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Pricing Options on Water in Texas

Quinn McColly*¹, Robert Mace², Philippe Tissot³, David Yoskowitz¹

Abstract: Water scarcity is a growing concern globally, in the United States, and in Texas. As Texans plan to meet this challenge, it is important to introduce new tools to help mitigate water shortages. Market mechanisms have historically provided methods to increase the allocative efficiency of scarce resources, though applying these mechanisms to facilitate water trading is not widespread. Cash markets have successfully been implemented under the Watermaster in the Rio Grande Valley, but the use of water markets is not prevalent throughout Texas. In addition to cash transactions for water, the 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. This paper establishes a method to price water options on agricultural water and applies that method to a cash crop in Texas. Market mechanisms will not be a panacea for water woes, but they are an important and effective tool for helping planners deal with increasing demand amid uncertain supplies.

Keywords: water options, water trading, water markets, water pricing

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Terms used in paper

Acronym/Initialism	Descriptive Name
ac-ft	acre-feet
BSM	Black-Scholes-Merton model
EAA	Edwards Aquifer Authority
FR	Fruitful Rim
HEFR	Hydrology-Based Environmental Flow Regime
PG	Prairie Gateway
RGV	Rio Grande Valley
SAC	Science Advisory Committee for Environmental Flows
SB	Senate Bill
TCEQ	Texas Commission on Environmental Quality
USDA	U.S. Department of Agriculture
VISPO	Voluntary Irrigation Suspension Program Option

INTRODUCTION

Purpose

Noted geographer John Wesley Powell used the 100th Meridian as the dividing line between the wet and arid regions of the country. This line runs through Central Texas; roughly half of the state is positioned where it is wet, the other half where it is arid (Powell 1879). More recently, it has been shown that the dividing line has shifted to the east (Figure 1) and now runs down the 98th Meridian, which means the state is getting drier (Seager et al. 2018). Climate change is altering patterns in precipitation, which makes future planning—especially around water—challenging given this increased variability (Chang et al. 2016). Even if the dry line is shifting slowly, much of Texas is on the arid side. Population is also projected to increase in Texas and will put upward pressure on water demands (Dore 2005). The Texas Water Development Board estimates that if plans are not implemented to secure more water and there is a drought of record in the year 2070, a third of municipalities will only have half of the water they need to serve their citizens, much less the environment (TWDB 2017). Adaptable solutions are needed because half the state is historically dry, more of the state may be getting drier, and projections predict increased scarcity resulting from a variety of factors.

Planning to meet water needs has two temporal components: what is needed today and what will be needed in the future. This work is focused on the latter and seeks to illustrate how future needs can be addressed using the concepts of

financial derivatives to build an option market for water. An option allows a buyer to purchase a contract for a cash payment (premium) that entitles them to make a future purchase of a specified amount of something at a specified price within an agreed-upon timeline at a specific location. For example, consider a t-shirt manufacturer who buys cotton for production and the company is profitable when they buy cotton for \$0.75 per pound or less. Today, the price of cotton is \$0.70 per pound and the t-shirt manufacturer is concerned about rising prices. The manufacturer could simply buy cotton today, but this presents three main problems: the manufacturer must store it, they may not get shirt orders to require the cotton, and the price of cotton could go down, putting the t-shirt maker at a disadvantage.

Here is where the option is useful. When a company buys options, they are securing the right to an amount of cotton at a price by a specific date. This privilege does cost the manufacturer some money (called the premium) but allows the t-shirt maker to mitigate their risk if prices climb. Options increase flexibility in planning for future needs as they allow the buyer to adapt to changing conditions affecting both supply and demand and allow the buyer to mitigate some of the risk associated with future uncertainty (Colby et al. 2014; Hearne and Donoso 2014). While most options in the United States are built with 3-month lifespans—particularly those widely traded on established exchanges such as the Chicago Board of Options Exchange—water contracts in this work will be considered using longer horizons (5–10 years).



Figure 1. The "dry line" in the United States has shifted approximately 2 degrees (from the blue line to the yellow line) to the east over the past 100 years, this means more of Texas is receiving less rain. Adapted from Seager et al. (2018).

The initial motivation for this research stemmed from trying to find a tool to help interested parties obtain water for the environment. Environmental flows of water into bays and estuaries provide critical ecological functions to the system, and those flows have been greatly diminished by human extraction and impoundment upstream (Meijer and Van Beek 2011; Montagna et al. 2009; Montagna et al. 2018a). In naturally occurring low flow years, human needs persist. During these times, it would be beneficial if environmental managers had access to

water that could be left in stream to flow to the coast. Obtaining additional flows in times of drought could significantly aid in protecting the water quality at the head of the bay in low flow years. This would give estuarine-dependent fauna a refuge from the low flow conditions and shorten recovery times. This strategic deployment of freshwater has been referred to as "focused flows" (Montagna et al. in press).

Protecting and securing environmental water has proven to be difficult in Texas as regulations regarding environmental

considerations only pertain to new permits, and spot market transactions are challenging to execute in markets that do not have well established institutional support ([Meadows Center: Texas environmental flows initiative 2019](#); [White et al. 2017](#); [Yoskowitz 1999](#)). Derivatives, options in particular, are a viable solution to deliver the kind of situational adaptivity required to meet demands for reliable water. The applicability and utility of these water contracts goes beyond environmental uses. People from municipalities and industry, farmers, and anyone exposed to the risks associated with the uncertain reliability of water supplies can benefit from the use of water contracts.

Option pricing efforts to date

Efforts have been made to price water options in foreign and domestic markets ([Cui and Schreider 2009](#); [Villinski 2003](#); [Williamson et al. 2008](#)). Although much of this work has been done using traditionally accepted pricing mechanisms, novel work has been conducted to price options based on the cost of the next least expensive alternative, with the difference representing price ([Michelsen and Young 1993](#)). While the previous work does advance the understanding of the price of water as an option, it does not calculate a price for the premium. In other words, the method offers no way to calculate the cash price to be paid to the seller for the assumed risk of the option being exercised (known as being “called”). There have been other pricing efforts like Michelsen and Young’s based on scarcity. This scarcity pricing can be tied to the cost of the alternative (à la Michelsen), based on changes in operating costs, or more dynamic pricing that sets a schedule based on readings of a chosen scarcity metric like dam levels ([Frontier Economics 2011](#)). These efforts have improved the understanding of how water contracts can be constructed but have not resulted in definitive pricing methodology. However, efforts have been made to construct these contracts. Facing drought in the 1990s, California took steps to enhance allocative strategies with the establishment of a Water Bank and water supply options ([Jercich 1997](#)). This fledgling market was in the process of issuing options, but market activity was curtailed when rains came and ended the drought.

One issue with pricing water options in Texas and other locations throughout the United States is the limited availability of cash market pricing on which to base options values, particularly if the method uses traditional pricing mechanisms. The most popular pricing model for options is the Black-Scholes-Merton (BSM) model, which is the foundation for derivatives theory ([Glantz and Kissell 2013](#)). To address challenges created by data deficiency, previous work has been conducted in California to build options based on 72 years of simulated price data extrapolated from an actual 18-month price history ([Williams 2007](#)). Simulating price data can be difficult, as simulat-

ed data can only act within the bounds of the sample it is based on, and market price and the variables that drive them often set new highs and new lows, and act in new ways.

The Rio Grande Valley (RGV) has the most active spot (cash) market in Texas. It was in the RGV that Villinski ([2003](#)) tried to use traditional option pricing mechanisms (BSM) but found markets to be too thin to yield reliable prices using these methods. The RGV does offer a natural water delivery system via the Rio Grande River and a Watermaster system conducive to trade, so this region may still be a good candidate for trading options in the future. There are four Watermaster areas in the state—the Brazos, Concho, Rio Grande, and South Texas (Figure 2)—and the ability to facilitate trading in the different Watermaster areas varies. For a more in-depth discussion of water rights in Texas and the role of the Watermaster, see *The Case for a Texas Water Market* ([White et al. 2017](#)). Institutional characteristics for trading surface water efficiently across Texas is not consistent and lacking in many cases; for example, the junior rights provision is a significant barrier to trade ([White et al. 2017](#)). In economic terms, efficiency is the idea that goods are allocated to their most valuable uses, and waste is reduced as much as possible.

There are examples of options used for environmental water in Texas. The Edwards Aquifer Habitat Conservation Plan offers options styled programs available to irrigation permit holders ([Patoski n.d.](#)). One is the Voluntary Irrigation Suspension Program Option (VISPO), which pays enrolled rights holders on an annual basis for participating in the program and makes an additional payment in years the triggering event occurs. This water is not called at the discretion of the buyer but happens automatically if a triggering event takes place. The trigger is the water level of the J-17 Index Well located at the base of the water tower near the national cemetery at Fort Sam Houston in San Antonio. If the water level is at or below 635 feet on the October 1 of each year, the participants suspend use of their water for the following year ([Patoski n.d.](#)). In short, VISPO is designed to leave groundwater in the system when levels are low. The Edwards Aquifer, located in the southern half of central Texas, is comprised of a contributing zone, a recharge zone, and an artesian zone (Figure 3).

The Edwards Aquifer is managed by the Edwards Aquifer Authority (EAA), which was created in 1993 by the Texas Legislature in response to legal battles of spring flow levels and endangered species ([Patoski n.d.](#)). There are many important aspects of the creation, implementation, and growth of the EAA, but regarding VISPO, there is one administrative feature regarding water rights that is particularly important. When the EAA allocated water rights, it provided two acre-feet (ac-ft) for every acre of irrigated land. One of these ac-ft can be traded away at the farmers’ discretion, even if this involves changing the use of the water. In this way, irrigators can enter the for-



Figure 2. Texas Watermaster Areas, tceq.texas.gov.

bearance program without having to file a change-of-use application—as they would in the case of surface water—with the Texas Commission on Environmental Quality (TCEQ), who administers water rights in the state.

This change-of-use component” is important for burgeoning water markets (spot or option), as the more regulatory hurdles there are, there are often increased uncertainty and administrative barriers to entry. If a sale, lease, or other transfer of a surface-water right from one entity to another involves a change in the use of the water allocated by that permit, then an application must be filed with TCEQ (Dowell 2013). It is important to note that VISPO is designed to option water from irrigators accessing groundwater. In the case of the Edwards Aquifer, there is some crossover because the groundwater does feed the Comal and San Marcos springs, thus becoming surface water. While our work is concerned with developing water markets for surface water, the pricing of water by the EAA is used for comparison due to the limited availability of transactional data surrounding surface water outside of the RGV.

METHODS

Study site and approach

The approach to building a long-term water option in Texas is a synthesis of a novel pricing mechanism for water options combined with elements commonly found in derivatives. This methodology can be applied anywhere water is traded, but in this case, it was applied to Texas. While Texas may be too large to price an option that can be used statewide, the method described here is best suited for a basin level approach. Regardless of pricing difficulties across regional geographies, if the water is to be delivered, the limiting factor will likely be conveyance rather than price. There are two components that comprise an options contract: the elements that make it a contract and the elements that define it as an option. To be considered a contract in general, the agreement must have mutual assent, offer and acceptance, adequate consideration, capacity, and legality (Legal Information Institute 2019).



Figure 3. Edwards Aquifer contributing zone, recharge zone, and artesian zone. From the Edwards Aquifer Recovery Implementation Program.

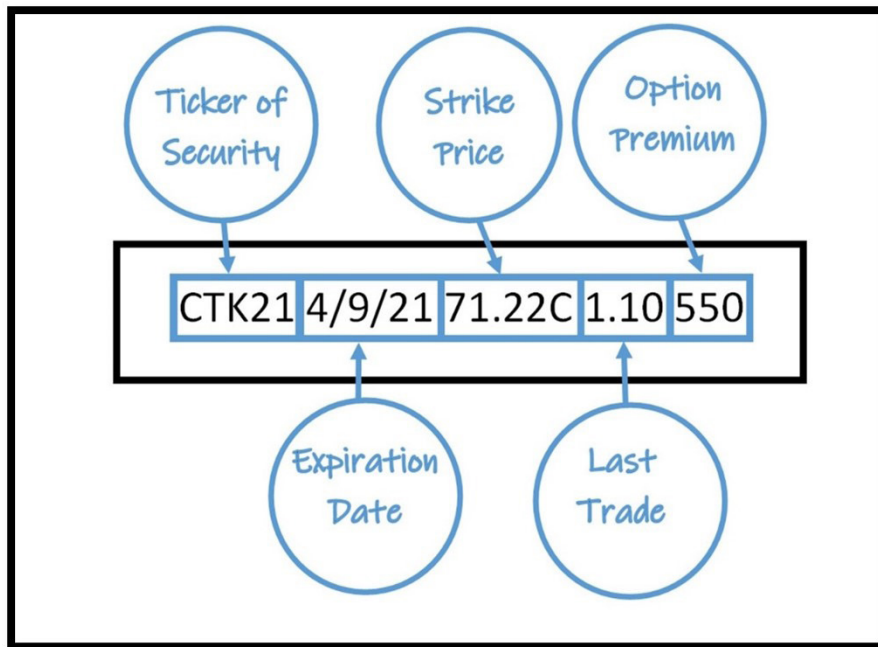


Figure 4. Example of an option description with labels.

To make a contract an option, it needs to be an arrangement where the holder (who bought the contract for consideration) can buy or sell an amount of an underlying asset during a specified time at a specified price ([Windcli et al. 2001](#)). In the case of a water option, the buyer of an option would be buying the right to take delivery of a specific amount of water from the seller anytime between the time of purchase of the option and an expiration date, with payment for the water due when exercised. Much of the important information regarding an option contract offered for sale is found in its listing (Figure 4).

The ticker symbol is the asset the option is based on; for CTK21, the CT is cotton, the K represents the month code (May), and the 21 is the year 2021 (Figure 4). The expiration date is the date by which the option must be exercised, or it expires worthless, and the strike price is the price at which the asset can be optioned, with the C next to it indicating it is a call (the right to buy). The last trade is the last transaction price as expressed in terms of option points (here one option point equals \$500), which translates to \$550 in option premium the buyer pays the seller for the contract. There is no mention of contract size, as by definition cotton contracts represent 50,000 pounds (approximately 100 bales), for example. In the United States, one stock option is generally worth 100 shares of common stock. The expiration date indicates the date when the option contract is no longer valid. The strike price is the price per share (or by volume in commodities, i.e., one cotton contract represents 50,000 pounds, about 100 bales) at which the option may be exercised, and the option price is how much the option contract costs initially. This work takes the common elements of an option contract and adjusts their application so that they may be applied to water; call options are constructed by using standard elements in an options contract and combining them with an approach to pricing water using opportunity cost.

WATER OPTION SPECIFICATIONS

Contract size

The amount of water that an option contract represents can be anything the buyer and seller agree on, but for ease of standardization a common volume is useful. If one contract equals one ac-ft, many contracts would have to be executed to transact meaningful quantities of water. If contracts are set at 100 ac-ft, it would be onerous to create one-off contracts for sizes under that. For utility, one contract might represent 10 ac-ft to accommodate the sub-100 acre-foot market, another standard contract could be set to 100 ac-ft, and a 1000 ac-ft contract would facilitate the execution of larger transactions. Again, these volumes can be set to anything, but there are benefits of standardization in the marketplace. By standardizing contracts,

market efficiency is increased, legal fees are lowered, product knowledge is simplified, and competition is encouraged by making it easy to compare terms ([Patterson 2013](#)).

Prices: Options and water

Price will be a critical component driving the success or failure of water option contracts. The sale of the permanent water right is not being considered here, only the use of the water allocated to that right in a given year. These would be considered cash or spot transactions if they occur at the time the trade is consummated. They can also be referred to as short-term leases because when an individual sells their water in a given year, they are effectively leasing out the water right ([Brown 2006](#)). This distinction is important, because when aggregating data for cash transactions, some transactions may be recorded as short-term leases but are effectively cash transactions.

An option for surface water has two payments: one for the option and one for the water itself. This arrangement is akin to the composition of commonly traded options for stocks and commodities: there is the premium (the payment for the option) and the cost to pay for the underlying asset when called (at the strike price). The payment for the water would be constructed first, then the payment for the option would be produced as a function of that price. This method may be useful to price water diverted from any use, but in this case the water being priced would have been used for irrigation as outlined in a permit.

As spot markets develop, it may be possible to use modeling techniques and volatility calculations to price U.S. water options. However, these techniques depend on markets with continuous trading that are operating efficiently. Until there are more robust spot markets in the United States, these methods may not work reliably, considering the BSM model of options pricing uses the cash price as an input ([Black and Scholes 1973](#)). Existing water transactions can provide the range of current and historical prices, but this range is so great, and the geographic variability so high, that historical pricing information will be of limited utility to formulate an option pricing tool that can be broadly applied. While the pricing information may help inform a localized market, the following discussion of price history will illustrate the breadth of range and variation.

In the United States there are often price differences between geographies and price disparities between user groups. The general trend is that agricultural to urban trades are priced higher than those between agricultural interests ([Brewer et al. 2008](#)). Similarly, in the RGV, mining and oil and gas interests paid more for their water than the agricultural interests charged each other ([Yoskowitz 1999](#)). These price differences can be significant and persist over long timeframes (Table 1).

Table 1. Price differences between agricultural and urban interests from 1987 to 2005, compiled from the Water Strategist for Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Wyoming, and Washington, in price per acre foot ([Brewer et al. 2008](#)).

	Ag-to-Urban Lease	Ag-to-Ag Lease	Ag-to-Urban Sales	Ag-to-Ag Sales
Mean price	\$114	\$29	\$4,366	\$1,747
Median price	\$40	\$10	\$2,643	\$1,235
# of observations	189	178	1,013	169

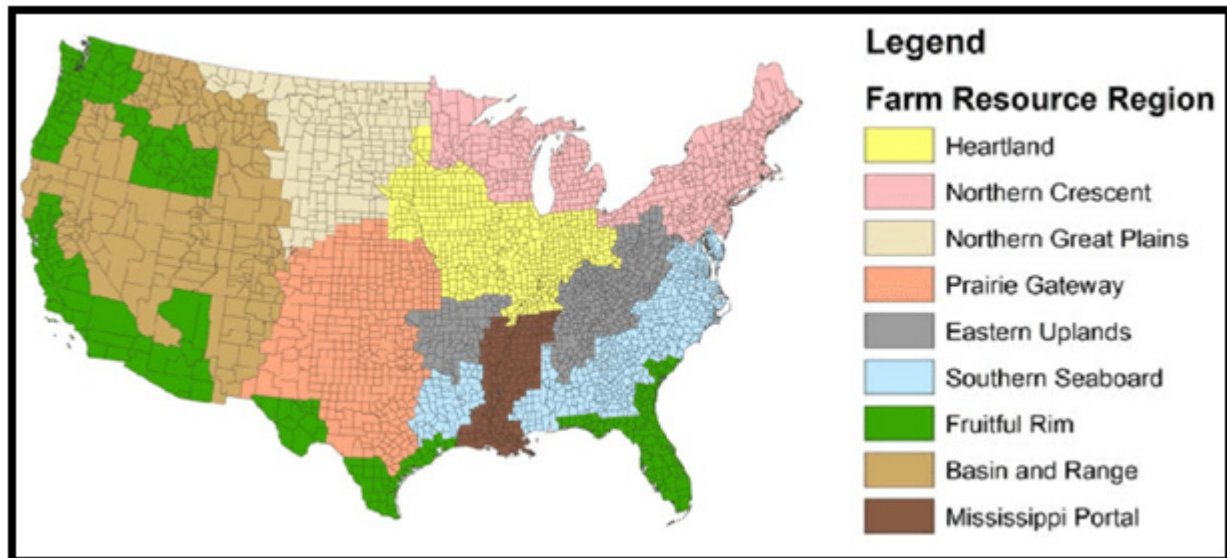


Figure 5. Farm Resource Regions defined by USDA in 2000 to compartmentalize farming specialization by region ([West et al. 2011](#)).

Prices not only differ when user groups are compared but across different geographies as well. For example, in Southern California's Imperial Irrigation District in 2001, farmers were paying \$13.50 per ac-ft, while a real estate developer near the South Rim of Grand Canyon National Park was willing to pay \$20,000 per ac-ft for water from the Colorado River ([Brewer et al. 2008](#)). With these regional and user anomalies, it will be very difficult to create an option contract that can accommodate all situations. The method for valuation may be transferable, but the resulting prices may deter transactions in some locations and market participants can expect price differences across geographies.

However, the reason for the price disparities may illuminate how to construct an option. Price disparities exist as an expression of the sellers' understanding that water can be transferred to a higher value use and their desire to be compensated for it (Table 1). It is unlikely that potential sellers will be willing to lose money in a transaction with a lower-value user, but they

might be willing to trade if they are paid what they would have made had they kept it and used it themselves, with the knowledge that the resulting use equates to equal or lesser economic value. For example, a farmer would have used that water as an input for crop production and, given the right conditions, would have earned a profit from producing and selling the crop. If farmers can be compensated for at least the amount of profit foregone, the gate may be opened for an opportunity for water to flow to a use with a higher ecological value, and there is evidence that buyers will participate ([Yoskowitz and Montagna 2009](#)).

The approach used here to price options finds the monetary value of what the user is sacrificing (the opportunity cost) by leasing out their water for environmental or other purposes. This valuation method has been explored in the Pacific Northwest to boost streamflow to sustain native fish by having farmers decrease their level of irrigation ([Jaeger and Mikesell 2002](#)). To find pricing tools, water sales and leases were examined

Table 2. Cost and return data for the 2018 cotton crop in the Prairie Gateway (PG) and Fruitful Rim (FR) regions, excluding government payments; all numbers are U.S. dollars per acre unless otherwise stated ([Commodity Costs and Returns 1997–2020](#)).

2018 cost/return (in U.S. dollars unless stated otherwise)	FR	PG
<i>Gross value of production</i>		
Primary product cotton lint	\$732.60	\$313.17
Secondary product cottonseed	131.67	48.51
Total gross value of production	864.27	361.68
<i>Operating costs</i>		
Seed	81.70	47.61
Fertilizer	78.27	20.47
Chemicals	94.00	34.83
Custom services	31.18	8.99
Fuel, lube, and electricity	80.33	42.98
Repairs	67.49	43.44
Ginning	150.19	56.14
Purchased irrigation water	35.97	0.02
Interest on operating inputs	6.47	2.66
Total operating costs	625.60	257.14
<i>Allocated overhead</i>		
Hired labor	40.66	13.80
Opportunity cost of unpaid labor	33.03	49.46
Capital recovery of machinery and equipment	207.02	130.33
Opportunity cost of land	157.14	40.89
Taxes and insurance	15.30	10.21
General farm overhead	33.72	11.24
Total allocated overhead	486.87	255.93
<i>Costs listed</i>		
Total costs listed	1112.47	513.07
<i>Net</i>		
Value of production (less total costs listed)	-248.20	-151.39
Value of production (less operating costs)	238.67	104.54
<i>Supporting Information</i>		
Yield (pounds per planted acre)	740	429
Price (dollars per pound)	0.99	0.73
Cottonseed yield (pounds per planted acre)	1197	693
Cottonseed price (dollars per pound)	0.11	0.07
Enterprise size (planted acres)	370	931
<i>Production practices</i>		
Dryland (percent of acres)	46%	72%
Irrigated (percent of acres)	54%	28%

Table 3. Components of allocated overhead in farm operations, if they will be included in adjusting water payments, and the reason.

Allocated overhead	Included in payment? (Y/N)	Reason
Cost for hired labor	N	Not needed that year
Opportunity cost of unpaid labor	N	Farmer can look for work
Capital recovery of machinery	N	Book as depreciating asset
Opportunity cost of land	N	Farmer can lease or use it
Taxes and insurance	Y	Remain a fixed liability
General overhead	Y	Remain a fixed liability

Table 4. Fruitful Rim and Prairie Gateway adjustments to prices to buy cotton farmer's water in 2018 U.S. dollars.

Adjustment components	Price (U.S. dollars)	
	Fruitful Rim cotton	Prairie Gateway cotton
Gross value of production	864.27	361.68
Total operating costs	625.60	257.14
Net	238.67	104.54
<i>Allocation cost adjustments</i>		
Taxes and insurance	15.30	10.21
General Farm overhead	33.72	11.24
Total water payment	287.69	125.99

as well as estimates derived from land sales, economic models, and contingent contracts, with the contracts operating on a triggered basis similar to VISPO (Jaeger and Mikesell 2002). Other environmental water pricing methods have been explored when the federal government was evaluating how to acquire water; the methods include bilateral bargaining, standing offers, and auctions (Simon 1998). The opportunity cost method may also afford the seller some benefits in addition to their water payment. For example, the seller may rest their field in years the water is called, take time off, or perform farm maintenance. Furthermore, the farmer could decide to switch crops and convert to dry land farming for the year, essentially allowing them to work the land twice that year. They would be paid for the water they did not use and be paid for the dry land crop they raised in place of the irrigated crop.

Calculating the monetary value of the water in an option

An irrigator's water is priced at the intersection of what they are willing to accept and what a buyer is willing to pay. To help find a reasonable pricing mechanism based on opportunity cost, the U.S. Department of Agriculture (USDA) publishes cost and return statistics for crops in various geographies (Figure 5; Commodity Costs and Returns 1997–2020).

When considering these statistics, it is important to note the differences for the same crop among regions. This is largely driven by variations in yield. For example, the difference in cotton costs and returns for 2018 between the coastal Fruitful Rim (FR) and the Prairie Gateway (PG) are considerable (Table 2).

Price differences among regions highlight the benefit of having an option contract that allows for locally adjusted price information to be used when water options contracts are structured (Table 2). For both FR and the PG cotton, and across the spectrum of crops generally, there is a consistent theme in the net category; net value of production less total listed costs is generally a loss, and net value less operating costs generally shows a profit (Commodity Costs and Returns 1997–2020). Neither of these scenarios account for government payments, so government payments aside, the payment to the irrigator for water will probably need to be between the net of operating costs and total cost numbers to account for some overhead that will remain a liability even in years the land is not farmed.

To illustrate what may incentivize the irrigator to engage in an options contract, the water for 1 acre of cotton from the FR and the PG will be priced. First, the value of production and operating costs will be taken at face value, though these numbers could be adjusted during negotiations with sellers to account for local farm gate pricing or other variables such as

silage costs. Allocated overhead should be examined considered and is where adjustments may have to be made to the net (Table 3). Given that the farmer will not incur operating costs, those costs are deducted from the value of production to arrive at a net number (Table 4).

Cost for hired labor can be removed, as there is no need to hire help to produce the crop that the water would have been used for. Opportunity cost of unpaid labor can also be removed, as in any year the water is called the farmer has an opportunity to look for other work (Table 2). Capital recovery of machinery can be removed as the farmer can book this as a depreciating asset for tax purposes. Opportunity cost of land can be omitted, as the farmer is free to lease or farm it with a dry land crop in a called year. Taxes and insurance still need to be paid as does the general overhead, so they are added to the net to calculate a total water payment (Table 4).

The above calculations are a blueprint of how the opportunity cost pricing mechanism can work and is only intended to illustrate a starting point for negotiations between a farmer growing cotton and a potential buyer. It is important to remember that the decision setting includes a complex combination of economic and hydrological conditions and multi-year agreements, and the timing of contract utilization will affect how irrigators' returns are impacted. Also, if it is found that the average seller lacks the capacity to execute this analysis, a third party may need to be engaged to provide guidance. When establishing payment, a calculation involving the amount of precipitation the sellers' location receives during the growing season will need to be factored in to understand how much irrigation water is going onto an acre of land. In addition to the listed operating and allocated costs, there may be other considerations important to sellers that come to light as further research is conducted. Given the differing financial realities in various locations, having an instrument that can suit these unique situations may encourage participation in an options market.

There is also a significant consideration in the data regarding the cost of irrigation (Table 2). The cost to irrigate the FR is almost \$36.00 per acre, while the cost is \$0.02 per acre for the PG. These prices are distorted as they represent a weighted average cost with a large proportion of the cost being diluted by the zero-irrigation cost in the dryland acres; this illustrates why it is critical to replace the USDA cost numbers with actual costs in the geography where options are being priced. This variability in the data is also important because the option contract must specify how much water it represents, and an irrigator can only option water they can deliver, so when identifying likely markets, an understanding of how much irrigation is a result of precipitation is important. Therefore, the pricing must be clearly communicated in terms of how much water goes with the contract, as well as the specific point of delivery.

To determine what crop price a farmer receives for water may entail looking at their farming activity and basing the price on the highest percentage of land cover, on farmers' most valuable crop, or on a prorated basis based on land use.

To begin trading options contracts, it might be easiest to find areas in Texas where farmers generally rely on an ac-ft of irrigation per acre of irrigated land. This would mean that to lease a farmer's water by paying them lost revenue for 100 acres of crop, the buyer would receive a 100 ac-ft of water. This one-for-one arrangement would facilitate transactions by making the terms clear and easy to understand. While this will not work for all situations (consider if groundwater is a portion of a farmer's irrigation strategy) nor for all geographies, it will be a good place to begin executing transactions to demonstrate the method.

In addition to paying for the water, the buyer will also have to pay a premium to the seller for entering the transaction. Historically, the value of an option premium has been calculated using BSM ([Black and Scholes 1973](#); [Villinski 2003](#); [Williamson et al. 2008](#)). The value of an option premium using this method includes components that are not available for the methodology outlined here, but there is a useful lesson in BSM for pricing the option premium. The maximum value that BSM will produce for an option premium is the cash value of the underlying asset, and that premium allows the buyer to exercise the option one time. In the absence of an existing method to price the value of the premium on these long-term water options in Texas, using the maximum value might be a reasonable place to start.

Expiration and call features

Options for many U.S. securities have a 3-month lifespan, expiring on a quarterly basis. The options discussed here focus on longer-term contracts. As mentioned above, this work was initially conceived to craft a mitigating solution to the longer-term implications of low flow years affecting environmental flows, and for an option to be relevant in this space it needs to have a lifespan that can accommodate inter-annual variability of water flow rates. Therefore, options are constructed with 5- and 10-year expirations to give buyers a high degree of long-term risk management.

With a traditional American option, the buyer of the option can exercise it once or before expiration date. To make long-term water options as useful as possible, this call feature will be expanded. In addition to greater flexibility, expansion of the call feature will help lower the number of transactions that buyers need to achieve their risk management goals. For water options, call features have been constructed to align with the probable needs of the buyers based on statistical frequency of low flow years.

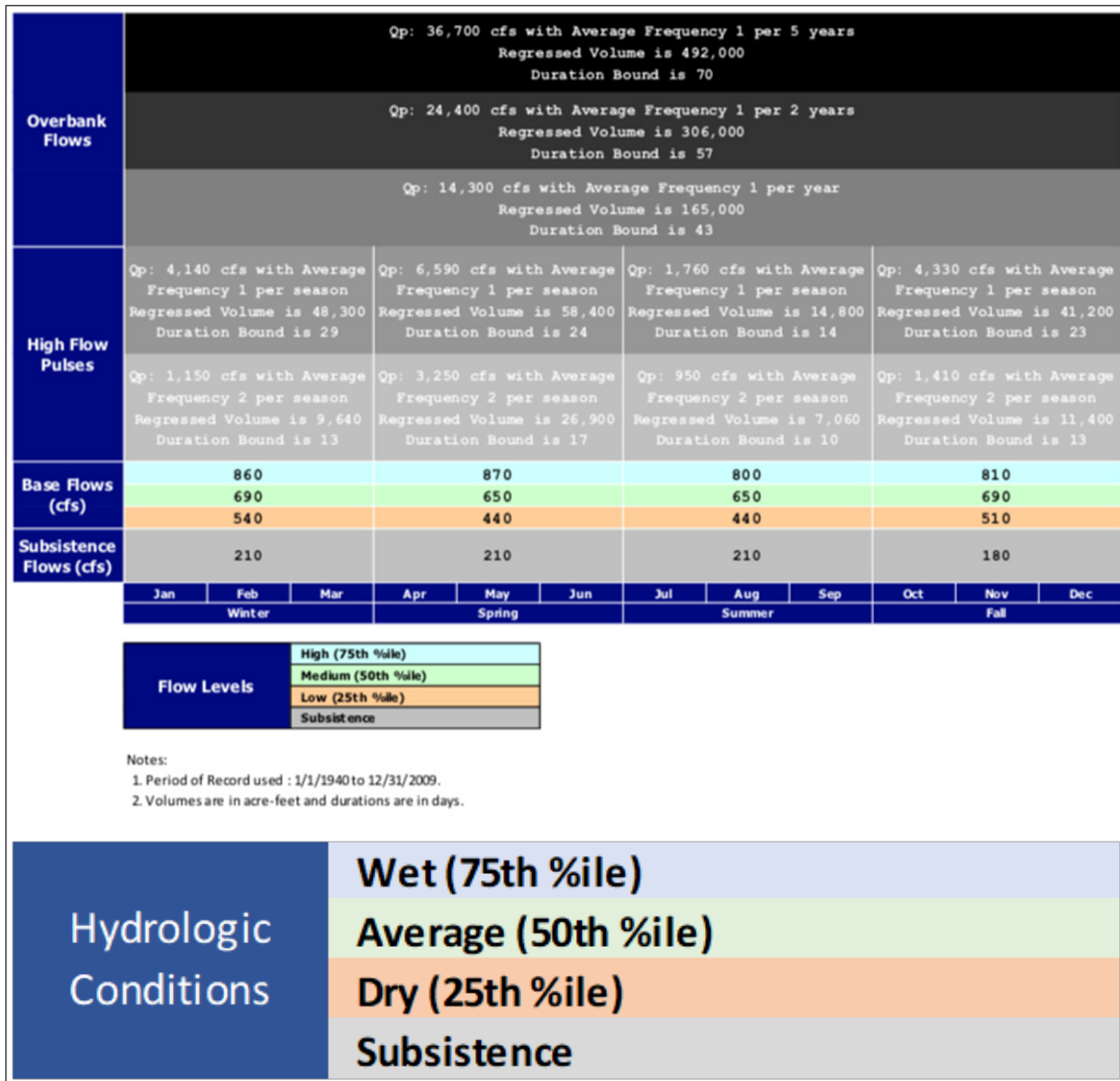


Figure 6. Environmental flow regime recommendation for the Guadalupe River at Gonzales and a zoomed view of how the flow levels are described ([GSA BBEST 2011](#)).

Senate Bill 3 (SB 3, 80th Texas Legislature) was designed to determine environmental flow standards for the major bay systems and major river basins in Texas ([Statewide Environmental Flows n.d.](#)). From there, the SB 3 Science Advisory Committee for Environmental Flows (SAC) offered guidance to use the Hydrology-Based Environmental Flow Regime (HEFR) to help basin advisory groups develop flow recommendations ([Sabine-Neches BBEST 2009](#)). HEFR methodology is described in detail in the Sabine-Neches BBEST guide ([2009](#)), where they offer a two-step process that outputs a flow matrix of values for wet, average, and dry conditions. Using an approach that characterizes the frequency curve by bounding the average conditions at the 25th and 75th percentile to mark

the dry and wet conditions has been used in the past ([Richter et al. 1996, 1998](#)). This is not the only accepted method in use. The standard precipitation index approach has been modified to establish probabilities for wet and dry conditions at 31% each, and normal conditions at 38% ([McKee et al. 1993; Svoboda et al. 2002](#)). Hydrological systems are dynamic and complex and involve base flows and pulse events, which both affect ecological functions, so the best method to discuss frequency will be partly determined by the use intended ([Ramírez-Hernández et al. 2015](#)). In the environmental flows recommendations reports, recommendations are made that characterize the frequency curve of available water in terms of quartiles (Figure 6, bottom left).

Table 5. Essential Elements of a water options contract.

Element	Description
Expiration	This describes the lifespan of the contract. Options contracts contain a date that specifies the date by which the contract can be exercised before it expires and is no longer valid. The key difference between water options and other options is that the lifespan is expected to be much longer (5–10 years instead of a few months).
Call feature	This describes how and when the buyer may exercise the contract. Options on other assets can generally be called once. Given the longer-term nature of water options, a starting point for negotiations would be to have 5-year options callable once and 10-year options callable twice; this approximates the 25% frequency of low flow years produced by the HEFR methodology.
Strike price	This specifies how much the buyer will pay the seller for the asset in the event the option is exercised. The opportunity cost method would make this payment equal to the income forgone by the seller incurred by not using water in the called year. Again, a point of negotiation will be if this price is determined when the contract is signed or is based on market value in the called year.
Premium	This is the option price—how much the buyer pays the seller for entering the contract. The maximum value BSM can output is equal to the cash value of the asset and could be used in discussions around premium. An important discussion point will be how this is structured in the 5-year option as opposed to the 10-year.

For structuring the call feature of a water option, we use the value classifications outlined in Figure 6. The conditions are usually associated—in terms of frequency—with the 25th percentile, median, and 75th percentile of the frequency curve; thus HEFR outputs are designed to identify low flow conditions at the values on the curve associated with the 25th percentile of occurrence or at a point specified by the user (Figure 7; [Opdyke et al. 2014](#)).

Flow frequency curves are readily available (Figure 7) and can be used by buyers and sellers to align call features with their preferred mitigation strategy. If buyers of water options are concerned with risk mitigation in low flow years, then aligning the call feature with the probability of occurrence presented by the HEFR output should meet their needs, so an option should be callable around 25% of the time. To mesh with this percentage, options could be structured to have lifespans of 4 or 8 years, making the call feature 1/4 or 2/8 years. While there will likely be negotiations around the specifics, options contracts for water will share some essential elements (Table 5).

DISCUSSION

Water options in Texas

Based on the success of the cash markets in the RGV and the success of the option-styled VISPO arrangements, it certainly

seems plausible that there is enough demand for water trading products to take them to the next level. The methods set out here illustrate how an agricultural irrigator might be compensated. However, the goal was to find a method that can work knowing that some of the details will have to be negotiated. We used a specific example to illustrate the idea of an option market in Texas, but it is only a beginning for many conversations around unique instruments that can be used to facilitate the transfer of water. When possible, standardization of as many contracts as possible helps market participants and can create efficiencies.

Irrigators have shown willingness to engage in long-term contractual commitments involving their water. VISPO has offered 5-year and 10-year enrollment options and has had success with both. VISPO has been successful in offering water purchase programs that are based on a triggered style of water option. The more traditional option outlined here enhances the trading product in two primary ways. In terms of the buyer, the contract is exercised at buyers' discretion, giving them greater control over when the contract is called as opposed to when call features are triggered by an event. From the sellers' standpoint, these contracts have a clear path to pricing that attempts to adequately compensate them for the revenue they will lose by participating through fair determination of strike price, plus an added incentive to participate in the arrangement via the premium payment.

There may be additional sellers who are willing to use a pricing structure based on payments to irrigators to option some of their water. For example, river authorities may be willing to option some of their water if their current needs are met. Additionally, industrial interests hold permits representing large amounts of water. For example, Dow Chemical Company holds many permits adding up to millions of acre-feet of water. When the company is experiencing a slow business cycle, production may be down, so some of that water may not be in use, which could create an opportunity to engage them as a seller of water options.

In negotiating with irrigators, it is important to remember that farming and ranching have a unique and deep-rooted cultural identity and ownership, and use of water is a big part of that identity ([McSweeney and Raish 2012](#)). In addition, while not within the scope of this work, it is imperative to consider the economic implications to farming and ranching communities when taking arable land out of production or reducing the amount of cattle. There could be significant ripple effects resulting from the execution of water options contracts that need to be considered. In future work, attention will be given to what percentage of farming activity may be suspended in a region before the impact of those economic ripples is unacceptably high. The experience of the Owens Valley dealing with the city of Los Angeles at the dawn of the 20th century provides an extreme example of what effect these ripples can have. Whether or not the gains Los Angeles made by purchasing the water from Owens Valley justify the cost to the latter is debatable. Regardless, the effects on the Owens Valley were tremendous, ultimately killing the farming industry and communities ([Reisner 1986](#)).

The opportunity cost pricing method may be useful in establishing guidance for options contracts when the alternative use for the water has less measurable value than the foregone crop but may not effectively compete with high value buyers willing to bid for water. For example, if the opportunity cost method is applied to a corn crop and calculates a payment to the farmer of \$125 per acre, a manufacturing interest may be willing to pay a much higher price for the same water. Knowing that these buyers exist may hinder sellers' willingness to enter long-term contracts where their payments are determined by the profits from their land use instead of a negotiation between what the buyer is willing to pay and what the farmer is willing to accept. The combination of the opportunity cost pricing method with the enhanced call feature (at buyers' discretion in lieu of triggering) and the long-term lifespan of the contracts eliminates some of the issues raised in pricing in the Pacific Northwest and when procuring water for the U.S. government ([Jaeger and Mikesell 2002](#); [Simon 1998](#)). Long-term contracts reduce transaction costs as compared to bilateral bargaining and avoid the possibility of collusion that accompanies auc-

tions for water markets. A key requirement will be establishing and maintaining credible commitments by the parties involved in the transactions ([Simon 1998](#)).

The permitting process may also hinder these transactions, particularly if a change of use necessitates TCEQ approval for a contract. Even if the change of use applications is approved for the years of an option where water is called, it is at best an administrative barrier to trade. At worst, this requirement could effectively deter market participants from conducting business because the risks associated with buying and selling contracts that have no guarantee of being approved by TCEQ may present too many challenges.

When should options be exercised?

Existing forbearance programs have aspects that resemble options, but one notable difference is that the option is triggered by water levels as opposed to simply being called at the option holders' discretion. The options described in this work are intended to be callable at the buyer's discretion. Along the longitudes that Texas covers, there is incredible variation in the amount of precipitation, and there are several very diverse groups that use large volumes of water in the state ([TWDB 2003](#); [Montagna et al. 2018b](#)). Therefore, it is impossible to craft a call metric that will be useful to all user groups across geographies, but a brief description may offer guidance as to how these metrics might be constructed for the environmental manager and an authority that manages supplies. For example, one buyer might be primarily concerned with salinity at a particular time of year, while another might be concerned with dissolved oxygen, pH, or overbank flows.

Environmental managers concerned with environmental flows of water to bays and estuaries could use existing HEFR outputs to establish their own triggering mechanisms. If a manager is not satisfied with HEFR, they could possibly use salinity as an indicator of flow levels. Work has explored both salinity values as well as the amount of salinity variation, and one or a combination of these measurements could inform decisions ([Montagna et al. 2009](#); [Montagna et al. 2002](#); [Montagna et al. 2018b](#)). Additional information, such as reference conditions or the optimum conditions of their chosen metric, could provide additional information about a system that may be under duress. With changes in precipitation across the state come changes in flow regimes, so it is important to remember that each system will have its own salinity values and variations that indicate normal functioning.

Municipalities could look to their reservoir levels and make some determinations about what levels would cause them to act to secure additional water. These decisions can be made proactively, as having the reservoir is akin to having a bank. If water options are procured upstream and then called, the

municipality can augment supplies to avoid imposing water restrictions or even sell the water downstream. These options can offer great flexibility to organizations that can bank their own water and would allow organizations the ability to option water to account for potential future growth. If the growth comes, the option can be called, and if the growth does not ensue, the option cost is a fraction of alternative infrastructure.

The RGV offers a good example of an active spot market for water in Texas, making it a strong candidate for implementation of an options market (Villinski 2003; Yoskowitz 1999). However, the Watermaster system in place in the RGV gives that market some unique characteristics not found throughout the state, such as the surface rights being correlative. Correlative rights are allocated differently than rights under a seniority system. Instead of curtailing water delivery to junior rights holders when supplies are low, all users' allocations are reduced proportionally when shortages occur (TWDB 2003). The implication is that if options contracts are successfully marketed in the RGV that are based on these characteristics, it does not assure that similarly structured contracts will be of use elsewhere in Texas. Institutional frameworks in each basin system that provide the space for effective markets to develop will be critical. It may be possible to design options for use under a Watermaster using more traditional pricing methods and use the method outlined here for other parts of the state, but there is no reason that the methods designed here could not be applied to areas with a Watermaster.

CONCLUSION

The flexibility that options contracts offer make them a promising solution to the issues of scarcity facing Texas. These contracts can be an attractive tool to the myriad of water users throughout the state, including the environment. To bring these contracts to market, more work will have to be done to make sure that buyer and seller needs are met in the product. A logical next step would be to engage those user groups to better understand how interested they are at different price points and what elements would have to be present in the contracts to buy or sell them. There are regulatory hurdles that will have to be addressed to allow for the development of water markets and their attendant derivatives in Texas. Even with the roadblocks to progress, these contracts offer the possibility of enough benefits that further investigation and development of them is warranted, and if transactions are kept between participants in the same basin, they may be deployable under current governance. Pricing options using more conventional tools would require more transactional data from cash water markets. To help those markets grow, water pricing models have been built and are being refined and distributed (McColly 2020). The model

outlined here offers a method to price water options and is applied in Texas, but this model will likely need to be adapted to accommodate unforeseen issues. This is a starting point for negotiations that can advance the growth of water options along a trajectory leading to opportunities for implementation statewide and possibly beyond.

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