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Interjecting Economics into the Surface Water Dialogue

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Abstract: This paper applies the conceptual lens of economic efficiency as a criterion by which to evaluate surface water in Texas. We identify two major problems. First, Texas has a water allocation problem limiting the ability to substitute groundwater for surface water to move water between river basins and to facilitate transfers within a river basin. Second, surface water is both underpriced and unresponsive to drought conditions preventing it from being used at its highest and best use. We propose a variety of partial solutions, which include facilitating greater reliance on water markets as well as a water tax that would vary across regions and over time to encourage conservation.

Keywords: surface water regulations, surface water allocation, surface water tax

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Terms used in paper

Acronym	Descriptive term
CFS	cubic feet per second
CIF	Community Involvement Fund
GDP	gross domestic product
GCD(s)	groundwater conservation districts
LCRA	Lower Colorado River Authority
MSB	marginal social benefit
MSC	marginal social cost
MWD	Metropolitan Water District
PVID	Palo Verde Valley Irrigation District
PDSI	Palmer Drought Severity Index
SWIFT	State Water Implementation Fund for Texas
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board
WAM	Water Availability Model

INTRODUCTION

Paradoxically, while Texas is a leader in the science of modelling surface water flows (see Wurbs 2015), economic efficiency has taken a back seat to other criteria in the surface water policy dialogue. These other criteria can include protecting existing stakeholders, guaranteeing environmental flows to bays and estuaries, protecting water for local use, and so forth.[1] Each criteria yields separate, and often conflicting, policy recommendations around which various interest groups coalesce. The result is an emotion-charged political patchwork fashioned during severe droughts. In the past, ignoring economic criteria was relatively costless because Texas had an abundance of both surface water and groundwater. But with population growing from 11.2 million in 1970 to an estimated 29.1 million by 2019[2] and the state's gross domestic product (GDP) topping all but 10 countries,[3] we can no longer afford to exempt Texas' water resources from economic scrutiny. Griffin (2017) offered a critique of groundwater policy from an economics perspective. This sequel paper offers an economic critique of surface water regulation and is based on a 2017 Bush School Capstone report (Vaca et al. 2017) to State Comptroller Glenn Hegar.

By adopting the conceptual lens of "economic efficiency" as this paper's evaluation criterion, further justification is in order. Economic efficiency requires that for the last tranche of water consumed, the marginal social cost (MSC) of providing water just equals its marginal social benefits (MSB).[4] Note that the terms "social" costs and "social" benefits implies that we adopt a holistic approach looking at society as a whole in which environmental costs are factored in. Economic inefficiency can occur either with too little (MSC>MSC) or too much (MSB<MSC) water consumption. Particularly, when water is misallocated from high-valued uses to low-valued uses, the welfare loss (or efficiency loss) to society as a whole would be measured by the difference between the two. For example, if surface water is diverted from an industrial user willing to pay $1000/acre-foot to a cotton farmer only able to pay $100/acre-foot, then the welfare loss from this misallocation is $900/acre-foot. Note that this calculation is value neutral between

[1] Other examples include protecting: touristic areas, animals and wildlife, other economic activities.

[2] Texas State Demographer. https://uspopulation2019.com/population-of-texas-2019.html

[3] This ranking is obtained by comparing the GDP of countries from the World Bank Data (2018) and the Texas GDP from the Texas Comptroller 2018 website.

[4] See Gruber (2013).

the choice of producing cotton or producing industrial products. Normally in the absence of significant externalities in the form of environmental effects, the market value for water used in cotton versus industrial production will prescribe that the water should flow to its highest valued use.[5]

This papers proceeds as follows. First, it will go over the case for adopting economic efficiency as an evaluation criterion, which will set the basis to justify our later policy recommendations. Second, we will explain two main problem areas for economic efficiency in surface water that arise from current regulations and policies and propose alternative solutions to each of these problems.

THE CASE FOR ADOPTING ECONOMIC EFFICIENCY AS AN EVALUATION CRITERION

Opposition to adopting the economic efficiency criterion rests primarily on the notion that some group or groups will be negatively impacted. Economists have long recognized that the policies promoting economic efficiency will produce winners and losers. This is called the equity versus efficiency tradeoff.[6] Even though society as a whole is a net winner from efficiency-enhancing policies, some individuals and groups may be worse off. Particularly, if a policy severely impacted the poorest segments of society, policy makers should seek ways to compensate the disadvantaged group and if that was not possible, the efficiency-enhancing policy might be scrapped. Likewise, with water, emotional fears of running out of water, whether grounded in reality or imagination, can raise strong equity concerns. Thus, "equity" and economic efficiency can be in conflict. Even though the winners gain more than the losers lose, there may be no simple way to compensate the losers and equity trumps efficiency. For example, on efficiency grounds a universal poll tax avoids all the labor-leisure distortions resulting from the progressive income tax; yet, there is little support for such a tax because of its impact on the poor. At the other extreme, we have antitrust laws designed to curb the exercise of monopoly power. Clearly, in this case, the disadvantaged group from antitrust prosecution is the monopolist; yet the public shows little sympathy to the monopolist. Efficiency trumps equity.

In struggling to reconcile equity versus efficiency, economists look at the following three things:[7]

(1) the magnitude of the efficiency gains; (2) the identity and magnitude of the loss to the disadvantaged group; and (3) the feasibility of compensating the losers.

First, are the efficiency gains potentially large? Going back to the cotton/industrial product example, is the difference in value between the two, $900/acre-foot or only $10/acre-foot? At a $900/acre-foot difference, the efficiency gains are potentially large, particularly if there are substantial quantities of water being relegated to low-valued uses.

Second, who would lose from the efficiency-enhancing policy and how much? Both the identity and the magnitude of the loss are relevant. Clearly, there are situations where the affected group deserves no consideration, such as a monopolist losing his monopoly profits due to antitrust prosecution. The case of the cotton farmer is more problematic. Is there a national security justification for subsidizing cotton production by providing cheap water? Are there other justifications such as cotton farmers representing a unique culture that is worth preserving? And if so, how much of a subsidy is justified to maintain this culture?

Third, when equity concerns are real and a severe impediment to economic efficiency, policy makers should look to find ways of compensating the losers so that everyone is a winner. As an example, in a Brady et al. (2016) analysis of groundwater, they proposed a mitigation fund for rural homeowners who might find their well dry.

Ultimately, the political process will answer these questions and choose a trade-off between equity versus efficiency, but that is not the focus here. By choosing to look only at the economic efficiency attributes in this paper, we avoid the subjective and value-laden calculus of determining when equity considerations trump efficiency.

There is an important word of warning regarding the excessive use of equity justifications to block efficiency-enhancing policies in cases where it is not feasible to compensate the losers. Excessive concern for equity can become a mantra for the status quo, which may lead to even worse problems in the future. In a vibrant market economy with continual technological advances, new products, and changing consumer tastes, some investors and some workers routinely find themselves the victims of these unforeseen events. Certainly, one would not want to stifle change in general, because when balanced over time, rising standards of living have made all of us better off. Unfortunately, in many instances the feasibility of compensating every individual for his/her bad fortune (and thereby making everyone winners) may be impractical.

A final attribute of using economic efficiency as a metric to evaluate policy options is that market prices can often provide valuable common sense signals. In a properly functioning market, prices send signals of relative abundance or extreme scarcity. In turn, consumers respond to high prices by reducing con-

[5] In the event there are significant environmental externalities that are not internalized in the costs of producing the cotton or the industrial products, the values for each would be adjusted accordingly.

[6] See Gruber (2013)

[7] See Pascual et al. (2010) and Martini (2007)

sumption while producers respond by increasing production. By examining water prices during periods of droughts and abundance, we can see if prices are sending the proper signals to conserve and increase supplies. The absence of the proper price signals forms a prima facie case for economic inefficiency. Because of the importance of markets sending the proper price signals, this report will frequently center on markets and the price signals being sent.

PROBLEM AREAS AND SOLUTIONS

Our study of surface water (Vaca et al. 2017) identified two basic sources of economic inefficiency. The first problem is that Texas has a water allocation problem with significant impediments to moving water from low-valued uses to high-valued uses. The second problem is that surface water in Texas is underpriced and inflexible in the face of droughts. The current pricing practices do not include a scarcity premium for raw water.[8] Gold commands a scarcity premium far in excess of the basic cost to mine and refine the ore. Yet, Texas surface water, a far more essential resource, commands no such scarcity premium. Especially during a drought, it is critical for prices to rise, encouraging conservation.

Problem area 1: Texas has a water allocation problem

The state has abundant water resources in certain locations where they are being relatively underutilized and relative scarcity in other areas. If low-cost mechanisms can be found to move water to the areas of greater need, Texas can delay having to implement high-cost alternatives like seawater desalination in the near term. It is useful to think of improving water allocation through three avenues: (1) greater conjunctive use of groundwater and surface water (2) reallocation of water resources within a river basin and (3) reallocation of surface water between river basins.

Problem 1.1: Limited transfers between groundwater and surface water

As there is a hydrological interconnection between surface water and groundwater,[9] there is also an economic relationship of substitutability between both of them. For instance, for many raw water uses, such as municipal, industrial, and agricultural uses, there is no major quality difference between surface water and groundwater. To the extent there are quality differences, inexpensive treatment costs may make the two equivalent.[10] Consequently, in the case that groundwater and surface water are equally available, the choice of which one to use should fall almost exclusively on costs.[11] However, from a policy perspective, the independent regulation of surface water and groundwater often overlooks this substitutability. Specifically, even though the State owns the surface water and landowners own the groundwater, there is no inherent reason that regulatory constraints should prevent their substitution particularly during droughts.

The fact that groundwater is generally available with greater certainty,[12] while surface water is intermittent and characterized by uncertainty, means that allowing emergency conjunctive use of groundwater and surface water can bring major efficiency gains for consumers and the environment. Let us consider the case of a very severe drought that affects many surface water streams and their users. Currently, there is no policy that incentivizes groundwater owners to react to droughts by increasing groundwater pumping to sources normally supplied by surface water. Usage-based groundwater conservation district (GCD) regulations effectively preclude an irrigator from selling his groundwater to a nearby municipality or power plant whose surface water is facing curtailment or depletion (Brady et al. 2016). Yet, during this hypothetical drought, the economic benefits of the conjunctive use would be very large: surface water users would benefit from water that would not be available otherwise, and groundwater users would be very highly compensated from selling their water. In addition, added groundwater would augment stream flows stressed by the drought helping to alleviate environmental effects (McKinney 2012).

Solution: Eliminate usage-based regulations by the GCDs and Texas Commission on Environmental Quality (TCEQ).

In order for these transfers to occur, the usage-based regulations by the GCDs and TCEQ should be eliminated for short-term transfers. If groundwater is going toward a beneficial use as specified by the Texas Water Code[13] and the transfer is specified for a short period of time as during a drought, there should be no further regulation on where a groundwater right holder can use their water.

[8] Some drought contingency plans do include a surcharge if a contract holder does not reduce usage when required under the plan. For example, the Gulf Coast Waster Authority's plan includes the surcharge. In effect, if a user does not reduce its use, the cost for water is higher.

[9] See Winter (1998), Sophocleous (2002).

[10] For an overview of different treatment options and costs, see Bhojwani et al. (2019).

[11] By this cost, we refer to a total cost of using surface water or groundwater including any treatment necessary to get a certain quality of water.

[12] The one exception is for the Edwards Aquifer, which is subject to mandatory cutbacks during droughts.

[13] Texas Water Code Chapter 11 defines "beneficial use" to include domestic and municipal, agricultural and industrial, mining, hydroelectric, navigation, recreation and pleasure, public parks and game preserves.

Problem 1.2: Restrictions on interbasin transfers

According to former TCEQ Commissioner and Texas Water Development Board (TWDB) Chairman Carlos Rubinstein, Texas will not be able to fix its water problems until we can successfully move water from "where it is, to where it is not" (Personal Communication in January 16, 2017 meeting). One way to do this is through interbasin transfers, moving water from abundant areas in East Texas to Central and West Texas. A major issue that arises when discussing interbasin transfers is the junior rights provision included in Senate Bill 1. When a transfer outside of the basin occurs, the junior rights provision changes the water right's original priority date and becomes the most junior prior appropriation. In the current prior appropriation system,[14] this provision is intended to protect the basin of origin. However, the junior provision can reduce economic efficiency by degrading the value of a water right and thereby reducing the incentive for interbasin transfers.

How does the junior rights provision affects economic efficiency?

The junior rights provision affects economic efficiency because the value of the water is greatly diminished when the priority date is changed. This reduction in the value of water rights minimizes the incentives to sell or buy water from other basins, even when there are economic gains from doing so.[15] For instance, buyers can be reluctant to invest in a costly pipeline that might only be used a fraction of the year or only during very wet years, when junior right holders can divert. It is important to note that when there is plenty of water in the basin of origin, the junior provision becomes irrelevant and would not prevent any transfer from happening. However, it is the combination of uncertainty about drought conditions and a loss of priority that reduce the incentives to buy water from another basin under the junior rights provision. A system created to pump water out of one river and transport it through a pipeline is very expensive. If the system can only be used when there is abundant water in the basin of origin, the system could sit idle for years. The cost per acre-foot of water for the project would become untenable. Consequently, the change in priority date favors the basin of origin regardless of the fact that the benefits of the transfer can outweigh its costs. Even though there is no explicit proof that the junior rights provision has prevented transfers from happening, Votteler et al. (2007) show that there is a reduction in the number of non-exempt interbasin transfers after the junior rights provision was passed in Senate Bill 1 in 1997. Before that year, a total of 28 interbasin transfers had occurred over the period 1980 to 1996. After Senate Bill 1, only three transfers have occurred in the period between 1997 and 2006.[16] Since 2006, we found only one interbasin transfer for water already owned by the City of Houston.[17] These data strongly support the conclusion that the junior rights provision has definitely reduced interbasin transfers.

Since supporters of the junior rights provision rest their support for it on equity grounds, it is important to ask the three questions outlined earlier regarding the case for economic efficiency:

1. *Are the efficiency benefits of interbasin transfers likely to be large?*

Let us consider an example of a basin where its municipal users are desperately in need of more water than the basin can supply. A study by Cai and McCarl (2007) develops an integrated economic-hydrological model to examine proposed interbasin transfers in Texas and find that they can alleviate water shortages issues, especially for large cities. As additional water would greatly benefit all these users, their willingness to pay for water will be very high. For the basin of origin, let us assume there are some irrigators holders that would be willing to sell their water at a price above its agricultural uses. For these sellers, they are fully compensated so that seemingly if the municipality is willing to pay a higher price than the irrigators' reservation price, economic efficiency dictates that the transfer occurs.

According to a report by R.W. Beck, Inc. for the TWDB in 2006 (R. W. Beck 2006), interbasin transfers in Texas can have significant net economic benefits and that "while the economic impacts are more than offset by the economic benefits which accrue to the Basin of Origin, all competing policy objectives must be considered in pursuing such transfers." So the answer to the first question is that the efficiency benefits of interbasin transfers are potentially quite large.

2. *Who are the affected parties in the basin of origin?*

Next, let us turn to the question of the identity and magnitude of the loss to the disadvantaged group. In the above example, the party selling their water rights are voluntarily selling their rights, so they cannot claim injury. Nevertheless, as Gould (1988) points out, third party effects on other downstream users in the area of origin can be substantial. Moreover, they are not normally compensated. For example, with the irrigator's water leaving the basin of origin, downstream users under the prior appropriation doctrine are deprived of runoff that returns to the basin of origin. At issue then is the magni-

[14] A system with no clear compensation mechanism established for the basin or origin.

[15] This argument is particularly applicable to run of the river rights. For transfers from reservoir storage, the impacts of the junior rights may be substantially diminished.

[16] Figure 1 of Votteler et al. (2007).

[17] The Luce Bayou Interbasin Transfer Project that is currently under construction transfers "existing surface water rights previously held by the City of Houston in the Trinity River to Lake Houston in the San Jacinto basin" (TWDB 2018). The amendments for this transfer were tied to permits and interbasin transfers granted before Senate Bill 1 so the Junior Provision did not apply in this case.

tude of the return flow and the economic consequence of its absence on third parties.

3. Can the losers be compensated and how?

While we support the elimination of the junior rights provision, we recognize the necessity for providing compensation for the area of origin. We propose that river basins and communities in Texas use an arbitrator to create their own context-specific mitigation funds. The first part of this mitigation process would consist of requiring monetary compensation for the basin of origin. For instance, some western states require compensation to be paid to the local governments within the basin of origin (Castleberry and Acevedo 2017). These payments can be done through mitigation funds. Mitigation funds can be established in different ways and can be set to compensate the losers affected by the transfer including economic and environmental costs. Hanak et al. (2011) explains that these funds should consider potential employment losses, increases in social service costs and reductions in tax revenues.

There are several examples of successful mitigation funds from surface water transfers in other states. For example, in an interbasin water contract in California between the Metropolitan Water District (MWD) and the Palo Verdo Valley Irrigation District's (PVID), the MWD (buyer) provides a Community Involvement Fund (CIF) to address community effects (Hanak et al. 2011). The CIF compensates the area of origin in the form of training programs for community members, support for small business, and cash per acre-foot of water diverted (WGA 2012). In Nevada, areas of origin simply impose a $10 fee/acre-foot on all water that is transferred out of the county (WGA 2012).

Another example of how a mitigation fund could work could be based on the compensation fund established after the Gulf Coast oil spill in 2010. In 2012, Congress passed the RESTORE Act that dedicated 80% of all penalties from responsible parties to a Gulf Coast Restoration Trust Fund (Restore the Gulf 2018). It is clearly outlined how the resources from the fund can be used to restore and protect the natural resources and the economy of the Gulf Coast. Similar mitigation funds can be created for interbasin transfers, where the percentages of the funds are clearly established to compensate the economic and environmental costs of the transfers.

Problem 1.3: Inadequate intrabasin transfers

Transfers of water within a river basin face several regulatory impediments as well. The primary impediment to transfers within a river basin is the complicated regulatory process imposed by the TCEQ in its effort to comply with legislative and legal constraints. The amendment process of a permit to change the use or diversion point requires the TCEQ to perform a technical review using the Water Availability Model (WAM) dataset to see how the amendment will affect water right holders in the basin. The objective of this process is to avoid any negative effect of amending a permit to other users. However, in the commitment to avoiding injury and respecting seniority, the bureaucratic process has become impractical and time consuming for potential buyers and sellers particularly in responding to droughts. According to the instructions of the TCEQ, an application is typically processed in 300 days.[18] This amendment process is particularly troublesome during a drought when permit holders not using their full allocation would like to lease (temporarily sell) their water to another party at a different diversion point.[19] As surface water becomes scarce and the demand for water expands, the inability to easily transfer water rights (either by short-term leases or outright sales of water rights) limits the market from allocating water to its highest value uses.

How to increase the number of intrabasin transfers?

In order to promote intrabasin transfers, we basically need to facilitate the transaction process. Vaca et al. (2017) propose three alternatives in which the transaction process can be simplified to increase the number of intrabasin transfers. In this paper we will briefly discuss the first two alternatives and will focus on a detailed explanation of the third alternative.[20] The first of these alternatives consists of changing and shortening some of the current procedures that are required to amend a water right.[21] As described in Vaca et al. (2017), this would involve using Web 2.0 technology to inform potentially impacted parties and to accelerate the process for impacted third parties to prove up their claim for damages. Particularly for short-term leases to deal with drought situations, this process could cut through the red tape. This can incentivize more buyers and sellers to participate in intrabasin transfers as they would know that they can get the water they need by the time they need it.

The second alternative outlined in Vaca et al. (2017) involved the implementation of watermasters in other basins. Currently,

[18] TCEQ (2017a) Instructions for Completing the Water Rights Permitting Application. Note that this very long period is in part created by the applicants themselves who occasionally file a permit as a placeholder and leave it pending as leverage in a water dispute or for other reasons.

[19] It is important to note that during drought emergencies, river authorities have been able to amend some of their rights temporarily as part of their Water Management Plan (see TCEQ Emergency Order for the LCRA in 2013). However, other users (i.e. not river authorities) that wish to sell their water would have to go through the normal amendment process. In addition to emergency amendments, Senate Bill 1430 approved in 2017 allows for "expedited amendments for existing water rights permits where the permit holder is off-setting freshwater use with desalinated seawater" (TCEQ 2018, SB 1430). Senate Bill 1430 intends to encourage seawater desalination.

[20] For a more detailed explanation of the other alternatives, see Vaca et al. (2017).

[21] House Bill 1964 attempts to shorten the process, but even slight changes in point of diversions require WAM analysis.

in addition to the highly successful Rio Grande Watermaster Program, there are an additional three[22] watermasters covering various segments of river systems in the state. Watermaster systems are probably not a panacea. While popular in some areas, in others there is opposition because it is costly to administer. In essence, the administrative costs may be overshadowing the efficiency gains that it generates, particularly in water abundant river systems. The third alternative is the implementation of a "Watermaster Lite System" designed to reduce the administration costs.

Watermaster Lite

The goal of the Watermaster Lite System is to ensure that water can be transferred quickly by bypassing some of the regulatory burdens set forth by the TCEQ permitting process but does so at a much lower cost than a full-blown Watermaster System. In proposing this alternative, we recognize that its implementation would require legislative action to modify the prior appropriation doctrine as well devising an entire new set of bureaucratic procedures. We also recognize that elaborating and proposing solutions to these issues could easily entail a lengthy study in itself. In the spirit of this paper, our focus is to describe how such a novel system might work and what the economic efficiency gains it might confer. Clearly, the Watermaster Lite System should be tried on an experimental basis to ensure it is effective before being implemented elsewhere. The economic efficiency gains of this system are intended to dramatically shorten the TCEQ processing time, increase market transactions, reduce transaction costs, and require less financial resources to administer than the traditional Watermaster System requires.

1. *How to implement the Watermaster Lite?*

The river will be divided into segments and each segment will have flow detectors installed to measure stream flow. Within each segment of the river basin, the basin's water right holders will then be divided and assigned a color based upon their seniority and their permitted acre-feet. By grouping rights by seniority into color categories, the process to make an intrabasin transfer will be simplified and at the same time, the prior appropriation doctrine will still be respected by group. In addition, in case of an extreme drought, right holders can still make a priority call within their color categories and thus the basic features of the prior appropriation system are maintained. The Watermaster Lite System will require the TCEQ to calculate all of the total water permits in the basin based off their acre-feet withdrawal limits. For example, in the Brazos River Basin there is a total of 7,932,481 acre-feet allocated to divert.[23] Thereafter, water right holders would be divided into five groups. The most senior quintile of the 1,983,120 acre-feet would be categorized into the color "black;" the second most senior quintile of the 1,983,120 acre-feet would be categorized in the color "red;" the third set of junior diverters will be categorized into "orange;" the next quintile would be "yellow;" and the most junior 1,983,120 acre-feet would be categorized into "green." Under this system, the whole river basin will be grouped by the acre footage and seniority of its diverters. Additionally, each river segment will be assigned a minimum flow rate corresponding to the different color categories.

This system aims to create a spot market based off short-term (less than a year) changes in diversions that will be automatically granted provided three conditions are met. (1) The first condition is the flow rate in their river segment and permit type is satisfied within a 10% margin of error. The flow rate will incorporate TCEQ's adopted environmental flow standards, which is the flow restriction TCEQ would apply to moves of diversion points under the current permitting system. (2) A second condition is that the change in diversion will incorporate stream flow losses (including evaporation effects). For example, if the original permit called for a diversion rate of 10 acre-feet daily and there was a 10% evaporation and transportation loss, the recipient would only be entitled to divert 9 acre-feet daily. (3) The permit would be subject to curtailment in the event of a senior right call.

This system is better stated with an example. Suppose we are dealing with a lower segment of the river basin where the stream flows are greater. Diverter A, from Figure 1, is the most senior water right holder in the basin and is allowed to divert 100 acre-feet annually. Thereby, Diverter A is assigned the color "Black," which means he/she can divert water even when the flows are less than 936 cubic feet per second (CFS). However, Diverter B is a more junior water right holder and assigned the color "Yellow," which indicates that when the flow rates are below 2000 CFS, he/she cannot divert water. In this scenario, Diverter B is no longer allowed to divert water; however Diverter B needs an additional 75 acre-feet for his/her crops. Meanwhile, Diverter A only needs 25 acre-feet. Since Diverter A has a senior water right and is not using all of his/her allocated share of water, under this system Diverter A could lease the remaining 75 acre-feet to Diverter B. Such transactions would be allowed to take place on a monthly basis. For example, for a 30-day transfer, the annual rate would be prorated to the daily equivalent of the permit's allocated amount.

The Watermaster Lite System is proposed as an experimental option. Its application would no doubt require addi-

[22] The other three watermasters are Brazos Watermaster Program, Concho River Watermaster Program, and South Texas Watermaster Program. (Nueces, San Antonio, and Guadalupe Rivers).

[23] The total number of permitted acre-feet is based on TCEQ (2017b). For the purpose of this exercise, we assume that all of the water rights are allocated for consumptive uses.

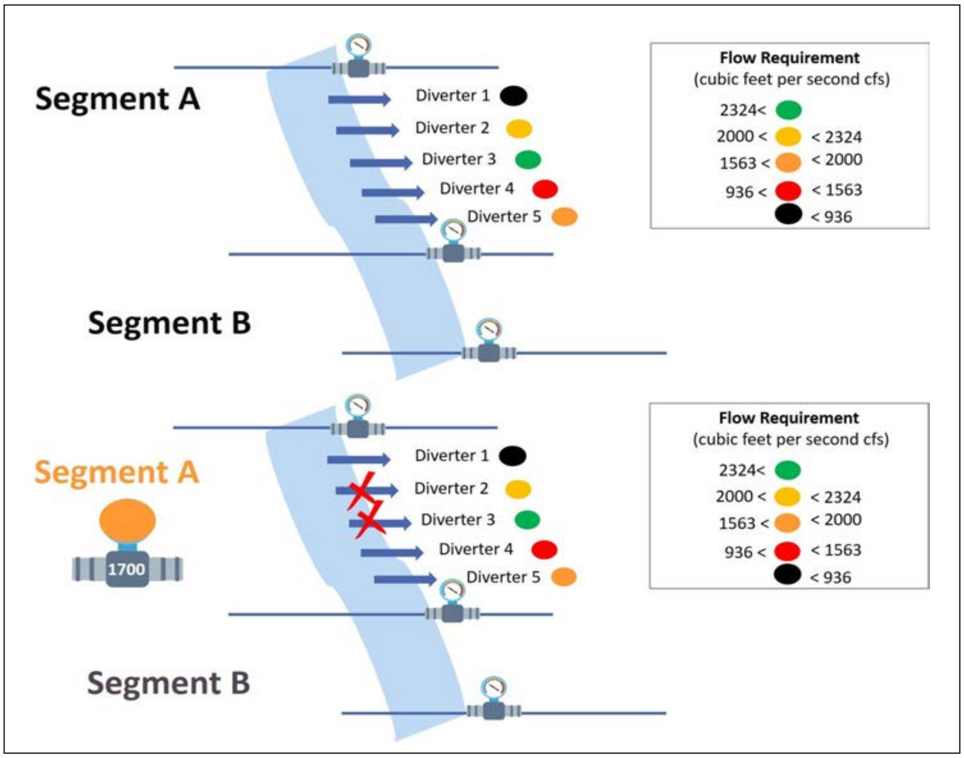

Figure 1. Example of Watermaster Lite System: segments and diverters by color.

tional adjustments and should first be refined for a particular river basin with abundant water.[24] The system would also need adjustments for periods of drought. To succeed during a drought, the Watermaster Lite System must be cheap to administer and have the flexibility to allow temporary changes in diversion points.

The attraction of the Watermaster Lite System is that it retains many of the features of a watermaster system, but would be potentially much cheaper to administer and would have desirable self-policing attributes. Also, permit holders are likely to view it as less intrusive[25] than a watermaster system.

Problem area 2: Water prices are artificially cheap and inflexible

A reoccurring theme within the literature and our surface water policy research (Vaca et al. 2017) revolves around the underpricing of water in Texas (Griffin 2011). The current price scheme of surface water is not economically efficient because it does not reflect how much water is available to use, i.e. it does not include a scarcity premium and thus water prices are artificially low. The main reason why there is no scarcity premium is related to the large amount of permitted water that river authorities sell to their customers at regulated rates based on historical costs. In many basins, river authorities typically control the bulk of diversion permits within a river basin.[26]

Currently, the regulated nature of surface water pricing by river authorities leads to the underpricing of water for two reasons. First, it omits altogether a scarcity premium to reflect the inherent scarcity of water. Second, as quasi-governmental entities, river authorities are constrained to charge rates[27] that only recover their costs. Consequently, the market prices observed in transactions between river authorities and their customers

[24] For example, the number of colors could vary depending on the volume of water rights in adjoining groups. The beauty of the system is that within a color group, all pumpers are treated equally, eliminating conflicts. Nevertheless, conflicts can exist if that pumper was assigned to a different group that would have gained access but was prevented by the original assignment of colors and stream flow limits.

[25] This system can be less intrusive than a watermaster because it would not require the site visits and users would not be required to call in their diversions and get permission to divert.

[26] A prominent exception is the Trinity River Basin where various municipalities already own significant appropriations.

[27] Raw water sold by river authorities or potable water provided by municipalities are based on an average of current and past infrastructure costs. This allows for water to remain underpriced. Neither do they include a scarcity premium. The presence of regulated rates for the transportation, treatment, and local delivery of water is a good thing by protecting consumers from the exercise of monopoly power by wholesale providers. Nevertheless, a byproduct of this regulatory scheme is that prices are too low and inflexible. [Another byproduct is that water is not being conserved because the incentives are lacking.]

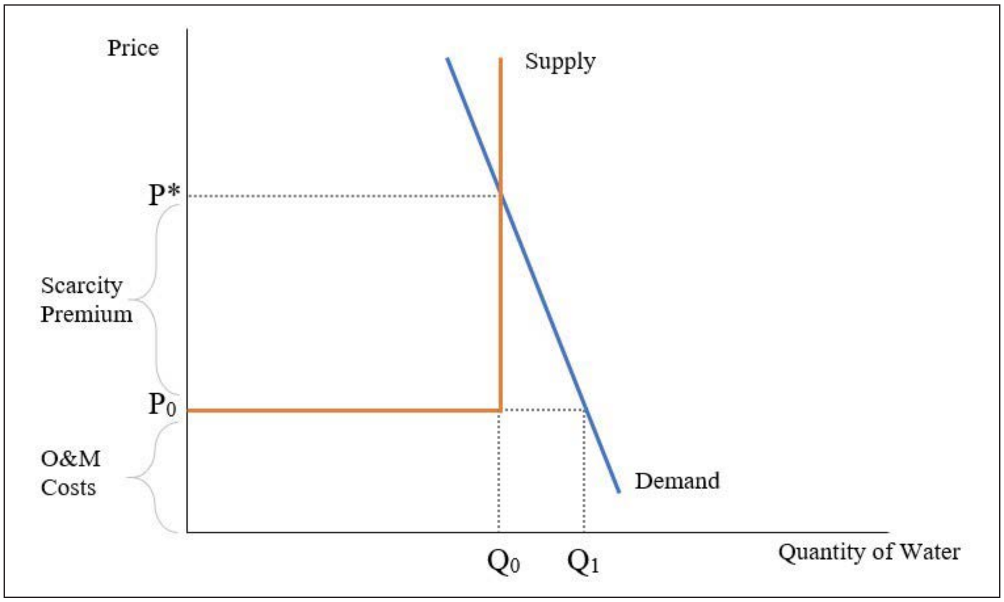

Figure 2. Regulated vs. economic efficient prices.

fail to account for true scarcity and often create a shortage of unmet demand at that regulated price. Figure 2 illustrates the problem. Assume in the example that the river authority has available only Q0 of water available, which it offers for sale to municipal users at the regulated price P0, which covers its operation and maintenance costs. Note that at this price there is unmet demand equal to Q1 – Q0. Typically, to deal with the shortage, the river authority will exercise curtailments across its customer base.

Economic efficiency would dictate that the water goes to its highest valued uses. If in Figure 2, the transaction price were allowed to rise to P*, only users who were willing to pay this price or higher would receive the water. The difference between the regulated price P0 and P* measures in this case the true scarcity premium of the water as shown on Figure 2. From an economic efficiency viewpoint, allowing the price P* to occur guarantees that only the higher valued uses—between 0 and Q0—get the water and the lower valued uses—between Q0 and Q1—are excluded. The alternative of curtailing all uses proportionally has no mechanism to filter out the lower valued uses.

The key takeaways are that if observed market prices do not include the scarcity premium, they understate the true value of water. The regulated prices coupled with rationing are neither efficient nor useful as guides for policy. Price signals from properly functioning markets should fluctuate in response to droughts and furthermore should trend upward in response to population growth and economic activity. Figure 3 shows an example of how prices do not vary according scarcity. This figure shows the regulated rate charged by the Lower Colorado River Authority (LCRA) to its municipal customers over the period 2010 to 2016. Figure 3 also shows the Palmer Drought Severity Index (PDSI) drought index showing the most severe drought in history in 2011. Note that LCRA's prices, which were based solely on operational and infrastructure costs,[28] showed no response to the drought. Paradoxically, when water was abundant in 2015-16, regulated rates actually increased.

In contrast, Figure 4 shows in theory how prices should behave in response to economic growth and droughts. Prices should increase sharply during droughts while maintaining a relative stable but gradual trend when there are no droughts. Population and economic growth should increase the demand of water over time, which means that prices should have an upward trend.

The second reason that surface water prices do not include a scarcity premium refers to limited opportunities to trade surface water rights. As explained in the water allocation section, there are regulatory barriers that can reduce the number of transfers of water. Not allowing these transactions during a drought and relying mostly on river authorities (with regulated rates) prevents water to be priced at its true scarcity price (P* in Figure 2).

In order to promote economically efficient pricing of surface water, policy makers have one of two options. The first option is to create the conditions that give rise to a vibrant water market by doing the three things outlined above: (1) encouraging conjunctive use of groundwater and surface water (2) promoting interbasin transfers, and (3) promoting intrabasin transfers.

[28] LCRA (2014) shows that its rates are calculated as the ratio of cost of services divided by the number of billing units. The costs of services include labor, operation and maintenance, and debt service. By regulation, river authorities such as LCRA are not allowed to charge rates that reflect water scarcity per se but only to recover their operational and infrastructure costs.

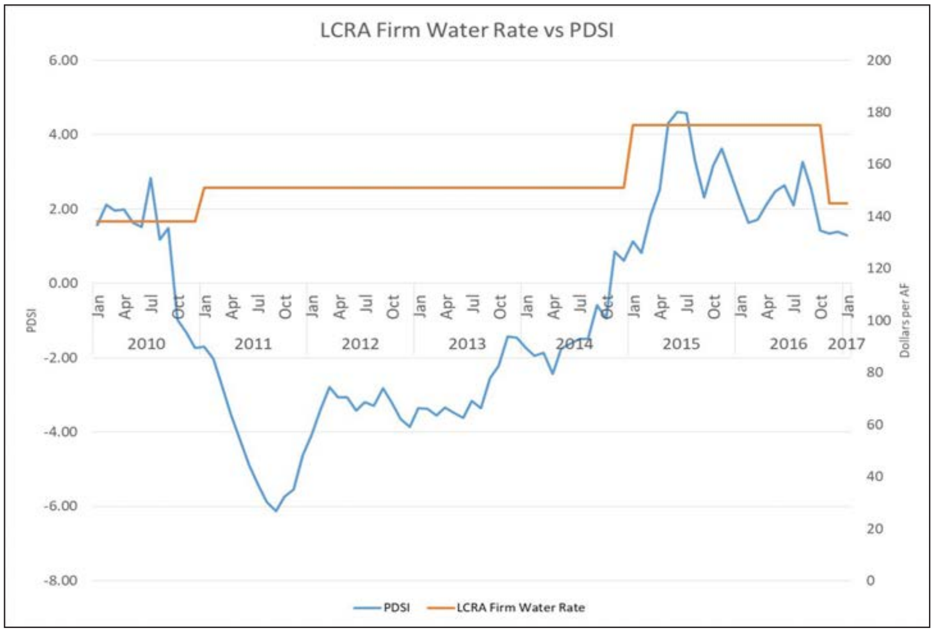

Figure 3. LCRA firm water rate vs. PDSI. Source: [LCRA 2015](), [LCRA 2017](), [Water Data for Texas 2017]().

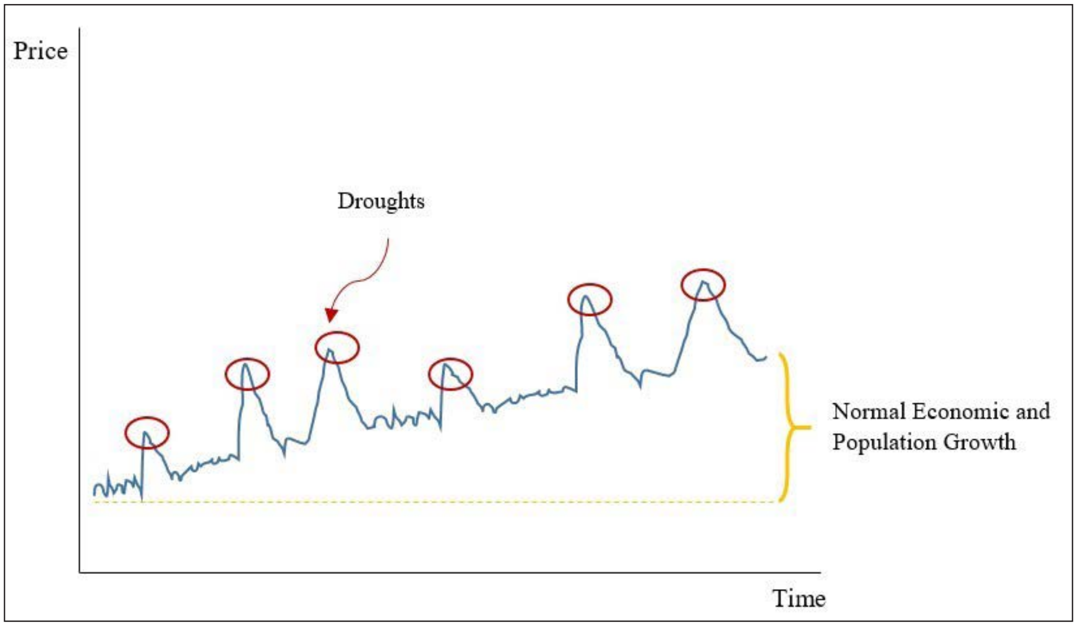

Figure 4. Hypothetical price fluctuations in a well-functioning market.

With the addition of these added sources of supply, market prices should more likely approximate Figure 4 instead of Figure 3.

There is, however, another option that, while less preferable to the authors, will nevertheless promote economically efficient pricing. Let us now turn to the option of a water tax.

Regional water taxes: that vary with water availability by region.

A water tax is designed to address the problem that water prices are artificially cheap and inflexible during droughts. First, the water tax can solve the lack of a scarcity premium because it would vary with water availability by region and can be altered by the State accordingly to address long-term water needs. Second, as the value of the tax will automatically vary

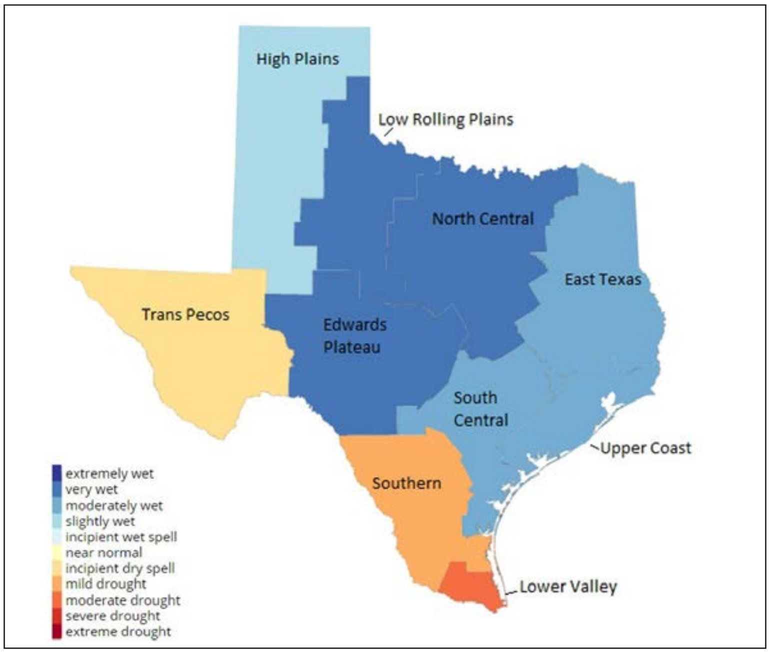

Figure 5. Texas regions for PDSI. Source: [Water Data for Texas – PDSI October 2016](#).

with monthly water availability, it will increase water prices during droughts. Thus, a water tax will act as a water scarcity signal and create incentives to conserve.[29] In fact, Olmstead et al. (2009) suggest that using price mechanisms to allocate scarce water supply is more cost effective than implementing other programs for water conservation. It is important to emphasize that the water tax will not solve the water allocation problem because it will not directly incentivize water transactions nor will it remedy existing administrative problems. Its sole function is to promote conservation.

1. *How the tax would work*

a) The tax should vary with water availability

The most important characteristic of the tax is that it must vary with water availability, reflecting the true value of water in the short and long term. This means that the tax should increase when there is less water available like in the case of a drought.

Another feature is that the tax should vary regionally to reflect water availability. As shown in Figure 5, a regional drought indicator, the PDSI can be used as a measure of water availability to determine the value of the tax.[30] According to Water Data for Texas (2017), the PDSI index is "a meteorological drought index based on recent precipitation and temperature and is used to assess the severity of dry or wet spells of weather." The PDSI generally varies between -6 and +6, where negative values denote dry spells. In recent years, the lowest value that the PDSI has reached in Texas was in September 2011 in the Low Rolling Plains (-6.99).

The proposed tax contemplates one major exemption.[31] The proposed tax offers an 80% discount for agricultural users. Charging a lower tax for agricultural users can be justified by the fact that agricultural users usually face lower water rates (e.g. from interruptible contracts with river authorities), which would mean that even if they had the same price elasticity as that of other consumers, the price increase due to the tax will affect them disproportionally.

[29] Note that this proposal differs fundamentally from the increasing block tariff schedules implemented by many cities whereby high use residential users pay more per thousand gallons. The increasing block tariffs typically do not vary with overall water availability as our tax would and instead act as a mechanism to spread high fixed costs onto high residential users with swimming pools and large lots with sprinkler systems. The latter do not vary over time to incentivize conservation during droughts.

[30] Although the PDSI may not be the hydrologically perfect measure of water supply considering the water in reservoirs, the PDSI does track in advance the changes in water availability in reservoirs. For example see Figure A1 in appendix 1. As an alternative to the PDSI based on nine regions, one could consider computing a PDSI type index for the sixteen state water planning jurisdictions because it might facilitate better water planning and administration. Thus, the illustration here is simply designed to lay out how such an index could be used to determine tax rates that vary regionally.

[31] In addition to an exemption to agricultural users, we propose that the Rio Grande Watermaster be exempt from the tax because it is a basin that works differently from other basins in Texas. It does have a functioning water market, which means that the price of water in this region already implicitly includes a scarcity premium. We also propose to exclude 1 acre-feet of water/month to all permit holders. This exemption reduces the impact and administration burden on small users

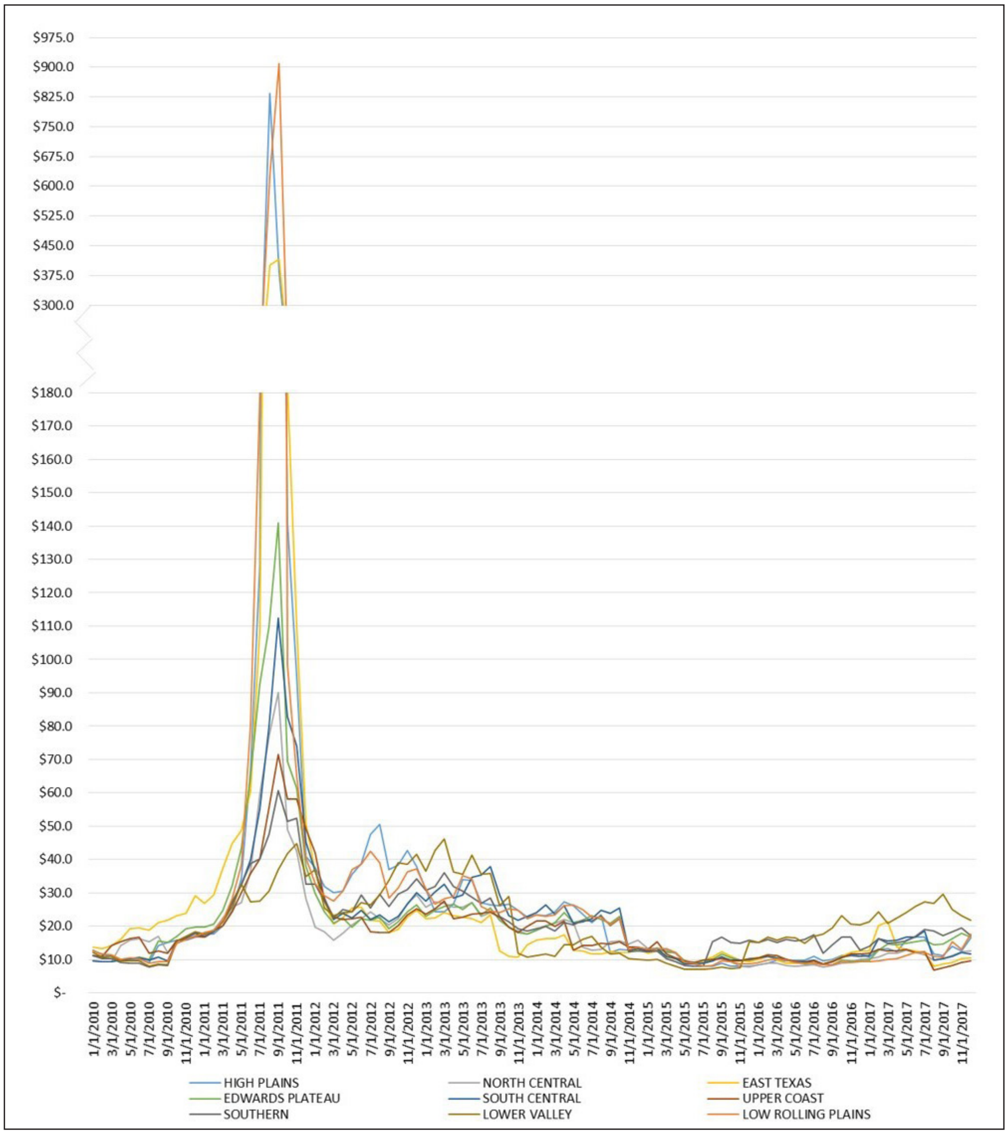

Figure 6. Tax values by region (2010 – Jan 2017) Y=100. Source: Capstone Team Estimations.

b) Payment options and enforcement mechanisms

In order to facilitate payments and revenue collection, all water users will have access to an online account where they will report their monthly water consumption to the TCEQ, who will act as the tax collector.[32] This account will show the tax rate for that month and the total amount owed by the user. To have the optimal effect on users' behavior, monthly bills, rather than quarterly or annual bills, are preferable.

2. *Tax formula and estimation of scenarios*

The main objective of the tax is to reflect the true scarcity of water and thereby encourage the optimal level of conservation. The proposed tax can be calculated using Equation 1. This equation shows that the value of the tax depends on three factors: (1) the numerator (*Y*), (2) a fixed parameter (*Z*) in the denominator, and (3) the PDSI. After simulating with different parameter numbers, we use a value of 7.1 for (*Z*), which in absolute values is slightly larger than the lowest PDSI (during the drought of 2011). In Vaca et al. (2017) we calculated three base scenarios with values of *Y* of 50, 100, and 200. For expositional purposes here, we adopt Y=100.

$$Tax_{rt} = Y/(Z + PDSI_{rt}) \quad \text{Equation 1}$$

In equation 1, *Tax* represents the water tax per acre-foot for a region *r* in a month *t*. The tax for agricultural users will follow the same equation but be only 20% of the calculated value generated by Equation 1. We estimate the corresponding tax values, water conservation, and revenue that would have been

[32] The funds could be used for general revenue purposes or earmarked for special purposes

generated in the period 2010–2016 for the nine[33] regions in Texas.

a) Tax values

The estimation of the tax that each region would have faced since 2010 shows two important points. The first is that the tax structure allows the value to vary considerably with water availability and that the starting value of the tax has an important effect in the average values and level of variability of the tax. The variability of the tax with water availability is also showed graphically as the tax values dramatically increase in 2011 (the year of the drought) and the values decrease in wet years like 2016 (See Figure 6).

The second important conclusion from these estimations is that most of the time, when water is abundant, the tax is relatively low. Whereas, during drought conditions the value of the tax can reach very large values, which is a desirable feature of the tax. If water is scarce, it should cost more to encourage consumers to conserve. Although the tax can reach high values, these peaks rarely occur, and the majority of the regions would face low tax values each month since 2010. For a Y=100, 83.3% of tax values would have been less or equal to $30/acre-foot.[34] Conversely, the tax exceeded $100/acre-foot in only 2.2% of the cases.

b) Water Conservation

Applying a water tax will allow users to face the real scarcity cost of water in their region, which will result in water conservation.[35] This means that the tax will achieve one of its objectives, which is to reduce water consumption, especially in drought conditions like 2011. Based on the values of the tax previously calculated, we can estimate the percentage reduction in water consumption for each month. Equation 2 shows that water conservation depends on the price elasticity of demand for water, the value of the tax and the original water price.[36]

$$\textit{Conservation (\%)} = \textit{elasticity} \times (\textit{Tax}/(\textit{Water Price}) \times 100\%$$

Equation 2

For this estimation, the short run water price elasticity[37] used is 0.38.

Water conservation resulting from the tax can be equivalent to increasing water supply by a certain percentage as it decreases the water deficit. For instance, in 2011 a tax with a *Y=100* would have been equivalent to an increase in supply of surface water by 13.7% for non-agricultural uses and 11.9% for agricultural users. The average water savings for non-agricultural users based on the estimations of the period 2010 to 2017 is 4.4%.

Clearly, Figure 6 shows that a state water tax that varies regionally and monthly could solve the problem that water prices are artificially underpriced and inflexible during droughts. The resulting conservation (Figure 7) during droughts will go a long way toward forcing society to use water more efficiently.

c) Tax revenue collection

As any other tax, the water tax will generate revenue for the state of Texas. As the primary purpose of the tax is to reflect water scarcity and promote conservation during droughts, how revenues of the tax are spent is not the main priority and what agency collects the tax does not have an impact on whether the tax is an economically efficient tool or not. However, we propose that the tax be collected by TCEQ as it is the primary regulatory agency for surface water. In addition, as the revenue comes from water users, it would be good to use these resources for water purposes. One alternative would be for the tax revenues to be put in a fund to cover operational expenses for agencies like TCEQ and TWDB. Another alternative would be to place all revenues of the tax in a fund like State Water Implementation Fund for Texas (SWIFT) that is used for financing water infrastructure projects.

CONCLUSIONS

The intention of the Vaca et al. (2017) report, Surface Water Regulation in Texas: Problems and Solutions, was to stimulate discussion on the pressing policy issues of surface water management in Texas. For purposes of policy analysis, we have adopted the conceptual lens of economic efficiency. We recognize that the inability to fully compensate the losers may cause policy makers to choose equity over economic efficiency. It is, nevertheless, a useful exercise to apply the conceptual

[33] As the Rio Grande is exempted from the fee, the estimations exclude the Trans Pecos regions, which mean that estimations are done only for nine of the 10 regions.

[34] For a starting value of $50, 91% of the tax values would have been below $20/acre-foot and for a starting value of $200, 73.7% of the tax values would have below $50/acre-foot.

[35] There are other policy alternatives that can result in conservation, such as mandatory rationing. As rationing can achieve a precise percentage of conservation, the fact that everyone had to conserve the same proportion makes it economically inefficient. For example, let's consider the mandatory effect of rationing for two users. The first user is an environmentally concerned citizen and has already reduced her water consumption to a minimum. The second user is not so concerned with environment: has inefficient irrigation practices for his yard and sometimes even leaves the faucet running because he forgot. Rationing would force equally both users to conserve an x%, which would be nearly impossible for user 1 while user 2 could conserve more than that %. The tax solves this problem by making water more expensive and thus leading water to its highest and best use automatically.

[36] For this estimation we use an approximation of wholesale water rates for residential users ($3/1000 gallons) and for other users we use the LCRA rates.

[37] See Espey et al. (1997).

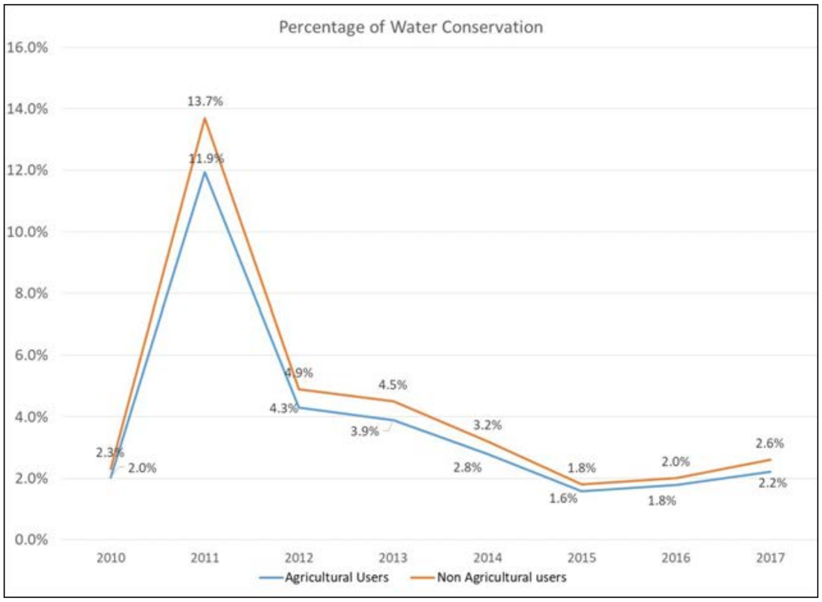

Figure 7. Percentage of water conservation across all regions (2010 – Jan 2017) (Y=100). Source: Capstone Team Estimations.

lens of economic efficiency to surface water policy to look at the benefits foregone to protect various interest groups. This paper focuses on how we can use existing water supplies more efficiently by improving water allocation and water pricing. To improve water allocation and to move water from lower valued uses to higher valued uses, we identified the following three mechanisms: (1) encouraging conjunctive water use, (2) removing roadblocks to interbasin transfers and (3) facilitating intrabasin transfers. The latter proposed a Watermaster Lite System.

To correct the current water pricing system that undervalues water and is inflexible to droughts, we present two alternatives—a water tax and an active water market. In contrast to the current artificially low and inflexible pricing system, water taxes that vary regionally in response to drought conditions could be a powerful force for conservation. The other alternative, creating an active water market, is perhaps an even more daunting task since it will require reforming legal and administrative procedures to facilitate trading of water. Nevertheless, we believe that a vibrant water market is superior to a tax because it will solve both the issues of water pricing as well as the water allocation problem.

REFERENCES

Bhojwani S, Topolski K, Mukherjee R, Sengupta D, El-Halwagi M. 2019. Technology review and data analysis for cost assessment of water treatment systems. Science of the Total Environment. 651:2749–2761.

Brady R, Beckermann W, Capps A, Kennedy B, McGee P, Northcut K, Parish M, Qadeer A, Shan S, Griffin J. 2016. Reorganizing groundwater regulation in Texas. Capstone Project, Bush School of Government- Report to State Comptroller, Glenn Hegar.

Cai Y, McCarl B. 2007. Economic, hydrologic and environmental appraisal of Texas inter-basin water transfers: model development and initial appraisal. College Station (Texas): Texas Water Resource Institute. TR-301. [accessed 2018 May 8]. Available from: https://oaktrust.library.tamu.edu/handle/1969.1/6074.

Castleberry B, Acevedo A. 2017. Water barons for the water barren? A survey of interbasin water transfer laws in western state. Texas Water Journal. 8(1):29–41.

Espey M, Espey J, Shaw WD. 1997. Price elasticity of residential demand for water: A meta-analysis. Water Resources Research. 33(6):1369-1374.

Gould G. 1988. Water rights transfers and third-party effects. 23 Land & Water Law Review. 1.

Griffin RC. 2011. Water policy in Texas: responding to the rise of scarcity. Washington (District of Columbia): RFF Press and Earthscan.

Griffin JM. 2017. Interjecting economics into the groundwater policy dialogue. Texas Water Journal. 8(1):97-112.

Gruber J. 2013. Public finance and public policy. New York (New York): Worth Publishers.

Hanak E, Lund J, Dinar A, Gray B, Howitt R, Mount J, Moyle P, Thompson B. 2011. Managing California's water: from conflict to reconciliation. San Francisco (California): Public Policy Institute of California. [accessed 2018 May 14]. Available from: http://www.ppic.org/publication/managing-californias-water-from-conflict-to-reconciliation/.

[LCRA] Lower Colorado River Authority. 2014. Cost of service. Austin (Texas): Lower Colorado River Authority [accessed 2018 May 8]. Available from: https://www.lcra.org/water/water-supply/Documents/Cost-of-Service-Fact-Sheet-1-14-14.pdf.

[LCRA] Lower Colorado River Authority. 2015. LCRA water rate. Austin (Texas): Lower Colorado River Authority [accessed 2017 January]. Available from: http://www.lcra.org/water/water-supply/water-supply-contracts/Documents/2015-11-6-LCRA-Water-Rates.pdf.

[LCRA] Lower Colorado River Authority. 2017. Water supply contracts. Austin (Texas): Lower Colorado River Authority [accessed 2017 April 1]. Available from: https://www.lcra.org/water/water-supply/water-supply-contracts/Pages/default.aspx.

Martini R. 2007. The role of compensation in policy reform. OECD Food, Agriculture and Fisheries Working Papers. 5. Publishing. doi:10.1787/125487536033

McKinney L. 2012. Groundwater ruling's dire consequences. Texas Living Waters. [accessed 2018 May 8]. Available from: http://texaslivingwaters.org/wp-content/uploads/2013/03/tlw-news-3-12-12.pdf.

Olmstead SM. 2009. Comparing price and nonprice approaches to urban water conservation. Water Resources Research. 45(4).

Pascual U, Muradian R, Rodríguez LC, Duraiappah A. 2010. Exploring the links between equity and efficiency in payments for environmental services: a conceptual approach. Ecological economics. 69(6):1237-1244.

Potter L, Hoque N. 2014. Texas population projection 2010 to 2050. Office of The State Demographer. [accessed 2018 May 8]. Available from: http://demographics.texas.gov/Resources/Publications/2014/2014-11_ProjectionBrief.pdf.

Restore the Gulf. 2018. About the RESTORE Act. Restore the Gulf. [accessed 2018 May 8]. Available from: https://www.restorethegulf.gov/history/about-restore-act.

RW. Beck Inc.. 2006. Socioeconomic analysis of selected interbasin transfers in Texas. R.W. Beck, Inc. Report prepared for Texas Water Development Board.

Sophocleous M. 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal. 10(1):52-67.

[TCEQ] Texas Commission on Environmental Quality. 2013. An emergency order. Austin (Texas): Texas Commission On Environmental Quality. [accessed 2018 May 8]. Available from: https://www.tceq.texas.gov/assets/public/response/drought/emergency-mods/01-29-13-lcra-order.pdf.

[TCEQ] Texas Commission on Environmental Quality. 2017a. Instructions for completing the water rights permitting application. Austin (Texas): Texas Commission on Environmental Quality.

[TCEQ] Texas Commission on Environmental Quality. 2017b. Water rights and water use data. Austin (Texas): Texas Commission on Environmental Quality. [accessed 2017 April 1]. Available from: https://www.tceq.texas.gov/permitting/water_rights/wr-permitting/wrwud.

[TCEQ] Texas Commission on Environmental Quality. 2018. 85th Texas legislative highlights: SB 1430. Austin (Texas): Texas Commission on Environmental Quality. [accessed 2018 May 14]. Available from: https://wayback.archive-it.org/414/20180904115302/https://www.tceq.texas.gov/news/tceqnews/features/85th-texas-legislative-highlights#sb1430.

Texas Comptroller. 2018. Economy. Comptroller Texas. [accessed 2018 May 8]. Available from: https://comptroller.texas.gov/economy/50state/.

Texas Water Code 11.085(s)

[TWDB] Texas Water Development Board. 2018. Houston metro success story: Luce Bayou interbasin transfer project. Austin (Texas): Texas Water Development Board. [accessed 2018 May 14]. Available from: http://www.twdb.texas.gov/newsmedia/featured/projects/luce_bayou/index.asp.

Vaca M, Richards S, Davis A, Jackson K, Timur N, Manzoor F, Azam S, Feltman RJ. 2017. Surface water regulation in Texas: problems and solutions. Capstone Project, Bush School of Government- Report to State Comptroller, Glenn Hegar.

Votteler T, Alexander K, Moore J. 2007. The evolution of surface water interbasin transfer policy in Texas: viable options for future water, water grabs, or just pipe dreams. State Bar of Texas Environmental Law Journal. 36(3):125.

Water Data for Texas. 2017. Palmer Drought Severity Index (Monthly). [accessed 2017 March 22]. Available from: https://waterdatafortexas.org/drought/pdsi/monthly?time=2016-10.

Winter TC, Harvey JW, Franke OL, Alley WM. 1998. Ground water and surface water a single resource. Denver (Colorado): U.S. Geological Survey. 79 p. U.S. Geological Survey Circular 1139.

World Bank Data. 2018. GDP Current US$. The World Bank. [accessed 2018 May 8]. Available from: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?name_desc=true.

Wurbs RA. 2015. Sustainable statewide water resources management in Texas. Journal of Water Resources Planning and Management. 141(12).

[WGA] Western Governors Associations. 2012. Water transfers in the West. Western Governors Association. [accessed 2017 April 6]. Available from: http://westgov.org/images/editor/Water_transfers_in_the_West_December_2012.pdf.

APPENDIX 1

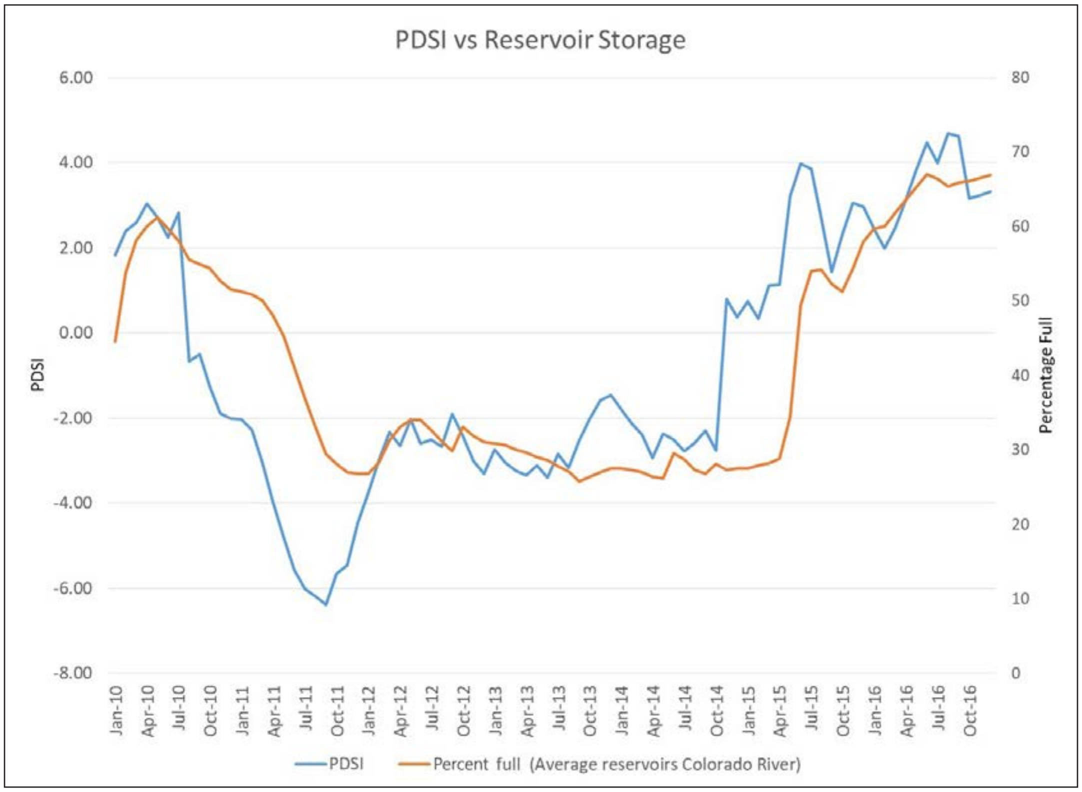

Figure A.1 PDSI and Reservoir Storage. Source: Date from Water Data for Texas 2017.

Although the PDSI may not be the hydrologically perfect measure of water supply considering the water in reservoirs, the PDSI does track in advance the changes in water availability in reservoirs. Figure A.1 shows how that the PDSI moves in the same direction as the Reservoir Storage. The correlation coefficient between these two variables is 0.73 and is statistically significant at the 1% level. In addition, Table A.1 shows the results of two simple regressions between these variables. The first line shows the results for the regression of the PDSI on Reservoir Storage with an R2 of .542. The second line also includes the lag of the PDSI (1 month before) on Reservoir Storage and the R2 increases to .64, which means that PDSI has power to predict the next month of Reservoir Storage.

Table A.1. Regression Analysis of PDSI and Reservoir Storage.

Regression	R2
Percentage Storage on PDSI	.542
Percentage Storage on PDSI and One Month Lagged PDSI	.640