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Cover photo: Anzelduas Dam in Hidalgo County. Photo courtesy of the Texas Water Development Board.

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Groundwater use in the Eagle Ford Shale: some policy recommendations

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Abstract: Advances in hydraulic fracturing (fracking) and horizontal drilling have allowed oil and gas companies to tap into Texas' previously inaccessible shale reserves. Fracking in the state has grown at an exponential rate and is not expected to decline until 2025. Fracking requires the consumption of vast amounts of groundwater, a resource that is already strained. This study quantifies the water consumption associated with fracking in the Eagle Ford Shale, evaluates the current regulatory framework, and proposes 3 policy recommendations. The data show that fracking has become the primary consumer of groundwater in the most active counties within the Eagle Ford. Our study proposes 3 policy solutions to ensure that groundwater is consumed in an economically efficient manner in these areas. These solutions are a more thorough system for reporting consumption, tax incentives for oil and gas companies to use substitutes for fresh groundwater, and an alternative property rights system to the current rule of capture system.

Keywords: Hydraulic fracturing, policy recommendations, groundwater, fracking incentives, groundwater bank accounts

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Terms used in paper

Short name or acronym	Descriptive name
DFC(s)	desired future condition(s)
GCD(s)	groundwater conservation district(s)
MAG(s)	modeled available groundwater(s)
RRC	Railroad Commission of Texas
TWDB	Texas Water Development Board
UWCD	underground water conservation district

INTRODUCTION

The proliferation of hydraulic fracturing (fracking) has allowed oil and gas companies to tap into the United States' vast and previously inaccessible shale resources. In just a few years, fracking for shale resources has transformed the energy landscape within the United States, placing the country on a path toward increased energy security. Nowhere has the growth been more profound than in the Eagle Ford Shale. As shown in Figure 1, the Eagle Ford Shale formation extends beneath 30 Texas counties, stretching from Brazos County (Bryan/College Station) to Webb County (Laredo).

According to the Railroad Commission of Texas (RRC), "the Eagle Ford Shale is considered one of the top-producing shale plays in North America, serving as the second largest tight oil play and ranking fifth in terms of shale gas production (RRC

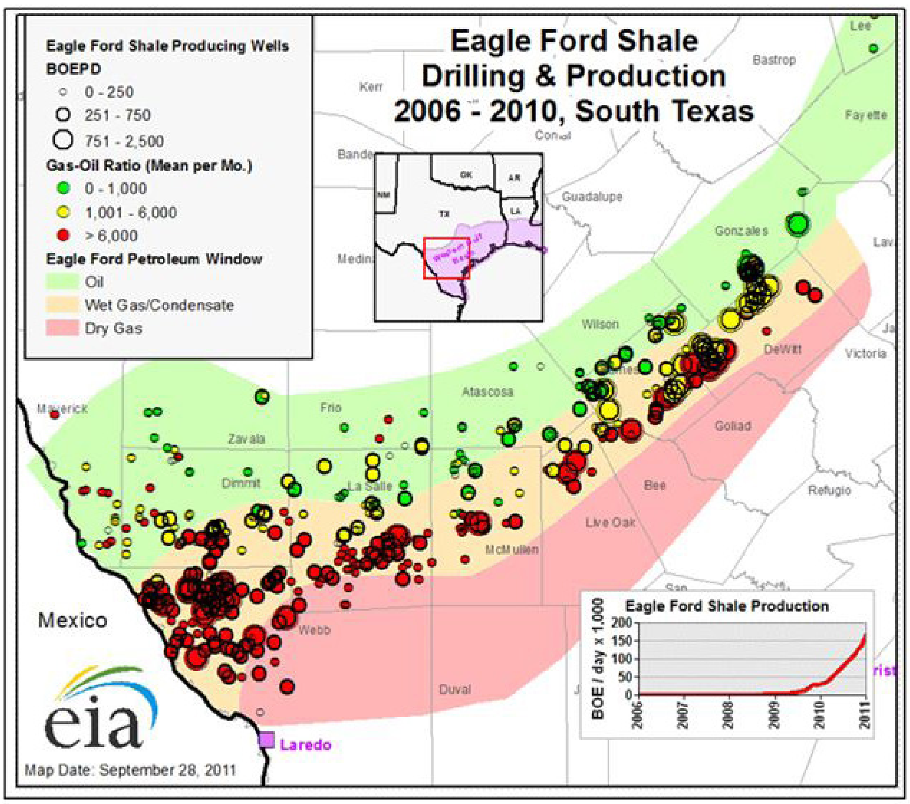

Figure 1. Map of the Eagle Ford Shale oil, gas and condensate play (EIA 2011).

2013).” What is perhaps most remarkable about oil and gas production in the Eagle Ford Shale is not only the phenomenal rate at which production continues to increase but also the short period of time in which the Eagle Ford has been under development. The area’s first well wasn’t drilled until 2008, but by 2012 there were 1,260 oil-producing wells and 875 gas-producing wells within the Eagle Ford (RRC 2013).

The large production growth seen in the Eagle Ford to date only represents a fraction of the potential production that could occur in the region. If gas prices rise and oil prices remain above $80 per barrel, then this rapid growth can be expected to continue. With January 2015 oil prices hovering near $50 per barrel, these lower prices will obviously slow the development of this area. Ultimately, prices are likely to rise again, meaning this development has simply been shifted forward into the future. A typical fracking well in the Eagle Ford is estimated to consume about 13 acre-feet of water for a standard 5,000-foot lateral (Arnett et al. 2014). Approximately 90% of water for fracking comes from fresh groundwater aquifers (Arnett et al. 2014).

At this point there has been no study to critically analyze the current state of water use for fracking operations versus other water uses within the Eagle Ford nor has there been any assessment of policy alternatives to the status quo. Using statistics and economics, this paper quantifies the relative importance of fresh groundwater use for fracking in the Eagle Ford counties and contrasts these with other uses. Next, we briefly describe the existing regulatory framework within which fresh groundwater is consumed. Finally, this paper concludes with 3 policy recommendations.

PIECING TOGETHER GROUNDWATER USE AND RECHARGE ESTIMATES

Through our research, we identified several potential issues with current groundwater trends in the Eagle Ford. The following sections show the relationship of water to recharge rates for the entire Eagle Ford and the groundwater usage in the 7 most active counties in terms of drilling activity in the play.

To determine water use by industry, we used water-use data from the Texas Water Development Board (TWDB) (TWDB 2015) for municipal, mining, irrigation, manufacturing, livestock, and power-generation sources. We combined power, manufacturing, and livestock into one category, which is listed as other, since these sources are typically minor in these counties. Under TWDB nomenclature, mining is essentially all oil and gas consumption. Unfortunately, its data for mining makes no attempt to measure water consumption for fracking. Thus, we replaced the TWDB mining estimate with oil and gas by relying on data reported to the RRC. After estimating the total water used for fracking in the Eagle Ford over the 4-year period, we assumed 90% of that water came from fresh groundwater, with the bulk coming from the Carrizo-Wilcox, Sparta, and Queen City aquifers (Industry interview 2014). Because of the semi-arid nature of the area, surface water supplies are quite limited, explaining the reliance on groundwater (Scanlon et al. 2014). The following 21 counties were used in this analysis: Atascosa, Bee, Brazos, Burleson, DeWitt, Dimmit, Fayette, Frio, Gonzales, Grimes, Karnes, La Salle, Lavaca, Lee, Live Oak, Madison, Maverick, McMullen, Webb, Wilson, and Zavala.

Each groundwater conservation district (GCD) publishes a water management plan, which includes annual recharge rates for each aquifer within the GCD. We totaled these rates to get the total annual recharge rate for the GCD and then aggregated across counties. This is represented in Figure 2 by the line labeled “recharge estimate.” It is important to realize that in confined aquifers, the recharge rate will be small, so usage will, often by necessity, exceed the recharge rate. Furthermore, much of the oil and gas activity in the Eagle Ford appears to be concentrated in the confined portion of the Carrizo-Wilcox Aquifer (Scanlon et al. 2014). The GCD management plans used in this paper came from Bee GCD (2012), Bluebonnet GCD (2013), Brazos Valley GCD (2010), Evergreen UWCD (2011), Fayette County GCD (2013), Gonzales County UWCD (2014), Lost Pines GCD (2012), McMullen County GCD (2008), Mid-East Texas GCD (2009), Pecan Valley GCD (2009), Post Oak Savannah GCD (2012), and Wintergarden GCD (2011). The most up-to-date management plans available at the time of this article were used.

More than 500,000 acre-feet per year of fresh groundwater are used annually within the study area (TWDB 2015). This was calculated by totaling the TWDB historical use estimates for counties in the Eagle Ford Shale region. This use level exceeds the estimated recharge rate for counties in the play by more than 300,000 acre-feet per year. The aquifers in this area are being drawn down at about 2.5 times their estimated average recharge rates. As shown in Figure 2, groundwater used for fracking operations has been increasing every year since 2010 and now makes up the third largest use of groundwater in the area (64,000 acre-feet per year or 12.5%). Despite the growth in this sector, irrigation still makes up more than half of all groundwater used in the study area, reflecting the rural nature of these counties. The amount of groundwater being used for irrigation alone exceeds the recharge rate by more than 50%.

The development of hydraulic fracturing activities within the Eagle Ford is still relatively recent, and further development is just a matter of time, price, and technology. If natural gas prices rise and oil prices return to 2014 levels, we can expect fracking operations to use an increasing amount of the

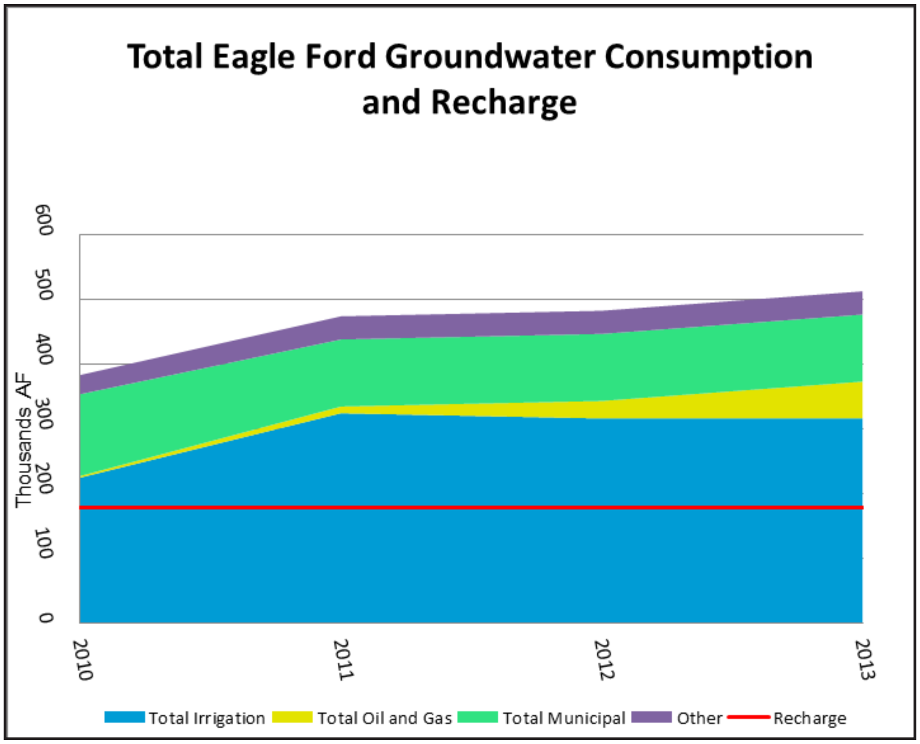

Figure 2. Total Eagle Ford groundwater use and recharge in acre-feet.

region's groundwater. To show how drilling could increase in the less-developed counties in the future, Figure 3 shows groundwater usage by sector for the top 7 counties in terms of drilling activity in the Eagle Ford: DeWitt, Dimmit, Gonzales, Karnes, La Salle, McMullen, and Webb. In 2013, these 7 counties accounted for 84.6% of the wells drilled in the Eagle Ford.

In Figure 3, the aggregation of counties shows the magnitude

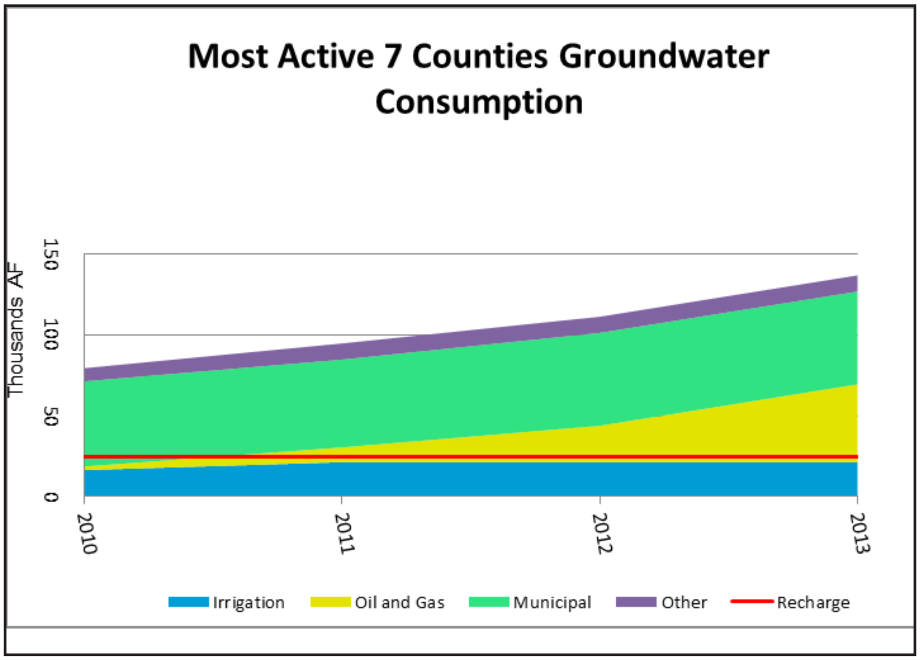

Figure 3. Groundwater use and recharge in acre-feet for the 7 most active counties in terms of drilling activity in the Eagle Ford Shale.

and speed at which fracking has grown in the area. In 2010, fracking was a minor user of groundwater. However, in just 4 years it has become the second highest user of fresh groundwater and currently makes up 30% of total consumption. By 2013, total consumption exceeded the average estimated recharge by 3.8 times. The rapid growth in drilling activity in these counties demonstrates the difficulty of predicting the growth of groundwater use for fracking operations and the potential to see rapid growth in other Eagle Ford counties under the right conditions.

As mentioned earlier, the Eagle Ford is still relatively young in its development despite the large growth already seen in the region. Table 1 shows the total freshwater used for fracking from 2010 to 2013 compared to the potential water needed to fully develop the estimated potential reserves of the Eagle Ford based on an estimated 13.6 billion barrels of oil and 119 trillion cubic feet of natural gas (ARI 2013).

Table 1 outlines the assumptions used to estimate future groundwater requirements assuming the status quo. These numbers should be used as a general reference and not an exact forecast due to the many factors that affect the Eagle Ford's development. These figures assume that oil and gas prices will eventually rise to a point where all of the proved reserve oil and gas in the Eagle Ford are economic to produce. These assumptions are made without a time frame restriction on drilling. We also assume that water consumption per well and the percentage of water from fresh groundwater will remain constant in the future. As explained later, unless there are policy changes, these assumptions appear to be realistic. Under these assumptions, past usage is only 6.7% of the total fresh groundwater that will be eventually needed, and future usage could require an additional 1.35 million acre-feet for fracking. But, is this realistic given the rapid technological changes in this industry?

Much of the analysis of water use for fracking within the Eagle Ford Shale, and across the state of Texas, has relied on data from the *Oil and Gas Water Use in Texas: Update to the 2011 Mining Water Use Report* (Nicot et al. 2012). This report indicates that over time technological improvements would allow the industry to drastically curtail its use of all water, including fresh groundwater for fracking operations. For some areas in Texas this may be true; however, our analysis concluded, at least in the Eagle Ford, this is not likely to be the case. In studying the rate of water use within the Eagle Ford over a 4-year period (2010–2013), it became apparent that, on a per-well basis, water use for fracking operations had indeed decreased, particularly in 2011 and 2012. However, by 2013 we did not observe any additional water-saving technological changes, suggesting that the technology had matured.

Arnett et al. (2014) concluded that the changes measured for water use in fracking operations are not the result of major discrete technological advances but of an industry learning to perfect its craft. The change in fracking water use seen from 2010 to 2011 and in 2012 and 2013 indicates there is a learn-

Table 1. Future fracking water potential consumption.

Assumptions	
Acre-feet/well	13.23
Fresh groundwater (%)	90%
Potential gas reserves (10^{12} cubic feet)	119
Reserves/well (10^{9} cubic feet)	2
Total potential wells	59,500
Potential oil reserves (10^{9} barrels)	13.6
Barrels/well	220,000
Total potential wells	61,818
Implied fresh groundwater use	
Potential acre-feet for gas wells	787,371
Potential acre-feet for oil wells	818,048
Total potential water (acre-feet) for oil and gas	1,605,420
Total potential groundwater (acre-feet) oil and gas	1,444,878
Previous consumption 2010–2013 (acre-feet)	97,157
Percent of total	6.72%
Potential future consumption (acre-feet)	1,347,721

ing curve present, thus there is little basis for assuming large water savings from technological improvements in the future. We hypothesize that without policy changes, fresh groundwater use for fracking within the Eagle Ford Shale will not decouple from drilling activity as was stated in the report by Nicot et al. (2012).

CURRENT REGULATORY APPARATUS: THE RULE OF CAPTURE AND GCDS

Groundwater use in Texas is primarily governed through the oversight of GCDs; however, that regulatory power has been significantly circumscribed by the rule of capture. For a detailed history, see Drummond et al. (2004). The rule of capture applies to groundwater and, prior to regulation by the RRC, to oil and natural gas. The principle behind the rule of capture is that, absent malice or willful waste, landowners have the right to take all the water they can capture under their land and do with it as they please, and they will not be liable to neighboring landowners even if they deprive their neighbors of the water use (Potter 2004). Absent strict regulatory limitations from GCDs, this creates a strong incentive for groundwater owners to pump as much as they can as quickly as they can, lest their neighbor captures the same groundwater.

In many key counties within the Eagle Ford Shale, there exists a real conflict between current and future fresh groundwater consumers, as well as between irrigation, municipal, and oil and gas users (Jervis 2014). Under the status quo, consumers of fresh groundwater place a scarcity value on fresh groundwater that is essentially zero. In this context, scarcity value is defined as the increased value of a resource as it is depleted. The primary cost of groundwater is the cost of drilling and pumping the water well. A water well used for fracking is assumed to cost an average of approximately $500,000 (Industry interview 2014). In oil and gas production, after fracking is completed, the water well becomes essentially free to the landowner, pursuant to the terms of the lease for oil or gas development. With no designated monetary value on the scarcity value of water, there is little incentive to use less today and save for future consumption. Whether for livestock, municipal, irrigation, or oil and gas, the average water producer consumes as much water as they like, only to the extent GCDs restrict their use. But this regulation is typically non-binding since GCDs set the ceiling for irrigation in excess of actual water usage. For oil and gas companies, Section 36.117b of the Texas Water Code exempts oil and gas companies use of water for drilling and exploration (Texas Water Code Ann. § 36.117). Some ambiguity arises about whether water for fracking is considered a part of drilling and exploration activity; nevertheless, GCDs have been reluctant to restrict permitting or water use, though they may limit groundwater pumped off the lease to other locations.

Thus, large-scale water users are competing for a diminishing aquifer resource with no market signals of increasing scarcity, which would otherwise moderate consumption. Huang et al. (2012) report drops of 100 feet to more than 300 feet in the Carrizo Aquifer in the southern portion of the Carrizo-Wilcox Aquifer—the primary aquifer for fresh groundwater in the Eagle Ford. Even if oil and gas drilling were not prevalent in this region, the Eagle Ford aquifers would still be drained by unrestrained use for other purposes. This reduction is because consumers of water resources are not slowed either by a price function or by the existing GCD regulatory structure in Texas. As a general matter, agricultural users usually have exemptions or an allotment, which is rarely exceeded. Statutorily, GCDs may not require a permit for a water well supplying water to a rig actively engaged in drilling or exploration, though the water well must conform to GCD rules on casing, piping, and fittings (Texas Water Code Ann. § 36.117). Even simple metering is not required or enforced for either agricultural or oil and gas users. Assigning blame to either category of user without adequately addressing the overall problem in Texas misses the crux of the water issue.

Other than wells used for oil and gas development, GCDs have the power to restrict drilling of wells and pumping of water, using a variety of approaches, including spacing rules and limiting proportionality of production to acreage stipulations (unless exempt, as with oil and gas). GCDs also develop periodically updated desired future conditions (DFCs), which are used in conjunction with modeled available groundwater (MAGs) and become the basis to permit, deny, or restrict groundwater use (Mace 2006). MAGs are quantitative descriptions of groundwater resources in a management area. GCDs preparing DFCs pursuant to recommendations for their groundwater management areas must identify aquifers, identify acceptable change to such aquifers over time, and produce a 50-year planning horizon in 10-year increments. In principle, the requirements to achieve the DFC within a groundwater management area should require GCDs to have rules with teeth. However, in practice GCDs can come back periodically and change to a more permissive DFC, thus avoiding regulations that significantly impact current uses.

As noted above, the ambiguous regulatory power of GCDs over wells drilled and groundwater pumped in connection with oil and gas exploration results in minimal enforcement. Furthermore, irrigation wells that fall under GCDs authority are assigned allotments of water that guarantee their maximum usage. Essentially, only physical waste is prohibited. Likewise, municipalities are allowed to pump their required allotments, which are based on their needs and not the drawdown of the aquifer. Although GCDs presumably have the power to reduce water use, it appears to be rarely done—at least in the Eagle Ford area.

Curiously, GCDs do restrict pumping in a peculiar, perverse manner. Typically, a landowner must receive GCD approval (an export permit) to sell groundwater to someone outside the boundary of the GCD. With a major city such as San Antonio nearby, rationality indicates that an irrigator growing corn for ethanol should instead be allowed to sell his water to San Antonio. Clearly, water for San Antonio has higher value than irrigated corn production. However, selling water outside the GCD is contingent; local control of GCDs results in electing board members who are likely to thwart water sales outside the GCD.

GCD power is further circumscribed by the rule of capture. The currently constituted powers of GCDs are in tension and potentially conflict with the rule of capture in light of recent case law. Regulatory overreach by GCDs may amount to a "taking" of property rights. Similarly, tighter regulation by GCDs may lead to courts narrowing GCD powers by declaring something close to a per se taking.

Eliminating the rule of capture doctrine in Texas may amount to a taking of property rights under the Fifth Amendment to the U.S. Constitution and Article I, section 17 of the Texas Constitution. The Takings Clauses of the U.S. and Texas constitutions are straightforward, though their application may not be. The Fifth Amendment states, "private property [shall not] be taken for public use, without just compensation." Article I, section 17 of the Texas Constitution guarantees,"No person's property shall be taken, damaged or destroyed for or applied to public use without adequate compensation being made." These Takings Clauses were "designed to bar Government from forcing some people alone to bear public burdens which, in all fairness and justice, should be borne by the public as a whole." (*Armstrong v. United States* 1960)

In 2012, *Edwards Aquifer Authority and Texas v. Day and McDaniel* held that, under Article I, section 17 of the Texas Constitution, regulators can limit water usage, but land ownership still includes an interest in groundwater in place, which cannot be taken for public use without compensation (*Edwards Aquifer Authority and Texas v. Day and McDaniel* 2012). Thus, tension exists between landowners' ownership of percolating water and Texas groundwater districts' statutory assertion of regulatory rights over such property. Under Chapter 36 of the Texas Water Code, GCDs have power to adopt minimum well spacing or tract size requirements, set water production shares according to acreage owned, and set production limits on specific wells.

Under the existing legal rulings and GCD structure, we appear headed for endless litigation, for which GCDs are ill-equipped. GCDs are funded by local tax sources and are likely unable to finance protracted litigation. The goal of our third proposal is to clearly define property rights of groundwater and thereby end the possibility of endless litigation.

In sum, the inherent problems in the Texas regulatory scheme for managing underground freshwater use cannot be solved by GCDs themselves. In addition to the political problems, GCDs are limited in power and resources. Some will argue that GCDs, through decades of tepid effectiveness, have contributed to the present magnitude of the problem. Even if GCDs were historically more effective, a new wave of takings cases asserting the primacy of the rule of capture and the Fifth Amendment could potentially bankrupt any GCD inclined to try to flex its regulatory muscle.

OVERVIEW OF POLICY RECOMMENDATIONS

Our 3 policy recommendations are organized in order of their ease of implementation. The first requires mandatory metering of groundwater use. This is a prerequisite to informed policy. Currently, the state relies on a mishmash of sources and estimates. Water has simply become too valuable to treat it as a free resource. Second, we propose a combination of incentives and public commendation to encourage oil and gas companies active in the Eagle Ford to avoid using fresh groundwater by substituting with brackish water, municipal treated wastewater, or recycled water. This proposal will allow the continued development of the Eagle Ford and have the advantage of removing the oil and gas industry from the future conflict over fresh groundwater. Our third recommendation is admittedly politically problematic and would face many hurdles. Nevertheless, its ambitious focus is on alleviating the perverse incentives of the rule of capture via a groundwater banking system.

Policy recommendation 1: mandatory reporting for all water uses

A prerequisite to any informed water policy is the need for accurate data on water consumption. Categorically, this means improving the transparency of data reporting by irrigation, municipal, oil and gas, and other use categories. Below is a summary of the status quo as it pertains to data reporting:

- ***Irrigation:*** The TWDB merely estimates the acre-feet of water consumption per observed crop and irrigation acreage by aerial and fence-line approximations.
- ***Livestock:*** Rural landowners' and ranchers' water consumption is formula-based in accordance with livestock and other miscellaneous factors. However, wells used solely for domestic and livestock purposes require no reporting of pumping or use.
- ***Municipal use:*** Municipalities and non-oil and gas-related industries have the most accurate data, as they measure production and use, including retail customer sales. However, the split between surface water uses versus fresh groundwater uses is not always clear.

- ***Industrial:*** Industrial and power plants that are not customers of local municipal utility companies may or may not have metering and accurate pumping data.
- ***Oil and gas:*** Beginning in February 2012, the RRC required a report for each well drilled that includes the number of barrels of water used for drilling and fracking purposes (1 16 TAC §3.29). However, the RRC reporting requirement does not require that the respondent provide either the type of water—surface water, fresh groundwater, brackish groundwater, or recycled water—nor the source—well depth and location.

If reported, these data are submitted either to the GCDs, the TWDB, or the RRC. There appears to be little coordination of data gathering and little ability to monitor the correctness of the data. For example, the water usage reported to the RRC had numerous errors where the respondent may have entered barrels instead of gallons. Out of 6,752 wells reported, our analysis indicated there were 3,002 wells either with implausible volumes of water used for fracking or missing data. To alleviate this lack of transparency, our policy recommendation will make all well depths and water consumption categories, including salinity of the water, reportable.

Our proposal is for groundwater consumption data to be reported online and subject to spot checks. Specifically, this proposal would cover the following groups:

- Irrigation users should be required to install metering equipment and report usage to the GCDs or equivalent county reporting agency.
- Rural homeowners with a water well would be exempt from metering but not from reporting estimated usage. In an applied system, we recommend the development of a formula to handle water consumption, estimating user consumption under a certain threshold. This information would be reported to the resident's GCD or equivalent county reporting agency.
- Other agricultural users, such as ranchers and poultry operations, would be required to meter groundwater usage. This information would be reported to the TWDB.
- Municipalities should be required to meter groundwater consumption and to distinguish between brackish and fresh groundwater. This includes requiring residential customers within the municipality's service areas who drill personal wells to meter and report to the utility. This information would be reported to the TWDB.
- Industrial users served by their own wells should be required to meter and report usage to the TWDB.
- Power plants with their own well should also be required to meter and report usage. This information would be reported to the TWDB.
- Oil and gas companies would be required to report not only total water uses (which they currently do) but the type of water—surface, fresh groundwater, brackish groundwater (with salinity content), or recycled water—in addition to water well location and depth. This information would be reported to the RRC.

Reliable consumption data is fundamental to informed policy and a necessary building block to reforming the current regulatory structure. Thus, our policy recommendation is a fundamental first step for which there should be little opposition.

Policy recommendation 2: incentivizing the substitution away from fresh groundwater

Our second policy recommendation is a 2-part plan to encourage oil and gas operators to use less fresh groundwater when possible. The options include using surface water, recycled water, brackish groundwater, or even municipal treated wastewater. The individual operators would be free to choose their preferred substitute for fresh groundwater. Based on the high cost of recycled water and limited supplies of municipal treated wastewater in the area, the least-cost choice for most operators will be brackish groundwater, which is available in abundant supply. First, operators would receive recognition from a proposed Green Star program through the RRC (and possibly the TCEQ) if they take the pledge to dramatically reduce their use of fresh groundwater. This program would consist of a bronze, silver, and gold tier, depending on the percentage of fresh groundwater used for fracking. Part 2 involves a severance tax reduction for wells drilled by Green Star operators that have qualified for at least bronze level status in the Green Star program. Together, these two components would provide operators a financial and social incentive to conserve fresh groundwater. As noted above, the pledge to dramatically reduce fresh groundwater use could, in principle, involve substituting recycled water (flowback and produced water). However, in most instances, this option is likely to be far more expensive than simply using brackish water (Slutz et al. 2012). For most areas of the Eagle Ford, brackish groundwater supplies are abundant and the least expensive option to fresh groundwater. Nevertheless, some companies might experiment with these other sources, which would be a good thing.

The Green Star program would recognize that it may not be reasonable to avoid using fresh groundwater in all instances because of inadequate supplies of surface water, brackish water, or recycled water. (Very slow flowback of produced water makes recycling prohibitively expensive.) At the very lowest level of participation in the Green Star program, an operator could use no more than 30% fresh groundwater for fracking. Given the current practice of using 90% fresh groundwater for fracking, this program would significantly reduce fresh groundwater consumption.

The incentive component of our proposal consists of granting Green Star operators a severance tax abatement of $50,000 per Eagle Ford well for using alternatives to fresh groundwater. This is not a large cost to the state, given that a typical well will pay many multiples of that in severance taxes. Arnett et al. (2014) compute that the fiscal impact on severance tax revenues would mean when oil prices are $100 per barrel, the severance tax collected would fall from 4.6% to about 4% in the first year of production and be unaffected thereafter. At $50 per barrel , the first year severance tax reduction would fall from 4.6% to about 3.4% just for the first year of production. In effect, this incentive would have a relatively minor effect on severance tax revenues and a substantial environmental benefit.

From the operators' perspective, this tax break would offset much of the cost of using brackish groundwater. Fresh groundwater typically sells for $0.50 per barrel in the Eagle Ford. Thus, a typical operator in the Eagle Ford would expect to spend $50,000 per 100,000 barrels of water on any well. A $50,000 severance tax savings would allow operators to double their investment in water, without taking a financial hit. Particularly for an operator drilling 8 to 10 wells on a lease, an incentive bundle of $400,000 to $500,000 should be sufficient to offset the added cost of drilling a deeper water well to tap into brackish water formations. Since most operators in an immediate area will be drilling multiple wells, 1 brackish groundwater well costing an additional $400,000 could provide water to a number of wells and would be justified on a cost basis.

The other essential component of this policy is to publically recognize Green Star operators as being environmentally responsible. By recognizing operators who pledge to use less fresh groundwater while abiding with other TCEQ and RRC environmental regulations, these companies could demonstrate that they are willing to do more than simply talk about being environmentally responsible.

In order to qualify for Green Star recognition at the bronze level, operators could only use fresh groundwater for 30% or less of their wells and be compliant with all other regulations. This would earn them bronze level status in the program and make them eligible for the aforementioned tax incentives. In order to qualify for the silver level, operators would have to lower this number to 20%. To qualify for the gold level, operators would use fresh groundwater for no more than 10% of their wells. While the silver and gold levels do not offer any additional tax benefits, they will show the public how much an operator is willing to conserve fresh groundwater.

The potential public relations benefits to Green Star operators are many. First, these operators will be drilling and producing oil and gas in the Eagle Ford for many decades to come. By curtailing the use of fresh groundwater for fracking, Green Star companies would no longer be competitors with irrigators and municipalities for increasingly scarce fresh groundwater supplies. Second, the Green Star designation would be something that the firms and the industry should welcome. Not only would it be a mechanism to improve the public image of individual companies, but, if widely adopted by the 200 plus operators in the Eagle Ford, it could vastly improve the industry's image. An additional benefit to the RRC is that this program would be evidence of the commission's forward-looking agenda and demonstrate its proactive efforts to solve both a quantitative and qualitative environmental problem.

The Eagle Ford Shale has provided the state budget with an enormous windfall. Using a small portion of this windfall to incentivize shifting away from using fresh groundwater is a wise long-term investment in Texas. For oil and gas operators, and the industry as a whole, these incentives should be adequate to tip the balance in favor of using brackish groundwater and greatly enhance their public image in the process. Farmers, ranchers, and municipalities in these counties would benefit from the reduced consumption of freshwater supplies. Finally, it demonstrates Texas' ability to solve its own problems and proactively address an important issue without interference from the Environmental Protection Agency.

A futuristic idea: groundwater bank accounts

As mentioned earlier in this paper, property rights for groundwater in Texas are defined primarily under the rule of capture. This legal precedent creates an incentive to consume water as quickly as possible and prices water close to the cost of extraction with little respect to its rising scarcity value. In a water-scarce region, such as the Eagle Ford, the result of this policy is artificially cheap water today and much more expensive water in the future once the cheap sources are depleted. In the past, when water use more closely matched aquifer recharge rates, the rule of capture as a means of defining property rights was sensible and administratively simple—water users were rarely pumping enough to impact their neighbor's water consumption. However, when consumption greatly exceeds the recharge rate, the rule of capture allows the landowner with the fastest pump to pull water from the surrounding area and use it as if it were a free resource. This incentive structure is similar to early difficulties with Texas oil and gas, where property owners had little power to control the resources they rightfully owned.

There is a variety of alternative ways to define property rights other than through the rule of capture. In many countries and most U.S. states, groundwater is the property of the state, so this eliminates competition between landowners. Regulators then face the dilemma of who can produce the water and how much. Yet another method of defining property rights is to allow private ownership but limit water consumption to a predetermined quantity each year. In researching these various means, it became apparent that few free market systems are in place throughout the nation; as a result, we began to think of how the market could solve the problem while still protecting private property rights. Below are several steps that would shift groundwater in the Eagle Ford toward a more open market structure that would both respect private property rights and provide for efficient consumption and pricing of water over time.

The idea is to create groundwater bank accounts that would work as follows:

- Determine the magnitude of the fresh groundwater geographically: Based on hydrological studies for a county or GCD, determine the acre-feet of fresh groundwater in major aquifers as defined on a per acre basis. The TWDB maintains detailed hydrological models of the various aquifers in the Eagle Ford area as well as in other areas of the state. These models provide, on a 1 square mile grid, the total estimated recoverable storage. These estimates, called total estimated recoverable storage, assume that between 25% and 75% of groundwater held in an aquifer can be recovered through pumping. Thus within a 1 square mile area, it is possible to compute an estimate of the acre-feet of groundwater underlying a landowner's property. The estimate of acre-feet of water per acre of surface area will vary across the county or GCD because these aquifers are not homogeneous.
- Define water as a resource similar to mineral rights: In doing this, landowners could now know with some certainty the quantity of water in place under their property and have the right to use, sell, or save that water as they see fit.
- Calculate year-to-year debits to each owner's groundwater bank: Each year, the landowner's quantity of water-in-place would be reduced by the number of acre-feet pumped by wells on his property. In principle, every 10 to 20 years, landowners could receive credits for recharge, based on new data. As a practical matter, this could be very difficult to measure with any precision. Recharge rates remain one of the most difficult numbers to quantify.
- Allow free trade of water rights: Landowners would be free to sell water either within or outside its GCD with no permit required.

The benefit of this policy recommendation is that it should greatly improve the inter-temporal consumption of groundwater. Clearly, the price of water will reflect the willingness to pay of the consumer and the opportunity costs of the supplier. This would ensure that water is allocated efficiently not only to the present generation but also to future generations. Landowners would have an incentive to include the potential for higher future demand and scarcity in their decisions to either use the water internally or sell it to other users who may choose to store or use the water. They would not have to fear that their water might be taken from them, as they do now under the rule of capture. As the price of water today increases as a result of resource scarcity, its price will rise gradually, forcing more conservation today. The transition to alternatives (i.e. desalination, importing water, and others) will become smoother with less drastic price jumps in the future.

Despite these obvious advantages, the transition to a system of groundwater bank accounts faces a number of roadblocks due to the existing regulatory landscape, administrative costs, underlying science, and legal obstacles. First, even though we found the GCDs in the Eagle Ford exercised little restraint on the rate of pumping, they potentially could exercise broad powers in the future. Turning the GCDs into metering and monitoring agencies would be opposed by users currently facing no effective restraints. Second, the groundwater bank accounts depend critically on our first proposal—mandatory metering of water use. Associated with this monitoring and reporting function would be significant administrative costs, which would be ideally handled at the GCD level. Third, the science of accurately measuring the groundwater under a given landowner's property is necessarily imprecise. While tremendous scientific progress has been made, these models are continually being refined and remain subject to error. As new information becomes available, it might become necessary to adjust the balances in the bank accounts. Fourth, just as the existing regulatory scheme has spawned a variety of lawsuits, this alternative would not be immune to challenges that the total estimated recoverable storage, which is based upon the TWDB's models, are in error. While the burden of proof would at least fall on the plaintiff, an end to legal challenges seems unlikely. Nevertheless, it should end the issue of takings since a landowner's property rights are protected.

CONCLUSION

A combination of the rule of capture, minimal regulation by GCDs, and the evolving law of takings has resulted in a dysfunctional regulatory apparatus. With the advent of substantial fresh groundwater use in the Eagle Ford Shale, the problem has only been exacerbated.

This paper proposes 3 policy recommendations to address this issue. First, it is necessary to better measure fresh groundwater pumping rates. Second, tax incentives plus recognition of environmentally responsible oil and gas companies, could lead to widespread substitution of fresh groundwater. Given large reserves of brackish groundwater, substituting brackish groundwater is the most obvious solution. Third, an entirely new approach to governing groundwater consumption, involving the creation of groundwater bank accounts, should be developed. We believe this change would fundamentally alter the incentives to conserve increasingly scarce groundwater resources.

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