grew significantly between 2001 and 2015, overall urban water use declined, primarily due to efficiency and conservation measures enacted by Californians, including during the drought in 2014 to 2016. Similarly, improvements in irrigation efficiency facilitated the downward trend in water use by the agricultural sector.

2.2.2. Water Trading

California's water markets are comprised of transferring rights either in the short-term (less than one year) or long-term (greater than one year). The majority of California's water rights are held by the farm sector, which has the majority of water sales primarily in California's San Joaquin Valley. More recently, lease activity has increased, dominating the market share in terms of traded volume and value. In terms of the average annual volume (Figure 3c), from 2009 to 2018, nearly 1.1 MAF of water was traded in the form of leases and slightly over 29,000 AF in the form of permanent sales. Given California's overall annual water allocation is around 61 MAF, water trades account for around 2% of the supply, having decreased slightly over the past decade.

Figure 3d illustrates how the total value of water trades have changed over the past ten years. As shown, during the height of the most recent drought, the value of sales soared up to nearly $800 million in 2015, dropping precipitously to nearly $300 million in 2018 after the drought subsided. In the past two years, the number of permanent sales decreased significantly, with nearly 79% of the trade value tied up in leases. In terms of water prices, columns 5–7 in Table 1 indicate that the price of an acre-foot of leased water reached its apex in 2015 during the worst period of the drought, which is also when the price of permanent water also reached its highest level (over double its ten-year average). In terms of prices, leases, on average, sold for around $277/AF, while permanent sales sold for around $4268/AF. As expected, prices tend to increase during periods of significant drought.



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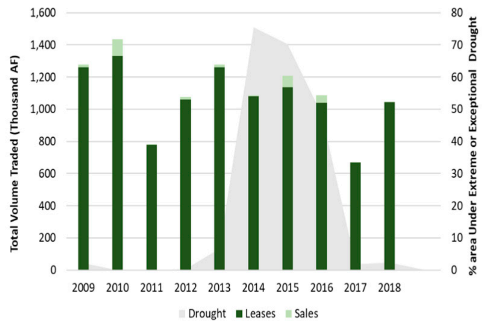

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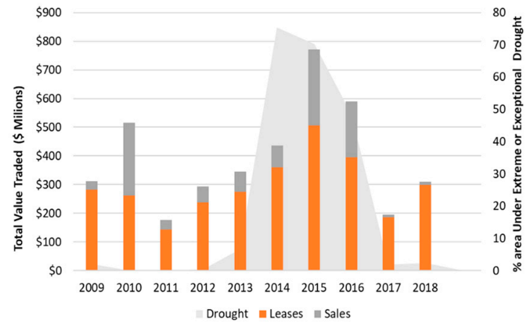


(**d**)

Figure 3. (**a**) Water supply by source, (**b**) water demand by sector, (**c**) total volume traded, and (**d**) total value traded in California. Source: Authors' calculations, California Water Plan updates [26], and WestWater Research. Drought data are from the US drought monitor [27]. All prices are in real 2009$ using the CPI—All Urban Consumers Average from the BLS.

2.3. Texas

Water laws and policies in Texas are continuously changing in order to accommodate the growing population and demands while adjusting to changing climate and drought. The state's primary abundance of resources, such as cattle, agriculture, and oil are dependent on the water supply in a state with significant climate variability. Precipitation varies from around 9 inches, on average, in the west and southern part of Texas to approximately 60 inches in the east and northern parts. The temperature varies between 16 °F and 50 °F (with an average of 32 °F across the state) in January to between 88 °F and 100 °F in July (with an average of 94 °F). While average statewide precipitation of around 27 inches may seem significant, the overall demand for water based on predicted population growth is projected to increase by up to 22% by 2060. This population growth, when coupled with climate change and other factors contributing to drought, including increased evaporation and ground absorption, presents significant challenges to Texas in its efforts to confront water scarcity. Challenges include an estimate water shortage of 8.9 MAF annually in 2070, caused by current supply allocation problems [28].

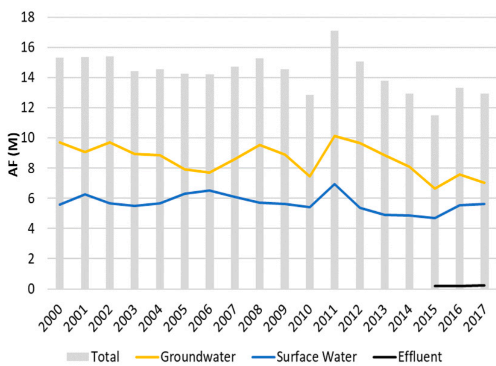
2.3.1. Water Supply and Demand

The water supply resources in Texas emanate primarily from two sources: groundwater and surface water [29]. As illustrated in Figure 4a, groundwater, which comprises approximately 54% of the state's overall supplies, has been decreasing over the past two decades, dropping from around 10 MAF to around 7.5 MAF. Surface water, which comprises nearly 43% of the state's overall supply, has experienced some variability over the past two decades but has generally remained slightly below 6 MAF. Recycling has contributed a minor amount to Texas's overall water supply portfolio. The overall decline in available water supplies in Texas nearly mirrors the decline in aquifer storage.

Similar to other states, the major diverter of water in Texas is agriculture, which uses approximately 60% of the state's overall supply, followed by the municipal sector, which uses approximately 1/3rd of the overall water. While municipal water demand has slightly increased since the 2000s, agricultural water use has declined somewhat significantly, from slightly less than 10 MAF in 2000 to slightly less than 8 MAF in 2017 for an approximate 20% reduction. Industrial use, approximately 1 MAF per year, has trended slightly downward as well. According to a water usage summary report for 2017 conducted by the Texas Water Development Board (TWDB) [29], municipal water is primarily sourced from surface waters, approximately 64%, while groundwater supplies municipalities with approximately 32% of its needs, with the remaining 4% coming from effluent (Figure 4b).

2.3.2. Water Trading

In Texas, groundwater trading is much more prominent compared to Arizona and California. For example, approximately 69% of the total value traded in Texas between 2010 and 2014 came from Edwards Aquifer, an active market for sales and leases of groundwater entitlements [30]. From 2009 to 2016, the volume of water traded in Texas increased annually up to nearly 240,000 AF, which is about 2.4 times the amount that was traded in 2009. For 2017 and 2018, there was a slight drop to approximately 200,000 AF annually. Given that there is approximately 13 MAF used annually in Texas, trading accounts for less than 2% of this usage. As Figure 4c shows, there was a spike in permanent sales during the height of the drought in 2011, but otherwise traded volumes mostly occurred through leases.



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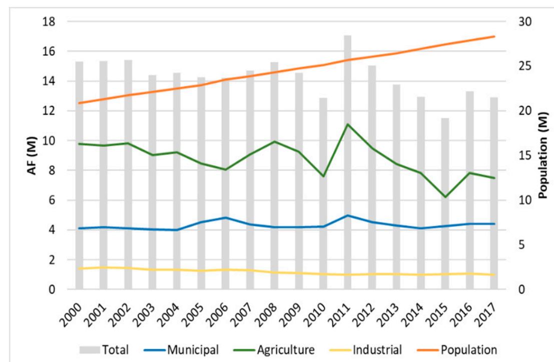

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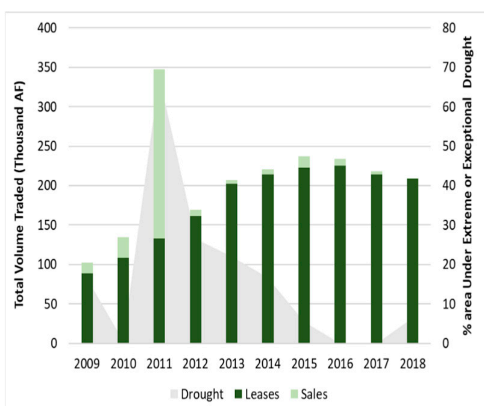

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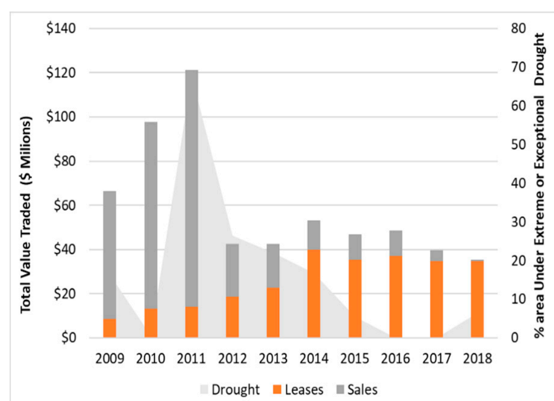


(**d**)

Figure 4. (**a**) Water supply by source, (**b**) water demand by sector, (**c**) total volume traded, and (**d**) total value traded in Texas. Source: Authors' calculations, Texas Department of Water Resources, and WestWater Research. Drought data are from the US drought monitor [31]. All prices are in real 2009$ using the CPI—All Urban Consumers Average from the BLS.

In terms of value, we see quite a different story. The years 2009 to 2011 saw the highest value in water trading over the past ten years, with 2011 reaching nearly $120 million in sales (primarily due to permanent water sales). The trading value decreased quite significantly from 2012 to 2018, with permanent sales decreasing significantly (Figure 4d). Interestingly, in considering columns 8–10 in Table 1, we see that while the price per unit of permanent water transfers and leases was highest in 2012 and 2013, the volume traded was low, as was the overall value, especially relative to 2011 which experienced significantly lower prices but higher volumes.

3. Discussion

In this section, we first provide a comparison between the three states in terms of water demand and supply by sector and source. We then provide a discussion of notable water market characteristics—both similarities and differences—across the three states. We conclude with a brief discussion on the importance of developing more transparent and efficient markets to facilitate the usefulness of this tool in helping states confront rising water scarcity.

As illustrated in Table 2, across all three states, the agricultural sector requires the highest volume of water, with it consuming 58% of the water in Texas, 51% in California, and 46% in Arizona. Note that while we use the term "consuming," a more accurate term would be "diverting" since a fraction of the water not transpired or evaporated often returns to the system [32]. However, while agriculture consumes the most water, its overall use has gone down over the past two to three decades, most notably in Arizona (~22%) and Texas (~12%). Improvements in irrigation efficiency are responsible for much of this decline. On the municipal side, demand is trending slightly up in Texas, is somewhat stable in Arizona, and trending slightly downward in California over the past two decades, with water efficiency measures again playing a significant role in counteracting significant population growth in all three states. As the agricultural and municipal sectors adopt more efficient water use behavior and technologies, demand hardening (i.e., as farmers/households become more efficient, it becomes more difficult to further reduce demand during a shortage or drought) will ensue thereby increasing the potential benefits of water markets as a tool to address increased future water scarcity.

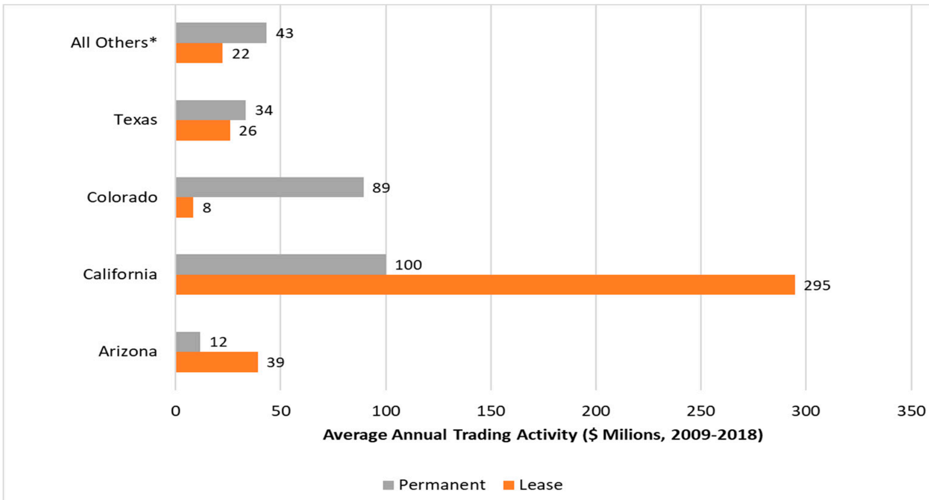
Table 2. Comparison of demand share for each sector and supply share from each source in percentage terms across the three states.

	Demand			Supply		
	Agriculture	Municipal	Industrial	Surface	Groundwater	Effluent
Arizona [1]	46.28	35.02	7.26	55.22 [2]	38.73	6.05
California [3]	50.55	10.92	-	47.97	35.78	16.25
Texas [1]	58.01	34.22	7.77	39.01	54.44	1.58

[1] Using the most recent available data in 2017. Arizona also includes demand by Native Americans (11.44%). [2] Sum of surface water share (22.51%) and water from the Colorado River (32.71%). [3] Using the most recent data in 2015. Demand-side in California also includes demand for the environment (38.53%).

In terms of source supply, surface water is the primary provider in Arizona (55%) and California (48%), but in Texas, groundwater is the primary source (54%). Unlike the role the Colorado River played for Arizona during the 1980s and 1990s, surface water sources are unlikely to provide any new volumes to these states moving forward, and groundwater supplies are in decline in all three states. Furthermore, with the enactment of new groundwater sustainability legislation in California in 2014, groundwater pumping is likely to decrease even more than it currently is. As such, water markets again can play an increasingly important role in responding to an increased level of water scarcity due to declining or less reliable water supplies in each state. Of course, effluent in the form of treated municipal wastewater may help assuage such scarcity in local markets, as is taking place in California, yet such efforts require significant infrastructure investments, along with other costs due to technological constraints [33,34], to play a more significant role.

Since 2009, our data suggest that water markets in all three states are functioning to help address water scarcity, although there is likely plenty of opportunities for improvements and growth. While California has by far the highest amount of water trading—both in terms of volume and value—Arizona's market transactions comprise approximately 4% of the overall water used in the state, double the approximate 2% that defines both California and Texas (Figure 5a,b). However, even at 2%, approximately $3.9 billion of water was exchanged in California over the past decade. Most of the activity and value is derived through temporary leases rather than permanent sales, on average. Exceptions to this include significant increases in the price of permanent water sales in California during its most recent drought, although trading activity did not change significantly, and permanent sales and the value of those sales in Texas during the drought in 2010 and 2011. Overall trading activity, though, has been on the rise in Arizona, somewhat stable in Texas, and quite variable in California over the past decade, highlighting the importance of the heterogeneous market, environmental, and institutional conditions across states, conditions that determine market performance.



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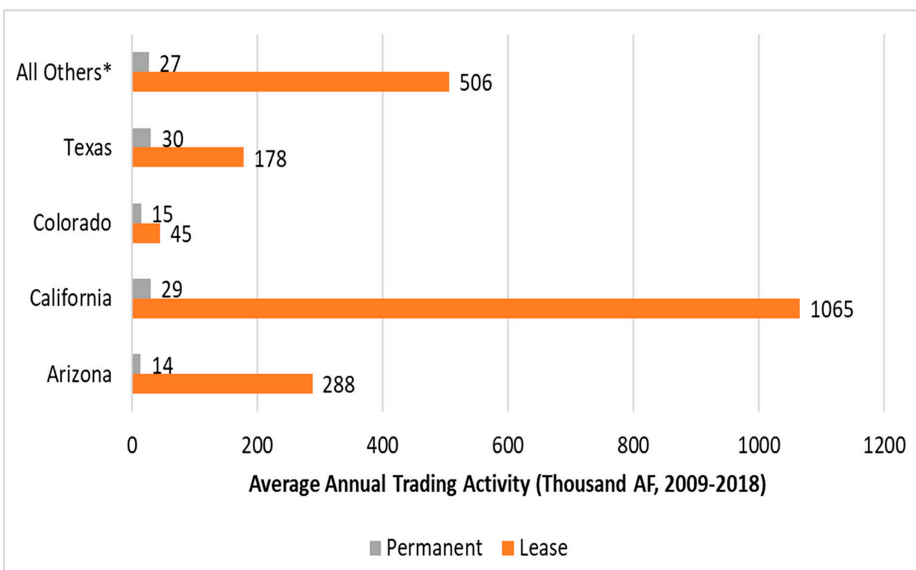

(**b**)

Figure 5. Average annual trading activity by state and trade type (2009–2018). (**a**) Average annual trading activity ($ Milions, 2009-2018); (**b**) Average annual trading activity (Thousand AF, 2009–2019); Source: Authors' calculations and WestWater Research. Notes: * All others include other western states, including Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

In terms of who is selling and/or leasing the water, Figure 6 provides a comparison of the sources of supply and demand for water trades and transfers in California (Figure 6a,b), Texas (Figure 6c,d), and the Western US (Figure 6e,f) across the major sectors. In California, agricultural water rights holders provided most of the water to the market over the past ten years (Figure 6a). Approximately 76% of the total volume transacted over this timeframe originated from the agricultural sector, followed by the municipal sector (19%). Agriculture's market share as a supplier has increased over the last ten years by around 2%, although it should be recalled that overall traded volumes have gone down slightly.

Figure 6. Summary of water trade activity by sector in California, Texas, and Western US (2009–2018). (**a**) Volume sold by sector (1000 AF) in California; (**b**) volume purchased by sector (1000 AF) in California; (**c**) volume sold by sector (1000 AF) in Texas; (**d**) volume purchased by sector (1000 AF) in Texas; (**e**) Volume sold by sector (1000 AF) in the Western US; (**f**) volume purchased by sector (1000 AF) in the Western US. Source: Authors' calculations and WestWater Research. Note: The western states include Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming. Note that we did not have state-level data on Arizona.

In terms of major buyers in California, the municipal sector purchased/leased the most water, on average, over the past ten years, followed by agriculture and then the environment (Figure 6b). While the municipal sector had a somewhat stable level of purchases from 2009 to 2016 (on average they comprise approximately 55% of the total market share), there was a slight decrease in 2017 and 2018 potentially due to (i) lower incentives to trade due to drought subsiding in 2017, and (ii) increased acreage of higher revenue perennial (e.g., tree and orchard) plantings whose significant capital investments increase the opportunity cost of fallowing land. While the agricultural sector has comprised approximately 25% of the market purchases over the past ten years, there was a noticeable and significant increase in the year 2018, as the drought eased and groundwater regulations were tightened under the recently passed Sustainable Groundwater Management Act of 2014. The environment, meanwhile, also plays a significant role in California water markets, comprising approximately 18% of total transactions by volume traded.

In Texas, similar to California, agricultural water rights holders provided most of the water to the market over the past ten years (Figure 6c). Approximately 89% of the total volume transacted over this timeframe originated from the agricultural sector, followed by the industrial sector (8%). In terms of major buyers, the municipal sector purchased/leased the most water, on average, over the past ten years (84%), followed by agriculture (13%) (Figure 6d).

The Western States in this figure include Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming. Not surprisingly, water is sourced primarily from the agriculture sector. Over the past ten years, approximately 73% of the total volume transacted in the Western US originated from the agricultural sector (Figure 6e). The municipal sector is the second-largest supplier, comprising approximately 23% of the overall sourced supply in the Western US. The industrial sector is responsible for approximately 4% of the sourced water. Note that while in Texas the agricultural sector is responsible for typically around 90–95% of the overall water sales/leases in the state, in absolute terms it is relatively minor compared to California, where the municipal sector is responsible for around the same volume of water sales/leases compared with the agricultural sector in Texas.

On the demand side, participation remains relatively stable, with municipalities continuing to be the largest buyer with 46% of total market share over the past ten years (Figure 6f), although it plays a much more significant role in percentage terms in California and Texas (Figure 6b,d). Environmental buyers, usually comprised of private entities, conservation groups, but also state and federal agencies in efforts to maintain or meet obligations associated with environmental quality, instream-flows, and wildlife habitat [35,36], also play a significant role in western water markets—mostly arising in California—comprising approximately 26% of total transactions by volume traded, followed by agricultural (16%) and industrial (12%) sectors. As noted in Szeptycki, Forgie, Hook, Lorick, and Womble [35], there is significant variation in how water transfers for the environment are regulated across western states, and these differences can significantly limit the type and scope of transfer. While all three states we considered have opportunities to reduce obstacles that are hindering environmental transfers, particularly the administrative burden buyers and sellers confront exercising such transactions, California and Texas are noted to confront fewer of the legal challenges than Arizona in terms of the scope, certainty, and permissibility of environmental water transfers.

In considering the year-to-year variation, we see that there were some significant volumes purchased by the agricultural sector in Texas during the drought years between 2011 and 2014, but on average, over 90% of the volume bought was by the municipal sector. While purchases of permanent water or leases by industrial users do happen, the percentage of the overall volume is quite small. Finally, and what perhaps California's experience in 2018 forebodes for the rest of the West, water supply firming for agriculture associated with the increase in permanent cropping, especially in California, has prompted agriculture to participate in the demand side in higher proportions. As shown in Figure 6b, California's agriculture demand-side market participation has increased by 6% and 15% by value and volume traded, respectively, over the last ten years.

4. Concluding Remarks

Water markets at their core, as with any market, are intended to help reduce the impacts of scarcity by facilitating the transfer of water to its highest-valued uses. What this review has shown in evaluating three western states, is that water scarcity is likely to increase significantly moving forward, primarily due to population growth and the added water demand associated with such growth. Of course, improvements in water use efficiency, both in the agricultural and municipal sectors, have helped society respond to date (indeed, overall water use in California has decreased in the agricultural and municipal sectors). However, demand will harden, and thus such efficiency gains will be harder to come by, resulting in water demand rising with population growth. Scarcity will also heighten due to lower and/or more variable supplies coupled with increased regulation surrounding groundwater pumping and use. These conditions, increasing demand coupled with stagnating or declining and more variable supplies, which seem to characterize each of the three states we examined, suggest an increasingly important role for water markets.

Our analysis has also shown how water markets have played an essential role in water reallocation throughout the Western US. In the recent data we analyzed here, most of the transfers are associated with leases as opposed to permanent water sales. Nevertheless, the overall amount of water that is transferred is small relative to the total water used, between 2% and 4%. This suggests that plenty of opportunities exist for the market to expand, which will require attention from market developers, regulators, and stakeholder input. For instance, during California's most recent drought, trading activity did not seem to respond in any appreciable manner, yet the price of both leases and permanent sales rose significantly (e.g., the price of permanent sales rose from $3797 per acre-foot in 2013 to over $9230 per acre-foot in 2014, yet actual trading activity in the state declined). There are multiple factors —that differ across states— that likely contribute to inhibiting the market from achieving its full potential, including high transaction costs associated with often multiple layers of approval, a lack of transparency, poor and incomplete information flows, along with conveyance and infrastructure limitations.. So while markets have been serving as a means to help change the temporal and spatial distribution of water allocations to their higher-valued uses, significant opportunities exist to both better understand the drivers that influence water market performance and expand the market through the creation of a more transparent, flexible, and user-friendly system.

While water transfers can lead to an overall increase in the net benefits water use from a social perspective, concerns of third-party effects and externalities on other users can create challenges and limit the full functioning of a water market [37]. For instance, if water transferred out of a region results in impacts on local employment and income, such third-party effects can lead to transfers being politically unattractive (and lead to limits on transfers). Of course, if the transfers occur within a particular region, then such third-party effects will be minimal. In response to these third party effects, governments often respond by limiting out-of-region transfers via mandates or fees. Alternatively, if transfers incentivize greater groundwater pumping in agricultural-based communities, this may have impacts on the availability of municipal water for those communities dependent on groundwater for health and hygiene [38]. Careful hydrological monitoring, or employment of a general water accounting framework, can help policy makers better understand the potential implications of transfers on groundwater levels and other users.

Note that the "water market" we describe in this paper is comprised of significantly different water trading and transfer schemes both within and across the three states analyzed. While our focus was on traded water entitlements, surface and groundwater rights are the most commonly traded asset class within the Western US market. However, there are other types of ownership interests in water that are also traded. For example, in Arizona and California, groundwater banking is also traded. Entitlement to use treated wastewater is traded in Arizona, California, and Colorado. Entitlement to store water for use in a surface reservoir, known as "Storage Water Rights", is observed in California and Colorado [39]. As such, there are many opportunities and forms of markets that can be used to help the Western US cope with rising water scarcity, but it requires significant planning, cooperation, collaboration, and evaluation by policymakers with stakeholders to facilitate the development and implementation of such markets.

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