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THE TEXAS WATER JOURNAL is an online, peer-reviewed journal devoted to the timely consideration of Texas water resources management, research, and policy issues. The journal provides in-depth analysis of Texas water resources management and policies from a multidisciplinary perspective that integrates science, engineering, law, planning, and other disciplines. It also provides updates on key state legislation and policy changes by Texas administrative agencies.

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make every drop count

Cover photo: Jacob's Well, in Hays County, Texas. © 2015. Andy Heatwole.

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Commentary: The regional water planning process: a Texas success story

Bech Bruun[1]

Editor's Note: The opinion expressed in this commentary is the opinion of the individual author and not the opinion of the Texas Water Journal or the Texas Water Resources Institute.

Abstract: In 1997, in the wake of a severe, statewide drought, the Texas Legislature passed an omnibus water bill that, among other things, fundamentally changed how Texas develops its state water plans. The resulting 5-year, bottom-up regional approach to planning has since formed the basis of the last 4 state water plans. Nearly a generation after the regional water planning process began, we can now point to some significant achievements and identify key factors in the success of the process.

Keywords: Water, planning, infrastructure, state water plan

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Terms used in paper

Acronym	Descriptive term
SWIFT	State Water Implementation Fund for Texas
SWIRFT	State Water Implementation Revenue Fund for Texas
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board

INTRODUCTION

One might say that the old adage "*Life is what happens while you are busy making plans*" could be applied to the relative disconnect between water plans and water development in Texas prior to 1997. Although the state began developing state water plans in 1961, too few water projects were being implemented to address the state's drought risks and its need for adequate water supplies for a growing population. There was a significant "reality gap" between the state's water plans and what was actually being implemented.

In 1997, however, visionary state leadership created a new, cyclical, "bottom up" regional water planning process. The cyclical process ensures a realistic assessment of water needs and feasible responses to meeting those needs. At the same time, the cyclical process keeps the state water plan relevant by incorporating new information, the latest science, and recent legislative policy every 5 years. As a result, the reality gap between planning and implementation has been greatly reduced over the last 20 years.

With the experience of nearly 2 decades of regional water planning behind us and the release of the 2017 State Water Plan, our fourth state water plan under this new process, now marks a good time to reflect on what has been achieved.

Tremendous future population growth and our vibrant economy require that Texas continue to map out future water supplies and ensure that we will continue to have enough for future generations. As observed by the Texas Senate in 1997, "water, more than any other natural resource, challenges Texas' future."[1]

TEXAS WATER PLANNING HISTORY

The Texas Water Development Board (TWDB)'s predecessor agency and state water planning, in general, came about as a direct response to the drought of the 1950s, which remains Texas' worst statewide drought of record. The Water Planning Act of 1957 charged the agency with the responsibility for water resource planning, including developing state water plans, and in 1961 the agency produced the first state water plan. An observation in that plan has continued to ring true throughout the past 60 years: *"If Texans cannot change the weather, they can at least, through sound, farsighted planning, conserve and develop water resources to supply their needs."*[2]

In 1996, another severe statewide drought revealed once again Texas' vulnerability to drought and served as a catalyst in 1997 to the Texas Legislature's deliberate move to change how Texas plans for water supply. The new approach, built on a more stakeholder, regionally driven approach formalized a regional water planning process based on 16 self-governing planning groups representing 16 regional water planning areas (A–P).[3] Each planning group was required to prepare its own regional water plan on 5-year cycles. The goal was to try to improve state water planning so that more projects would be developed to meet Texas' rapidly growing water needs to provide for public health and safety and our economy under drought conditions.

The shift to a regional water planning approach was partly an indication that many of the previous state water plans were not viewed as realistic or specific enough to forecast or facilitate actual project implementation.[4] A more local approach to developing state water plans made sense considering it was (and remains) the local and regional water providers that directly implement and pay for water projects. Other than providing financial assistance programs, primarily in the form of low-interest loans, the State of Texas, does not, in general, sponsor or directly pay for state water plan projects.[5] At the same time, the regional water planning process needed to be balanced enough to develop meaningful state water plans while protecting the state's interests and upholding certain planning principles. The last 4 state water plans (2002, 2007, 2012, and 2017) have been successfully developed under the new, regional approach that develops water plans every 5 years.

The new regional planning process also fundamentally changed the dynamic of water planning by shifting the decision-making about water management strategies from the state's purview to regional water planning groups. Up until then, the state had been responsible for recommending the projects in the state water plan. The result was that large portions of the state water plans were effectively gathering dust on a shelf while water providers either proceeded differently or did not proceed at all to implement many projects.

[1] http://www.capitol.state.tx.us/tlodocs/75R/analysis/html/SB00001S.htm

[2] Texas Board of Water Engineers. 1961. A plan for meeting the 1980 water requirements of Texas. Austin (Texas): Texas Board of Water Engineers. Available from: http://www.twdb.texas.gov/publications/State_Water_Plan/1961/1961.pdf

[3] Once the "initial coordinating bodies" of each planning group were designated by the TWDB through a nomination process, each was charged with self-governance including maintaining the minimum statutorily required membership categories (counties, municipalities, industries, agriculture, environment, small business, electric generation utilities, river authorities, water districts, water utilities, the general public, and groundwater management areas). They are not considered political subdivisions of the state.

[4] Although any 50-year plan has a significant amount of uncertainty and therefore remains subject to change, it is important to both policy-makers and water providers that what is laid out in each plan is at least credibly feasible, particularly as it applies to the near-term timeframe.

[5] The TWDB takes partial ownership interest in a very limited number of larger capacity projects that are eventually bought out by sponsors as their need for water reaches the full project capacity.

The new process set Texas apart from other states primarily by

- designating regional water planning areas and regional water planning group members that develop plans in a bottom-up manner,
- basing the state water plan on the 16 regional water plans,
- requiring the development of regional and state water plans every 5 years,
- providing regular legislative appropriations, and
- using the historical drought conditions as the benchmark for the plan development.

The legislature's bold shift to regional planning meant that 16 planning groups now had the responsibility to identify the best approaches to meeting Texas' future water needs. The legislature incentivized participation in the process through water rights and the state's financial assistance programs. The Texas Commission on Environmental Quality (TCEQ) may not issue a water right unless it addresses a water supply need in a manner consistent with the regional and state water plans. Projects applying for financial assistance from the TWDB must also be consistent with the plans.

The shift to regional planning also meant that because the state water plan incorporated the regional water plans, the state would not, as a matter of course, directly add or remove specific projects as long as the planning groups developed their regional plans in accordance with statute and rules.[6] The TWDB shapes the regional and state water plans through developing and implementing its own rules and guidance and by making state policy recommendations in the state water plans. The Board is also responsible for resolving interregional conflicts and may be approached directly by any local water provider that believes its requested change to a regional plan was not sufficiently addressed by a regional water planning group.[7]

As a part of the new process, planning groups were required to evaluate how each municipal and non-municipal water user group (and numerous major water providers) would fare under drought conditions over the next 50 years by

- forecasting population and water demands;
- assessing existing water supplies;
- identifying water needs (potential shortages); and
- recommending strategies for each entity to meet those potential shortages under drought conditions.

The resulting water plans provide detailed "snapshots" of what Texas water supplies would look like if drought conditions were to recur within each of the next 5 decades. The plans recommend, in detail, feasible actions to respond to drought and address potential water shortages.

ACHIEVEMENTS

That Texas' regional water planning process has successfully produced 4 comprehensive and highly credible state water plans with relatively little controversy is an achievement in itself. Each plan is based on an enormous amount of stakeholder input and is the result of 5 years of planning effort by hundreds of planning group members and their consultants.[8] There are many dimensions to these successes that other states and countries might find enviable. Perhaps most notably, no other fast-growing state has produced a water plan that more clearly demonstrates how its local water suppliers can provide affordable water to its citizens over the long term.

More substance and less conjecture

The state water plans developed through the regional water planning process have increased the amount and quality of direct stakeholder input, which in turn provides more accurate, detailed, actionable information about very specific water sources, water users, and recommended projects than previous state water plans.

By more directly involving those responsible for implementing projects and developing detailed numerical analyses, the new plans—and hence the overall state plan—better articulate the basis for and coherent path to implementing each project. The most recent 2017 State Water Plan shows very explicitly how Texas can affordably meet nearly all of its anticipated municipal water demands for the next 50 years.[9] This conclusion does not rely on over-simplified aggregations of water demands and supplies and optimistic prose. It is based, instead, on detailed assessments of projected water demands, existing supplies that users are already connected to, and strategy recommendations for each of the more than 2,600 water users identified in this cycle of planning. The 5,500 recommended strategies are, in turn, associated with a specific water source (such as a reservoir or aquifer) that has been further evaluated to ensure that implementation of each strategy would not overextend its dedicated water source. Finally, these strategies would require 2,500 specific capital investments, each of which has an estimated cost and online date. Importantly, the vast majority of projects also have a named sponsor entity to take ownership, implement, and pay for the infrastructure.

[6] In accordance with statute (TWC § 16.053 31 TAC §§ 357, 358), the TWDB reviews and approves each plan. Throughout this document, TWC refers to Texas Water Code and TAC refers to the Texas Administrative Code.

[7] TWC § 16.054; 31 TAC 357.51

[8] The 2017 State Water Plan, at 133 pages, only summarizes the more than 20,000 pages that make up the 16 regional water plans.

[9] There are a few municipal needs that are shown as unmet by the plan but that may be significantly less depending upon future regulatory decisions and, in all cases, would not be expected to impact public health and safety.

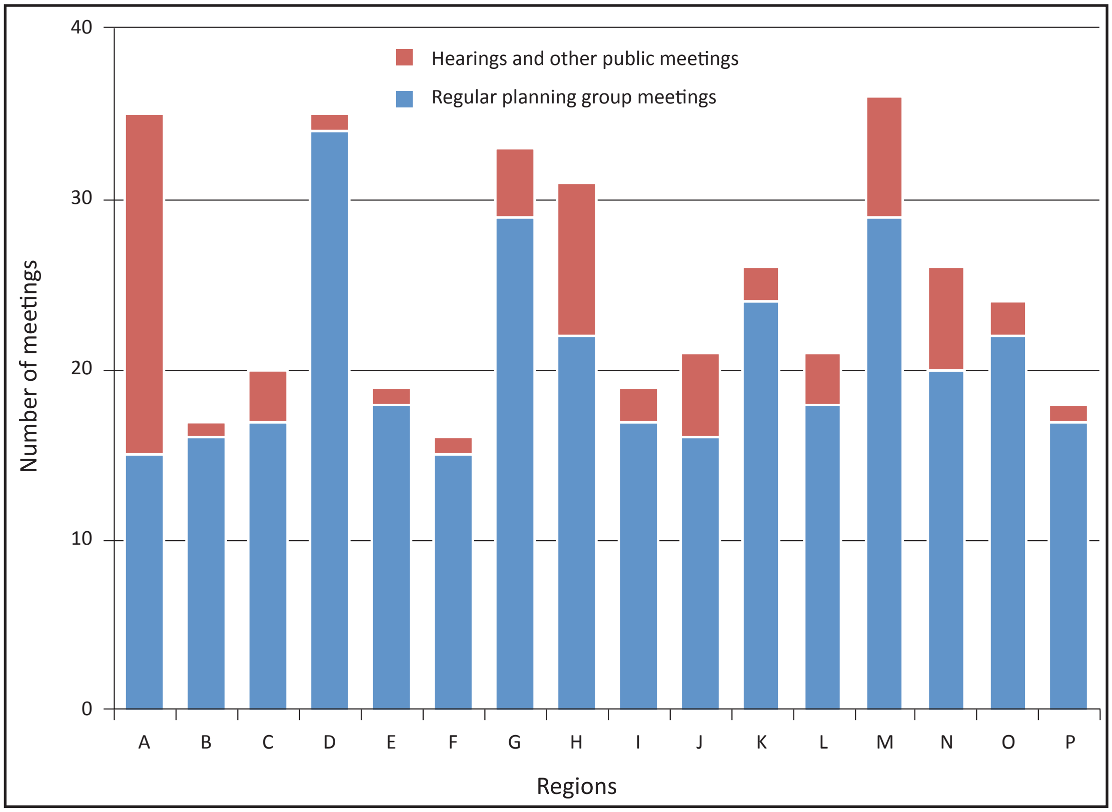

Figure 1. Number of regional planning group meetings and hearings on 2016 plans.

Local involvement and transparency

The regional water planning process requires the participation and efforts of hundreds of individuals. For example, in the last planning cycle, there were more than 450 voting members on the regional planning groups. In addition, all planning group meetings must be open to the public. The regional water planning process for the 2017 State Water Plan included approximately 400 public meetings and hearings held in the 16 regions and extensive data gathering from water users and water providers (Figure 1).[10] Most of these meetings were an integral part of developing information for the draft regional water plans, including the process of making decisions about the plan contents. The public and other stakeholders could participate in and speak at all of these public meetings. There were also 16 public hearings held in each respective region once the draft plans were prepared. Additional public meetings at which the planning groups considered and responded to public and other comments and made final changes to the plans followed those meetings. Finally, a public hearing was held on the state water plan in Austin.[11]

Comprehensive, balanced plans

As demonstrated over the last 4 planning cycles, independent planning groups are capable of operating effectively to develop sensible water plans.

A cursory comparison of the general types and shares of strategies recommended in the last 4 state water plans indicates that, at an aggregate level, planning groups are not influenced by political fads and the overall process is robust.[12] Although the terms "update" or "revision" are sometimes used in discussing water plans, each regional and state water plan is, in fact, a stand-alone plan that is based on a renewed look at water demands, potential shortages, and potentially feasible strategies.

[10] Planning groups are required to follow the Texas Open Meetings Act.

[11] In previous years, multiple hearings had been held on the state water plan, but due to the low turnout and a related internal audit recommendation, one was held. The low turnout at state water plan hearings can be attributed largely to 2 things: the level of stakeholder involvement that has already occurred at the regional levels and the generally high level of public acceptance of regional plans.

[12] As further evidence of the sensibility of the regional water plans, there were no sudden wholesale revisions or an upending of the regional water plan recommendations when the SWIFT funding program and its associated prioritization processes was overlaid *onto the existing 2012 State Water Plan*. Instead of causing disruption, the new funding source and prioritization process were integrated into the planning and implementation processes based on the same feasible projects that were already vetted and recommended by the planning groups.

Though there are seldom drastic changes in plans from cycle to cycle, the planning groups do revisit all strategies in each cycle to replace those strategies that are no longer feasible in the new plan. Even strategies that may have been recommended in previous plans must be updated, for example, to reflect updated costs, and, if appropriate, recommended anew. Not surprisingly, some strategies appear in multiple, sequential plans, whereas other strategies and projects that may have been previously recommended are not recommended in the next plan. Cycle-to-cycle changes to a region's recommended water management strategies are the result of a variety of factors. These factors include changes in each cycle's water demand projections and quantified water availability (for example, as a result of new managed available groundwater values or new drought of record conditions), completed implementation of projects, and other new or changed information.

Examples of changes between water plans that are not associated with project implementation include the following:

- A number of surface water projects, including major reservoirs, that over the years were recommended strategies in at least 1 regional water planning cycle are no longer recommended strategies. These include Bedias Reservoir, Lake 8, Little River Main-stem Reservoir, Post Reservoir, Nueces Off-channel Reservoir, and Texana Stage II Reservoir. Both the Laredo and Brownsville weir projects and a major Lower Colorado River Authority-San Antonio Water System project are no longer recommended strategies in the state water plan. On the other hand, there are new strategies in the 2017 State Water Plan to dredge Lake Lavon and Lake Wright Patman.
- The Region K seawater desalination project, located in Matagorda Count and recommended in the 2007 State Water Plan, is no longer a proposed strategy. Both the Laguna Madre and Laguna Vista seawater desalination projects recommended in the 2012 plan are not included in the 2017 plan due to feasibility issues. Between the 2012 and 2017 plans, the Freeport seawater desalination project capacity was reduced to approximately one-third its previously recommended size, and the proposed Brownsville project capacity was increased 4-fold over the previous plan.
- There is a new aquifer storage and recovery strategy recommended for New Braunfels in the 2017 State Water Plan. On the other hand, the previously proposed City of Bandera aquifer storage and recovery strategy is not in the current state water plan.
- To respond to new desired future conditions of aquifers, numerous strategies have been changed, including downsizing of projects. One clear change involves the 2012 State Water Plan strategy called *Overdraft of Trinity Aquifer* in Region C that became infeasible due to new desired future conditions and was therefore not included in the 2017 State Water Plan.

The lack of volatility between water plans is due to various factors, including the planning groups' ability to maintain their membership, strong planning group leadership, and, most importantly, the thorough regional water planning framework that guides the overall process. Throughout their work, the planning groups also benefit from local water plans and the deep knowledge and perspectives brought to the table by those water providers who will have to implement the plan.

Individual planning group members do not recommend strategies in a vacuum. The regional water planning process requires that the planning group identify, evaluate, and consider potential strategies all while requiring public input on those strategies. In addition, the process relies on certain required technical evaluations performed by professional technical consultants. Not surprisingly then, the plans for the most part have changed in a logical and reasonable fashion from one to the next.

KEY FACTORS IN WATER PLANNING SUCCESS

A number of features contribute to the success of Texas' regional water planning process, including the science-based data, the involvement of local and regional entities who will sponsor and pay for the projects, the stability of the planning process, the cyclic nature of planning, and the role of the state. The adherence to basic planning parameters and the frequent opportunity to improve the process have resulted in comprehensive, credible state water plans that provide a coherent picture of how Texas can move forward to meet its water needs. Whereas other states' water plans often include large amounts of text and limited numbers and specifics, one of the strengths of Texas' water plan is the detailed numbers that speak for themselves.

Science-based, quantitative planning

The only responsible way to ensure that cities and businesses aren't short of water is to use realistic forecasts and plan for only the amount of water that can legally and physically be pumped in drought conditions without over-allocating any water sources. The emphasis on constraint-based, numerical water planning using the best available, actionable information has obligated planning groups to explicitly recognize water resource limits and develop credible plans within those limits.

Because the regional water plans are founded on science-based, water resource constraints, they have been highly defensible and meaningful. Managing natural resources responsibly requires translating policy decisions into numbers in the same way that producing a responsible financial budget requires a detailed balance sheet with expected income and expenditures. Thanks to significant investments by the Texas Legislature in developing surface water and groundwater models, we are well ahead of most other states in our ability to translate state and local level policy into quantifiable surface water and groundwater availabilities for each of our river basins and aquifers. Those numerical models have played a key role in shaping and legitimizing the adopted regional and state water plans.[13]

The integrity and coherency of the regional and state water plans rely on the consistent use of a variety of credible data and consistent application of widely accepted technical analyses. Municipal water demand forecasts in all 16 regional water plans, for example, are based on federal census data, a common set of statewide, historic water use data collected by the TWDB, and sophisticated population projections modeled by the State Demographer at the Texas State Data Center. Although regions have the ability to request justified changes to this projection data, the TWDB maintains the overall integrity of the statewide numbers, including limits at the county, regional, and state level, by acting as the sole arbiter of the final projections.

The regions' reservoir firm yield analyses must also follow a common methodology based on industry practice. Additionally, project cost estimates are based on a common set of assumptions and are supported by a standardized costing tool developed by the TWDB specifically for use by the regions.

The overarching framework of the regional water planning process does not permit planning groups to simply ignore unpleasant realities or to entirely sidestep the most difficult issues that require tough decisions. Statute and planning rules require that planning groups address specific water planning steps, each structured to lead to a concrete numerical outcome or recommendation. These processes have led to conflicts that must be resolved by those best suited to address them head on: regional water planning group members and their stakeholders. The resulting conflicts have been productive. Conflicts tend to improve stakeholder understanding, strengthen the basis for decision-making, and advance research and policy discussions that help avoid, or at least better inform, future conflicts.

Conflict means that there is something at stake and participants are wrestling with important water issues that probably do not have easy solutions. Acknowledging conflicts and making associated recommendations in the plans can provide stakeholders and project sponsors with greater certainty than if the issues are left unresolved indefinitely. Because regional plans cannot simply ignore disagreements or plaster over numerical discrepancies with vague and optimistic language, they must work at resolving these conflicts in a public setting, which strengthens the water plans.

Essential role of project sponsors

A natural tension exists between the local and regional providers that must implement water supply projects, the regional water planning stakeholder process, and the scale and goals of a state water plan. In the end, planning groups and those responsible for actually developing water projects naturally consider their own interests and geography. Thus far, planning groups have recommended projects, large and small, that, in the current context of water rights and water provision, are considered feasible and make the best economic and logistic sense with regard to actual implementation. As long as the cost is borne by local entities, planning groups will continue to choose strategies that they believe can be reasonably implemented and financed by local sponsors in a timely manner.

The current planning framework provides the opportunity for multi-region projects that serve large areas of Texas but does not require it. To this end, planning groups already include representation of interests outside their region and cooperate in the planning process.[14] In developing their plans, the planning groups consider water resources, including state-owned surface water, located outside the regional water planning area and may consider including water providers and water users outside their region when developing strategies. In the 2017 State Water Plan, roughly one-fifth of all new water supplies associated with recommended water management strategies in 2070 originate from water sources associated with other planning regions.[15]

The state has a clear role in setting the overall course and goals of the planning process, including providing guidance and requiring that each plan attempt to meet statewide water needs where feasible. Texas' planning framework does not promote

[13] Firm surface water supply estimates are based on the surface water models that are used for permitting and maintained by the TCEQ. Groundwater availability is limited by the requirement that regional water plans must be consistent with desired future conditions. Desired future conditions represent the desired, quantified conditions of groundwater resources, such as water levels, water quality, spring flows, or volumes, at a specified time or times in the future or in perpetuity. The vast majority of groundwater that can be pumped in drought is determined through policy decisions of conservation districts within a single groundwater management area that are then translated into modeled available groundwater values using the TWDB-approved groundwater availability models.

[14] Each planning group includes liaisons from adjacent planning groups who facilitate the sharing of information and help coordinate planning activities. The limited number of multi-region strategies is at least partly the product of well-chosen regional planning areas.

[15] Regional water planning areas serve as administrative and planning boundaries only and do not include any authority to limit other regional water planning groups, water providers, or water users' ability to maintain existing or shared water supplies or to secure additional water supplies that may be located within any other regional water planning area.

any one technology over another, for example through direct financial incentives. The Texas Water Code's agnostic approach toward both the type of technology and the scale of projects that may be recommended makes sense for a large, diverse state but also means that, in the end, strategy recommendations remain those of planning groups.[16]

Stability of planning group memberships

Planning groups remain relatively stable as bodies and continue to implement the state's regional water planning process in a conscientious manner. The groups have consistently made a good faith effort to fill member vacancies as they arise, and the membership of planning groups has generally not experienced upheaval or disruptive levels of turnover.[17] They maintain their own bylaws and adjust and replenish their membership as needed in accordance with their bylaws.

In the fall of 2016, the TWDB solicited public comments and held a public work session specifically to consider the membership and operation of the planning groups. A Board member roundtable discussion with the chairs or designated representatives of the 16 planning groups considered the public comments received and a summary of the 16 regional planning groups' existing bylaws and membership requirements.[18] Based on that discussion as well as the limited number of and nature of the public comments the TWDB received, it was apparent that there are not significant issues with the legal requirements for regional water planning group membership or widespread concerns with how planning groups maintain their membership.[19] The discussion revealed that the planning groups have flexibility to successfully recruit engaged planning group members who represent the required interest categories and have successfully accommodated statutory changes to their planning group membership. In addition, many planning groups have more than the required number of voting positions to ensure that a broader number of interests are represented on the planning groups (Figure 2).

Regular planning cycles

The regularity of 5-year regional and state planning cycles required by current statute, together with the built-in flexibility of the process, facilitates a predictable and stable planning process that rapidly incorporates legislative policy direction, new information, and innovations as they arise.

Developing regional and state water plans every 5 years encourages engagement and retention of institutional knowledge by planning group members, stakeholders, consultants, and state agency resources. Developing the same type of detailed, bottom-up regional water plans on either a more intermittent basis or on significantly longer planning cycle timeframes would at some point become very challenging as planning group members and other participants would have to be entirely reoriented to each new cycle. Extended periods of inactivity would pose practical challenges. One of those challenges would be the reduced expertise of technical consultants and agency staff that support the nuts and bolts of the planning process. The quality of the plans would reflect these drawbacks.

Cyclical planning sets up an inevitable feedback loop in which water plans and the planning process are responsive to criticisms and legislative policy changes, remain updated and relevant, and incorporate new scientific data and other improvements. The regular cycles of plan development also serve to test the viability and longevity of proposed projects. The result is that projects that no longer make sense, for example due to changing economics, are sifted out along the way. The planning process itself has been adjusted over the years so that plan content and delivery mode are continually improving.

Our agency continues to look for ways to improve the plans and add value to the process. The Interactive 2017 State Water Plan website is the most notable product of a long series of improvements in how we collect, organize, and deliver planning data. It allows stakeholders to easily explore and consume the enormous amount of planning information, which informs subsequent planning cycles.

Keeping the regional and state water plans up-to-date helps ensure continuity in funding state water plan projects**.** Because projects funded through the State Water Implementation Fund for Texas (SWIFT) program must be included in the state water plan, it is beneficial to regularly update the state water plan to ensure that stakeholders know when to participate and propose projects so that the plans contain current informa-

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[16] TWC 16.053(e)(5). Planning groups are required to consider all potentially feasible strategies when addressing their future water needs. Statute does not describe the universe of potential strategy types that must be considered but does specifically name a number of categories of particular interest. Under planning rules, conservation, in particular, has a somewhat higher threshold of consideration in that after conservation is considered but is not recommended for an entity with an anticipated shortage, the planning group must also *document the reason* for not recommending conservation (31 TAC 357.34(g)((2)(B)).

[17] Each planning group has maintained and governed itself since the TWDB designated the "initial coordinating body" members and provided each with model bylaws in 1998. Each planning group membership has varied depending on the regions' preferences and other factors but must, at a minimum include at least 12 statutorily required voting membership categories, as applicable. Total planning group membership has grown from approximately 270 voting members of the initial coordinating bodies named by the TWDB to the current approximately 360 voting members.

[18] November 17, 2016, at the Stephen F. Austin building. Video available at http://texasadmin.com/tx/twdb/work_session/20161117/.

[19] Eight organizations and 3 individuals submitted comments.

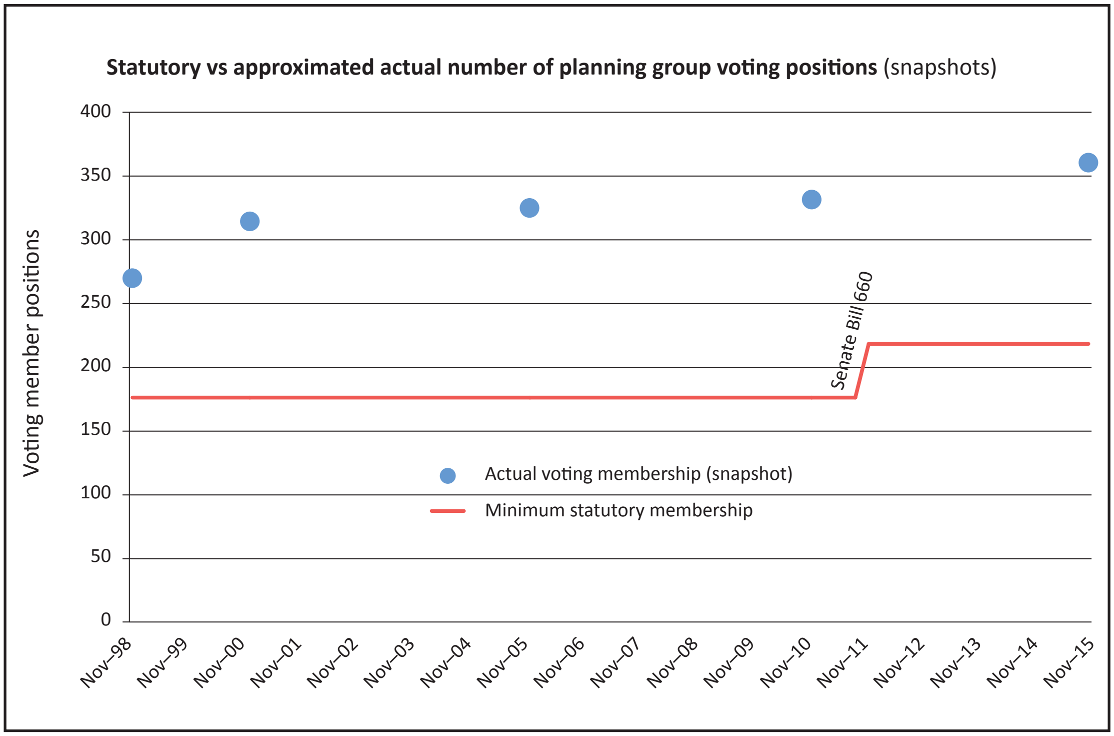

Figure 2. Number of statutory versus actual planning group voting positions over time.

tion on projects that are eligible for SWIFT.[20] The alternative would likely involve frequent but irregular amendments to the regional water plans.

Since 1997, there has been a variety of changes introduced to the plans and planning process.

Second cycle changes (2003–2007)

After criticisms of the first regional water planning cycle, most conservation water savings were shifted to the water strategy *supply* side instead of embedding it on the forecast water *demand* side of things where it had been mistakenly assumed to occur passively.[21] The second planning cycle also expanded to include the first rural water utilities incorporated recently completed TCEQ surface water availability models and the initial TWDB groundwater availability models, and required reporting of state financial assistance needed to implement the plan.[22]

Third cycle changes (2008–2012)

The third cycle of planning added new groundwater management area representatives to the planning groups and incorporated updated power and mining (including hydraulic fracturing) water demand projections in response to a rapidly changing energy market.

Fourth cycle changes (2013–2017)

The recently completed planning cycle incorporated project prioritizations required by House Bill 4 from the 84th Texas Legislature. It also included many new modeled available groundwater values statewide and took into consideration the recent 2010–14 drought conditions as well as the TCEQ's newly adopted environmental flow standards. In addition,

[20] In 2013, the Texas Legislature and Texas voters created the State Water Implementation Fund for Texas (SWIFT) and the State Water Implementation Revenue Fund for Texas (SWIRFT) and authorized a $2 billion transfer from the state's Rainy Day Fund to finance projects in the state water plan. The SWIFT program leverages SWIFT funds through the issuance of SWIRFT revenue bonds.

[21] During the first cycle of regional water planning, a portion of water savings generated through non-passive conservation strategies, beyond those anticipated to be achieved due to existing state and federal plumbing standards, was incorporated directly into the water demand projections developed by the TWDB. That approach could be interpreted to suggest that an additional lowering of per capita water use, for example, was inevitable. In response to subsequent criticisms of that approach, estimates of future non-passive water savings have since been shifted from the demand side of the planning equation to the supply side. This current approach better reflects the fact that a significant portion of future water savings will only be realized through the proactive implementation of conservation strategies by sponsors.

[22] Six river basins were completed by December 31, 1999, and remaining basins were completed by December 31, 2001.

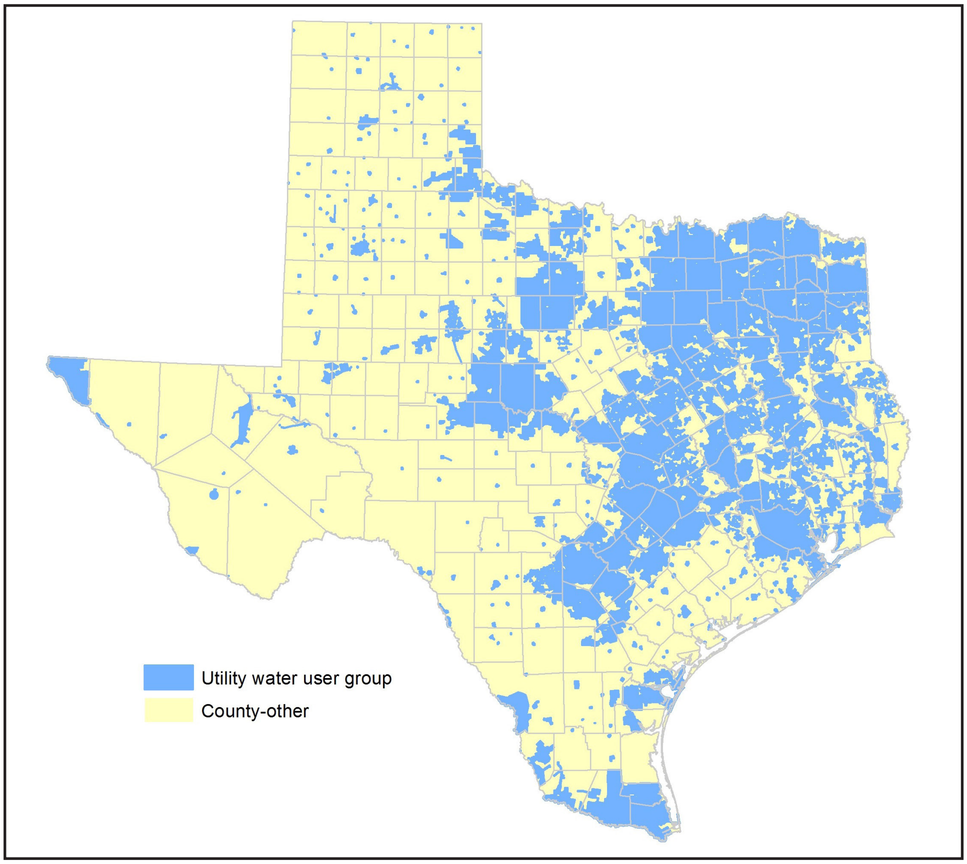

Figure 3. Statewide municipal water user group designations.

this cycle expanded on the state's drought response planning, which included requiring new information aimed at addressing the drought risks of small municipalities. Each regional plan included a chapter on drought response. Planning groups identified potential alternative water sources for small water suppliers that rely on a single source of water. The groups also identified existing emergency interconnects between water systems and potential new emergency water supply connections.

Fifth cycle changes (2018–2022)

For the fifth cycle of state and regional water planning, the agency has revised planning rules to provide an earlier opportunity for planning groups to review each other's plans to address potential interregional conflicts. In response to stakeholder concerns during the fourth cycle, the TWDB has also revised its planning rules to include a modeled available groundwater "peak factor" that ensures regional water plans have the ability to fully reflect how, under current statute, the groundwater conservation districts anticipate managing groundwater pumping in drought conditions.[23]

In addition, the TWDB responded to stakeholder input by implementing a shift to utility-based water planning instead of using the political boundaries of municipalities. This means that the next plan will include population, water demands, potential water shortages, and strategies that reflect specific retail water providers. This change will improve the understanding of the planning process, better align historical data with planning and implementation, reduce work effort, and make it easier to align state water plan project loans with sponsors and beneficiaries. This major improvement requires significant agency effort on the front-end but is expected to greatly improve the planning process. As a result, it will be easier to understand which entities actually need water and who will implement projects.

We also have also increased the granularity of information on rural water providers in the next water plan. To accomplish this, we standardized and lowered the utility threshold criteria for identifying individual municipal water user groups that will be explicitly planned for. This will shift approximately 1 million rural water users from the current aggregated "county-other"

[23] 31 TAC 357.10 (20); process 357.32(d)(3). This rule change eliminated the effect of managed available groundwater values acting as immovable, "hard caps" on groundwater *pumping* that could be reflected the regional water plans.

category (Figure 3) into their own, separate water user groups. As a result, approximately 1 million more citizens served by rural category utilities will be able to find more specific information in the plans about the water needs and recommended strategies for their communities.

Significant state role

The successful development of a coherent, credible state water plan is partly due to a strong state role in the form of a thorough statutory and administrative rule framework that requires active state involvement.

Statute, administrative rules, and agency guidance lay out certain steps and constraints to be considered before planning decisions are made. This framework includes statutory goals, fundamental planning principles laid out in administrative rules, and very specific guidance requirements for what must be calculated and presented in the plans. These requirements ensure that planning groups meet minimum levels of detail, perform prescribed analyses, and consider certain types of strategies before making recommendations. Together with the TWDB's extensive plan reviews and approval, the entire process ensures credibility and produces regional plans that combine to form a meaningful state water plan.

The TWDB continues to play an active role in overseeing and facilitating certain activities, key among them is developing and adopting all population and water demand projections. We use information from the Texas State Demographer and our historical water use survey data to develop the projections, and the drafts are vetted through the planning groups who receive public input. At the beginning of each 5-year planning cycle, the TWDB develops these statewide projections and maintains control over them throughout the process. Whereas planning groups adopt their regional water plans, the water demands are adopted well ahead of time by the TWDB's Board in consultation with our sister agencies, Texas Parks and Wildlife Department, the TCEQ, and the Texas Department of Agriculture. These projections underpin each planning cycle and must be not only well founded but widely accepted.[24]

As a knowledgeable arbiter, the TWDB maintains final control over these long-range forecasts to maintain the credibility of the water plan. Otherwise, the plan might be undermined by overinflated local projections containing over-optimistic growth projections. In doing so, the TWDB solicits and relies on stakeholders for information to strengthen and improve the accuracy of these projections. At any time, planning groups may request revisions to these projections that, if adopted by the Board, would also amend the state water plan.

We have been recently reminded of the scrutiny these projections attract and the importance of maintaining their credibility as we cooperate with the U.S. Army Corps of Engineers and the Environmental Protection Agency in support of state water plan projects that are now pursuing federal permits. Justification of projects depends partly on whether these agencies are convinced of the veracity and reasonableness of the underlying water demands.

Throughout each 5-year cycle, regional water planning groups rely on the TWDB's proactive, day-to-day technical and administrative assistance. In addition to detailed guidance documents and technical consultant support, a TWDB planning team member supports each planning group and attends every planning group meeting as a non-voting member. This TWDB staff member provides unbiased administrative and technical assistance to ensure the planning group meets deadlines and requirements. By providing answers in real time during meetings, TWDB staff has been an invaluable resource that frequently helps participants to avoid confusion, understand requirements, and expend their limited funds wisely.[25]

CONCLUSION

Texas has produced 4 state water plans through this 5-year regional planning process that take a hard look at what we could face in future droughts and very specifically address those challenges. The results of 20 years of regional planning have demonstrated

- the benefits of cyclical water planning performed at a regional level;
- that a very open, bottom-up stakeholder-driven process can be stable and robust;
- the paramount importance of good science and data, which underpin the process and plans; and
- the importance of maintaining a strong and active state role in both funding and guiding the process, including as the arbiter of population and water demand forecasts.

In addition to those tangible benefits, other equally important intangible benefits exist that result from a credible, up-to-date state water plan. For instance, bond underwriters, rating agencies, and potential bond investors beyond Texas have made it clear that having an up-to-date state water plan as the backdrop for the SWIFT loan program enhances the appeal of our bond offerings. The resulting demand for, prices of, and

[24] Partly in response to comment on the 2017 State Water Plan, the agency is in the process of updating its methods of projecting irrigation, power generation, and manufacturing water demands to improve both their quality and the ease with which they can be updated by the TWDB.

[25] Despite the growing scope and increased quality of the state and regional water plans and planning tools that the TWDB provides, the number of full-time state agency planning staff directly supporting the regional water planning program and developing the state water plan has decreased since the inception of regional water planning in 1998.

confidence in our bond sales translate to lower interest rates that the TWDB is able to pass along through our project loans.

Other benefits include an accessible and transparent water plan that Texans can understand, take ownership of, and improve upon. The very public process of regional water planning has taught many citizens about water issues and water planning. This, in turn, encourages greater involvement of stakeholders in subsequent planning cycles. It also promotes general public awareness of where their water comes from, which studies show is the best way to increase conservation efforts of Texans.

Regular planning cycles and feedback drive continual improvements in the planning process and better inform state water policies. The creation of the SWIFT financial assistance program, for example, was a vital new addition to the state's ability to implement state water plan projects. Finally, it is difficult to quantify the impact that a credible, comprehensive, and up-to-date state water plan has on Texas' ability to attract businesses and talented people.

When representatives of the 16 regional planning groups met in Austin in November 2016 to discuss the regional planning process, there was clear consensus on the success of the process. It provides the planning groups with the flexibility to determine their own solutions while also ensuring there is structure and guidance from the state.

The goal of the regional water planning process, however, is not to just produce plans. It is to guide and facilitate the development of sufficient water supply for our state's growing population and vigorous economy. The most telling question that must be answered about the regional and state water planning process, then, is this: is more water for Texas being developed because of these water plans? And the answer is a very simple, but definite, "Yes." The 2017 State Water Plan details strategies capable of producing approximately 8.3 million acre-feet of water when completed. More than $1.6 billion has already been put toward state water plan projects in just the first 2 funding cycles of the SWIFT. Those projects alone, once completed, will produce more than 1.2 million acre-feet of additional water supply for Texas. In other words, we *know* the process is working.

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Commentaries: Key Texas Senate and House water committee chairmen discuss water issues of the 85th Legislature

Editor-in-Chief's note: In every odd-numbered year, the Texas Legislature convenes in regular session for 140 days. With this in mind, the Texas Water Journal invited Senator Charles Perry, Chairman of the Senate Agriculture, Water & Rural Affairs Committee, and Representative Lyle Larson, Chairman of the House Natural Resources Committee, to discuss their priorities and visions for Texas water and the regular session of the 85th Texas Legislature. The opinions expressed in these commentaries are the opinions of the individuals and not the opinions of the Texas Water Journal or the Texas Water Resources Institute.

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WATER PRIORITIES FOR THE 85TH LEGISLATIVE SESSION

By Senator Charles Perry, Texas Senate; Chairman, Senate Committee on Agriculture, Water & Rural Affairs

By 2070, the population of Texas is projected to reach 51 million, and the demand for water is expected to reach approximately 21.6 million acre-feet per year.[1] The existing supply of water that we can rely on in times of drought, however, is expected to fall to 13.6 million acre-feet during that same period.[2] It doesn't take a mathematician to see the dire circumstances we face in the coming decades. Meeting this need will not be easy; it will require effort and cooperation by all Texans, for many years to come. So the question is this: where do we begin?

When the Texas Legislature gaveled in at the beginning of this year, there were several issues weighing on our hearts and minds. Even in the short amount of time during the interim of the 84th Legislative Session, the state of Texas and our nation as a whole faced numerous challenges. The sustained growth of our state continues to provide new difficulties to address, but I am confident that my colleagues and I are prepared to do what is necessary for the good of Texas.

For the second session in a row, I am blessed to be selected by Lieutenant Governor Patrick to serve as the Chairman for the Senate Committee on Agriculture, Water & Rural Affairs. I cannot think of three more important topics to this state, and especially my constituents. In a state with approximately 168 million acres, more than 84% of the land area is considered rural.[3] The agriculture industry provides more than $80 billion to the Texas economy each year, evidenced by the fact that we are first in the nation in production of many agricultural commodities.[4] In my district alone, we had more than $3 billion in agricultural cash receipts per the 2012 census.[5] However, the success of this major economic driver, all of the rural areas, and the entirety of our state hinges on the topic of water.

Crops cannot grow without water. Manufacturing processes cannot function without water. Most of our energy cannot be produced without water. Simply put, water is life; this is especially demonstrated throughout the Bible where water is used for the cleansing of one's soul and providing life-sustaining subsistence. With a resource this important, it is crucial to make sure we have a thorough understanding of our supply to manage the growing demand.

In 1904, the Texas Supreme Court decision in *Houston & Texas Central Railroad Company vs. W. A. East* labeled "underground waters" as "secret, occult, and concealed," so much so that "an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would therefore be practically impossible."[6] I will consider my tenure as Chairman of this committee a complete success if I can help shed a little more light into the "secret" and "occult" world that is water. This process begins with encouraging all of our regulatory bodies to promote the continued use of the best available science for monitoring and modeling data. I cannot stress enough the importance of having strong, scientifically sound data and research regarding our water resources in this state. As the Texas Supreme Court pointed out in the East case, administering legal rules for a resource that you don't adequately comprehend is practically impossible. One of the bills I have filed is Senate Bill 696, which requires the Texas Commission on Environmental Quality to obtain updated water availability models (WAMs) in several river basins. These WAMs are a crucial part of our surface water permitting process. Most of the current models are over a decade old. If there was a new drought of record in a river basin since the last time the models were updated—which many people believe has occurred in some basins—the WAMs would reflect that impact and provide the state with a clearer picture of the actual amount of water that may be available for permitting.

An important part of the drive for more prolific data also centers on the need to better understand our aquifers. Since groundwater accounts for approximately 60% of the annual water use in Texas, it is crucial to ensure a complete understanding of its structure, ability to recharge, and viability as a source of clean water.[7] The geographic diversity of Texas lends itself to a complex network of aquifers that vary among numerous aspects. These variations often require their own unique set of regulations to manage the aquifer. For example, subsidence is a major factor along the Texas coast and drives regulatory decision making in their water districts. Other districts in the state, however, do not necessarily face the same problem—although they certainly have their own unique challenges and opportunities. We must allow our water districts enough ability to justifiably manage the unique aspects of their aquifers as needed for their specific constituencies. On the other hand,

[1] Texas Water Development Board, 2017 State Water Plan.

[2] *Id.*

[3] Texas Department of Agriculture.

[4] *Id.*

[5] *Id.*

[6] *Houston & Texas Central Railroad Company v. W. A. East*, 98 Tex. 146, (Texas 1904)

[7] Texas Water Development Board, https://www.twdb.texas.gov/groundwater/

where there are multiple districts sharing jurisdiction over an aquifer that acts and reacts uniformly, it is incumbent upon those districts to manage that shared resource accordingly. Once again, all justifications for regulations of these water sources should be rooted in scientific data and beyond reproach.

One more priority I have this session, and have always had since I began my tenure in the Legislature, is to continue cutting down on frivolous litigation. In the water business, this means guaranteeing fairness and equitability when applying regulations, tightening the standards by which permit applications are reviewed, and ensuring that all stakeholders grasp the consequences of their actions ahead of time to aid in their decision making. One way I'm hoping to address this is through Senate Bill 862. This bill will ensure that all parties to a suit involving a groundwater conservation district know, prior to filing that suit, that they could be responsible for paying the costs associated with that legal proceeding if they are not the prevailing party. From a groundwater district perspective, the district must strive to implement defensible regulations. For potential litigants, they must be aware that arbitrary lawsuits in pursuit of easy money could actually result in a detrimental outcome.

Another bill that I have filed is Senate Bill 1009, which was crafted in coordination with the Texas Water Conservation Association. This bill seeks to tighten the groundwater permit application process by clarifying what can be considered in a permit review to determine if the application is administratively complete. Clarifications to ambiguous language in the water code, and all legal statutes, are a necessary part of getting in front of needless court proceedings.

The challenges we face regarding the future water needs in this state are only achievable if we have participation from everyone. The Texas Senate Committee on Agriculture, Water & Rural Affairs is generally scheduled to meet on Monday afternoons upon adjournment of the Senate. Having input from all stakeholders is a crucial part of the democratic process, and I truly value diverse opinions. Just as I place a high importance in having quality, plentiful data regarding our water resources, the same is true for legislation and that begins with feedback from the public. I cannot promise we will always see eye to eye on the issues, but I can guarantee that everyone's concerns will be heard and considered.

The good news is that Texas has been blessed with enough water resources to meet our future needs. Doing so will require a combination of a better understanding of our current supply, development of new and innovative technologies, conservation and protection against waste, and ensuring fairness in the application of all regulations. If we fail to meet this challenge, we only have ourselves to blame. Together, we can sustain this vital natural resource for the benefit of many future generations of Texans.

THE THIRST OF TEXAS TOMORROW IS OUR RESPONSIBILITY TODAY

By Representative Lyle Larson, Texas House of Representatives; Chairman, House Natural Resources Committee

If we fail to plan, we're planning to fail.

The State of Texas, along with local entities, including municipalities and groundwater districts, need to work together to ensure we have the water we need for future generations of Texans. The drought of 2011, the worst one-year drought in Texas history, resulted in towns literally running out of water. We can't accept this as a way of life in our great state.

Recently, my office tasked the Texas Water Development Board to model what our state's groundwater and surface water resources would look like if the drought of 2011 had endured for 2 to 5 years, as climatologists predict will happen in the next century based on tree ring analysis and data collected over the last 5 centuries. According to the Board's model, if 2011 conditions persisted, 70 of the state's 117 reservoirs would be dried up at the end of 5 years. Aggregate surface water storage would drop from 19.4 million acre feet at the end of 2011 to 4.9 million acre-feet at the end of 2015. The projected effect on groundwater resources is equally devastating, with median aquifer levels decreasing anywhere from 9% to 84% depending on the aquifer. This virtual model projects what Texas will experience sometime in the next century and should drive policymakers to take bold steps to prepare for the next drought as our predecessors did in response to the drought of the 1950s.

During the 85th Legislative Session, we intend to build on the policy successes of last session, when we passed meaningful legislation to drought-proof Texas. We have major challenges ahead of us when it comes to securing Texas' water future, but we're confident it can be done if we continue working together as Texans and resist the temptation to fight each other along arbitrary political boundaries.

One of the impediments we have in developing groundwater resources for our population centers is the parochial mindset inherent in the groundwater conservation districts that have been set up over the last two decades in Texas. While a majority of groundwater conservation districts understand the law and respect property rights, a few hold the view that their purpose is to block access to anyone outside of their immediate community from using groundwater for future water supplies. State law and recent case law indicates they are on the wrong side of the property rights dispute and we will pursue groundwater reforms to remove the ability for this type of discrimination to occur.

In the state water planning process, we fight each other fiercely along regional planning lines and the state has abdicated its role in facilitating a comprehensive statewide water plan. The balkanization of our state into regions has proven to be the biggest hindrance to building the large-scale regional projects we need to serve rapidly growing areas. This session we will be advocating for better cooperation between the regions.

In addition, we will continue to work to promote the use of new technologies, such as aquifer storage and recovery (ASR), to bolster our water supply. Texas lost more than 94 million acre-feet of excess flood flows in 2015 alone. Instead of allowing this water to flow out into the Gulf of Mexico with no beneficial use, we need to capture it and store it for future times of need. Legislation that we passed last session includes a bill that removed regulatory impediments to developing ASR projects, and we have filed 2 pieces of legislation this session that will build upon that effort.

The first piece tasks the Texas Water Development Board with studying the geologic formations along the river basins to determine which aquifers are most conducive for underground storage. The second requires the Texas Commission on Environmental Quality to develop an excess flows credits program that will allow surface water permit holders to commit to harvesting and storing excess flows that are above base flow and environmental flow requirements and that would otherwise evaporate or flow into the ocean, so they can be given an additional percentage of the water they are entitled to, based on their existing permit.

Desalination is the new horizon for Texas water. Last session we passed legislation to identify areas of highly productive aquifers that hold brackish groundwater throughout the state that can enable brackish desalination. Identifying these highly productive brackish zones was an important step in determining where our future water supplies are. As San Antonio just completed the first phase of its brackish desalination plant in southern Bexar County, many cities will look to brackish water as a source to meet future growth demands. Going forward, we will continue to work with stakeholders on legislation that clearly defines how brackish groundwater should be regulated to ensure that this resource can be accessed and developed for future generations.

We will also continue to work to help foster the development of Texas's first seawater desalination plant along the coast. As countries such as Israel and Australia, as well as California, have embarked on investing in seawater desalination, the State of Texas needs to facilitate the development of 3 large-scale seawater desalination plants in Corpus Christi, the League City area, and Brownsville. Harvesting water from a virtually unlimited water supply like the Gulf of Mexico is necessary as droughts driven both by climate and by demography continue to cause increased pressure on existing resources.

We must continue to work with neighboring states to bring new water to bear. Last session we passed legislation that created the Southwestern States Water Commission. The creation of this Commission is an attempt to take disputes with neighboring states out of the courtroom and, instead, facilitate a dialogue between the Southwestern states that share contiguous bodies of water to effectively solve the ongoing problem of allocating a scarce and precious resource. As we face prolonged droughts in this part of the country, the Commission will take the lead in developing regional strategies to address water shortages. Large-scale water projects such as the Toledo Bend Reservoir and Lake Texoma were realized only through cooperation by parties in both states. To this end, my office has been meeting with leaders in neighboring states about regional water issues and I believe we need to continue on this path to bring a cooperative spirit back to solve our region's challenges.

My office has also been active in participating in meetings with officials from the Mexican government, representatives of the International Boundary and Water Commission, and Governor Abbott's office in Austin to discuss our shared water resources and the 1944 water treaty between the United States and Mexico. We must hold Mexico accountable. We have a lot of work to do to ensure that Mexico complies with the 1944 water treaty. This water is necessary for irrigation and other uses in the Rio Grande Valley and we owe it to those folks to make sure Mexico releases the water as required by the treaty. We continue to advocate for synchronization of the Colorado River and Rio Grande within the treaty to ensure that Texans receive the total allocation of water to which they are entitled.

The exponential population growth Texas is experiencing should be met with a focused agenda brought forth by the leadership in Austin. This session we will bring forward constructive and innovative approaches to governing both ground and surface water with a commitment to future Texans in mind.

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Evaluation of potential *E. coli* transport from on-site sewage facilities in a Texas watershed

Derek Morrison[1], Raghupathy Karthikeyan[1*], Clyde Munster[1], John Jacob[2], Terry Gentry[3]

Abstract: Potential *E. coli* contamination in surface waters from on-site sewage facilities was investigated in the Dickinson Bayou watershed, Texas. This watershed is listed as impaired due to bacteria by the Texas Commission on Environmental Quality. Two water quality monitoring stations, with flow meters and automatic water samplers, were installed in the watershed to assess *E. coli* concentrations in surface runoff. One monitoring station was installed in a neighborhood that solely used an on-site sewage facility (OSSF) and the second monitoring station, the control site, was installed in a neighborhood connected to a municipal sewage plant. For 16 runoff events at the OSSF site, the combined geometric mean *E. coli* concentration was 639 colony forming units (CFU)/100milliters while the geometric mean *E. coli* concentration for 13 runoff events at the control site was 371 CFU/100milliliters. The *E. coli* concentrations from the 2 sites were not statistically different, suggesting that OSSFs may not be the major cause of bacterial contamination in the Dickinson Bayou watershed. In addition, a bacterial source tracking method was employed, which concluded that a portion of the *E. coli* from both sites were of human origin.

Keywords: *E. coli*, on-site sewage facilities, surface water, Texas coastal watershed, bacterial source tracking

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Terms used in paper

Acronym	Descriptive term
BST	bacteria source tracking
CFU	colony forming unit
EPA	Environmental Protection Agency
E. coli	*Escherichia coli*
ERIC-PCR	repetitive intergenic consensus sequence-polymerase chain reaction
RP	riboprinting
HGAC	Houston-Galveston Area Council
OSSF	on-site sewage facility
NELAP	National Environmental Laboratory Accreditation Program
TCEQ	Texas Commission on Environmental Quality
USGS	U.S. Geological Survey

INTRODUCTION

The Dickinson Bayou watershed is located in Fort Bend and Galveston counties in southeast Texas and contains portions of nearby cities including Alvin, Dickinson, Friendswood, League City, Manvel, Santa Fe, and Texas City (Figure 1). Dickinson Bayou flows through Dickinson Bay to arrive ultimately in Galveston Bay. Even though all surrounding point sources, which include many wastewater treatment plants, are constantly monitored and assessed, Dickinson Bayou, Dickinson Bay, and Galveston Bay all have high levels of bacteria. All 3 water bodies are on the Texas Commission on Environmental Quality's (TCEQ) 303(d) list, a summary of waters in and around Texas that fail to meet their intended use regulatory standard, and have been since 1996 due to impairment by elevated bacterial concentrations (TCEQ 2012).

Dickinson Bayou and Dickinson Bay are used by many residents of the area for fishing, boating, and other recreational activities. However, nearly half of all residents in the Dickinson Bayou watershed are not aware of the bacterial problem in the watershed even though excess bacteria in the area has been widely reported (Quigg et al. 2009; TAMUPPRI 2012). Specifically, *E. coli*, which is found in excess in both Dickinson Bay and Dickinson Bayou, causes intestinal problems in humans (Smith Jr. et al. 2004; Teague 2007; Riebschleager et al. 2012) and has been documented as an economic issue (Overstreet 1988; Soller et al. 2010). High levels of bacteria in fish and shellfish limit the amount of seafood that can be sold and cause significant economic problems in areas that rely on fishing as a livelihood.

Previous research has suggested that failing OSSFs may be a factor in elevated bacterial levels in nearby Buffalo Bayou (Platt 2006). Both anaerobic and aerobic on-site sewage facilities (OSSFs) are found in the Dickinson Bayou watershed. Anaerobic systems use a holding tank (septic tank) for primary treatment and utilize soil microbes for secondary treatment when the effluent is discharged through a series of subsurface drainage pipes (TAMAE 2008). When the soil surrounding the drainage field has low permeability, infiltration of the wastewater through the soil profile is greatly reduced and has been shown to be a factor in septic system failure (Carr et. al. 2009; Conn et al. 2011; Withers et. al. 2011). When infiltration rates are low, the wastewater may rise to the surface and untreated wastewater can runoff directly into nearby surface waters. In addition, previous research has also shown that when high water tables are present near the drainage pipes, anaerobic systems have the ability to directly contaminate groundwater (Scandura and Sobsey 1997; Humphrey et. al. 2011; Lapworth et. al. 2012).

Aerobic systems employ a holding tank, an aerobic treatment unit with a disinfectant system (typically chlorine), and a spray system to dispose of the effluent (TAMAE 2008). If the aerobic system is not well maintained, the efficiency of aerobic OSSFs is greatly diminished and the surface soil becomes the primary treatment medium (Levett et. al. 2010). If the soil has low infiltration rates, the irrigated wastewater may pond on the surface and run off to nearby ditches and streams. Furthermore, studies have shown that *E. coli* is capable of attaching to suspended solids during runoff (Parker et. al. 2010; Soupir et. al. 2010). Bacteria sprayed onto the soil surface from improperly maintained aerobic OSSFs may be transported by sediment in runoff to nearby ditches and streams.

There are approximately 5,000 OSSFs in the Dickinson Bayou watershed (DBWP 2007). The vast majority of OSSFs built before 1997 were anaerobic systems. However, in 1997 Texas began requiring a soil inspection before an OSSF could be installed (TCEQ 2014). Heavy clay soils with shallow groundwater present in most of Galveston County prevented homeowners from building new anaerobic OSSFs. Therefore, aerobic OSSFs started becoming the most commonly installed OSSF type after 1997.

A project was developed to explore the potential for local OSSFs to cause bacterial loads in stormwater runoff in the Dickinson Bayou watershed by sampling runoff from 2 sites within the watershed. One monitoring site was in a neighborhood that used only OSSFs (the OSSF site) to treat wastewater. The second monitoring site was in a neighborhood that used a municipal sewage plant to treat wastewater (the Control site). Various indicator bacteria can be used to gauge bacterial contamination in coastal water bodies. Groundwater, potentially affected from anaerobic systems, was not taken into consideration for this study. To directly compare with results from previous studies in the Dickinson Bayou watershed, *E. coli* was chosen as the indicator bacteria for this project. The project's main objective was to determine if OSSFs in residential areas were contributing to the elevated *E. coli* concentrations in Dickinson Bayou.

METHODS

Two water quality monitoring stations were installed in the Dickinson Bayou watershed, as indicated by the star symbols in Figure 1. The first, known as the OSSF site, was located in Santa Fe, Texas (29° 25' 00.82"N, 95° 06' 18.69"W), in a neighborhood that uses only OSSFs for wastewater treatment. Of the 28 houses in the watershed, 19 use the anaerobic OSSF and the remaining 9 use the aerobic OSSF (HGAC 2013a). Approximately 10% of the OSSF watershed consisted of impervious surfaces.

The second water quality monitoring station, known as the Control site, was located in Dickinson, Texas (29° 27' 02.54"N, 95° 03' 40.43"W) in a neighborhood that used a municipal

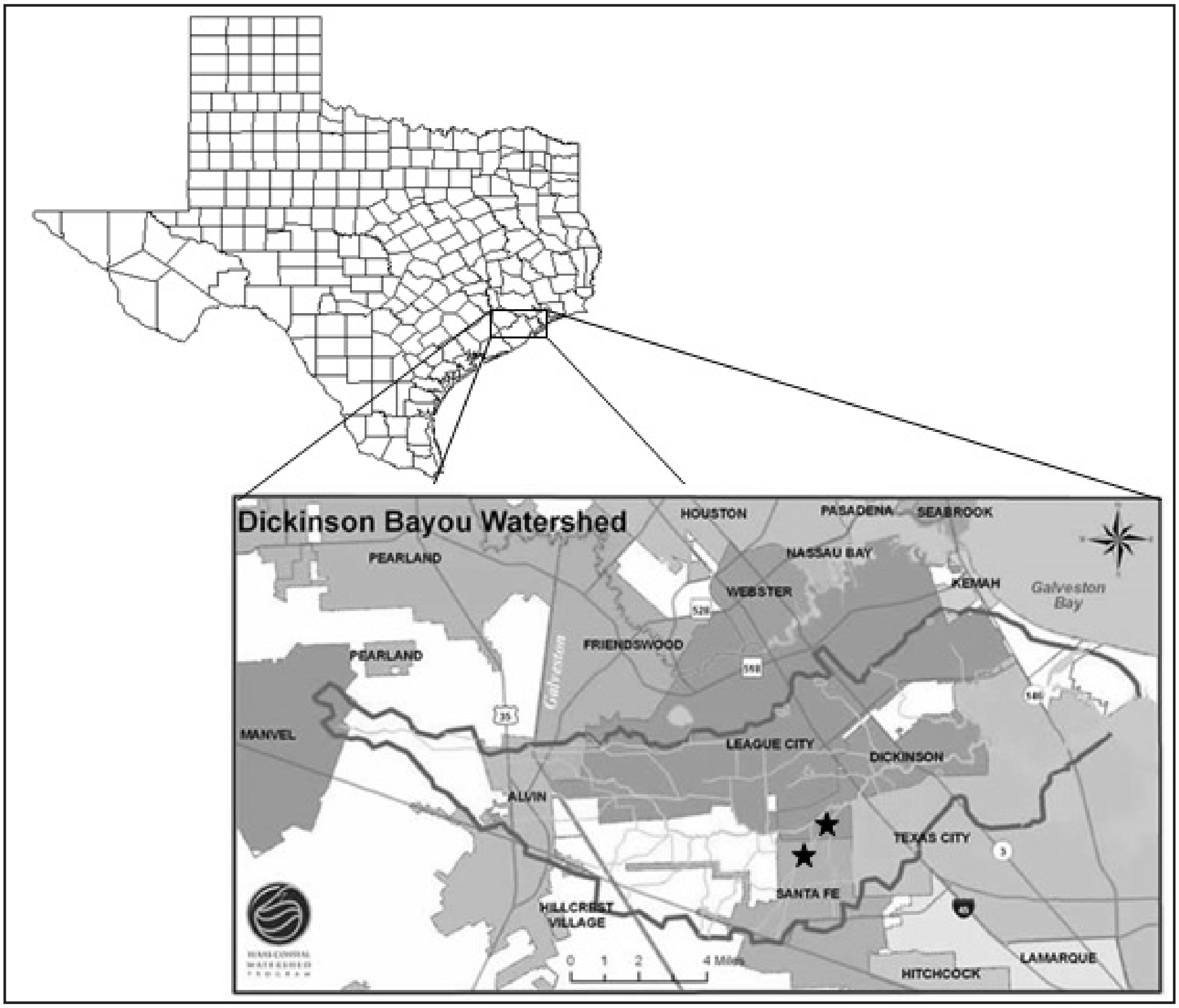

Figure 1. Map of the Dickinson Bayou watershed and the locations of the OSSF and Control sites indicated by the southern and northern star symbols, respectively..

treatment plant for wastewater treatment. All of the houses are connected to the municipal wastewater treatment plant via a series of clay sewer pipes. Impervious surfaces account for approximately 38% of the watershed.

The 2 monitoring stations were approximately 8 kilometers from each other and in both watersheds, a system of drainage ditches direct surface runoff to a single location before it flowed into Dickinson Bayou. The monitoring stations were installed at these runoff collection points. Meteorological data were collected from a nearby weather station that is located approximately 4 kilometers from the OSSF site (WU 2013).

Both monitoring sites were instrumented with bubbler flow meters (4230, Teledyne ISCO, Lincoln, NE) and automatic water samplers (3700, Teledyne ISCO, Lincoln, NE). The bubbler flow meter was interfaced with the automatic water sampler and the sampler was triggered to collect samples when the runoff levels were approximately 32 millimeters deep. In order to ensure that no cross-contamination of bacteria occurred in the field, 1 bottle, out of 24 total, remained empty and was used as a field control.

Preliminary hydrographs from the bubbler flow meter were used to create a sample programming schedule for the automatic water samplers. Water samples were obtained during pre-peak (rising limb), peak, and post-peak (recession limb) runoff time periods to assess how *E. coli* concentrations were changing during runoff events.

Within 8 hours of the first samples being taken during a runoff event, the sample bottles were put on ice, transported immediately to the laboratory, and tested within 24 hours of the first sample, using Environmental Protection Agency (EPA) Method 1603 (Stumpf et al. 2010; Hathaway and Hunt 2011). No samples were composited in the laboratory. Seven samples bottles were selected from each runoff event to be used as representative samples. For most runoff events, 3 samples were chosen to characterize the pre-peak runoff, 1 was chosen for the peak runoff, and 3 were chosen to represent the post-peak runoff. Due to the natural variability in the duration of each runoff event, these guidelines could not be used for every event but were used whenever possible. In total, 17 samples were analyzed for each runoff event: 1 lab control, 1 field control from the OSSF monitoring site, 7 samples from the OSSF monitoring site, 1 field control from the Control site, and 7 samples from the Control site.

Antecedent moisture conditions were assessed for each rainfall-runoff event to help determine if periods without rainfall were causing a buildup of treated wastewater from the surface application from the aerobic OSSFs. Antecedent moisture conditions were based on the amount of rain received during the 7 days prior to the sampling event (James and Roulet 2009). Antecedent moisture was considered dry if the previous 7 days received less than 6.35 millimeters of rainfall. Average antecedent moisture conditions were assigned if the previous 7 days received between 6.35 and 25.4 millimeters of rainfall. Wet antecedent moisture conditions were assigned if the previous 7 days received greater than 25.4 millimeters of rainfall.

EPA Method 1603 was used to enumerate *E. coli* in the runoff (EPA 2009). This process uses membrane filtration and a specific agar to allow the growth of *E. coli* for enumeration. *E. coli* counts lower than the lower detection limit, 10 CFU/100milliliters, were reported as non-detect. The lower detection limit was estimated by dividing the lowest possible colony count (1 colony) in the maximum undiluted sample volume (10 milliliters), then multiplying by 100 to convert to CFU/100milliliters. All non-detects were included in figures and statistical calculations as 5 CFU/100milliliters (1/2 of lower detection limit). To rule-out cross-contamination, both lab and field blanks were analyzed for every sampling event. Samples were periodically split with a third-party laboratory that was National Environmental Laboratory Accreditation Program (NELAP)-approved to validate the *E. coli* concentrations.

To determine the source of *E. coli* in runoff, a bacterial source tracking (BST) assessment was performed on *E. coli* isolates from a set of runoff samples taken on 3/4/14. A previous BST analysis performed on *E. coli* isolates from Oyster Creek watershed (northwest of the Dickinson Bayou watershed) indicated that 43% of *E. coli* was coming from wildlife, 19% was from livestock, 14% was from humans, and 9% was from domestic pets (Martin 2013). One isolate was taken from each of the 7 *E. coli* samples from the OSSF site (n=7 from the OSSF site) and 1 isolate was taken from each of the 7 samples from the Control site (n=7 from the Control site) using EPA Method 1603. Isolates were then DNA-fingerprinted using enterobacterial repetitive intergenic consensus sequence-polymerase chain reaction (ERIC-PCR) and riboprinting (RP) as described by Casarez et al. (2007). A DNA fingerprint was performed on 1 individual *E. coli* colony, or isolate, from each sample. Fingerprints for each of the isolates were compared against the Texas *E. coli* BST Library (ver. 6-13). This library contains DNA fingerprints for 1,524 *E. coli* isolates from 1,358 different fecal samples representing over 50 animal subclasses (Di Giovanni et al. 2013). Source-identified *E. coli* water isolates were divided into 3 source categories: human, wildlife, and livestock/domestic animals. A water isolate's category was chosen based on the highest percentage match to a known-source isolate in the library, with 80% being the lowest acceptable percentage match (Di Giovanni et al. 2013). If a water isolate's DNA fingerprint was not at least 80% similar to any known-source isolate in the library, then the water isolate was classified as unidentified with respect to its source.

RESULTS

E. coli concentrations

E. coli were found in 13 of 16 sampling events at the OSSF site and in 12 of 13 sampling events at the Control site. The *E. coli* concentrations detected at the OSSF site and the Control site are summarized in the box plots in Figure 2. The dashed horizontal line in Figure 2 represents the EPA and Texas state contact standard (126 CFU/100milliliters) of *E. coli* in recreational freshwaters. For the 16 runoff events at the OSSF site, the combined geometric mean *E. coli* concentration was 639 CFU/100millilters while the geometric mean *E. coli* concentration for 13 runoff events at the control site was 371 CFU/100milliliters.

E. coli concentrations at both the OSSF site and the Control site were typically well above the Texas state standard: 126 CFU/100milliliters. The geometric mean *E. coli* concentration for 12 of the runoff events (16 total events) at the OSSF site exceeded the regulatory use standard and at the Control site the geometric mean for 9 of the runoff events (13 total events) exceeded the regulatory use standard. It should be noted that there were 3 runoff events at the OSSF site and 1 runoff event at the Control site that yielded no culturable *E. coli* in all samples. With these exceptions, all runoff events had at least 1 sample that exceeded the regulatory standard. These samples showed that not only was there *E. coli* present at both sites, it was present in concentrations that routinely exceeded the EPA and Texas state recreational freshwater contact standard.

Statistical analysis

A paired t-test was used to compare the untransformed (normal) *E. coli* concentrations at the 2 sites to determine if

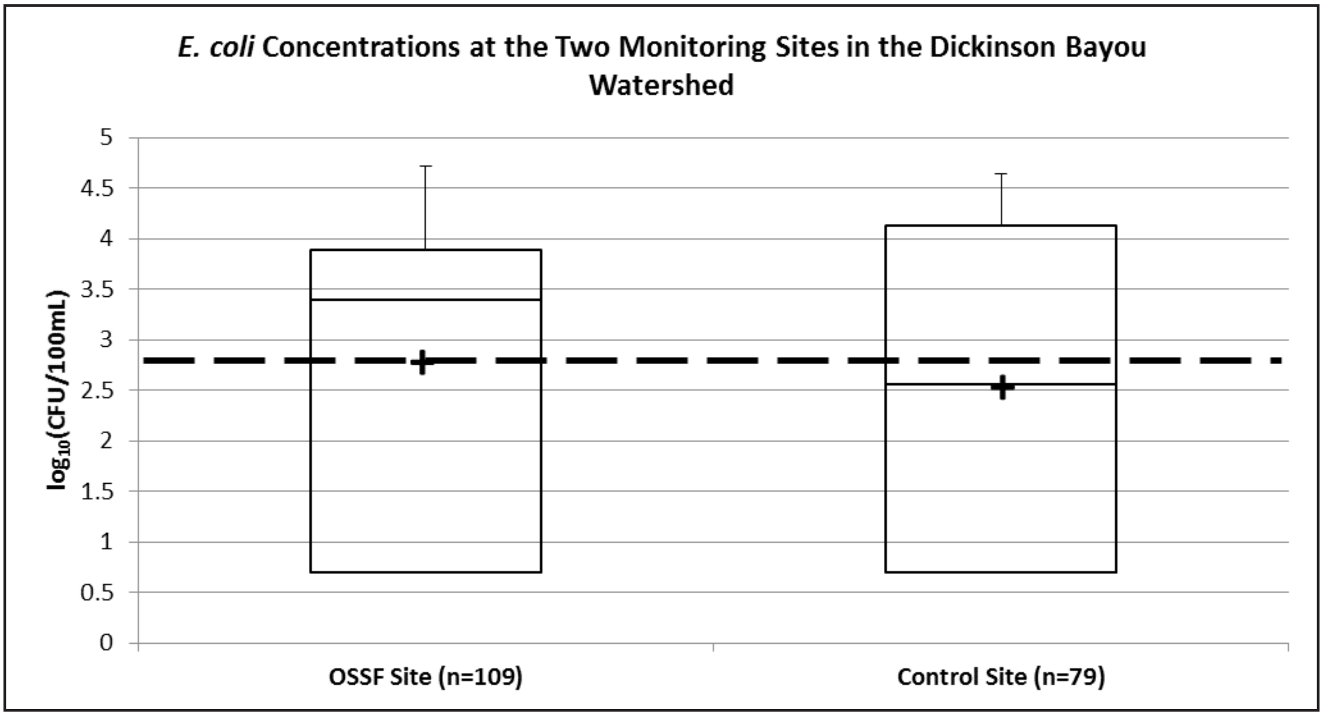

Figure 2. Cumulative distribution plots of *E. coli* concentrations found in runoff at the 2 monitoring sites in the Dickinson Bayou watershed. The dashed line represents the Texas state recreational contact standard for *E. coli*.

there was a significant difference between the 2 sample sets ($\alpha = 0.05$). Results from this analysis showed that there was no statistical difference between the concentrations found at the OSSF site and those found at the Control site ($p = 0.9335$). Previous research performed in the Dickinson Bayou watershed by the Galveston County Health District between 1992 and 1996 also concluded that "There was no clear difference in coliform concentrations between sewered and unsewered areas" (GCHD 1998).

A paired t-test was also used on a case-by-case basis to determine if there were any individual rainfall events that had *E. coli* concentrations that were statistically different between the 2 monitoring sites. Three events were found that had statistically different concentrations. The first 2 runoff events with statistically different *E. coli* concentrations occurred on 9/20/13 and 5/26/14, and the concentrations were higher at the OSSF site for both events ($p = 0.0451$ and $p = 0.0039$, respectively). These dates produced the 2 largest runoff volumes at the Control site during dry antecedent moisture conditions (21.17 millimeters and 11.52 millimeters, respectively). It is possible that the larger-than-typical runoff amounts at the Control site led to higher dilution and therefore lower concentrations at the Control site. The third event with statistically different *E. coli* concentrations occurred on 5/30/14 and had concentrations that were higher at the Control site ($p = 0.0002$). This particular event had the second highest runoff volume during wet antecedent moisture conditions at the Control site (50.64 millimeters) while the runoff volume at the OSSF site was typical for wet antecedent moisture conditions (4.31 millimeters). It should be noted that the largest runoff volume for wet antecedent moisture conditions at the Control site was due to an intense storm that also caused flooding at the OSSF monitoring site, leading to the largest runoff volume at the OSSF site.

Potential correlations considered for each individual sample were flow rate, temperature, antecedent moisture conditions, and the amount of time since the last sampling event. The linear regression analysis (R^2) values for each of the correlation variables at the OSSF site were less than 0.0301, while the R^2 values for each of the correlation variables at the Control site were less than 0.1963. The U.S. Geological Survey (USGS) had found elevated *E. coli* concentrations for high flow rates and seasonal differences, but these results were not correlated in this study (USGS 2003). In a fecal coliform study in nearby Buffalo and White Oak bayous by Petersen et al. (2006), there were almost no statistical differences between cooler and warmer months at multiple stations in the 2 bayous.

While no correlations were made for the individual sampling events between *E. coli* concentration and flow rate, temperature, antecedent moisture conditions, and the time between sampling events, statistical differences were found when the combined concentrations from all events at each of the sites were based on antecedent moisture conditions. Figure 3 shows the combined *E. coli* concentrations from the 2 sites divided by

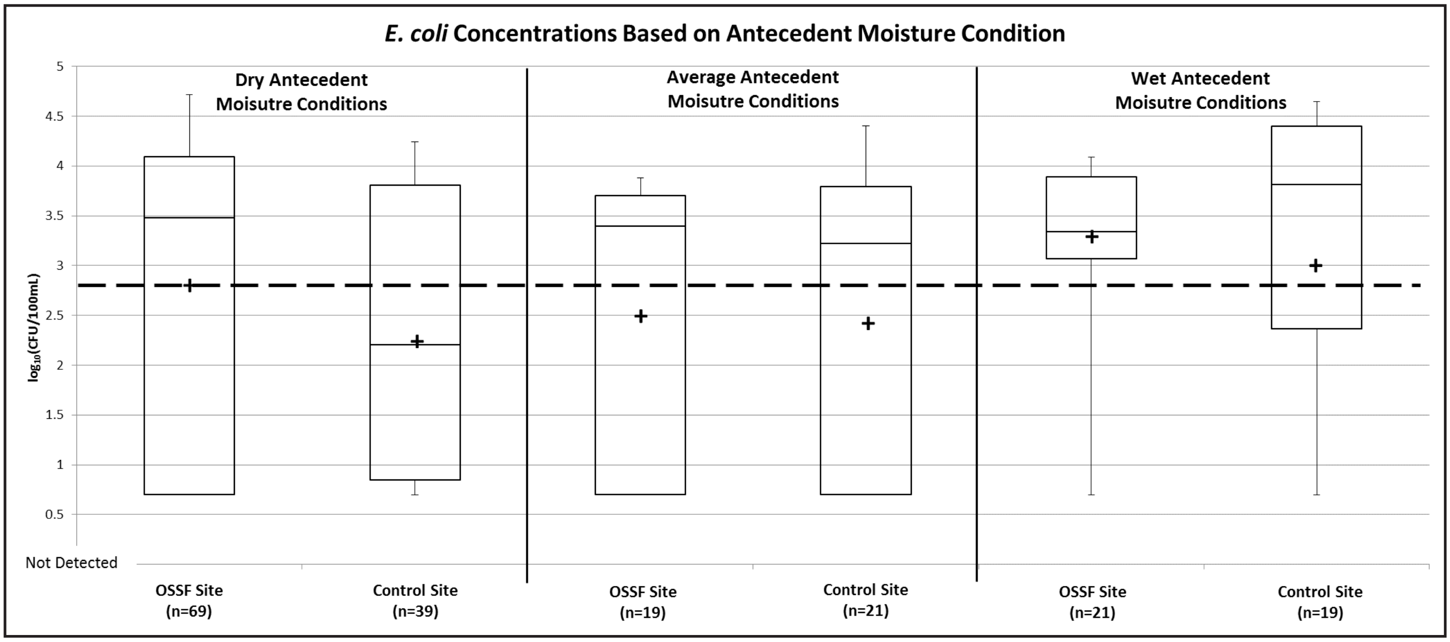

Figure 3. Quartile plots of *E. coli* concentrations found in runoff at the 2 monitoring sites in the Dickinson Bayou watershed separated by antecedent moisture conditions. The plus symbol represents the mean value of each of the 2 datasets. The dashed line represents the Texas state recreational contact standard for *E. coli*.

antecedent moisture conditions. As shown in Figure 3, runoff from the OSSF site had the highest *E. coli* concentrations during dry antecedent moisture conditions (p = 0.0170). On the other hand, runoff from the Control site had the highest *E. coli* concentrations during wet antecedent moisture conditions (p = 0.0226).

Evidence of elevated *E. coli* concentrations before the peak runoff rate, first flush, should be present if contaminated wastewater from aerobic systems had pooled on the surface of the low permeability soils. First flush was not found to occur at either the OSSF site or the Control site (p = 0.7711 and p = 0.3965, respectively; see Figure 4). In addition, no first flush

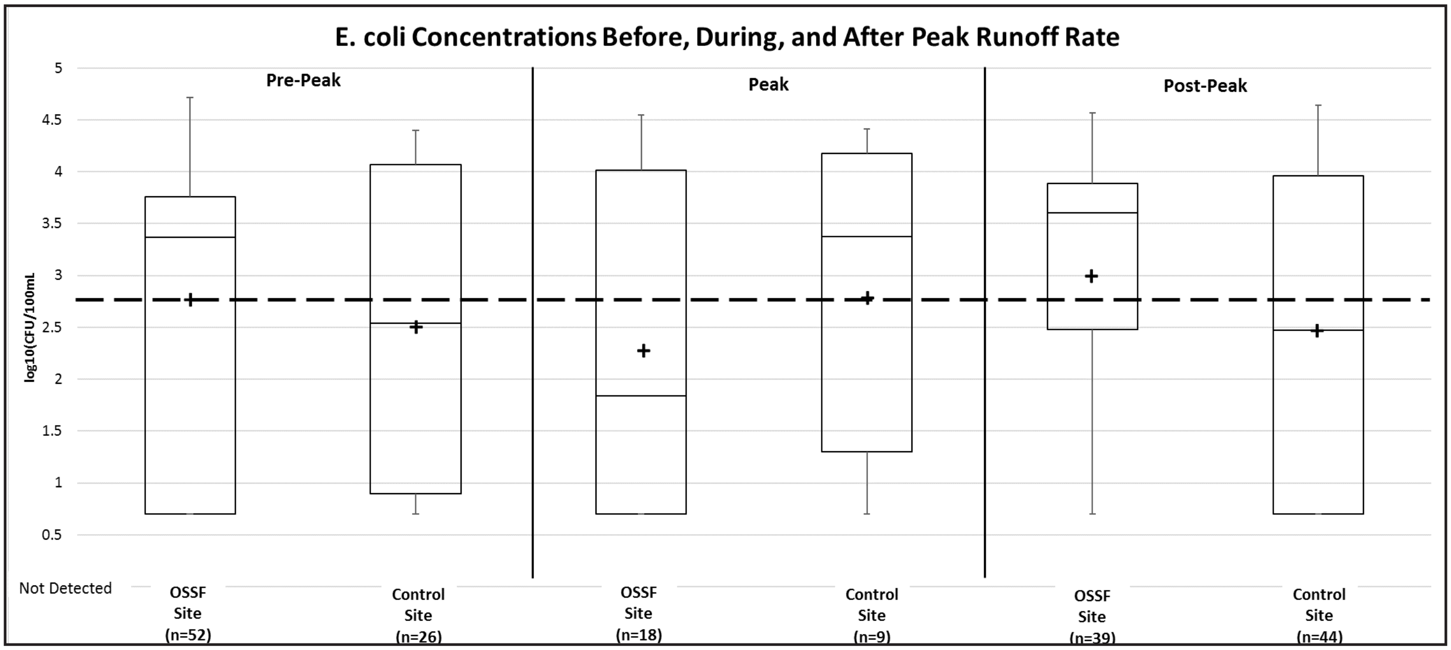

Figure 4. Quartile plots of *E. coli* concentrations found in runoff at the 2 monitoring sites in the Dickinson Bayou watershed separated by occurrence before, during, or after the peak flow rates. The plus symbol represents the mean value of each of the 2 datasets. The dashed line represents the Texas state recreational contact standard for *E. coli*.

Table 1. The statistical analysis of *E. coli* concentrations in the first flush runoff for the OSSF and Control sites based on antecedent moisture conditions.

Site	Antecedent Moisture Condition	p Value
OSSF site	Entire Dataset	0.7711
	Dry	0.1540
	Average	0.6139
	Wet	0.4298
Control site	Entire Dataset	0.3965
	Dry	0.5215
	Average	0.1936
	Wet	0.4299

effects for *E. coli* concentrations were observed at either site when the sampling events were divided based on antecedent moisture conditions. The respective *p* values for each site and antecedent moisture condition is shown in Table 1.

Bacterial source tracking analysis

Similar *E. coli* concentrations at both sites during each rainfall event can lead to a number of possible conclusions with varying combinations of *E. coli* sources. When looking specifically for the possibility of failing OSSFs as the primary contamination source, 2 main possibilities exist. First, the OSSFs may be the primary contributors to the contamination at the OSSF site, and at the Control site a combination of wildlife, domestic animals, and the possibility of the municipal sewage pipes in the neighborhood failing could equal the OSSF site. However, it may also be possible that the OSSFs at the OSSF site and the sewer pipes at the Control site are operating properly and all *E. coli* in the runoff from the 2 sites is coming from either wildlife or domestic animals. Therefore, additional site investigations were undertaken.

While BST analyses have been performed in neighboring watersheds, this study was the first to employ the analysis in the Dickinson Bayou watershed (Martin 2013). As discussed in the Methods section, 7 *E. coli* isolates were taken from each site from the runoff event on 3/4/14 to perform the BST. Results of the BST indicated that human fecal material contributed to *E. coli* levels at both the OSSF and Control sites. Human fecal contamination was a larger source of *E. coli* in runoff at the Control site, 43% of isolates, than the OSSF site, 14% of isolates. Breaking down the remainder of the isolates from the OSSF and Control sites, wildlife accounted for 86% and 28%, respectively and domesticated animals accounted for 0% and 28%, respectively.

DISCUSSION

Continuous monitoring efforts performed by both the USGS, in cooperation with the TCEQ, and the Houston-Galveston Area Council (HGAC), with the help of the Texas Stream Team, have found similarly high, and variable, *E. coli* concentrations in Dickinson Bayou and Dickinson Bay. The USGS performed a major study of the Dickinson Bayou watershed from 2000 to 2002 and found *E. coli* concentrations ranging from 0–16,000 CFU/100milliliters (USGS 2003). Likewise, data from HGAC shows *E. coli* concentrations ranging from 5–20,000 CFU/100milliliters (HGAC 2013b). Both of these ranges are consistent with what was found at both the OSSF site (0–52,000 CFU/100milliliters) and the Control site (0 – 44,000 CFU/100milliliters). The USGS also noted that "Densities of both bacteria varied over wide ranges, particularly in Dickinson Bayou," both bacteria being *E. coli* and fecal coliforms (USGS 2003).

The maintenance and complaint records for 2013 and 2014 for the sewer pipes in the Control site watershed were obtained from the Galveston County Water Control and Improvement District #1. These documents showed that there had been cracks and leaks found in the sewage pipes caused by invasive roots and shifting soils. Also, a maintenance engineer with the Galveston County Water Control and Improvement District #1 said that occasionally during exceptionally large rainfall events or periods of rain for many days the sewage lines sometimes overflow through manhole covers found in dead-end streets (District #1, personal communication, April 18, 2014). Therefore, failing sewage pipes could potentially be a reason for the high *E. coli* concentrations at the Control site. In addition, this study found that wet antecedent moisture conditions led to higher *E. coli* concentrations at the Control site. The BST evidence agrees with the possibility of leaking clay pipes at the Control site being a cause of *E. coli* concentrations in the runoff.

Detection of *E. coli* from human sources at the OSSF site would point towards OSSFs since they are the only identifiable human source in this watershed. This study's finding that dry antecedent moisture conditions have higher *E. coli* concentrations than wet conditions may also agree with the OSSF finding. If OSSFs are the cause of the human-borne *E. coli* the bacteria on the surface would collect on the surface during the dry events and be carried away during the first runoff event. The wet conditions would contribute less *E. coli* because there had been less time for *E. coli* to collect since the last runoff event. While first flush was not found for each event, it is likely that at the OSSF site the first runoff event during the dry conditions were effectively acting as a long-term first flush event for the *E. coli*.

In order to effectively remedy the excess bacteria levels, the major source(s) of contamination should be identified and verified. As in most cases, finding the source of nonpoint source pollution has proven difficult. With BST analyses, the primary sources of bacterial contamination can be identified. Similar projects near coastal areas should consider the use of a BST analysis or another analysis to measure human-specific bacterial markers, during every sampled rainfall event to determine the extent of the human fecal source presence. Using BST analyses in future studies should also provide more information as to the specific cause of the contamination. In addition, future projects in coastal areas should look into monitoring not only residential areas but also natural areas in an attempt to create a baseline *E. coli* concentration from natural sources.

CONCLUSIONS

Dickinson Bayou is contaminated with *E. coli* concentrations higher than the EPA and Texas state recreational freshwater contact standard. Stormwater runoff collected from the site containing OSSFs and the site connected directly to the municipal sewage facility consistently exhibited *E. coli* concentrations higher than the EPA and Texas recreational freshwater contact standard, yet no statistical difference between the overall *E. coli* concentrations at the 2 sites was found. Further differentiation between the various potential *E. coli* sources was made by using a BST analysis; this was the first time such analysis has been performed on runoff samples in the Dickinson Bayou watershed. Results from the BST analysis confirmed a human fecal presence at both sites.

While it was not confirmed that OSSFs were failing at the OSSF site, OSSFs are the only ostensible source of human fecal contamination and are most likely in part to blame for the increased bacterial contamination in the Dickinson Bayou watershed. Homeowners of OSSFs should follow a regular maintenance and check-up schedule with a qualified professional to minimize the possibility of failure. Conversely, there are no apparent human sources of fecal material at the Control site, yet *E. coli* from human sources was still confirmed. Broken or leaky municipal sewage lines may be the cause of the human fecal material present in runoff and should be investigated further since no definitive source of pollution was identified in this study.

Assuming the single BST analysis performed in this study is indicative of all runoff events, less than half of the *E. coli* at both sites are from human sources. From this it can be assumed that animals, both domestic and wildlife, are the primary contributors of bacteria to Dickinson Bayou. Besides picking up after pets, little can be done to prevent contamination due to animals. The primary way of preventing bacterial contamination in the Dickinson Bayou watershed would be to focus on reducing the human sources by means discussed above.

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Water barons for the water barren? A survey of interbasin water transfer laws in western states

Brad Castleberry[1] and Ashleigh Acevedo[1*]

Abstract: Interbasin transfers of water have become an increasingly popular water management tool—especially among the western states—to address vulnerability to water shortages in those regions susceptible to widely fluctuating drought conditions and population growth. Such transfers offer a practical resolution to the geographic limitations and disparate distribution of water availability. The regulatory frameworks for interbasin transfers adopted across western states, however, vary rather drastically in balancing the practicality of interbasin transfers with equity to the basin of origin. Like its counterparts, Texas has adopted an interbasin transfer statute—Texas Water Code § 11.085—that includes common elements of interbasin transfer regulations aimed at maintaining this balance, including protecting the basin of origin, requiring a distinct demonstration of purpose and need, maintaining existing water rights, and promoting the public interest. However, in comparison to other western states, Texas has a relatively strict framework for interbasin transfers that does not always facilitate the use of such transfers when it is otherwise pragmatic to do so. Policymakers and stakeholders in Texas should thus consider whether and to what extent the balance struck by interbasin transfer laws of other western states is appropriate for Texas and more conducive to using interbasin transfers as a water management strategy across the state.

Keywords: Interbasin transfer, water transfer, transbasin diversion, Texas Water Code § 11.085, water supply, water management

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Terms used in paper

Acronym	Descriptive name
AMA(s)	active management area(s)
IBT(s)	interbasin transfer(s)
NPDES	National Pollutant Discharge Elimination System
TCEQ	Texas Commission on Envrionmental Quality

INTRODUCTION

The American West conjures images of a scorching, arid desert that is sparsely inhabited and where water is the paramount commodity. In this way, scarcity has been the defining feature of water policy in the west. The scarcity results not only from simple supply issues but also is created by immense population growth, environmental constraints, changing weather patterns, and increased mobility. Governments are chronically engaged in evaluating the ability of water supply systems to keep up with demand, especially as population centers grow, often in locations without reliable, long-term supplies. Consequently, strategic methods are necessary to address water supply concerns.

In recent years, interbasin transfers of water have become a more popular and more practical water management tool to address water shortages. An interbasin transfer, otherwise known as a transbasin diversion or IBT, is a transfer of water from one watershed or river basin to another.[1] Although not specifically defined in Texas, it is implied that an IBT is the transfer from one river basin to another.[2] Some states also include transfers of groundwater within their IBT programs. [3]

IBTs are a viable option to address water shortages in states such as Texas that are susceptible to widely fluctuating drought conditions and population growth.[4] Those in favor of IBTs recognize and promote the flexibility that IBTs can offer in terms of managing dynamic water supply conditions across the state. Opponents of IBTs, however, raise concerns with reallocating such a vital resource into non-native basins.[5] For decades, Texas has increasingly employed IBTs as a long-term management tool to address water shortages. But, as a state with high agricultural production and significant urban centers that are among some of the fastest growing in the nation, Texas is facing fundamental questions: are its IBT laws equitable and efficient; do they support both high agricultural production and fast-growing urban centers?

Stakeholders and lawmakers have been grappling over appropriate terms and conditions to impose when a water right holder desires to sidestep the geographical limitations of the basin of origin in order to move water elsewhere. Since 1997 when the Texas IBT statute, Texas Water Code § 11.085, was substantively amended bt Senate Bill 1 (S.B. 1)to significantly increase the burden on IBT permit applicants, the equilibrium between equity and efficiency has been the subject of much debate at the Texas Legislature. In the 2015 legislative session, IBTs were of significant interest to lawmakers, with the introduction of four bills that sought to make approval for certain IBTs easier, although none succeeded.[6] The overhaul in 1997 and the record at the 2015 legislative session depict a hostile environment for IBTs in Texas, but Texas's IBT laws are not the most restrictive among many western states facing similar water constraints. That said, the legal framework in Texas is also not the most flexible. Some stakeholders maintain that the requirements to obtain an IBT in Texas hinder the implementation of effective and readily available water management practices in those areas of the state where diverse management is most desperately needed.

This article establishes a framework within which policymakers and stakeholders can consider a reformation or, at the very least, a reevaluation of the Texas IBT laws. Specifically, this article analyzes and compares commonly recurring elements of the legal framework for IBTs among western states facing similar water constraints as Texas: Arizona, California, Colorado, Idaho, Nevada, New Mexico, and Oregon. This comparative analysis is intended to demonstrate how these western states facilitate or impede IBTs through prioritization

[1] *E.g.* Tex. Water Code Ann. § 11.085 (indicating that "[n]o person may take or divert any state water from a river basin . . . and transfer such water to any other river basin without first applying . . . ."); Colo. Rev. Stat. Ann. § 37-83-101 (indicating that an IBT is from one public stream into another); Or. Rev. Stat. §537.801(1)(a).

[2] Todd Votteler, Kathy Alexander, Joe Moore, T*he Evolution of Surface Water Interbasin Transfer Policy in Texas: Viable Options for Future Water, Water Grabs, or Just Pipe Dreams?*, 36 Tex. Envtl. L.J. 125, 125 (2006).

[3] *See, e.g.*, Nev. Rev. Stat. § 533.007.

[4] Water can be shifted from water-rich areas to those areas experiencing or that will imminently experience water supply shortages. Such diversions may increase flow in water bodies and, by increasing assimilative capacity, may ultimately improve the quality of those bodies. Additionally, the interbasin transfers could also be utilized to meet new or changing agricultural and hydropower demands. Although generally not recognized as an affirmatively beneficial tool to water-rich areas, interbasin transfers can also be used as a flood management tool.

[5] Among those concerns are the fact that interbasin transfers may affect the natural flow of the river, which may alter or compromise wetlands and riparian habitats downstream. Additionally, there is a concern about water quality in both the basin of origin and the receiving basin, such as the introduction of pollutants and foreign species. The most significant opposition stems from the movement of water resources from rural areas to urban centers – often referred to as "buy and dry" – resulting in an economic burden on the rural, and thus primarily agricultural, sector. Votteler et al., *supra note* 2, at 126-27.

[6] Tex. H.B. 1153, 84th Leg., R.S. (2015) (relating to the repeal of the junior priority of a water right authorizing an interbasin transfer within the state; not referred to committee); Tex. H.B. 2805, 84th Leg., R.S. (2015) (excepting from the requirement that an interbasin transfer subordinates the underlying water right to all other rights established prior to the date of the application for the transfer of any water between certain water control and improvement districts and certain municipalities; not referred to committee); Tex. H.B. 3324, 84th Leg., R.S. (2015) (seeking an interbasin transfer exception for a substitution or exchange of reclaimed or desalinated water and reclaimed water or return flow from the basin of discharge to the basin of origin; not referred to committee); Tex. S.B. 1411, 84th Leg., R.S. (2015) (seeking an IBT exception for a transfer from a basin to an adjoining basin; not referred to committee).

of protecting the basin of origin, requiring a distinct demonstration of purpose and need, maintaining existing water rights, and promoting the public interest, among others. The purpose of this article is not to advocate for any particular revision to Texas Water Code § 11.085 or corresponding regulations, but rather to contextualize elements of Texas's IBT laws and provide a vignette of the spectrum of real-life ways in which potential variations to these elements have been applied elsewhere and may be applied in Texas. Given this context, this article makes recommendations on how Texas could revise its IBT regulations to encourage IBTs as a larger scale water management strategy should policymakers and stakeholders so choose.

A COMPARISON OF STATE REGULATION OF IBTS

The need for "new" water supplies is a constant in western states. In response, new laws, programs, and incentives have emerged to encourage innovative supply solutions, particularly IBTs. Underpinned by the prior appropriation doctrine, western states have modified their water regulations to integrate IBTs. The overall legal framework for IBTs varies among the western states, but certain regulatory elements—although nuanced among each state—recur in regulating IBTs.

Demonstration of need or purpose

In obtaining the requisite approvals to transfer water between basins, some western states require that the transferor demonstrate, or the relevant agency consider, the purpose or the need for the water in the receiving basin. The Texas IBT statute provides that when the Texas Commission on Environmental Quality (TCEQ) is considering an IBT application, it must perform a balancing test that weighs the effects of the proposed transfer in the native basin by considering the need for the water for the duration of the period for which the water is requested (but that consideration should not exceed a fifty-year period even if a longer period is requested)[7] and the need for water in the receiving basin.[8] In addition, the amount of water needed and the proposed purpose or purposes must also be considered along with the continued need to use the water for the existing purpose.[9] Notably, Texas requires the consideration of need in terms of both water supply and a proposed use within the receiving basin.[10]

Likewise, in Nevada, the state engineer (the governmental entity charged with evaluating IBT applications) must consider whether the applicant for an IBT has demonstrated a justified need for the water in the receiving basin to import water from another basin.[11] The remaining states evaluated do not make demonstrable need a prerequisite to authorization of an IBT.

With respect to demonstration of need or purpose, Texas's IBT statute is among the most restrictive of the 8 states analyzed herein. Texas and Nevada explicitly require the permitting authority to find that there is a need for the water in the receiving basin, and Texas's consideration involves a multitude of factors absent in the Nevada requirement to demonstrate the need for the transfer.

Beneficial use requirement

The cornerstone of the appropriation doctrine is that the right to water is obtained through a demonstration of beneficial use, regardless of the place of use.[12] In the western states, beneficial use generally means use that is "reasonable and useful and beneficial to the appropriator, and at the same time is consistent with interests of the public in the best utilization of water supplies," although some variations further refine beneficial use requirements.[13]

For IBTs in Texas, the TCEQ must consider the proposed method by which the transferred water will be put to a beneficial use.[14] In Texas, beneficial use is defined as "the use of the amount of water which is economically necessary for a purpose authorized by this chapter, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose . . . ."[15]

Colorado, Oregon, and Idaho likewise require that a change in a water right—such as an amendment seeking an IBT—be for a beneficial use.[16] In Idaho, however, if the water is not applied to a beneficial use within five years, the right to the water is forfeited to the state, but unlike in other states, minimum streamflows and out-of-state water use are both

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[7] Tex. Water Code Ann. § 11.085(k)(1); 30 Tex. Admin. Code Ann. § 297.45(b)(4).

[8] *Id.*

[9] Tex. Water Code Ann. § 11.085(k)(2)(B); 30 Tex. Admin. Code Ann. § 295.13.

[10] *See id.*

[11] Nev. Rev. Stat. Ann. § 533.370(3)(a).

[12] Max Main, *Fundamental Principles Of Water Law In The Western United States,* 34C RMMLF-INST 5 (1994).

[13] *Id.*

[14] Tex. Water Code Ann. § 11.085(k)(2)(D); 30 Tex. Admin. Code Ann. § 295.13.

[15] Tex. Water Code Ann. § 11.002(4).

[16] Colo. Rev. Stat. § 37-92-103(4); Or. Rev. Stat. §§ 540.539, 540.610; Idaho Code Ann. § 42-222(1).

considered beneficial uses in Idaho.[17] Colorado's policy has long been that "the true test of appropriation of water is the successful application thereof to the beneficial use."[18] Correspondingly, every 10 years, Colorado requires the division engineer to evaluate and determine whether any water right has been abandoned.[19] Upon judgment and decree, the list of abandoned rights developed during each review period is conclusive as to absolute water rights or portions thereof determined to be abandoned.[20] To be considered abandoned in Colorado, the owner of the water right must have failed for a period of 10 years or more to fully apply a beneficial use to the water available under said right.[21] Colorado's requirement that an appropriation—for IBTs or in general—be for a beneficial use is the underlying driver of Colorado's strict antispeculation policy.[22] In short, antispeculation means "no appropriation of water . . . shall be held to occur when the proposed appropriation is based upon the speculative sale or transfer of the appropriative rights to persons not parties to the proposed appropriation . . . ."[23] The Colorado Supreme Court once explained that "[o]ur constitution guarantees a right to appropriate, not a right to speculate. The right to appropriate is for use, not merely for profit."[24] Thus, the prioritization of beneficial use over speculation has become a staple of Colorado water policy, not just with respect to IBTs.[25] Effectively, before a change of use can occur in Colorado, the purchaser must have final contracts in place and be able to identify both the point of diversion and the place of use.[26]

Similarly, Nevada water law provides that, so long as certain conditions are met, the state engineer shall approve an application that contemplates the application of water to beneficial use, including diversion.[27] However, Nevada's beneficial use requirements are also refined by the antispeculation doctrine. According to the Nevada Supreme Court, the applicant for an interbasin water transfer need not be the person putting the water to a beneficial use; the applicant need only have a relationship with someone who will put that water to a beneficial use.[28]

Therefore, among the states with a beneficial use requirement, Texas has a fairly standard requirement, although it is not as liberal in its interpretation as some states, such as Idaho and Nevada.

Source area and basin of origin protection laws

Most of the western states have laws designed to protect the source area or basin of origin. Typically, the scope of protection has one of the following objectives: limiting detrimental economic impacts of the transfer on the local community or limiting specific amounts of water that may be transferred out of the basin of origin. However, each state has unique protections for basins of origin.

In Texas, prior to issuance of a permit for a transfer, the impacts reasonably expected to occur as a result of the water transfer—including economic impacts and need in the basin of origin for up to fifty years—must be considered.[29] The impacts to the receiving basin are also considered.[30] An IBT can only be granted to the extent that the detriments to the basin of origin during the transfer period are less than the benefits to the receiving basin. Additionally, the Texas no injury rule provides that the change in the water right shall not cause adverse impact to the environment on the stream of greater magnitude than under circumstances in which the existing permit was fully exercised in accordance with its terms

[17] Idaho Code Ann. § 42-1501.

[18] *Thomas v. Guiraud*, 6 Colo. 530, 533 (1883).

[19] Colo. Rev. Stat. § 37-92-401(1)(c).

[20] *Id.* §§ 37-92-401(1)(c), 37-92-402(1)(b).

[21] *Id.* § 37-92-402(11).

[22] *High Plains A&M, LLC v. SE Water Conservancy Dist.*, 120 P.3d 710, 713 (Colo. 2005) (stating that "[t]he anti-speculation doctrine rooted in the requirement that appropriation of Colorado's water resource must be for an actual beneficial use.").

[23] *Id.* § 37-92-103(3)(a); see also *High Plains A & M, LLC*, 120 P.3d at 714.

[24] *Colo. Riv. Water Conserv. Dist. v. Vidler Water Co.*, 594 P.2d 566, 568 (Colo. 1979).

[25] Colo. Rev. Stat. §§ 37-92-103(3)(a), 37-92-305; *Dallas Creek Water Co. v. Huey*, 933 P.2s 27, 37 (Colo. 1997) (explaining that "[a]ccumulation of conditional water rights is subject to Colorado's anti-speculation doctrine. Speculation on the market, or sale expectancy, is wholly foreign to the principle of keeping life in a proprietary right and is no excuse for failure to perform that which the law requires. A conditional decree may not be entered if the proposed appropriation is based upon the speculative sale or transfer of the appropriative rights to persons not parties to the proposed appropriation."); see *Pagosa Area Water & Sanitation Dist. v. Trout Unlimited*, 170 P.2d 307, 317-18 (Colo. 2007).

[26] *See High Plains A & M*, 120 P.3d at 720-21; Lawrence J. MacDonnell, *Public Water—Private Water: Anti-Speculation, Water Reallocations, and High Plains A&M, LLC v. Southeastern Colorado Water Conservancy District*, 10 U. Denv. Water L. Rev. 1, 2 (2006).

[27] Nev. Rev. Stat. Ann. §§ 533.370(1), 553.055; *see also id.* § 533.030(1).

[28] *Bacher v. Office of the State Eng'r of the State of Nev.*, 146 P.3d 793, 798 (2006).

[29] Tex. Water Code Ann. § 11.085(k). Other factors include the availability of feasible and practicable alternative supplies in the receiving basin; the amount and purposes for which water is needed; proposed conservation efforts in the receiving basin; expected impacts to water quality, aquatic and riparian habitat, and bays and estuaries; proposed mitigation and compensation; and continued need to use the water.

[30] *Id.*

and conditions prior to the proposed amendment.[31]

Idaho and Colorado go beyond this blanket requirement to protect the economy of the source area; both states contain a special agricultural protection. In Idaho, the IBT shall not be approved if the nature of the use will change from agricultural use and such change would significantly affect the agricultural base of the source area.[32] Only the local economy of the source area is considered in Idaho; the proposed transfer cannot adversely affect the local economy from which the water originates.[33] In Colorado, if a change of use of water right is from agricultural or irrigation purposes, the transfer is conditioned on reasonable revegetation and noxious weed management of lands from which the irrigated water is transferred to another basin.[34]

The source area protection law in Nevada is unique. It goes beyond evaluating the economic affects and requires consideration of the amount of water that may be transferred to protect the water supply and environment in the basin of origin. First, before an IBT may even be considered, the state water engineer must inventory the basin of origin and determine the amount of water (both surface and ground) that is available for appropriation from the basin.[35] Ultimately, the application must be rejected if there is insufficient water in the basin of origin to maintain the perennial yield or safe yield of that particular source.[36] Then, in considering the IBT application, the state engineer is required to conduct an evaluation of the economic impacts of the transfer on the basin of origin.[37] Specifically, the engineer must consider whether the proposed transfer will inhibit future growth and development in the basin of origin.[38] However, the Nevada statute additionally requires the state engineer to evaluate whether the proposed transfer is an environmentally sound practice for the basin of origin.[39] Environmental soundness relates to "whether the use of the water is sustainable over the long-term without unreasonable impacts to the water resources and the hydrologic-related natural resources that are dependent on those water resources."[40] In this way, Nevada's legal framework for IBTs is one of the most protective of the basin of origin.

California's protections for the basin of origin are also unique, but this difference arises from California's dual transfer system: temporary changes involving transfers and long-term transfers. For temporary transfers (*i.e.*, less than one year), the source area is protected by limiting the amount of water that may be transferred to that which would have been consumptively used or stored by the permittee without the temporary change.[41] However, there is no similar protection for long-term transfers.[42]

For IBTs in Oregon, there are numerous protections for the basin of origin. The application must include information on, among other things, the types of benefits that the basin of origin presently enjoys that would be eliminated if the transfer were approved; the hydrologic correlation between the surface water and groundwater within the basin of origin and whether the proposed transfer would harm either source; and alternative sources of water that would allow the basin of origin to maintain its supply.[43] Oregon also requires an analysis of whether the IBT will interfere with planned use and development within the basin of origin. The Legislature must provide consent if a transfer is for 50 cubic feet per second or more, with very limited exceptions.[44] Moreover, the Oregon Water Resources Commission can only approve or recommend approval of an IBT if it reserves an amount of water adequate for future needs in the basin of origin and subordinates the use out of basin to that reservation.[45]

In Arizona, IBTs are allowed in limited circumstances for groundwater, which is the only state evaluated herein with such an authorization. However, Arizona's unique and complex groundwater regulation structure makes interbasin water transfers very difficult. In short, groundwater may be transferred within the same subbasin if the subbasins fall within active management areas (AMAs), which strictly regulate groundwater use in Arizona.[46] IBTs, on the other hand, are mostly prohibited unless they are covered by certain grandfathered exceptions.[47] When such an exception is allowed, damages may be awarded for any injury or impairment was caused to the

[31] *Id.* § 11.122(b).

[32] Idaho Code Ann. § 42-222(1).

[33] *Id.*

[34] Colo. Rev. Stat. § 37-92-305(4.5). This requirement does not apply to dry land agriculture. *Id.*

[35] Nev. Rev. Stat. Ann. § 533.364(1).

[36] *Id.* § 533.371(4) (requiring rejection of the application if the application is incomplete; the application fees have not been paid; the proposed use is not temporary; the proposed use conflicts with existing rights; or the proposed use threatens to prove detrimental to the public interest).

[37] *Id.* § 533.570(3)(d).

[38] *Id.*

[39] Nev. Rev. Stat. § 533.570(3)(c).

[40] Nevada State Engineer Ruling No. 6127, at 26 (July 15, 2011).

[41] Cal. Water Code Ann. § 1725.

[42] *See id.* §§ 1735, 1736.

[43] Or. Rev. Stat. Ann. § 537.803(1).

[44] *Id.* § 537.809.

[45] *Id.* §§ 537.356, 540.531.

[46] Ariz. Rev. Stat. Ann. §§ 45-541-45-547.

[47] *Id.* § 45-544.

water supply from the basin of origin.[48] Moreover, with certain exceptions, a person may not use a well for withdrawing water for transport to an AMA without approval from the relevant state agency.[49]

The protections in Texas for the basin of origin appear to be on par when compared to other western states. Although Texas does not limit its consideration to economic impacts in the basin of origin, the general nature of Texas's basin of origin protections do not evaluate environmental impacts, hydrology of the basin, or the volume of water to be transferred. This general nature allows equal emphasis on all considerations, which seems to facilitate IBTs.

Future need and demand in the basin of origin

Aside from demonstrating that the transferred water can be put to a beneficial use in the receiving basin, some states also require consideration of the need for the water to remain in the basin of origin and the potential adverse effects of removing water from the basin of origin. Texas is one such state. Its IBT statute mandates evaluation of the need for the water in both the receiving and native basins.[50] However, "need" is not defined.[51] Nevada also requires the consideration of whether an IBT is "an appropriate long-term use which will not unduly limit the future growth and development" in the basin of origin.[52]

The most stringent laws for protecting the water supply in the basin of origin for future needs are in Oregon. Its law requires that prior to approving an IBT, the Water Resources Commission reserve an amount of water adequate for future needs in the basin of origin, including an amount sufficient to protect public uses, and, as in Texas, subordinates the out-of-basin use to that reservation.[53] Oregon requires an applicant for an IBT to disclose the projected future needs for water in the basin of origin.[54] Similarly, California reserves water for the county of origin that may be needed future development.[55] However, unlike in Nevada, the applicant in California—not the relevant state agency—is responsible for the determining the amount of water available in the basin of origin available for future appropriation.[56]

Although Texas is among the few states that require consideration of the future water demand in the basin of origin, Texas does not require the applicant or TCEQ to ensure that a specific volume of water will remain in the basin of origin or to earmark water for future needs in the basin of origin. In other words, future availability is only a consideration in Texas, and it does not require a detailed accounting and set-asides for future use. Texas relies more on its state and regional water planning process in this regard.

Transfer fees

To ensure economic viability and mitigate the negative impacts on tax revenue on the basin of origin, some western states allow (or even require) compensation be paid to the local governments within the basin of origin. Thus, in conjunction with protecting the basin by reserving water for anticipated future needs, the detriment of the transfer is offset monetarily. Generally, such compensation takes the form of a transfer fee per acre-foot of water transferred.

Texas considers compensation to the basin of origin but does not obligate the payment of transfer fees.[57] With input from each county judge of a county located entirely or even partially within the basin of origin, the parties to an IBT may contract for transfer fees and other mitigation.[58] Any such compensation agreed to by the parties must also be considered by the TCEQ in determining whether to grant the transfer.[59] However, neither the statute nor the accompanying regulations indicate to whom such compensation should be delivered; nor do they specify an amount or method for determining an amount.[60]

Nevada also allows the county of origin to impose a $10 per acre-foot transfer fee on all groundwater transfers with permission from the state engineer,[61] or an applicant and the county may reach an agreement through which the adverse economic effects of the transfer will be mitigated by compensation, reservation of water rights, or other appropriate methods.[62] Unlike

48 *Id.* § 45-545(A).

49 *Id.* § 45-559 (conditioning approval on a determination that the withdrawal will not "unreasonably increase damage to surrounding land").

50 Tex. Water Code Ann. § 11.085(k)(1).

51 *See id.*

52 Nev. Rev. Stat. Ann. § 533.370(3)(d).

53 Or. Rev. Stat. § 537.809.

54 *See id.*

55 Cal. Water Code Ann. §§ 10505, 10505.5.

56 *Id.*

57 Tex. Water Code Ann. § 11.085(o).

58 *Id.*

59 Tex. Water Code Ann. § 11.085(k)(3).

60 *See id.*; 30 Tex. Admin. Code Ann. § 295.13; Suzanne Schwartz, *Whiskey is for Drinking, Water is for Fighting: A Texas Perspective on the Issues and Pressures Relating to Conflicts over Water*, 20 Tex. Tech L. Rev. 1011, 1016(2006).

61 Nev. Rev. Stat. Ann. § 533.438(1).

62 *Id.* § 533.4385(1)-(2). In this case, the plan just must be submitted to the state engineer to verify its compliance with other laws and its practicability. *Id.* § 533.4385(3).

other states, the Nevada transfer law earmarks this money for use by the county only for economic development, health care, and education purposes.[63]

On the other hand, in Arizona, a person who transports groundwater—either directly or indirectly—withdrawn from a groundwater basin or subbasin, must annually pay transfer fees to the county in which the basin of origin is located.[64] The fee is determined for each acre-foot of water transported less any amount of the Central Arizona Project water used on the property from which the water is transported.[65] The fixed fee per acre-foot is established by the statute and updated annually to adjust for inflation.[66] However, unlike other western states that impose or allow fees, certain credits are allowed in Arizona.[67]

Colorado has an entirely different compensation scheme for IBTs when the transfer involves a conservancy district project that takes water from the Colorado River Basin. It requires the diversion facilities to incorporate features that will protect consumptive uses in that basin without resulting in an increased cost of water.[68] In reality, this provision has prompted importing districts to build additional storage reservoirs to provide "compensatory storage" for the basin of origin.[69] Additionally, Colorado law authorizes its water courts to impose transition mitigation and bonded indebtedness payments on any person who files an application for removal of water as a part of a significant water development activity.[70]

The laws in Texas do not require the imposition of transfer fees. In this way, Texas arguably encourages IBTs by balancing the ability of the source area to seek compensation while not impeding transfers with large or complex fees to effectuate the transfer.

No injury rule

Common among the western states is that most, if not all, of the available water was appropriated decades ago. Where there is no water available for appropriation, an IBT must involve existing rights. The no injury rule is a "basic tenant of western water common law" that has worked its way into some states' statutory schemes. It provides that the transfer of an existing water right can only be made if it causes no injury to other existing water rights. [71] The rule is intended to serve as a safeguard of the interests of existing water rights holders, both senior and junior. Ultimately, it reduces the amount of water that may be transferred even though more water may appear to be available for transfer.[72] Generally, the claimed injury arises from the transition from non-use of water to possible use, which may adversely impact junior water rights holders who were reliant upon the water allocated to senior rights. Typically, the burden of demonstrating that no injury will result is on the applicant.[73] Some western states have since codified the no injury rule to their general water code or regulations or others have adopted it with respect to their specific IBT law.

In Texas, the no injury rule applies generally to all water rights amendments.[74] For IBTs in particular, the Texas statute specifies that any proposed IBT of all or part of a water right is junior in priority to water rights granted before the application is accepted for filing by TCEQ.[75] In other words, the transfer of a water right out of the basin reorders the priority such that the transferred right gets a new priority date and therefore becomes the most junior right in the basin. This reordering often serves as a disincentive and discourages IBTs. It should be noted, however, that interbasin transfers are evaluated differently depending on whether the IBT is a new appropriation. Regardless, a new appropriation will be the most junior water right in the basin. Thus, the effect of junior prioritization is

[63] *Id.* § 533.438(5).

[64] Ariz. Rev. Stat. Ann. § 45-556(A).

[65] *Id.*

[66] *Id.* § 45-556(C).

[67] *Id.* § 45-556(D). The exclusive list of credits are: the amount of any increase in property tax revenues, an amount equal to the market value of land donated to the county if the country prohibits or limits groundwater withdrawal from the land, and an amount agreed by intergovernmental agreement between the county and the city, town, or other person transporting the groundwater. *Id.* § 45-556(E).

[68] Colo. Rev. Stat. Ann. § 37-45-118.

[69] Lawrence J. MacDonnell, *Area-of-Origin Protection in Transbasin Water Diversions: An Evaluation of Alternative Approaches*, 57 U. Colo. L. Rev. 527, 537 (1986).

[70] Colo. Rev. Stat. Ann. § 37-92-305(4.5)(b)(I). The transition mitigation payment is imposed to balance the impacts of transfers on tax revenue in the source area. The bonded indebtedness payment is imposed in an amount equal to the reduction in bond repayment revenues that are attributable to the removal of water from the source and, money collected is distributed among the entities with bonded indebtedness proportionate to their share of the indebtedness.

[71] Barbara Cosens et al., *The Eternal Quest for Water: Historical Overview and Current Examination of Interbasin Transfers of Water*, 55 RMMLF-INST 17-1, § 17.02 (2009).

[72] *Id.*

[73] *See, e.g.*, 30 Tex. Admin. Code Ann. § 297.45(d).

[74] Tex. Water Code Ann. § 11.122(b); 30 Tex. Admin. Code Ann. § 297.45; *compare with* Tex. Water Code Ann. § 11.085.

[75] Tex. Water Code Ann. § 11.085(s). Exceptions include transfers to adjoining coastal basins, emergency transfers, and transfers to any area of a county or municipality outside the basin in which the county or municipality is located, and transfers involving less than 3,000 acre-feet of water per year from a given water right, and transfers from a source wholly outside of the state for use in Texas that is transported using the bed and banks of any flowing, natural stream. *Id.* § 11.085(v).

most significant for existing appropriations with more senior priority that are being proposed to be transferred out of the basin.

Idaho has a similar no injury rule. It provides that the director of the Department of Water Resources shall approve a change in a water right in whole or in part if, among other requirements, no other water rights are injured thereby, which is sufficiently broad to protect both junior and senior rights holders.[76] In California, both the temporary and long-term transfer provisions contain a no injury rule.[77] However, this rule is qualified in that no *substantial* injury may result, which seems to provide less protection to existing water rights holders.[78] Oregon also follows this basic requirement that no injury to existing water rights may be caused by an IBT with the additional requirement that an IBT may not be approved if it will interfere with planned use or development within the basin of origin.[79] As in Texas, Oregon also subordinates rights that are transferred.[80]

New Mexico's no injury rule provides that it will be unlawful for anyone to divert waters for use in other reservoirs or valleys "to the impairment of valid and subsisting prior appropriators of such waters."[81] Moreover, a violation of New Mexico's no injury rule is punishable by a fine or imprisonment in a county jail.[82] If irrigation water is being severed and transferred, it does not lose its priority; however, such a transfer is limited by the no injury rule in that the transfer cannot cause detriment to any existing water rights.[83]

Under the Colorado no injury rule, changes in water rights or use must "not injuriously affect the owner of or persons entitled to use water under a vested water right or a decreed conditional water right."[84]If injury is anticipated, the water judge may impose terms or conditions in the water right that mitigate or even prevent such injury.[85] Such conditions may also address impacts to water quality.[86]

In Nevada, the no injury rule likewise applies to existing rights and protectable interests in existing domestic wells.[87] However, unlike with protecting the basin of origin, the state engineer does not have to inventory all of the vested surface water and groundwater rights within the basin of origin prior to granting an IBT.[88] In Arizona, a person may not use a well for the withdrawing of water for transport to an AMA without approval from the relevant state agency; that approval is conditioned on a determination that the withdrawal will not "unreasonably increase damage . . . other water users from the concentration of the well."[89]

Although all the western states discussed herein have some form of a no injury rule, Texas and Oregon are the most restrictive. Unlike the other states, an IBT in Texas requires the subordination of the water right to the date on which the transfer application was filed. More than any other element, this rule seems to be the most limiting for IBTs in Texas.

Public interest criteria and the public trust doctrine

Most western states have codified the common law public trust doctrine either directly in their water law or indirectly by embodying its essence in the form of public interest considerations required to be met in order for a water right or use to be granted. In this regard, the provision requires that a water right be denied if it is, in some way, detrimental or contrary to the public interest or welfare. Often, this protection is subsumed into the public trust doctrine in states that have specifically determined—judicially or statutorily—that water resources are held in trust for the benefit of the public.

In Texas, the waters of the state are explicitly held in trust for the public.[90] Thus, the preservation and conservation of water resources within the state are public duties.[91] [92] This express adoption of the public trust doctrine is contrasted by states such as New Mexico that have only indirectly applied the public trust doctrine in the form of public interest considerations. In New Mexico, the state engineer *may* deny an application for a new water right if it is "contrary to the conservation of water within the state or detrimental to the public welfare of the state."[93]

[76] Idaho Code Ann. § 42-222(1).

[77] Cal. Water Code. Ann. §§ 1725, 1736.

[78] *Id.*

[79] Or. Rev. Stat. §§ 537.803(1)(e), 537.860; *see also id.* § 540.530.

[80] *Id.* § 537.809.

[81] N.M. Stat. Ann. § 72-8-5.

[82] *Id.*

[83] *Id.* § 72-5-23.

[84] Colo. Rev. Stat. § 37-92-305(3)(a).

[85] *Id.* § 37-92-305.

[86] *Id.*

[87] Nev. Rev. Stat. Ann. §§ 533.370(2), 533.371(5).

[88] *Id.* § 533.364(2)(a).

[89] Ariz. Rev. Stat. Ann. § 45-559.

[90] Tex. Const. Art. XVI § 59; Tex. Water Code Ann. § 11.0235(a).

[91] *City of Marshall v. City of Uncertain*, 206 S.W.3d 97, 101 (Tex. 2006).

[92] Additionally, the Commission, when making a decision on an application, must consider whether the proposed appropriation is "detrimental to the public welfare." Tex. Water Code Ann. § 11.134(b)(3)(C).

[93] N.M. Stat. Ann. § 72-5-7; *see also id.* § 72-5-23 (prohibiting he severance and transfer of irrigation water rights that are detrimental to the public welfare of the state); *id.* §72-12B-1 (recognizing that it is not in conflict with the public welfare of the state or the citizens of New Mexico to allow interstate water transfers).

Idaho has, in a general sense, codified the public trust doctrine for public lands.[94] However, in application, the Idaho public trust doctrine is just a limitation on the power of the state to alienate or encumber navigable waters on the state.[95] Moreover, the Idaho statute specifically limits the application of the public trust doctrine as it relates to appropriation of use of water and water rights.[96] However, the change of diversion statute still utilizes the general requirement that any change to a point of diversion, such as an IBT, be in the local public interest.[97] In Idaho, "local public interest" means "interest that the people in the area directly affected by a proposed water use have in the effects of such use on the public resource."[98] Therefore, the public interest of both the receiving basin and basin of origin must be considered prior to granting a change to a point of diversion, irrespective of whether the public trust doctrine applies to such a change.[99] Unlike other states, Idaho also prohibits the director of the Department of Water Resources from approving a change of use "where such change would significantly affect the agricultural base of a local area."[100]

In Nevada, the water also belongs to the public.[101] Although there is not an express codification of the public trust doctrine, an IBT cannot be approved if it is detrimental to the public interest.[102] However, unlike all the other western states, Nevada also provides that a change in the place of beneficial use of water may involve energy generation outside of the state so long as it is in the public interest and economic welfare of Nevada.[103]

Most western states have some sort of public interest consideration—whether a specific codification of the public trust doctrine or an enumerated statutory provision to consider impacts to the public. The laws and regulations concerning the public's interest appear to be in line with other western states.

Stream flow and water quality protection

Following 2 rounds of litigation in which the Second Circuit ultimately held that IBTs were a "discharge of pollutants" requiring a National Pollutant Discharge Elimination System (NPDES) permit under the Clean Water Act,[104] the Environmental Protection Agency issued a final rule in 2008 stating that "water transfers, as defined by the rule, do not require NPDES permits because they do not result in the 'addition' of a pollutant."[105] However, the rule makes clear that although an NPDES permit is not required, states are allowed to impose water quality criteria on water transfers.[106] Some western states have exercised this right and imposed various water quality considerations and restrictions in their IBT laws.

Texas's IBT statute only requires consideration of the impacts to water quality that are reasonably expected to occur as a result of the transfer.[107] However, although not specifically in the IBT legislation, the Texas Water Code explicitly provides that the TCEQ is required to "balance[] all other public interests to consider and . . . provide for the freshwater inflows and instream flows necessary to maintain the viability of the state's streams, rivers, and bay and estuary systems . . . ."[108] Permits may be suspended to ensure that these environmental flows are maintained under certain circumstances to ensure the "biological soundness" of the state's water systems.[109] Conversely, environmental flow requirements are also subject to temporary suspensions during emergencies, if necessary, so that water can instead be applied to essential beneficial uses. It should be noted, however, an amendment to an existing water right for an IBT that does not change the diversion point or diversion rate would not have to address environmental flows. If the application is for a new appropriation, on the other hand, TCEQ applies the environmental flow criteria in Texas Water Code § 11.147 (or the criteria in 11.147(e)(3), depending on the basin in which the new appropriation is located). Texas's environmental flow requirement for a new appropriation is similar to Idaho, described below, in that Texas has adopted environmental flow standards for nineteen river basins and bay systems in the state.

Colorado, like Texas, grants the Colorado Water Conservation Board the exclusive authority to appropriate "such waters of natural streams and lakes as the board determines may be required for minimum streamflows . . . to preserve the natural

94 *See* Idaho Code Ann. § 58-1203.

95 *Id.* at § 58-1203(1)

96 *Id.* (indicating that "the public trust doctrine shall not apply to . . . [t]he appropriation or use of water, or the granting, transfer, administration, or adjudication of water or water rights . . . .").

97 *Id.* § 42-222(1).

98 Idaho Code Ann. § 42-202B(3).

99 *See id.*

100 *Id.* § 42-222(1).

101 Nev. Rev. Stat. Ann. §§ 533.025, 533.371.

102 *Id.* § 533.370(2).

103 *Id.* § 533.372.

104 *Catskill Mountains Chapter of Trout Unlimited, Inc. v. City of New York*, 273 F.3d 481 (2d Cir. 2001) (Catskills I); *Catskills Mountains Chapter of Trout Unlimited, Inc. v. City of New York*, 451 F.3d 77 (2d Cir. 2006) (Catskills II).

105 National Pollutant Discharge Elimination System (NPDES) Water Transfers Rule, 73 Fed. Reg. 33,697, 33,699 (June 13, 2008).

106 73 Fed. Reg. at 33,699.

107 Tex. Water Code Ann. § 11.085(k)(2)(F); 30 Tex. Admin. Code Ann. § 297.45(b)(5)(B).

108 Tex. Water Code Ann. § 11.0235(c).

109 *Id.*

environment to a reasonable degree."[110] Although not within the context of an IBT, this requirement underpins all decisions relating to the appropriation of water.

Idaho's IBT provision specifically mentions the maintenance of minimum streamflows.[111] The requisite criteria for minimum streamflow are not the local public interest, but rather the standard(s) established by the minimum streamflow statute elsewhere in the code.[112] Generally, the minimum streamflow requirement for Idaho is what is needed for "the protection of fish and wildlife habitat, aquatic life, recreation, aesthetic beauty, transportation and navigation rules, and water quality."[113], [114]

Unlike other states, Oregon only requires information on water quality; it does not require the permitting authority to consider water quality impacts. The applicant must provide information regarding whether the proposed use of the transferred water will adversely affect the quality of water that remains available for domestic and municipal use within the basin of origin.[115]

Texas's requirement that environmental flows be maintained is 1 of the most stringent streamflow and water quality protections built into IBTs in the western states. Given the ongoing debate over what constitutes adequate environmental flows, this condition may limit or otherwise impose an obstacle to the utilization of IBTs in the state.

Fish and wildlife protection

Similar to the protections for streamflows and water quality, the IBT laws of the western states provide a range of protections for fish and wildlife that span from mere consideration of the impacts to outright mitigation.

The IBT law in Texas does not itself directly require consideration of fish and wildlife impacts nor does it directly require mitigation of any potential impact.[116] It does, however, provide that the impacts to aquatic and riparian habitat must be considered along with the instream uses.[117] However, in applications for new appropriations, which is applicable to IBTs, the granting of that right is contingent upon a favorable evaluation of the impact of the permit on fish and wildlife habitats.[118] The permit may ultimately require the applicant to take reasonable measures to mitigate any adverse impacts to such habitat.[119] However, when granting a permit, the net benefit that may result from the project may be considered and used to offset mitigation required under federal law.[120] Additionally, if a new appropriation is located in one of the basins for which Texas has adopted environmental flow standards, as described above, those adopted environmental flow standards would apply instead.[121]

In California, on the other hand, transfers (both temporary and long-term) are explicitly prohibited from unreasonably affecting fish or wildlife.[122] In comparison to California, wildlife protection is only a secondary concern in Texas for the approval of an IBT. Other states vary in whether they have direct or indirect protection for fish and wildlife impacts. Texas appears to be more balanced in how it approaches this issue.

Balancing test for final approval

Administratively, the approval process for IBTs varies significantly across the western states. Some states mandate automatic approval of the transfer if certain conditions are met. For instance, the Idaho IBT law provides that "[t]he director of the department of water resources shall examine all the evidence and available information and *shall* approve the change in whole, or in part, or upon conditions, provided no water rights are injured thereby."[123] Other IBT laws, however, are permissive and provide for approval if certain specified conditions are met. In these states, a balance test is often employed to weigh the value of transfer against the potential harm of the transfer.

Texas employs a balancing test in determining whether an IBT permit should be approved. The TCEQ *may* grant, in whole or in part, an application for an IBT "to the extent that . . . the detriments to the basin of origin during the proposed period are less than the benefits to the receiving basin during the proposed transfer period, as determined by the commission based on consideration of the factors described by [the IBT statute]."[124] Additionally, TCEQ may only approve the IBT if

[110] Colo. Rev. Stat. § 37-92-102(3).

[111] Idaho Code Ann. § 42.222(1).

[112] *Id.*

[113] *Id.* § 42-1501.

[114] Notably, Idaho also considers the minimum streamflow to be a beneficial use of the water. *Id.*

[115] Or. Rev. Stat. § 537.803(f).

[116] Tex. Water Code Ann. § 11.085(k)(2)(F); 30 Tex. Admin. Code Ann. § 297.45(b)(5)(B).

[117] *Id.*

[118] *Id.* § 11.152.

[119] *Id.*

[120] *Id.*

[121] *Id.* §§ 11.125; 11.147(e)(3); 30 Tex. Admin. Code, ch. 298.

[122] Cal. Water Code Ann. §§ 1725, 1736.

[123] Idaho Code §42-222(1) (emphasis added).

[124] Tex. Water Code Ann. § 11.085(l)(1). This balancing test was first articulated in *City of San Antonio v. Texas Water Commission*, 407 S.W.2d 752, 758 (Tex. 1966).

the applicant prepares a drought contingency plan and develops and implements a water conservation plan that employs the "highest practicable levels of water conservation and efficiency achievable within the jurisdiction of the applicant," which is a much higher standard than non-IBT applications.[125] The intent and degree of implementation of this provision of law is currently embroiled in litigation.[126]

The language of the California temporary and long-term transfer statutes has been interpreted to mean that the agency will apply a subjective balancing test in determining whether to grant the transfer. In relevant part, the code specifies that "[t]he board . . . *may* approve such a petition for a long-term transfer where the change would not result in *substantial* injury to any legal user of water and would not *unreasonably* affect fish, wildlife, or other instream beneficial uses."[127] Again, this language does not specify the degree to which fish and wildlife are protected, but such effects must be considered and appropriately weighed in the consideration of whether to grant the transfer. Oregon also uses a balancing test when evaluating the transfer of water. In its analysis, however, the commission *must* consider the cumulative impacts of changing the water right and approve the transfer accordingly.[128]

Among the states that employ a balancing test in determining whether to grant an IBT, Texas's regulations appear to be reasonable. Although Texas may be strict in its water supply considerations, it does not necessitate consideration of some factors that are vital in other states.

Special interstate rules and compacts

In addition to intrastate transfers, some states also provide regulation of interstate, IBTs, through either special rules or interstate compacts. In Texas, the IBT statute specifically excludes from the scope of its coverage a transfer of water that is imported entirely from outside of Texas—except for transfers imported from Mexico—for use within Texas and transported using the bed and banks of a flowing, natural stream.[129]

Interstate transfers of water are also allowed in California. However, an appropriation of water in California for beneficial use in another state may be made only when that state has a reciprocal law in which it may likewise transfer water into California.[130] Idaho also allows the use of public waters outside of the state so long as a number of criteria are met, namely that sufficient water is available to Idaho presently and into the future, the receiving state needs the water, and how the transfer exacerbates the burden to Idaho's water sources should the out-of-state use be granted.[131]

Colorado's interstate IBT laws require a permit to transport water out of the state by ditch, canal, pipe, conduit, natural streams, watercourses, or otherwise.[132] As a prerequisite to approval, the state engineer or judge must determine that the proposed use of water outside of the state is expressly authorized by an interstate compact or credited as a delivery to another state; alternatively, the proposed use must not impair the ability of the state to comply with its own water obligations.[133] Additionally, the use must maintain reasonable conservation of water resources and not deprive any Colorado citizen of the beneficial use of water.[134] The state engineer is allowed to assess and collect a fifty-dollar per acre-foot fee on all water transferred in Colorado for beneficial use in another state.[135]

New Mexico allows water to be transferred out of state upon the successful completion of an application to the New Mexico Environment Department that involves public participation of affected persons.[136] The application for an interstate transfer may be approved if it satisfies the no injury rule, is not contrary to the state's conservation goals, and is not detrimental to the public welfare of the citizens of New Mexico.[137] To make such a determination, the available water supply, the future water demands, water shortages, feasible transportation options, and the intended use in the receiving basin are all to be considered by the state engineer.[138]

Arizona also requires an approval to transport water out of state. The beneficial use within another state must be considered along with the legal basis for acquiring and transporting the water, the proposed purpose for use, the amount of water requested annually, the duration of the permit (not to exceed

[125] Tex. Water Code Ann. § 11.085(l)(2).

[126] Briefs for Appellant and Appellee, *Upper Trinity Reg'l Water Dist. & Tex. Comm'n on Envtl. Qual. v. Nat'l Wildlife Fed'n*, No. 01-15-00374-CV (Tex. App.—Houston [1st Dist.] 2015).

[127] Cal. Water Code § 1736 (emphasis added).

[128] Or. Rev. Stat. § 540.530.

[129] Tex. Water Code Ann. § 11.085(v)(5); 30 Tex. Admin. Code Ann. § 297.45(c)(5).

[130] *See* Cal. Water Code § 1230.

[131] Idaho Code Ann. § 42-401(3).

[132] *See* Colo. Rev. Stat. Ann. § 37-81-101(2)(b).

[133] *Id.* § 37-81-101(3)(a).

[134] Id. § 37-81-101(3)(b)-(c). The Colorado transfer statute also provides that return flows or water introduced from a foreign source from an unconnected stream is unappropriated and an appropriator may make a succession of uses to the extent the volume from the foreign source can be distinguished from the volume of the stream. Id. § 37-82-106(1).

[135] *Id.* § 37-81-104(1)(a).

[136] N.M. Stat. Ann. § 72-12B-1(B).

[137] *Id.*

[138] *Id.* § 72-12B-1(D).

fifty years), and studies demonstrating the hydrologic impact on the basin of origin.[139] Additionally, consistency with state water conservation goals, potential harm to the public welfare, the future water demands of Arizona, the feasibility of transport, and the availability of alternative sources are also considered.[140] Unique to Arizona, the director must continue to monitor a granted interstate transfer for compliance.[141]

California and Nevada have developed an interstate compact that permits IBTs between the states.[142] In relevant part, it allows both states to use waters of the Truckee River in the Lake Tahoe Basin or the Carson River Basin and the waters of the Carson River in the Lake Tahoe Basin or the Truckee River Basin so long as the transfers do not adversely affect the other state.[143]

Unlike other states, Texas does not explicitly have interstate IBT requirements, either generally or for specific basins. Thus, the presumption in Texas is that should an entity apply for an IBT, such a transfer would not be subject to any additional or special requirements as it would in other states. However, the no injury rule and other standards may apply.

RECOMMENDATIONS

Among the western states considered herein, Texas appears to have relatively strict IBT regulations. With more and more competing demands for limited water supplies, voluntary and efficient IBTs should be encouraged to address those needs as they arise.

To provide for a more balanced, robust, and efficient IBT framework and to reduce some of the impediments and high transaction costs associated with IBTs, Texas should at least consider revisions to its laws. These adjustments could be made in a way that facilitates transfers while still mitigating adverse impacts. Most importantly, Texas should repeal that portion of the IBT statute that subordinates the priority of an existing water right that is approved for an IBT, which seems, in practice, to be the most prevalent impediment to IBTs. Because most basins are already fully appropriated, this provision significantly disincentivizes IBTs. Additionally, Texas should consider eliminating the requirement that the applicant demonstrate the need for the transfer. Texas is one of two states that have such a requirement, and the purpose of this provision is already adequately addressed by the beneficial use provision and the source area protections in place. And, finally, the IBT provision already includes certain exceptions in Texas Water Code § 11.085(v). These exceptions could be broadened to address issues and experiences that Texas has witnessed since implementation of S.B. 1.

[139] Ariz. Rev. Stat. Ann. § 45-292.

[140] *Id.*

[141] *Id.* § 45-293.

[142] Nev. Rev. Stat. Ann. § 538.600.

[143] *Id.*

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A recharge-discharge water budget and evaluation of water budgets for the Edwards Aquifer associated with Barton Springs

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Abstract: The Barton Springs segment of the Edwards Aquifer represents a small, relatively independent part of the aquifer. Data for the sources of recharge and especially for discharge from the aquifer are well documented. Based on a 6-year water budget of surface recharge and surface discharge, the volumes match within 5%, which is within the potential error limits of the recharge and discharge values. Recharge volumes include increased runoff due to urbanization in the recharge area. A previous water budget based on an earlier period also displayed a balance between recharge and discharge volumes. Both budgets are based on slightly "wetter" than long-term mean recharge and discharge conditions, thus subsurface recharge from south of the aquifer segment, which is documented to occur during dry conditions, was an insignificant source of recharge during the budget periods.

The recharge volumes are based on data from streamflow gaging stations operated by the U.S. Geological Survey. However, one of the stations (Bear Creek near Brodie Lane) was discontinued in 2010; this station is needed to calculate recharge volumes on Bear Creek and Little Bear Creek. Because of the discontinuance of the station, any calculations of recharge volumes after 2010 would contain substantial potential error.

Keywords: Edwards Aquifer, water budget, karst

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Terms used in paper

Acronym	Descriptive term
USGS	U.S. Geological Survey
BSEACD	Barton Springs Edwards Aquifer Conservation District
IC	Impervious cover
RC	Runoff coefficient
ET	Evapotranspiration
TWDB	Texas Water Development Board

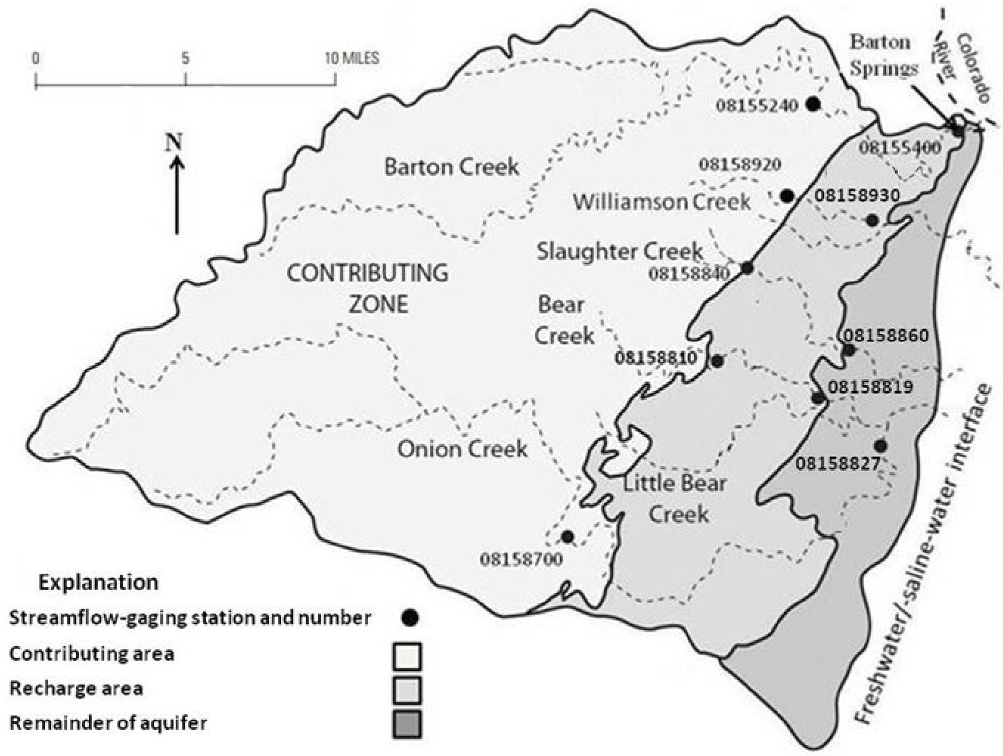

Figure 1. Boundaries for the aquifer, recharge area, and contributing area and locations of streamflow gaging stations.

INTRODUCTION

Barton Springs discharges a relatively hydrologically independent part of the Edwards Aquifer, commonly referred to as the Barton Springs segment of the Edwards Aquifer. The boundaries for this part of the aquifer are presented in Figure 1. The recharge area for the aquifer is composed mostly of the outcrop of rocks that form the aquifer. The western boundary for the aquifer coincides with the western boundary of the recharge area.

Each of the 6 major creeks that cross the recharge area has a basin that extends upstream of the aquifer. Figure 1 identifies the 264-square-mile contributing area—the surface drainage area upstream from the recharge area (Slade 1986). The contributing area is about 3 times larger than the 90-square-mile recharge area.

By 1979, with funding assistance from the city of Austin, the U.S. Geological Survey (USGS) installed and operated streamflow-gaging stations near the upstream and downstream boundaries of the recharge area on 5 of the 6 streams, so that runoff and recharge volumes could be calculated. Because of the relatively small contributing area for Little Bear Creek (about 3.3 square miles), a streamflow station was not installed at the upstream boundary of its recharge area. Recharge volumes are calculated as explained below. Other small streams exist in the recharge area, but their contributions to recharge are deemed minimal because their basins are much smaller than those for the 6 major streams. The basins for the 6 major stream identified in Figure 1 represent about 96% of the drainage area within the recharge area (Naismith Engineering Inc. 2005). Additionally, the USGS installed and operated 12 precipitation gages throughout the contributing and recharge areas.

Subsurface discharge is believed to be minimal compared to surface sources (Slade et al. 1986). Subsurface recharge from the adjacent and underlying Trinity Aquifer also is believed to be minimal (Slade et al. 1986). Additionally, subsurface recharge from the Edwards Aquifer south of the aquifer boundary is deemed as nonexistent or minimal except during low-flow conditions (Johnson et al. 2012 and Casteel et al. 2013).

Barton Springs represents the major discharge from the aquifer. The USGS has systematically measured its discharge since 1917 and gaged its discharge hourly since 1978. Cold Springs discharges a small part of the aquifer; its mean flow is documented based on about a dozen discharge measurements. A few other small springs represent minor discharges from the aquifer. Groundwater withdrawal volumes are mostly gaged. Therefore, the vast majority of discharge from the aquifer is gaged.

PURPOSE OF PAPER

The purpose of this paper is to present, for the Barton Springs segment of the Edwards Aquifer, a recharge-discharge water budget based on impervious cover (IC)-founded calculations of runoff and recharge volumes. An additional purpose is to present a summary and evaluation of all identified recharge-discharge water budgets conducted for the aquifer.

METHOD TO CALCULATE RECHARGE VOLUMES

The method of estimating surface recharge to the Edwards Aquifer was first introduced by Garza (1962). Recharge consists of the infiltration of streamflow plus direct infiltration of runoff in the interstream areas. The approach of estimating recharge in each stream basin is a water-balance equation, in which the recharge value within a stream basin represents the difference between gaged streamflow upstream and downstream from the recharge area, plus the estimated runoff in the intervening area. The intervening area is the drainage area within the recharge area between the 2 streamflow-gaging stations in each stream basin. Runoff from the recharge area is estimated on the basis of unit runoff from the area upstream from the recharge area. Such an assumption is deemed reasonable because the land slopes, soil and vegetation type and extent, and precipitation characteristics generally are similar in both areas. Estimates of monthly recharge during periods of high runoff probably contain the major errors (Puente 1978).

The basic equation for computing monthly recharge is as follows:

$R = Q_u + SI - Q_d$

where R is monthly recharge volume;

Q_u is the monthly flow volume at the upstream gaging station;

SI is the estimated monthly runoff volume, including infiltration, resulting from precipitation in the intervening recharge area; and

Q_d is the monthly flow volume at the downstream gaging station.

The general equation used for estimating the total runoff derived from direct precipitation in the areas between the upstream and downstream gaging stations is expressed as follows:

$SI = Q_u / A_u \Delta A$

where,

Q_u is the monthly flow volume at the upstream gaging station;

A_u is the drainage area for the upstream gaging station, in square miles; and

ΔA is the intervening drainage area between the upstream and downstream gaging station, in square miles.

Based on the above equations, unit runoff (runoff per square mile) from the recharge area is assumed to represent that from the upstream contributing area. However, available precipitation records that document the distribution of rainfall for each month can be used to adjust the estimated runoff from the recharge area. The adjustment to the estimated unit runoff often is based on a precipitation depth ratio determined from the mean precipitation in the contributing and intervening areas. However, little information is available regarding the spatial focusing of recharge in particular locations. Additionally, during the past 20 to 25 years, the recharge area has experienced rapid urban development compared to that in the contributing area which is more remote from the Austin city limits. Therefore, due to greater IC density, the recharge area likely experiences greater unit runoff than that from the contributing area.

LONG-TERM MEAN DISCHARGE FROM THE EDWARDS AQUIFER

Barton Springs and withdrawals

The long-term (1917–2013) mean discharge from Barton Springs is 54 cubic feet per second. The mean discharge is based on daily-mean gaged discharges from 1978 to 2013 and on 725 instantaneous discharge measurements made from 1917 to 1978. The earlier discharge measurements were plotted on monthly hydrographs with daily resolution. Precipitation records for gages in Austin and San Marcos were used, along with known springflow recession rates from 1978 to 82, to estimate daily and monthly-mean discharges for the 1917–78 period (Slade 1986).

A limited discharge of intermittent springflow occurs in the reach of Barton Creek immediately upstream from Barton Springs. Such springflow varies from zero when groundwater levels are below the streambed, to about 5 cubic feet per second when local groundwater levels are extremely high. When Barton Springs discharges 54 cubic feet per second (its long-term mean), the springflow from the streambed is about 0.8 cubic feet per second (Slade 2014).

Monthly-mean groundwater withdrawals from 1917 to 2013 were provided by the Barton Springs Edwards Aquifer Conservation District (BSEACD). The vast majority of pumpage is metered, thus withdrawal rates are considered to have minimal potential error. Privately-owned wells are not metered but their pumpage volumes are estimated. Based on these data, the 1917–2013 mean total pumpage is 2.7 cubic feet per second. Monthly-mean pumpage ranges from 0.10 cubic feet per second in 1917 and later to 13.57 cubic feet per second in June 2008. Some of the withdrawal volumes likely are lost as leakage from transmission pipes, ineffective irrigation, or effluent discharges, but the vast majority of such losses are consid-

Table 1. Discharge measurements of Cold Springs.

Date	Cold Springs discharge (cubic feet per second)	Barton Springs discharge (cubic feet per second)
Aug ? 1914[1]	4.2	unknown
Aug ? 1917[2]	4.2	15
Aug 1, 1918[3]	7.5	14
Aug 6, 1918[3]	4.2	14
Aug 10, 1918[4]	3.7	14.3
Aug 8, 1921[3]	10.7	39
Aug 13, 1930[3]	12.0	24
Feb 8, 1941[2,3]	3.0	61
1955[2]	0.0	17
May ? 1972[2]	2.9	84
Dec 19, 1979[5]	2.6	46
Aug 18, 1996[6]	4.1	18
Aug 6, 1997[7]	7.3	107
Nov 4, 1997[8,9]	6.4	84
Oct 18, 1999[8]	4.8	33
Jan 29, 2008[8]	8.2	66
Mean value	6.48	41.5
Adjusted mean value	**8.4**	**54**

Mean discharge for Cold Springs adjusted by ratio of 54/41.5 in order to estimate its mean value associated with mean flow of Barton Springs (54 cubic feet per second).

Measurements in red made by indirect method and subject to large potential error.

Measurements in blue not used for calculation of mean value. Barton Springs discharge unknown or part of springflow likely below lake level. 1955 measurement not used due to severe drought.

[1] Brune and Duffin 1983
[2] Brune 1975
[3] TBWE 1959
[4] TBWE 1960
[5] Mike Dorsey, USGS, personal commun.
[6] Hauwert et al. 2004
[7] Hauwert et al. 2004
[8] David Johns, Watershed Management Dept., City of Austin, personal commun.
[9] 4.5 cubic feet per second measured directly and 1.9 cubic feet per second estimated.

ered to have a direct fate as evapotranspiration (ET). Therefore, only a minimal amount of pumpage is deemed to be directly lost as recharge to the Edwards Aquifer, thus gross withdrawal volumes are represented as discharge for the water budget.

Other discharges

Cold Springs is located on the southern bank of the Colorado River, about a mile northwest of Barton Springs (Slade 2014). Its recharge source probably represents Dry Creek, a small creek north of Barton Creek, and likely part of the flow in Barton Creek. All known direct and indirect discharge measurements for Cold Springs are aggregated and presented in Table 1. Based on 11 discharge measurements, the mean discharge for Cold Springs is 6.48 cubic feet per second. Some of the springflow is known to discharge below the normal level of Lady Bird Lake, built in 1960; measurements made during such conditions were excluded from the calculation of the mean springflow value. The discharge for Barton Springs was estimated for each of the measurement dates for Cold Springs (Table 1). The mean discharge of Barton Springs for the 11 measurements is 41.5 cubic feet per second, which is 77% of its long-term mean discharge of 54 cubic feet per second. The assumption was made that the mean measured discharge for Cold Springs (6.48 cubic feet per second) also is 77% of its long-term mean discharge. Based on this assumption, the long-term mean discharge for Cold Springs is estimated to be 8.4 cubic feet per second.

A limited amount of outflow is believed to discharge the Edwards Aquifer as seeps or springflow into Lady Bird Lake (the Colorado River) adjacent to the northern boundary of the aquifer (Figure 1). Prior to the construction of the dam forming the lake, a streamflow gain-loss study conducted on August 10, 1918, indicated an unaccounted gain of 0.4 cubic feet per second in the river reach adjacent to the Edwards Aquifer; an additional study of a similar reach in 1925 indicated a gain of 1.0 cubic feet per second. These gains could result from: groundwater discharge through terrace deposits along the river; groundwater discharge from the north side of the river; or surficial runoff outside the Edwards Aquifer. Also, it is possible that no streamflow gain occurred due to potential error in the streamflow measurements. However, even if both gains represent discharges from the Barton Springs part of the Edwards Aquifer, their discharge are minor compared to other discharges from the aquifer. For purposes of documenting such discharges from the aquifer, the assumption is made that the mean discharge from the Colorado River bank is 0.7 cubic feet per second, the mean value for the 2 streamflow gain studies. Additional information and references regarding this analysis is reported by Slade (2014). Also, additional information that documents Colorado River bank discharges to represent limited outflow from the aquifer is contained in the section “Other discharges” within the “Supplemental information” section.

Based on the 5 sources for discharge documented above, the total mean discharge from the aquifer calculates to be 67 cubic feet per second. The long-term mean recharge rate is deemed to be equivalent to this value.

A NEW RECHARGE-DISCHARGE WATER BUDGET

The first recharge-discharge water budget for the Barton Springs segment of the Edwards Aquifer was published by Slade et al. (1986) and later verified and slightly refined by Slade (2014). The budget represents the period December 1, 1979 through July 31, 1982 and is based on recharge calculations as described above and on discharges from Barton Springs and withdrawals. Based on the budget, the recharge volume exceeded the discharge volume by 3.3% (Slade 2014).

Based on the recharge calculation method described earlier, the recharge volume was calculated for a recent long-term period. Discharge values were compared to the recharge values in order to assess the sources and values of recharge and discharge included in the budget.

Discharge and precipitation

The new water budget period represents the 6-year period from November 1, 2003 through October 31, 2009. Barton Springs discharge was 50 cubic feet per second at the beginning of the period and 51 cubic feet per second at the end. Springflow discharge is indicative of groundwater levels in the aquifer (Slade et al.1986); therefore change in aquifer storage is deemed to be minimal during the budget period and thus an exempt component of the budget.

The mean discharge from Barton Springs during the period is 54.8 cubic feet per second. The mean withdrawal from the aquifer during the period is 7.8 cubic feet per second (BSEACD 2014, written commun.). During the period, a mean springflow of about 0.8 cubic feet per second discharged from the reach of Barton Creek immediately upstream from Barton Springs (Slade 2014). Discharge from the aquifer to Lady Bird Lake was assumed to represent 0.7 cubic feet per second during the period. Finally, the discharge from Cold Springs was assumed to represent its long-term mean value of 8.4 cubic feet per second, as documented earlier.

Therefore the total discharge for the budget period has a mean value of 72.5 cubic feet per second.

Precipitation during the period is based on 6 gages within the stream basins; 5 are operated by the Lower Colorado River Authority and 1 is operated by the National Weather Service. Based on data for the 6 gages, the mean precipitation depth during the period ranges from 163.92 inches to 191.31 inches and has a mean value of 179.20 inches, which is equivalent to 29.87 inches per year.

Recharge

Recharge volumes were calculated for the budget period, based on streamflow data for gaging stations upstream and downstream from the recharge area. Each of the stations used in the calculations are designated in Figure 1 and the data are available from an interactive map online at http://maps.waterdata.usgs.gov/mapper/index.html?state=tx. Recharge was calculated as explained above except that, where applicable, runoff volumes for the recharge area were adjusted to account for runoff due to differences in IC densities between the contributing and recharge areas. An explanation for this adjustment follows.

A search for IC density values for the contributing and recharge areas within each major stream basin identified only one source (Naismith Engineering Inc. 2005). Table 2 presents estimated IC densities for the year 2003.

In order to calculate the runoff in the recharge area due

Table 2. Impervious cover densities for the contributing and recharge areas of the streams providing recharge to the Edwards Aquifer, 2003.

Watershed	Area in RZ (Ac)	Area in CZ (Ac)	Area in PR (Ac)	RZ IC (Ac)	RZ IC (%)	CZ IC (Ac)	CZ IC (%)	Total
Little Barton Creek	0	7,300	7,300	0	-	459	6.29%	6.29%
Barton Creek	4,956	64,521	69,477	1,096	22.11%	2,975	4.61%	5.86%
Bee Creek	96	1,824	1,920	15	15.37%	280	15.37%	15.38%
Little Bee Creek	397	243.2	640	80	20.04%	49	20.05%	20.08%
Eanes Creek	1,587	973	2,560	433	27.25%	265	27.25%	27.26%
Williamson Creek	5,205	5,811	11,016	1,361	26.14%	925	15.91%	20.75%
Slaughter Creek	6,743	7,256	13,999	775	11.50%	538	7.41%	9.38%
Bear Creek	4,126	11,477	15,603	179	4.33%	568	4.95%	4.78%
Little Bear Creek	11,412	1,608	13,020	337	2.95%	35	2.16%	2.86%
Onion Creek	15,739	90,986	106,725	324	2.06%	2,890	3.18%	3.01%
Total	**50,262**	**191,999**	**242,260**	**4,598**		**8,982**		

RZ designates the recharge zone; CA the contributing zone; and the PR the Planning Region for the report. IC designates impervious cover and AC represent acres. IC densities exceeing 10% are highlighted.

to differences in IC densities between the contributing and recharge areas, runoff volumes associated with IC densities need to be represented. The most pertinent documentation identified regarding the relations between IC densities and runoff volumes in the Austin, Texas area is presented by the city of Austin (2009). The report includes the IC density (%), the runoff coefficient (RC), and a summary of the major land use for each basin represented by about 36 streamflow gaging sites in the Austin area. The RC represents the runoff volume expressed as a ratio of precipitation volume. Based on IC and

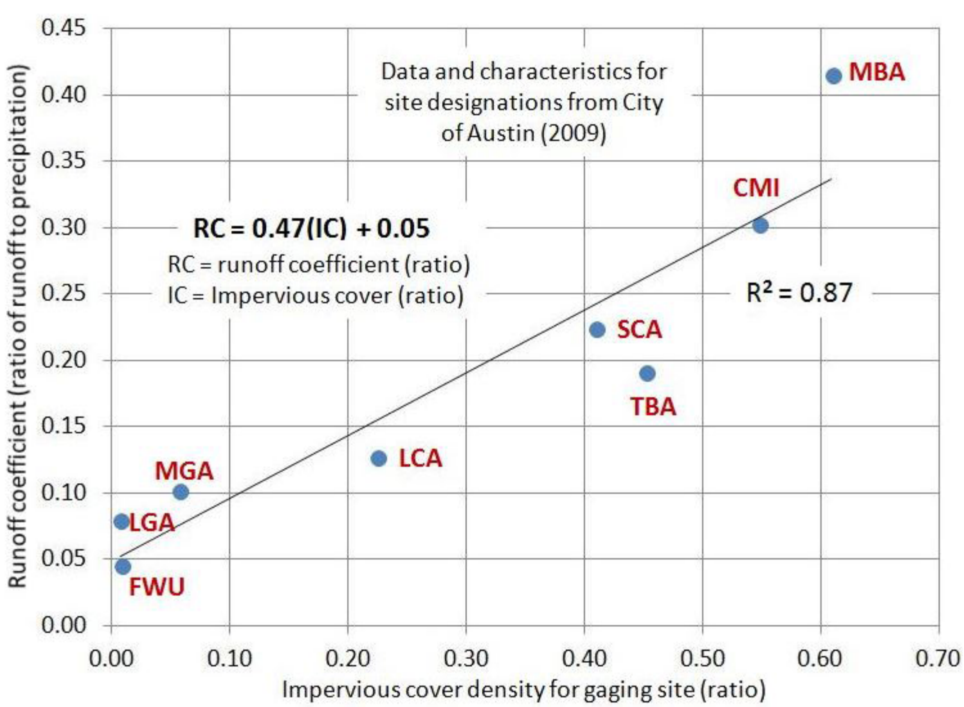

Figure 2. Relation between impervious cover densities and runoff coefficients for selected streamflow gaging sites. CMA=Central Market Influent, FWU=Windago Way Undeveloped, LCA=Lost Creek Subdivision, LGA=Lost Creek Golf Course Undeveloped, MBA=Metric Blvd., MGA=Lions Municipal Golf Course, SCA-Burnet Road @ 40th Street, TBA=Tar Branch at Carriage Parkway

RC values for selected pertinent sites, a statistical relation was developed by which to calculate runoff volumes based on IC densities (Figure 2). The approach for such calculations is presented in the "Recharge" section within the "Supplemental information" section.

Based on the recharge calculations as explained, the total mean recharge calculated to be 69.1 cubic feet per second, of which 4.2 cubic feet per second (about 6% of total recharge) is attributed to greater IC densities in the recharge area than in the contributing area. The total recharge due to IC densities exceeding zero is much greater than 6% of total recharge. The total mean recharge (69.1 cubic feet per second) calculates to be about 5% less that the total mean discharge for the period (72.5 cubic feet per second). The difference is within the range of the potential error for the calculations, thus the subsurface recharge volume is deemed to be insignificant during the period.

The mean recharge rate can be expressed as a percentage of precipitation on the contributing and recharge areas. The mean precipitation for the budget period is 179.20 inches, comparable to 29.87 inches per year. Converting the precipitation depth and recharge volume to comparable units documents the mean recharge value of 69.1 cubic feet per second to represent 9% of precipitation over the entire contributing and recharge areas. Runoff from the recharge area (total discharge for the streamflow stations downstream from the recharge area) represents a mean value of 79.8 cubic feet per second, which is equivalent to 10% of precipitation on the total contributing and recharge area. ET rates for the total area can be expressed as ET = Precipitation - recharge - runoff from the recharge area, thus ET calculates to represent 81% of precipitation on the total contributing and recharge area.

Maximum recharge rates in the main channels of the major streams

Due to limited infiltration of recharge in the streambeds, the main channel for each of the 6 major streams has a limiting capacity for the rate of recharge that can be conveyed to the aquifer (Slade 2014). With the exception of Little Bear Creek, streamflow gain-loss studies and gaged streamflow at the upstream and downstream boundaries of the recharge area were used to document the maximum recharge rate for each of the streams. These rates are presented in Table 3.

Table 3. Maximum recharge rates for main streambeds.

Stream	Maximum recharge (cubic feet per second)
Barton	30 to about 70
Williamson	13
Slaughter	52
Bear	33
Little Bear	about 30
Onion	about 120

The main channel of Barton Creek has a maximum recharge rate that ranges from 30 cubic feet per second to about 70 cubic feet per second, depending upon the relative height of groundwater levels under the streambed (Slade 2014). When groundwater levels proximate to the lower reach of Barton Creek are low, the saturated zone is below the altitude of the entire main channel of Barton Creek, thus a maximum recharge of about 70 cubic feet per second occurs in the main channel. When groundwater levels are relatively high, their altitudes are comparable to or higher than the altitude of the streambed reach immediately upstream from Barton Springs, and thus, that reach rejects recharge. During periods of extreme high groundwater levels, a maximum of only about 30 cubic feet per second of recharge will occur in the main channel of Barton Creek. Barton Springs discharge value is highly indicative of groundwater levels in the lower Barton Creek Basin. Therefore, a statistical relation was developed between values for Barton Springs discharge and the maximum recharge rate for Barton Creek (Slade 2014). As explained below, the best fit formula for that relation was used to calculate, for the water budget documented by Slade (2014) and for the budget in this paper, the recharge volume in the main channel of Barton Creek.

Recharge volumes in the main channels of the major streams

Calculation of recharge volumes in the main channels of the major streams is based on daily-mean streamflow values for each of the 5 streamflow stations upstream from the recharge area (Figure 1). Little Bear Creek was excluded from this calculation because a streamflow station was not installed at the upstream boundary of its recharge area. For each station and each day, the gaged daily-mean discharge was compared to the maximum recharge rate for the stream. The daily recharge rate on the main streambed was assumed to represent, for each stream, the lesser value of the maximum recharge rate or the gaged discharge upstream from the recharge area. The daily-mean recharge values were summed for each stream and for the budget period. For the Barton Creek streambed, the maximum recharge rate was based on the formula as discussed in the previous section.

Based on the calculations, the total mean recharge rate for the 5 main channels represents 43.2 cubic feet per second, which includes 3.8 cubic feet per second for Bear Creek. Little Bear and Bear Creek are adjacent basins and have similar drainage areas at the downstream boundaries of their recharge areas.

However, the contributing area for the Little Bear Creek Basin is only about 27% of that for the Bear Creek Basin, thus the main channel recharge for Little Bear Creek was assumed to be 1.0 cubic feet per second, a value representing 27% of the main channel recharge for Bear Creek (3.8 cubic feet per second). Therefore, total mean main-channel recharge from the contributing area represents 44.2 cubic feet per second.

However, 44.2 cubic feet per second of main channel recharge represents a minimum value because runoff from the recharge area sometimes enters the main channel when the main channel flow rate is less than its maximum recharge rate—such runoff would represent, for each major stream, additional recharge on the main channel. However, data do not exist by which to calculate this additional recharge. Based on analyses of the daily main channel recharge rates, about 52% of main channel recharge (22.9 cubic feet per second) occurred when the flow rate in the channels was less than its maximum recharge rate. During such periods, any runoff from the recharge area would increase the recharge rate in the main channels. For each basin, the assumption was made that main channel recharge from he recharge area represents one-half of the unit runoff from the contributing area when its flow rate was less than the maximum recharge rate. Based on such, the recharge area produces 7.0 cubic feet per second of main channel recharge, thus total main channel recharge represents 51.2 ft^3, a value representing 74% of the total mean recharge of 69.1 $ft^3/3$.

Interstream recharge

Of the 69.1 cubic feet per second of total mean recharge during the budget period, 51.2 cubic feet per second occurs in the main channels of the 6 streams crossing the recharge area, thus the remaining 17.9 cubic feet per second of recharge occurs in the interstream area outside the main channels. Based on the precipitation depth of 179.20 inches during the budget period, interstream recharge thus represents 9% of precipitation on the recharge area.

ANALYSIS OF OTHER RECHARGE DISCHARGE BUDGETS FOR THE AQUIFER

Five partial or complete recharge-discharge water budgets have been identified for the Barton Springs segment of the Edwards Aquifer (Table 4). However, only 2 of the budgets (Slade 1986 and 2014, and this paper) independently document and compare recharge and discharge volumes.

Budget for 2003 to 2007

Hauwert (2011) presents a recharge-discharge water budget for what he describes as the portion of the aquifer that discharges to Barton Springs (82 square miles). In order to document daily recharge values for each stream, Hauwert subtracted the same-date daily-mean discharge value for the gaging station near the downstream boundary of the recharge area from the discharge at the station near the upstream boundary. However, this approach is inconsistent with several principles of surface-water hydrology and open-channel hydraulics. To obtain meaningful values, recharge calculations should be performed for discharges occurring only during steady-state flow conditions—conditions that do not occur except during very low-flow conditions. The vast majority of recharge to the aquifer occurs during storm runoff when only non-steady flow occurs. Additionally, the streamflow time of travel between the gaging station upstream of the recharge area and that downstream of the recharge area varies between streams and with flow conditions. For example, the 2 gaging stations on the Onion Creek main channel are separated by about 22 stream miles. Based on the mean streamflow velocity measured by the USGS, the time of travel between these stations varies from about 11 hours to about 7 days. Also, streamflow dispersion characteristics are not available for any of the streams, thus such characteristics are not considered in the Hauwert (2011) approach. Finally, Hauwert does not account for inflow to the streams from the intervening drainage area between the gaging stations.

Hauwert's (2011) approach assumes the difference between the total main channel recharge volume and the total discharge volume (Barton Springs discharge and gross withdrawals) to represent the interstream recharge volume. However, as demonstrated above, main channel recharge volumes as calculated by Hauwert (2011) likely are erroneous, as would be the values for interstream recharge. Additionally, the total recharge volume is not calculated independently from discharge volume and Hauwert could not compare the recharge volume to the total discharge volume for verification of a budget balance. As part of his calculations and estimations, Hauwet documented values for the volume of precipitation on the recharge area, deemed as 82 square miles (2011). The fate of such precipitation as a percent of the total precipitation volume is reported as follows: interstream recharge (15%); recharge on the main channels of the major streams (7%); and runoff from the recharge area (15%). The residual 63% of precipitation is assumed to represent ET from the recharge area (Table 4).

Within the recharge area, however, flow in the main channels of the major streams is a mixture of that from the contributing area and from within the recharge area. Likewise, runoff from the recharge area also is a mixture of water from both source areas. Data do not exist by which to distinguish the specific sources of recharge on the main channels or for runoff from the recharge area. Therefore, the volumes for both values should be treated as estimates, as should the resulting value for ET.

Table 4. Summary of water budgets conducted on the Barton Springs part of the Edwards Aquifer.

NA--Not applicable; NR--Not reported

	Portion of recharge area used as basis for budget	Budget Period	Budget duration (years)	% recharge exceeds or less than (-) discharge (%)	Mean discharge as % of long-term mean[1]
Woodruff (1984)	entire area	7/1979 – 12/1982	3.5	NA	110%
Slade (1986 and 2014)	entire area	12/1979 – 7/1982	2.7	3.3%[2]	112%
Hauwert (2011)[3]	most area	5/31/2003 – 9/19/2007	4.3	NR	128%
Hauwert and Sharp (2014)[4]	0.07 square miles	4/2/2004 – 8/20/2005	1.4	NA	166%
This report	entire area	11/1/2003 – 10/31/2009	6.0	-5.0%	110%

	Fate of precipitation on contributing and recharge area as % of such precipitation				Recharge on main channels as % of total recharge	Runoff from contributing area as % of precipitation on contributing area
	Total recharge	Main channel recharge	Runoff	Evapo-transpiration[5]		
Woodruff (1984)	6%	NA	9%	85%	NA	NA
Slade (1986 and 2014)	8%	6%	12%	80%	75%	17%
Hauwert (2011)	NR	NR	NR	NR	56-67%	NR
Hauwert and Sharp (2014)[4]	NA	NA	NA	NA	NA	NA
This report	9%	7%	10%	81%	74%	16%

	Fate of precipitation on recharge area as % of such precipitation				% of total recharge from contributing area
	Interstream recharge	Main channel recharge	Runoff from recharge area	Evapo-transpiration	
Woodruff (1984)	NA	NA	NA	NA	NA
Slade (1986 and 2014)	6.6%	NR[6]	NR[6]	NR[7]	NR[6]
Hauwert (2011)	15%	7%[6]	15%[6]	63%[7]	39-50%[6]
Hauwert and Sharp (2014)[4]	32%	0	0	68%	NA
This report	9%	4[8]	17%[9]	70%[9]	64%[9]

[1] Based on 1917-2013 mean discharge of 57 cubic feet per second for Barton Springs plus withdrawals.

[2] Based on Cold Springs mean discharge of 5.5 cubic feet per second (Slade, 2014 p. 15)

[3] Excludes the "Cold Springs Basin" thus represents only 82 square miles recharge area rather than 90 square miles

[4] Based on small closed basin (0.07 square miles) within the 90 square mile recharge area

[5] Recharge loss to Trinity Aquifer in contributing area not included—probably about 3% to 4% of precipitation on contributing and recharge areas

[6] Data do not exist to calculate values for source (contributing area or recharge area) of main channel recharge, runoff from recharge area, or recharge from contributing area.

[7] Without directly measured ET data at sites representative of recharge area, its value must be calculated as residual of recharge area water budget: ET = precipitation - recharge - runoff. However, 2 components of budget (total recharge within recharge area and runoff from recharge area) are unknown. See footnote 6.

[8] Estimated as explained in section "Recharge volumes in the main channels of the major streams"

[9] Based on estimation of main channel recharge

Finally, Hauwert's (2011) budget was conducted for a period during which Barton Springs discharge plus withdrawals totaled 128% of its long-term mean value (Table 4). During such "wet" periods, recharge and runoff as a percent of precipitation would logically be greater than their long-term mean values and ET would be less than its long-term mean value.

Budget for 2004 to 2005

Hauwert and Sharp (2014) present a short-duration budget for a small basin (0.07 square miles) within the recharge area but closed to runoff from the recharge area. ET is measured directly via flux tower instrumentation within the basin. Because the small basin is closed to runoff from the basin, interstream recharge is calculated as the difference between the volume of precipitation on the basin and the volume of ET from the basin. Based on these calculations, ET represents 68% of precipitation and interstream recharge was thus deemed to be 32% of precipitation (Table 4).

However, Hauwert and Sharp (2014) report that more than 90% of the 90 square-mile recharge area is not within a closed basin. Based on analysis of streamflow discharge data for the USGS gages on the streams providing recharge, much runoff from the interstream area of the entire recharge area becomes recharge in the main channels of the major streams—runoff that does not recharge the aquifer, discharges from the recharge area. For many "wet" durations within the Hauwert and Sharp (2014) budget period, the streamflow at the station downstream from the recharge area exceeds that at the upstream end, often by more than 100%. During such periods, the amount by which the downstream flow exceeds the upstream flow represents runoff from the recharge area. Therefore, the Hauwert and Sharp (2014) water budget for the small closed basin does not represent that for the entire recharge area.

Also, the budget represents an extremely "wet" period during which time discharge from Barton Springs plus withdrawals equaled 166% of its long-term mean value (Table 4). Therefore, for the budget period, recharge as a percent of precipitation would logically be much greater than its long-term mean value, and ET would be much less than its long-term mean value. Additionally, the budget period is short—less than 17 months. Although data apparently were collected for a much longer period representative of "more normal" flow conditions, the analysis of such data is not reported.

Hauwert and Sharp (2014) concluded that "Based on compilation of ET data from other flux towers in Central Texas under a wide variety of annual precipitation conditions, it can be estimated that under average precipitation conditions, 69% of rainfall leaves as ET; 28% of rainfall percolates as autogenic recharge into the Edwards Aquifer." The flux tower study nearest to the Barton Springs watershed was conducted for the Edwards Aquifer on the Freeman Ranch near San Marcos in Hays County. However, for the Freeman Ranch study, which was not referenced by Hauwert and Sharp (2014), ET was found to be 92% of precipitation, thus limiting recharge to 8% of precipitation (Heilman et al. 2009).

The only ET study referenced by Hauwert and Sharp (2014) was conducted by Dugas et al. (1998); however, many problems deem the results of that water-budget study to be of little, if any, relevance to the Barton Spring Edwards Aquifer area. For example, the Dugas et al. (1998) study was conducted on the Trinity Aquifer rather than on the Edwards Aquifer. Additionally, the Dugas study was on the Seco Creek Basin in Uvalde County, which is of considerable distance from the Barton Springs study area. The annual-mean precipitation in the Uvalde study area is only 22% of that in the Barton Springs Edwards Aquifer area. Also, ET data were not collected during the Dugas et al. (1998) study for the months of November through February, nor were they subsequently estimated. Finally, Wilcox (2008) states: "According to USGS streamflow measurements for the same years as the Dugas et al, 1998 study, Seco Creek streamflow makes up 20% of the water budget; therefore on the basis of the water budget method, ET would constitute around 80%, a figure 15% higher than that (65%) derived by Dugas et al, (1998)."

Additionally, Jones, et al. (2011) aggregate recharge rates for the Hill Country Trinity Aquifer from every creditable investigation. Table 5-1 in that report presents recharge as a percent of mean precipitation for each of the 10 studies. Based on the studies, the recharge rates range from 1.5% of precipitation to 11% of precipitation; the mean value for the 10 studies is 6% of precipitation. Most of the reports were authored by the TWDB or USGS. The TWDB Groundwater Availability Model used a recharge rate equivalent to 3.5% to 5% of average annual precipitation for the Hill Country Trinity Aquifer (Jones et al. 2011).

The following is a simple long-term budget of precipitation and recharge volumes, which indicates interstream recharge to be much less than 28% of precipitation on the recharge area as reported by Hauwert and Sharp (2014).

1. Based on long-term precipitation data from the National Weather Service gage in Austin, the annual-mean precipitation is about 33 inches per year, as documented online at http://www.weather.gov/climate/xmacis.php?wfo=ewx
2. Thirty-three inches of annual-mean precipitation over the 90 square-mile recharge area produces a precipitation volume of 158,400 acre-feet per year.
3. Applying 28% of that precipitation as interstream recharge produces 44,400 acre-feet per year, a value equivalent to 61 cubic feet per second.

As shown in Table 4, Hauwert (2011) concludes that 56% to 67% of total recharge occurs on the main channels of the major streams; Slade (1986 and 2014) indicate 75% of total recharge to occur on the main channels; and this (Slade) paper documents 74% of total recharge to occur on the main channels. Based on these reports, interstream recharge (61 cubic feet per second as referenced above) thus ranges from 25% to 44% of total recharge. Therefore, based on Hauwert and Sharp's (2014) interstream recharge rate of 28% of precipitation, long-term total mean recharge would represent a range of 139 cubic feet per second to 244 cubic feet per second. However, as documented in the section "Long-term mean discharge from the Edwards Aquifer", the long-term (1917–2013) mean discharge, and thus recharge, for the Barton Springs segment of the Edwards Aquifer is 67 cubic feet per second. Accordingly, an interstream recharge rate of 28% of precipitation produces recharge values that range from 207% to 364% of the documented long-term mean recharge value.

This same type of analysis documents that interstream recharge as 15% of precipitation, as claimed by the Hauwert 2011 budget (Table 4), also would produce total long-term recharge volumes much greater than documented.

Because the long-term mean recharge and recharge contributed by the major streambeds is known, the long-term mean interstream recharge to the aquifer can be calculated and expressed as a percent of mean-annual precipitation on the recharge area. Table 4 documents recharge on the main channels as a percent of total recharge. Based on the 3 studies with such values, 70% represents the mean value for main channel recharge as a percent of total recharge. Therefore, 30% of total recharge occurs as interstream recharge. As documented earlier, the long-term mean discharge from the aquifer is 67 cubic feet per second, as is the long-term mean recharge. Therefore, interstream recharge calculates to be 20 cubic feet per second or 14,500 acre-feet per year. Interstream recharge thus represents 0.25 feet of depth over the recharge area of 90 square miles or 57,600 acres. Based on the mean-annual precipitation value of 33 inches (2.75 feet) per year over the recharge area, interstream recharge thus calculates to be 9% of precipitation. As Table 4 shows, 9% of interstream recharge as a percent of precipitation on the recharge area represents a value much less than those produced by Hauwert (2011) and Hauwert and Sharp (2014).

SUMMARY AND RECOMMENDATIONS

The Barton Springs segment of the Edwards Aquifer represents a small, relatively independent part of the aquifer. Data for the sources of recharge and especially for discharge from the aquifer are well documented. Based on the 2 water budgets that include documentation of surface recharge and surface discharge values (Slade 2014) and the one herein, the volumes match within 5%, which is within the potential error limits of the recharge and discharge values. Each budget includes only surface sources of recharge and discharge. However, each budget represents discharges slightly greater than long-term mean-flow conditions, during which time subsurface recharge to the aquifer likely is minimal or nonexistent. During some low-flow conditions, subsurface recharge enters the Barton Springs segment of the Edwards Aquifer from south of the segment boundary through discharge from the Blanco River watershed.

All streamflow gaging stations needed to conduct water budgets for present or future periods remain in operation except for the station on Bear Creek near Brodie Lane. That station, located near the downstream boundary of the recharge area, was discontinued on September 30, 2010. An alternative station that could be used to calculate recharge volumes for the Bear Creek Basin does not exist. Additionally, this basin is important for budget calculations because its recharge data are used to estimate recharge volumes for the adjacent Little Bear Creek Basin, which also is not gaged. Therefore, without a gaging station on Bear Creek downstream from the recharge area, water budgets for periods after September 2010 would potentially contain substantial errors.

Substantial urban development is occurring atop the Edwards Aquifer. About 60,000 people depend on the Barton Springs segment of this aquifer as their sole-source water supply. However, only 2 complete water budgets have been identified for the aquifer. Water budgets for future conditions should be complied and used to document changes in the sources and volumes of recharge and discharge. For example, as groundwater withdrawals increase, it is likely that groundwater levels would decrease and therefore cause groundwater gradients to increase toward the area of pumping from south of the Barton Springs segment. Such steeping of the gradient could induce additional and more frequent subsurface recharge from the Blanco River.

Much data are being collected and many studies are continuing to document the quality of surface and subsurface water within the aquifer boundaries. Additionally, the city of Austin, BSEACD, and many other governmental and private organizations are documenting, evaluating, and regulating specific land-use practices within the contributing and recharge areas in order to protect the water quality of the aquifer. However, if subsurface recharge increases from the Blanco River, the water quality of the river and adjacent aquifer should be assessed. Additionally, land-use practices within the Blanco River Basin would need to be monitored and evaluated as potential sources of contamination. However, the best documentation of the occurrence and distribution of recharge from the Blanco River would be obtained from water budget recharge-discharge analyses—analyses that unfortunately cannot be decisively conducted since October 2010 because of the discontinuance of the Bear Creek streamflow station.

SUPPLEMENTAL INFORMATION

Other discharges

From 1916 to 1930 many discharge measurements were made on the Colorado River immediately downstream from the Austin Dam (now Tom Miller Dam). For many of these measurements, near same-date measurements were made for Barton Springs discharge, and, during the period, the USGS operated a streamflow-gaging station on the Colorado River at Congress Avenue (Table 5). When Barton Creek was no-flow upstream from Barton Springs, the springs represented the only major source of water to the river reach between Tom Miller Dam and Congress Avenue. The only other major sources

Table 5. Discharge measurements made on the Colorado River along the contact between the river and the Edwards Aquifer.

	Measured discharge at site (cubic feet per second)			
Date	Below Austin Dam[1]	Barton Springs[2]	Streamflow gaging station at Congress Ave.[3]	Flow gain (+) or loss (-) in reach
Sep. 06, 1916	109	28.0	138	1.0
Aug. 22, 1917	53.4	15.0	68	-0.4
Aug. 24, 1917	45.3	15.4	60	-0.7
Aug. 28, 1917	39.2	14.3	52	-1.5
Aug. 21, 1918	10.2	14.0	24	-0.2
Aug. 22, 1918	9.1	14.0	25	1.9
Aug. 08, 1921	66	39.0	112	7.0
Aug. 13, 1930	18.9	24.0	45	2.1
Mean values		**20.5**		**1.2**

Measuring sites other than Barton Springs are on the Colorado River
[1] TBWE 1959
[2] TBWE 1959
[3] http://waterdata.usgs.gov/tx/nwis/nwisman/?site_no=08158000&agency_cd=USGS

represented discharge from Cold Springs, runoff from streams such as Shoal and Waller Creeks, and any discharges from the Edwards Aquifer to the river. In order to document the total discharge for the other sources, the sum of the same-date discharges for the river below the dam and Barton Springs was subtracted from the same-date discharge gaged at Congress Avenue. Selected dates represent those which occurred during relatively steady-state flow conditions, had discharges less than 150 cubic feet per second at Congress Avenue, and had no flow for Barton Creek upstream from Barton Springs. The potential error for gaged discharges is about 5%; discharges exceeding 150 cubic feet per second could have potential errors that adversely affect the values of the components of the budget.

The calculated gain in the river represents the discharge for Cold Springs plus stream runoff and discharges from the Edwards Aquifer to the river. As Table 5 documents, the gain is minor. In some cases a minor loss rather than gain in the reach is indicated, likely due to errors in the discharge measurements. The mean discharge gain for the 8 measurements is only 1.2 cubic feet per second, part of which could represent stream runoff. Therefore, based on the dates, the gain from the Edwards Aquifer is limited to a maximum of only 1.2 cubic feet per second. However, the mean discharge for Barton Springs for the measurement dates is only 20.5 cubic feet per second, which, based on springflow data from 1917 to 1982, is about 38% of its long-term mean discharge of 54 cubic feet per second as documented earlier. Therefore, the discharge for Cold Springs and any other Edwards springs likely is minimal during low-flow conditions for Barton Springs.

Recharge

Selected for analysis within the city of Austin (2009) report is all but one streamflow-gaging site with less than about 60% IC and located in or near the contributing area for the Edwards Aquifer (Figure 2). The gaging site designated as WBA was excluded because its is a civic center, which is not representative of typical urban development. Those sites within the recharge area were excluded from this analysis because some of the runoff would likely be lost as recharge thus not gaged as outflow from the basin. An upper limit for IC densities is used herein because the coefficient of determination between values of IC and RC substantially decreases for sites that include the full range in IC values. Additionally, the IC values for the contributing and recharge areas are less than 30% (Table 2). The relation between the IC densities and RC is presented in Figure 2 for the 8 sites that meet the criteria for inclusion. The equation for calculating the RC based on the IC value also is included in Figure 2. The coefficient of determination for the relation is 0.87.

An explanation for the use of urban runoff within the recharge volume calculation follows. The equation for calculating the runoff coefficient is RC = 0.47 (IC) + 0.05 as shown in Figure 2. For example, the contributing area for Slaughter Creek has an IC density of 7.41% (Table 2); based on the RC formula, the RC calculates to be 8.5% of precipitation for the contributing area. The IC density for the recharge area is 11.5%; based on the RC formula, the RC calculates to be 10.4% of precipitation. Therefore, the RC for the recharge area exceeds that for the contributing area by 1.9%. In order to estimate runoff from the recharge area, the unit value (runoff per square mile) from the contributing area thus was multiplied by 1.019 and then multiplied by the drainage area for the recharge area.

However, for calculating the increase in RC (from the contributing area to the recharge area) based on the increase in IC, the formula offset of 0.05 would not be applicable. Therefore, the formula becomes $\Delta RC = 0.47 (\Delta IC)$, where ΔRC represents the increase in RC and ΔIC represents the increase in IC density. Based on the example for Slaughter Creek in the previous paragraph, the recharge area has an IC density about 4.1% greater than that for the contributing area. Therefore, based on the ΔRC formula, the RC for the recharge area calculates to be 1.9% greater than that for the contributing area.

For the contributing and recharge areas, the largest difference between IC values exists for Barton Creek; the recharge area has an IC density that exceeds that of the contributing area by 17.5% (Table 2). However, Little Barton Creek is a tributary to Barton Creek, thus with the inclusion of Little Barton Creek, the IC density for the entire Barton Creek contributing area calculates to be 4.8%, which is 17.3% less than that in the recharge area. For each of the Bear, Little Bear, and Onion Creek basins, the IC densities for the contributing and recharge areas are comparable; thus no IC adjustment was made for recharge calculations for those basins.

The recharge calculation adjustment is based on the IC density values for the year 2003. A later (2006) documentation of IC densities for the basins was provided by Erin Wood (City of Austin, written commun.). However, for the 2006 documentation, the IC densities are aggregated by total basin area and do not include separate density values for the contributing areas or recharge areas. For the entire basins, increases in the IC densities from 2003 to 2006 are as follows: Barton Creek (0%); Williamson Creek (3%); Slaughter Creek (3%); Bear Creek (1%); Little Bear Creek (0%); and Onion creek (2%). Based on these minimal increases in IC densities for each of the entire basins, it is likely, for each basin, that differences in IC densities between the contributing and recharge areas had minimal if any changes from 2003 to 2006. It is also likely that the IC differences had minimal if any changes from 2006 to the end of the budget period in 2009. Therefore, the difference between IC densities between the contributing and recharge areas as used herein are believed to represent that for the entire budget period.

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Modeling bacterial load scenarios in a Texas coastal watershed to support decision-making for improving water quality

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Abstract: The planning for improved health of a stream can be optimized by assessing the watershed system as a whole; state and federal agencies have embraced this watershed approach for managing water quality (USEPA 2008). Using the watershed approach, bacteria loads in the Double Bayou watershed were modeled to identify critical loading areas and develop appropriate voluntary management measures as part of a watershed protection plan. The Spatially Explicit Load Enrichment Calculation Tool (SELECT) model was developed by the Department of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University to estimate potential pollutant loadings from fecal indicator bacteria. For this study, SELECT modeling was performed to estimate bacterial loadings from the distribution of livestock, wildlife, a wastewater treatment facility, and on-site sewage facilities. Rankings of each contributing source were assessed for the entire watershed. The objective of this study was to analyze the success of using SELECT to evaluate bacteria loads in a rural coastal watershed; results showed SELECT was successful in the Double Bayou watershed in ranking categories of bacteria sources and revealing spatial load aggregations. This analysis guides discussion on the prioritization of management measures to improve water quality in the Double Bayou watershed.

Keywords: bacteria, bacterial load modeling, watersheds, water quality

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Terms used in paper

Short name or acronym	Descriptive name
AU	Animal unit
BST	Bacterial source tracking
C-CAP	Coastal Change Analysis Program
CFU	Colony forming units
GPD	Gallons per day
MGD	Million gallons per day
OSSFs	On-site sewage facilities
RMU	Resource management unit
SELECT	Spatially Explicit Load Enrichment Calculation Tool
TCEQ	Texas Commission on Envrionmental Quality
USDA	U.S. Department of Agriculture
USEPA	U.S. Envrionmental Protection Agency
WPP	Watershed protection plan
WWTF	Wastewater treatment facility

INTRODUCTION

The planning for improved water quality can be optimized by assessing the watershed system as a whole (Flotemersch et al. 2015). State and federal water resource management and environmental protection agencies have embraced the watershed approach for managing water quality (USEPA 2008). In Texas, the Texas Commission on Environmental Quality (TCEQ) manages programs to prevent and abate urban nonpoint source pollution and the Texas State Soil and Water Conservation Board manages programs to prevent and abate agriculture/silvicultural nonpoint source pollution. The TCEQ is charged with managing the quality of Texas' water bodies and water resources, including establishing the state's surface water quality standards and setting the surface water quality criteria.

Management plans in the form of regulatory total maximum daily loads or nonregulatory watershed protection plans (WPPs) are necessary tools to develop tailored best management practices for specific watersheds. Due to their nonregulatory holistic approach, WPPs are increasingly favored across Texas. The watershed approach is successful because watershed stakeholders bring together their collective knowledge and experience to preserve, protect, and improve water quality. The result is a collection of watershed-specific plans that can serve as a framework for regional water quality improvement and guidance for watershed management.

Pathogens are the most common source of water body impairments in the state. In 2014, Texas had 508 water body segments listed as impaired; of those, 346 (68%) were listed as impaired for contact recreation due to elevated levels of bacteria (TCEQ 2014). To develop a WPP that contains specifications for the technical and financial framework designed to reduce water quality impairments due to pathogens, bacteria source contributions must be characterized and understood at the watershed scale.

Due to the complex and resource-intensive approach of monitoring and identifying individual pathogens in the environment, fecal indicator bacteria are utilized to estimate the level of potential health risk from fecal contamination (Field and Samadpour 2007). According to the U.S. Environmental Protection Agency (USEPA), Enterococci are the preferred indicator bacterium to determine the level of health risk of fecal contamination in estuarine and tidal waters used for recreation, while *E. coli* are most commonly utilized to assess nontidal waterways (USEPA 2012). Indicator bacteria are an effective alternative monitoring strategy because they are enteric in nature, residing in the gastrointestinal tract of warm-blooded animals, and therefore are capable of alerting resource managers that associated harmful pathogens are present in the environment (Katouli 2010; Pandey et al. 2014). Although monitoring water quality for bacteria can quantify presence, it does not indicate the source or location of potential contributors.

Fecal waste can be introduced through a variety of pathways: directly to surface waters from wastewater treatment facility effluents, sanitary sewer overflows, and boater waste discharge events; indirectly from stormwater runoff containing pet, wildlife, and agricultural waste; and from leaking on-site septic systems (Perkins et al. 2014). Bacterial source tracking (BST) can help identify possible source categories, but the high cost of the practice compared to the limited information the results provide make it impractical to implement for many WPPs. Therefore, models that can characterize and rank source-specific bacterial loads such as the Spatially Explicit Load Enrichment Calculation Tool (SELECT) are utilized to assist with the development of watershed-specific best management practices (Teague et al. 2009).

This discussion focuses on SELECT methodology used to rank and spatially aggregate source-specific bacterial loads for the Double Bayou WPP. SELECT was developed by the Department of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University (Riebschleager et al. 2012). SELECT has been successfully used to estimate bacteria loads in other Texas watersheds, including the inland rural watersheds of Buck Creek, Little Brazos River, and Lampasas River; the readily developing mixed land-use Plum Creek watershed, the coastal mixed land-use transitional Cedar Bayou watershed, and the coastal rural Mission River and Aransas River watersheds (Borel et al. 2012a; Borel et al. 2015). The Double Bayou watershed SELECT analysis provides a case study showing that SELECT can successfully be applied in rural coastal watersheds with limited historical water quality and flow data.

STUDY WATERSHED

The Double Bayou watershed is located in the upper Texas Gulf Coast on the eastern shore of Trinity Bay predominantly in Chambers County, Texas. The primary waterways in the watershed are the East Fork Double Bayou and the West Fork Double Bayou. The watershed drains 62,764 acres of predominantly rural and agricultural land directly into the Trinity Bay system and ultimately into Galveston Bay. The most abundant land-use/land-cover class is pasture/hay (34,853 acres) followed by cultivated crops (12,993 acres). There are several residential centers located in the watershed. The city of Anahuac, Texas is located on the Trinity River and the northeast bank of Trinity Bay and has a total area of 1,277 acres. This rural community is the largest area of developed land in the watershed. Half of the unincorporated community of Oak Island is located in the Double Bayou watershed. Double Bayou, a third smaller community in the watershed is located in proximity to the East Fork.

The East Fork of Double Bayou originates in Liberty County (Figure 1) and follows a relatively straight channel southwest toward Trinity Bay for a total of 43 kilometers. The West Fork of Double Bayou is approximately 22 kilometers and is characterized by a meandering channel. The lower portions of the bayous are tidally influenced. The 2 bayous form a 400-meter confluence before joining Trinity Bay at Oak Island, Texas. Trinity Bay is 78,720 acres and is designated as unclassified oyster waters and as a classified estuary.

Both East Fork Double Bayou and West Fork Double Bayou are listed as impaired for contact recreation on the 2014 Texas Integrated Report for elevated levels of bacteria (TCEQ 2014). This study is the first bacteria load monitoring or modeling performed for the watershed, outside of the TCEQ's routine surface water quality monitoring. To effectively plan for mitigation, the bacteria source contribution and fate and transport processes must be characterized and understood at the watershed scale. Possible contributing sources of bacteria in the Double Bayou watershed include leaking septic systems, sanitary sewer overflows, cattle, horses, deer, feral hogs, and goats. The bacteria impairments of Double Bayou could economically dampen one of the last remaining rural watersheds in the Houston-Galveston region. In addition, the bayou system drains into Trinity Bay, just up-current from the largest oyster harvesting operation in Texas.

METHODOLOGY

SELECT modeling for the Double Bayou watershed was performed to estimate bacterial loadings from point and nonpoint sources to identify critical loading areas within the watershed. SELECT Version 1 was used for the Double Bayou watershed modeling. SELECT data inputs included land-use, location and numbers of bacterial sources, bacterial productions rates and population estimates. All model inputs and results were discussed with stakeholders and outputs were assessed for management measure implementations.

Using the ArcHydro model (a component of ArcGIS), the Double Bayou watershed was delineated into 22 subwatersheds (Figure 1). The ArcHydro model incorporates elevation and hydrological characteristics into a watershed delineation process. The results of the SELECT model are individual 30-meter grid cell raster files for each identified bacterial source. The raster files were added together spatially to create a total load raster for the entire watershed. Units for the SELECT analysis are discussed in *E. coli* concentrations, colony forming units (cfu); note, however, water quality analysis results will use appropriate *E. coli* (nontidal) or Enterococci (tidal) cfu, depending on the location in watershed.

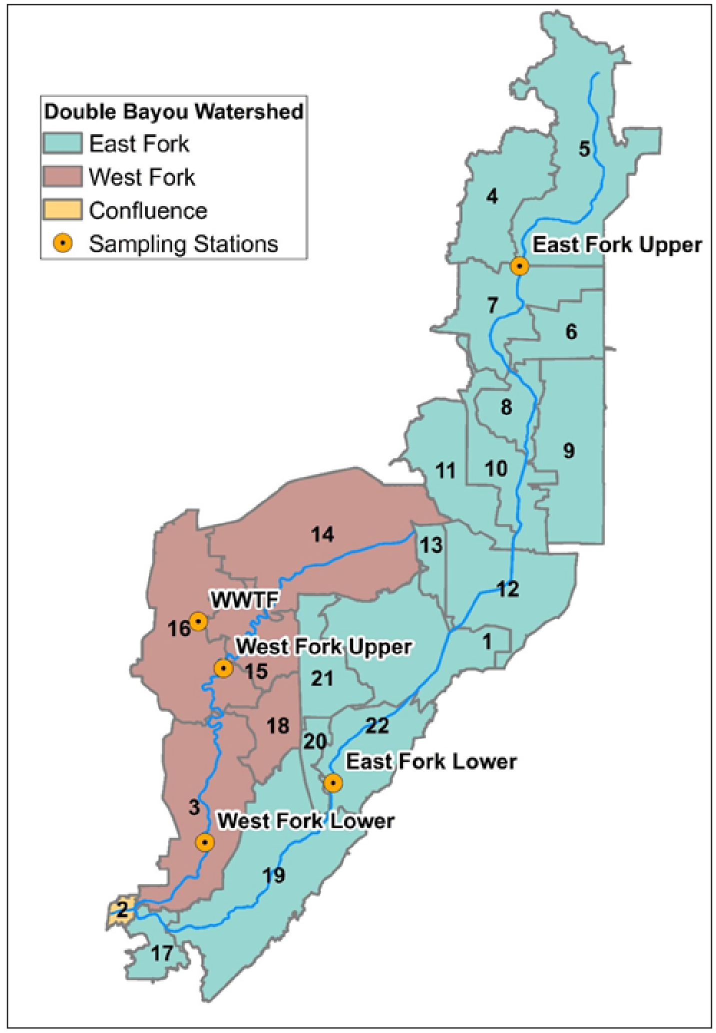

Figure 1. Double Bayou watershed in Texas.

Land use is a critical SELECT input and analysis was completed by using 2010 NOAA Coastal Change Analysis Program (C-CAP) land-cover data based upon 30-meter Landsat imagery. To increase model accuracy, stakeholder input was used as local knowledge to better define land-cover inputs because they were aware of recent land-use changes (i.e. changing of farm to ranch land or new developments). Land-cover categories used as inputs for SELECT reflect an aggregation of the 22 types of land-use classes available in the 2010 C-CAP data. These 22 land-cover classes were distilled into 7: Grassland/Pasture, Cultivated Crops, Mixed Forest/Forested Wetland, Developed, Water, Marsh/Emergent Wetland, and Scrub/Shrub Variety (Figure 2). Furthermore, stakeholders recognized that certain Grassland/Pasture areas were strictly hay (unfenced, cannot hold livestock) and some Scrub/Shrub land was left without cattle. These land classes were removed from SELECT modeled land-cover inputs.

The land cover is considered a "snapshot" of land use in

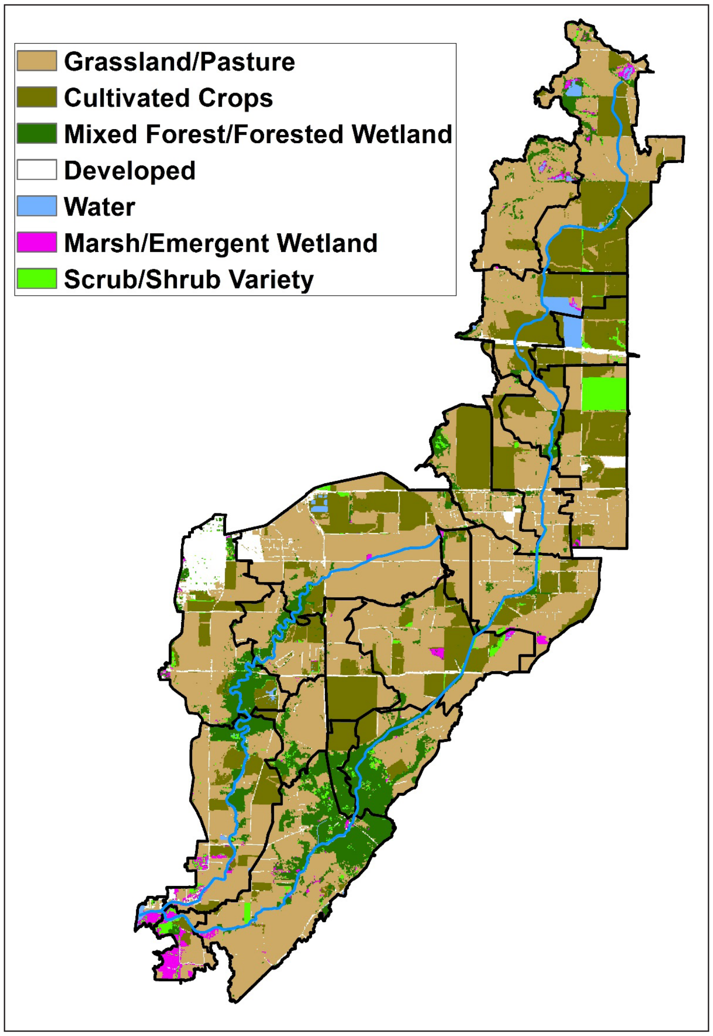

Figure 2. Land cover in the Double Bayou watershed.

the watershed. Agriculture practices are dynamic and may vary depending on the growing season, weather, and livestock grazing requirements. These changing practices may shift the distribution of the associated nonpoint source pollutants to different locations within the watershed from year to year. For example, rice crops may be rotated to different fields and then alternated with other agricultural crops, cattle, or left fallow. The alternating fields typically remain in the same subwatershed. However, the overall number of cattle and acres of crop land in the watershed do not change significantly even when they are rotated between subwatersheds, so this would not greatly impact the overall load contribution.

SELECT was used to generate high, mid, and low bacteria loading scenarios according to the range of loading parameters decided upon by the stakeholders. This sensitivity analysis accommodated a range of scenarios and provided insight on the approximate range of potential load from a given source. High and low scenarios were developed for sources that had variable population inputs; on-site sewage facilities (OSSFs) (malfunction rate of system), cattle (stocking density), and feral hogs (population density). High, medium and low scenarios were generated for the wastewater treatment facility (WWTF). Single scenarios were generated for horse, goat, and deer sources because their population assumptions were based upon fixed values. Stakeholders decided to use high loading scenarios for all possible sources to determine priority and placement of management measures.

Modifications to certain SELECT data inputs were implemented with stakeholder feedback to achieve a more accurate model taking into account data availability and specific characteristics of the watershed (similar types of data input modifications were suggested in Borel et al. 2012b). For example, feral hogs were evaluated as SELECT inputs at 2 different densities since stakeholder input reflected that feral hogs have a high potential to utilize most land classes in the watershed. In addition, the WWTF SELECT input was modified by water quality monitoring results. The effluent quality and flow rate of the WWTF was monitored at the point of release to formulate SELECT input for the WWTF (except for the mid-range scenario, which is based on permitted bacteria and flow rates). Based on these assumptions, SELECT generated an estimated maximum loading for the WWTF under a high rain event scenario.

Water quality monitoring was conducted as part of the Double Bayou Watershed Protection Plan development process under an USEPA-approved Quality Assurance Protection Plan. Routine water quality monitoring dates were scheduled to measure ambient water quality conditions. Targeted water quality monitoring was conducted during rain events to measure water quality conditions during high flow events. Water quality monitoring stations were located on both bayous (Figure 1) (marked as WWTF, West Fork Upper, West Fork Lower, East Fork Upper, and East Fork Lower). Over a 20-month sampling period (October 2013 through June 2015), a total of 194 water quality samples were collected during 39 sampling days (38 at the WWTF station).

POTENTIAL BACTERIAL SOURCES AND LOAD ESTIMATION IN THE DOUBLE BAYOU WATERSHED

To identify the various sources of bacteria pollution, stakeholders discussed all possible primary point and nonpoint source contributors with known quantifiable bacteria source excretion rates and population inputs for SELECT analysis. The remainder of this section is dedicated to the discussion of source variables and loading rates for each bacterial source.

Deer

Due to data restraints, the only native wildlife analyzed with SELECT was deer. Although other wildlife, such as migratory birds or raccoons, are likely contributors to bacterial loads in the watershed, their potential bacteria contributions and population dynamics are unknown. A total deer population estimate was based on the Texas Parks and Wildlife Department's deer density for Resource Management Unit 13 (RMU 13), where Double Bayou watershed is located. RMU 13 has an average estimated deer density of 5.15 deer/1,000 acres, with a 95% confidence interval of 2.2-12.3 deer/1,000 acres. Stakeholders agreed that the average estimated deer density provided a reasonable assumption. The mixed forest/forested wetland land class was determined to be the only land class suitable for deer (Figure 2). The population estimate of 5.15 deer/1,000 acres was applied to the 6,321 acres of suitable habitat generating a total watershed deer population of 33 animals.

The average potential cfu per daily *E. coli* load was estimated for each subwatershed as

$$Deer\ Load\ =\ \#\ Deer * 3.5x10^{8}\ cfu/day * 0.63,$$

where 3.5* cfu/day *0.63 (*E. coli* conversion factor) is the average daily *E. coli* production per deer (USEPA 2001).

Feral hogs

There are no direct measurements of feral hog density in Texas. However, several studies estimate feral hog densities depending on land use and location. For the Double Bayou watershed project, an estimated maximum feral hog density of 33.3 acres per hog and a minimum density of 50.7 acres per hog was applied (Borel et al. 2012c; Timmons et al. 2012). The SELECT scenario applied 33.3 acres per feral hog to the land-cover categories of Grassland/Pasture, Scrub/Shrub Variety, Mixed Forest/Forested Wetland, and Cultivated Crops, plus a 100-meter buffer zone from any water source, including flooded rice fields. A density of 50.7 acres per hog was applied to the remaining watershed land-cover categories. Based on these rates, the feral hog population was estimated to be 1,519 hogs.

The average potential daily *E. coli* load for each subwatershed was estimated by

$$Feral\ Hog\ Load\ =\ \#\ Hogs * 1.1x10^{10}\ cfu/day * 0.63,$$

where $1.1*10^{10}$ cfu/day *0.63 (*E. coli* conversion factor) is the average daily *E. coli* production per pig (used as a proxy for feral hog) (USEPA 2001).

Cattle

Most cattle operations within the watershed are cow-calf. There are no confined animal feeding operations. The SELECT land-cover input categories for cattle are grassland/pasture and scrub/shrub. An animal unit (AU) is a standardized unit of measure used for agricultural planning. One AU is equivalent to 1 adult cow and a nursing calf. Using local knowledge of the watershed, stakeholders generated estimated stocking rates of 1 ac/AU, 7-8 ac/AU, 9 ac/AU, and 12-15 ac/AU, and spatially allocated the densities to appropriate sections of the watershed. The total number of cattle was calculated based on these stocking rates. The total estimate of cattle in the watershed was determined to be 4,074 AUs. This stakeholder estimate of cattle population compared favorably with county estimates from the U.S. Department of Agriculture (USDA) Census of Agriculture (USDA 2012).

The average potential daily *E. coli* load for each subwatershed was estimated by

$$Cattle\ Load\ =\ \#\ Cattle * 1x10^{10}\ cfu/day * 0.63,$$

where $1*10^{10}$ cfu/day *0.63 (*E. coli* conversion factor) is the SELECT model default average daily *E. coli* production per head of cattle (USEPA 2001).

Horses

The bacteria nonpoint source contributions from horses were modeled based on an estimated population of 294 horses in the Double Bayou watershed. This estimate came from the 2012 Census of Agriculture, the percent of suitable land in watershed/county and input from the stakeholder workgroup (USDA 2012). The land-cover categories for horses were determined to be the same as cattle (grassland/pasture and scrub/shrub). Stakeholders noted that in Double Bayou, horses are typically used to support cattle ranching operations and are spread out over the watershed (not concentrated for agricultural production).

The average potential daily *E. coli* load for each subwatershed was estimated by

$$Horse\ Load = \#\ Horse * 4.2x10^{8}\ cfu/day * 0.63,$$

where $4.2*10^{8}$ cfu/day *0.63 (*E. coli* conversion factor) is the average daily *E. coli* production per horse (USEPA 2001).

Goats

Stakeholders stated that goats are not used for agricultural production but are kept by some landowners for subsistence use. Based on Texas Agricultural Statistics, 11 goats were identified in the Liberty County portion of the watershed. According to the Texas Agricultural Statistics, there were no goats in Chambers County at the time of this study. However, stakeholders determined that an estimated 200 goats existed in the Chambers County portion of the watershed. A population of 211 goats was determined to be a reasonable watershed estimate. The bacterial loading rate for sheep of $1.2*10^{10}$ cfu per sheep per day was used as a proxy for goats because no SELECT bacterial loading rate for goats is available (Borel et al. 2012a).

The average potential daily *E. coli* load for each subwatershed was estimated by

$$Goat\ Load\ =\ \#\ Goat * 1.2x10^{10}\ cfu/day * 0.63,$$

where $1.2*10^{10}$ cfu/day *0.63 (*E. coli* conversion factor) is the average daily *E. coli* production per sheep (known goat SELECT loading rate is not available) (USEPA 2001).

Wastewater treatment facility

The Anahuac WWTF was identified by the stakeholders as a potential point source of bacteria in the watershed. Because the Anahuac WWTF is a point source, the bacteria contributions are from a fixed location and can be allocated to 1 subwatershed. The maximum potential *E. coli* loading rate of 49,000 cfu/100 mL and the approximate daily maximum flow of 1,000,000 MGD (million gallons per day) were used as SELECT model inputs to generate the high scenario for the facility. The maximum potential *E. coli* loading rate is based on the highest recorded wet weather (rain event) bacteria sample collected at the outfall of the WWTF and the daily maximum flow from the USEPA's Enforcement and Compliance History Online database.

The average potential daily *E. coli* load was estimated by

$$WWTF\ Maximum\ Load = \frac{49{,}000\ cfu}{100\ mL} * \frac{3{,}785\ mL}{gallon} * 1{,}000{,}000\ GPD.$$

On-site sewage facilities

Locations of 91 of the estimated 465 OSSFs in the watershed were obtained from Houston-Galveston Area Council's OSSF database. Additional OSSF locations were identified by stakeholders who have in-depth local knowledge. The identified systems were then overlaid and filtered to eliminate the possibility of double counting OSSFs. The majority of identified OSSFs were found to be distributed in subwatersheds 19 and 20 to the southeast and subwatersheds 16 and 14 to the northwest. The SELECT model considers the effectiveness of OSSFs based on soil type (different types of soils have different rates of wastewater absorption), the age of the system, and the estimated failure rate. The clay, clay loam, or sandy clay loam soils of the watershed have a low capacity for absorption, which means effluent from the septic tank cannot be effectively treated by soil microorganisms.

Table 1. SELECT results: potential contribution to bacterial load by source.

Source	cfu/day
Cattle	2.7E+13
Feral Hog	1.1E+13
WWTF	1.9E+12
Goat	2.4E+11
Horse	7.8E+10
OSSF	1.2E+10
Deer	7.2E+09
Total	**4E+13**

To establish SELECT OSSF inputs, stakeholders discussed and generated system age, based on a neighborhood-by-neighborhood analysis. The age ranges established for OSSFs were: 0-15 years old, 16-30 years old, and greater than 31 years old. The OSSF stakeholder workgroup assigned approximate malfunction rates to systems, based on age and known failure rates. A failure rate of 10% was applied to the 0-15 age group; 30% to the 16-30 age groups; and a 50% failure rate was applied to the 31+ age group. A U.S. Census average of 2.4 people per household was used.

The average potential daily *E. coli* load for each subwatershed was estimated by

$$Septic\ Load = OSSFs * Malfunction\ Rate * \frac{10x10^6\ cfu}{100\ mL} * \frac{60gal}{\frac{person}{day}} * 0.63.$$

RESULTS AND DISCUSSION

In the Double Bayou watershed, the SELECT analysis indicated that each of the 22 subwatersheds has the potential to contribute total daily bacterial loads ranging from 5.4E+10 to 5.4E+12 cfu/day (Figure 3). Of the total potential bacteria contributions, cattle was the leading source category followed by feral hogs, the WWTF, goats, horses, OSSFs, and deer. The 2 highest ranked categories of cattle and feral hogs contribute 95% of the total potential daily bacteria load in the Double Bayou watershed (Table 1). The ratio of potential daily contribution to bacterial load for the sources goat, horse, OSSFs,

Table 2. Bacteria geometric means for samples collected bi-monthly from October 2013 through June 2015.

Nontidal, *E. coli*, geometric mean criterion 126 cfu/100 mL		**Tidal, Enterococci, geometric mean criterion 35 cfu/100mL**		
WWTF	East Fork Upper	East Fork Lower	West Fork Upper	West Fork Lower
5 cfu/100 mL	94 cfu/100 mL	72 cfu/100 mL	123 cfu/100 mL	78 cfu/100 mL

and deer were a smaller magnitude; they are not visible in the subwatershed's ratio of total potential load (Figure 3). SELECT determined subwatersheds 14, 16, 5, 19, and 1, in that order, to be the subwatersheds with the highest potential total daily load contributions although the source ratios within each subwatershed vary. However, cattle and feral hogs are consistently the 2 leading source contribution categories in all subwatersheds except in subwatershed 16 where the WWTF is located (Figure 3).

Table 2 contains the bacteria geometric means calculated for water quality samples collected during the project. TCEQ uses criteria based on the geometric mean to indicate impairments for recreational uses of water bodies due to bacteria levels; the geometric mean criterion for *E. coli* is 126 cfu/100 mL while the geometric mean criterion for Enterococci is 35 cfu/100 mL (TCEQ 2014). All 3 Double Bayou tidal monitoring stations exceeded the criteria; of the 3 tidal stations, the West Fork Upper station had the highest geometric mean, while the East Fork Lower station had the lowest. The East Fork Upper station did not exceed the geometric mean criterion and the WWTF station had a geometric mean significantly lower.

Only routine ambient water quality samples are used to calculate bacteria geometric means; targeted samples, collected during rain events, resulted in higher bacteria levels. Rain events can cause greater amounts of bacteria to be transported from the land to the bayou in associated surface runoff. The stations with the highest magnitude of bacteria geometric means spatially correspond to the subwatersheds with the highest potential contribution load as determined by SELECT (Figure 1). Subwatersheds 14 and 16 were determined to have the highest potential contribution load, and West Fork Upper had the highest bacteria geometric mean sampling results. The results of the water quality sampling support the potential contribution load results of SELECT.

As discussed in the Introduction, SELECT has been previously successful in estimating bacterial loads in Texas watersheds. Previous studies that used SELECT analysis in rural and mixed land use Texas watersheds confirms that cattle are the leading contributor to bacteria impairments followed by other livestock (horses, goats, and sheep) (Borel et al. 2012a; Borel et al. 2015). The SELECT results generated for the Double Bayou watershed support the assumption that cattle are the leading contributor to bacteria impairments in rural watersheds. However, the remaining livestock categories (horses, goats, and sheep), which are found to be high contributors for these previous studies, were shown to have a low degree of contribution in the Double Bayou watershed (sheep were not included for analysis because stakeholders determined that a substantial population was not present). For Double Bayou, feral hogs were ranked as the second leading contributors of bacteria.

Analysis of the feral hog SELECT category across Texas watersheds where SELECT has been applied indicates that feral hogs are typically ranked toward the bottom of bacteria

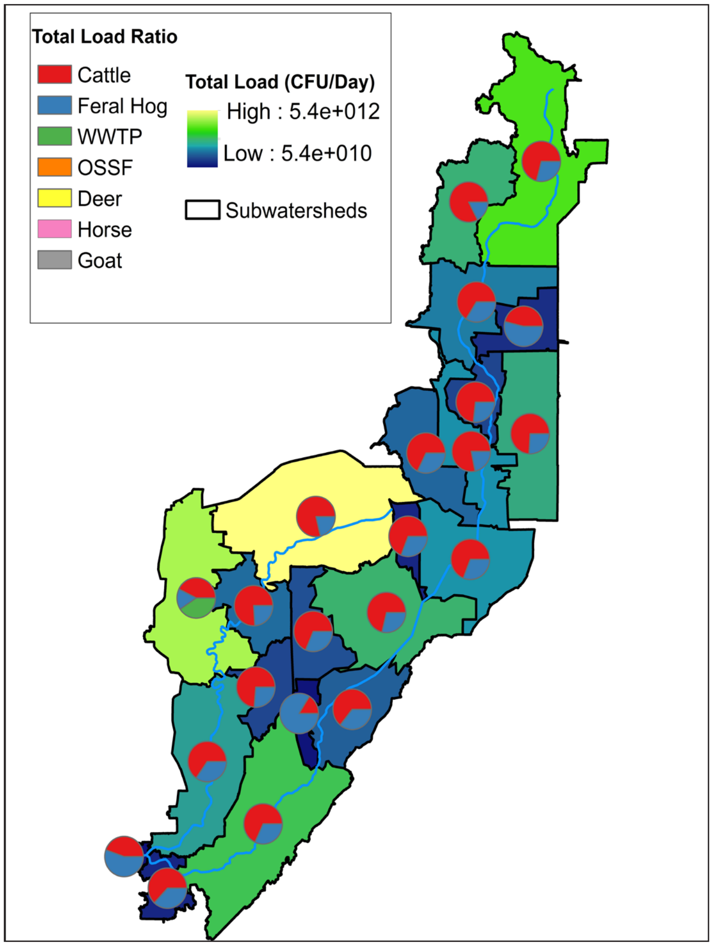

Figure 3. Double Bayou Load Contribution by subwatershed. (Note that all sources were used in the total load calculations, but that the percent contribution of the total load for deer, OSSFs, goat and horse were a minor portion of the overall load and therefore are not visible in the contribution pie charts)

source categories, even in rural watersheds. This distinction between current literature and the use of SELECT in Double Bayou reflects the degree of influence that stakeholders' collective experiences have over the SELECT and watershed protection planning process. In the Double Bayou SELECT analysis, stakeholders familiar with the habits of feral hogs in their watershed determined that feral hogs should be evaluated at a higher density per acre on preferred land-cover classes plus a 100-meter buffer zone from any water source, including flooded rice fields. As a result of the analysis in Double Bayou, feral hog management will be a focus of implementation across the watershed and will likely have lasting effects toward improving instream bacteria concentrations.

The WWTF analysis for Double Bayou used mid- and low-range scenarios to represent permitted and average ambient conditions, respectively. Previous SELECT studies have used only 1 input for the WWTF analysis (Borel et al. 2012a; Borel et al. 2015). By monitoring effluent quality at the point of release, more accurate SELECT scenarios were generated because SELECT assumptions have traditionally been based on the maximum permitted discharge and criterion for the maximum allowable bacteria concentration in the facilities' effluent, which may not represent actual conditions. Stakeholders wanted to plan for the worst case, so the maximum scenario was used for analysis. However, the low scenario, which assumes the WWTF effluent contains a minimal concentration of *E. coli* (3.51 cfu/100 mL) and releases at a flow rate of 300,000 GPD, is likely the best representation of average ambient contributions.

In recent years, BST studies in rural watersheds with similar characteristics to the Double Bayou watershed have concluded average instream bacteria contributions can be attributed to 55% wildlife, 21% domestic livestock, 16% unidentified, and 8% human source categories (averaged BST results from the Buck Creek, Little Brazos River, and Big Cypress Creek watersheds) (Giovanni et al. 2013). These results attribute a larger proportion of instream bacteria to wildlife than earlier studies indicated. The wildlife category from these BST studies includes bacteria contributions from feral hogs. These findings support the Double Bayou SELECT results that determined feral hogs as a major potential bacteria source (Table 1). Had the full contribution of wildlife inputs been available for inclusion to SELECT, the potential wildlife and feral hog load would be much higher. Many of the management measures implemented in the watershed to control bacteria inputs from livestock and overland flow can also reduce bacteria contributions from feral hogs and native wildlife. A BST study specific to the Double Bayou watershed could further validate the SELECT results and guide adaptive governance during the implementation phase.

SELECT could be strengthened by adding the capability to analyze direct or near stream deposition of fecal waste by livestock and wildlife (including *Sus scrofa*). Direct deposition is the most concentrated delivery mechanism of bacteria to instream water quality. For example, the amount of bacteria cattle may contribute to the bayou (Larsen et al. 1988) correlates with the stocking rate of the adjacent land, distance from the bayou, and the amount of time cattle spend near or in the bayou. In Larsen et al. 1988, a manure deposition distance of 0.61 meters and 2.1 meters from a stream showed an 83% and 95% reduction of bacteria compared to fecal waste that is directly deposited into the stream (Larsen et al. 1988). Providing cattle with alternative water sources has been shown (Wagner et al. 2013) to reduce the overall loading rate from $1.11*10^7$ cfu/day to $6.34*10^6$ cfu/day (Larsen et al. 1988). The amount of time cattle spent instream was also reduced by 43% with the provision of alternative water sources.

SELECT model analysis could be strengthened with additional analysis on environmental fate and transport mechanisms. Inputs of death and decay rates, differences of absorptive capacity between native and invasive riparian vegetation, and the inclusion of varying meteorological conditions such as precipitation and UV radiation would allow the SELECT model to better predict instream bacteria source contributions. However, the current edition of the SELECT model weighs the input-benefit analysis with the goal of the model outcome and has the added benefit of requiring limited data. The inclusion of the above variables would lead to a data and resource intensive modeling process that could provide insight on important fate and transport mechanisms but would also be more costly and time-consuming, limiting the use in the development of stakeholder driven WPPs.

CONCLUSIONS

The primary objective of SELECT analysis is to rank categories of bacteria sources and reveal spatial aggregations to provide stakeholders information to improve their local waterways; in this capacity, SELECT was successful in the Double Bayou watershed. A total estimated load scenario was created for analysis by summing SELECT results for potential bacterial loads from 22 Double Bayou subwatersheds. Since data were not available for all potential source contributors, such as a variety of specific wildlife sources, the SELECT model results did not reflect the entire suite of the Double Bayou watershed's potential bacterial load contributors, but it provided comprehensive bacteria spatial patterns from the available data.

The SELECT model results determined that feral hogs and cattle were the largest sources of potential contributors. Results indicated that the majority of cattle source loads can be attributed to subwatersheds that are predominately grassland/pasture and that feral hog densities were determined to be highest in riparian forested wetlands. The analysis can help guide discussion on the prioritization of management measures that result in the greatest reduction of bacteria. To have the greatest impact, management measures can be prioritized to subwatersheds with the highest potential daily bacterial loads as well as focused specifically on the range of sources identified as the largest potential contributors.

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Commentary: 85th Texas State Legislature: summaries of water-related legislative action

Editor-in-Chief's Note: September 1 of every odd-numbered year is the date when new legislation from the most recent session of the Texas Legislature typically goes into effect. With this in mind, the Texas Water Journal invited four organizations that work closely with the Texas Legislature to provide their take on the changes to Texas water policy and law that were made during the 2017 session. The opinions expressed in these summaries are the opinions of the individual organizations and not the opinions of the Texas Water Journal or the Texas Water Resources Institute.

Organizations:

- Texas Water Conservation Association
- Sierra Club, Lone Star Chapter
- Texas Water Infrastructure Network
- Texas Alliance of Groundwater Districts

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Terms used in paper

Short name or acronym	Descriptive name
ASR	aquifer storage and recovery
DFC(s)	desired future condition(s)
GCD(s)	groundwater conservation district(s)
GMA(s)	groundwater management area(s)
HB	House Bill
HNRC	House Natural Resources Committee
RFQ	request for qualifications
RFP	request for proposals
SWIFT	State Water Implementation Fund for Texas
SWIRFT	State Water Implementation Revenue Fund for Texas
SB	Senate Bill
SAWRAC	Senate Committee on Agriculture, Water and Rural Affairs
TAGD	Texas Alliance of Groundwater Districts
TCEQ	Texas Commission on Environmental Quality
TWCA	Texas Water Conservation Association
TWDB	Texas Water Development Board
TxWIN	Texas Water Infrastructure Network
WAMs	water availability models
TERS	total estimated recoverable storage

TEXAS WATER CONSERVATION ASSOCIATION 85TH LEGISLATIVE SESSION WRAP-UP

By Stacey Allison Steinbach, Texas Water Conservation Association

Ask any legislator, staffer, or lobbyist, and they will tell you the 85th Legislative session was one like no other. And though most in the political sphere say that at the end of every session, this year it is true. In 2017, legislators filed 6,631 bills, second only to the 2009 session. And just 1,211 of those bills passed both chambers by sine die. Governor Greg Abbott then vetoed 51 bills, the most vetoes by a governor in more than a decade. The 17.5% bill passage rate is also the lowest seen in more than a decade, attributable in large part to political disagreements between the chambers and delays in processing legislation.

The 85th was also unusual in that water legislation did not draw a great deal of attention among legislators and the media. It may be that the state's wet years since the 2011 drought have caused policymakers to focus on other issues. This year, the spotlight was on tax reform, social issues, and school matters. And it still is—the Governor called a special session to continue legislative efforts on these fronts.

As in past sessions, the Texas Water Conservation Association (TWCA) closely tracked bills of possible interest to its members. TWCA staff followed nearly 450 bills in 2017, designating more than a third of those bills as high-priority. Fewer than 20% of those bills will became law. Summaries for the most significant bills are provided below.

TWCA Groundwater Committee

TWCA's longstanding Groundwater Committee, chaired by Hope Wells of the San Antonio Water System and Brian Sledge, an attorney in private practice, reached consensus on 11 groundwater-related legislative proposals in advance of the 85th Legislature. Ten of those bills were filed, five were sent to the Governor, and four are now law or will be effective on September 1. It is interesting to note that these four bills are the only bills to amend Chapter 36 of the Texas Water Code (relating to groundwater conservation districts) this session:

House Bill (HB) 2215: Desired Future Condition (DFC) Adoption Dates (Price/Miles)

This bill amends the deadlines for proposing and adopting DFCs by groundwater conservation districts (GCDs) to best align the process with the state water planning process. Groundwater management areas must now propose DFCs for adoption by May 1, 2021, adopt them by January 5, 2022, and repeat the process every five years thereafter.

Senate Bill (SB) 864: Use of Groundwater in Conjunction with a Water Right (Perry/King)

This bill amends Chapter 11 of the Water Code to require special notice when an applicant for a surface water right at the Texas Commission on Environmental Quality (TCEQ) proposes to use groundwater from a well located within a GCD as an alternative source of water. This bill also came through TWCA's Surface Water Committee.

SB 865: GCDs and Direct Deposit (Perry/Burns)

One of the least controversial bills we tracked this session, SB 865 authorizes GCDs to use online banking tools, such as direct deposit, online bill pay, and other electronic banking applications that increase efficiency in financial transactions.

SB 1009: Administratively Complete Permit Applications (Perry/Larson)

This bill limits the list of items a GCD can require in a permit application to what is already listed in statute as well as other relevant information included in a GCD's rules. A GCD is prohibited from requiring any additional information for a determination of administrative completeness.

TWCA Surface Water Committee

The 85th is the first session where the TWCA convened a formal "Surface Water Committee" during the interim to address matters related to the state's permitting of surface water. The committee, chaired by Lyn Clancy, Lower Colorado River Authority, and Bob Brandes, a water resources consultant, included more than 130 TWCA members and approved four consensus bills (including one groundwater committee bill) and one legislative concept, all of which were filed during session. Three of those bills are now law. In addition to SB 864, described above, the Surface Water Committee bills that passed this session include:

HB 3735: Chapter 11 Clean Up (Frank/Rodriguez)

The TWCA-initiated version of this bill aimed to conform the requirements of a water rights application with current TCEQ practice and modern technology. It was amended on the House floor to remove language related to whether a water right application or amendment is consistent with the state water plan, and again in the Senate Committee on Agriculture, Water and Rural Affairs to add SB 1430.

HB 3177: Actions by the Executive Director (Lucio III/Estes)

This bill defines when a matter becomes uncontested before parties are named at the TCEQ and clarifies the process for challenging an action of TCEQ's Executive Director with the agency's commission first and then by filing a district court appeal.

Other bills of interest

Though only a handful of other water-specific bills made it to the finish line this session, we also saw some non-water bills that will impact Texas water provider operations. The list below includes the session's most significant water and local government bills.

SB 1511: State Water Planning (Perry/Price)

This bill requires that the state water plan include implementation information on projects previously deemed high priority by the Texas Water Development Board (TWDB). It also adds representatives of the Texas State Soil and Water Conservation Board as ex officio members of each regional water planning group, requires regional water planning groups to amend plans to exclude "infeasible" water management strategies or projects, and authorizes a simplified, every-other-five-year planning cycle if there have been no significant changes to a planning group's water availability, supply or demand.

SB 1430: Water Rights and Desalinated Seawater (Perry/Lucio III)

This bill requires the TCEQ to expedite processing of applications to amend existing water rights when the applicant is using desalinated seawater after acquiring the water right that is being amended. The bill also limits a contested case hearing on such an application to 270 days. This bill was also added to HB 3735 (see section II, above).

SB 1289: U.S. Steel Bill (Creighton/Paddie)

This bill drew a great deal of attention during the session, especially with respect to provisions related to TWDB funding under the State Water Implementation Fund for Texas (SWIFT) and State Water Implementation Revenue Fund for Texas (SWIRFT). As relevant to this article, the bill requires that projects financed with SWIFT or SWIRFT funding must use iron and steel products that are produced in the United States. The bill provides for an exemption when the iron or steel is not available or of satisfactory quality or when the use of U.S. steel or iron will increase the cost of the project by more than 20%. The requirement does not apply to a project "formally approved" by the TWDB before May 1, 2019 or in cases where complying with the requirements would be "inconsistent with the public interest." As required by the bill, the TWDB is currently in the process of developing a report for the state auditor that includes information on recently funded construction projects and potential impacts of the new requirements.

SB 347: Regional Water Planning Groups and Open Government (Watson/Phelan)

This bill makes regional water planning groups and their committees subject to the Open Meetings Act and the Public Information Act.

SB 1172: Local Government Regulation of Seed (Perry/Geren)

This bill prohibits a political subdivision from adopting an order, ordinance, or other measure that regulates agricultural seed, vegetable seed, weed seed, or any other seed in any manner, including planting seed or cultivating plants grown from seed. Though this bill was not intended to address any water-related matters, some water providers became concerned during the session that the broad language could unintentionally pull in certain water regulations, including stormwater, drought contingency plans, and water conservation plans. The enrolled version expressly excludes these regulations to avoid any confusion.

SB 625: Special Purpose District Public Information Database (Kolkhorst/Stephenson)

This bill requires the Comptroller to create a Special Purpose District Public Information Database that includes information related to each district's board, staff, revenue, bonds, taxing authority, and budget. Districts that do not cooperate with information requests from the Comptroller may be charged $1,000.

HB 544: Rural Water Assistance Fund (Anderson/Hinojosa)

This bill amends Chapter 15, Water Code, to include "planning" as an eligible use of TWDB's rural water assistance fund.

HB 1257: Criminal Mischief (Kacal/Birdwell)

This bill adds "property used for flood control purposes or a dam" to the criminal mischief provision of the Penal Code, making violations punishable as a state jail felony.

HB 1573: Training for Water Loss Auditors (Price/Creighton)

This bill requires the TWDB to establish training standards for certified water loss auditors and make the required training available on its website free of charge.

HB 1648: Water Conservation Coordinator (Price/Seliger)

This bill requires that water conservation plans filed under section 13.146, Water Code, include a designated water conservation coordinator responsible for implementing the plan.

SB 622: Public Notice Expenses (Burton/Lozano)

This bill requires political subdivisions located in counties with a population of 50,000 or more to include a line item indicating expenditures for a state-required published notice that allows a clear comparison between those expenditures in the proposed budget and actual expenditures for the same purpose in the preceding year.

Bills that did not make the cut

In sessions like the 85th, sometimes it is just as important to track the bills that didn't pass as it is to track those that did. These high-priority bills made it far enough in the process or commanded enough attention to suggest that we will see similar versions in 2019, and in fact, some were refiled this summer during the special session, as identified below.

HB 2378: Export Permit Renewals (Larson/Perry)

In 2015, the 84th Texas Legislature passed SB 854, allowing for automatic renewals of certain groundwater operating permits. However, many GCDs also require "export permits" when groundwater will be exported out of the GCD. This TWCA-initiated bill would have clarified that export permits must be renewed consistent with the corresponding operating permit. The Governor vetoed this bill on June 15, but Representative Ashby filed the bill as HB 275 and Chairman Larson included the language HB 26 during the special session.

HB 2377: Brackish Groundwater (Larson/Perry)

This bill would have expanded upon Chairman Larson's 2015 brackish groundwater study bill by authorizing a GCD, upon petition or its own motion, to designate a brackish groundwater production zone where brackish groundwater can be produced without unreasonable negative impacts on groundwater, existing users, and DFCs. Designations would not be allowed in formations that serve as a primary source of water supply for municipal or agricultural purposes. After the designation of a zone, a production permit would be issued in the same manner as an uncontested application, with permit terms equal to the expected project financing term but no longer than 30 years.

Versions of this bill have been considered by the Legislature as far back as 2013, and this broad-based consensus effort was one of the last bills to pass the Senate. It was amended on the Senate floor to include HBs 180 and 3417, but those bills were stripped in conference committee. The Governor vetoed the bill on June 15, citing its complexity, and Chairman Larson refiled it as HB 27 during the special session.

HB 3742/ SB 225: Contested Case Hearings for Water Rights (Phelan/Taylor)

These bills were not companions, but they both would have significantly amended the contested case hearings process for water rights applications and amendments. HB 3742 came out of TWCA's Surface Water Committee, and it eventually merged with SB 225 via committee substitutes in both chambers. Legislators and stakeholders have been working on some form of this bill for at least three sessions, so we expect to see it reworked yet again in 2019.

SB 696: Water Availability Model Updates (Perry/Larson)

This bill would have required updating certain water availability models (WAMs) at the TCEQ. Though the bill passed the Senate and was voted out of the House Natural Resources Committee, it stalled when the funding component did not survive budget negotiations. Chairman Larson refiled this bill as HB 282 during the special session.

HB 31/ SB 1392: Groundwater Management (Larson/Perry)

Though these bills were not companions, both were omnibus groundwater bills that addressed numerous provisions of Chapter 36, Water Code. Groundwater stakeholders worked with the Chairmen and their staff on multiple drafts throughout session, reaching consensus on some major issues. Ultimately, the bills ran out of time, but we expect the work on these bills to continue in advance of the 86th session. Elements of HB 31 are included in the special session's HB 26.

SB 226: Notice of Amendments to Water Rights (Taylor/Frank)

This bill would have amended the Water Code to exempt certain types of water right amendments from any requirements of a statute or commission rule regarding notice and hearing or technical review, consistent with the Texas Supreme Court's decision in *Marshall v. Uncertain*. It did not get enough votes in the House Natural Resources Committee to move to the House floor.

HB 3417: Consideration of Registered Wells in Permitting (King)

This bill, initiated by TWCA's Groundwater Committee, would have required a GCD to consider whether a proposed use of water unreasonably affects registered wells exempt from permit requirements in addition to existing groundwater and surface water resources and existing permit holders when issuing permits or permit amendments. It passed the House but did not receive a hearing in the Senate. It was later added to HB 2377 on the Senate floor, only to be removed in conference committee.

HB 3166: Modeled Sustainable Groundwater (Lucio III)

This bill, initiated by TWCA's Groundwater Committee, would have added a definition of "modeled sustainable groundwater pumping" to Chapter 36 of the Water Code as the maximum amount of groundwater that the executive administrator of the TWDB determines may be produced from an aquifer on an annual basis in perpetuity using the best available science. It would also have included "modeled sustainable groundwater pumping" in the list of hydrological conditions considered by groundwater management areas in developing DFCs. The bill passed the House but did not receive a hearing in the Senate.

HB 180: State Audit Review of GCDs (Lucio III)

This bill, initiated by TWCA's Groundwater Committee in 2015 and 2017, would have limited the powers of the State Auditor's Office to review a GCD's financial records only, consistent with Chapter 49 water district audits. The bill passed the House in both sessions but did not make it through the Senate Committee on Agriculture, Water and Rural Affairs. This session, the bill was added to HB 2377 on the Senate floor, only to be removed in conference committee.

Looking ahead

Though the 85th Legislature has adjourned sine die, their work continued in a special session convened by the Governor on July 18. The priority was to pass legislation for a handful of state agencies subject to sunset this year, but the call included 21 topics, ranging from political subdivision powers to abortion to education. The TWCA actively tracked more than 50 bills, mostly addressing taxing and other authorities of political subdivisions, but we also followed nine high priority, water-specific bills. In addition to the bills referenced in the previous section, legislators filed two TWDB funding bills, two bills related to aquifer storage and recovery, and one bill creating an "interregional planning council" of regional water planning group representatives to improve state water plan coordination. None of those bills were approved by the Legislature during the special session. Now that the special session has ended, the TWCA will continue its efforts to find common ground among stakeholders and legislators on water-related priorities at the capitol and look forward to beginning again in 2019.

SIERRA CLUB
WATER IN THE 85TH TEXAS LEGISLATURE: PERSONALITIES, POLITICS, AND POLICY

By Ken Kramer and Christopher Mullins, Lone Star Chapter of the Sierra Club

The outcome of water issues in the 85th Texas Legislature was a good reminder that personalities and politics are often more important than policy considerations in determining the fate of legislation. Perhaps this situation is more likely when the legislation involves an issue that is not seen as a priority during the legislative session.

Certainly, the management of the state's water resources was not the topic that garnered the attention of most legislators or the Texas news media in the 2017 regular session. Instead of addressing the issue of how we should sustainably manage our water resources for people and the environment, the 85th Legislature focused on such issues as who gets to use which bathroom.

Attention to water resources has fared better in previous legislative sessions. Water—or at least funding for projects in the state water plan—was a priority for the Legislature in 2013 and led to the creation of the State Water Implementation Fund for Texas (SWIFT) and a related fund, as well as the revamping of the Texas Water Development Board (TWDB). True to form, the Texas Legislature tends to put a subject on the backburner for a while after passing major legislation to address that issue. Therefore, no one was surprised that water did not make any one's "top ten" list for the 85th Legislature.

Nevertheless, there was no lack of bills relating to water introduced in the 2017 regular session, in part, because there are many significant water questions left unanswered for Texas and no shortage of viewpoints about the best answers to those questions. Among those questions are the following:

- Should groundwater be managed primarily for production or for conservation or for some balance between those two goals?
- Are the procedures for allocating groundwater and surface water unduly hampering the use of certain water supplies, or are they necessary to assure that all "affected parties" have a say in those decisions?
- Is our current state and regional water planning process working well to advance realistic water projects to meet the state's growing demands for water?
- How accurate are those demand forecasts, and to what extent might additional actions for water conservation and efficiency reduce those demands?
- Are we "behind the curve" in pursuing "innovative water projects" (insert your definition of "innovative" here), or are many of these "innovative" projects simply new versions of grandiose water projects that have been rejected before due to cost, lack of need, environmental impacts, or other factors?
- Are existing environmental flow standards sufficient to maintain our rivers and streams and the ecology and productivity of our coastal bays and estuaries, especially in light of new proposals to divert surface water for various projects?

All of these questions are deserving of consideration and, indeed, bills were introduced in 2017 that attempted to answer most of these policy questions, whether correctly or incorrectly.

Groundwater management

By far, the largest number of water-related bills filed focused on groundwater. The deluge of groundwater bills was not unexpected. Groundwater was a 2016 interim study topic of the Texas House and Senate committees with jurisdiction over water. Legislative leaders had also asked the Texas Water Conservation Association (TWCA)—the trade association for major water suppliers and the related "water industry"—to develop "consensus" recommendations on groundwater management.

Groundwater was also the focus of a 2015-2016 policy research project by graduate students at the Texas A&M University Bush School of Government and Public Service, which caught the attention of state legislators. Moreover, groundwater marketing and transport projects such as the San Antonio Water System Vista Ridge project and numerous private groundwater marketing ventures have been stirring controversy for years as private landowners, rural communities, and environmental groups express concerns for the future of springs and aquifers while many cities search for new water supplies.

These factors led to approximately 40 groundwater bills introduced in this "non-water" session. The most notable bills fell into three broad categories. First, two omnibus bills were introduced that sought to make numerous additions and changes to laws governing planning and permitting by groundwater conservation districts (GCDs). Second, several more targeted bills were aimed at curbing specific regulatory powers of GCDs in order to favor groundwater production. Finally, some legislation was introduced to address the risks associated with abandoned water wells.

The two omnibus bills were House Bill (HB) 31 and Senate Bill (SB) 1392. HB 31 (House sponsor: Representative Lyle Larson, Chairman of the House Natural Resources Committee) would have combined groundwater production and groundwater transport permits, prescribed certain procedures for GCDs, repealed portions of Chapter 36 of the Water Code, and made extensions of groundwater permits automatic. All of these changes generally favored the transport and marketing of groundwater by large water utilities and others. However, by working with some stakeholders, Chairman Larson was able to craft a somewhat more balanced bill that gained the support of many GCDs. However, the bill did not see floor action in the Senate after passing in the House and being reported out of the Senate committee.

The second omnibus bill, SB 1392 (sponsor: Senator Charles Perry, Chairman of the Senate Committee on Agriculture, Water and Rural Affairs) would have modified the joint groundwater planning process, weakened protections for conservation of groundwater resources, limited groundwater export fees, and constrained the ability of GCDs to place special conditions on permits. These changes would have limited the regulatory powers and flexibility of GCDs. The bill ran into a firestorm of opposition, especially to its initial (later deleted) provision to prohibit GCDs from employing "historic use" by the permit applicant as the basis for allocating volumes of groundwater permitted. A version of SB 1392 was eventually reported favorably out of committee after Chairman Perry agreed to continue working with members of his committee on changes to the bill, but the legislation was never brought to the floor of the Senate. In part that was because HB 31, which had a broad caption, was passed by the House and sent to the Senate and was then seen as the vehicle for incorporating aspects of SB 1392. Ultimately that strategy failed, and neither bill was enacted.

Several more targeted bills attempted to weaken the regulatory power of GCDs and tip the scales in favor of production rather than conservation. In some respects, these bills were similar to the omnibus bills in that they were seen as legislation to curb what water marketers and some others characterized, rightly or wrong, as arbitrary and unfair decisions by GCDs in permitting and rulemaking.

In this category of groundwater legislation, HB 3028 (sponsor: Representative DeWayne Burns) would have had the greatest potential impact on the current groundwater regulatory system. In the wake of the Texas Supreme Court's decision in the *Day* case, one major question for many legislators has been "do we legislate more concepts from oil and gas law into groundwater regulation?" HB 3028 answered this question with a resounding "yes" from those who wish to maximize groundwater pumping. Specifically, the bill would have introduced controversial, unclear, and ambiguous "fair share" language from oil and gas law, under the concept of correlative rights, into Chapter 36 of the Water Code. As filed, HB 3028 would have also required that the desired future conditions (DFCs) for different aquifers or portions of aquifers allow the highest practicable level of groundwater production based on total estimated recoverable storage (TERS) of water from the aquifer (as contrasted, for example, to limiting production to levels that would sustain the aquifers over the long term).

A reasonable question regarding HB 3028 that stumped many of its proponents was "fair share of what?" The concept of "fair share" has never been applied to groundwater, so it is unclear how it would be determined or defined. In addition, TERS does not recognize all of the relevant practical and scientific information. For example, the TERS concept ignores that groundwater production in excess of aquifer recharge might negatively affect spring flows and water quality. In the final analysis, it appears HB 3028 was thrown into the hopper by its author to see how correlative rights would be received by other state legislators. At best, it seems that correlative rights applied to groundwater is an idea whose time has not yet come. Nevertheless, this issue will likely arise again next session.

Another targeted bill, SB 862 (sponsor: Chairman Perry) was focused on a specific legal area regarding the powers given by the Legislature to GCDs. Because GCDs are not defended in lawsuits by the Attorney General and often have extremely limited funding, they are currently awarded automatic attorney's fees on any issues they prevail on in a lawsuit. This allows them to make rules and enforce them without worrying about the specter of bankruptcy due to court costs. However, many parties who have brought lawsuits challenging district rules believe this is unfair, as in, for example, a case where the challenger prevails in a lawsuit but loses as some of its claims.

SB 862 would have automatically awarded attorney's fees to the prevailing party on any issue in a case involving regulation by a GCD. However, this ignores the importance of the policy decision that was made in setting the current procedure regarding fees. GCDs are the only regulatory entities that have both a limited budget and are tasked with managing a vast resource claimed as a property right by every landowner. This kind of responsibility invites lawsuits, and those who see the value of pro-active groundwater management feel that the risk of litigation should not be a barrier to reasonable and necessary regulatory actions by districts. Due to pressure from stakeholders, the bill did not make it out of the House Natural Resources Committee after passing the Senate.

Another targeted groundwater management bill was HB 4122 (House sponsor: Representative Kyle Kacal). As filed, HB 4122 would have allowed the owner of a piece of land greater than 1,000 acres, and within the jurisdiction of two or more GCDs, to request that the entire property be transferred to the territory of a single district of the landowner's choice. A later amendment gave the relevant GCD veto power over such a change. However, this kind of exception would set a dangerous precedent by encouraging "district shopping" (similar to "forum shopping" in litigation). It appears that this bill was initiated by powerful and resourceful landowners seeking to come under the jurisdiction of GCDs with fewer financial resources and more limited authority. A version of HB 4122 passed the House and was voted favorably from the Senate Committee on Agriculture, Water and Rural Affairs but was never brought up on the Senate floor.

In addition to bills to manage groundwater quantity, legislation was introduced this session to address groundwater quality. Abandoned water wells may pollute groundwater by serving as a conduit for pollutants on the surface to enter underground water supplies. Both HB 3025 (Sponsor: Representative Tracy King) and SB 2068 (Sponsor: Senator Dawn Buckingham) sought to remedy this problem, albeit in different ways. HB 3025 would have required a landowner or other person who has a deteriorated well to repair or plug the well within 180 days of discovering its condition. GCDs would have been able to enforce this requirement 10 days after notice was given to the landowner and to go onto his or her land to repair or plug a well. The landowner would then be liable to the district for the associated costs. HB 3025 would have been a way to make sure landowners were held accountable for their wells. However, Governor Abbott vetoed the bill with the stated objection that he found it too intrusive on a landowner's private property rights, despite the propensity of abandoned wells to harm neighboring landowners' groundwater property interests.

In contrast, SB 2068 took a more localized approach, applying provisions to a specific area and regulatory entity. SB 2068 authorizes the Bandera County River Authority and Groundwater District to use revenue gained from fees and other sources to cap abandoned, deteriorated, open, or uncovered water wells. Reasonable expenses could then be charged to the property on which the well is located by attaching a lien. This bill passed and was signed by Governor Abbott.

Overall, the flurry of groundwater bills introduced produced much sound and fury but few results in the form of enacted legislation. In part that was due to the complexity of groundwater issues and the lack of consensus on how to address all of those issues. However, the outcomes were also based, in part, on factors other than groundwater policy considerations.

Gubernatorial vetoes

The demise of HB 31, for example, illustrates the impact that personalities and politics have in the state legislative process. While there were significant concerns about HB 31 and SB 1392 as they were originally filed, the last version of HB 31, as it was expected to be brought to the Senate floor, was a legitimate compromise that most stakeholders could accept even though it might not have addressed all concerns. The compromise was the outcome of deliberations among many (but not all) of those stakeholders, more so on the Senate side than on the House side. But it also apparently became embroiled in a personal political dispute that probably had little to do with the substance of the legislation.

By the end of the legislative session, it was very clear that there was friction between the House sponsor of HB 31 – Chairman Larson – and Governor Abbott. In part, the strained relationship resulted from Chairman Larson's lead sponsorship of a bill that would have prevented a Governor of Texas from appointing persons who had donated $2,500 or more to a Governor's most recent campaign for that office to various state government boards and commissions. This legislation was rather clearly aimed at Governor Abbott and may have arisen not only from ethics concerns but also from dissatisfaction with one or more of Governor Abbott's appointees on the Texas Parks and Wildlife Commission. Those appointees have taken strong positions on issues such as how to respond to incidences of chronic wasting disease in Texas deer, positions that are not popular with deer-breeding interests who have been supportive of Chairman Larson's political races.

Although HB 31 never made it to the Governor's desk, there is speculation that the abrupt halt to final movement on that legislation in the Senate may have stemmed from behind-the-scenes signals from the Governor that the bill, a signature one for Chairman Larson, would be dead on arrival on his desk. That speculation is lent credence by the fact that numerous other Larson-sponsored bills were vetoed by the Governor after the conclusion of the session. In addition to two relatively minor Larson groundwater bills, HB 2377 (relating to production of brackish groundwater in designated zones) and HB 2378 (relating to groundwater production and transport permits), that list included the following House bills authored by Chairman Larson and Senate bills sponsored by Chairman Larson in the House:

- **HB 2943** – a bill to clarify that the state water pollution control revolving fund could be used to finance the acquisition of conservation easements for water quality protection
- **HB 3987** – a bill to authorize the TWDB to finance and own all or part of an aquifer storage and recovery (ASR) project or desalination facility
- **SB 1525** – a Senate bill authored by Chairman Perry in the Senate and sponsored by Chairman Larson in the House that would have required the TWDB to assess and report on the water supplies and needs of the state and specific types of projects to meet identified needs.

Some other bills sponsored by Chairman Larson apparently failed due to House-Senate tensions over other legislative issues that had nothing to do with water or the environment. There was obvious disagreement between the House and Senate leadership over a number of contentious issues, such as the transgender bathroom legislation, and the Lt. Governor was clearly not happy with the reticence of the House to deal with certain issues that were a priority for him. Whether the result of retribution or not, approximately 50 bills that passed the House and were sent to the Senate never were referred to a Senate committee, essentially killing the bills. These included some of Chairman Larson's bills—HB 2005 (requiring studies and reports on possible areas for ASR), HB 2802 (taking river authorities out of the sunset review process), and HB 3991 (capturing "excess" surface water flows for ASR projects)—although the Chairman was only one of many House members whose bills fell victim to this fate. Once again, however, water bills were caught in what appears to have been a political trap.

There were areas of water legislation in the 2017 session whose outcomes appear, however, to reflect policy considerations rather than the effect of personalities or politics: water conservation legislation, bills dealing with surface water rights, and the "excess flows" issue, for examples. In all three areas, the results were generally positive in the view of environmental and conservation organizations and allies.

Water conservation legislation

Several bills were introduced to advance water conservation. Although not all were able to make it through the legislative gauntlet, the bills that passed are considered by conservation advocates as positive, if modest, steps forward.

An important impetus to these bills was the December 2016 report to the Legislature by the state's Water Conservation Advisory Council. For the first time, due to legislation passed in 2015, the Council's biennial report included recommendations on statutory changes and funding for water conservation. Members of the Council, acting as individuals or as representatives of their respective advocacy groups, were successful in getting the recommended statutory changes introduced as bills or included in other bills.

The Legislature enacted three of those recommendations in the following bills:

- **HB 1573** (sponsors: Representative Four Price/Senator Brandon Creighton) – requires the person who conducts a water loss audit for a water utility to be trained in water loss auditing and requires the TWDB to make that training available without charge from the agency's website; advocates view this as a step forward in improving the accuracy of water audits and thus helping utilities pinpoint ways of curbing water loss in their distribution systems
- **HB 1648** (sponsors: Representative Price/Senator Kel Seliger) – requires a retail public water utility serving 3,300 or more connections to designate a water conservation coordinator responsible for implementation of that utility's water conservation plan; this new requirement is seen as a way to help ensure that conservation plans are actually implemented, leading to more efficient use of existing water supplies
- **SB 1511** (sponsors: Senator Perry/Representative Price) – includes a new requirement, as part of a broader bill on state and regional water planning, that a representative of the Texas State Soil and Water Conservation Board serve as an ex office member of each of the state's 16 regional water planning groups; this change is considered important for better integration of that agency's water conservation and management activities with water supply planning

One of the Water Conservation Advisory Council's recommended statutory changes, which was embodied in HB 2240 (sponsor: Representative Eddie Lucio III), was not enacted. HB 2240 would have required certain recipients of state financial assistance for water projects to have enforceable "time-of-day" limits on outdoor watering (to prevent waste of water from evaporation during hot summer afternoons, for example). The bill was heard in the House Natural Resources Committee and was favorably reported from the Committee. However, the bill was not set on the House Calendar for floor debate before the legislative session ended. The bill did set the issue of outdoor landscape watering on the legislative agenda, however, and future action to address that issue is expected.

Surface water rights legislation

Surface water, unlike groundwater, is owned by the State and held in trust for the benefit of all Texans. As both a resource and a part of our State's heritage, the Texas Constitution and regulatory structure recognizes that it must be used in a manner that carefully balances production and conservation. This is especially important when it comes to surface water rights permitting. Surface water rights are perpetual permits that allow holders to produce a certain amount of state water based on Texas Commission on Environmental Quality (TCEQ) guidelines. Occasionally, the road to attaining a permit can be long because our state is facing growing water demands coupled with a limited supply of unpermitted surface water. Moreover, the TCEQ has insufficient funding and resources to process expeditiously the complex and technical applications associated with attaining permits. In response to complaints regarding the few instances where the permitting process has been especially lengthy, several legislators introduced bills this session that sought to fast track the surface water rights permitting process. On paper, this goal might seem commendable; however, these bills would have accomplished it in ways that would have grossly favored production over conservation, without actually addressing the underlying issues mentioned above. The most notable bills are below.

- **HB 3742** (sponsor: Representative Dade Phelan) and

SB 225 (sponsor: Senator Van Taylor) would have arbitrarily restricted contested case hearings by limiting the scope and number of issues that could be addressed, restricting affected party status (a doctrine akin to standing in court cases), and providing for a narrow 270-day deadline for the completion of hearings. These changes were problematic for several reasons. Contested case hearings are a critical check on the power of the TCEQ to make decisions affecting the landowners, hunters and anglers; recreational river users; and environmental interests. Just as decisions on the initial surface water rights applications are complex so are contested case hearings. Thus, these hearings on perpetual permits warrant an approach that ensures the state gets its decision right the first time. The state needs to ensure that all relevant issues that arise during a hearing are considered, and proceedings are limited only in a reasonable manner, on a case-by-case basis. Ultimately, the arguments that killed these bills involved affected party status. The potential danger regarding a landowner not being able to protect his or her property rights was simply too great. There were seven revised versions of SB 225; however, none made it out of committee. HB 3742 was favorably reported from the House Natural Resources Committee but stalled in the House Calendars Committee. The persistence of proponents of the legislation indicates that this issue is likely to reappear in the next regular session.

- **HB 3314** (sponsor: Representative James Frank) and SB 226 (sponsor: Senator Van Taylor) would have directed the TCEQ to exempt applications for certain identified types of amendments to surface water rights from technical review, public notification, and contested case hearings. SB 226 had to be revised a few times before it could pass the Senate. Most egregiously, the first committee substitute would have granted the exemption even to those amendments not listed in the bill, meaning potentially any amendment could qualify. In addition, the final bill did not include any sort of public notification provision or limits on the exemption to amendments that move a diversion point downstream. Moving a diversion point downstream is a critical change because it affects landowners and ecosystems over sometimes large stretches of land by potentially reducing the streamflow between the original point of diversion and the new diversion point. Some Senators voted for the bill on the basis that it appeared to be a very limited streamlining of part of the water rights permitting process. This was an erroneous assumption, however, because of the lack of public notice and collaborative input in the process and the potential effects and unintended effects on streamflow. The bill passed the Senate anyway but failed in the House Natural Resources Committee.
- **HB 2894** (sponsor: Representative Lucio) and SB 1430 (sponsor: Chairman Perry) sought to fast-track applications for certain surface water rights related to seawater desalination in a way similar to SB 225 and HB 3742. Concerns about the bill's restrictions on length of permit hearings were brought to the attention of the House author. However, these were rejected, in part, because the proposed restrictions on hearings were limited to seawater desalination projects. Ideally, the bill would have allowed administrative law judges to extend hearings past the proposed 270-day deadline based on the individual facts of a case. However, this compromise did not end up in the final bill, and SB 1430 was passed by both houses and signed by Governor Abbott.
- **HB 3735** (sponsor: Representative Frank) sought several reasonable and practical updates to provisions in the Water Code governing surface water rights applications. The introduced version would have also required, however, that an application be "not inconsistent" with the state and applicable regional water plan. Currently, the Water Code states that an application must be "consistent" with these plans. This change made the bill problematic because it would have weakened the directive to the TCEQ to give meaningful consideration in its permitting decisions to the water management strategies recommended in state and regional water plans. It appeared to many that the change in language from "consistent" to "not inconsistent" was initiated by people or groups connected with the Brazos River Authority Systems Operation permit—a controversial permit that has been appealed to state court and where "consistency" with water plans is an issue. Fortunately, the "not inconsistent" language was removed by an amendment on the House floor by Chairman Larson, with pressure from Representative Larry Phillips. This resulted in a clean bill that was passed and signed into law by Governor Abbott.

The "excess flows" issue

Another controversial issue revolved around a piece of legislation—HB 3991—that Chairman Larson considered a priority for his legislative agenda. Chairman Larson is a strong advocate for ASR projects, especially as an alternative to surface water reservoirs with their high rates of water loss through evaporation (among other problems with reservoirs). Generally speaking, groups such as the Sierra Club also view ASR in a positive light, at least where aquifer characteristics, groundwater conditions, and other factors are compatible with this water supply approach. However, the Sierra Club and National Wildlife Federation opposed HB 3991 because of concerns about specific provisions to facilitate or promote ASR projects and because the legislation was based on a misunderstanding of how it might affect surface water flows necessary to sustain the environment.

The bill would have established new provisions governing TCEQ approvals for the appropriation of surface water for storage in ASR projects. HB 3991 would also have established a system whereby the developers of new surface water projects permitted by the TCEQ but not yet constructed could convert their appropriation to storage in an aquifer rather than a surface reservoir. As an enhancement to do so, the TCEQ would grant an "evaporation credit" to the project developer allowing the developer to divert an additional amount of surface water than originally allowed by their water right. The evaporation credit was supposed to reflect the volume of water that would have been lost to evaporation if stored in a surface water reservoir rather than stored in an aquifer. Although considered innovative by some observers, this process was seen as impractical and unworkable by others, including the Sierra Club.

The most contentious aspect of HB 3991, however, was the concept promoted in the bill that the surface water that would be stored in ASR projects would be "excess flows…that would otherwise flow into the Gulf of Mexico," implying that this water is now wasted. The bill essentially, although not explicitly, defined "excess flows" as those flows over and above what was needed to meet existing water rights in the same river basin and applicable environmental flow standards adopted by the TCEQ. However, the false assumption in that concept was that TCEQ environmental flow standards were sufficient to meet freshwater inflows for the state's coastal bays and estuaries, which reflects a misunderstanding of what those standards mean. In reality, those environmental flow standards in river basins and their associated bays and estuaries were established within the last several years after the vast majority of the volume of available surface water in our state's streams was already allocated to water rights holders for consumptive use. The standards merely provide a benchmark for putting conditions on new surface water rights to maintain some flows for environmental purposes and do not reflect what flows may be necessary to assure the health and productivity of our state's bays and estuaries.

Despite the fundamental flaw in the basis for HB 3991, the bill was voted favorably from the House Natural Resources Committee and eventually passed the House. HB 3991 was one of the Larson bills not referred to committee in the Senate, however. The language from HB 3991 was resurrected near the end of the session as a House amendment to SB 1511, the water planning bill. A concerted effort by environmental, hunting and angling organizations was successful in convincing the conference committee on SB 1511, appointed to reconcile the differences between the House and Senate versions of that bill, to delete the HB 3991 language from the final version of SB 1511. Senators Lois Kolkhorst and Chuy Hinojosa, conference committee members representing coastal districts, were particularly instrumental in making sure that freshwater inflows to bays and estuaries were protected.

Promotion of ASR and interest in using surface water for storage in ASR projects remain priorities for Chairman Larson, however, who has already reached out to opponents of HB 3991 such as the Galveston Bay Foundation to find ways to continue this effort. The interim before the next legislative session will see considerable discussion on this issue but hopefully one based on attention to facts and science and a better understanding of "environmental flows."

Looking ahead

Although predicting the actions of future Texas Legislatures is an inherently risky business, the death of so many pieces of water legislation this session and the unresolved issues left in their wake suggest that we are likely to see most of these issues, and perhaps some identical bills, resurface in the 2019 session. Whether water is likely to be a priority in the 86th Texas Legislature remains to be seen, of course. A lot depends upon the vagaries of the weather. Drought has a way of increasing our thirst for water legislation. Rain has a way of dampening our interest.

Whether water is a 2019 legislative priority or not, however, water continues to be a major challenge in Texas, one that will only grow more challenging in light of climate change. Meeting that challenge will require a more inclusive and balanced approach than evidenced by the way most water legislation was handled in the 2017 regular session. More openness on the part of legislative water leaders to other ideas and to constructive criticism may help avoid situations in future legislative sessions where personalities and politics trump policy considerations. That in turn would provide a better likelihood for successful outcomes on water legislation—something that will be increasingly important to Texas as the state moves forward in the 21st century.

TEXAS WATER INFRASTRUCTURE NETWORK THE 85TH REGULAR SESSION OF THE TEXAS LEGISLATURE

By Perry L. Fowler, Executive Director, Texas Water Infrastructure Network

By all measures the 85th Regular Session of the Texas State Legislature was one of the most complicated, least productive and conflict-laden Texas Legislative sessions in recent history with the distinction of also having one of the highest numbers of bills filed, and the least bills passed in the last 20 years. The politics of the 85th Texas Legislative Session were a reflection of the broader political environment. As a result of the antagonistic environment, this was a session for bills to die. Those that lived were heavily negotiated, shielded by leadership, or non-controversial in nature.

Of the 4,333 House bills and 2,298 Senate bills filed this session. Texas Water Infrastructure Network (TxWIN) tracked 500 bills that were deemed relevant or directly related to our member interests; approximately 330 bills in our track did not pass. Fourteen bills on the TxWIN track were subsequently vetoed by Governor Greg Abbott.

To gain an even greater understanding of how difficult this session was in a broader context, almost 3,000 (45%) bills did not even receive hearings in their body of origin, of those 139 were bills on the TxWIN track. Construction legislation in particular did not do well this session. This session was also characterized by massive bill kill-offs and fighting (literally on the floor of the House on the last day or sine die). Of 6,631 bills filed this session, only 700 in the House bills and 511 Senate bills were sent to the Governor for his signature (approximately 18%).

The following is a summary of the most important bills that TxWIN worked on and tracked, directly and indirectly related to water infrastructure markets in Texas.

Contracting-related law that passed with implications for Texas water projects

Senate Bill (SB) 1289 Creighton, Brandon (R) Paddie, Chris (R) Signed by Governor on 6/9/17 effective 9/1/17

Relating to the purchase of iron and steel products made in the United States for certain governmental entity projects.

SB 1289 and the House companion House Bill (HB) 2780 represented one of the most controversial topics of the 85th. TxWIN was heavily engaged in successfully advocating for changes in this legislation expanding "Buy American" requirements for state-funded construction projects. Since passage of HB 4 in 2013, which created the State Water Implementation Fund for Texas (SWIFT) and the funding mechanism known as SWIRFT, projects receiving state-funded financial assistance such as the D-Fund were subject to "U.S. Iron and Steel" requirements, which were comprehensive and covered not only iron and steel products but manufactured goods and systems incorporated into water and wastewater treatment plants, which is very problematic for a number of reasons.

Through TxWIN efforts, manufactured goods and systems incorporated into water and other projects were exempted from current Texas Water Development Board (TWDB) requirements, and the application of the law was limited to "Iron and Steel products" such as structural, steel, pipe and other such items. TxWIN also secured broad "public interest" waiver authority that will allow for further project, categorical and other waivers as necessary. TxWIN also secured rulemaking language in this legislation to ensure a clear process for implementation and compliance.

Effectively TxWIN accomplished the policy goals of our "Buy American" repeal legislation (HB 2204/SB 1416) through this bill because of lengthy negotiations and persistent advocacy.

Other key aspects of SB 1289 include grandfather provisions for certain projects in the Harris County area, a delay for implementation for SWIFT projects until May 2019, and a study on costs associated with the requirement. The next step in the process to implement SB 1289 will be the rulemaking process that was scheduled to begin in August 2017. TxWIN will continue working to ensure that there is a clear process and flexibility to ensure compliance is achievable.

For those dealing with these issues, it is important to note that there is a distinct difference between rules associated with federally assisted construction financial assistance from the U.S. Environmental Protection Agency "American Iron and Steel" SRF requirements administered by the TWDB and financial assistance without federal funds, which has been referred to as "U.S. Iron and Steel." We strongly encourage all participants in projects to exercise caution in all phases of design and to create project specifications to ensure clarity in bid documents and that available waiver processes available under state and federal law are utilized as necessary.

SB 533 Nelson, Jane (R) Geren, Charlie (R) Signed by Governor on 6/9/17 effective 9/1/17

Relating to state agency contracting.

Most of the subject matter in this bill applies only to direct state contracting, but there were 10 amendments adopted on the floor of the House on a broad range of subject matter. Only two amendments adopted in the House survived the conference committee and both are relevant to Government Code 2269 procurements.

One such amendment by Representative Jeff Leach (R-Plano) was a third reading floor amendment that instructs government entities under the jurisdiction of Gov. Code 2269 to provide a detailed methodology for scoring request for qualifications (RFQ) and request for proposals (RFP) criteria. It is unclear how broadly this change will apply, but it should assist public owners and contractors proposing on procurements with qualifications components to ensure that bid documents are precise, which should improve the quality of submissions and any potential ambiguities.

The second amendment adopted in the House was by Representative Carol Alvarado (D-Houston), which changes language for civil works design-build relative to RFQ/RFP response times, "clarifying" that 180 days is not a mandatory minimum to respond to design-build RFQs. The Alvarado amendment did not impact project or population limits currently in place for design-build procurements.

SB 807 Creighton, Brandon (R) Workman, Paul (R) Signed by Governor on 6/9/17 effective 9/1/17

Relating to choice of law and venue for certain construction contracts.

SB 807 amends the Business and Commerce Code to change the type of construction-related contract to which the statutory provision making voidable a contract provision that subjects the contract or any conflict arising under the contract to another state's law, litigation in the courts of another state, or arbitration in another state applies from a contract principally for the construction or repair of an improvement to real property located in Texas to a construction contract, as defined by the bill, concerning real property located in Texas or an agreement collateral to or affecting the construction contract. The bill changes the party that may void the provision from the party obligated by the contract to perform the construction or repair to the party obligated by the contract or agreement to perform the work that is the subject of the construction contract.

Contracting, ethics and disclosure

HB 501 Capriglione, Giovanni (R) Taylor, Van (R) Signed by Governor on 6/6/17 effective 1/8/19

Relating to the disclosure of certain contracts, services, and compensation in personal financial statements filed by public officers and candidates.

HB 501 expands this reporting requirement to require that elected officials disclose contracts for goods or services that they or their spouse or dependent child have with governmental entities. Specifically, HB 501 expands the personal financial statement reporting requirements for each state officer, elected official, or candidate to include the disclosure of written contracts for goods or services with governmental entities if the aggregate value of those contracts exceeds $10,000 per reporting year. HB 501 also requires that Legislature members who provide bond counsel services to a public issuer disclose specific information regarding each issuance, including the amount of the bond issuance, the name of the issuer, and the fees paid to the member or their firm. HB 501 further requires that state officers disclose referrals and associated fees.

Water financial assistance

HB 544 Anderson, Doc (R) Hinojosa, Chuy (D) Signed by Governor on 5/26/17 effective immediately

Relating to the use of the rural water assistance fund.

HB 544 would allow the TWDB to use money in the Rural Water Assistance Fund to contract for certain services to assist rural local governments in obtaining financing from any source for eligible water and wastewater projects. The bill also would add planning to the list of contracted services.

Water utility management

HB 294 Walle, Armando (D) Garcia, Sylvia (D) Signed by Governor on 5/26/17 effective 9/1/17

Relating to the revocation of certain water utilities' certificate of public convenience and necessity for major rules violations.

Primarily introduced to address issues in certain unincorporated areas of Harris County with poor water utility management, HB 294 would require the Attorney General, at the request of the Public Utility Commission or the Texas Commission on Environmental Quality (TCEQ), to bring suit to appoint a receiver to collect the assets and carry on the business of a water or sewer utility that violated a final judgment issued by a district court in a suit brought by the Attorney General under Water Code, ch. 13 or ch. 7, or Health and Safety Code, ch. 341.

SB 814 Hinojosa, Chuy (D) Canales, Terry (D) Signed by Governor on 6/9/17 effective 9/1/17

Relating to the board of directors of the Agua Special Utility District.

SB 814 amends the Special District Local Laws Code to replace one of the directors of the Agua Special Utility District elected at-large to represent the part of the district that is not included in specified municipalities with a director elected by the voters of the part of the City of La Joya within the district to represent that part of the city. The bill includes temporary provisions set to expire September 1, 2020, providing for the transition for such replacement.

SB 814 prohibits the district's board of directors from employing as an employee, as a consultant, or on a contract basis, an elected official of the largest public employer in the service area of the district or a person related to such an elected official within the third degree by consanguinity or affinity. The bill does not subject a person employed by the district on the bill's effective date who is such an elected official to the prohibition until the date the person's term as an elected official expires and authorizes the board to continue to employ the person until that date.

Water planning

SB 1511 Perry, Charles (R) Price, Four (R) Signed by Governor on 6/15/17 effective 9/1/17

Relating to the state and regional water planning process and the funding of projects included in the state water plan.

Omnibus water planning bill to evaluate effectiveness, streamline processes and reduce interregional conflicts.

HB 2215 Price, Four (R) Miles, Borris (F)(D) Signed by Governor on 6/9/17 effective immediately

Relating to the adoption of desired future conditions (DFCs) for aquifers in groundwater management areas and the consideration of those conditions in the regional water planning process.

HB 2215 amends the Water Code to change the DFCs with which a regional water planning group's regional water plan is required to be consistent from the DFCs adopted as of the date of the TWDB's most recently adopted a state water plan or, at the option of the regional water planning group, established subsequent to the adoption of the most recent plan to the DFCs adopted as of the most recent deadline for the TWDB to adopt the state water plan or, at the option of the regional water planning group, established subsequent to the adoption of the most recent plan.

Desalination

SB 1430 Perry, Charles (R) Lucio III, Eddie (D) Signed by Governor on 6/1/17 effective 9/1/17

Relating to desalinated seawater and a requirement that the TCEQ provide expedited consideration of certain applications to amend water rights.

SB 1430 should encourage development of desalination projects. SB 1430 amends the Water Code doing the following:

- Establishes that a holder of a water right who begins using desalinated seawater after acquiring the water right has a right to expedited consideration of an application for an amendment to the water right if the amendment authorizes the applicant to divert water from a diversion point that is different from or in addition to the point or points from which the applicant was authorized to divert water before the requested amendment.
- Authorizes the applicant to divert from the different or additional diversion point an amount of water that is equal to or less than the amount of desalinated seawater used by the applicant.
- Authorizes the applicant to divert from all of the diversion points authorized by the water right an amount of water that is equal to or less than the amount of water the applicant was authorized to divert under the water right before the requested amendment.
- Authorizes the applicant to divert water from all of the diversion points authorized by the water right at a combined rate that is equal to or less than the combined rate at which the applicant was authorized to divert water under the water right before the requested amendment and does not authorize the water diverted from the different or additional diversion point to be transferred to another river basin.

Water conservation

HB 1573 Price, Four (R) Creighton, Brandon (R) Signed by Governor on 6/1/17 effective 9/1/17

Relating to personnel requirements for water loss auditors.

HB 1573 requires that water loss audits be completed by a person trained to conduct the auditing. The TWDB shall make training on water loss auditing available without charge from TWDB's website. The TWDB may provide training in person or by video or a functionally similar and widely available medium. Training must include comprehensive knowledge of water utility systems and terminology and any tools available for analyzing audit results.

HB 1648 Price, Four (R) Seliger, Kel (R) Signed by Governor on 5/26/17 effective 9/1/17

Relating to the designation of a water conservation coordinator by a retail public water utility to implement a water conservation plan.

HB 1648 amends current law relating to the designation of a water conservation coordinator by a retail public water utility to implement a water conservation plan.

Groundwater

SB 1009 Perry, Charles (R) Larson, Lyle (R) Signed by Governor on 6/15/17 effective 9/1/17

Relating to administrative completeness requirements for permit and permit amendment applications for groundwater conservation districts.

SB 1009 would limit the information a groundwater conservation district could require for an operating permit or permit amendment application to information required by current law, other information included in a district rule in effect on the date the application was submitted, and information reasonably related to an issue the district was authorized to consider. A district could not require additional information to be included in an application for a determination of "administrative completeness."

Open meetings and public notice

SB 347 Watson, Kirk (D) Phelan, Dade (R) Signed by Governor on 5/16/17 effective 9/1/17

Relating to the applicability of open meetings and public information laws to regional water planning groups and their committees.

SB 347 provides statutory clarity that the business of the regional water planning groups, including their committees and/or subcommittees, shall be conducted in accordance with the Texas Open Meetings and Public Information Acts. With the establishment of the SWIFT, the importance of the regional water planning groups has grown immensely, and SB 347 ensures the planning process is open and transparent for the sake of efficient and effective future planning and for public participation in how the state's resources and finances are used.

SB 554 Kolkhorst, Lois (R) Metcalf, Will (R) Signed by Governor on 6/15/17 effective 9/1/17

Relating to notice requirements for certain special districts that hold board meetings outside the district.

SB 554 amends the Water Code to require certain water districts that do not have a meeting place within the district, respectively, to include in the required notice for a district's first meeting of each calendar year a description of the petition process for the TCEQ to designate a meeting place.

Insurance/workers compensation

HB 1989 Shine, Hugh (R) Zaffirini, Judith (D) Signed by Governor on 6/15/17 effective 9/1/17

Relating to the requirements for withdrawal by a certified self-insurer from workers' compensation self-insurance.

Current law allows a certified self-insurer to withdraw from self-insurance with the approval of the commissioner of workers' compensation (commissioner) if it shows to the satisfaction of the commissioner that it has established an adequate program to pay all incurred losses, including unreported losses, that arise out of accidents or occupational diseases first distinctly manifested during the period of operation as a certified self-insurer. To add clarity to current law and to reduce compliance burdens on self-insurers choosing to withdraw, HB 1989 would provide that, for purposes of withdrawal, an "adequate program" includes one in which the self-insurer has insured or reinsured all of its incurred workers' compensation obligations with an authorized insurer under an agreement that is filed with and approved in writing by the commissioner.

HB 2111 Romero, Ramon (D) Zaffirini, Judith (D) Signed by Governor on 6/15/17 effective 9/1/17

Relating to changing statutory references to hearing officer and hearings officer to administrative law judge under the workers' compensation system.

Under current law, when a dispute arises regarding a workers' compensation claim, the dispute may be resolved through a quasi-judicial process involving a hearing. The Division of Workers' Compensation personnel who preside at these hearings are referred to in current law as "hearing officers." HB 2111 amends current law relating to changing statutory references to hearing officer and hearings officer to administrative law judge under the workers' compensation system.

HB 2112 Romero, Ramon (D) Zaffirini, Judith (D) Signed by Governor on 6/15/17 effective 9/1/17

Relating to certain workers' compensation reporting requirements.

HB 2112 amends current law relating to certain workers' compensation reporting requirements by requiring an employer who terminates workers' compensation insurance coverage obtained under this subtitle to file a written notice with the division of workers' compensation of the Texas Department of Insurance (division), rather than with the division by certified mail, not later than a certain date.

HB 2443 Gonzalez, Mary (D) Zaffirini, Judith (D) Signed by Governor on 6/9/17 effective 9/1/17

Relating to the electronic submission of a wage claim to the Texas Workforce Commission.

HB 2443 amends current law allowing the electronic submission of a wage claim to the Texas Workforce Commission.

Additional thoughts and noteworthy issues for consideration

The majority of water infrastructure-related bills that passed this session were actually related to the establishment of municipal utility districts and other similar types of special districts, approximately 70, which is indicative of the amount of growth currently occurring in Texas. The growth that we are experiencing will continue to stress our water resources and will necessitate additional investments in developing water supplies and water infrastructure. In order to meet that demand, we depend on sound public policy.

A number of very substantive water bills were vetoed by Governor Abbott, many of which were re-introduced during the special session. Included in the group of water bills vetoed was legislation relating to transfer of groundwater permits (HB 2377), water reuse (HB 2798), development of brackish groundwater (HB 2378), use of funds in the state water pollution control revolving fund (HB 2943), use of the TWDB participation fund for desalination projects and aquifer storage and recovery projects (HB 3987), and a bill related to a study by the TWDB of water needs and potential alternative water sources (SB 1525). These are important water issues for the State of Texas, and it is unfortunate that they were vetoed. These bills were all re-filed in the special session and include HBs 26, 27, 226, 228, 229, 230, 275, and 277. Unfortunately, these re-filed bills did not move in the Senate since they had already been vetoed and were not part of the Governor's "call."

Another significant bill vetoed by the Governor was SB 1215 relating to responsibility for the consequences of defects in the plans, specifications, or other documents for the construction or repair of an improvement to real property. SB 1215 was one of the most controversial bills for the construction industry this session. The legislation originally clarified that contractors should not be liable for defective plans and specifications. This legislation was met with great animosity from the architects, engineers, oil and gas industry, and numerous other public and private owners groups. House sponsors amended the bill on the floor to mandate a study on the topic in the interim. Despite that this legislation was significantly amended to instruct further research and stakeholder input, it was subsequently vetoed. The owner and designer (architecture and engineering) communities should strive to work with the construction industry to reach consensus on the issues of fair risk allocation and appropriate assignment of liability. For non-negotiated public works contracts, this is especially important. We anticipate a robust discussion on this and related topics in the interim, which has already begun with a hearing called by House Business and Industry Chairman Rene Oliveira on July 25, 2017.

TxWIN also supported introduction of additional legislation related to public works contracting and retainage on construction contracts; the legislation was heavily negotiated with owner group representatives. Consensus was reached on a compromise bill that established a fair process with reasonable limits on retainage withholding that died due to the clock. Retainage policies vary greatly across the state, and TxWIN strongly believes that a change in law is necessary to provide for fairness in withholding and payment of retainage on construction contracts. Additionally, TxWIN supported legislation related to pre-qualification of public works contractors on competitive bidding projects that also addressed competitive sealed proposals and some related public contracting law issues. Both of these bills would have benefited construction contractors and public owners. TxWIN intends to seek their re-introduction in the next session.

In terms of other legislation introduced in the "Special Session" call by the Governor, two items constitute the biggest threat to local water projects, including funding programs established to fund the Texas state water plan. HB 18 by Estes et al. and HB 206 by Villalba seek to artificially cap spending by political subdivisions based on previous budget years, population growth, and inflation factors. Both bills constitute an egregious overreach by the state government under the banner of promoting fiscal responsibility. TxWIN has respectfully requested that the authors exempt water projects that are necessary for public health and safety. There are too many potential unintended consequences that could occur as a result of both pieces of legislation, and it is TxWIN's assertion that projects that involve years to plan, permit, design and construct should not be subjected to potential delays due to arbitrary and artificial spending caps.

TxWIN and the TxWIN membership is committed to working with representatives of the water infrastructure owner and design community in the interim to promote fair and reasonable policy that promotes competition, fair risk allocation, sound construction contract law, value for public owners, and the public whom they serve. We appreciate our relationships with all parties with an interest in the legislative process relative to Texas water. We are committed to sound policy based on consensus and fairness.

TEXAS ALLIANCE OF GROUNDWATER DISTRICTS LEGISLATIVE WRAP-UP

By Sarah Rountree Schlessinger, Executive Director, Texas Alliance of Groundwater Districts

The 85th Texas Legislative Session, Regular Session, saw the introduction of 6,631 bills. Of these, the Texas Alliance of Groundwater Districts (TAGD) identified 41 bills as statewide priority groundwater bills and an additional 40 bills as proposed local groundwater conservation district (GCD) legislation. Of the 41 statewide priority groundwater bills, nine bills made it across the May 29 finish line, and only five bills survived the Governor's veto pen.

Of the 6,631 bills that were filed, 1,211 bills passed, and 50 bills were vetoed. In what could be described as a particularly tense legislative session, several pieces of groundwater legislation were significantly impacted by political factors beyond the groundwater debate. As such, the groundwater policy dialogue is as affected by what did not pass, as it is by what did.

Following a busy legislative interim for groundwater issues, the 85th Texas Legislature picked up several of the interim's emerging themes. Those topics, as expressed in both interim hearings and reports, predominately included discussion on regulatory certainty, uniformity, permitting approaches/procedures, regional planning, and GCD performance. While it would be difficult to cover the full expanse of filed legislation in this summary, the groundwater legislation filed this session can largely be allocated into those five themes.

Omnibus bills: regulatory certainty and uniformity

Creating a symmetrical effect and holding the bulk of this session's groundwater focus, the chairmen of both the Senate Committee on Agriculture, Water and Rural Affairs (SAWRAC) and the House Natural Resources Committee (HNRC) each filed one omnibus groundwater bill and one issue-specific bill. Each of the four ranked as high priority groundwater bills, with significant committee and stakeholder time dedicated to them. While two of the four bills passed, both were ultimately vetoed.

Responding to interim concerns on a groundwater permit applicant's regulatory certainty and incorporating concepts discussed by groundwater consensus groups, Chairman Larson's omnibus House Bill (HB) 31 was comprised of five sections that addressed subjects such as export permits, moratoriums, and administrative completeness for permit applications. TAGD members voted in support of this bill and the issues it addressed. While there was little opposition to it, HB 31 was passed by the full House but did not make it out of the SAWRAC.

Chairman Perry's omnibus SB 1392 met more concern, with the originally filed version consisting of 27 pages and addressing tough subjects such as the adoption of common rules in a groundwater reservoir and restrictions on a district's ability to issue special permit conditions. While subsequent committee substitutes made significant efforts to meet concerns while still addressing the issue of uniformity, TAGD did not support SB 1392 and it did not pass.

Issue-specific bills: brackish groundwater and attorney's fees

Following the previous legislative session's efforts in HB 30, Chairman Larson's HB 2377 sought to establish the permitting procedures for brackish groundwater production permits within the Texas Water Development Board (TWDB) identified brackish groundwater production zones. While the originally filed version of HB 2377 caused some concern within TAGD, a strong stakeholder process ultimately produced a bill that was agreeable to all parties and gained TAGD's support. HB 2377 was ultimately vetoed by Governor Greg Abbott.

If you heard Chairman Perry speak during the legislative interim, you know that he was consistent in his concern regarding a landowner's ability to pursue his or her groundwater rights in a courtroom. As such, the filing of SB 862 on the award of attorney's fees in a suit involving a GCD was not a surprise. With subsequent committee substitutes seeking to balance concerns, testimony against the bill focused on historical context for current provisions and a regulatory body's ability to take enforcement decisions without fear of its ability to finance it. Amid significant tension, TAGD members did not support SB 862.

Permitting approaches/procedures

Beyond the wide array of subjects addressed by the omnibus and issue-specific bills, there were a number of additional pieces of legislation filed that addressed GCD permitting approaches and procedures. Many of these bills were a result of either Texas Water Conservation Association (TWCA)'s groundwater committee's consensus efforts or a response to those GCD critiques raised during the legislative interim. Of the nine total permit-related bills, four bills passed and two were vetoed.

Larger conceptual efforts to reformat GCD permitting structures included Chairman Perry's omnibus SB 1392, HB 1318, and HB 3028, all three of which were related to a correlative rights GCD permitting structure in some way. Representative Lucio's HB 1318, relating to the regulation of production wells for a retail public utility by a GCD, sought to put legislation in place to protect a water utility's ability to be allocated a permit in a correlative rights model based on their service area, rather than land ownership. Representative Burn's HB 3028 related specifically to groundwater ownership and rights, attempting to put into legislation the concept of fair share allocation based on property ownership. While neither bill was passed, the discussion of fair share allocation, correlative rights permitting, and the ability to protect those activities and industries that depend on groundwater was front and center in the groundwater policy debate.

Less controversial legislation on permitting approaches and procedures included SB 1009, SB 864, HB 2378, and HB 3417. Chairman Larson's HB 2378, relating to extensions of an expired permit for the transfer of groundwater from a GCD, was a TWCA consensus bill that applied to transfer permits the same automatic renewal provision passed in the previous session for production permits. This bill was supported by TAGD but was unfortunately, along with several other bills by Chairman Larson, vetoed. Representative King's HB 3417 was also a TAGD-supported consensus bill that addressed what a district considers when issuing a permit, specifically the ability to look at exempt and registered wells for potential impact.

Chairman Perry's SB 1009 and SB 864 were the only permitting bills that passed this session. SB 864 is a consensus piece of legislation that promotes increased coordination between the Texas Commission on Environmental Quality (TCEQ) and GCDs when issuing a right to use state water if the applicant intends to use groundwater as an alternative supply. TAGD supported this effort. SB 1009 is also a piece of consensus legislation that addresses those requirements that may be requested by a GCD for a permit or permit amendment to be considered administratively complete. As a response to one of the frequent GCD critiques during the interim, TAGD strongly supported SB 1009.

Regional planning and joint groundwater management

Like the GCD permitting legislation, there were a number of pieces of legislation that address regional planning and joint groundwater management procedures. Most notably, these included SB 1053, SB 1392, SB 1511, HB 2215, HB 3043, and HB 3166.

Of those listed above, only SB 1511 and HB 2215 ultimately passed. Representative Price's HB 2215 addresses the timeline of desired future condition adoption as it relates to both the groundwater management areas (GMAs) and state water plan, and is a direct result of interim discussions and recommendations made in interim reports. It is a piece of TWCA consensus groundwater legislation and had full TAGD support. Similarly, Chairman Perry's SB 1511 gained TAGD's full support as an attempt to better address which projects receive funding in the state water plan.

GCD performance, annexation and administration

While a principal topic of discussion during the legislative interim hearings and reports, the subject of GCD performance only surfaced in the form of HB 180 and GCD-specific sunset legislation. Filed again from the previous session, HB 180 addressed the role the State Auditor's Office plays in GCD performance review and sought to improve the oversight function. While this bill received no testimony in opposition, had full TAGD support, and was voted out of the full House, the bill was not voted out of SAWRAC.

The subject of GCD territory and annexation received a substantial amount of attention during this session, with numerous testimonies on the merits of HB 4122 discussed. Following significant stakeholder discussion, Representative Kacal's HB 4122 committee substitute, which provided a landowner with a certain amount of property the ability to seek annexation into another GCD, landed in the neutral zone for TAGD. HB 4122 was passed out of the full House but was not passed out of the full Senate.

On an administrative front, two significant bills were passed this session, but only one will become law. Representative King's HB 3025 related to open, uncovered, abandoned or deteriorated wells, and would have provided GCDs with the ability to plug deteriorated wells before they cause significant harm to groundwater quality. Due to political factors, this bill was unfortunately vetoed. Chairman Perry's SB 865, however, relating to a GCDs ability to use electronic funds transfers, was signed with an immediate effective date.

Summary

TAGD's positions on the 41 statewide priority groundwater-filed bills ultimately resulted in support for 22 bills, neutral on 12, and opposed to six. Broadly speaking, these numbers appear to indicate a willingness from the GCD industry to respond to concerns and work through those topics of regulatory certainty, uniformity, permitting, regional planning, and GCD performance.

While several pieces of significant groundwater legislation were not ultimately signed into law, the outcome in groundwater legislation during the 85th appeared much more positive than the initial outlook at the bill filing deadline. With TAGD strongly supporting all five of the groundwater bills that have or will become law, it seems reasonable to conclude that it was a good session for GCDs.

Looking ahead, it is clear there will be more discussion both inside and outside the Texas Legislature on those topics that did not pass into law during the 85th Legislative Session, particularly on the topic of attorney's fees and uniformity.

What passed

HB 2377 Vetoed

Relating to the development of brackish groundwater.

HB 2378 Vetoed

Relating to extensions of an expired permit for the transfer of groundwater from a GCD.

HB 3025 Vetoed

Relating to open, uncovered, abandoned, or deteriorated wells.

SB 1525 Vetoed

Relating to a study by the TWDB of water needs and availability in this state.

SB 865 6/09/17 Effective Date

Relating to a GCD's use of electronic fund transfers.

HB 2215 6/09/17 Effective Date

Relating to the adoption of desired future conditions (DFCs) for aquifers in GMAs and the consideration of those conditions in the regional water planning process.

SB 1009 9/01/17 Effective Date

Relating to administrative completeness requirements for permit and permit amendment applications for GCDs.

SB 864 6/09/17 Effective Date

Relating to the procedure for obtaining a right to use state water if the applicant proposes an alternative source of water that is not state water.

SB 1511 9/01/17 Effective Date

Relating to the state and regional water planning process and the funding of projects included in the state water plan.

What did not

SB 1392

Relating to GCDs.

SB 862

Relating to the award of attorney's fees and other costs in certain proceedings involving a GCD.

HB 31

Relating to the regulation of groundwater.

HB 4122

Relating to the transference of certain territory from one GCD to another.

HB 3166

Relating to the consideration of modeled sustainable groundwater pumping in the adoption of DFCs in GCDs.

HB 180

Relating to the review of GCDs by the state auditor.

HB 1318

Relating to regulation of production of wells for retail public utilities by a GCD.

HB 3028

Relating to groundwater ownership and rights.

HB 3043

Relating to the joint planning process for groundwater management.

HB 3417

Relating to the criteria considered by GCDs before granting or denying a permit.

SB 189

Relating to notice of an application for a permit to drill certain injection wells within a certain distance of a GCD.

SB 1053

Relating to an appeal of a desired future condition in a GMA.

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Coyote Lake Ranch v. City of Lubbock: a ranch, a city and the battle over surface use

James D. Bradbury[1*], Courtney Cox Smith[1], Avery Ory[2]

Abstract: In a time when the competition for water resources is increasing, water law and policy for groundwater is evolving, bringing to the fore the conflict between surface use and groundwater. Unlike the oil and gas context where the mineral estate is dominant, the superiority of severed groundwater to the surface estate has remained uncertain. The recent Texas Supreme Court case, *Coyote Lake Ranch v. City of Lubbock*, addressed this question, holding that the accommodation doctrine (long applied to mineral estates) applied to groundwater interests in that case. On its face, the case was a dispute between a Texas city and a landowner over the use and damage to surface property caused by groundwater development. The implications of the Supreme Court's holding, however, run deep and are significant in this time of growing water scarcity. The *Coyote Lake Ranch* case signals a continued push toward unifying the law governing mineral and groundwater law and emphasizes the need for the courts and the Texas Legislature to be proactive in balancing the interests and rights of all parties.

Key words: Coyote Lake Ranch, Lubbock, accommodation doctrine, groundwater, surface use

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INTRODUCTION

In an age where surface water resources are over-allocated while the competition among urban, industrial, and agricultural uses for water is increasing because of the higher uncertainty in available water resources, the ownership, control, and conservation of groundwater is on the leading edge of water law and policy. Large-scale commercial projects make control over groundwater and surface uses critically important to landowners and business owners alike. For example, the Vista Ridge Pipeline Project intends to pump 50,000 acre-feet of groundwater per year for 30 years from the Carrizo-Wilcox Aquifer in Burleson County, Texas to supply San Antonio and its growing population and water demand with water. Similar projects are either underway or in the planning stage. Groundwater is the new battlefield on which competing interests for water are fighting for control.

In conjunction with the changing water law and policy for groundwater, the conflict between surface use and groundwater is equally pressing. Texas has no surface-use statute in either the oil and gas or groundwater context, which can leave landowners at odds with those attempting to access and use groundwater resources. Unlike with oil and gas where the mineral estate is dominant to the surface estate, Texas law had not yet addressed whether severed groundwater could be superior to the surface estate. Accessing groundwater can be just as devastating to the surface area as oil and gas production, and it provides yet another aspect of a growing tension between landowners and those who seek to access and use groundwater.

Under this backdrop comes the recent *Coyote Lake Ranch v. City of Lubbock* case. On its face, it is a dispute between a Texas city and a landowner over the use and damage to surface property caused by groundwater development. Beneath the surface is an epic battle between severed groundwater estates and surface owners and the extent to which a surface owner can control the method and means by which groundwater is accessed. The city of Lubbock long ago acquired the groundwater rights underlying the Coyote Lake Ranch, which is a large ranch about 90 miles northwest of the city. Although a written deed memorialized the conveyance, in 2013 the ranch sought to enjoin the city from taking steps to access the groundwater, alleging that the city's actions were unreasonably interfering with the ranch's use of the property and that access to the groundwater could be accomplished by other reasonable alternative means that minimized impacts to the landowner's surface uses. Through the suit, the courts were faced with a new question for groundwater law: should the accommodation doctrine (long applied in the oil and gas context to mineral estates) now be applied to groundwater in the surface estate? The implications of this case run deep and are more important than ever in a time when water resources are growing scarce, the demand for groundwater is increasing, and conflicts between surface uses and groundwater access are on the rise.

GROUNDWATER: A NEW FRONTIER IN SEVERED ESTATES

The inception of modern groundwater law in Texas is slightly more than a century old. This beginning may be found not in the Texas Constitution or statutes but in the courts of Texas in the 1904 Texas Supreme Court case, *Houston & Texas Central Railway Co. v. East*. The *East* case takes place in the small North Texas town of Denison at the turn of the 20th century. The railroad company found itself in the midst of a severe drought and was in need of water for its passengers and steam locomotives.[1] It found a location near Denison where several other groundwater wells existed and were producing. The railroad company drilled its own well, which produced 25,000 gallons per day.[2] Other railroad companies had wells in the area as well, producing hundreds of thousands of gallons of groundwater per day.[3] It was not long before the other smaller wells of residents, like East, began to run dry.[4] East filed suit seeking damages.[5] The district court found in favor of the railroad holding that no correlative rights existed between the parties as to the groundwater.[6] East appealed to the Dallas Court of Appeals, who reversed the district court relying on the reasonable use doctrine and awarded damages to East.[7] The Texas Supreme Court heard the case in 1904 and unanimously reversed the Court of Appeals.[8] For the first time, the rule of capture was applied to groundwater:

> An owner of soil may divert percolating water, consume or cut it off, with impunity…So the owner of land is the absolute owner of the soil and of percolating water, which is part of, and not different from, the soil. No action lies against the owner for interfering with or destroying percolating or circulating water under the earth's surface.[9]

In 1917, the Texas Legislature identified water, including groundwater, as a natural resource in the state worthy of protection and conservation. It amended the Texas Constitution to add article XVI, section 59, allowing the Legislature to make

[1] *Hous. & Tex. Cent. Ry. Co. v. East,* 81 S.W. 279, 280 (Tex. 1904).

[2] *Id.*

[3] *Id.*

[4] *Id.*

[5] *Id.*

[6] *East*, 81 S.W. at 280.

[7] *Id.*

[8] *Id.* at 282.

[9] *Id.* at 281.

laws relating to the conservation of natural resources (such as water) and providing authority to set up conservation and reclamation districts to manage such resources.[10] From the beginning, the conservation of natural resources focused on minerals (primarily oil and gas) and water, and the law followed suit. In 1949, the Legislature passed the Groundwater Conservation District Act of 1949,[11] establishing groundwater conservation districts and giving them the power to regulate by rule groundwater in Texas.[12] For many decades following this Act, the Legislature and courts left regulation and management of groundwater issues primarily to local control by the districts.[13]

In 1993, the Legislature was faced with a new threat of federal intervention concerning over-production of groundwater resources, more specifically the resources in the Edwards Aquifer.[14] After the Sierra Club filed suit alleging the taking of endangered species because of a failure to ensure adequate water levels in the Edwards Aquifer, a federal judge ordered that the State take action or the Edwards Aquifer would become subject to regulation by the U.S. Fish and Wildlife Service.[15] In response, the Texas Legislature passed the Edwards Aquifer Authority Act that created the Edwards Aquifer Authority and placed certain permit limits and rulemaking by the authority to ensure continued spring flow during drought. In an effort to "split the baby" between the pressure for local control versus the pressure for greater mainstream regulation and conservation of groundwater resources, the Legislature created this new category of regulation in the Edwards Aquifer Authority, which would become significant in the development of groundwater law over the years to come.

In 1997, the Texas Legislature undertook a substantial overhaul of the Texas Water Code through Senate Bill 1.[16] One of the most important aspects of this overhaul in the groundwater context was the confirmation that groundwater conservation districts are the preferred method of regulation of groundwater in the State of Texas.[17] Local control won the day yet again.

In 1999, the Texas Supreme Court took up the issue of groundwater ownership for the first time in decades. In *Sipriano v. Great Spring Waters of America, Inc.*, the Court considered a case between a landowner and Ozarka concerning depletion of groundwater resources.[18] Ozarka moved to dismiss the case relying on the rule of capture and ownership in place.[19] Sipriano and other landowners argued that their action fell within one of the exceptions to the rule of capture of negligent subsidence, waste, or malice.[20] The landowners asked the Court to overturn the rule of capture. But the trial court was not persuaded and found in favor of Ozarka. The landowners appealed to the Tyler Court of Appeals, which affirmed the district court's summary judgment in Ozarka's favor, stating that if the absolute ownership rule is to be overturned it should be done so by the Legislature or the Texas Supreme Court.[21] Although it recognized the extensive criticism of the rule of capture, the Texas Supreme Court upheld the application of the rule in Texas, reasoning that the actions taken by the Legislature should be given time to work.[22] Though concurring with the opinion of the Court, Justice Hecht identified the shortcomings of the rule of capture, noted that Texas is the only state still applying the rule of capture, and stated that the rule should be overturned.[23] Justice Hecht, however, agreed with the conclusion of the Court to wait to see if the Legislature's actions would address the problems.[24]

In 2011, the Texas Legislature took up the issue of groundwater ownership through Senate Bill 332. Prior to this action, the Water Code's statement of ownership of groundwater did not address whether a right in groundwater arose only upon capture or existed while in place beneath the owner's property.[25] Senate Bill 332 attempted to clarify this point of contention by stating unequivocally that a landowner had a vested right in the groundwater beneath its land.[26]

Beginning in 2012, a succession of seminal cases came before the Texas Supreme Court that initiated a new burst of progres-

[10] Tex. Const. art XVI, § 59.

[11] Act of May 23, 1949, 51st Leg., R.S., ch. 306, 1949 Tex. Gen. Laws 559 (codified at Tex. Water Code § 36.002.

[12] "The ownership and rights of the owners of land and their lessees and assigns in groundwater are hereby recognized, and nothing in this code shall be construed as depriving or divesting the owners or their lessees and assigns of the ownership or rights, subject to rules promulgated by the district." Tex. Water Code § 36.002.

[13] Corwin W. Johnson, *Texas Groundwater Law: A Survey and Some Proposals*, 22 Nat. Resources J. 1017, 1022 (1982).

[14] Fred O. Boadu et al., *An Empirical Investigation of Institutional Change in Groundwater Management in Texas: The Edwards Aquifer Case*, 47 Nat. Resources J. 117, 125-27 (2007).

[15] *Id.* at 126; *see Sierra Club v. Lujan*, No. MO-91-CA-069, 36 ERC 1533, 1993 WL 151353, at 34 (W.D. Tex. Feb. 1, 1993). 1993 WL 151353, at 34 (W.D. Tex. Feb. 1, 1993).

[16] Tex. S.B. 1, 75th R. S. (Tex. 1997).

[17] Act of June 2, 1997, S.B. 1, 75th Lege., R.S., ch. 1010, § 4.21, 1997 Tex. Gen. Laws 3610-3683 (codified at Tex. Water Code § 36.0015).

[18] *Sipriano v. Great Spring Waters of Am., Inc*, 1 S.W.3d 75 (Tex. 1999).

[19] *Id.*

[20] *Id.* at 76-78.

[21] 973 S.W.2d 327, 330 (Tex. App.—Tyler 1993, writ granted).

[22] 1 S.W.3d at 80-81.

[23] *Id.* at 81-82.

[24] *Id.* at 83.

[25] *See* Tex. Water Code § 36.002.

[26] Act of May 29, 2011, 82nd Leg., R.S., ch. 1207, § 1, 2011 Tex. Gen. Laws 3224 (codified at Tex. Water Code § 36.002).

sion in Texas groundwater law by reliance on long-established oil and gas law. In 2012, the Texas Supreme Court considered the issue of "ownership in place" and its application to groundwater. In the landmark case *Edwards Aquifer Authority v. Day*, the Court held that ownership in place applies to groundwater.[27] The *Day* case involved two farmers who bought nearly 400 acres overlying the Edwards Aquifer on which they planned to grow oats and peanuts and to graze cattle.[28] Day applied to the Edwards Aquifer Authority for a permit to pump water from an existing well on his property for irrigation purposes.[29] After some back and forth, the Authority granted his application but limited it to 14 acre-feet a year. Day appealed through the administrative process and later filed suit alleging a taking of his property. Concluding that Day had a constitutionally protected interest in the groundwater in place beneath his property, the Court analogized groundwater to oil and gas, reasoning that both are governed by a single principle: that each is a shared resource and must be conserved.[30] The concept of ownership in place seeks to achieve this end.[31] Out of *Day*, two trends arose: 1) the Texas Supreme Court took an active role in setting water policy; and 2) the Court relied on oil and gas law to govern groundwater.

Having clarified the groundwater ownership regime in *Day*, another important case found its way to the San Antonio Court of Appeals. In *Edwards Aquifer Authority v. Bragg*, the Court answered the specific question of whether the Edwards Aquifer Authority's denial of a permit and reduction of water allowed under another permit constituted a taking.[32] In this case, the landowner owned pecan orchards and requested allowances to use groundwater for irrigation.[33] The Edwards Aquifer Authority allowed a lower amount of water than requested for one permit and denied the other permit request outright based on the landowner's failure to adequately demonstrate historic use. The landowner sued for damages, alleging the denial of the permit was a taking.[34] Relying on *Day*, the Court found the action to be a taking and went on to address how compensation should be determined, remanding the case to the trial court for a determination of damages.[35] The Texas Supreme Court notably declined to hear the case, allowing the San Antonio Court of Appeals decision to stand.[36] On remand, a jury awarded $2.5 million to the Braggs for the regulatory takings.

The Texas Supreme Court has emerged as the key policymaker on water law. While the Texas Legislature has been politically unable to refine the law, the courts have taken up the mantle. Both *Day* and *Bragg* leave open questions about the extent to which groundwater rights may be limited by regulation. The cases marked a subtle shift by the courts to balance the interests between landowners and regulation and management of groundwater by groundwater conservation districts. Although local control still reigns supreme in groundwater management, courts are showing a shift concerning the competing interests of landowners, businesses exploiting groundwater resources for their interests, and management by groundwater conservation districts. These cases focused on ownership and control by conservation districts relying on oil and gas law. The cases said little about the coming disputes over the right to sever and produce groundwater versus the right to the surface. Texas has no surface damage act, and Texas policy has long recognized the dominant mineral estate right to reasonably utilize the surface for production without compensation.[37] These conflicts have existed for decades and have spawned many small wars in the oil and gas context. Alongside this shifting of groundwater policy came the *Coyote Lake Ranch* case, providing courts with an opportunity to consider and adjust the balance of groundwater regulation by applying the accommodation doctrine to severed groundwater in the surface estate. With the growth of groundwater and size of projects coming online, a fight over use of the surface by groundwater developers was sure to arise. It did with *Coyote Lake Ranch v. City of Lubbock.*

THE ACCOMMODATION DOCTRINE: THEN AND NOW

The accommodation doctrine is a common law doctrine that addresses the inevitable conflict between owners of severed estates. The doctrine is triggered when on a severed estate, a mineral interest owner substantially interferes with an existing surface use. The rights of a mineral owner to use the surface are well recognized but not well defined. They are in the eye of the beholder. Texas courts attempt to strike a balance between

[27] *Edwards Aquifer Auth. v. Day*, 369 S.W.3d 814, 832 (Tex. 2012).

[28] *Id*. at 818.

[29] *Id*. at 820.

[30] *Id*. at 823.

[31] *Id*. at 842.

[32] *Edwards Aquifer Auth. v. Bragg*, 421 S.W.3d 118, 126 (Tex. App.—San Antonio 2013, pet. denied). Notably, the modern groundwater ownership jurisprudence has involved the Edwards Aquifer Authority, and while these cases may be analogized and applied to general groundwater conservation districts, the courts have yet to do so.

[33] *Id*. at 124.

[34] *Id*. at 126.

[35] *Id*. at 146, 152.

[36] *Id*. at 126.

[37] *See* Andrew M. Miller, Comment, *A Journey Through Mineral Estate Dominance, The Accommodation Doctrine, and Beyond: Why Texas is Ready to Take the Next Step with a Surface Damage Act*; 40 Hous. L. Rev. 461 465, 491-97 (2003); *see also* Andrew D. Lewis, Comment, *The Ever-Protruding Stick in the Bundle: The Accommodation of Groundwater Rights in Texas in Oil and Gas,* 2 Tex. A&M L. Rev. 79, 82 (2014).

the interests of enjoyment and use of the surface and the interest in development and production of minerals. Courts do not always find it easy to keep the peace between Texans who believe their property rights are sacred and an oil industry that has fueled the state's economy for decades.

The Texas Supreme Court first adopted the accommodation doctrine in 1971, in its landmark decision of *Getty Oil Co. v. Jones*.[38] In *Getty*, a surface estate owner brought suit against a mineral lessee seeking to enjoin its installation of beam-type pumping units,[39] arguing that it would prevent the operation of an irrigation system, which the surface owner used to cultivate cotton. The Texas Supreme Court ruled in favor of the surface owner, reasoning that mineral owners may be forced to accommodate preexisting surface uses.

In its arguments, Getty Oil Company contended that it acted in a reasonable manner[40] in its installation and use of the pumping units, and alternatively, that its rights to use the air above the surface were absolute and subject to no qualifications. The Court disagreed with the latter argument, stating that "the rights implied in favor of the mineral estate are to be exercised with *due regard* for the rights of the owner of the servient estate."[41] At first glance, the principle articulated by the Court appeared to simply reaffirm that mineral owner amay exercise their rights pursuant to their property interest, but in doing so, must also abide by the rule of reasonable use and use no more of the surface than is reasonably necessary to achieve development of the minerals.

From the decision in *Getty Oil*, the legend of the accommodation doctrine was born. The Court set forth a test to determine whether a mineral owner may be required to accommodate a surface owner: (1) where there is a preexisting use of the surface; (2) the mineral interest owner's use of the surface precludes or substantially impairs the existing use of the surface; and (3) there are industry-established alternatives available on the tract to recover the minerals.[42]

Just one year after *Getty Oil*, the Texas Supreme Court again examined the bounds of the delicate balance between the interests of mineral owners and surface owners. In a decision that many consider to be a retreat from the headway it forged in *Getty Oil*, the Court held that an oil company was entitled to the use of a substantial amount of water—which is considered part of the surface estate—in its secondary recovery waterflood operation.[43] Here, the Court permitted Sun Oil Company to use up to 100,000 gallons of freshwater per day in its oil production operation, even though the harvest of that large amount of water would deplete an underground reservoir and hinder the surface owner's ability to farm crops. The Court distinguished *Sun Oil* from *Getty Oil* under the third element of the accommodation doctrine, finding that no alternative methods were available for Sun Oil to accomplish its purpose under the lease.[44] Requiring Sun Oil to compensate the surface owner for damages for failed crops or forcing the company to go outside of the tract to acquire the necessary amount of water for its operation would degrade the rights of the dominant estate.[45]

In 2013, the Texas Supreme Court seemed poised to reexamine its three-element accommodation doctrine and determine its applicability to a non-continuous, but annually recurring surface use.[46] Homer Merriman, a pharmacist by occupation and cattle rancher by hobby, owned a 40-acre tract where XTO Energy held a lease to the severed mineral estate. Once a year, Merriman used the tract to sort and work his cattle; he did so in permanently installed fenced corrals. XTO approached Merriman about drilling a natural gas well on the tract and commenced operations despite Merriman's opposition and fear that it would interfere with his cattle operations.[47]

The Court in *Merriman* departed from the established accommodation doctrine. Under a traditional analysis of the three elements of the accommodation doctrine, Merriman would likely have prevailed.[48] Instead, the Texas Supreme Court adjusted the goalposts by shifting the burden to the landowner to prove that he did not have any reasonable alternatives for *his* surface use. Before *Merriman*, courts required the landowner to prove only that the mineral owner had an industry accepted alternative on the tract to recover the minerals. After *Merriman*, in order for a landowner to prevail on an accommodation doctrine claim, it appears that a surface owner must now prove a fourth element—that the surface owner himself

[38] *Getty Oil Co. v. Jones*, 470 S.W.2d 618, 621-22 (Tex. 1971).

[39] The beam-type pumping units at issue here are vertical in nature, extending approximately 17 feet from the ground. At the time Jones brought his suit, Getty had already installed one beam-type pumping unit on one well located in the northwest corner of the tract. This unit was placed just outside the circumference of Jones' pivoting irrigation system, so it did not interfere with Jones' surface activities. *See Getty*, 470 S.W.2d at 620.

[40] *See supra* note 34. The right of ingress and egress gives the mineral interest owner the right to use the surface insofar as reasonably necessary to develop the minerals.

[41] *Getty Oil*, 470 S.W.2d at 621 (emphasis added).

[42] *Id.* at 622.

[43] *Sun Oil Co. v. Whitaker*, 483 S.W.2d 808, 809-10 (Tex. 1972).

[44] *Id.* at 812.

[45] *Id.* ("To hold that Sun can be required to purchase water from other sources or owners of other tracts in the area, would be in derogation of the dominant estate.").

[46] *Merriman v. XTO Energy, Inc.*, 407 S.W.3d 244 (Tex. 2013).

[47] *Id.* at 247.

[48] *See* Courtney R. Potter, *The Accommodation Doctrine Revisited: Implications in Law and in Policy*, 46 St. Mary's L. J. 75, 88-90 (2014).

does not have any reasonable alternatives to his surface use.[49] It appears the mineral owner now can avoid accommodating a surface use simply by pointing at a reasonable alternative to the landowner's surface use.

Ultimately, the purpose of the accommodation doctrine is a noble one—to properly balance the rights of the mineral owner with the interests of the surface owner and to ensure fairness in a complicated arrangement of severed estates. Given the dominance of the mineral estate and the absence of a surface-use statute in Texas, the accommodation doctrine is the only real protection held by a surface owner. But as seen in *Merriman*, even that protection can be a pretty small stick. But as discussed above, the spirit of the doctrine does not always prevail, and Texas courts struggle to find the equilibrium. Yet, the accommodation doctrine is the current umbrella under which surface owners may seek refuge against unreasonable and destructive activities of the mineral estate owners and lessees. With this history of groundwater law and the accommodation doctrine before it, the *Coyote Lake Ranch* case reached the courts.

THE ACCOMMODATION DOCTRINE AND GROUNDWATER: COYOTE LAKE RANCH

A little background

In 1953, West Texas found itself in the middle of an exceptional and devastating drought.[50] This, for Texas, was the drought of record.[51] Cities were scrambling for untapped sources of water to supply residents. Hazel and L.A. Putrell owned a ranch in Bailey County, Texas, located approximately 90 miles northwest of the city of Lubbock.[52] The ranch, known as Coyote Lake Ranch, is now around 40 square miles, covers 26,000 acres, and rests over the Ogallala Aquifer. The Ogallala Aquifer is the principal source of water for the Texas High Plains, spanning a large area beneath eight states from Texas to South Dakota.[53] The ranch is covered with sand dunes that are protected by natural grasses. These grasslands also serve as a natural habitat for the Lesser Prairie Chicken, which has been designated a threatened species by the U.S. Fish & Wildlife Service.[54] Currently, the ranch is used for agricultural operations, grazing cattle, and hunting.[55]

Knowing that water was a diminishing resource, the city of Lubbock presciently looked decades ahead to identify a known source of future water supply. The city found its answer with a significant acquisition of groundwater rights from Coyote Lake Ranch. On January 30, 1953, the Putrells conveyed to the city of Lubbock the ranch's groundwater, reserving some water for domestic use, ranching operations, oil and gas production, and agricultural irrigation.[56] Consistent with the early sophistication in the Texas Panhandle and South Plains regarding groundwater, the deed conveying the groundwater rights for the ranch to the city was lengthy and detailed. As part of its reservation of water, the ranch was allowed to drill one or two wells in each of 16 specified areas for agricultural irrigation.[57] Over time, the ranch drilled 18 irrigation wells for watering wheat and other crops. The wells irrigate nine crop circles, each spanning 128 acres in area.[58] The remaining groundwater belonged to the city of Lubbock.[59]

In addition to specifying conditions for use of the groundwater by the ranch, the deed sets forth specific parameters and requirements concerning the city's right to use the surface when accessing the groundwater.[60] Among the lengthy and detailed provisions, the deed states that the city of Lubbock would:

- pay $3.00/acre per year for all ground surface occupied by housing facilities, fenced enclosures, and roads constructed and used by it;
- pay for damages to any surface property proximately caused by the operations or activities on the land by the city;
- install and maintain gates and cattle guards on its roads;
- have full rights of ingress and egress on the ranch and may drill water wells and test wells on the land except that no well may be drilled within one-fourth mile of any presently existing windmill;
- have the right to use all or part of the ranch necessary or incidental to the taking production, treating, transmis-

[49] *Id.* at 250-51. ("Therefore, we consider only whether Merriman produced legally significant evidence that he did not have any reasonable alternatives for conducting his cattle operations on the tract . . . .").

[50] Robert L. Lowry, Jr., *A Study of Droughts in Texas*, Tex. Water Dev. Bd., at 17-18 (Dec. 1959), *available at* https://www.twdb.texas.gov/publications/reports/bulletins/doc/B5914/B5914.pdf.

[51] *Id.* at 19-20.

[52] *Coyote Lake Ranch, LLC v. City of Lubbock*, No. 14-0572, Pet'r's Merits Br. at App'x. 4, (Tex. Apr. 1, 2015) [hereinafter Pet'r's Br.].

[53] Tex. Water Dev. Bd, *Ogallala Aquifer*, *available at* http://www.twdb.texas.gov/groundwater/aquifer/majors/ogallala.asp (last visited Jan. 12, 2017).

[54] Tex. Parks & Wildlife Dep't, *Lesser Prairie Chicken Wildlife Management Plan*, PWD 1046-W7000, *available at* https://tpwd.texas.gov/publications/pwdforms/media/pwd_1046b_w7000_lesser_prairie_chicken_wmp.pdf (Dec. 2006).

[55] Pet'r's Br. at 16.

[56] *Id.* at 16, App'x 4, 165-66.

[57] *Id.* at App'x 4, 165-66.

[58] *Id.* at 16.

[59] *Id.* at App'x 4, 165-66.

[60] *Id.* at App'x 4, 166.

sion and delivery or water; and

- be entitled to construct certain facilities (including water lines, fuel lines, power lines, communication lines, barricades, and access roads) on, over and under the ranch lands necessary or incidental to the city's operations to access the water.[61]

Prior to the suit, the city drilled seven wells on the northern side of the ranch. For nearly 60 years, the agreement between the ranch and the city functioned without issue.[62] After new owners acquired the ranch, the city's actions began to create conflict as the actions threatened to disrupt the new owners' surface use of the ranch.

In 2012, facing yet another exceptional drought, the city began exploring plans to exercise its rights and increase water extraction from the ranch. As a part of its plans, the city indicated it may drill as many as 80 wells—20 test wells in the middle of the ranch and an additional 60 wells spread across the ranch.[63] The ranch objected to the city's announced plans, contending that such extensive drilling would irrevocably damage the surface and increase erosion of the fragile sand dunes.[64] The city pointed to the broad rights given to it by the 1953 deed and began mowing paths through the ranch lands to possible drill sites. The ranch then filed suit to enjoin the city from proceeding,[65]presenting a first-of-its-kind legal fight between a surface owner and a severed groundwater owner, a fight that had existed for decades in oil and gas.

At the same time the battle over the ranch's surface and groundwater use was brewing, Texas courts were busy considering and changing the face of groundwater law, shifting toward greater protection of landowners and conservation of groundwater resources through cases such as *Day* and *Bragg*.[66] Both cases signaled a shift by the Texas Supreme Court toward taking a more active role in setting water policy. Although the Texas Legislature attempted to establish and refine groundwater law and policy by passing Senate Bill 1 and Senate Bill 332, among several other statutes, the need for clarity and further policy-making persisted. With the Texas Legislature limited by political constraints and faced with the rapidly developing issues in groundwater, the Texas Supreme Court became the logical alternative for refining the law through reliance on oil and gas law and other key jurisprudence, such as takings liability for groundwater regulation. The *Day* and *Bragg* cases also signaled a definite trend by the Court toward following and applying oil and gas law and principles to groundwater law.

To the courthouse

After Lubbock took steps to begin testing for the proposed plan, the ranch sued the city, alleging claims of inverse condemnation, breach of contract, negligence, and declaratory judgment.[67] As a part of its suit, the ranch sought injunctive relief to stop the city's encroachment on and damage to the ranch.[68] The trial court granted the ranch's request for a temporary restraining order and later a temporary injunction. In its order granting the temporary injunction, the trial court focused on the potential damage to the ranch by the city's actions and stated "[the City]'s proposed well field plan is likely accomplished through *reasonable* alternative means that do not unreasonably interfere with [the Ranch]'s current uses."[69] The court then set the case for trial.[70]

The city interlocutorily appealed the injunction to the Amarillo Court of Appeals. The city alleged that the trial court abused its discretion by issuing a temporary injunction based on a misapplication of the accommodation doctrine to the case. The parties agreed that the primary issue in the appeal was whether the accommodation doctrine from oil and gas law could be applied to groundwater.[71]

The city argued that the express terms of the 1953 deed governed the relationship between the city and the ranch concerning the city's use of the surface to access the groundwater. In the city's view, the accommodation doctrine could not apply to the groundwater context because, unlike with mineral estates, neither the surface estate nor the groundwater estate are dominant.[72] The city also argued that even if the accommodation doctrine could apply in the groundwater context, it does not apply in this particular case because the terms of the 1953 deed would govern over the common law doctrine.[73]

The ranch, on the other hand, argued that the groundwater estate is similar to the mineral estate, claiming that the owner of a severed groundwater estate owes the same "due regard" for the surface owner that an oil and gas lessee owes a surface

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[61] *Id.*

[62] *Id.* at 16.

[63] *Id.* at 17.

[64] *Id.*

[65] *See Coyote Lake Ranch, LLC v. City of Lubbock*, No. 9245, Pl.'s First Am. Orig. Pet. & App. for Temp. Restraining Order, (287th Dist. Ct., Bailey Cty, Tex. Nov. 26, 2013) [hereinafter Pl.'s First Am. Orig. Pet.].

[66] *See Edwards Aquifer Auth. v. Day*, 369 S.W.3d 814, 832 (Tex. 2012).*;* *Edwards Aquifer Auth. v. Bragg*, 421 S.W.3d 118, 126 (Tex. App.—San Antonio 2013, pet. denied).

[67] Pl.'s First Am. Orig. Pet. at 17.

[68] *Id.*

[69] *City of Lubbock v. Coyote Lake Ranch, LLC*, 440 S.W.3d 267, 270 (Tex. App.—Amarillo 2014, pet. granted). (emphasis added).

[70] *Id.*

[71] *Id. at 272.*

[72] *Id.* at 273.

[73] *Id.* at 273, n. 2.

owner.[74] The ranch contended that applying the accommodation doctrine to groundwater estates is a logical and necessary extension of recent Texas Supreme Court authority explicitly extending other oil and gas doctrines to the groundwater context.[75]

The Court of Appeals decision

The question presented to the Amarillo Court of Appeals was whether the accommodation doctrine could be applied to severed groundwater estate owners.[76] At the outset, the Court of Appeals acknowledged that *Coyote Lake* was a case of first impression.[77] The Court of Appeals considered the ranch's argument to apply the accommodation doctrine and declined to do so. Citing a lack of authority to support the ranch's position, the Court reasoned that *Day* did not support such an extension of the accommodation doctrine in the groundwater context, and that even if it did, it should be left to the Texas Supreme Court (or the Texas Legislature) to recognize and pronounce such an extension of the law.[78] Finding the injunction to be an abuse of discretion, the Court of Appeals reversed the trial court's decision and remanded the case for further proceedings.[79]

The Texas Supreme Court steps in

The ranch sought review before the Texas Supreme Court. It argued once again that the accommodation doctrine should apply to groundwater in the surface estate just as it does for mineral estates. Amicus curiae briefs were filed on behalf of both sides by a number of organizations, including the Texas Farm Bureau, the Texas and Southwestern Cattle Raisers Association and Texas Cattle Feeders Association supporting the ranch's position and the Texas Municipal League supporting the city's position.

The Court first looked closely at the 1953 deed between the city and the ranch. The city maintained that the deed controlled and determined the rights between the parties. The Court reasoned that although the deed touched upon certain aspects of the rights conferred to the city and the ranch, it did not resolve the dispute between the parties.[80]

The Court proceeded to set forth the history of the accommodation doctrine as applied to mineral estates, beginning with *Getty Oil*, the case in which the doctrine was first announced:

> [W]here there is an existing use by the surface owner which would otherwise be precluded or impaired, and where under the established practices in the industry there are alternatives available to the lessee whereby the minerals can be recovered, the rules of reasonable usage of the surface may require the adoption of an alternative by the lessee….Under such circumstances the right of the surface owner to an accommodation between the two estates may be shown.[81]

The Court continued its examination of the history of the accommodation doctrine with *Sun Oil*, where it broadened the application of the accommodation doctrine in the oil and gas context.[82] In *Sun Oil*, the Court highlighted the importance and trend toward conflict resolution and accommodation of both estates.[83]

The Court next drew a line to its decision in *Humble Oil & Refining Co. v. West*, where it discussed how the accommodation doctrine was applied in a "different situation"—that of "adjusting correlative rights."[84] Applying the accommodation doctrine in the context of royalty interests on native gas, the Court remanded the case for a balancing of the interests of the parties.[85] In *Tarrant County Water Control and Improvement District No. One v. Haupt, Inc.*, the Court applied the doctrine to a governmental entity in the condemnation context.[86] More recently in the Court's 2013 decision in *Merriman v. XTO Energy, Inc.*, it reiterated the importance of fairness to the parties and balancing their rights and interests when applying the accommodation doctrine.[87]

In highlighting the benefits of the accommodation doctrine, the Court reasoned:

> The accommodation doctrine, based on the principle that conflicting estates should act with due regard for each other's rights, has provided a sound and workable basis for resolving conflicts between ownership interests. The paucity of reported cases applying the doctrine suggests that it is well-understood and not of-

[74] *Id.* at 273.

[75] *Id.*

[76] *Id.*

[77] *Id.* at 273-74

[78] *Id.* at 275.

[79] *Id.*

[80] *Coyote Lake Ranch, LLC v. City of Lubbock*, 498 S.W.3d 53, 59-60 (Tex. May 27, 2016).

[81] *Getty Oil Co. v. Jones*, 470 S.W.2d 618, 622-23 (Tex. 1971).

[82] *Coyote Lake Ranch*, 498 S.W.3d at 62; *Sun Oil Co. v. Whitaker*, 483 S.W.2d 808, 817 (Tex. 1972).

[83] *Sun Oil,* 483 S.W.2d at 817.

[84] *Coyote Lake Ranch,* 498 S.W.3d at 62; *Humble Oil & Refining Co. v. West*, 508 S.W.2d 812, 815 (Tex. 1974).

[85] *Humble Oil*, 508 S.W.2d at 819.

[86] *Coyote Lake Ranch,* 498 S.W.3d at 62; *Tarrant Cty. Water Control & Improvement Dist. No. 1 v. Haupt, Inc.*, 854 S.W.2d 909, 911-12 (Tex. 1993).

[87] *Coyote Lake Ranch,* 498 S.W.3d at 62-63; *Merriman v. XTO Energy, Inc.*, 407 S.W.3d 244, 250 (Tex. 2013).

> ten disputed. We have applied the doctrine only when mineral interests are involved. But similarities between mineral and groundwater estates, as well as in their conflicts with surface estates, persuade us to extend the accommodation doctrine to groundwater interests.[88]

Bolstering its holding further, the Court set forth a number of ways in which mineral and groundwater estates are similar:

1. Both exist in subterranean reservoirs in which they are fugacious.
2. Both can be severed from the land as a separate estate.
3. Both severed estates have the same right to use the surface.
4. Both estates are subject to the rule of capture.
5. Both are protected from waste.
6. Both are owned by the landowner in place.[89]

Although there are obvious differences between water and minerals, the differences provide no basis for treating the estates differently in terms of ownership or the accommodation doctrine.[90] The Court explained:

> Common law rules governing mineral and groundwater estates are not merely similar; they are drawn from each other or from the same source. The dispute here over the City's right to use the Ranch is much the same as the disagreement between Getty Oil and Jones. Resolution of both requires an interpretation of the severed estate's implied right to sue the surface. The accommodation doctrine has proved its worth in such cases.[91]

In addressing the city's chief argument against extension of the accommodation doctrine to groundwater estates—that it has never been held to be "dominant" as is a mineral estate—the Court reiterated that dominant in this context means only "benefitted" not "superior."[92] "[T]he estate is dominant for the same reason a mineral estate is; it is benefitted by an implied right to the reasonable use of the surface. The surface estate is not servient because it is lesser or inferior but because it must allow the exercise of that implied right."[93] According to the Court, although the 1953 deed gave the city the implied right of reasonable use of the surface as well as the right to do what is necessary and incidental to access the groundwater, it does not define what is reasonable, necessary or incidental. Such use is to be determined with due regard for the rights of the surface estate, which is the heart and soul of the accommodation doctrine.[94]

The Court held that the accommodation doctrine, well known in oil and gas law, would now apply to govern conflicts between severed groundwater and the surface estate.[95] While it declined to state so directly, the Court's opinion masked the implicit conclusion that groundwater is and has always been dominant to the surface estate. While not a part of this opinion, the issue of groundwater dominance will undoubtedly be an issue for the Court in the future.

Following the modification in *Merriman*, as stated by the Court, the burden rests with a surface owner to prove:

1. the groundwater owner's use of the surface completely precludes or substantially impairs the existing use,
2. the surface owner has no available, reasonable alternative to continue the existing use, and
3. given the particular circumstances, the groundwater owner has available reasonable, customary, and industry-accepted methods to access and produce the water and allow continuation of the surface owner's existing use.[96]

Although the Court affirmed the Court of Appeals' judgment reversing the temporary injunction, it noted that the remanded proceedings must be consistent with the Court's opinion.[97] As of the publication of this article, the case remains pending at the trial court on remand.

GROUNDWATER IN A POST-*COYOTE LAKE RANCH* WORLD: IMPLICATIONS AND BEST PRACTICES

The implications of *Coyote Lake Ranch* are significant. It solidifies the Texas Supreme Court's recent trend aligning the law over groundwater and minerals in Texas. This will not end here. In this regard, it raises the questions of what other ways and what other doctrines will be extended from the oil and gas context to groundwater. For example, should the Legislature consider drafting specific provisions concerning surface use by severed groundwater (and mineral) estates? *Coyote Lake Ranch* also raises the following issues:

1. The Texas Supreme Court has emerged as policy-making body for groundwater.
2. Questions remain. Was the Court correct in its decision in *Coyote Lake Ranch*? Is this an issue the Legislature should address? How would the accommodation doctrine and the rule of capture apply to cases where the

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88 *Coyote Lake Ranch,* 498 S.W.3d at 63.

89 *Id.* at 63-64

90 *Id.*

91 *Id.* at 64.

92 *Id.*

93 *Id.*

94 *Id.*

95 *Id.*

96 *Id.* at 64-65.

97 *Id.* at 65.

groundwater rights are split into percentages? In the case when production continues to the point that it destroys all economically viable use of the surface estate (i.e., no groundwater left for irrigation of the surface), can the accommodation doctrine be used to moderate production volumes and, in turn, the rule of capture?

3. As for the accommodation doctrine, questions as to its application remain and will undoubtedly emerge. Namely, does the doctrine apply equally where there are no contractual provisions as there were in *Coyote Lake Ranch*?
4. Is a continued path by the Court to apply oil and gas law to groundwater the most prudent course?
5. Tension remains fierce between surface use and development of the severed groundwater estate. Does *Coyote Lake Ranch* suggest that the Legislature should look at creation of a new doctrine or surface damages legislation applicable to groundwater?

While many questions remain, one thing is certain: *Coyote Lake Ranch* will be at the heart of many groundwater law and policy discussions for some time to come.

This shift comes at a critical time when large-scale commercial projects, such as the Vista Ridge Project and others like it, are at their zenith. The implications for water scarcity are substantial. First with *Day* and ownership of groundwater in place and now with *Coyote Lake Ranch* and the accommodation doctrine balancing surface uses and the right to access groundwater, landowners have opportunities to exercise power in ways they have not before. But this new power is a double-edged sword as it can work not only to slow groundwater access and depletion in some cases but also provide a basis for allowing large-scale projects to move forward that may threaten long-term groundwater resources.

What should landowners take away from *Coyote Lake Ranch*? Perhaps the best way landowners can benefit from *Coyote Lake Ranch* is to get a surface-use agreement when severing groundwater rights. As the Court in *Coyote Lake Ranch* explained, the terms of the agreement would control over the common law if they are sufficiently drawn to do so. The reason the deed did not control was because it did not address the disputed issues between the parties—what was reasonable, necessary and incidental to accessing the groundwater.[98] A well-drafted surface-use agreement will address issues of use, damage to the property, easements, area, allowances, and restrictions. These agreements should be drafted with future owners, title concerns, lenders, and property value in mind. The deed in *Coyote Lake Ranch* was highly developed, thoroughly addressed the intended surface uses, and accomplished many of these concerns, and yet, it nonetheless fell short in the eyes of the Court. Perhaps additional language constituting a statement of cooperation between the surface owner and the groundwater holder could help avoid litigation in future cases and ensure production activities do not unreasonably impact the surface uses of the property beyond the needs of production. Additionally, agreements should describe more completely the activities that may be considered reasonably, necessary, and incidental to producing the groundwater.

It is more important than ever to counsel clients carefully when buying a ranch or when severing groundwater rights. Severing groundwater rights is not what it was in 1953 when the Putrells conveyed their interests to the city of Lubbock. Severing groundwater is as technical as leasing oil and gas interests, perhaps even more so given the paucity of law in the area. Large commercial projects can threaten to drain aquifers, cause significant damage to surface uses and land, and disrupt or destroy a landowner's use and enjoyment of his property. Lawyers must provide strong counsel on surface-use agreements when groundwater rights are severed. These agreements should be forward-thinking and drafted with an eye toward minimizing intrusions and damage to the surface use. It is important to note too that until the Texas Legislature addresses the open questions regarding severed groundwater and surface rights, including the accommodation doctrine, the holding of *Coyote Lake Ranch* will remain the sole standard to landowners. And the possibility always remains that the pendulum could shift away from landowners with a shift in perspective on the Court. Therefore, ensuring landowners have carefully crafted well-drafted surface-use agreements is key.

CONCLUSION

The push toward unifying the law governing mineral and groundwater law is gaining momentum. *Coyote Lake Ranch* is only the latest in a recent spate of cases aligning the two areas of law. Although the law is moving in the direction of broadening landowner rights, landowners must be diligent in protecting those rights. The severance of groundwater rights requires careful consideration, negotiation, and written agreements setting forth the specific terms of how the surface may be used by the holder of the severed groundwater estate. Perhaps the lesson from *Coyote Lake Ranch* is that, in an era when groundwater use is ever-increasing and ever-changing, the courts and the Texas Legislature must be proactive in defining the parameters of these uses and balancing the interests and rights of all parties.

[98] *Coyote Lake Ranch,* 498 S.W.3d at 59.

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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).

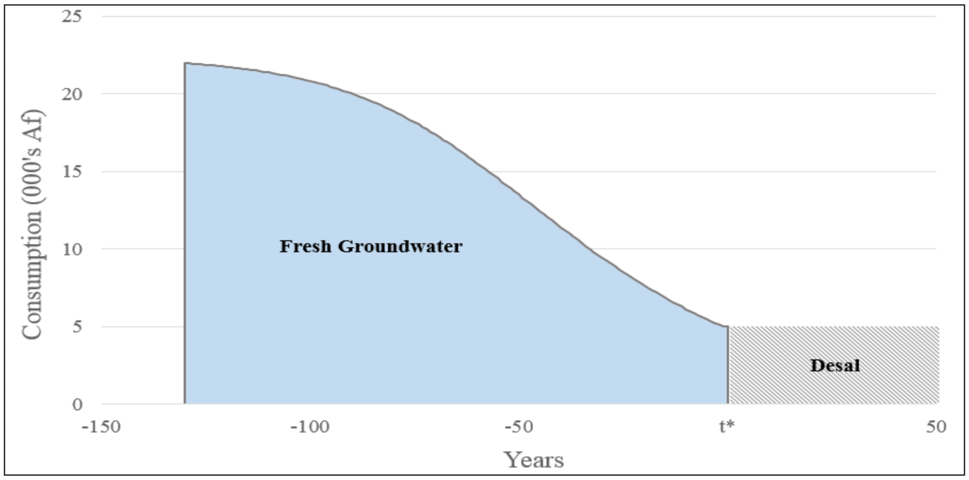

Figure 1a. Price path with well-defined property rights.

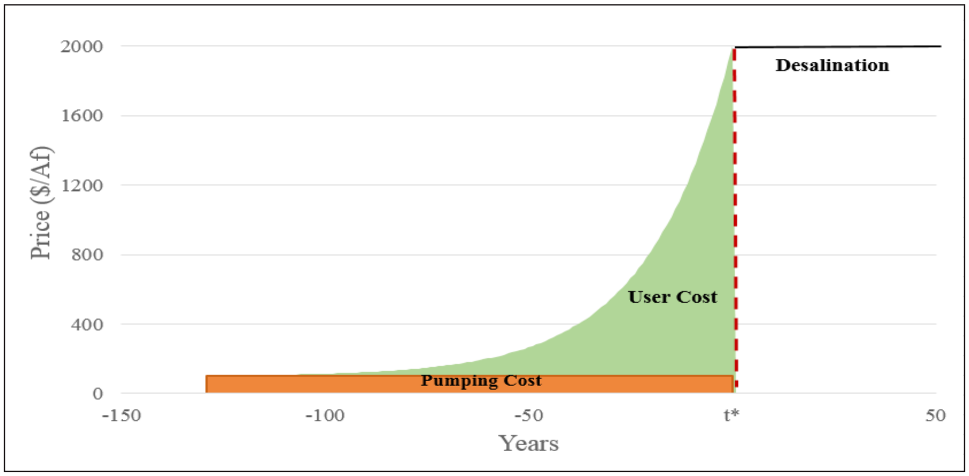

Figure 1b. Consumption path with well-defined property rights.

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.

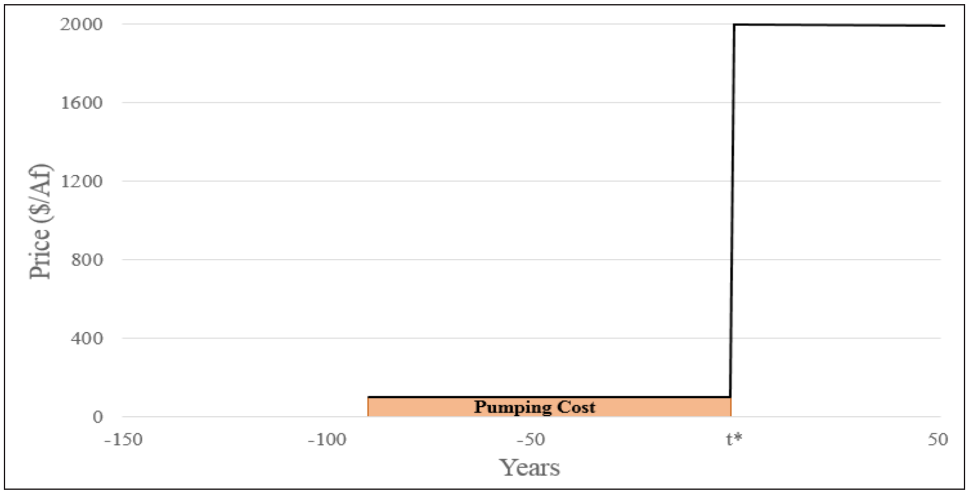

Figure 2a. Price path with rule of capture.

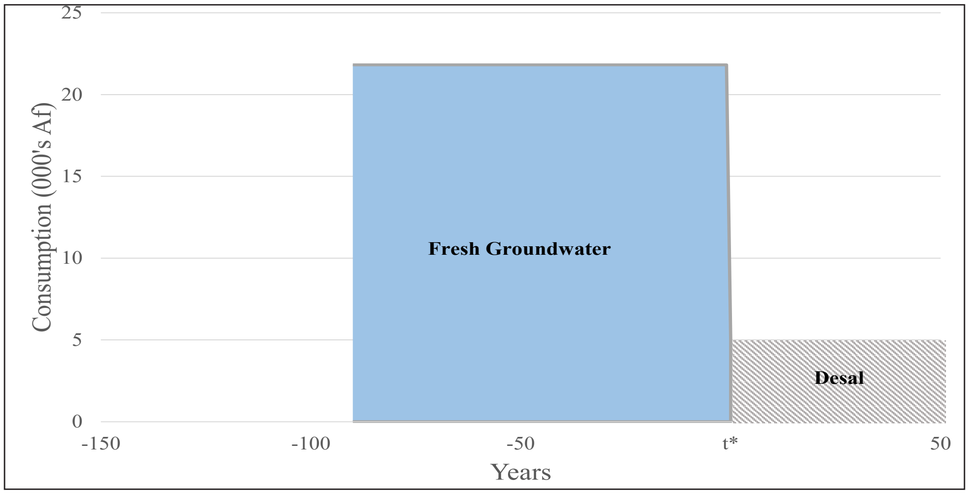

Figure 2b. Consumption path with rule of capture.

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.

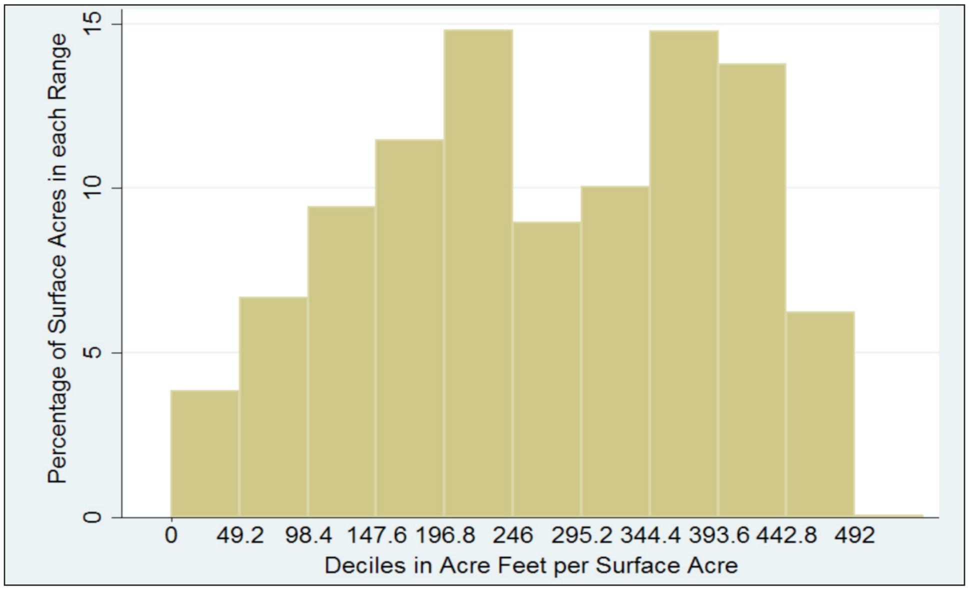

Figure 3. Heterogeneity of surface acres in the Carrizo-Wilcox in the Evergreen GCD.

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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Book review:
Texas through time—Lone Star geology, landscapes, and resources

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Despite being deemed the "Undergraduate Geology Scholar" when I graduated from New Mexico Tech, I'm not a geologist. My undergraduate degree is in geophysics, which meant drinking wine with physicists and mathematicians more frequently than drinking beer with geologists (which is why geologists tend to be suspicious of geophysicists). My graduate studies were focused on hydrogeology, which is more about wet rocks than the rocks themselves. I say all this to put my review of Thomas Ewing's book—*Texas Through Time: Lone Star Geology, Landscapes, and Resources*—into perspective: I'm interested in geology, but I don't wake up every morning eager to lick rocks.

Texas takes many forms. Culturally, there's the Texas of lore—the battles for independence from Mexico, cowboys and their dusty hats herding cattle, and swashbuckling oilmen with pockets full of cash one moment and air the next. Archeologically, there's the Texas of antiquity, ranging from the Caddos, whose word Tejas—meaning "friends"—was bequeathed by Spaniards to the area, back through the pre-Clovis Paleoindians that came here some 20,000 years ago. And then, geologically, there's the Texas beneath our feet, the dirt and rock of this place we Texans call home.

This book follows Texas as a hunk of rock and sediments from its beginnings some 1.7 billion years ago to the present. It's a story of Earth's ever-changing crust building mountains and then gnawing them to nothing, ever-waxing and waning seas, evaporating oceans, impacting meteors, venting volcanoes, and the inexorable tag-team nibbling of water and time. It's a story bigger than Texas, but the author aptly tells the tale in 431 pages of this beautiful, full-color book.

Ewing—with 35 years of experience as an Earth scientist in Texas—humbly characterizes his tome as an "extremely brief and incomplete summary of the history of geologic research" in Texas. After all, each page covers, on average, four million years, but he rightly hits the mark in providing an excellent overview of the geologic history of the state. The most recent attempt at overviewing this topic is the 1932 classic *The Geology of Texas—Volume 1: Stratigraphy* by E.H. Sellards, W.S. Adkins, and F.B. Plummer. Ewing's book is far more approachable than Sellards et al. and, given its recent publication, includes the latest research on the geologic history of the state.

Ewing divides the book into ten chapters: (1) Landscapes of Texas; (2) What is geology?; (3) Texas in space and time: An overview; (4) A long time ago in a world not so far away: Texas in the Proterozoic (1,700–700 Ma); (5) Buried mountains and salt seas: Texas in the Paleozoic (700–250 Ma); (6) Life in a newborn gulf: Mesozoic seas of Texas (265–252 Ma); (7) A world re-formed: Texas Cenozoic (65–0 Ma); (8) Humans in the geologic landscape: The last 20,000 years; (9) Earth resources of Texas: Soils, minerals, water, and energy; and (10) Earth impacts and hazards: Geology and the environment. The book also includes a foreword by Dr. Scott Tinker, director of the Bureau of Economic Geology; a glossary (with key words bolded in the text); an index; and a helpful appendix of where to see the rocks of the state.

Chapters and topics are well-balanced—Ewing doesn't dwell disproportionately on any single topic. The first three chapters take just under 50 pages to introduce Texas' current landscape, geology, and the concept of Texas over time. And, except for the 20 pages dedicated to the Proterozoic period, he spends about 60 pages on each geologic era of the Paleozoic, Mesozoic, and Cenozoic. The last three chapters, representing 88 pages, answers the question: Why do we care about the geologic history of Texas? In short, if you care about people, agriculture, water, energy, earthquakes, climate, and flooding, you care about geology!

Ewing begins his narrative of the geologic eras 1.7 billion years ago with the oldest rocks in Texas, probably located beneath the Panhandle ('probably' because rocks of this age are exposed in New Mexico to the west and probably extend beneath our state). The oldest dated rock in Texas comes from beneath Amarillo at 1.384 billion years old (with Van Horn a close second at 1.383 billion years). After the next billion years of volcanic activity to form the Proterozoic crust, Texas spent much of the next 700 million years south of the Equator, as far south as the modern-day Falkland Islands. Half a billion years ago, Texas was turned 100 degrees clockwise such that West Texas was North Texas and East Texas was South Texas.

Appalachian mountain building about 300 million years ago reached deep into Texas, following present-day I-35 down to San Antonio and then continuing west out to Marathon (where rocks from that time are exposed [there's a historical marker on U.S. Highway 90 east out of Marathon noting the rocks in the base of a nearby mountain]). About 250 million years ago, Texas was near the center of the supercontinent Pangea. About 150 million years ago, as Pangea slowly exploded apart, the Gulf of Mexico opened with beaches just a 15-minute drive away from the present-day locations of Dallas, Waco, Austin, and San Antonio. About 100 million years ago, increased volcanic activity in the oceans raised sea levels, moving the beach to Amarillo and El Paso. About 80 million years ago, some 200 shallow-sea volcanoes popped off in Central Texas near Austin (Saint Edwards University in Austin perches on top of an old volcano!) and south of Uvalde. Shortly thereafter, we had dinosaurs crawling all over the state, including the mighty Alamosaurus, the largest known dinosaur from North America at 100 feet long and 80 tons (sadly, this glorious beast was not named after the beloved mission in San Antonio but instead for the formation from which it was originally found, the Ojo Alamo Formation in New Mexico).

About 66 million years ago, a 6-mile-wide asteroid traveling at 50,000 miles per hour slammed into the Yucatan with a force equivalent to 100 million megatons of TNT (5,000 times more powerful than all the nuclear weapons on Earth). The impact sent waves of water over Texas at heights of hundreds to possibly thousands of feet high, scraping the landscape and dumping a "Cretaceous cocktail" of sediment in the gulf. The meteor's impact sent sky-darkening dust and sulphuric acid around the globe, leading to the demise of 75% of all species, including most of the dinosaurs. This massive impact and subsequent die-off allowed for the rise of the mammals (i.e., us).

As the Rocky Mountains formed between 80 to 40 million years ago, they began to erode, creating an apron of sediment now known as the Ogallala that fell across western New Mexico into northwestern Texas as far east as Wichita Falls. After the Pecos River—assisted by the dissolution of ancient sea sediments beneath it—ate its way from West Texas into northern New Mexico, cutting the Ogallala from its sediment source, the aquifer began to erode westward, a process that continues today at a rate of one inch a year.

When humans first arrived in Texas 20,000 years ago during the last ice age, the shoreline for the Gulf of Mexico was 100 miles out from today, near the shelf break, and the Sabine and Neches rivers emptied into the Trinity River. Then, as the glaciers retreated, sea levels rose. If you've ever wondered why the Brazos, Colorado, and Rio Grande do not have bays, it's because they carried enough sediment to fill their retreating basins as sea levels rose. In the other bays, sea levels rose faster than sedimentation. Today, sea levels are rising at 2.1 to 6.3 mm per year (0.7 to 2.1 feet per 100 years) along the Gulf Coast; thus, about 80% of the Texas shoreline is retreating.

Ewing includes a fascinating discussion on global temperatures over the last 65 million years and the possible effects of the configuration of oceans and continents, mountain building, solar radiation, variations in the Earth's orbit, and burps of Arctic methane from gas hydrates. The Antarctic ice sheet formed about 35 million years ago when global deep-ocean temperatures were about 11° Celsius warmer than today, and the northern ice sheet formed when temperatures were about 3° Celsius warmer—potential clues to what a warmer planet means for our current ice caps.

Even though I'm not a geologist proper, I come from the general direction of geoscience, so the book was an easy—and thoroughly enjoyable—read, a testament to how well-written it is. As a hydrologist, I particularly loved learning more about the geologic history of the state's aquifers and rivers and why they are the way they are. However, I should admit that some of the thorough descriptions of the comings and goings of seas got old after a few hundred million years: You need to bleed silt to be interested in that level of detail. Besides that small (selfish) observation, there's not much to quibble about in this book.

Texas Through Time should grace every geologist's and hydrogeologist's bookshelf and, perhaps, the bookshelves of more advanced geologic amateurs. As a geologic amateur, I know that I will be referring to this book time and again in future years.

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Commentary: The route to water security for Texas: the 2015–2016 Texas Water Roadmap Forums

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Abstract: Three forums were held between February 2015 and November 2016, bringing together Texas water experts from business, industry, government, academia, research, and the investment community in impartially facilitated sessions to determine ways to secure Texas' water future through accelerating growth of infrastructure, technologies, research, education, and sustainable use. Consensus emerged after the first forum that Texas is approaching a water crisis reflecting matters of supply, allocation, and quality that demands immediate action to ensure water security and equitable access to this vital resource. Participant focus rested on new technology acceleration and investment, workforce education, research underway and desired by segments of the water sector, the water-energy-food nexus, outreach and public education, data management and access, water valuation, water security, and legal and regulatory frameworks. Participants also examined funding and partnership options for development of water treatment and supply infrastructure, water rights and allocation methods, aging infrastructure, and conservation, as well as the nearly ubiquitous fragmenting and compartmentalizing of just about everything having to do with water throughout the entire water sector. The forums generated and summarized a wealth of information that can be used by any party to make progress toward the goal of building a Texas water roadmap. This report summarizes the discussions and the path forward for securing Texas' water resources.

Keywords: water planning, water management, water policy, water research, water education

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Terms used in paper

Short name or acronym	Descriptive name
NSF/RCN-CE³SAR	National Science Foundation Research Coordination Network for Climate, Energy, Environment and Engagement in Semiarid Regions
SWIFT	State Water Implementation Fund for Texas

INTRODUCTION

In December 2014, the Wells Fargo Foundation granted funds to the Texas State University to define the most pressing water-related technology deficiencies for which applicable intellectual property or researched solutions may be available already. Work evolved through a series of partnerships into an expanded effort to develop a novel water technology roadmap that would address pressing needs of the state and use this approach to help position Texas as a global leader in water technology and sustainable water use. By invitation, key thought leaders in the water sector from throughout Texas were brought together in the Texas Water Technology Roadmap Forum to help lay that groundwork. The forum was underwritten by the Wells Fargo Foundation, with co-sponsorship by the Meadows Foundation, the Texas Research and Technology Foundation, and the National Science Foundation Research Coordination Network on Climate, Energy, Environment and Engagement in Semiarid Regions (NSF/RCN-CE³SAR). In advance, the leadership team developed the plenary and charrette facilitation process that would guide the roadmap process in the months ahead. The first forum was hosted by the Water Institute of Texas on the campus of the University of Texas at San Antonio on February 25, 2015. The meeting was also supported by AccelerateH2O, the Meadows Center for Water and the Environment and Science, Technology, and Advanced Research Park at the Texas State University. A full report on the forum was published (Rosen 2015).

The Texas A&M University System and Area 41, a special Texas A&M System project seed fund, co-sponsored the second water forum with the Texas A&M University-San Antonio serving as the host. This two-day event was held November 17–18, 2015, with sessions split between an in-town conference facility and the nearby campus of the Texas A&M University-San Antonio. This forum focused on the water-energy-food nexus and included identifying and developing responses to local, state, national, and global challenges and opportunities relative to water resources in research, education, outreach, and policy implementation (Mohtar and Rosen 2015). Other forum topics included holistic solutions to water security in Texas and ways to engange stakeholders at home and worldwide in dialogues aimed at preventing to the extent possible, and otherwise resolving, conflicts over water-energy-food resources. Small-group charrettes concentrated on the most critical problems facing water-energy-food resources and technology from the perspective of human, education, policy, and legal dimensions. The NSF/RCN-CE³SAR served as an independent source of facilitation for the charrettes.

The Texas Water Development Board and the NSF/RCN-CE³SAR co-sponsored the third and final forum called the 2016 Texas Water Roadmap Forum. Focused on workforce education, data management and access, and several categories of research, the forum was hosted by the Institute for Water Resources Science and Technology on the campus of the Texas A&M University-San Antonio on November 29, 2016. The NSF/RCN-CE³SAR developed the plenary and charrette facilitation process and provided facilitators. The full report on the forum also included review of key points addressed during the previous forums (Rosen 2017).

THE CHARRETTE PROCESS

The water forums were held to develop consensus on how to address important water-related topics. Consensus building was conducted through an intensive facilitated process called a charrette, which involved water experts working together under compressed deadlines. Charrettes provided an interactive process that brought together a limited number of stakeholders representing pluridisciplinary perspectives (i.e., multi-, inter-, cross-, and transdisciplinary). Participants followed a rigorous, vision-driven process to achieve specified outcome-oriented goals and objectives. The charrette process was adopted for use because it is particularly well-suited to encourage discussions that go beyond conventional thinking. It drove participants to think beyond what is to what can and must be for current obstacles to be overcome. Participants had opportunity to organize and express their thoughts in advance of the charrettes by completing a pre-charrette survey. The survey information was used to form questions and inform facilitators about areas of possible discussion, consensus, or divergence of opinion. Discussions during the sessions offered participants an opportunity to contribute information and learn from others.

Discussions were framed within a broad context that reflects the real-world complexity of dealing with water-related topics. Participants addressed this complexity by focusing group discussion around general categories of influence on planning for water security and general concern. These categories of discussion included economics, politics, social factors, environmental factors, technologies, and laws, policies and regulations. Focus on these categories helped narrow participant consensus building, but charrette facilitators also identified the interconnected, interrelated, and interdependent nature of these categories, and advised participants that water matters are also influenced by uncertainty, complexity, ambiguity and some measure of volatility (Figure 1).

Discussions during the sessions offered participants an opportunity to contribute information and learn from others. Discussion was an essential element of the charrettes, because it began the important process of developing a common understanding among participants about the topics at issue, barriers to resolution, and roles of the various stake-holding parties. Moving from generalized to detailed considerations, participants established agreements on solutions, near-term needs, gaps, and scenarios for collaboration, coordination, funding, and alignment of opportunities. After small-group sessions ended, plenary sessions provided participants an opportunity to hear highlights from each group and seek to form full-group consensus around solutions and actions.

THE FORUMS

Forum I – Texas Water Technology Roadmap Forum

The first water technology roadmap forum was convened with the idea that participants would focus on water technology identification, development, and implementation in Texas. A list of the most pressing water-related technology deficiencies for which applicable intellectual property or researched solutions may already exist was conceived as an initial target for intellectual property mapping. The results could have application in a range of water technologies and help lay the groundwork for developing a novel roadmap to guide Texas

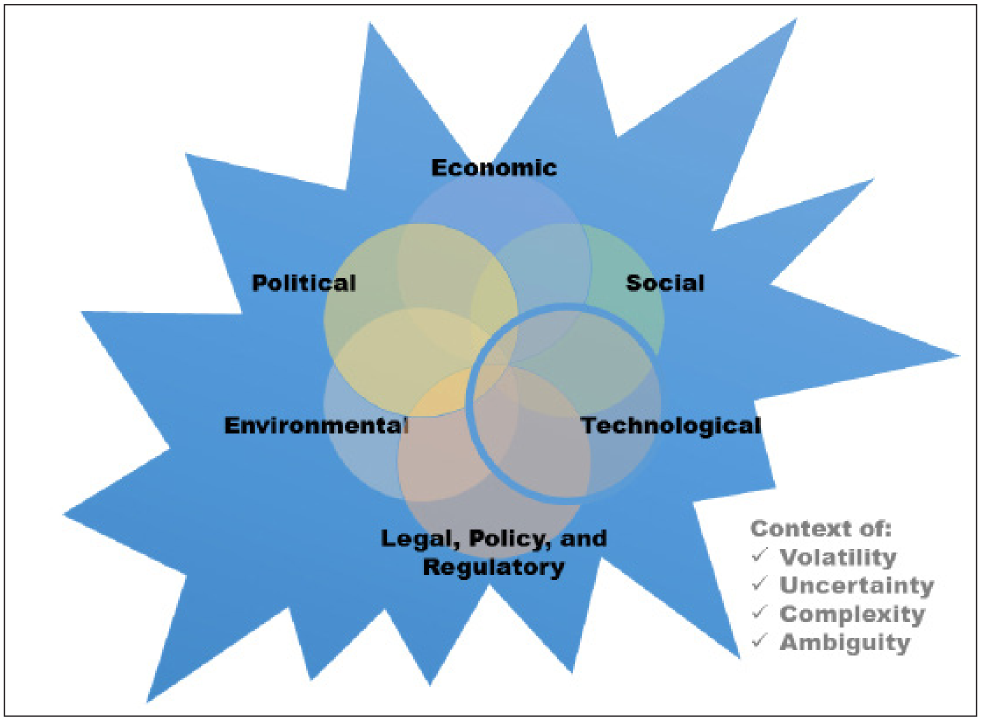

Figure 1. The charrette process.

toward global leadership in water technology and sustainable use. By invitation, nearly 100 key thought leaders in the Texas water sector from business, industry, government, academia, research, and the investment community were brought together to help meet the objectives laid out for the forum.

Participants met in plenary and breakout charrette sessions (Figure 2). A remarkable result was that, regardless of topic assigned, participants in each breakout session identified nearly identical problems in the water sector as critical and offered similar priority solutions. While participants agreed that new technology will play some role in Texas' water future, they concluded that many of the most critical matters to address have little to do with the availability of new technology or questions of science, engineering, or planning. Consensus emerged that Texas is rapidly approaching a water crisis reflecting matters of supply, use, and quality that demand immediate action to ensure water sustainability and equitable access. Participants described an immediate need to focus on regulatory and financial constraints to water management; deal with inadequate public investment in water infrastructure; address the undervaluation of water; upgrade and repair aging water infrastructure; enhance education about water; and increase data access, quality, and quantity. Participants agreed that failing to act now could have dire economic impacts to Texans through increased costs of water affecting the economy, loss of fresh water in some areas, effects on public health, civil unrest caused by disparities in access to and cost of water, adverse environmental impacts, and reduction of food production and consequent increase in cost. Participants believed that with action now, Texans can have a sustainable supply of safe water for all uses, including support of future growth in population and the economy.

Because the goal of the first water forum required a focus on water technology, participants also provided considerable insight on water technology development, despite their advice that technology alone was unlikely to solve the multiple problems identified as most important to securing Texas' water future. Participants urged continued development and implementation of water-smart technologies. In addition, water reuse should be expanded and supported by new technology along with creation of new markets for water residuals, such as for saline and gray water, and for water processing byproducts.

The key challenge for bringing technology to market was described as reducing the length of time it takes to bring technology products from the laboratory to general application. A need for reliable, unbiased evaluation of emerging and competing technologies also was identified. Participants identified fragmentation in the water sector and a dysfunctional system for water technology innovation. They believed a lack of adequate investment, with investors misunderstanding the current market environment, including inadequate and inaccurate valuing of water as a commodity, to be among the top constraints in moving technology to market and application. A high degree of regulation, not just over public safety concerns, but also across acquisition and supply chain management, was thought to obstruct bringing innovative water technology forward. Participants called for regulatory relief, industry standards, and accelerated research, development, demonstration, and deployment of new technology facilitated by technology-specific demonstrations.

Figure 2. Participants in working sessions at Forum I.

Forum II – Resource Nexus: Water, Energy, Food – Water Forum and Technology Roadmap

The second water forum was a two-day event that brought together 75 water experts, including many from outside of Texas. Participants were charged with enhancing discussion and improving understanding of the water-energy-food nexus in Texas. Topics addressed included identifying and responding to local, state, national, and global challenges and opportunities relative to water resources in research, education, outreach, and policy implementation. Other topics included seeking holistic solutions to water security in Texas and ways to engage water stakeholders in dialogues that will prevent to the extent possible, and otherwise resolve, conflicts over water-energy-food-related resources. The forum was timely because competition for water usage between food production, energy development, and general residual and commercial needs provides a compelling nexus globally. A striking example is found in the San Antonio region where a three-way demand on water resources for agriculture, hydraulic fracturing in energy production, and general residual and commercial use pull at a supply limited by natural availability, water quality concerns, and need for environmental flows in the region's streams.

The forum drew information and perspectives from a broad range of stakeholders, representing all aspects of the nexus community. It also engaged a comprehensive spectrum of the Texas A&M University System water experts currently working on aspects of the water-energy-food nexus. The Texas A&M University System already serves as a testbed for global efforts to bridge the gap between water availability and water demand, drawing on resources available at the Norman Borlaug Institute for International Agriculture, the Energy Institute, Texas A&M AgriLife Extension Service, the College of Engineering, the Bush School of Government and Public Service, a body of alumni working in the Texas water sector, and partnerships with government, business, and industry. Participants held a common interest in accelerating an understanding of nexus and related technologies.

There was consensus among participants on the consequences of failure to educate decision-makers and the public about water-energy-food, changes needed in education systems, barriers to action, and benefits if action is taken. There also was general agreement on what is most important to fix first and what needs to be done to fix it.

Strategic actions recommended during the forum's charrettes follow; specific examples, actions, and justifications are contained in the full report.

- Education and outreach is needed to develop understanding and support by the public for work on the water-energy-food nexus.
- Basic principles of the nexus as well as significance for future economic and environmental sustainability need to be taught to students through formal and informal educational means starting as early as possible and continuing through higher education.
- Technical and higher education must adapt their models for curricula development and research more quickly and place higher value on solution-based research and public-private-university partnerships to address nexus subject areas, related technologies, and workforce needs that accompany technology advancement. Participants believed that without such change, universities will become even less effective and increasingly irrelevant at meeting the needs for workforce education and become even farther removed from the technologies universities are helping create.
- Because responsibility for water, energy, and food programs is spread across many different work groups, agencies, colleges, departments, and other institutional divisions in government, industry, and universities, communication is critical among these separate responsible parties.
- Participants believed Texas' current legal and regulatory framework fails to fully reflect basic science (i.e., the fundamental physical processes) underlying the lifecycle of water and use by humans. They recommended education and outreach to create greater levels of awareness about the nexus, and for water in particular, to help pave the way for science-based policy change.

Figure 3. Kathleen Jackson, Texas Water Development Board member, addresses participants at Forum III.

- Universities and private research organizations should play a role as independent, unbiased evaluators of demonstrations of nexus-related technologies to accelerate commercialization and application.

Forum III – 2016 Texas Water Roadmap Forum: workforce education, data, and research

Focusing on workforce education, data, and several categories of research, the third water forum brought together more than 60 Texas water experts from technical, academic, research, management, and business backgrounds with a heavy emphasis on university sector participation (Figure 3). Participants were asked to envision a future Texas where water security is assured for people, industry, food production, and nature. They were then tasked through the charrette process to develop plans to set priorities for action and frame key milestones for progress with an overall goal of securing Texas' water future. Plenary sessions focused on state funding programs for water infrastructure development, such as the State Water Implementation Fund for Texas (SWIFT), and development of partnerships in water project financing, implementation, and related research. Four small-group charrettes were held to address four specific areas of focus identified in previous forums where progress can and must be made. These were (1) data management and information sharing; (2) workforce education; (3) research on water sources and transport; and (4) research on water use and enabling technologies. These charrettes were followed by two larger-group charrettes dedicated to examining funding and partnership opportunities available to take action in the areas identified by the smaller group charrettes. A short summary follows, with detail and listed points of action contained in the full report.

- In the area of data management, forum participants listed their vision for the future and actions to achieve the endpoints envisioned through enhanced data storage, use, and access. They concluded that governmental entities, but not any single one, are best suited to build and maintain water data platforms. They suggested a measured evolution by working through large-scale collaborations to create data repositories, develop standards and norms for the format and content of databases, and use big data analytic platforms and dashboards for data interpretation and visualization.
- For workforce education, participants recognized the challenges of meeting the needs of an industry rapidly evolving as new technologies and regulatory requirements change water workforce education requirements. They suggested students be offered a broader curriculum than is generally available through traditional civil engineering degree programs and supported establishing internships to provide students with experiential learning opportunities. They also advocated locally offered education for water industry jobs to address the need for the water workforce to be reflective of the society it serves and to meet the varying nature of water infrastructure of differently sized and rural communities.
- Participants listed and differentiated between research underway versus research that industry and government currently need. The two lists were markedly different, with only one broad area of overlap: desalination technologies and related energy demand. Participants from industry indicated a need for considerable research on human dimensions of water use and public understanding about water, while there was little indication of ongoing research at universities addressing these matters. There is a need for better communication among researchers, government, and industry, and coordination of needs and opportunities for research. Participants proposed follow-up response by forum attendees in 10 areas of water-related research or action: water planning, water availability, water policy and regulation, baseline data, use of big data, climate, identification of the body of existing information, local water supply and demand, meeting the water needs of society, and anticipating future needs.
- For funding and partnership development, participants believed that it will be more effective to work through existing partnerships than to create new ones. There is significant opportunity for new work on capital-related projects through the SWIFT and state revolving fund, with funding criteria flexible enough to allow for innovation on traditional water projects as well as development of water efficiency and conservation efforts that include the need for investment in capital infrastructure. Participants agreed to explore a series of collaborations, including two that received the greatest attention: (1) collaborating on a large-scale to improve dataset use and access, with the discussion to be hosted initially by the Texas Water Development Board; and (2) forming partnerships with small communities for new work on capital-related projects to help support community access to financing available through the SWIFT and the state revolving fund.

CONCLUSIONS AND FUTURE ACTIONS

The forums progressed from a point of departure initially focused on new water-related technology and how to accelerate the development of that technology from laboratory through marketing and on to industry application. It seemed like a relatively simple undertaking at the first forum to design a water technology roadmap to help advance Texas' water future. Participants were quickly confronted with the complexity of water, however, which frustrated completing that task as envisioned. The water sector is affected by historical, economic, social, environmental, political, regulatory, legal, and technological challenges. Furthermore, the water sector exists in a context of complexity, volatility, uncertainty, and ambiguity. The participants heard that many—perhaps most—of the problems the state faces in the water sector will not be solved through use of new technology. A different route emerged to help create a sustainable water future for Texas.

Critically important to Texas' water future is addressing obstacles such as undervaluation of water, counter-productive policies, old and failing infrastructure, inadequacy of higher education to adapt curricula to meet the needs for training the water workforce, failures to connect surface water and groundwater in policy and management, investment and market challenges, and compartmentalizing of just about everything related to water. All were considered impediments to achieving water security in Texas, while technology development was seen as providing new tools of value to achieve incremental gains.

Building on results of the first forum, the second focused on the nexus of water, food, and energy and how these coupled systems lack coherence at the policy, regulatory and organizational levels. This forum brought together participants from both within and beyond Texas to share their experiences. Despite the obvious linkages of water, energy, and food programs, education and research in these areas by the state's agencies, institutions, and industries are fragmented and generally unconnected. This lack of coherence thwarts implementation of truly sustainable solutions on the nexus of water, food, and energy. Current higher education systems are too slow in responding to the need for more integrated curricula in water degree programs, and they are failing to deliver job-ready workers for rapidly changing water industries. Participants expressed deep concern over a growing gap in public understanding about water matters, the water-energy-food nexus, a need to provide better outreach about water to all sectors of society, and the need for improved technical data storage and delivery industry wide.

The third forum explored challenges identified in the first two forums by attempting to further define communication, information management, data access and associated research regarding water resources. Forum participants also described needed improvements in education and training of a water workforce that will see considerable turnover and repositioning in the near future. This forum also brought a focus on available funding to address water development and partnership opportunities. This emphasis was made possible through support of the forum by the Texas Water Development Board and by examination of SWIFT and state revolving loan funds.

As a result of the road-mapping process, there has been action to follow through on initiatives outlined during the forums. In particular, a series of regional research projects on various aspects of the water-energy-food nexus in Texas are now underway and a grant from the National Science Foundation was received by the Texas A&M AgriLife Research and Extension, Texas A&M University-San Antonio, and University of California-Riverside to provide research on decision support for water stressed food-energy-water decisions, with much of the work to be centered in the San Antonio region. This initiative was driven in part by discussions at the second forum. A new water science and technology degree program now in the final approval process at Texas A&M University-San Antonio was conceived specifically to adapt to water workforce needs and resolve curriculum deficiencies noted by participants at all three forums. The new degree program was developed cooperatively with Northwest Vista College and the Texas A&M Engineering Extension Service, with recommendations from water sector experts at the forums on how to best structure a new water education program. Discussions have also begun around formation of a large-scale collaboration on improving dataset use and access. An initiative discussed at the third forum that may continue is initiation of discussions about support and partnerships with small communities for work on water project financing through SWIFT.

The forum reports may be among the most significant compendiums of impartial ideas available today to support accelerating growth of water infrastructure, technologies, industries, and sustainable water use to provide a secure water future for Texas. Although there has been progress on implementing specific recommendations on the water-food-energy nexus, workforce education, and data management, there were many other recommendations arising from the forums where progress has been more limited. Recognizing the importance and sensibility of acting on the shared recommendations, additional effort is needed by industry, government, academia, and the investment community to secure funding and stakeholder support required for continued implementation.

As a next step, the originally envisioned water roadmap should be completed. The forums have provided much of the basic information on essential areas of focus to get the process underway. A concise and clearly articulated roadmap can serve as a tool for communicating the broad-based consensus regarding water-related issues and means to resolve those issues. Although work toward achieving the recommendations has been modest to date, the high level of consensus on the need for and form of action on many of the matters identified at the forums has established a solid foundation for moving forward. Already, we have seen where action on the nexus, workforce education, and data management may have been hastened along by the forums. In other cases, activity may have been initiated with no specific connection to any particular forum. An example of such work may be the emphasis on better characterizing surface water and groundwater interactions, flows, and availability.

At the end of the final forum, the lead facilitator reflected on all three by urging participants to engage in one or two of the tangible action plans outlined in the forums. He advised that it would be impossible to solve all the issues identified through the series of one- and two-day forums. He suggested that even if the forums only resulted in efforts to address one, two, or three of the many challenges presented by participants, the forums will have been successful. With work underway on the water-food-energy nexus, workforce education, and data management, some measure of success is already assured.

The forums provided a wealth of information that can be used by any party to explore pathways for beneficial action on water in Texas in combination with, or in addition to, existing plans and action. Building a roadmap is a time- and resource-intensive process. Roadmaps are often used as a means to display and simplify complex processes where stakeholders help create consensus around performance targets, pathways, linkages, assets, priorities, obstacles, and time frames for research, development, demonstration, and deployment. Given the extent and complexity of information now available from the three forums, development of a water roadmap for Texas remains a reasonable goal should sufficient resources become available to support it.

Regardless of how results of the forums may be organized in the future, the forums have assembled basic information of importance about Texas water that is available nowhere else. Participants came from throughout the water sector to work collegially together without political or industry sector agendas. The forums were managed and documented in a similar fashion, with neutral facilitators and objective reporting. The result is an impartial listing of positive actions that can be taken to solve pressing needs in the various parts of the water sector in Texas. Information in the forum reports, participant consensus, and statements of action are compelling and constitute a call for action, along with basic directions on how to proceed forward.

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