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Interjecting economics into the groundwater policy dialogue

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Abstract: Historically, economic theory has played a minuscule role in groundwater policy deliberations because of its complexity. This paper is intended for practitioners. Its goal is to distill the seminal 1931 paper by Harold Hotelling and show how it can be applied to manage a quasi-nonrenewable resource like groundwater. Hotelling's framework is then used to critique both the rule of capture era and the current era of regulation by groundwater conservation districts. The latter also draws heavily on the analysis by Brady et al. in a 2016 Bush School Capstone Report. Finally, a regulatory fix is proposed based on the ideas of Nobel Laureate, Vernon Smith (1977) that would use groundwater bank accounts to assure the efficient use of groundwater over time.
Keywords: groundwater bank accounts, optimal intertemporal use

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Terms used in paper

Short name or acronym	Descriptive name
DFC	desired future condition
EAA	Edwards Aquifer Authority
FSHLP	Fort Stockton Holdings LP
GCD	groundwater conservation districts
MAG	modelled available groundwater
MPGCD	Middle Pecos Groundwater Conservation District

INTRODUCTION

Groundwater management can be distilled down to two basic problems. The first problem is to set aggregate aquifer pumping rates in both the present and the future. This is the "how much" to pump problem. The second problem is to determine "who pumps" by assigning individual pumping quotas. Conventional wisdom has it that only regulatory agencies can solve these two problems. By using scientifically grounded hydrology models, regulators are believed to omnisciently solve the "how much" problem. Likewise, the second problem of "who pumps" is solved by regulators who assign individual pumping rates among competing stakeholders. Building on the detailed analysis of Brady et al. (2016) and Beckermann et al. (2016), this paper shows that these solutions are neither efficient nor equitable. This paper furthermore challenges the conventional wisdom by proposing an alternative grounded in economics that is administratively simpler, more equitable, and promotes conservation.

Interjecting economics into the policy discussion is likely to evoke two images—both negative. One is an image of unbridled capitalism operating under the rule of capture in the East Texas oil field in the early 1930's with oil wells on city blocks furiously pumping all the oil they could. The second is an image of many readers sweating through a micro-economics final exam. Economics is difficult and it is even more difficult in the case of nonrenewable resources. As economics is typically taught in advanced undergraduate college courses, it takes no account of the finiteness of a nonrenewable resource. Economic thinking about groundwater requires acknowledging that consumption today most likely reduces supplies for the future. Thanks to Harold Hotelling (1931), a well-developed theory of how to optimally utilize a nonrenewable resource both today and in the future exists.

Some confined aquifers can be thought of as closely approximating a nonrenewable resource. While there is typically some recharge from the unconfined portions of a confined aquifer, as a percentage of the total aquifer storage, it tends to be very small. For the state's three largest confined aquifers, the percentages of annual recharge relative to total aquifer storage are as follows: 0.025% for the Gulf Coast, 0.007% for the Trinity, and 0.19% for the Carrizo-Wilcox (Brady et al. 2016). For the Trinity Aquifer with only 0.007% recharge relative to storage, we might disregard recharge and think of it as a purely nonrenewable resource. But for most confined aquifers and unconfined aquifers as well, recharge cannot be dismissed. Therefore, these confined aquifers are best characterized as a *quasi-nonrenewable* resource. As will be shown, even though Hotelling's model was intended only for nonrenewable resources, allowing for recharge is conceptually straightforward.

The first task of this paper is to provide policy-makers with an intuitive understanding of Hotelling's economic principles that can be applied to groundwater. Let the reader be warned that the economics of a *quasi-nonrenewable* resource is a bit dry and not simple. The investment may very well change the way you think about these two fundamental problems. The second section begins by applying the conceptual lens of economics to popular notions of sustainability. The word sustainable pervades the public and academic dialogue having been applied to any number of products consumed today, but what does sustainable mean in the context of groundwater usage? Does it differ from Hotelling's prescriptions for the efficient use over time of a nonrenewable or a *quasi-nonrenewable* resource? The third section addresses the second task of this paper—to critique the institutions that have determined Texas groundwater use historically. It begins with the rule of capture and ends with the desired future conditions (DFC) utilized by most groundwater conservation districts (GCD) today. We ask the question of how and why these institutions have failed to solve the two fundamental problems of groundwater management. The fourth section performs the third task of this paper—presenting a market-based alternative to the existing regulation-based system based on the writings of another economist—Nobel Laureate Vernon Smith. The final section recapitulates the key findings.

TASK 1: THE ECONOMICS OF A QUASI-NONRENEWABLE RESOURCE

The uniqueness of water

Water is essential for life on this planet. International development efforts often focus on developing clean and abundant sources of water as a first priority. Considering the universal importance of water raises some key fundamental questions. First, can we trust markets to produce water in quantities sufficient to balance current versus future needs? Second, if not, can regulators solve the two problems of determining how much water to pump and who can pump it?

Increasingly, the emphasis on sustainable resource development either explicitly or implicitly calls into question whether markets can be trusted to solve these two problems. There is a widespread fear that markets are incapable of taking a long-term view and simply opt for short-run profit, maximizing expedients. For this reason, policy-makers have turned to hydrologists to allow science to tell us what sustainable production means in the context of a *quasi-nonrenewable* resource like groundwater in a confined aquifer.

Sustainable yield: should we limit pumping to equal recharge?

Unfortunately, within the hydrology literature, there is considerable disagreement about what sustainability means. Two popular definitions are "safe yield" and "sustainable yield." Originally, safe yield meant pumping at some percentage of the rate of recharge, such as pumping equal to recharge. The more recent and broader term, sustainable yield, would prescribe a pumping rate that could be sustained indefinitely with no detrimental effects not only to the aquifer but to the whole ecosystem, etc. (Zhou 2009). There are two problems with such definitions. First, they are definitionally imprecise. Devlin and Sophocleous (2005), for example, debunk the water budget myth and its relationship to sustainability. Second, these criteria make no attempt to weigh the human benefits received from the water against the losses from the deterioration of the aquifer and/or the environment (Griffin 2006). To illustrate the problem, let us apply a simple definition of sustainable yield, interpreting it to mean pumping equal to recharge for two distinct cases. In each case, we show such a pumping rate makes no allowance for the human benefits foregone due to reduced pumping and are, therefore, useless as a policy guide.

First, consider pumping from a confined aquifer whose natural recharge rate is essentially zero. In this case, what is the safe yield? If recharge is zero, the answer has to be that the only sustainable pumping rate is zero. Any positive rate of pumping would ultimately deplete the aquifer and, therefore, would not be sustainable. In effect, by the sustainable yield criteria, we would leave the aquifer untapped indefinitely. No generation, either present or future, would derive any benefit from pumping the aquifer. Clearly, this definition of sustainability makes no sense in this example because it dismisses economic considerations of human benefits.

Second, consider pumping from a confined aquifer like the Trinity Aquifer whose annual recharge rate is .007% of storage. In this context, sustainable yield would call for setting the pumping rate at the recharge rate. Currently, the pumping rate is twice the recharge rate. If we assume for the purpose of discussion that storage in the aquifer could be roughly approximated using the perpetual inventory formula: [1]

storage in year t = storage in year t-1 + recharge in year t - consumption in year t

Then even at this pumping rate the aquifer could be sustained for 8,459 years before depleting half of the aquifer's storage. This calculation makes no allowance for the fact that pumping costs would surely rise as the aquifer is depleted (Brady et al. 2016).

In this case, we pit the benefits of the water to nearby generations versus very distant generations. Discounting the value of future benefits is accepted economic doctrine (Griffin 2006). Here again, this definition of sustainability leads us to bad policy prescriptions because they do not take into account human benefits in nearby generations versus very distant generations.

Economic notions of optimal aquifer use over time

A simple case following Hotelling's prescription

Consider an aquifer with the following five specialized characteristics:

1. No recharge.
2. A backstop alternative water source—desalinated seawater costing $2,000/acre-foot.
3. Groundwater pumping costs are constant at $100/acre-foot.[2]
4. The demand schedule for water is constant over time.

[1]For an explanation, see https://en.wikipedia.org/wiki/Perpetual_inventory

[2]Both assumptions (3) and (4) are made for pedagogical purposes. Optimal control techniques can be used to solve the more complex problems of rising costs and increasing demand.

5. Multiple owners each with well-defined property rights to a prescribed number of acre-feet of water.

Assumption (1), no recharge, allows us to confine the analysis to a nonrenewable resource and utilize, almost completely, Hotelling's famous article showing how the resource should be used over time. Imagine a huge enclosed swimming pool where water extraction costs are only $100/acre-foot (assumption (3)). Furthermore, assume a static economy with a constant demand schedule for water over time (assumption (4)). In Hotelling's model, ownership of the water is predetermined by some prior allocation mechanism (assumption (5)), assigning ownership on an acre-foot basis. Furthermore, by assumption (2), prices are capped at $2,000/acre-foot—the cost of desalinated seawater.

The genius of Hotelling's insight was that even with a competitive situation with multiple water owners, the price of water would not behave as your intuition might suggest. You might expect multiple water owners would vigorously compete to sell their water at a price slightly above the $100/acre-foot cost of pumping. Then after all the water had been sold, prices would skyrocket to the cost of desalination. Hotelling's insight was just the opposite. Hotelling realized that when resource owners sold their water, they incurred a "user cost." Once sold, they could no longer sell their water in another period. One might think of this user cost as a scarcity premium, owing to the intrinsic finiteness of the resource. Hotelling realized that the arbitrage principle would be at work. For owners to be willing to sell their water in any period, they had to be indifferent between selling it at various time periods. But for this to happen, the user cost had to be rising at the rate of interest to assure their indifference. That is, if the interest rate is 5%, a seller must earn a 5% return for holding the water to the next period and so on.

Consequently, Hotelling's model predicts that water prices would rise over time because the user costs would be rising over time at the rate of interest due to the arbitrage principle. Ultimately, at some point in time the price would equal the backstop price of desalination on the day the last tranche of fresh groundwater was sold.[3] Thereafter, the price of water would be equal to the backstop price ($2,000/acre-foot). Because of the infinite supply of seawater, the price after reaching the backstop would no longer be rising at the rate of interest; there would be no incentive to hold the groundwater after the backstop technology was reached. Thus, owners would sell their fresh groundwater before reaching the desalination backstop.

The logic of Hotelling's model is best illustrated by a graphical approach. Suppose that in Figure 1a the backstop price of desalinated seawater is $2,000/acre-foot. Clearly at some distant time period, t*, the last acre-foot of water would be sold at $2,000, so thereafter desalination would begin. At that point, the user cost is $1,900/acre-foot, which together with the pumping costs of $100/acre-foot equals the market price of $2,000/acre-foot. To make water owners indifferent between selling their water and collecting their user cost of $1,900/acre-foot in period t*, the user cost in period t*-1 must equal an amount invested at the market rate of interest that would equal $1,900 in period t*. If the market rate of interest is 5%, then the user cost would be $1,809.52.[4] With the user cost declining at 5%, the user cost in period t*-2, would be $1,723.35 and the market price would be $100/acre-foot more—$1,823.35/acre-foot. The arbitrage principle is satisfied since $1,723.35 invested at 5% would yield $1,900 two years later. In Figure 1a, moving back in time, we observe a price path consisting of two components—the pumping costs of $100/acre-foot and the user costs, which are falling at 5% as we move back in time to the present. At t*-50 years, the user cost is $165.69/acre-foot, implying that water owners are indifferent between receiving $165.69 versus $1,809.52 after 50 years. At t*-100 years, the user costs are $14.45/acre-foot because $14.45 invested at 5% equals $1,900 in 100 years.

In Hotelling's simple model, knowing the price at any point in time determines the consumption at that point in time. So in Figure 1b, we see that when the price reaches $2,000/acre-foot in year t*, the quantity demanded is 5,000 acre-feet. But as the price falls as we march back in time to the present from that distant time period t* (at which desalination begins), the lower prices stimulate increased consumption as illustrated in Figure 1b. But how do we know, how many years it will take to reach t*? The answer is that it depends on the amount of water in the swimming pool and consumers' response to rising prices. In this example, we assumed there are 2 million acre-feet in the pool and the price elasticity of demand for water is -0.5; so it will take 130 years before the user cost reaches t*and desalination begins. Obviously, how fast one moves along Figure 1b depends critically on the price elasticity of water demand. In the example in Figure 1b, the price elasticity of water demand is assumed to be -0.5—implying that every 5% reduction in the price increases water consumption by 2.5%.[5]

Figure 1b illustrates the importance of the price elasticity of demand as a device to encourage conservation. For example, suppose we are living at time period t*-130 (which is today), consumption is 22,000 acre-feet/year at today's price of $103.34/acre-foot. Figure 1b shows the effect of price rises from $103.34/acre-foot today to $2,000 in 130 years. Suppose instead that demand was unresponsive to the rising price of

[3]In reality there would be a transition period as the price became close to the cost of desalination at which time both desalination and fresh groundwater would be used in tandem.

[4]$1,809.52 invested at 5% will yield $1,900 in one year. So even though the user cost at t* is $1,900, in the year before t*, the user cost will be $1,809.52.

[5]For support for this estimate, *see* Scheierling and Loomis (2006).

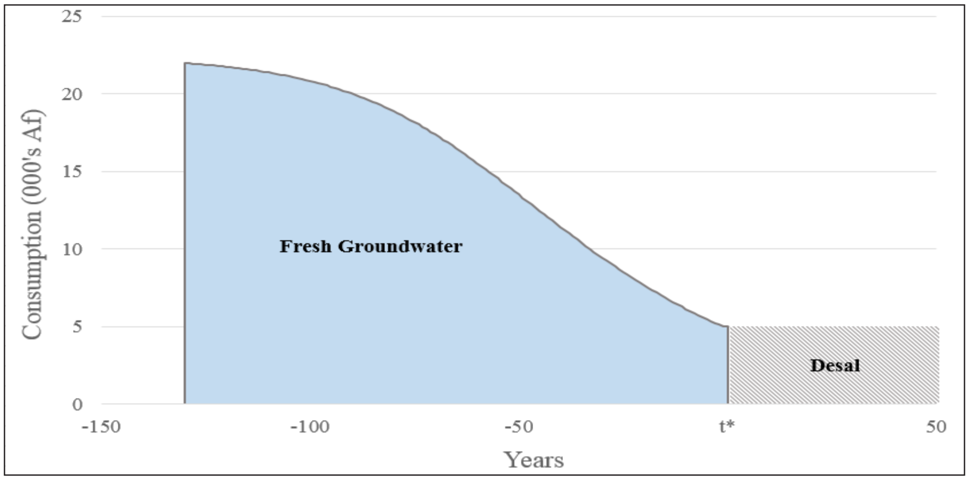

Figure 1a. Price path with well-defined property rights.

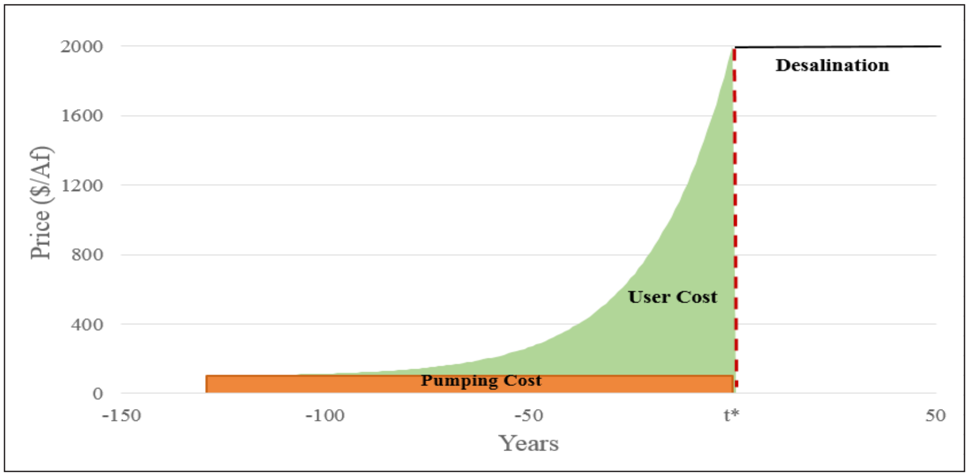

Figure 1b. Consumption path with well-defined property rights.

water and consumption was constant at 22,000 acre-feet over time. The 2 million acre-feet would be exhausted in about 90 years instead of 130 years! This is a striking example of why properly functioning markets can encourage conservation and extend the life of aquifers. For this reason, a great deal of economic research has centered on the magnitude of the price elasticity of demand (Griffin 2006). The greater the elasticity (in absolute magnitude), the more effective will markets be in promoting conservation and guiding water consumption to its best use. Elasticity estimates provide good news that all classes of water users are responsive to rising prices (Griffin 2006).

In the example in Figure 1b, the aquifer was completely de-watered because it was assumed that pumping costs did not rise as greater and greater amounts of storage were produced. The example also abstracted from the spatial allocation of fresh water, transportation costs, and differing desalination costs. In reality, to maintain production pumping costs would rise as pumps are lowered, more infill wells are drilled, and water is transported over greater distances. So rising production costs together with rising user costs would force even more conservation, extending the life of the aquifer beyond 130 years. For this reason, aquifers may never be completely de-watered even after desalination begins because desalinated brackish or seawater will be a least costly source.

Hotelling's model under the rule of capture

Now consider an aquifer with similar characteristics except for a new assumption (5):

1. No recharge.
2. A backstop alternative water source—desalinated seawater costing $2,000/acre-foot.
3. Groundwater pumping costs are $100/acre-foot.
4. The demand schedule for water is constant over time.
5. Multiple pumpers with access to the aquifer with no limit on individual pumping.

In the previous case, there were multiple owners of the water in the giant swimming pool but each was entitled to pump only what they owned.[6] But suppose each pumper is operating under the rule of capture—their ownership of water only occurs at the time they "capture" the water. Historically, the Texas Supreme Court adopted the rule of capture in 1904 in *Houston Texas Central Railroad Company vs. W. A. East*. Lacking an understanding of how groundwater flowed in the subsurface (Mace et al. 2004), the Court ruled that ownership occurs at the point of capture and any detrimental effects on others were not compensable.

To understand how landowners would behave in this situation, one must look to oil production in Texas prior to the advent of pro-rationing by the Texas Railroad Commission in 1931. Accounts of the East Texas field with wall-to-wall wells on city lots in Kilgore, Texas paint a fascinating picture of unrestrained production (Clark and Halbouty 1972) with oil prices plummeting to 10 cents/barrel in 1931 (RRC 1866-1939). With multiple owners, the incentive is to produce the oil before a neighbor does as long as the price exceeds the cost of pumping. In the jargon of economists, this is an example of the "tragedy of the commons."[7] Each owner maximizes his own profit with no regard for the effects on the reservoir and the higher profits that would be realized by cooperation with other well owners.

Consequently, under the rule of capture, each property owner looks only at their own pumping costs in determining their willingness to sell. Hotelling's user costs become irrelevant since there is no incentive to leave it in the ground for future sale. There is no assurance it will be there and accessible to the individual property owner in the future. Figure 2a and 2b describe just how important well-defined property rights are (assumption (5)). In Figure 2a, producers are assumed to pump as much water as they can at a price of $105/acre-foot—since with a $100/acre-foot cost of pumping they will opt to pump, thinking that $5/acre-foot is better than nothing. At the cheap price of $105/acre-foot, consumption is estimated at about 21,800 acre-feet/year. But as shown in Figure 2b, the pool is dry after only about 90 years. Then as shown in Figure 2a, at t*, the price suddenly jumps from $105/acre-foot to $2,000/acre-foot—the cost of desalination. Because there were no user costs to signal increasing scarcity, the economy experienced a price shock in t*.

Economists are generally quite critical of the rule of capture on grounds of economic efficiency (Griffin and Steele 1986), because (a) it encourages the overconsumption of a valuable resource at an artificially low price (that takes no account of the user costs) and then (b) abruptly forces future generations to prematurely transition to desalination well before they would otherwise do so. Contrasting, Figure 1b (well defined property rights) versus Figure 2b (rule of capture), the years before desalination were 130 years with well-defined property rights as contrasted with 90 years with the rule of capture. It should be noted that these examples are purely for pedagogical purposes so the comparison of 90 versus 130 years will vary depending on a number of assumptions such as the price elasticity of demand, the size of the aquifer, pumping costs, recharge, and growth in demand. But regardless of the assumptions, the rule of capture will under quite general conditions accelerate pumping and provide no signal of impending scarcity. In contrast, steadily rising prices that send price signals of increasing scarcity allow society time to adjust. In sum, the rule of capture is a conservationist's nightmare.

On equity grounds, the rule of capture can in no way be viewed as equitable. It rewards those who sequester their neighbor's water and punishes those who wish to conserve it. It also results in inequitable outcomes depending on a landowner's property location. Surface owners over the down-dip areas of an aquifer can in effect drain up-dip surface owners, potentially leaving them with dry wells. Because of these problems, in oil and natural gas litigation, the courts stepped in with safeguards to disadvantaged producers in the form of correlative rights. The Texas Railroad Commission restricted production in a common reservoir to give each landowner a fair chance to produce.[8]

Interestingly, the problem with the rule of capture is not with profit maximization or capitalism; rather the problem is that property rights are not well-defined or limited to the oil or water underlying the surface owner's acreage. To overcome the property rights problem, the courts have held that regulation designed to protect correlative rights is a legitimate solution. Basically, correlative rights first evolved in the case of oil and gas regulation and limits adjoining landowners' use of a common pool resource to a reasonable amount, typically based on surface acres. While there are a number of methods of protecting correlative rights, economists have been enamored with voluntary unitization of oil reservoirs, whereby each landowner receives a pro-rata share of the value of the oil produced from their reservoir. Unitization overcomes the perverse incentives to over-produce and drill excessive wells. Experience has shown, however, that voluntary agreements, absent regulatory mandates, are very difficult to obtain (Wiggins and Libecap 1985). Consequently, regulatory solutions for oil and natural gas to protect correlative rights have often relied on well spacing and well production limits (RRC 2001). As discussed later, regula-

[5]For example, suppose there are multiple owners of the surface area over the swimming pool. In this case, it would be a simple calculation to determine the acre-feet of water owned based on the surface acres owned.

[6]See the definition at http://whatis.techtarget.com/definition/tragedy-of-the-commons.

[7]For a 1944 case recognizing correlative rights, *see* Elliff v. Texon 146 Tex. 575, 210 S.W.2d 558.

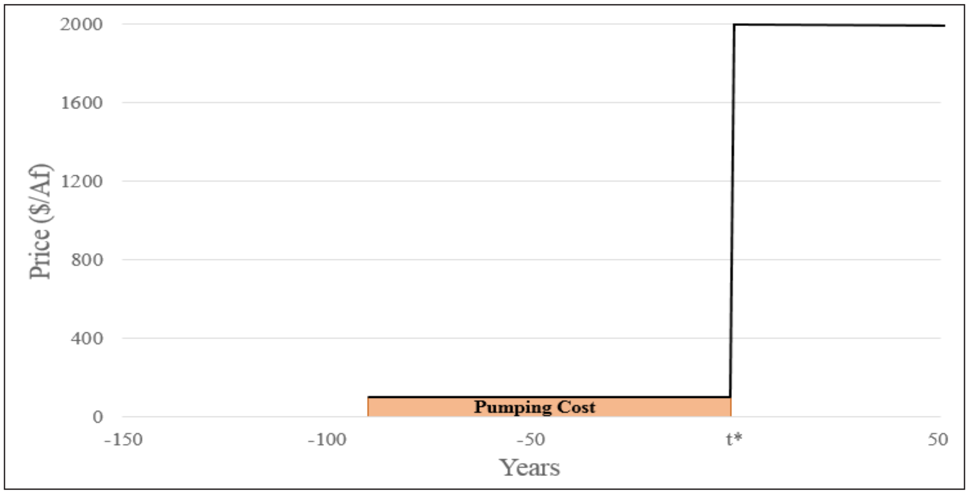

Figure 2a. Price path with rule of capture.

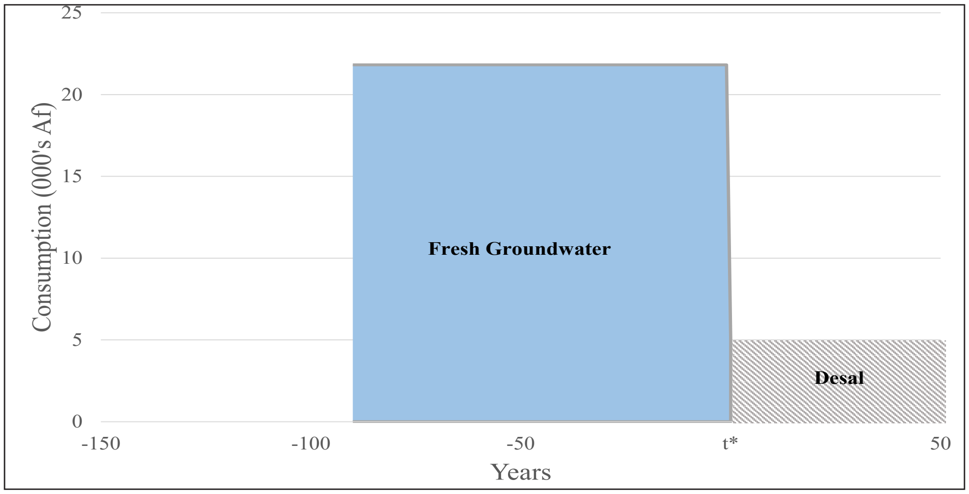

Figure 2b. Consumption path with rule of capture.

tory applications of correlative rights to groundwater have met with more mixed acceptance.

Pulling things together

Before looking at groundwater regulatory practices in Texas, we should recapitulate the key takeaways from the above:

- Sustainable yield, which would limit consumption to the rate of recharge, will not result in sustainable development even if it were definable. It makes no allowance for the lost human benefits from restricted pumping.
- But if sustainable yield is not a practicable criteria, does it follow that we should pump flat out today with no regard for future generations? Fortunately, Hotelling's 1931 paper provides an answer that will satisfy many of us. With well-defined property rights, the price of groundwater should rise reflecting its increasing scarcity, which in turn will promote conservation and extend aquifer life.
- Hotelling's model does not apply to the rule of capture because property rights are not well-defined. The rule of capture has the perverse incentive to pump one's well before his neighbor does. Pumpers have no incentive to recognize user costs since their pumping today only minimally limits their future pumping. Without user costs reflecting future scarcity, prices languish slightly above pumping costs until the aquifer is de-watered as in Figure 2a and then suddenly jump to the cost of desalination providing society little warning of the need for desalination.
- While in the example above assumptions (1) to (4) were fixed, they can be relaxed to include recharge, demand growth, rising pumping costs, and cost reductions in desalination. In particular, recharge is one of the easiest additions to the model. In effect, recharge simply augments the size of the original aquifer and increases t*—the time before reaching desalination. Interestingly,

with a combination of reduced consumption due to rising prices coupled with the increased recharge that will occur as the aquifer's storage decreases, production rates could potentially stabilize. Consequently, t* could be postponed indefinitely.[9]

- Hotelling's model provides a clear blue print to how groundwater should be managed over time, whether it is by the invisible hand of the market or by a team of regulators. To many the choice is a conundrum. Allowing the market to allocate water over time only works when property rights are well-defined, which does not occur under the rule of capture. Alternatively, the regulatory model only works when regulators fully understand Hotelling's model and are immune to special interests. When either markets or regulators fail to allocate resources efficiently over time, economists label these as either "market failures" or "regulatory failures." As shown in the subsequent section, groundwater management in Texas has an interesting assortment of both types of failures.

TASK 2: ASSESSING EVIDENCE OF BOTH MARKET AND REGULATORY INEFFICIENCIES IN TEXAS GROUNDWATER MANAGEMENT

The rule of capture era—market inefficiency

As noted above, the 1904 East decision clearly established that Texas groundwater was subject to the rule of capture, joining a club of five other states (Connecticut, Indiana, Louisiana, Maine, and Rhode Island) adhering to some form of the rule of capture.[10] Even though the Legislature passed the Groundwater District Act of 1949, which allowed for the creation of groundwater conservation districts (GCD), groundwater remained essentially free from regulatory control until quite recently. Even after passage of Senate Bill 1 in 1997 and Senate Bill 2 in 2001, GCDs had authority but no mandate to regulate the rate of pumping. Until House Bill 1763 in 2005 formalized the regulatory process, the rule of capture ruled supreme in Texas (Mace et al. 2008).

As shown above, the rule of capture violates one of Hotelling's key requirements—well-defined property rights. Since groundwater migrates underground, we have a classic case of the commons. The key to well-defined property rights is *exclusivity,* which, in the case of groundwater, is the right to exclude others from extracting water under their land. Under the rule of capture, the incentive is to pump the water before one's neighbor does with the same over-grazing outcome as the sheep in the tragedy of the commons. Pumpers have no incentive to conserve individually since a pumper's decision to pump less today would only be captured by other pumpers. Like Figures 2a and 2b, the aquifer will be prematurely de-watered, and prices will abruptly and prematurely jump to the backstop price.

Despite these obvious defects, proponents of the rule of capture may, with some justification, argue that *in the past* the rule of capture was simple and did relatively little harm. The enormous size of the aquifers compared to the relatively low demand for water, made the user cost so low as to be almost meaningless. At least initially, the price path would not be appreciably lower under the rule of capture as compared to a system with well-defined property rights. If desalination is so far in the distant future, the number of years before reaching t* may make only a small difference to current generations. Future generations would far prefer to avoid the rule of capture, but they are not here to register their preferences. Today, the once future generations are now here and we are well past the period when user costs should not matter. Consumption is occurring at far greater rates than in the past, moving us closer to the time of desalination.

Today, the inequity of the rule of capture has become magnified. For many years, the historically large pumpers have enjoyed the benefits of abundant water at an artificially low cost. Today, new pumpers will face higher pumping costs and reduced volumes because of widening cones of depression and reduced artesian head resulting from past pumping. While equity might suggest that historical pumpers should compensate new pumpers, the opposite appears true. Paradoxically, one of the side effects of current GCD regulation is to protect these historical pumpers at the expense of new pumpers.

The advent of GCD regulation and the era of regulatory inefficiency

As the ill effects of the rule of capture became apparent, it is to the credit of the legislative process that lawmakers sought to slow down the growth rate in pumping. They sought to remedy the first of our two problems—the "how much to pump" problem. Since the GCD institutions were already in place, it was logical to vest this regulatory power with the GCDs. Senate Bill 1, passed in 1997 began the process. Principally, the legislation sought to introduce a greater deal of semi-centralized, scientific objectivity into the groundwater planning process. The Texas Water Development Board (TWDB) was subsequently charged with managing the development of state, regional, and local water management strategies while defining regional water planning areas (Texas Water Code § 16.051, §

[8] I owe this observation to Darrell Peckham.

[9] *See* TARLOCK, *supra* note 8, § 4.6; WATER AND WATER RIGHTS, *supra* note 8, §§ 21.05, 21.07.

16.055, & § 36.1071). The bill also called for a state water plan to guide these regional plans with TWDB assistance to prevent interregional conflicts (Texas Water Code § 16.053 (h)(4)-(7)).

Then in 2001, Senate Bill 2 added additional infrastructure by requiring the TWDB to play a much more active role in the regulatory process. Article 2 of the bill requires, "…TWDB, in coordination with the regional water planning groups and the groundwater districts, to obtain or develop groundwater availability models for major and minor aquifers, and provide the models to groundwater conservation districts and regional water planning groups…." Furthermore, Article 2, "…clarifies that groundwater districts may regulate spacing and production of wells based on tract size and distance from property lines." It also directs the GCDs "to develop their management plans using the districts' best available data, and to forward those plans to the regional water planning group for consideration in their planning process…" Interestingly, the bill states: "…district rules can require permit amendment in order to transfer groundwater…" but, "…prohibits denial of a well permit based on the intention to export…" (TWDB 2001).

In 2005, House Bill 1763 formalized the regulatory process in place today. It required GCDs to work together with other districts in their groundwater management areas to establish desired future conditions (DFC) for each aquifer in their management area, even if the aquifer is outside the district's boundary…and all of them, for the first time, have to use the managed available groundwater (MAG) numbers from groundwater conservation districts as their measure of groundwater availability…. (Wythe 2014).

This change meant GCDs gained more power than regional water planning groups, which were originally able to determine groundwater availability numbers and heavily influence GCD management plans. For the first time, the GCDs had the power to restrict pumping because additional pumping would violate the desired future conditions (DFC) of the relevant aquifer in their GCD. As shown in Beckermann et al. (2016, Appendix B) 89 out of 94 GCD respondents set their DFCs based on some amount of drawdown of the artesian head in their aquifer.

Theoretically, the process would work as follows:

1. Using hydrological science, determine a drawdown rate (the DFC) consistent with prudent aquifer management.
2. Given the scientifically determined DFC, solve the groundwater flow models for the modeled available groundwater (the MAG) that would satisfy the DFC (which is typically the drawdown).
3. Knowing the MAG, the GCDs would then issue pumping permits as long as they fell under the MAG limits determined by the hydrologic models.

Letting science rather than local political pressures guide the regulatory process seemed quite logical and appealing. In reality, the simple elegance of this solution did not work as intended. A fundamental flaw occurs in step (1) because science alone cannot be used to identify prudent aquifer management. The whole notion of prudent aquifer management is highly complex and dependent on a variety of subjective factors. With an indeterminate scientific basis, the process was reversed as follows:

1. The 50-year projections of future demand effectively became the MAGs, which were then input into the hydrological models to determine the drawdown consistent with that pumping rate.
2. The resulting drawdown calculated from the models then became the DFC. Thus the local GCD could claim to have followed the intent of House Bill 1763 by developing its own DFC.

In reality, the hydrology models were used to give the process the patina of a scientific basis, but the GCDs own pumping plans determined the DFC. Rather than eliminating local politics from the process, local politics actually guided the process in step (1) with local pumping plans setting the future pumping rates (Mace et al. 2008). One might even ask if local projections of water needs are to determine allowed pumping, why expend the modelling efforts to calculate a drawdown rate and proceed with the masquerade of reporting "science-based" DFCs?

A key question is could the process be changed back to the theoretical ideal described above in which science, rather than local politics, guides the process. Unfortunately, hydrologists cannot agree on a DFC consistent with prudent aquifer management. In confined aquifers, declines in artesian head have very little to do with the reductions in the storage capacity of the aquifer (Harden 2016a). Then too, the relationship between reductions in storage and pumping costs are unclear. It then becomes largely a question of how much increase in pumping costs the residents of a GCD will accept, which is a political issue. Unfortunately, it seems impossible to eliminate local politics from the policy process (Mace et al. 2008).

More evidence of regulatory inefficiency

As the previous section demonstrated, for many of the GCDs using the drawdown of artesian head as a basis for setting their DFCs, it is highly improbable that they have correctly solved the problem of "how much." Reductions in artesian head are a poor measure of reductions in an aquifer's storage. Thus Hotelling would give these GCDs poor marks. Now let us turn to the second task that GCDs perform—assigning "who pumps."

As we shall see, to determine "who pumps," most GCDs have adopted a usage-based criterion to determine who pumps and how much. By adopting a usage-based criterion, GCDs protect historical users (whether irrigators or municipalities) (Beckermann et al. 2016). Even more subtly, should a user with historical permits for a given use wish to change the use of the water, be denied a change in use? As noted by Harden, a usage-based (or user-based in Harden's vernacular) criterion for who pumps differs fundamentally from a property-based criterion whereby assignment of who pumps is determined by property ownership (Harden 2016b). Some GCDs, particularly in the Post Oak Savannah GCD and the Guadalupe County GCD (Collins and Blumberg 2016) and some located in West Texas overlying the Ogallala Aquifer do assign pumping rights based on property ownership. So, for example, if the allocation is 2 acre-feet of groundwater/surface acre owned, all landowners can apply for a permit based on this formula. If aggregate pumping exceeds desired levels, pumpers all cut back proportionally. Property-based regulations like these are an example of a method to protect correlative rights. But in this section, we focus our critique on the more common GCD practice of utilizing a specific use-based criteria to decide who pumps and how much.

A clear agenda: protecting historical users

GCD regulation that reduces the aggregate rate of pumping is understandable, particularly following the rule of capture era when the incentives were to allow unrestrained development. Beckermann et al. (2016) argue that regulators were overly ambitious, resulting in a regulation-induced shortage of groundwater, whereby only three of the GCDs surveyed called for increased pumping out to 2060. Is it possible that we have gone from a system of "too fast" to "too slow" pumping in determining how much aggregate water to pump? Perhaps this can be explained by well-intentioned efforts to allocate water efficiently across multiple generations. But there is a more basic explanation.

Interestingly, if this were the only explanation, why then have GCDs gone out of their way to add another layer of regulation—usage-based as opposed to property-based allocation of pumping permits? Beckermann et al. (2016) find that GCDs generally treat historic and existing use permit holders in a special grandfathered class. In many GCDs, large irrigators and even municipal users who established pumping records under the rule of capture enjoy de facto types of status entitling them to special treatment.

Paradoxically, these historical permits provide an enduring legacy of the rule of capture. Particularly if a GCD is faced with cutting pumping to satisfy its DFC, protecting historical permit holders only increases the burden on recent and future pumpers. Economically, one must ask why should these groups be immune to cutbacks while others must shoulder proportionally larger cutbacks or be denied new permits altogether? Defenders of this system would point out that these are legitimate roles for GCDs, since the purpose of GCDs was to insure local control and avoid statewide control. They are sympathetic to preserving local communities and protecting historic users. To them, usage-based regulation of who pumps is a logical response despite its inconsistency with legal precedent (Johnson 2016).

In response to GCD power to limit pumping and curtail certain uses, the Texas Legislature responded by exempting groundwater for oil and natural gas exploration and local small domestic and livestock users. Wells located on no less than 10 acres and producing less than 25,000 gallons/day for domestic and livestock uses are exempt. Lesikar, Kaiser, and Silvy (2002) describe how the system could be gamed by placing multiple wells on 10-acre spacings. Interestingly, 25,000 gallons/day translates into 28 acre-feet/year. This is a very generous exemption since a family of four consumes about .45acre-feet/year (EPA 2008) and two horses consume about .03 acre-feet/year.

Exemption for oil and gas exploration activities would have been innocuous prior to the advent of fracking (Lashmet and Miller 2015). Prior to fracking, the drilling operation might consume only 130,000 gallons or .4 acre-feet/well, but fracking a well consumes 20 times that amount.[11] Steadman et al. find that for the seven most active drilling counties in the Eagle Ford shale, that fracking consumed approximately 30% of the groundwater in 2013 (Steadman et al. 2015).

Prevention of water export outside the GCD

Just as goods and services are traded throughout the state, the nation, and the world, one would expect groundwater to move from water-abundant areas to water-scarce areas. Surprisingly, this is not generally the case because GCDs tend to view water as something to be kept for local consumption. San Antonio is a prime example. Despite abundant supplies from the Carrizo-Wilcox Aquifer in the nearby Evergreen GCD, the city had to look to other sources. The Post Oak Savannah GCD, some 140 miles away, agreed to export water to San Antonio. The resulting Vista Ridge project is estimated to cost San Antonio residents $2,300/acre-foot (Brady et al. 2016). This leads us to ask why haven't irrigators in the nearby Evergreen GCD been allowed to sell their water for such a hefty sum? But this has not happened because for irrigators to change their permitted application from "irrigation" to "export" would probably not be granted.

The answer to this conundrum is two-fold. First, residents in the Evergreen GCD fear that massive exports to San Antonio would ultimately lead to a groundwater shortage in their area. Even though Brady et al. (2016) suggest there is considerable

[11]Based on estimates in the Wattenberg field in Colorado, *see* Goodwin et al. (2012).

capacity to export, there is a genuine fear that regulators would not limit future exports sufficiently to protect supplies for local residents. Fears of wells running dry seem ill-founded except in very limited areas of the up-dip portions of steeply down-dipped confined aquifers (Brady et al. 2016). For most wells, pumps will simply have to be lowered and pumping costs will rise only moderately but so will the value of water.[12] Residents served by local water districts or municipalities will probably experience modestly higher water bills, but the increased lifting costs represent only a relatively small portion of their water bills.[13]

A second factor inhibiting exports is the fear that the benefits of water export would accrue to only a select few landowners. Under the current method of allocating pumping permits, historical pumpers with large permits would be obvious winners. The benefits they enjoyed under the rule of capture would become even more profitable with export. But for landowners seeking a new permit for export, their permit application under the current DFC process would be problematic. In effect, the benefits to landowners as a group for exports may be quite unevenly distributed.

By law, GCDs cannot prevent the export of water outside their district.[14] Yet, in practice, GCDs have found ingenious ways of discouraging exports such that only six of the 97 GCD surveyed by Beckermann et al. (2016) show exports of more than 1% of pumping. These methods include direct price discrimination, a protracted approval process, and special provisions of the permit that vitiate the economics of the project. In the Bluebonnet GCD for example, exporters are charged a fee of $55.38/acre-foot as contrasted with $14.60/acre-foot for local municipalities and zero for local agricultural pumpers. A less obvious but more onerous expense is the legal costs of obtaining an export permit after a lengthy litigious period. Attorneys and expert witnesses on both sides are incentivized to prolong litigation and subsequently bill more hours.[15] Edmond McCarthy points out that water marketers are at a distinct disadvantage because they must pay the GCDs legal bill if they do not win appeals, and even if they do win, they may or may not be able to recover their own legal expenses.[16]

Yet another method to frustrate water marketers is for GCDs to approve projects but add special provisions that potentially vitiate the economics of the project. For example, in the Forestar case, the Lost Pines GCD originally denied the application for 45,000 acre-feet/year to be exported and granted only 12,000 acre-feet/year on the grounds that the full amount *might* violate the district's DFC sometime before 2060 (McCarthy 2013). Projects of this magnitude depend critically on economies of scale; restricting the volume would severely reduce the economic viability of the project. Yet another strategy to deter a project is to subject the project to added uncertainties such as the potential for arbitrary cutbacks in the future. Pipelines are extremely costly and their economics depends on maintaining its use at full capacity over a long period of its life. As noted earlier, an artificially stringent DFC can provide the GCD with a justification for future cutbacks in pumping.

Discrimination among categories of uses within a GCD

GCDs also use their regulatory authority to discriminate among different categories of use even within the GCD. This behavior seems puzzling, but there are reasons for these actions. Discrimination can involve price discrimination in the fees GCDs levy on different classes of users. It has also manifested itself in denying a permit holder from transferring its intended use from irrigation to municipal uses.[17] Interestingly, these cases are not restricted to export situations. Even for uses within a GCD, they have actively been involved in encouraging some classes of uses and discouraging others.

Even within a GCD, price discrimination among classes of water users is common. Municipal and industrial consumers pay higher prices than irrigators, who in turn pay more than exempt users. For example, in the Brazos GCD, municipalities pays $45/acre-foot, while irrigators pay $2/acre-foot and exempt users pay nothing (Beckermann et al. 2016, Appendix B). The most obvious explanations for this practice are that (a) the Texas Legislature has imposed a maximum fee of $2/acre-foot on agricultural users and (b) given the lack of metering, there is no ability to impose fees on producers with exempt wells. While the existence of this practice is politically understandable, it does impede water from being used at its highest valued uses.

Economic theory as applied to public utility regulation teaches that the fees charged should approximate the marginal costs of providing that service to each category of user. But in this case, the GCDs expenses are essentially general overhead—a fixed cost. Economic theory tells us that these overhead costs should

[12]At $.10/kwh electricity cost, every 100 feet of increased lift due to aquifer drawdown is estimated to cost $17.05/acre-foot or $.06/thousand gallons. Michael Thornhill, Feb. 16, 2016 email to Brady et al.

[13]A $15/acre-foot increase in pumping costs translates into 4.6 cents/1000 gallons.

[14]Section 36 §112 of the State Water Code explicitly prohibits this. The one exception is the Edwards Aquifer Agency.

[15]For a discussion of Clayton Williams' legal disputes with the Middle Pecos GCD, *see* Beckermann et al. (2016), pp. 51-52.

[16]Edmond McCarthy, Interview, November 24, 2015 with Bush School Capstone students.

[17]Curiously, in *Guitar Holding vs Hudspeth County UWCD*, the Court ruled that the GCD had to consider the purpose of use as well as the amount of use. This seems contrary to Section 36.116 (b) of the State Water Code.

be distributed so as to minimize the distortion among classes of users. In effect, the fees should be designed to have minimal effects on water consumption quantities in the absence of these charges (Walters 1993). This means that those uses that are the least price responsive should shoulder the highest fees while more price responsive uses should pay less. Given the ranges of price elasticities surveyed by Ron Griffin (2006), it seems plausible that municipal customers pay somewhat more than irrigators do, but why should exempt producers pay nothing? They are simply the beneficiaries of a legislative exemption. It seems very clear that the existing fee structures are due to political interest groups and not criteria of promoting water use at its highest and best use.

But GCD discrimination in its fee structure is not the only source of discrimination among types of uses. Changing the permitted use from irrigation to municipal use can be a problem. In 2005 the Middle Pecos Groundwater Conservation District (MPGCD) issued an irrigation groundwater production permit for 47,148 acre-feet/year to Clayton Williams Farms, and in 2009 the permit was transferred to another Williams' entity Fort Stockton Holdings LP (FSHLP). Also in 2009, FSHLP applied for a new 47,148 acre-feet/year municipal or industrial use permit, and essentially offered to suspend the irrigation permit. FSHLP's application did not specify an intent to market the groundwater outside the district to the Midland and Odessa area. The MPGCD board of directors, however, voted unanimously to deny the permit, which prompted an appeal based on the grounds that prohibiting the grandfathering of FSHLP' original permitted allocation for other than irrigation use was illegal (Beal 2015). After a four-year delay between the permit denial and a hearing due to a discrepancy regarding the filing date of appeal documents, the 83rd Judicial District's Pecos County Court 52 granted the MPGCD's motion for partial summary judgment. Judge Stephen Ables ultimately agreed with the MPGCD counsel's argument asserting "…changing the use of groundwater production currently permitted for irrigation is illegal…," and FSHLP's desire to redirect groundwater for water marketing, "…involves [an] illegal change of use and is, therefore, a fatal flaw in the application, and MPGCD's denial of the permit is legitimate…." (Beal 2015). FSHLP plans to file an appeal with the Eighth Court of Appeals in El Paso County and has decided to sever its permit denial appeal from an additional claim—that the MPGCD's denial represents a governmental taking of private property. Nevertheless, the key issue that remains is whether a GCD can deny changing a historical permit for irrigation uses to municipal and industrial uses.

While the Clayton Williams case was focused on the use of groundwater, the courts no doubt knew that the water would be exported. Interestingly, within the Edwards Aquifer Authority (EAA) we have another example where regulatory authorities are involved in limiting the transfer of water rights from one use to another that did not involve export. Initially, pumpers with irrigation permits issued based on 2 acre-feet/surface acre were able to transfer one of their two acre-feet permits to municipal or industrial users as long as the water was removed from the same pool. In effect, the Edwards Aquifer Authority held that it was in the public interest to maintain some irrigation uses in the Edwards Aquifer, even though the water was used within local confines.

So not only are regulatory authorities involved in determining the total pumping from an aquifer, they have shown a propensity to discriminate among classes of water use. Rather than allowing the market to determine the use of the water, regulators now want to intervene in this process. One must ask what special knowledge do regulators have in this regard? Particularly, in the Edwards Aquifer, which is centered over a rapidly developing part of the state, one would think that water use for municipal and industrial use would be a higher-valued use than that for irrigation. Why not let irrigators sell all of their water rights and their valuable land for development and move to less congested areas for their irrigation activities?

TASK 3: A PROPERTY-BASED SOLUTION TO THE TWO FUNDAMENTAL PROBLEMS FACING GROUNDWATER MANAGEMENT

In 1904 when the Supreme Court of Texas embraced the rule of capture, it had no ability to define property rights other than by whom captured the water. There was no practical way to determine the groundwater storage underlying a given landowner's acreage. Today, advances in seismic techniques and well logs give a reasonably accurate picture of the thickness of the aquifer and its saturated water content. Given these two pieces of information, it is possible to calculate water storage under individual tracts of land. Indeed, for the nine major aquifers in Texas, groundwater storage data is available on 1 square mile grids. In effect, if pumpers were limited to just the water underlying their property (and not their neighbors), Hotelling's requirement of well-defined property rights could be satisfied. But how would such a system work?

The idea is to create a groundwater bank account for each landowner. When the landowner pumps water, he withdraws water from his account. Once the balance in his bank account reaches zero, he must either stop pumping or purchase water from his neighbor's bank account. In effect, each landowner has only a finite amount of water at his disposal. Knowing that he has a fixed budget to live within, landowners will behave quite differently than under the rule of capture or an exempt producer who knows that each year he will receive a new allocation.

A critical distinguishing factor of the bank account is that it has conservation incentives built into it that the current system does not. In contrast, a historically exempt pumper with permits for 40,000 acre-feet/year faces very different incentives. He will pump his full annual allocation. Then the next year, he will do the same again and likewise, into the future. In effect, he knows that he should "use it or lose it." The only criteria is to pump as long as the water produces a return in excess of pumping costs—*not pumping costs plus user costs*.

With a bank account system, water not pumped this year remains in his bank account and can be used in future years. Future use could include selling the water to another user, leaving it in the ground for his grandchildren, or donating it to a nature conservancy. Knowing that water will become more valuable over time because of rising user costs creates an incentive to leave the water in the ground.

Interestingly, going back to the two fundamental problems of groundwater management, we find that the groundwater bank account is designed to deal with both problems. By setting bank account balances as a fraction of total storage, property rights are clearly defined. First, because of the built-in incentive to conserve, we are letting the market decide how much water is sold today versus the future. Adding up all the landowner's decisions to pump today versus leaving the water in their bank account solves the first problem of determining aggregate pumping and relieves the GCDs of the obligation to make this choice on behalf of current and future generations. The groundwater bank account also solves the second problem of who gets to pump how much. Landowners are free to make that choice *providing* they use no more than what is in their bank account. They are free to determine how they use the water as well—again relieving the local GCDs of the political caldron of allocating pumping rights.

How would the courts view a groundwater bank account system? There is good reason to think that they would gladly embrace it. Bank accounts based on the water underlying a landowner's property is a superior system to the rule of capture. In 1904, the rule of capture may have been the best the courts could do and still regard groundwater as a private property resource. The clear intent was to recognize that the groundwater underlying a landowner's property was his. Now scientific advances allow a much more accurate method of determining the water underlying a landowner's property. The language in the Day case states (Cruse 2012):

> *We decide in this case whether land ownership includes an interest in groundwater in place that cannot be taken for public use without adequate compensation guaranteed by article I, section 17(a) of the Texas Constitution. We hold that it does.*

There is still another reason why the courts would seem likely to embrace the groundwater bank account idea. It would eliminate costly takings cases arising from the existing GCD regulatory apparatus. Since each landowner would own the water underlying their property as determined on a particular date, they would have freedom to do with it as they please. Takings cases should in principle end.[18]

An important legal feature of the groundwater bank account is that it satisfies notions of correlative rights. First, it is property-based, recognizing that all property owners should have the right to do with the groundwater that is by law theirs. The bank account idea is not the only correlative rights system. For example, as described earlier all surface owners might receive the right to pump 2 acre-feet/surface acre and share proportionally if less need be withdrawn to protect the aquifer. This system implicitly assumes that the aquifer underlying their land is homogenous with equal storage per surface acre. A distinguishing characteristic of the groundwater bank account system is that it recognizes heterogeneities among different parcels of land. It recognizes the fact that different properties have different storage of groundwater. In effect it takes a snapshot in time showing the groundwater under each square mile and this becomes the basis for determining individual property owners' initial balances in their bank accounts.

Figure 3 addresses the fairness issue by illustrating the heterogeneity of groundwater reserves in the Carrizo-Wilcox Aquifer in the Evergreen GCD. The heterogeneity of groundwater storage under various square mile tracts is quite striking. For example, in about 4% of the area the formation is very thin with reserves ranging between zero and 49.2 acre-feet/surface acre. Then at the opposite end of the spectrum, as the formation down-dips, the thickness increases and about 6% of the surface area has between 442.8 and 492 acre-feet/surface acre. In effect, some land has 10 times more storage. In between these two extremes, there is considerable heterogeneity and its composition does not fit a traditional bell-shaped curve. Two peaks are observed where almost 15% of the surface areas contain quite different storage with one range between 196 and 248 acre-feet/surface acre and another ranging from 344 to 393 acre-feet/surface acre.

Paradoxically, not recognizing the heterogeneity of the aquifer will most likely disadvantage up-dip landowners subject to a correlative rights system in which all landowners are entitled to, for example, 2 acre-feet/surface acre. As the drawdown of the aquifer occurs, the up-dip landowners will no longer be

[18]Another type of takings case might evolve—based on disputes about the total storage underlying a given property. However, the burden of proof would lay with the litigant to prove that the TWDB's storage estimate for the square mile within which their property was situated was in error. Cases of this nature would be very costly to bring and the incentives to bring these cases would not seem nearly as large as the current takings cases.

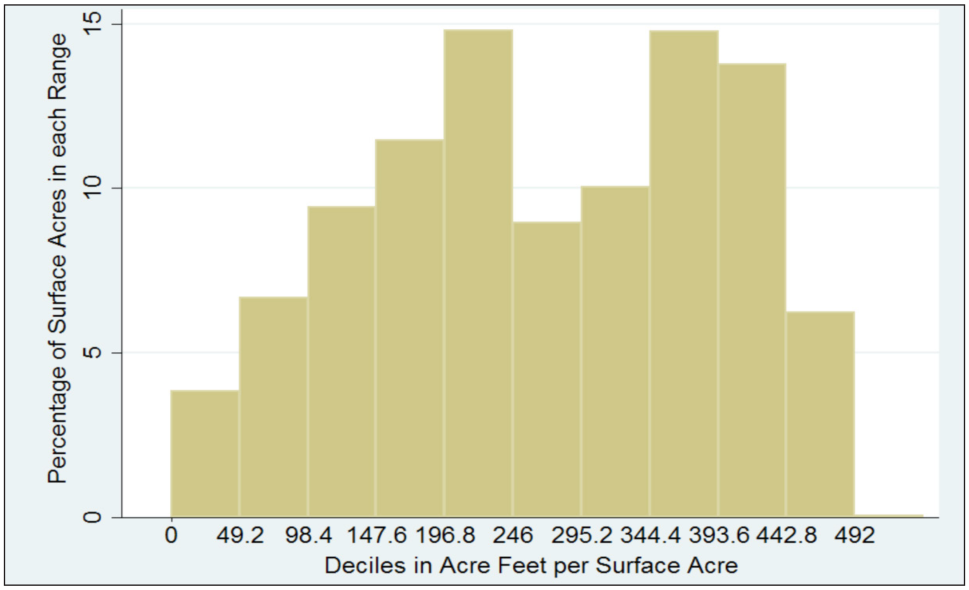

Figure 3. Heterogeneity of surface acres in the Carrizo-Wilcox in the Evergreen GCD.

able to pump their allotted 2 acre-feet/surface acre while down-dip landowners can. The up-dip pumpers could be out of luck. Meanwhile, the down dip pumpers will continue to drain those up-dip owners as the water table in the aquifer drops.[19]

The groundwater bank account system provides a much more palatable solution to the up-dip landowner than for the more common correlative rights system of 2 acre-feet/surface acre. Even though the up-dip owner may not be able to fully extract the groundwater to which he was originally entitled, he can be remunerated. The down-dip producer is limited in his pumping to only the groundwater *initially* in his bank account. The fact that up-dip water may have gravitated into his well zones after the initial determination of his storage does not give him a property right to this water. In order for him to be able to pump this water that has now gravitated to his property, he must purchase the bank account balances of the up-dip producers. In sum, even though the water may not be eventually pumped at the up-dip locations, up-dip owners are compensated for the groundwater that initially was located under their property and in their bank account.

In implementing such a groundwater bank account system, there are a number of details to be worked out. Many of these details are described in detail in Brady et al. (2016) and the reader is urged to seek that source. But here it is worth mentioning a few. First, in establishing the initial balance in each landowner's account, the suggestion is made to allocate 5% of total storage at the inception of the banking system. Recharge credits would be made at 10-year intervals with each landowner receiving his proportionate share of the recharge credits. These balances would be maintained for a 50-year period and then an additional deposit would be made as some percentage of total storage again based on the *original storage at the inception date.* In effect every 10 years, bank accounts would be adjusted for recharge and every 50 years original balances would be re-upped based on aquifer conditions.[20]

A key feature of this process is the incentive to conserve. Balances for the first 50 years will be rolled over in perpetuity. In contrast, a correlative rights system based on a common 2 acre-feet/surface acre, the incentive is to "use it or lose it." Likewise, with the current system granting permits for fixed rates of pumping, there is no incentive to leave the water in the ground since a cutback by any one pumper will not assure him any more future water from the common pool. To many, the unique conservation feature of the groundwater bank account system is its strongest feature. Increasingly, it is becoming more expensive to develop additional surface water supplies, so that conservation must play a larger role in the future. The groundwater bank account provides a voluntary mechanism for its achievement.

Other key features of the system would be that local GCDs would serve as the local banker, keeping records of debits (pumping and transfers to other parties) and credits (purchases and recharge) as well as the day-to-day administration of the bank accounts much like a bank does today. The local GCDs

[19]This problem may not even be important depending on the slope of the aquifer and the permeability of the up-dip sections.

[20]The reason that 50 years was chosen is that large-scale investments in pipelines and wells require elements of certainty and protection from regulation-induced changes that might otherwise vitiate a projects economics. On the other hand one can argue that a shorter time horizon will allow more flexibility in responding to aquifer conditions.

could define transfer zones within which property owners could exchange pumping rights. Having a local bank as well as a board to appeal to would keep an important element of local involvement. Decisions the monitoring of aquifer conditions regarding recharge credits and re-upping bank balances after 50 years would be made at the aquifer level, which could leverage off the current 16 groundwater management areas. Additional details are provided in Brady et al.

CONCLUSIONS

Hotelling's model tells us that well-defined property rights are a prerequisite for allowing the market to solve the first problem of "how much" water is produced today and how much is left for future generations. The rule of capture fails the test of protecting property rights and consequently produces groundwater "too fast." According to Brady et al. (2016), the GCD regulatory process, which has replaced it, has produced a regulation-induced shortage by limiting future pumping to "too slow." By grandfathering in historical pumpers, current GCD practices using artesian drawdown leave little room for new pumpers and actually rewards the beneficiaries of the rule of capture.

Unfortunately, neither the rule of capture nor the most common GCD regulatory process (DFCs based on artesian drawdown and discriminating among users and uses) appears up to the task of balancing current and future needs. It is particularly troubling that these GCDs have used their regulatory power to go well beyond determining "how much" water should be pumped. They have added a new layer of regulatory authority in the form of usage-based regulation. Besides violating principles of fairness and property rights, this system prevents groundwater from being used at its highest and best use. Brady et al. (2016) propose four alternatives methods for reorganizing groundwater regulation—all of which involve major regulatory changes. While I agree with their conclusions that all four options would be an improvement over the existing system, the most compelling option involves creating groundwater bank accounts, clearly defining property rights, and giving landowners the freedom to use their water as they wish. The appeal of this approach depends critically on understanding how Hotelling's user costs will be at work providing built-in incentives to conserve. It is time to interject economics into the groundwater policy dialogue.

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