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THE TEXAS WATER JOURNAL is an online, peer-reviewed journal devoted to the timely consideration of Texas water resources management 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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Cover photo: As Texas continues to face water challenges and drought, many communities are seeking to conserve water in various sectors, including lawn and landscape water use. ©Jose Manuel Gelpi Diaz, Crestock

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Effects of an off-stream watering facility on cattle behavior and instream *E. coli* levels

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Abstract: Excessive levels of fecal bacteria are the leading cause of water quality impairment in Texas, and livestock with direct access to water bodies are potentially a significant source of these bacteria. To help address this, the effect of providing alternative off-stream watering facilities to reduce manure, and thus bacterial, deposition in or near surface waters was evaluated from July 2007 to July 2009 in Clear Fork of Plum Creek in central Texas. An upstream-downstream, pre-treatment, and post-treatment monitoring design was used with off-stream water provided only during the second year of the study. Flow, *Escherichia coli* (*E. coli)* concentration, and turbidity were measured twice monthly. Cattle movements were tracked quarterly using global positioning system collars to assess the effect of providing alternative water on cattle behavior. Results showed that when alternative off-stream water was provided, the amount of time cattle spent in the creek was reduced 43%. As a result, direct deposition of *E. coli* into Clear Fork of Plum Creek was estimated to be reduced from 1.11×10^7 to 6.34×10^6 colony forming units per animal unit per day. Observed pre-treatment and post-treatment instream *E. coli* loads suggested similar reductions; however, these reductions were not statistically significant.
Keywords: cattle, *E. coli,* GPS collars, off-stream water, best management practice

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Terms used in paper

Short name or acronym	Descriptive name
AU	animal unit
BMP(s)	best management practice(s)
cfu	colony forming units
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GPS	global positioning system
TMDL	total maximum daily load
USGS	United States Geological Survey

INTRODUCTION

Livestock with direct access to water bodies have been identified as significant sources of bacteria in numerous bacterial total maximum daily loads (TMDLs) in Texas (TCEQ 2007a, 2007b). Because excessive levels of fecal indicator bacteria (*Escherichia coli* [*E. coli*], *Enterococcus*, and fecal coliforms) are the number one cause of water quality impairment in Texas, causing 295 of the 516 water quality impairments in the state (TCEQ 2008), and beef cattle production is the largest agricultural enterprise in Texas, it is critically important to identify effective and accepted management practices that address potential contributions. In the Plum Creek watershed, where this study takes place, there are an estimated 33,000 beef cattle, representing the primary class of livestock. Because livestock are often the easiest potential agricultural source to manipulate to reduce bacterial loads, the Plum Creek Watershed Protection Plan targeted agricultural nonpoint source management measures addressing the potential impact of animals grazed near streams or drainage areas or those permitted direct access to stream and riparian corridors (Berg et al. 2008).

Cattle are drawn to streams and adjacent riparian areas by water, shade, and the quality and variety of forage present (Kauffman and Krueger 1984). The length of time cattle spend in a stream, however, plays a significant role in potential fecal contamination (Mosley et al. 1999). When cattle have stream access, a portion of their fecal matter is deposited directly into the stream (Larsen et al. 1988) and can be a significant source of contamination. Gary et al. (1983) observed that cattle spent 5% of the day in or adjacent to the stream and that 6.7% to 10.5% of defecations were deposited directly in the stream. Feces deposited in streams have a greater impact on water quality than that deposited away from streams. Larsen et al. (1994) found that manure deposited 0.6 meters and 2.1 meters from a stream contributed 83% and 95% less bacteria, respectively, than that deposited directly in a stream.

Tiedemann et al. (1987) and Mosley et al. (1999) suggested that animal access to streams had a greater impact on stream bacterial levels than stocking density. Thus, riparian protection is needed to reduce manure deposition in or near surface waters (Ball et al. 2002). Exclusion of livestock from riparian areas by fencing of streams is frequently recommended to reduce manure inputs to surface water (Godwin and Miner 1996; McIver 2004). Numerous studies have shown that fencing of streams, alone or in combination with other best management practices (BMPs), can reduce *E. coli* levels by 37% to 46% (Meals 2001, 2004), *Enterococcus* by 57% (Line 2003), and fecal coliforms by 30% to 94% (Brenner et al. 1994; Brenner 1996; Cook 1998; Hagedorn et al. 1999; Lombardo et al. 2000; Meals 2001,; Line 2002; Line 2003; Meals 2004). However, exclusionary fencing is costly to install and maintain (Godwin and Miner 1996; Sheffield et al. 1997; Byers et al. 2005), results in loss of grazing area and ranching income, restricts access to reliable water sources, and may be inconvenient and impractical for many ranches. Thus, many ranchers oppose it (McIver 2004). Other concerns have recently been raised regarding the impact of increasing wildlife populations in fenced riparian zones, potentially negating *E. coli* loading reductions provided by restricting livestock access (Hagedorn 2012).

Another practice available to protect riparian areas and reduce manure deposition in or near surface waters is the development of alternative watering facilities (FCA 1999; Tate et al. 2003; Byers et al. 2005). A permanent or portable off-stream water supply provides livestock another drinking water source, which can be used alone or in conjunction with other practices to reduce the time livestock spend near surface waters and in riparian areas. To achieve optimum uniformity of grazing and the greatest use of alternative water sources, cattle should not have to travel more than 200 to 300 meters to water (McIver 2004). Alternative water sources benefit livestock producers by improving grazing distribution, reducing herd health risks caused by drinking or standing in contaminated water, decreasing herd injuries from cattle traversing steep or unstable streambanks, increasing water supply reliability during droughts, and increasing weight gains in beef cattle by 0.1 to 0.2 kilograms/day (Willms et al. 1994; Buchanan 1996; Porath et al. 2002; Willms et al. 2002; Veira 2003; Dickard 1998).

Alternative off-stream water supplies can also provide environmental benefits including reduced manure deposition and bacterial contamination of surface waters and reduced streambank destabilization and erosion due to trampling and overgrazing of banks. Previous research demonstrated that cattle spent 85% to 94% less time in streams (Miner et al. 1992; Clawson 1993; Sheffield et al. 1997) and 51% to 75% less time within 4.6 meters of streams when an off-stream watering facility was available (Godwin and Miner 1996; Sheffield et al. 1997). As a result, Godwin and Miner (1996) suggested that under baseflow conditions, off-stream watering was nearly as effective as fencing in reducing manure inputs to surface water, thus reducing water quality impacts of grazing cattle at a reduced cost. Sheffield et al. (1997) confirmed this, finding that as a result of the reduction in time cattle spent in and near streams, instream fecal coliform concentrations were reduced by an average of 51%. However, results varied among sites with statistically significant reductions in fecal coliform levels of 99%, 87%, and 57% being observed at 3 sites and a 53% increase, which was not statistically significant, being observed at 1 site. Further, Byers et al. (2005) found that providing water troughs decreased the amount of time cattle spent within 12 meters of a stream, but that the result was dependent on time of year with a reduction of 40% observed in March 2002, 96% in December 2002, and approximately 60% in July 2003. Byers et al. (2005) also found that although alternative water did not impact stormwater *E. coli* concentrations, median baseflow *E. coli* loads decreased 95% in 1 pasture and 85% in another when water troughs were available. However, as a result of drought, streamflow was 51% smaller in the second year of the study when the troughs were available, thus impacting the load differences.

With the exception of the study conducted by Byers et al. (2005), which used global positioning system (GPS) collars, previous studies used light beam counters (Godwin and Miner 1996), visual observations (Miner et al. 1992; Sheffield et al. 1997), and time-lapse cameras (Clawson 1993) to evaluate cattle behavior during daylight hours. However, nighttime observations can be critical because cattle exhibit bimodal grazing patterns (early morning and evening) with certain breeds spending a greater portion of the night grazing as compared to daytime (Pandey et al. 2009). The use of GPS and geographic information system (GIS) technology allows livestock behavior to be evaluated with greater spatial and temporal resolution. Animals can be tracked 24 hours a day using GPS receivers incorporated into animal collars (Pandey et al. 2009). Agouridis et al. (2005) evaluated GPS collars to determine accuracy for applications pertaining to animal tracking in grazed watersheds and found the collars were accurate within 4 to 5 meters and thus acceptable for most cattle operational areas (Pandey et al. 2009).

Observation periods of these earlier studies were also generally of short duration, focusing on specific seasons. These studies also targeted the Pacific Northwest (Miner et al. 1992; Clawson 1993; Godwin and Miner 1996), Eastern (Sheffield et al. 1997), and Southeastern United States (Byers et al. 2005). These are regions with conditions different from much of Texas and the mid-section of the country where a majority of U.S. cattle production occurs. Finally, these studies, with the exception of Byers et al. (2005), did not evaluate the impacts of off-stream water on *E. coli* levels, which are the focus of most TMDLs in Texas. Therefore, the objectives of this study were to assess the effect of providing an off-stream watering facility on reducing the percent time cattle spend in streams and riparian zones and the level of bacterial contamination of streams. Stakeholders, natural resource agencies, and others working to improve water quality need this information not only to better understand the effectiveness of alternative water as a water quality BMP but to improve the predictive capabilities of water quality models used for TMDLs and watershed-based plans. The results are applicable to Texas, the mid-section of the United States, and other regions around the world with similar climates and grazing systems.

MATERIALS AND METHODS

Site description

This study was conducted on a commercial cow-calf operation located in Caldwell County, Texas, bisected by Clear Fork of Plum Creek. Although the drainage area above the ranch is only 26 square kilometers, Clear Fork of Plum Creek is typically a perennial stream as a result of a number of springs. The creek is 0.3 to 10.3 meters wide and less than 1 meter deep. Thus, the creek is generally not of sufficient depth for cattle to cool off in. The average slope of the stream is 0.3% while the average slope perpendicular to the stream is 5.4%. Clear Fork of Plum Creek is a tributary of Plum Creek, which is listed on the 303(d) List as impaired by excessive levels of *E. coli* and is the focus of watershed restoration efforts through a watershed-based plan.

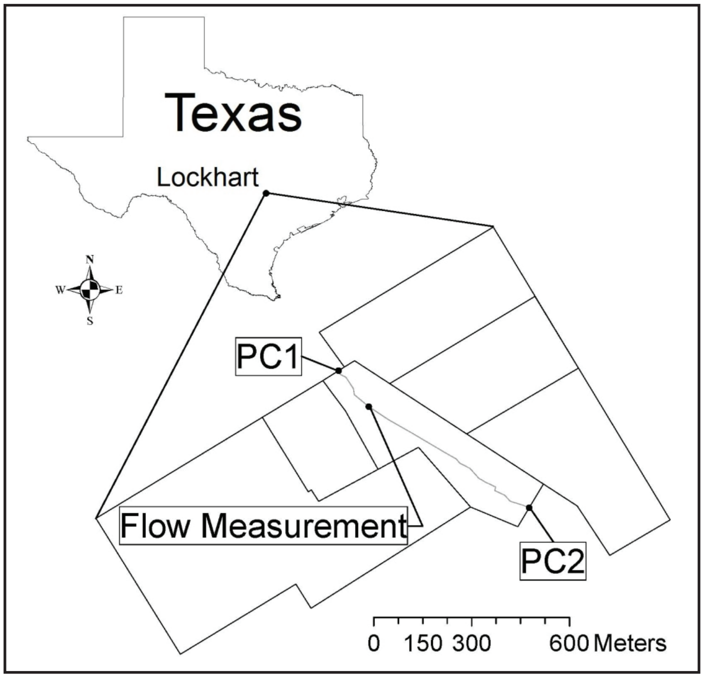
The ranch is in the Texas Blackland Prairies Ecoregion (Omernik 1987) where annual precipitation averages 89 centimeters. However, as the result of a severe drought, which began in the spring of 2008, only 56 centimeters of rainfall was received in Year 1 and 40 centimeters received in Year 2. Average annual temperatures were normal (20 °C) in Year 1 and higher than average (20.6 °C) during Year 2.

The flood plain soils along the creek are dominated by the Tinn series, a very deep, moderately well-drained, very slowly permeable soil formed in calcareous clayey alluvium. Upgradient of the Tinn soil is the Branyon clay, which, like the Tinn soil, is a very deep, moderately well-drained, very slowly permeable soil. Finally, soils in the upland areas of the ranch are comprised of Lewisville soils, very deep, well-drained, moderately permeable soils on slopes of 0% to 10% (Soil Survey Staff 2011).

The predominant forage in the creek pasture is common bermudagrass (*Cynodon dactylon* L.). Vegetation in the 3 off-creek pastures (Figure 1) is WW-B Dahl Bluestem (*Bothriochloa bladhii* L.), Old World Bluestem (*Bothriochloa ischaemum* L.), and native grasses. Vegetation along the creek consists primarily of common bermudagrass with few trees or other typical riparian vegetation present. Less than 5% of the stream and its riparian area is shaded; thus, shade is not a major attractant of cattle to the creek and riparian zone. With the exception of the creek pasture, most of the operation was in row crop production until 2003 when it was converted to pastureland in 2004.

The site of this study has many similarities to that of the Byers et al. (2005) study with a few notable exceptions. In general, stream slopes, forages present, and the climate of both sites are very similar. Daily highs and lows in this study area are on average only 2 °C and 3 °C warmer, respectively, than those of Byers et al. (2005). Rainfall is on average 28.9 centimeters lower in this study area compared to those of Byers

Figure 1. Pasture configuration, water sample collection sites, and flow measurement site at cooperating ranch near Lockhart, Texas.



et al. (2005) and as such, humidity is on average lower in this study area, as well. The most notable difference between study areas is the amount of riparian vegetation. In this study, riparian shade was present in less than 5% of the riparian area, whereas it comprised 78% to 85% of the riparian area of Byers et al. (2005). This is not surprising as the region of Byers et al. (2005) study was primarily forested (94% forested) whereas the region of this study was primarily comprised of crop and grass lands with only 14% forested.

Pasture management

Four pastures, ranging in size from 12 to 15 hectares were used during the study (Figure 1). Cattle had complete and continuous access to the creek and creek pasture throughout the study. Cattle were allowed access to the other pastures as needed. During the first year of the study (July 2007–July 2008), pastures were stocked with 54 crossbred cows with calves and 2 bulls (57 animal units [AUs]). During the second year of the study (July 2008–July 2009), the pastures were stocked with 72 cows with calves and 3 bulls (76 AUs). The stocking rate was increased in the second year as the cooperating landowner consolidated herds from 2 ranches in response to the severe drought, making feeding, watering, and caring for the livestock easier until conditions improved. Water troughs supplying well water were present in all pastures but were turned off during the first year of the study (with the exception of 2 weeks in January 2008), forcing the cattle to water in the creek only. In January 2008, several calves became ill with bovine respiratory disease and water troughs were activated for a period of 2 weeks then turned off again and remained off until July 6, 2008. The troughs were turned on for the second year of the study and provided cattle an alternative water source. Distance between the water trough and stream in the creek pasture was approximately 137 meters.

GPS tracking of cattle

Each quarter throughout the 2-year study, 6 to 8 randomly selected cows were collared with Lotek® GPS 3300LR collars (Lotek Wireless Inc., Newmarket, Ontario, Canada). The collar manufacturer reports that, with differential correction applied, horizontal accuracies of position readings have errors less than 5 meters. Positional readings were collected at a 5-minute fixed interval, providing up to 6,624 locations by each collar each quarter. Cattle movement was tracked for 21 to 23 days, and then the collars were removed.

Collar data were downloaded using Lotek host software and differentially corrected using data from the nearest National Geodetic Survey Continuously Operating Reference Stations base-station. Differentially corrected collar data were then combined with sensor data and converted to database files for analysis.

To analyze positional readings collected from the GPS collars, ArcView (ArcGIS 9, ArcMap Version 9.2, ESRI, Redlands, CA) software was used. For each collar, the number of positional points in the stream—within 0.6 meters of the midpoint of the stream and within 4.6 meters of the stream—were determined using the "Select by Location" function. Percent time spent within each distance from the stream was determined by dividing the number of positional points within each buffer by the total number of positional readings taken. Percent time was then converted to minutes per day.

Instream sampling procedures

Sites located at the inflow and outflow of Clear Fork of Plum Creek to the ranch, PC1 (29°53'35.81"N/97°45'21.06"W) and PC2 (29°53'23.28"N/97°45'2.67"W), respectively, were monitored to assess effectiveness of alternative off-stream water (Figure 1). These sites are approximately 0.8 kilometers apart. Grab samples were collected and analyzed on a semi-monthly basis at both sampling sites when water was flowing. Water samples were collected directly from the stream, midway in the water column into sterile Whirl-Pak® bags. Bags were held upstream of the sampler and care exercised to avoid contact with sediment and the surface micro layer of water. After collection, samples were placed on ice for transport to the lab where they were stored at 4 °C until analysis.

Flow calculation

Flow depth was measured semi-monthly in conjunction with water sample collection. Measurements were made in a 0.9 meter corrugated metal culvert located at a stream crossing 0.16 kilometers below PC1 and 0.64 kilometers above PC2. Manning's equation (Grant 1991) was used to estimate flow rate for each sampling event. The Manning roughness coefficient (n) was determined from field measurements of flow depth and velocity and compared to published values by Grant (1991) for corrugated metal subdrains. Slope (S) from PC1 to PC2 was determined using field evaluation of slope. Area (A) and hydraulic radius (R) were obtained from published values (Grant 1991) based on the observed depth (d) in relation to the culvert depth (D).

Analytical methods

Water sample analysis was conducted within 6 hours of collection. *E. coli* in water samples were enumerated using U.S. Environmental Protection Agency (EPA) Method 1603 (EPA 2006). If counts were greater than 200 colonies at the highest dilution, the count was reported as too numerous to count. Results were reported as colony forming units (cfu) per 100 milliliters. Finally, an AquaFluor™ Handheld Fluorometer/Turbidimeter (model 8000-010, Turner Designs, Sunnyvale, CA) was obtained in February 2008 allowing measurement of turbidity throughout the remainder of the study. Turbidity measured in water samples was reported in nephelometric turbidity units.

Additionally, to approximate deposition of *E. coli* in the stream before and after alternative off-stream water was provided, percent time spent by cattle in the stream as determined by the GPS collars was multiplied by published fecal coliform production values (5.4×10^9 cfu/AU/day) (Metcalf and Eddy 1991) and then converted to *E. coli* concentrations by multiplying the result by 0.63 as EPA suggests (Hamilton et al. 2005).

Evaluation of *E. coli* loads

Flow rate at the time of each grab sample was assumed to represent the daily average (cubic meters per second). These flow rates, along with the *E. coli* concentrations, were used to estimate the daily loads for the upstream and downstream sites, PC1 and PC2 respectively. The daily load contributed by the study area was calculated by subtracting the upstream load from the downstream load (PC2 – PC1). This was converted to an AU basis by dividing the daily loads contributed by the study area by the number of AUs present in the study area during the respective period (57 AUs during Year 1 and 76 AUs during Year 2).

Statistical analysis

The statistical software, Minitab (Minitab Inc., State College, Pennsylvania), was used for all statistical calculations. Basic statistics and graphical summaries of each dataset were created to evaluate means, medians, quartiles, confidence intervals, and normality using the Anderson-Darling Normality Test. As a majority of datasets were not normally distributed, they were evaluated with nonparametric statistics. The Mann-Whitney statistical test was used to assess the differences in median (1) minutes cattle spent per day instream and within 4.6 meters of the creek; (2) flows; (3) *E. coli* concentrations; (4) *E. coli* loads from the study area; and (5) turbidities observed between sites and/or periods (with versus without alternative water). An alpha level of 0.05 was used as the level of significance, thus results were considered statistically significant when $p < 0.05$. Regression analysis was used to evaluate the relationship between *E. coli* concentrations at PC1 and PC2, as well as between *E. coli* concentrations and turbidity. Coefficient of determination values were used to evaluate the strength of regression equations for *E. coli* concentrations. Finally, analyses of covariance were developed using the Minitab General Linear Model, specifying the responses as PC2 turbidity, the model as the treatment period (with alternative water) or calibration period (without alternative water), and the covariate as PC1 turbidity.

RESULTS AND DISCUSSION

GPS tracking of cattle

Comparison of the amount of time cattle spent in and near the creek with and without alternative water indicated that providing alternative off-stream water reduced the time cattle spent in the stream and within 4.6 meters of the creek (Figure 2).

Because shade along the riparian zone was limited (< 5%) and stream depth was not suitable for cooling, it can be assumed that observed reductions resulted from cattle drinking from the alternative water supply and not the stream. Analysis of the GPS collar data (Table 1) indicated that providing alternative off-stream water significantly reduced the median amount of time cattle spent in and near the creek ($p < 0.01$).

The amount of time cattle spent within 4.6 meters of the creek was reduced 52% from 25 to 2 minutes/AU/day when provided with off-stream water, compared to the 75% reduction from 15 to 4.25 minutes/AU/day found by Godwin and Miner (1996) and 51% reduction from 12.7 to 6.2 minutes/AU/day found by Sheffield et al. (1997). Although the percent reductions from this study were similar to those of Sheffield et al. (1997), the amount of time cattle spent near the stream varied substantially between the studies.

Further, this study found that providing alternative off-stream water reduced stream use from 3.0 to 1.7 minutes/AU/day, compared to reductions from 25.6 to 1.6 minutes/AU/day (Miner et al. 1992), 4.7 to 0.7 minutes/AU/day (Clawson 1993), and 6.7 to 0.7 minutes/AU/day (Sheffield et al. 1997). Based on the percent time cattle spent in the stream (as determined by the GPS collars), along with published fecal coliform loading rates (Metcalf and Eddy 1991) and the *E. coli* conversion factor suggested by EPA (Hamilton et al. 2005), we estimated the median daily deposition of *E. coli* in the stream was reduced from 1.11×10^7 cfu/AU/day to 6.3×10^6 cfu/AU/day when alternative water was provided.

The reduction in the percent time cattle spent in the stream observed by this study (43%) was half the reductions of 85% to 94% observed by previous studies (Miner et al. 1992; Clawson 1993; Sheffield et al. 1997). Additionally, the amount of time cattle spent in the stream varied substantially among studies from 3 minutes per day in this study to almost 26 minutes per day (Miner et al. 1992) indicating the site-specific nature of this measurement. Stream width, depth, accessibility, and adjacent shade play a major role in the amount of time cattle spend in and near streams, and thus the percent reductions achievable by providing alternative water. As such, TMDLs and other watershed studies that use percent time cattle spend in streams for assessing direct deposition rates would benefit from GPS collars studies to validate models. For example, it was estimated by Orange County, Texas, TMDL stakeholders that, on average, cattle drinking water from bayous spend 10 minutes per day in the stream during June, July, August, or September, and 5 minutes per day in March, April, May, October, and November, but that cattle did not stand in the bayous to drink from December through February (TCEQ 2007a). Using these assumptions from the TMDL, cattle spend 5.4 minutes/day in the stream on average overall throughout the year. Although this estimate is within the range observed by previous studies, it is 80% higher than the findings of this study, potentially overestimating the bacterial loading allocated to direct deposition from cattle into the creek. Because of this, evaluation of the time cattle spend in impaired water bodies using GPS collars or other suitable methods is suggested for development of TMDLs and other

Figure 2. Time (minutes/AU/day) that cattle spent in and near (within 4.6 meters) Clear Fork of Plum Creek with and without alternative off-stream water provided. The boundary of the box closest to zero indicates the 25th percentile, the solid line within the box represents the median, the dashed line represents the mean, the boundary of the box farthest from zero indicates the 75th percentile, the whiskers above and below the box indicate the 10th and 90th percentiles, and the circles indicate data points beyond the 10th and 90th percentiles.

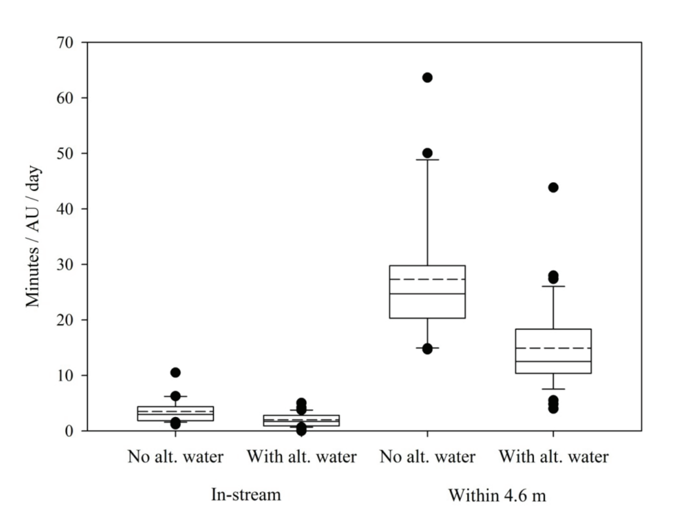


Table 1. Descriptive statistics of time, in minutes/day and percent of day (in parenthesis) that cattle spent in and near Clear Fork of Plum Creek with and without alternative off-stream water provided.

Distance from creek	Statistic	No alternative water min/day (%)	With alternative water min/day (%)	Percent reduction
Instream	Mean	3.5 (0.2%)	2.0 (0.1%)	
	sd	2.2 (0.1%)	1.2 (0.1%)	
	Median*	3.0 (0.2%)a	1.7 (0.1%)b	43%
	Max	10.5 (0.7%)	5.0 (0.3%)	
4.6 m	Mean	27 (1.9%)	15 (1.0%)	
	sd	12 (0.8%)	8 (0.6%)	
	Median*	25 (1.7%)a	12 (0.8%)b	52%
	Max	64 (4.4%)	44 (3.1%)	

*For each site, medians followed by same letter are not significantly different ($p < 0.05$).

watershed planning projects in order to improve the accuracy of associated water quality models.

Flow

Two continuously monitored United States Geological Survey (USGS) flow gages are located on Plum Creek, 1 at Lockhart and 1 at Luling. Flows at the USGS station at Lockhart are heavily influenced by wastewater discharges and, as such, were not well-correlated with those observed in Clear Fork of Plum Creek ($r^2 = 0.17$). However, observed flows were well-correlated ($r^2 = 0.79$) with Plum Creek flows at Luling (Figure 3).

Median streamflow observed during Year 2 (0.003 cubic square meters/second) was significantly lower ($p < 0.001$) than that observed during Year 1 (0.014 cubic square meters/second). From the spring of 2008 through the end of the study, the region experienced a severe drought (Figure 4). As a result, during the second year of the study when alternative water was provided, flow was reduced 79% compared to that observed during the previous year. Flow ceased in the creek for 3 months during Year 2 (mid-September–October 2008 and June 2009–July 2009).

This drought not only impacted flow but also impacted ranch management decisions (resulting in the increased stocking rate during Year 2), pasture condition (resulting in decreased forage availability and groundcover during Year 2), and ultimately instream *E. coli* levels and loading.

E. coli concentrations

A total of 84 samples were collected from the 2 water-sampling sites (PC1 and PC2), of which 48 were collected during Year 1 (July 2007 to July 2008) and 36 during Year 2 (July 2008 to July 2009). Fewer samples were collected during Year 2 as a result of periods with no streamflow as previously noted.

E. coli concentrations at PC2 were correlated with those at PC1 throughout the study ($p < 0.01$), indicating that inflowing *E. coli* concentrations significantly impacted *E. coli* concentrations at the downstream site. Further, coefficient of determination values were moderate to high for both Year 1 (r^2=0.58) and Year 2 (r^2=0.83). However, *E. coli* concentrations increased between PC1 and PC2 during both years (Figure 5), indicating that loading from the study area contributed to *E. coli* concentrations at the downstream site (PC2). During Year 1, median *E. coli* concentrations increased 73 cfu/100 milliliters ($p = 0.09$) from 88 cfu/100 milliliters at PC1 to 161 cfu/100 milliliters at PC2. During Year 2, the increase of 323 cfu/100 milliliters from 147 cfu/100 milliliters at PC1 to 470 cfu/100 milliliters at PC2 was significant ($p = 0.01$).

This increase during Year 2, when alternative water was provided, was unexpected and inconsistent with the estimated 43% reduction in direct deposition of *E. coli* calculated based on the GPS collar data. The extreme drought that reduced flows by 79% and influenced ranch management decisions to increase stocking rate 34% provide an explanation for much of this increase. With more cattle having access to the creek and less flow to dilute any direct deposition, it would be expected that concentrations would increase, even with the decreased amount of time cattle spent in the stream during Year 2. Based on Year 1 cattle numbers (57 AU), median flow (0.014 centimeters), and estimated median daily deposition of *E. coli* in the stream (1.11×10^7 cfu/AU/day), it was calculated that direct deposition would contribute 52 cfu/100 milliliters to the median inflowing (PC1) concentration (88 cfu/100 milliliters); therefore, inflowing *E. coli* and direct deposition together (140 cfu/100 milliliters) represent an estimated 87% of the median *E. coli* concentration observed at PC2 during

Figure 3. Comparison of flows measured in Clear Fork of Plum Creek to those measured at USGS gage at Luling, Texas.

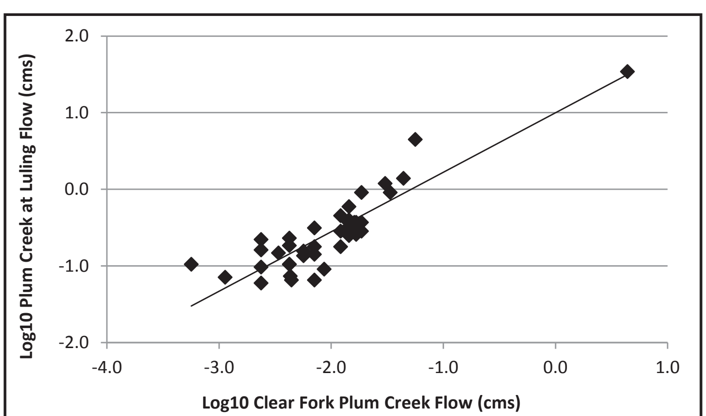
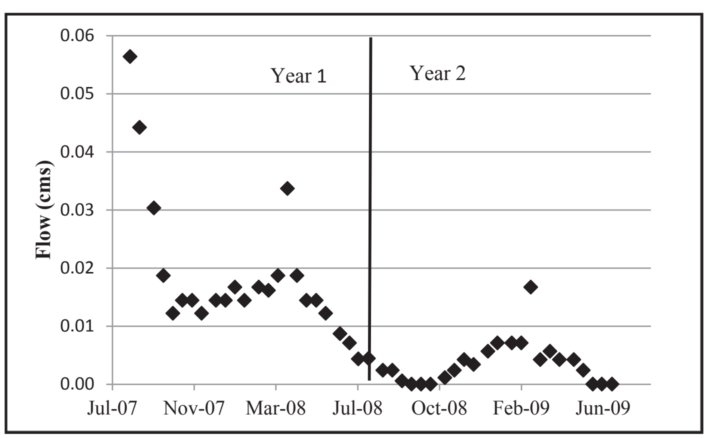


Figure 4. Discharge (centimeters) measured in Clear Fork of Plum Creek, July 2007–July 2009. Discharge measured on July 26, 2007, of 4.38 centimeters (154.83 cfu) is not shown.



Year 1 (161 cfu/100 milliliters). Using the same method for Year 2, it was calculated that direct deposition would contribute 186 cfu/100 milliliters to the median inflowing (PC1) concentration (147 cfu/100 milliliters); therefore, inflowing *E. coli* and direct deposition (333 cfu/100 milliliters) represent an estimated 71% of the median *E. coli* concentration observed at PC2 during Year 2 (470 cfu/100 milliliters).

This evaluation suggests inflowing *E. coli* concentrations, direct deposition by cattle, and reduced dilution resulting from reduced flow all contributed to the *E. coli* concentrations at PC2; however, they do not fully explain the concentrations observed. Approximately 13% of the *E. coli* during Year 1 and 29% during Year 2 are unaccounted for. A portion of the unaccounted *E. coli* likely results from the variability observed in the *E. coli* concentrations. *E. coli* concentrations were highly variable, with standard deviations often exceeding mean *E. coli* concentrations (Harmel et al. 2010; Wagner et al. 2012). Natural variability in *E. coli* concentrations resulting from the complex nature of bacterial deposition, survival, and transport is likely a significant factor in determining the observed *E. coli* concentrations (Harmel et al. 2010). Due to the drought and resulting increased stocking rate, degraded pasture conditions, and reduced flows during Year 2, significant changes in the fate and transport of *E. coli* likely occurred making comparisons of the 2 years difficult.

Measurement uncertainty may have also contributed to data variability. McCarthy et al. (2008) found that combined uncertainty in discrete *E. coli* samples ranged from 15% to 67% and averaged 33%. However, because the field technician, collection methods, lab analyst, and lab methods used were consistent throughout the study, this impact is considered to be consistent across sites and years.

Finally, although not quantified, increased use of the creek by wildlife during the drought could have also impacted *E. coli* concentrations during Year 2. It is logical that wildlife would increasingly use the creek as other water sources in the area were depleted. Thus, even though use of the stream by cattle as documented by the GPS collars decreased significantly when alternative water was provided, increased wildlife use likely contributed to the overall increase in *E. coli* concentrations as well. Further, as noted by Hagedorn (2012), removal of livestock can open areas to more wildlife contributions. Thus, it is a possibility that with cattle spending more time further from the stream, possibly more wildlife inhabited the riparian area as well.

E. coli loading

Contrary to the *E. coli* concentration results, daily *E. coli* loading to the stream per animal unit in the study area (cfu/AU/day) was substantially lower during Year 2 when alternative water was provided (Figure 6). These contradictory results are likely a result of the lower flows observed in Year 2. The median *E. coli* load in Year 2 (6.2×10^6 cfu/AU/day) was 57% lower than in Year 1 (1.44×10^7cfu/AU/day); however, the observed difference was not significant ($p = 0.47$). As a result of the variability in the daily loading observed during Year 1, a 99% change in loading or greater would have been required to observe a significant difference in the loadings between years. Despite this, these results are remarkably similar to the estimated Year 1 and 2 *E. coli* depositions in the stream of 1.11×10^7 and 6.34×10^6 cfu/AU/day, respectively, calculated using the GPS collar data and published fecal coliform data.

Even though observed *E. coli* loading and those estimated using GPS collar data are remarkably similar and both indicated reductions of more than 40%, this study cannot con-

Figure 5. *E. coli* concentrations at PC1 and PC2 in Year 1 (no alternative water provided) and Year 2 (alternative water provided).

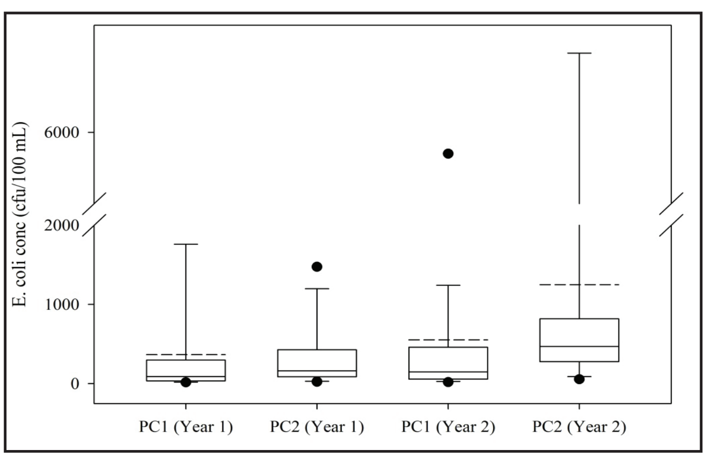
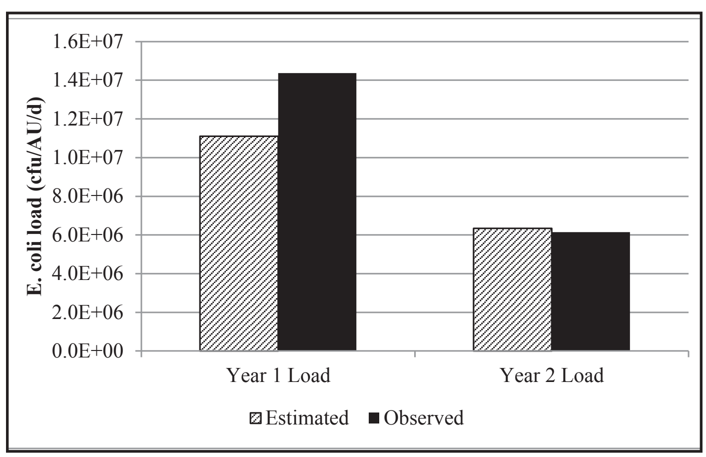


Figure 6. Estimated and observed instream *E. coli* loading (cfu/AU/day) during Year 1 (no alternative water) and Year 2 (alternative water provided).



clusively attribute *E. coli* loading reductions to the alternative water source because of the confounding influence of increased stocking rate, decreased streamflow, and likely increase in wildlife presence, which all contributed to increased *E. coli* concentrations in Year 2.

Turbidity

Median turbidity levels (Table 2) were typically 40% higher at PC1 than at PC2 indicating turbidity generally improved as the creek flowed through the ranch; however, differences were only significant for Year 1 ($p < 0.01$). Much of the observed turbidity at PC1 likely arose from a low water crossing located approximately 0.5 kilometers upstream of the site. Turbidity levels flowing into the study area played a greater role in determining the levels at PC2 during Year 2. During Year 2, turbidity at PC1 and PC2 were correlated ($p = 0.01$; r^2=0.36), unlike Year 1 when no correlation between sites was observed ($p = 0.98$, r^2=0.00). Analysis of covariance between observed turbidities in Years 1 and 2 indicated no significant treatment effect resulted from providing alternative water ($p = 0.93$).

Turbidity was primarily measured to evaluate its use as a predictor of *E. coli* concentration, as streambed sediment disturbance is suspected to influence *E. coli* levels (Jackson et al. 2011). However, regression analysis results indicated turbidity was not a good predictor of *E. coli* concentrations in Clear Fork of Plum Creek ($p = 0.51$; r^2=0.01). Similarly, McDonald et al. (2006) did not observe a significant correlation between fecal *enterococci* and turbidity. This differs from the findings of Huey and Meyer (2010) that turbidity is an effective predictor of *E. coli* in the upper Pecos River Basin in New Mexico. Collins (2003) developed a statistical model to determine median *E. coli* concentrations based on turbidity that explained 70% of the observed *E. coli* variance. Similarly, Brady et al. (2009) found that a model based on turbidity and rainfall performed well at predicting *E. coli* levels (81% correct responses) in the Cuyahoga River, Ohio. Thus, turbidity does have utility as a predictor in some watersheds; however, this should be determined on a case-by-case basis and used with caution.

Table 2. Turbidity levels, in nephelometric turbidity units, measured at PC1 and PC2 during Years 1 and 2.

Period	Statistic	PC1	PC2
Year 1	Mean	35	17
	sd	20	8
	Median*	29a	16b
	Max	62	31
Year 2	Mean	14	12
	sd	11	13
	Median*	10a	6a
	Max	43	47

*For each site, medians followed by same letter are not significantly different (α =0.05).

SUMMARY AND CONCLUSIONS

Use of GPS collars was found to be a very useful tool, one that would benefit not only future BMP evaluations but also TMDL studies that use percent time cattle spend in streams for assessing direct deposition rates. Performing GPS collar studies can enhance water quality models, allowing them to more accurately predict *E. coli* loading. In this study, GPS collars indicated the amount of time cattle spent in the stream could be reduced 43%, from 3.0 to 1.7 minutes/AU/day, by providing alternative off-stream water. As a result, direct deposition of *E. coli* into Clear Fork of Plum Creek was estimated to be reduced 4.8×10^6 cfu/AU/day from 1.11×10^7 cfu/AU/day when no alternative water was provided to 6.3×10^6 cfu/AU/day once alternative water was provided, and observed pre-treatment and post-treatment *E. coli* loads suggested similar reductions. However, drought-induced reductions in streamflow and increases in stocking rate and wildlife presence resulted in increased *E. coli* concentrations.

Although this study did not provide conclusive evidence of reduced *E. coli* concentrations resulting from providing alternative off-stream water supplies, this practice is still highly recommended due to the significant reductions observed in the time cattle spent in and near the stream, which has been shown in other studies to provide comparable bacteria reductions as exclusionary fencing of streams. Further, this study supports McIver (2004) who noted alternative water supplies alone would not achieve water quality improvements unless implemented in conjunction with good grazing management (appropriate stocking rate, evenly distributed grazing, avoiding grazing during vulnerable periods, and providing ample rest after grazing events). As a result of the severe drought during this study, these principles could not be strictly adhered to, thus likely confounding the even larger improvements in water quality that could have otherwise been achieved with the use of alternative water supplies.

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An evaluation of urban landscape water use in Texas

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Abstract: Irrigated agriculture is the largest user of water in Texas, followed by urban-municipal uses, which has landscape irrigation as its largest component. Data from various sources were used to estimate the extent of the state's urban landscaped area and its associated water use. The statewide area in golf courses is estimated at 115,000 acres, while 1,608,399 acres are ascribed to managed landscapes and lawns. While the total annual water use by golf courses is estimated at 0.364 million acre-feet, the volume projected for the landscape sector ranges from a low of 1.898 million acre-feet to a high of 4.021 million acre-feet. The sum of water use by golf courses with the low-end estimate for landscapes would represent 46.6% of the total use within the urban/municipal water sector and 12.6% of the total annual demand by all activities in Texas during 2010. This effectively positions urban irrigation as the state's third largest water user, after agricultural irrigation and other urban uses. Strategies and practices that can significantly conserve (reduce) water use for urban landscape irrigation include water-conserving native and adaptive plant materials, weather- and sensor-guided irrigation, deficit irrigation practices, and use of alternative (saline/brackish, reclaimed, and graywater) water sources.

Keywords: landscapes, lawns, irrigation, ornamental plants, water use and conservation

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Terms used in paper

Short name or acronym	Descriptive name
crop coefficients	K_c
evapotranspiration	ET
reference evapotranspiration	ETo
soil moisture sensors	SMS

INTRODUCTION

Landscape plantings, containing grass, plants, trees and associated hardscape components, are an essential component of the urban environment and provide an array of economic, environmental, human health, and psycho-social benefits (Frank 2003, Roberts and Roberts 1987). Some examples of these benefits include enhancing the real estate value/appraisal of residential and commercial properties, reducing the energy consumption (heating, cooling) and costs of these properties, attracting and positively influencing consumer attitudes and spending, reducing stress at home and work, promoting exercise activities, reducing air, water and noise pollution, minimizing soil erosion, etc. Landscaping activities are a component of the ornamental horticulture industry, also known as the "green industry," which is a significant sector of Texas agriculture. Green-industry components include production activities by greenhouse, nursery and sod growers, and other services and goods provided by florist shops and retail garden centers, in addition to landscaping and tree care/maintenance activities. The total economic contributions of all green industry activities in Texas for 2011 were estimated at $17.97 billion in output, plus $10.7 billion in value added and the industry provided employment for 200,303 people (Palma and Hall 2013).

Information from the 2012 state water plan indicates that the total projected annual water demand by all activities in Texas during 2010 accounted for about 18 million acre-feet (TWDB 2012). According to the water plan, 27% of water demand was attributed to municipal uses, which includes landscape irrigation, and 56% to agricultural irrigation, which includes ornamental crop (nursery-greenhouse) and sod production (Figure 1). While there is specific information available on irrigated agriculture, including the production sectors of the green industry (nursery, greenhouse and sod production), there is very limited data available on the extent of the actual or projected water use by the urban landscape sector.

The severe drought experienced by Texas since 2011 has brought a devastating effect to irrigated agriculture. According to Texas A&M AgriLife Extension Service economists, during 2011 the drought resulted in an overall loss of $7.62 billion to the state's agriculture, distinguishing it as the costliest drought on record (Fannin 2012). While it might be difficult to estimate what fraction of the total economic losses is attributed to green industry activities, the drought-related loss of 5.6 million trees in urban landscaped areas, representing up to 10% of the state's urban forest (Smith and Riley 2012), provides an insight on the serious effects of the drought on this industry. In comparison, drought-related losses of trees in the state's natural forests amounted to 301 million trees for the same year, accounting for an average 6.2% mortality across the state (Texas A&M Forest Service 2012). Across the state, many cities and municipalities have also enacted restrictive ordinances on urban landscape irrigation in an effort to conserve water as surface and groundwater supplies dwindle due to the ongoing drought (TWDB 2012). As of June 24, 2013, the Texas Commission on Environmental Quality (TCEQ) reported that 972 (20.8 %) of the state's 4,665 community water systems were under voluntary or mandatory use restrictions, and 30 other public water systems were at risk of running out of water within 45 to 180 days (TCEQ 2013).

Population growth in Texas, largely to be observed in urban areas, is expected to increase 82% in the next 5 decades, from 25.4 million in 2010 to an expected 46.3 million in 2060. Likewise, demand for municipal water over the same period is also expected to increase by 71.4%, from 4.9 million acre-feet in 2010 to 8.4 million acre-feet in 2060 (TWDB 2012). While there is quite a bit of information and track record on the projected water use by agricultural irrigation, until recently there has been limited information on water use by urban landscape irrigation. A recent analysis of metered water use across selected Texas cities, from 2004 through 2011, has shown that about 31% of single-family residential annual water consumption is dedicated to outdoor purposes, mostly landscape irrigation (Hermitte and Mace 2012).

The objective of this report is to provide a global assessment of the status of urban landscape water use in Texas to provide baseline information that can be used to gauge the current demands of this sector, and to consider some management practices and alternatives that can significantly contribute to water conservation in landscape irrigation activities.

ACREAGE AND WATER USE IN IRRIGATED AGRONOMIC AND ORNAMENTAL CROP COMMODITIES

Based on recent reports, in Texas there are 6.17 million acres of irrigated crops, mostly agronomic (cotton, corn, etc.), forage, and vegetables, with an estimated water use of 9.5 million acre-feet (NASS 2009; Turner et al. 2011; Wagner 2012). These figures yield an average annual irrigation rate of 18.5 inches (Table 1).

Within the irrigated acreage figures for Texas, only 59,212 acres were used in the production of ornamental horticulture crops and sod in 2007 (NASS 2009). Within these commodities, sod production had the greatest acreage, 36,805 acres (62% of the total; Figure 2), followed by nursery crops with 18,230 acres (31% of total). The combined area devoted to floriculture crops and propagative plant materials accounted for 4,177 acres (7% of the total). Most of the acreage devoted to nursery crops and sod is for outdoor (field) production, and

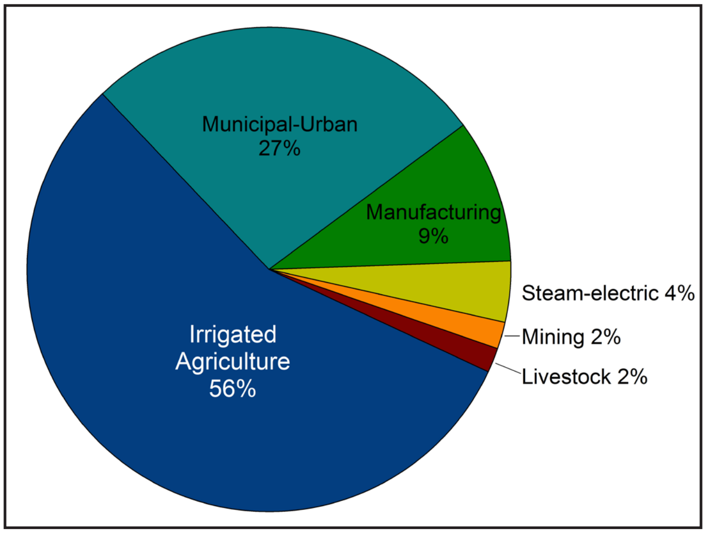

Figure 1. Relative water demand projected in 2010 for various activities in Texas (Drawn from data in the 2012 state water plan; TWDB 2012).

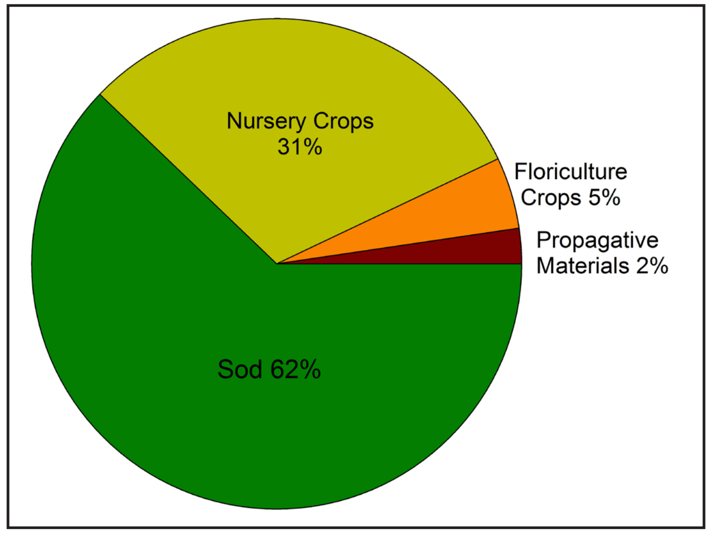

Figure 2. Relative distribution of the area devoted to the production of ornamental commodities and sod in Texas (From data in 2007 Census of Agriculture; NASS 2009).

protected structures (greenhouses) accounted only for 2% of the total (1,266 acres). While the area devoted to ornamental crop and sod production is minuscule compared to other irrigated crops in Texas (Table 1), the intensity of their management and productivity are associated with the highest reported irrigation rates, which approach 84 inches per year (Bailey et al. 1999, Fare et al. 1992, Warsaw et al. 2009), resulting in a potential statewide annual water use of 0.414 million acre-feet for this green industry sector.

GOLF COURSE AREA AND WATER USE

Golfing is a significant activity within the green industry. According to golf-related organizations (Lone Star Golf Course Superintendents Association; Texas Turfgrass Association), there are approximately 1,000 public and private golf courses in Texas. According to a recent survey (Throssell et al. 2009), the average golf course size in the southern United States is 115 acres, thus producing an estimated total golf course area of 115,000 acres for Texas. The annual irrigation rates for Texas golf courses average 38 inches, ranging from 29 inches in eastern part of the state to 47 inches in the western region (Duble 2013, Haydu and Hodges 2002, Throssell et al. 2009). This yields a potential total water use of up to 0.364 million acre-feet per year for the golf industry (Table 1).

ESTIMATING AREA IN STATEWIDE URBAN LANDSCAPES

Data from the US Census Bureau (2012; 2013b) show that in 2013 Texas had 7,675,050 single family (detached) housing units, each having a median lot size of 0.36 acres. Earlier estimates of the average lawn size indicated that for Texas it was 0.175 acres (Vinlove and Torla 1995). For this report a more conservative area of 0.15 acres (6,534 square feet) of mixed landscaped area (turf plus plants and trees) is employed, giving a total of 1,151,258 acres for all the single residential housing units in the state. A conservative 1-acre of landscaped area was assigned to each of the additional 96,948 multi-unit housing structures (apartment complexes with an estimated average of 25 units for each). We conducted a quick survey of 12 multi-unit housing structures in College Station, Texas, and found that their irrigated landscapes ranged from 1.5–8.2 acres, with a median value of 3.3 acres. Our chosen value of 1-acre of landscaped area to all the statewide multi-unit housing structures might be considered a bit conservative, but we believed it might be more representative. Adding the landscaped area of multi-unit housing with the area calculated for the single residential units, the total residential landscape area in Texas is 1,248,206 acres. This estimate is about 9% greater than the 1,145,242 acres of total home lawn area estimated for Texas by Vinlove and Torla in 1995, where they used a 16.7% larger lawn area per lot, although there were 42.8% fewer single residential housing units at the time. The 0.15 acres (6,534 square feet) home lawn/landscape area used for the present report is considered to better represent the more compact urban lot sizes where the bulk of the new housing construction has taken place in the last 2 decades (Van Lare and Arigoni 2006, US Census Bureau 2012). Furthermore, in some of the drier south and western urban areas of Texas (i.e. El Paso), there have been aggressive policies and incentives to significantly reduce the size of residential lawns and landscapes as

Table 1. Estimated area, average irrigation rate and total water use by irrigated agriculture and green industry activities in Texas.

Commodity	Area (acres)	Average annual irrigation rate feet (inches)	Estimated total annual water use (million acre-feet)
Irrigated agriculture	6,170,000	1.54 (18.5”)	9.502
Green Industry Activities			
Nursery-greenhouse-sod	59,212	7.00 (84.0”)	0.414
Golf courses	115,000	3.17 (38.0”)	0.364
Lawns/Landscapes*	1,608,399	High 2.50 (30.0”) Low 1.18 (14.2”)	High 4.021 Low 1.898

*Includes landscaped areas in residential, municipal, commercial (business) and educational sectors. See Figure 3 for its distribution and Table 2 for estimation of irrigation rates.

part of their urban water conservation efforts and measures (EPA 2009).

For the estimation of municipal lawns and landscapes (including municipal/city parks, cemeteries, street medians and urban right-of-ways), data from the US Census Bureau (2013b) was employed to generate a list of Texas cities with more than 1,000 inhabitants (976 cities, accounting for 77.1% of the state's population). For those with >70,000 inhabitants (a total of 47), information on total park and managed municipal landscaped areas was obtained from their parks and recreation departments (official websites) and The Trust for Public Land (2012). An analysis of these data showed that the average ratio of population to municipal park and landscape acreage was 106:1 (persons: acre) for cities with 200,000 to 2.1 million (i.e. Houston) inhabitants, and 136:1 for cities with 70,000 to 200,000 inhabitants, which were in between the national guideline ratios of 53:1 and 167:1 proposed by the National Recreation and Park Association (2012). These cities account for 49.1% of the state's population and their combined municipal parks, cemeteries and landscaped areas amounted to 175,635 acres. A sliding scale of ratios (people: municipal landscaped area) of 150:1 to 350:1 was used for the rest of the cities in 6 population categories (50,000–70,000, etc. down to 1,000–2,000), which added 34,176 more acres, for a grand total of 209,811 acres for all the municipal (city) landscaped areas in Texas. Not all municipal parks and grounds are actually irrigated, and for the estimation of water use in this report, we are assuming that only one-half are, thus yielding an adjusted area of 104,906 acres. This figure does not include any other landscaped areas managed by other local, state or federal entities within these cities.

According to data from the Economic Census (US Census Bureau 2013a), in Texas there were 172,841 business establishments with 20 to 500+ employees. Using information on the total number and size of each business firm (3 classes: 20–99, 100–499 and >500 employees) and multiplied by estimated landscaped areas for each (0.1, 1.0 and 2.0 acres, respectively for each business size class), this yielded an estimated statewide business (commercial) landscaped area of 228,776 acres.

Educational institutions in the state also have managed landscaped areas. The Texas Education Agency listed 8,322 public and private schools (K-12) in 2009, and assigning an estimated 3 acres of lawns/landscapes for each, this adds an area of 24,966 acres. A similar calculation was done for higher education institutions, with 103 listed in 2009 (Texas Higher Education Coordinating Board), and assigning a landscaped area of 15 acres per institution, it adds 1,545 acres. Altogether, 26,511 acres of lawns/landscapes were estimated in the education sector across the state.

The sum of all the areas calculated for all urban landscapes (residential, municipal, business, and educational) in the state amounts to 1,608,399 acres (Table 1). The distribution of the combined area for all urban landscapes and golf courses, which together add to a grand total of 1,723,399 acres, is shown in Figure 3. A recent study of satellite photography evaluated the relationships between impervious and vegetated surfaces across

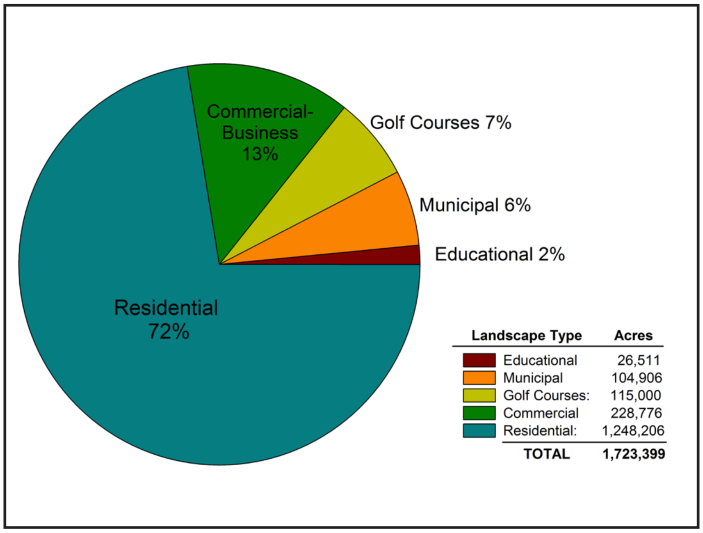

Figure 3. Distribution of the urban landscape (and lawn) area in Texas, including golf courses.

the country, estimating that Texas had at least 2,505,154 acres of urban residential, municipal, institutional, and commercial lawns/landscapes, including golf courses (Milesi et al. 2005). Expectedly, these areas were concentrated in urban areas (Figure 4), particularly in the triangle contained within the metropolitan boundaries between Dallas-Fort Worth, San Antonio, and Houston, where more than 75% of the Texas population reside (Neuman and Bright 2008).

The total landscape and golf course area estimated for Texas in the present report corresponds to 68.8% of the area modeled by Milesi et al. (2005), a difference attributed to a potential overestimation by the indirect approach used by these latter authors. Their modeling approach employed a 1-kilometer (0.621 mile) spatial resolution from satellite photography. In addition, for the development of the relationships between the proportions of constructed surfaces (roads, parking lots, buildings) versus the proportion of vegetated (turfgrasses and plants/trees) and other (undeveloped) surfaces, they employed a very limited number of high-resolution aerial photographs for the entire United States. These photographs, 80 in total, were collected along development transects distributed across only 13 major urban centers, and it is unknown how many were used to represent Texas. Their predictive model on the relationship between fractional urban impervious and vegetated areas, in fact, showed a moderate determination coefficient of R2 = 0.69, and as such we infer that the total urban landscape area for Texas calculated by our approach is effectively and conservatively within the low boundaries of the area modeled by Milesi et al. (2005). We acknowledge that the use of satellite imagery and associated analytical tools will become the preferred and more efficient avenues to evaluate the extent and dynamics of urban landscape areas and their water use, compared to the use of data from census and other sources (with their intrinsic limitations) and the need for educated assumptions to fill in the gaps.

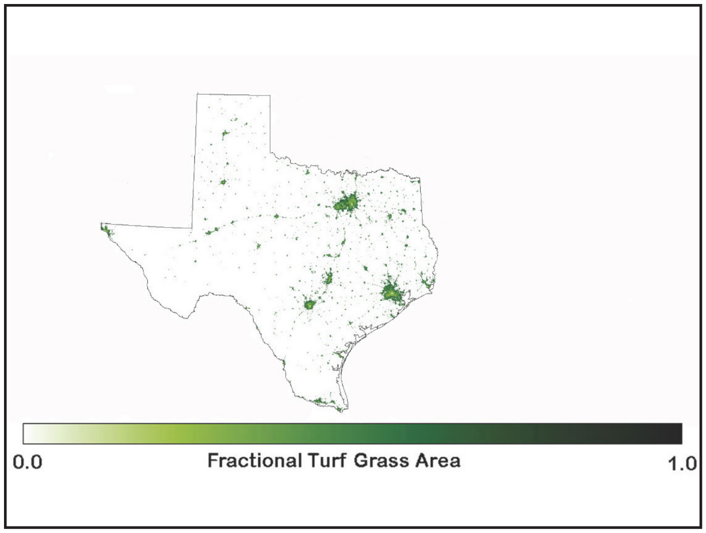

Figure 4. Geographical distribution of the turf and tree surface area (i.e. urban landscapes) in Texas, estimated from relationships between impervious and vegetated surfaces in high-resolution satellite photography tiles (Illustration adapted from Milesi et al. 2005).

WATER USE IN URBAN LANDSCAPES

The estimation of the total water used by all the landscaped areas in the residential, municipal, commercial, and educational sectors across the state can be challenging, as both recommended and actual irrigation rates can vary widely across the state depending on the types of turfgrasses and landscape plants/trees used, the soil types, weather (including temperature, relative humidity, rainfall, etc.), and the habits and perceptions of homeowners and landscaper/irrigation operators.

Information from some of the largest cities and municipal water suppliers in Texas, namely Dallas, Austin, and San Antonio (Austin Water Utility 2013; Dallas Water Utilities 2013a, 2013b; SAWS 2013c), along with several research and educational sources (Duble 2013), suggest weekly irrigation rates of 0.75 inch to 1 inch during the summer months, tapered in spring and fall and basically zero in the winter. Integrated over a year, these irrigation values approach up to 30 inches. This rate coincides with the average difference of 29.7 inches between historical annual precipitation and reference evapotranspiration (ETo) values for 21 cities across the state (Table 2). This average differential value represents the potential supplemental irrigation demanded if it was desired to meet 100% of ETo in each of these locations. Current recommendations, followed by licensed irrigators, employ crop coefficients (Kc), ranging from 0.4 to 0.7 Kc to calculate the actual irrigation replacement rates depending on location, the palette of plant and turfgrass materials, and other factors like stress and water quality (Pannkuk et al. 2010, Wherley 2011, White et al. 2004). The multiplication of a high average irrigation rate of 30 inches by the estimated total landscaped area of 1.608 million acres would yield a high total statewide water use of 4.021 million acre-feet per year for the landscape sector (Table 1).

Actual urban landscape water use in recent years, however, might be significantly less according to a study of single-family residential water usage between 2004 and 2011 in cities across Texas (Hermitte and Mace 2012). Analyses of metered water consumption data and patterns for single-family residences in these cities indicated that their estimated outdoor water usage, mostly devoted to lawns and landscapes, averaged an annual irrigation rate equivalent to 14.2 inches (Table 2). Multiplying this irrigation rate by the previously calculated landscaped area produces a total of 1.898 million acre-feet per year (Table

Table 2. Average annual precipitation and reference evapotranspiration (ETo), their difference, and metered residential outdoor water in several Texas cities.

	Total annual [a]			
Cities	**Precipitation (inches)**	**ETo (inches)**	**Difference (inches) [b]**	**Metered residential outdoor water use (inches/year) [c]**
Abilene	23.7	58.7	-35.0	--
Amarillo	19.8	55.5	-35.7	20.9
Austin	33.2	57.5	-24.4	13.0
Brownsville	25.6	56.2	-30.6	--
College Station	39.4	56.3	-17.0	19.2
Corpus Christi	30.3	55.7	-25.4	9.7
Dallas/Ft. Worth	34.8	55.9	-21.0	18.3
Del Rio	17.8	61.0	-43.3	--
El Paso	8.6	79.3	-70.7	15.4
Galveston	41.9	53.6	-11.7	--
Houston	47.7	54.9	- 7.2	5.4
Lubbock	18.5	59.1	-40.6	14.1
Midland	14.2	64.8	-50.6	17.4
Port Arthur	56.3	52.7	3.7	--
San Angelo	19.2	71.3	-52.1	--
San Antonio	30.1	58.2	-28.2	9.8
Uvalde	23.4	59.9	-36.5	19.3
Victoria	39.2	57.0	-17.9	7.6
Waco	32.3	53.2	-20.9	14.4
Weslaco	25.4	54.1	-28.7	--
Wichita Falls	27.9	58.6	-30.6	14.4
Average	**29.0**	**58.7**	**-29.7**	**14.2**

[a] Annualized data from Texas ET Network (2013). Data based on historical climate records averaged over the 31 to 99 years of available information for each location.
[b] Difference between precipitation and ETo, representing potential supplemental irrigation if desired to meet 100% ETo. Current recommendations, however, call for irrigation using crop coefficients (Kc) adequate to each location and landscape species.
[c] Calculated from data presented by Hermitte and Mace (2012) for the 2004–2011 period. It is presumed that most of this outdoor water use is devoted to lawn and landscape irrigation.

1), which might be considered a more realistic or conservative estimate of landscape water use in Texas.

Adding the water use estimated for golf courses, the total annual urban irrigation (i.e. landscapes plus golf courses) is 2.262 million acre-feet per year, representing about 46.6% of the use within the municipal water sector, and 12.6 % of the total projected annual demand by all activities in Texas during 2010 (Figure 1; TWDB 2012). With these calculations, urban irrigation is effectively positioned as the state's third largest water user, after agricultural irrigation and other urban (in-home and municipal) uses.

OPPORTUNITIES FOR WATER CONSERVATION IN URBAN LANDSCAPES

There are a number of strategies, tools, alternatives, and management practices that can significantly reduce (conserve) water usage in urban landscape irrigation.

Use of water-conserving landscape plants and suitable designs for each ecogeographical region (i.e. soil and climate) have been predominantly promoted as foundational components of water conservation. There are published and online listings of resource-efficient plants (e.g. Earthkind® plants), trees, and turfgrass species, both native and adapted, that can be targeted to specific regions, and even zip codes, within the state (Hipp et al. 1993, Texas A&M AgriLife Extension Service 2013, TWDB 2010, Welsh and Welch 2001). Several utilities, water districts, and municipalities in Texas promote, and even have ordinances about, the use of these plants through rebates and incentives, providing listings of preferred, approved, and non-acceptable species (City of Austin 2012, Kolenc 2011, SAWS 2013b, Texas A&M AgriLife Extension Service 2013).

Although limited information on actual water use or requirements by most of the recommended resource-efficient plants and grasses is available, we endorse the principle that the use of properly chosen native and adaptive species to each region (i.e. soil and climate) should ensure their survival and ornamental performance within the limits of the expected average precipitation with little-to-no supplemental irrigation. This contention improves on the principles and practices of xeriscaping (Welsh and Welch 2001) and Earthkind® landscaping (Texas AgriLife Extension Service 2010), which technically include recommendations for efficient irrigation, as well as wet zones within a landscape (Baxter 2010). Despite any past and present misconceptions that these water-saving landscaping plant palettes are mostly about desert plants (such as cactus and succulents), gravel, and rocks (Phipps 2013), there is a large array of the above mentioned resource- and water-use efficient plants to choose for each ecogeographical region and soil type. With proper design and maintenance (including soil conditioning and mulching), these plants should provide aesthetically pleasing and environment-friendly landscapes with minimal requirements or needs for supplemental irrigation.

Landscape irrigation applications and scheduling based on climatological (i.e. ETo) and soil moisture conditions have been investigated and promoted as viable practices that could lead to significant water conservation (Pannkuk et al. 2010, Dukes 2012). These concepts have led to the technological development of irrigation systems run by smart irrigation controllers based on evapotranspiration (ET) or soil moisture sensors, which in principle suggest the potential for significant water savings compared to the traditional time-based controllers and calendar-based irrigation schedules (Davis and Dukes 2012). The use of ET-based controllers has been shown, however, to result in over/under irrigation applications under both deficit irrigation and well-watered conditions (Devitt et al. 2008, Mayer et al. 2009, Swanson and Fipps 2012). Results from a detailed 3-year evaluation study of ET-based controllers in Texas indicate that most of the available units still have issues with programming using an adequate number of parameters specific to each zone (Burns 2011, Swanson and Fipps 2012). Improper calculation of ET and insufficient accounting for rainfall are among the main factors that cause for these controllers to over/under irrigate with respect to ETo, and these issues seem to be exacerbated by variable and erratic weather patterns. Based on results for 2011, the researchers found that controllers with on-site sensors generally performed better and more often irrigated closer to the recommendations of the TexasET Network than those that had ETo information sent to the controller (Swanson and Fipps 2012). Similar evaluations of ET-based controllers under wetter Florida conditions has found that several of them can match irrigation application with seasonal demand and in particular reduce irrigation in the winter when plant demands are dramatically reduced (Davis and Dukes 2012). On the other hand, when ET controllers were applied to sites irrigating at levels less than plant demand, they actually increased irrigation. A major observation of both the Florida and the Texas studies was that a proper accounting for rainfall was a challenge for most of the evaluated ET controllers.

Regarding landscape irrigation based on soil moisture sensors (SMS), a recent literature review (Dukes 2012) points out that its evaluation and demonstration of landscape irrigation has been very limited in comparison to ET controllers. These SMS require specific knowledge of the water-holding capacities of the soil(s) in each irrigation zone. Most by-pass SMS systems rely on a single sensor to control an entire irrigation system, requiring proper setting of the minimum moisture threshold that triggers irrigation and the run time cycles that will not exceed the water-holding capacities of the soil. The other SMS irrigation system, on-demand control, consists of a stand-alone controller and multiple soil moisture sensors, a set-up that completely replaces the timer. As such, this system requires careful setting of the high and low soil moisture limits so that irrigation occurs only within those limits. Expectedly, both SMS systems require careful and proper placement of the sensor(s) in representative area(s) of the landscape.

Rain sensors, also known as rain switches, are devices that interrupt the communication between timers or smart controllers in response to rainfall, stopping unneeded irrigation and conserving water (Dukes 2012, Meeks et al. 2012). While significant water savings have been attributed to these sensors, ranging from 10% during dry conditions to ~30% in rainy conditions in humid climates, their overall performance can be erratic, and they often need to be replaced annually (Meeks et al. 2012). A new generation of improved rain sensors suppress scheduled irrigation cycles based on forecast conditions, promising higher water savings compared to conventional rain sensors that will only suppress an irrigation cycle if a specific amount of rain has fallen. These forecasting rain sensors, like the idd™ (Irrigation Decision Device from Vepo LLC), rely entirely in systematically transmitted forecasting information, via FM radio signal, by the manufacturer, requiring registration, annual fees, and completion of specific certification courses.

Any drawbacks of smart irrigation controllers and rain sensors, which are becoming more efficient in each generation (Burns 2011, Swanson and Fipps 2012), can be overcome by proper and specific design of the irrigation system to the site, soil, plant materials, and their hydrozoning, and a thorough follow-up and fine-tuning after installation (Dukes 2012).

Incorporation of landscape crop coefficients to ET-based irrigation, effectively a deficit irrigation protocol, is a refinement that offers the potential for additional water savings while maintaining the aesthetic quality and function of ornamental plants and amenity turfgrasses (Wherley 2011). The development of these coefficients for mixed landscape plantings has, however, been found challenging in recent studies, particularly when combining traditional (exotic, introduced) and native species (Pannkuk et al. 2010). The only source of public, free of charge, and readily available (online) information on reference ET and plant/crop across the state is the Texas ET Network (2013). While this effort is gratefully acknowledged, the number of weather stations supplying information to this network is very small, and they are sparsely located, limiting their potential use and benefits across large areas of the state. The California CIMIS network (CIMIS 2013) is an outstanding example of an ET and irrigation online network that has effectively partnered a land-grant university and a state water agency, and which has achieved extensive benefits in water conservation efforts in a state with robust agricultural and urban sectors. Considering that agricultural and urban landscape irrigation are the first and third, respectively, largest users of water in Texas, it is imperative to promote the expansion of this ET network through adequate funding for suitable equipment and personnel. The same recommendation goes for the support and funding of projects and efforts to develop plant and crop coefficients (single and mixed plantings) for ornamental plants and turfgrasses recommended for water-conserving landscapes in Texas. Currently a team of horticulturists, agronomists, agricultural engineers, and extension personnel representing several Texas A&M University campus, agencies and centers, are proposing these efforts. Entities include Texas A&M AgriLife Research, the Texas A&M AgriLife Extension Service, Texas Water Resources Institute, Water Conservation and Technology Center, Texas A&M Engineering Experiment Station, Texas Center for Applied Technology, along with collaborating partners from other state and municipal water-related agencies.

Another viable option to conserve potable water in urban environments is the use of alternative waters to irrigate landscape plantings, including saline (brackish) water, reclaimed water, condensate water, and graywater. Brackish groundwater, whether it is from naturally saline aquifers (TWDB 2013) or those affected by coastal saltwater intrusion (Capuano and Lindsay 2004), is abundant in Texas, with an estimated volume of more than 2.7 billion acre-feet (TWDB 2013). The TWDB states that groundwater containing an electrical conductivity of up to 4.7 deciSiemens per meter (3,000 milligrams per liter of total dissolved salts) could be employed for irrigation in those locations or dwellings where it is readily available. This salinity level, however, surpasses the maximum level of 1.0–1.5 deciSiemens per meter recommended for most landscape plants, in addition to high concentrations of specific ions, sodium, chloride, and boron in particular, that are particularly toxic to a good number of these (Cabrera 2009, Duncan et al. 2009, Farnham et al. 1985). The aesthetics and performance of plants irrigated with such waters suffer significantly, more severely affecting woody shrubs and trees (Cabrera 2009), with foliage showing scorching, chlorosis, and necrosis leading to their eventual death (Niu and Cabrera 2010, Miyamoto and White 2002). Turfgrasses and other annual plants, however, tend to be more tolerant of waters with higher concentrations of total soluble salts and these specific ions (Duncan et al. 2009, Niu and Cabrera 2010). A judicious blending of some brackish and reclaimed waters with other high quality water sources can effectively be used to grow and maintain ornamental plants and crops, as highlighted by a successful commercial greenhouse operation in south Texas (Reed 1996).

Municipal reclaimed water has been considered a viable alternative for landscape irrigation. Depending on the degree of water treatment for reclaimed waters, however, they could have similar drawbacks as brackish water, with relatively high levels of total salinity and undesirable specific ions (Duncan et al. 2009, Miyamoto et al. 2001). The quality of the reclaimed water produced by the San Antonio Water System in 2012 and 2013 is fairly good, with an average salinity of 1.1 deciSiemens per meter, 180 milligrams per liter of alkalinity, 145 milligrams per liter of chlorides and 98 milligrams per liter of sodium. All these levels were slightly to moderately higher than those recommended for woody ornamental shrubs and trees, but still adequate for most annuals and turfgrasses (Cabrera 2009, Duncan et al. 2009, Farnham et al. 1985). Availability and supply of reclaimed water is unfortunately limited, as procedures regarding collection (of original raw sewage), treatment, and subsequent distribution are tightly regulated and require a separate pipeline system that only certain end-users can effectively have access to (SAWS 2013a). Depending on the ultimate quality of reclaimed water, its use in landscape irrigation might require the use of modified sprinkler systems or drippers that minimize the potential contact with plants to reduce salt scorching (Miyamoto and White 2002). These irrigation precautions are also required to minimize the risk of inadvertent human exposure to the recycled water, due to concerns with pathogenic microorganisms and other chemicals that could still be present in undesirable concentrations (Duncan et al. 2009, SAWS 2006, Toor and Lusk 2011).

The successful use of saline (brackish) and reclaimed waters requires a judicious use of salt-tolerant plant and grass species, appropriate irrigation systems and techniques, leaching requirements, and short- and long-term management of urban soils and their associated watershed to minimize the accumulation of salt build-up and undesirable effects on the overall urban ecosystem (Duncan et al. 2009, Farnham et al. 1985, Miyamoto and White 2002).

Condensate water from air-conditioning systems is a potential source for outdoor irrigation (Guz 2005), particularly in sites with a relatively large indoor footprint versus landscape footprint, offering the possibility of letting them be "off the potable water grid" for landscape irrigation. The quality of condensates can actually be really good and require minimal treatment for storage and/or immediate use. Condensate recovery systems in San Antonio have worked so well that it recently became the first city to require all new commercial buildings to design drain lines so that condensate capture is practical (Guz 2005). There are still design and engineering issues being addressed for their successful and cost-effective implementation, and in the case of landscape irrigation applications, these include storage, treatment (like chlorine injection to prevent bacterial growth), and hook-up to irrigation system.

An additional alternative water source that has potential for landscape irrigation is graywater, which in the strictest sense is defined as residential wastewater from laundry, showers, and bathtubs (Cabrera and Leskovar 2013). Graywater constitutes up to 60% of the total wastewater from a household, and might yield up to 30,000 gallons per year for an average family of 4 members (Roesner et al. 2006). The volume generated by clothes washing machines represents about one-half of the total graywater produced by a household, which could potentially provide up to 4 inches to 5 inches of irrigation for an average-sized lawn/landscape. The routing of the drain hose from washing machines to a simple drip irrigation set-up would be a relatively inexpensive option to reuse this graywater compared to plumbing retrofits to reroute, capture, and use graywater effluent from bathtubs and showers. This washing machine graywater reuse could represent a substantial saving of potable water supplies if coupled with a well-designed low-pressure drip irrigation system and with use of native and adaptive (resource-efficient) plant materials. Another feature of this simplified scenario would be the ability to reroute or reconnect the washing machine effluents back to the sewer system when not needed due to rainfall or low ET. Among the concerns that discourage an extensive and permitted use of graywater for landscape irrigation is a lack of documented knowledge (scientific and technical) on the short- and long-term effects of graywater on plants and soils. Furthermore, and as with reclaimed water, there is the imperative need to identify its associated pathogenic organisms and chemicals that might be of concern for public/human health, in addition to the irrigation equipment considerations and practices needed to successfully manage and apply graywater (Cabrera and Leskovar 2013, Roesner et al. 2006).

CONCLUDING REMARKS

Population and economic growth, competition and environmental changes (i.e. drought) are putting tremendous pressures in the overall water balance (demand-availability) for Texas today and in the decades ahead. While the agricultural sector has been the largest user of Texas water resources, the increased growth and economic development in the state's urban sector are shifting water use and allocation patterns, and concomitantly highlighting our limited knowledge on the actual water use efficiency by this latter sector and the documented improvements in the former. We believe the information and analysis provided in the present report makes a convincing argument for increased focus and funding to address current knowledge gaps and for the development of practices and recommendations that significantly enhance water conservation and use efficiency in urban activities, particularly landscape irrigation. A remarkable urban water conservation effort is that realized by the San Antonio Water System over the last 2 decades, basically using about the same amount of water that it used in 1984, despite a 67% increase in population — or dropping the per capita water use by ~40%, from 222 to 136 gallons (Atencio 2013, Postel 2011). Because peak demand during dry periods is a growing challenge as supplies are curtailed, the updated San Antonio Water System Water Management Plan (2012) puts particular emphasis on water conservation efforts, most of them targeted to significant reductions in landscape irrigation. While these efforts and programs certainly provide examples to study and emulate by other municipalities across the state, nevertheless, we contend that sound research-based results and outreach education efforts are still sorely needed to help these entities achieve their urban water use efficiency and conservation goals. We need studies, pilot and demonstrative projects, that provide refinements on, and ultimately integrate, the combined use of native and adaptive plants and mixed landscape crop coefficients suitable to specific ecogeographical regions, smart irrigation technologies and management of alternative water sources. Multidisciplinary, intra- and inter-institutional efforts and collaborations between research/educational institutions with local and state water-related agencies should expedite the generation of this knowledge, along with practical applications and solutions.

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Commentary: 83rd Texas State Legislature: Summaries of Water-related Legislative Action

Editor's Note: September 1 of every odd-numbered year is the date that new legislation from the Texas Legislature session that ended the previous spring typically goes into effect. With this in mind, the Texas Water Journal invited 4 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 2013 session. The opinions expressed in these summaries are the opinions of the individual organizations and not the opinion of the Texas Water Journal or the Texas Water Resources Institute.

Organizations:

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

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Terms used in paper

Short name or acronym	Descriptive name
ASR	aquifer storage and recovery
BPAT	backflow prevention assembly testers
DFC	desired future conditions
FY	fiscal year
GCD	groundwater conservation district
HCR	House Concurrent Resolution
HB	House Bill
HOA	homeowners' association
LBB	Legislative Budget Board
POA	property owners' association
PUC	Public Utility Commission of Texas
SB	Senate Bill
SECO	State Energy Conservation Office
SJR	Senate Joint Resolution
SSOs	sanitary sewer overflows
SWIFT	State Water Implementation Fund for Texas
SWIRFT	State Water Implementation Revenue Fund for Texas
TAGD	Texas Alliance of Groundwater Districts
TCEQ	Texas Commission on Environmental Quality
TWCA	Texas Water Conservation Association
TWDB	Texas Water Development Board
TDS	total dissolved solids

ON THE THRESHOLD OF SECURING THE STATE'S WATER FUTURE

By Dean Robbins, Texas Water Conservation Association

As the 83rd Texas Legislature edged closer to adjournment, the prospect of obtaining critical funding, once and for all, to secure the state's water future, was still uncertain. Questions about the appropriate balance of funding between water and education, and whether and how water-funding issues should be presented to the voters, still were unresolved.

Ultimately, those questions were addressed through the passage of House Bill (HB) 4, HB 1025, and Senate Joint Resolution (SJR) 1, and a special session on water funding was avoided.

HB 4, authored by State Representative Allan Ritter and sponsored by Senator Troy Fraser, creates a water implementation fund to be administered by a restructured Texas Water Development Board (TWDB) to provide low interest loans for projects in the state water plan.

HB 1025, by Representative Jim Pitts and Senator Tommy Williams, is a supplemental appropriations bill that transfers $2 billion out of the Economic Stabilization Fund (the Rainy Day Fund) to the water implementation fund contingent upon voter approval of SJR 1.

SJR 1 is a joint resolution by Senator Williams and Representative Pitts that, if approved by the voters in November, will amend the Texas Constitution to create funding mechanisms in the state treasury but outside the general revenue fund that will allow the TWDB to provide the financial assistance prescribed in HB 4.

"Chairmen Ritter and Fraser deserve special recognition for their visionary efforts," commented Leroy Goodson, TWCA's general manager. "Chairman Ritter was correct when he observed that it is absolutely critical to secure viable, long-term funding for water infrastructure, which is undeniably the lifeblood of the sustained economic growth and development of our state," Goodson continued. "We must not squander this exceptional opportunity to leave such a critical legacy for future Texans. Our economy depends on it, our municipalities depend on it, and when you get right down to it, our quality of life depends on it."

Governor Rick Perry, Lieutenant Governor David Dewhurst, and House Speaker Joe Straus also worked diligently to find solutions to the issues that might have otherwise derailed the water-funding plan. The 2012 state water plan, prepared by the TWDB, recommends 562 unique water supply projects to meet the state's projected needs for additional water supplies over the next 50 years. If implemented, these projects would result in an additional 9 million acre-feet per year by 2060 to meet the anticipated 8.3 million acre-feet shortfall. Although the TWDB has provided financial assistance for water projects for decades, Texas previously has not had a comprehensive strategy for funding the state water plan.

It's Our Turn Now

Just ahead is the critical juncture where policy and people converge — where voters must take ownership of future water supply issues by confirming this landmark legislation at the ballot box in November. What citizens do with this unique opportunity will depend in large measure upon what water leaders do to promote understanding that: 1) The long-term stability and growth of the Texas economy depend on the provision of ample water for household, commercial, industrial, and agricultural use; and 2) State funding can significantly reduce the total cost of financing regional and local projects.

What very well could provide a viable template for this upcoming election is the process through which a proposed constitutional amendment (Proposition 2) gained voter approval during the November 8, 2011 general election. This amendment allows the TWDB to authorize bonds on an ongoing basis so long as the dollar amount of bonds outstanding at any one time does not exceed $6 billion.

As with Proposition 2, there are many and varied stakeholders who are committed to assuring that SJR 1 is passed. Without voter approval, the new funding mechanisms will not exist and the $2 billion from the Rainy Day Fund will not be available for use. Much can and should be done to educate the voters on this critical election. TWCA will be working with its members and others to ensure success.

For additional and ongoing information about this crucial effort, please visit www.twca.org. More details about the water-funding legislation and a comprehensive summary of other water legislation passed by the 83rd Texas Legislature can be obtained on our website.

Priority Bills Passed by 83rd (R)

House Bills (HB)

HB 4: Ritter, Allan (R); Fraser, Troy (R)

Relating to the creation and funding of the state water implementation fund for Texas to assist the Texas Water Development Board (TWDB) in the funding of certain water-related projects.

General Remarks: Chapter 6, Water Code, is amended to change the governance of the TWDB to a full-time 3 member board with expertise in engineering, finance, and the field of law. Geographic diversity is also required. Chapter 15, Water

Code, is amended to establish a State Water Implementation Fund for Texas to be administered by the TWDB. The fund consists of any money transferred, deposited, or dedicated to the fund by law. A trust company shall hold and invest the fund. The TWDB may use the fund to establish a revolving loan program to implement the state water plan. The TWDB is given guidance on the percentage of money to be applied to rural, conservation, and reuse projects. The TWDB may make loans for up to 30 years at an interest rate not less than 50% of the rate of interest available to the board. Regional water planning groups are directed to prioritize projects using criteria in the legislation. The board shall establish a system for prioritizing projects pursuant to legislative criteria. The board may transfer money to various other accounts authorized by law. An advisory committee to the TWDB is created. Conforming amendments are made to Chapter 15 and 17, Water Code. See also Senate Joint Resolution (SJR) 1, HB 1025.

Last Action: 9-1-13 G Earliest effective date

HB 252: Larson, Lyle (R); Hegar, Glenn (R)

Relating to water shortage reporting by water utilities.

General Remarks: Chapter 13, Water Code, is amended to require a retail public utility and each entity from which the utility is obtaining wholesale water service for the utility's retail system to notify the Texas Commission on Environmental Quality (TCEQ) when the utility or entity is reasonably certain that the water supply will be available for less than 180 days. The TCEQ is required to adopt rules to implement the legislation.

Last Action: 9-1-13 G Earliest effective date

HB 597: Guillen, Ryan (D); Eltife, Kevin (R)

Relating to boater education and examinations on preventing the spread of exotic harmful or potentially harmful aquatic plants, fish, and shellfish.

General Remarks: Chapter 31, Parks and Wildlife Code, is amended to require that a boater education course or equivalency examination under this section include information on how to prevent the spread of exotic harmful or potentially harmful aquatic plants, fish, and shellfish, including methods for cleaning boating equipment.

Last Action: 5-24-13 G Earliest effective date

HB 677: Geren, Charlie (R); Eltife, Kevin (R)

Relating to the regulation and enforcement of dam safety by the TCEQ.

General Remarks: Section 12.052, Water Code, is amended to exempt from state dam safety requirements dams located on private property if the dam impounds less than 500 acre-feet at maximum capacity, has a hazard classification of low or significant, is located in a county with a population of less than 350,000, and is not located in a city.

Last Action: 9-1-13 G Earliest effective date

HB 738: Crownover, Myra (R); Nelson, Jane (R)

Relating to the review of the creation of certain proposed municipal utility districts by county commissioners courts.

General Remarks: Section 54.0161, Water Code, is amended to modify procedures for the TCEQ to receive input from a commissioners court on the proposed creation of a municipal utility district in the county but outside the corporate limits of a municipality.

Last Action: 9-1-13 G Earliest effective date

HB 788: Smith, Wayne (R); Hinojosa, Chuy (D)

Relating to regulation of greenhouse gas emissions by the TCEQ.

General Remarks: Chapter 382, Health and Safety Code, is amended allow the TCEQ to issue permits for greenhouse gas emission to the extent required by federal law. Permit processes are not subject to a contested case hearing. The TCEQ may impose fees only to the extent necessary to cover costs of implementation.

Last Action: 6-14-13 G Earliest effective date

HB 857: Lucio III, Eddie (D); Ellis, Rodney (D)

Relating to the frequency of water audits by certain retail public utilities.

General Remarks: Chapter 16, Water Code, currently requires all utilities providing potable water service to perform and file with the TWDB every 5 years an audit computing the utility's water loss. Water utilities that receive financial assistance from the board are required to do this annually. The board is required to develop appropriate methodologies and submission dates based on population served. This legislation requires all retail public utilities providing potable water service to a population of more than 3,300 connections or receiving financial assistance from the TWDB to perform and file the audit annually. All other retail public utilities would still be required to perform and file the report every 5 years.

Last Action: 9-1-13 G Earliest effective date

HB 1025: Pitts, Jim (R); Williams, Tommy (R)

Relating to making supplemental appropriations and reductions in appropriations and giving direction and adjustment authority regarding appropriations.

General Remarks: Section 33 of the bill appropriates $2 billion out of the economic stabilization fund to the state water implementation fund of Texas contingent upon voter approval of SJR 1 and passage of HB 4.

Last Action: 6-14-13 G Earliest effective date

HB 1079: Smith, Wayne (R); Hancock, Kelly (R)

Relating to the procedural requirements for action by the TCEQ on applications for production area authorizations.

General Remarks: Chapter 27, Water Code, is amended to exempt certain applications related to uranium from the contested case hearing process. A uranium mining application must incorporate certain information relating to groundwater quality.

Last Action: 6-14-13 G Earliest effective date

HB 1106: Larson, Lyle (R); Estes, Craig (R)

Relating to the identification and operation of vessels in the waters of this state.

General Remarks: Procedures and information required for boater registration are modified. Certain vessels operated on coastal waters must be equipped with visual distress signals.

Last Action: 9-1-13 G Earliest effective date

HB 1241: Guillen, Ryan (D); Deuell, Bob (R)

Relating to the adoption of rules by the Parks and Wildlife Commission to protect the public water of this state.

General Remarks: Chapter 66, Parks and Wildlife Code, is amended to allow the TPWD to adopt and enforce rules to require a person leaving public water to drain from a vessel or portable container on board the vessel any water that has been collected from or come in contact with public water. These rules do not apply to salt water.

Last Action: 6-14-13 G Earliest effective date

HB 1461: Aycock, Jimmie Don (R); Fraser, Troy (R)

Relating to customer notification of significant water loss by a retail public utility.

General Remarks: Chapter 13, Water Code, is amended to require a retail public utility that files a water audit required by Water Code Section 16.021, to notify each of its customers of the water loss reported. The utility may do so either on its annual consumer confidence report or on the next water bill a customer receives after the water audit is filed.

Last Action: 9-1-13 G Earliest effective date

HB 1554: Rodriguez, Justin (D); Campbell, Donna (R)

Relating to the authority of a municipality to file a lien for the costs of abatement of a floodplain ordinance violation.

General Remarks: Chapter 54, Local Government Code, is amended to establish a procedure for a municipality to abate a violation of a floodplain ordinance by causing the work necessary to bring the real property into compliance and placing a lien on the property to recover the costs incurred.

Last Action: 9-1-13 G Earliest effective date

HB 1563: King, Tracy (D); Hegar, Glenn (R)

Relating to fees of office for directors of groundwater conservation districts.

General Remarks: Chapter 36, Water Code, is amended to increase the fees for a director of a groundwater district from $150 per day to $250 per day. The annual cap would remain $9,000.

Last Action: 9-1-13 G Earliest effective date

HB 1600: Cook, Byron (R); Nichols, Robert (R)

Relating to the continuation and functions of the Public Utility Commission of Texas (PUC), to the transfer of certain functions from the TCEQ to the PUC.

General Remarks: This is the PUC Sunset bill. It includes the transfer to the PUC of the TCEQ's water and wastewater rate jurisdiction under Chapters 12 and 13 Water Code. See also SB567.

Last Action: 9-1-13 G Earliest effective date

HB 1675: Bonnen, Dennis (R); Nichols, Robert (R)

Relating to governmental entities subject to the sunset review process.

General Remarks: Section 2.03 of the bill places the Sulphur River Basin Authority under the Texas Sunset Act as if it were a state agency. Unless the authority is continued in existence, it is abolished on Sept. 1, 2017.

Last Action: 6-14-13 G Earliest effective date

HB 1685: Price, Four (R); Whitmire, John (D)

Relating to the continuation of the self-directed and semi- independent status of the Texas State Board of Public Accountancy, the Texas Board of Professional Engineers, and the Texas Board of Architectural Examiners.

General Remarks: The Self-Directed Semi-Independent Agency Project Act describing the responsibilities and powers of The Texas Board of Professional Engineers, the Texas State

Board of Public Accountancy, and the Texas Board of Architectural Examiners, is redesignated as Chapter 472, Government Code. Numerous changes are made.

Last Action: 9-1-13 G Earliest effective date

HB 1973: Lucio III, Eddie (D); Hegar, Glenn (R)

Relating to the provision of water by a public utility or water supply or sewer service corporation for use in fire suppression.

General Remarks: Chapter 341, Health and Safety Code, is amended to authorize a municipality to adopt fire flow standards established by the TCEQ for an investor-owned utility or water supply corporation providing service to certain residential areas within the city or its extraterritorial jurisdiction. The applicability to certain residential areas and minimum standards are prescribed in the bill.

Last Action: 9-1-13 G Earliest effective date

HB 2105: Lucio III, Eddie (D); Lucio, Eddie (D)

Relating to municipally owned utility systems.

General Remarks: Section 1502, Government Code, relating to public securities for municipal utilities, is amended to authorize a municipality to acquire and maintain channels or bodies of water known as resacas. A utility system located in a county contiguous to the Gulf and bordering the United States may collect service charges authorized under this section.

Last Action: 6-14-13 G Earliest effective date

HB 2362: Keffer, Jim (R); Birdwell, Brian (R)

Relating to the audit and review of river authorities.

General Remarks: Chapter 49, Water Code, and Chapter 322, Government Code, are amended to authorize the Legislative Budget Board (LBB) to periodically review the effectiveness and efficiency of the policies, management, fiscal affairs, and operations of a river authority. The LBB must conduct a review of the Lower Colorado River Authority and the Brazos River Authority before conducting a review of other river authorities.

Last Action: 9-1-13 G Earliest effective date

HB 2615: Johnson, Eric (D); Fraser, Troy (R)

Relating to reporting and information availability requirements for persons impounding, diverting, or otherwise using state water.

General Remarks: Chapter 11, Water Code, is amended to increase the penalty for failure to timely file a water use report and to establish a penalty for failure to make monthly water use information available to the TCEQ upon request. The penalty for either violation is established as \$100 per day for a surface water right authorizing the appropriation of 5,000 acre-feet or less per year and \$500 per day for a water right authorizing the appropriation of more than 5,000 acre-feet per year. A surface water right is exempt from cancellation for non-use to the extent the non-use results from drought or curtailment of water by the TCEQ.

Last Action: 9-1-13 G Earliest effective date

HB 2704: Callegari, Bill (R); Hegar, Glenn (R)

Relating to the electronic submission of bids for construction contracts for certain conservation and reclamation districts.

General Remarks: Chapter 49, Water Code, is amended to authorize a district to receive bids by electronic transmission. The aggregate of change orders allowed is increased from 10% to 25% of the original contract price.

Last Action: 6-14-13 G Earliest effective date

HB 2781: Fletcher, Allen (R); Campbell, Donna (R)

Relating to rainwater harvesting and other water conservation initiatives.

General Remarks: Chapter 447, Government Code, is amended so that requirements for rainwater harvesting systems for state buildings apply to both indoor and outdoor water use. Chapter 341, Health and Safety Code, is amended to require that a privately owned rainwater harvesting systems with a capacity of more than 500 gallons that has an auxiliary water supply have a backflow prevention assembly or air gap. Chapter 580, Local Government Code, is amended to expand the applicability of training requirements for cities and counties related to rainwater harvesting standards.

Last Action: 9-1-13 G Earliest effective date

HB 3233: Ritter, Allan (R); Fraser, Troy (R)

Relating to interbasin transfers of state water.

General Remarks: Section 11.085, Water Code, relating to interbasin transfers of water, is amended to eliminate a provision requiring an assessment of the projected effect on user rates and fees for each class of ratepayers; to ensure that an evidentiary hearing be limited to issues related to requirements in this section; to make the notice requirement more manageable; to clarify the factors to be considered to assess whether detriments to the basin of origin are less than the benefits to the receiving basin; to allow for an extension or renewal of a contract that is the basis of the transfer; and to exempt from the requirements a transfer to serve a retail water utility located partly within and partly outside the basin of origin.

Last Action: 9-1-13 G Earliest effective date

HB 3511: Ritter, Allan (R); Eltife, Kevin (R)

Relating to adjudication of claims under water contracts with local government entities.

General Remarks: Chapter 271, Local Government Code, is amended to waive sovereign immunity to suit for a local government for adjudicating a claim for a breach of contract regarding the sale or delivery by a local government of not less than 1,000 acre-feet of reclaimed water intended for industrial use. Damages for breach of such a contract may include actual damages, specific performance, or injunctive relief. The bill also contains the provisions of SB 958.

Last Action: 6-14-13 G Earliest effective date

HB 3604: Burnam, Lon (D); Hegar, Glenn (R)

Relating to the implementation of a drought contingency plan by wholesale and retail public water suppliers and irrigation districts.

General Remarks: Section 16.055, Water Code, currently requires implementation of water conservation and drought plans in areas of the state w here an emergency due to drought has been declared by the Governor or a political subdivision. This bill would provide for penalties for failure to implement the conservation or drought plan.

Last Action: 9-1-13 G Earliest effective date

HB 3605: Burnam, Lon (D); Hegar, Glenn (R)

Relating to the evaluation by the TWDB of applications for financial assistance for certain retail public utilities.

General Remarks: Chapter 17, Water Code, is amended to require the TWDB, for a retail public utility serving 3,300 or more connections that applies for financial assistance, to review the utility's water conservation plan for compliance with the board's best management practices and issue a report to the utility and the Legislature.

Last Action: 9-1-13 G Earliest effective date

Senate Bills (SB)

SB 198: Watson, Kirk (D); Dukes, Dawnna (D)

Relating to restrictive covenants regulating drought- resistant landscaping or water-conserving turf.

General Remarks: Chapter 202, Property Code, is amended to prohibit a property owners' association (POA) from restricting a property owner from using drought-resistant landscaping or water-conserving natural turf. The POA may require the submission of a landscape plan for review and approval to ensure aesthetic compatibility with other landscaping in the subdivision.

Last Action: 9-1-13 G Earliest effective date

SB 204: Nichols, Robert (R); Price, Four (R)

Relating to the continuation and functions of the Texas Board of Professional Engineers.

General Remarks: Chapter 1001, Occupations Code, is amended to continue in existence the Texas Board of Professional Engineers to 2025. Various changes are made to the agency's authority.

Last Action: 9-1-13 G Earliest effective date

SB 293: Williams, Tommy (R); Ritter, Allan (R)

Relating to the authority of certain water districts to hold meetings by teleconference or videoconference.

General Remarks: Chapter 551, Government Code, is amended to allow a water district or authority whose territory includes land in 3 or more counties to hold certain special called meetings by conference call.

Last Action: 5-10-13 G Earliest effective date

SB 567: Watson, Kirk (D); Geren, Charlie (R)

Relating to rates for water service, to the transfer of functions relating to the economic regulation of water and sewer service from the TCEQ to the PUC.

General Remarks: The rate jurisdiction of the TCEQ under Chapters 12 and 13, Water Code, are transferred to the PUC. Comprehensive procedural changes are made to the rate-making process for investor-owned utilities. These procedures vary depending on the number of taps or connections served. Conforming changes are made to other chapters of the Water Code and the Special District Local Laws Code. The changes generally take effect September 1, 2014, except the Office of Public Utility Counsel may begin intervening in cases at the TCEQ effective September 1, 2013.

Last Action: 9-1-13 G Earliest effective date

SB 611: Lucio, Eddie (D); Lucio III, Eddie (D)

Relating to the irrigation powers and functions of certain water districts.

General Remarks: Numerous changes are made to Chapters 51, 55, and 58, Water Code, to change the manner in which water control and improvement districts, water improvement districts, and irrigation districts engaged in the delivery of irrigation water determine assessments and charges against irrigable land. These changes arise from the urbanization of districts that originally delivered primarily irrigation water. A provision in Chapter 58, Water Code, requiring a district engineer to study and investigate certain construction plans is repealed. Chapter 51 is also amended to address the authority of a preservation district as related to a particular water supply project.

Last Action: 9-1-13 G Earliest effective date

SB 634: Davis, Wendy (D); Collier, Nicole (D)

Relating to regulating faulty on-site sewage disposal systems in the unincorporated areas of a county as a public nuisance.

General Remarks: Chapter 343, Health and Safety Code, is amended to include in the definition of public nuisance a surface discharge from an on-site sewage disposal system. The county may use any reasonable means of abatement necessary to bring the system into compliance if the owner fails to abate the nuisance as ordered by the court.

Last Action: 6-14-13 G Earliest effective date

SB 654: West, Royce (D); Anchia, Rafael (D)

Relating to the enforcement of water conservation and animal care and control ordinances of a municipality by civil action or quasi-judicial enforcement.

General Remarks: Chapter 54, Local Government Code, is amended to authorize a municipality to bring a civil action or a quasi- judicial action for the enforcement of an ordinance relating to water conservation measures, including watering restrictions, and relating to animal care and control.

Last Action: 9-1-13 G Earliest effective date

SB 655: Birdwell, Brian (R); King, Phil (R)

Relating to the exercise of the power of eminent domain by certain authorized entities.

General Remarks: Chapter 1, Special District Local Laws Code, and Chapter 1, Water Code, are amended to authorize an entity governed by either code to exercise the power of eminent domain only for a public use in accordance with Section 17, Article I, Texas Constitution.

Last Action: 5-18-13 G Earliest effective date

SB 656: Paxton, Ken (R); Button, Angie (R)

Relating to providing transparency in the taxing and budgeting process of certain local governments.

General Remarks: Various provisions of Chapters 102 and 111, Local Government Code, are amended to establish additional procedural requirements for a municipality or county to adopt a budget. The procedures require a record vote and details about revenues to be collected.

Last Action: 9-1-13 G Earliest effective date

SB 902: Fraser, Troy (R); Callegari, Bill (R)

Relating to the operation, powers, and duties of certain water districts.

General Remarks: T his approximately 30-page bill generally supported by water districts makes numerous changes to the authority of water districts contained in Chapters 49, 51, and 54, Water Code. Related provisions of Chapter 388, Health and Safety Code, and Chapters 375 and 552, Local Government Code, are also amended. Districts operating under the applicable chapters of the Water Code should review these changes carefully. Groundwater districts and water supply corporations may also be impacted by certain provisions.

Last Action: 9-1-13 G Earliest effective date

SB 958: Fraser, Troy (R); Keffer, Jim (R)

Relating to the liability of certain special-purpose districts or authorities providing water to a purchaser for the generation of electricity.

General Remarks: Chapter 113, Civil Practices and Remedies Code, is amended to waive sovereign immunity for any water district or authority for breach of a written water supply contract under which water is to be provided to a purchaser for use in connection with the generation of electricity. Remedies may include any remedy available for breach of contract that is not inconsistent with the terms of the contract, but may not include consequential or exemplary damages. Sovereign immunity is not waived in federal court or for a cause of action for a negligent or intentional tort.

Last Action: 6-14-13 G Earliest effective date

SB 1212: Estes, Craig (R); Phillips, Larry (R)

Relating to the applicability of certain provisions concerning the transfer of exotic species to certain transfers of water that supply populous areas.

General Remarks: Chapter 66, Parks and Wildlife Code, is amended so that certain water transfers (appears to be bracketed for the North Texas Municipal Water District situation) do not create violations of statutes prohibiting the import of harmful species and do not require a permit under this section.

Last Action: 5-24-13 G Earliest effective date

SB 1282: Duncan, Robert (R); Price, Four (R)

Relating to deadlines for proposals for adoption by certain districts or authorities of desired future conditions of relevant aquifers.

General Remarks: Chapter 36, Water Code, is amended to ensure that a proposal for the adoption of desired future conditions is not required before May 1, 2016. Districts in a management area are not prevented from voting on a proposal before that date.

Last Action: 9-1-13 G Earliest effective date

SB 1297: Watson, Kirk (D); Branch, Dan (R)

Relating to written electronic communications between members of a governmental body.

Generalal Remarks: Chapter 551, Government Code, is amended to provide that written communications between members of a governmental body about public business do not constitute a meeting or deliberation so long as they are posted to an on-line message board meeting specified requirements.

Last Action: 9-1-13 G Earliest effective date

Senate Joint Resolution (SJR)

SJR 1: Williams, Tommy (R); Pitts, Jim (R)

Proposing a constitutional amendment providing for the creation and use of funds in the state treasury to provide financial assistance for certain projects related to economic development and water infrastructure.

General Remarks: A constitutional amendment is proposed to create 2 new accounts outside of the general revenue fund, the State Water Implementation Fund of Texas (SWIFT) and the State Water Implementation Revenue Fund of Texas (SWIRFT), to be administered by the TWDB to finance projects included in the state water plan. Also see HB 4 and HB 1025.

Last Action: 11-5-13 G Election date

WATER ENVIRONMENT ASSOCIATION OF TEXAS: LEGISLATIVE WRAP-UP OF BILLS RELATED TO WATER QUALITY

By Carol Batterton, Executive Director, Water Environment Association of Texas, and Brad Castleberry, Lloyd Gosselink Rochelle & Townsend, P.C.[1]

The 83rd regular session of the Texas Legislature adjourned May 27, 2013. According to Texas Legislature Online, 5,868 House and Senate bills were introduced, and 1,413 bills passed. This session addressed water, transportation, education, and tax reductions, although in some cases not to the extent that everyone wished. This article highlights those bills that passed, as well as those that did not pass, that relate to water quality. A table is included that summarizes an expanded list of highlighted bills passed by the Legislature this session.

State Water Plan Funding

The most notable accomplishment of this session was the funding of the state water plan. In the end, all 3 pieces of legislation addressing funding of the state water plan passed and received the requisite signature of the Governor (albeit with a line item veto for House Bill (HB) 1025). **Voters will still need to approve a constitutional amendment in November to actually fund the water plan,** and so public education efforts must continue to keep the focus on water until that time. The following are the key pieces of legislation related to water plan funding:

- HB 4 (Ritter) defines the State Water Implementation Fund for Texas (SWIFT), the State Water Implementation Revenue Fund for Texas (SWIRFT), and how these funds will be managed by the Texas Water Development Board (TWDB).
- HB 1025 (Pitts) is the supplemental appropriations bill that will allocate the $2 billion for use by the SWIFT if voters approve the constitutional amendment in SJR 1.
- Senate Joint Resolution 1 (Williams) is the joint resolution that will amend the **c**onstitution to create the SWIFT and SWIRFT, allowing the $2 billion to be dedicated for water infrastructure needs. This resolution will need voter approval in November.

Other bills that passed:

- **Desalination:** The Legislature passed House Concurrent Resolution (HCR) 59, which creates a joint interim committee to study seawater desalination on the Texas coast.
- **Drought:** HB 252 (Larson) requires retail public utilities and wholesale water and sewer service suppliers to notify the Texas Commission on Environmental Quality (TCEQ) when the certainty of the utility's water supply is less than 180 days from being compromised.
- **Conservation:** HB 857 (Lucio III) requires annual water loss audits for utilities over 3,300 connections, and HB 1461 (Aycock) requires a retail public utility that is required to file a water audit with the TWDB to notify each of the utility's customers as well.
- **Water rates:** HB 1600 (Cook), the Public Utility Commission of Texas (PUC) Sunset bill, among other things, transfers the TCEQ's water and wastewater rate jurisdiction to the PUC.
- **Interbasin transfers:** HB 3233 (Ritter) streamlines the interbasin transfer permitting process for surface water rights at the TCEQ.
- **Professional engineers:** Senate Bill (SB) 204 (Nichols) requires professional engineers to be fingerprinted in order to apply for an initial or renewal license.

Bills that did not pass:

- **SSO reporting:** Unfortunately, HB 824 (Callegari), which would have exempted sanitary sewer overflows (SSOs) less than 1,000 gallons from being reported to the TCEQ within 24 hours, did not pass. The good news is that as a result of hearing testimony, the TCEQ and members of the Legislature are now aware of the issues with reporting of minor spills on a 24-hour basis.
- **Biosolids:** None of the bills proposing to change the definition of Class B sludge passed. These were HBs 2996, 2997, 2998, and 3678. In addition, HB 3255 (Kacal), which would have prohibited sale of composted biosolids by a political subdivision outside its boundaries, did not pass.
- **Compliance history:** HB 1714 (Smith) would have discontinued TCEQ's compliance history program.
- **BPAT licensing:** HB 2179 (Davis) would have transferred the backflow prevention assembly testers (BPAT) licensing program from the TCEQ to the Texas State Board of Plumbing Examiners.
- **Stormwater professionals:** HB 3289 (Martinez) would have required licensing of stormwater professionals.

[1]*Assistance also provided by Sarah Wells, 3rd-year law student, University of Texas School of Law*

Other key issues:

TCEQ procedure

The much-discussed and controversial SB 957, by Troy Fraser, which proposed a change from the current TCEQ permitting process to an Environmental Protection Agency-type notice and comment process, failed to come to fruition following intensive and thorough negotiations. As part of the negotiations, the proposal for the bill was changed to maintain the basic structure of the current contested case hearing process, but the proposal included tighter timelines and other restrictions to shorten the time the process takes from start to finish. However, the measure still failed to move forward. We anticipate that the Legislature and stakeholders will work together in the interim to find a balanced approach to this problem that will be able to move forward next session.

Open government

The Legislature also made a concerted effort this session to improve government transparency on many fronts. High-profile transparency measures initiated by the Texas Comptroller of Public Accounts, including HB 14 and SB 14, were the subject of intense negotiations with political subdivisions due largely to additional compliance costs and rumored potential impacts to public bond ratings. However, these 2 bills ultimately failed to become law because of a successful parliamentary procedure challenge. The measures that did succeed in becoming law included these amendments to the Open Meetings Act:

- HB 2414 (Button) amends current legal requirements to open meetings of governmental bodies held by videoconference.
- SB 293 (Williams) sets forth new procedures by which certain large water districts are permitted to hold a meeting by videoconference or telephone conference call.
- SB 1368 (Davis) and SB 1297 (Watson) both allow public officials to make certain communications outside of a proper public meeting via message boards that are visible to the public.

See Water Environment Association of Texas' summary of bill highlights in Table 1 and also at www.weat.org.

Table 1. 83rd Session Water Environment Association of Texas bill highlights

Bill	Author	Summary
HB 4	Ritter	Relating to the creation and funding of the state water implementation fund for Texas to assist the TWDB in the funding of certain water-related projects.
HB 45/ SB 162	Flynn/Van de Putte	Relating to the occupational licensing of members of the military and spouses of members of the military HB 45 and SB162 were companion bills. SB 162 passed.
HB 168/ SB 902	Callegari/ Fraser	Relating to the operation, powers, and duties of certain water districts. HB 168 and SB 902 were companion bills. SB 902 passed.
HB 252	Larson	Requires that all retail public utilities report how long they have available water supplies to TCEQ. The bill includes additional notification requirements for utilities with supplies of less than 180 days.
HB 340/ SB 1532	Rodriguez, Eddie/ Zaffirini	Relating to the power of TCEQ to authorize certain injection wells that transect or terminate in the Edwards Aquifer. HB 340 and SB 1532 were companion bills. SB 1532 passed.
HB 597	Guillen	Relating to boater education and examinations on preventing the spread of exotic harmful or potentially harmful aquatic plants, fish, and shellfish.
HB 857	Lucio III	Relating to the frequency of water audits by certain retail public utilities.
HB 970	Rodriguez, Eddie	Relating to regulation of cottage food products and cottage food production operations.
HB 1025	Pitts	Relating to making supplemental appropriations and reductions in appropriations and giving direction and adjustment authority regarding appropriations.
HB 1241	Guillen	Relating to the adoption of rules by the Parks and Wildlife Commission to protect the public water of this state from the spread of aquatic invasive species.
HB 1307/SB 567	Geren/ Watson	Relating to rates for water service, to the transfer of functions relating to the economic regulation of water and sewer service from the TCEQ to other PUC, and to the duties of the Office of Public Utility Counsel regarding the economic regulation of water service. HB 1307 and SB 567 were companion bills. SB 567 passed.
HB 1461	Aycock	Relating to customer notification of significant water loss by a retail public utility.
HB 1509/SB 654	Anchia/ West	Relating to the enforcement of water conservation and animal care and control ordinances of a municipality by civil action or quasi-judicial enforcement; providing civil penalties. HB 1509 and SB 654 were companion bills. SB 654 passed.
HB 1600/SB 206	Cook/ Nichols	Relating to the continuation and functions of the PUC, to the transfer of certain functions from the TCEQ to the PUC, to the rates for water service, and to the functions of the Office of Public Utility Counsel; authorizing a fee. HB 1600 and SB 206 were companion bills. HB 1600 passed.
HB 2105/SB 1817	Lucio III/ Lucio	Relating to municipally owned utility systems; authorizing the imposition of fees by a utility board of trustees. HB 2105 and SB 1817 were companion bills. HB 2105 passed.
SJR 1	Williams	Proposing a constitutional amendment providing for the creation of the SWIFT and the SWIRFT for Texas to assist in the financing of priority projects in the state water plan. **Constitutional Amendment must be passed by voters in November.**
SB 204/ HB 1676	Nichols/ Price	Relating to the continuation and functions of the Texas Board of Professional Engineers; changing a fee. SB 204 and HB 1676 were companion bills. SB 204 passed.
HB 3233	Ritter	Relating to interbasin transfers of state water.
SB 634/ HB 1932	Davis/ Strickland	Relating to regulating faulty on-site sewage disposal systems in the unincorporated areas of a county as a public nuisance; providing a criminal penalty. SB 634 and HB 1932 were companion bills. SB 634 passed.

SIERRA CLUB: ADVANCING WATER CONSERVATION AND MANAGEMENT

By Ken Kramer, Water Resources Chair, Lone Star Chapter, Sierra Club

Without a doubt the most publicly visible water issue in the regular session of the 83rd Texas Legislature was the debate over "funding the state water plan." The proposal of a state constitutional amendment to create new funding mechanisms for projects in the state water plan, the passage of House Bill (HB) 4, and the transfer of $2 billion out of the so-called Rainy Day Fund for the new State Water Implementation Fund for Texas (SWIFT) — taken together — constitute historic water legislation. Of course, history will only be made if Texas voters in November 2013 approve the constitutional amendment. The funding structure and process outlined in HB 4 and the actual transfer of money out of the Rainy Day Fund (in HB 1025) will take effect only if the constitutional amendment passes muster with the voters.

The public and media attention to the fight at the Capitol over "funding the state water plan," however, obscured other important water decisions made by state legislators in the regular session. The Texas Legislature took action to advance water conservation, curb water loss, respond more effectively to drought situations, and enhance water management in certain other ways. Those actions included seminal appropriations for water conservation and environmental flow studies and the enactment of a variety of new water management laws, including several key provisions of HB 4 that have garnered only limited attention. Also important is that the Legislature turned away many other pieces of legislation that would have undermined management and protection of our state's water resources.

Spending State Money for Water Management

As is usually the case, the Texas Legislature in its biennial state appropriations bill allocated tens of millions of dollars to the Texas Water Development Board (TWDB), the state's primary water planning and financing agency. Other water programs and activities, of course, were funded at the Texas Commission on Environmental Quality (TCEQ), Texas State Soil and Water Conservation Board, Texas Parks and Wildlife Department, and other state agencies. Thanks to a relatively healthy state revenue forecast for the 2014–2015 biennium, these programs were funded at decent, although hardly spectacular, levels.

Buried in the appropriations for the TWDB, however, were some interesting earmarks. These earmarks, which reflected a growing interest in water management activities (and the willingness of key legislators to get money appropriated for those activities), included

- $1 million for Fiscal Year (FY) 2014 for competitive grants to water conservation education groups (may require matching funds);
- $1.8 million in each year of the biennium for the Texas Alliance for Water Conservation Demonstration Project, a partnership project in the Texas Panhandle to enhance agricultural water efficiency to extend the life of the Ogallala Aquifer;
- $1.5 million in each year of the biennium for grants to groundwater districts for agricultural water conservation (grants will only go to districts that require metering of water use and may only be used to offset half the cost of each meter);
- $407,000+ in FY 2014 and $326,000+ in FY 2015 to develop an online tool to consolidate water use, annual water loss, and annual water conservation reports and make them publicly viewable online; and
- $2 million in FY 2014 for the continued study of environmental flows and instream flows for river basins, of which at least $750,000 shall be used in the bay/basin area that covers the Guadalupe River Basin and San Antonio Bay.

Two disappointments were the failure of the Legislature once again to appropriate requested funds for the state's water education program, known as Water IQ, and the Governor's veto of a line item appropriating funds to the Houston Advanced Research Center for aquifer research. Some lawmakers dismiss Water IQ as just an "advertising campaign." Exactly — just as legislators use "advertising campaigns" to get voters to vote for their re-election, Water IQ uses "advertising" to get the public's attention and to educate people about the sources of their water and the need to conserve it. Several entities, such as North Texas Municipal Water District, have spent their own money to implement Water IQ and have experienced positive results in water savings. Supporters of Water IQ think those results could be replicated statewide. Indeed the Legislative Budget Board (LBB) staff in its *Texas State Government Efficiency and Effectiveness Report* released early in the session recommended a $6 million appropriation for Water IQ for the biennium, but to no avail.

The Governor's veto of the $1.5 million per year appropriation for aquifer research was publicly explained on the basis that the appropriation was duplicative of an appropriation to the TWDB for *demonstration projects related to water reuse, aquifer storage and recovery, and other innovative water storage approaches.* While the Legislature did appropriate $3 million to the TWDB for FY 2014 for such demonstration projects, the money that would have gone to the Houston Advanced Research Center, however, was money for basic research about aquifers, not funding for water supply demonstration projects.

Overall, though, the legislative appropriations for water management activities for the 2014–2015 biennium represent incremental steps forward. If these expenditures become part of the base budgets of the agencies and are increased over time, they will represent a very positive development. At the least they show that legislative appropriators are interested in water management and not just water infrastructure.

Using State Financial Assistance Wisely

Legislative leaders also demonstrated a serious concern that decisions about state financial assistance for water projects and programs reflect commitments to advancing water conservation, curbing water loss, and prioritizing projects based on rational criteria. For example, among its extensive provisions for funding the state water plan for restructuring the TWDB, HB 4

- requires the TWDB to undertake to apply not less than 20% of the money disbursed in each 5-year period to support projects, including agricultural irrigation projects, that are designed for water conservation or reuse;
- requires the TWDB to undertake to apply not less than 10% of the money disbursed in each 5-year period to support projects for rural political subdivisions or agricultural water conservation;
- prohibits the use of state financial assistance for a water project if the applicant has failed to submit or implement a water conservation plan;
- requires regional water planning groups in their prioritization of projects for state financial assistance to consider at a minimum such factors as the feasibility, viability, sustainability, and cost-effectiveness of a project — factors which should work in favor of conservation projects; and
- requires the TWDB in its process for prioritization of projects to receive state financial assistance to consider (among other criteria) the demonstrated or projected effect of the project on water conservation, including preventing the loss of water (taking into consideration whether the applicant has filed a water audit that demonstrates the applicant is accountable with regard to reducing water loss and increasing efficiency in the distribution of water).

In addition, another significant but unheralded piece of legislation enacted by the 83rd Legislature, HB 3605 by State Representatives Burnam, Callegari, and Lucio III (Senate sponsor: Senator Hegar)

- requires a retail public water utility that receives financial assistance from the TWDB to use a portion of that assistance or any additional assistance provided by the TWDB to mitigate the utility's system water loss if, based on its water audit, the water loss meets or exceeds a threshold to be established by TWDB rule;
- requires the TWDB in passing on an application for financial assistance from a retail public water utility serving 3,300 or more connections to evaluate the utility's water conservation plan for compliance with TWDB's best management practices for water conservation and issue a report to the utility detailing the results of that evaluation; and
- requires the TWDB not later than January 1 of each odd-numbered year to submit to the Legislature a written summary of the results of the evaluations noted above.

Thus, not only does HB 3605 have the potential to address water loss directly and to promote the use of best management practices for water conservation by utilities, it also has the potential for providing important data to legislators and the public about how well utilities are progressing in achieving water conservation. If utilities are not seen as making strides in that regard, the stage could be set for new water conservation requirements imposed by the Legislature.

Avoiding Water Waste and Advancing Water Efficiency

In addition to the use of state financial assistance to guide the actions of water suppliers seeking that assistance, the Legislature also took steps through direct legislation to encourage water utilities to avoid water waste and advance water efficiency. Among the myriad of new laws enacted by the Legislature in that regard were the following:

HB 857 (Lucio III/Hegar) requires each retail public water utility with more than 3,300 connections to conduct a water audit annually to determine its water loss and to submit that audit to the TWDB (a retail public water utility with 3,300 or less connections will continue to be required to conduct and submit a water audit once every 5 years computing the utility's system water loss during the preceding year) — the initial annual water audit must be submitted by May 1, 2014.

HB 1461 (Aycock/Fraser) requires each retail public water utility required to file a water audit with the TWDB to notify each of the utility's customers of the water loss reported in the water audit (The TCEQ will adopt rules to implement this requirement, but the notice may be done through the utility's annual consumer confidence report or on the next bill the customer receives after the water audit is filed).

Senate Bill (SB) 198 (Watson/Dukes) prevents a homeowners' association (HOA) from prohibiting or restricting a property owner from using drought-resistant landscaping or water-conserving natural turf but allows a HOA to require the property owner to submit a detailed description of a plan for the installation of such landscaping or turf for review and approval by the HOA to ensure to the extent practicable maximum aesthetic compatibility with other landscaping in the subdivision. The legislation also states that the HOA may not unreasonably deny or withhold approval of the plan or unreasonably determine that the proposed installation is aesthetically incompatible.

SB 385 (Carona/Keffer) authorizes a municipality or a county or a combination thereof to establish and implement a program to provide directly or through a third party financing for a permanent improvement to real property that is intended to decrease water or energy consumption or demand, with the repayment of the financing of a qualified project to be done through an assessment collected with property taxes on the assessed property; sets out the procedures, requirements, and options by which such a program may be established, implemented, and operated by the local government through contracts and other mechanisms.

SB 654 (West/Anchia) specifically grants to municipalities the authority to enforce through a civil action ordinances related to water conservation measures, including watering restrictions (although some municipalities have taken the position that they already had this authority, this legislation makes it clear that they do and gives municipalities more flexibility in enforcing water conservation ordinances since there may be a reluctance to use criminal law in this regard).

SB 700 (Hegar/Kacal, Raney) requires

- the State Energy Conservation Office (SECO) to develop a template for state agencies and higher education institutions to use in preparing their respective comprehensive energy and water management plan (such a plan is already required);
- each agency and higher education institution to set percentage goals for reducing its use of water, electricity, gasoline, and natural gas and include those goals in its energy and water management plan;
- the plan to be updated annually (currently updates are required biennially);
- SECO biennially to report to the Governor and the LBB the state and effectiveness of management and conservation activities of the agencies and higher education institutions; and
- SECO to post that report on its website.

Getting Serious about Water Data and Management

The Legislature also proved receptive in its 83rd Regular Session to other initiatives to make sure that water utilities and others were getting serious about such important responsibilities as reporting water use, overseeing rainwater harvesting systems, and implementing drought contingency plans. Examples of such efforts that were enacted into law include the following:

HB 2615 (Johnson/Fraser) increases the penalty for failure of a water rights holder to submit an annual water use report to the TCEQ (in part because the penalties previously were so low, only about 60% of water rights holders outside watermaster areas reported their annual water use by the deadline) and requires the TCEQ to establish a process for submitting these reports electronically through the Internet.

HB 2781 (Fletcher/Campbell) makes a number of changes in current law governing the use and oversight of rainwater harvesting systems. For example HB 2781

- requires a privately owned rainwater harvesting system with a capacity of more than 500 gallons that has an auxiliary water supply to have a specified mechanism for ensuring physical separation between the rainwater system and the auxiliary supply (to prevent any possible contamination) and
- requires the permitting staff of each county and municipality with a population of 10,000 or more whose work relates directly to permits involving rainwater harvesting to receive appropriate training (provided by the TWDB) regarding rainwater harvesting standards.

HB 3604 (Burnam, Lucio III/Hegar) requires an entity to implement its water conservation plan and its drought contingency plan, as applicable, when it is notified that the Governor has declared its respective county or counties as a disaster area based on drought conditions; clarifies the authority of the TCEQ to enforce this requirement. (previously the law only required the entity to implement either plan, despite the fact that water conservation should be an ongoing activity as contrasted to short-term responses to drought conditions; during the 2011 drought a number of entities in drought disaster areas reportedly did not implement mandatory water use restrictions).

Holding the Line on Some Questionable Legislation

The story of the legislative process, of course, is not just a story of the bills that passed into law. More often it is the story of the bills that did not become law. There were many positive pieces of legislation that failed to run the gauntlet of the legislative process, including, for example, all of the bills that would have clarified the authority of the state Water Conservation Advisory Council to make statutory and appropriations recommendations.

By and large, however, the majority of water bills that died were ones that were opposed by the environmental community and/or by other interests concerned about proper management and protection of water resources.

Following are some examples of these bills of concern that died:

HB 824 (Callegari) would have eliminated the requirement that all sewer overflows be reported to the TCEQ within 24 hours (the threshold for reporting would have been more than 1,000 gallons; overflows below that level would have been exempted from reporting). HB 824 passed the House in amended form but never made it out of the Senate Natural Resources Committee.

HB 3234 (Ritter/Fraser) would have set what many water attorneys considered unrealistic deadlines for the processing of water rights permits that could have led to inadequate review of permit applications and might have interfered with the public's opportunity to impact permitting decisions. HB 3234 passed the House but was voted down in Senate Natural Resources Committee.

SB 1894 (Fraser) would have prevented the revision and possible strengthening of adopted state standards for instream flows and freshwater inflows to bays and estuaries until at least 2022, far beyond the time specified for review by most of the bay/basin area stakeholder committees that were set up under the environmental flows standards setting process created by SB 3 in 2007. SB 1894 was withdrawn from the Senate Natural Resources Committee hearing agenda and never seen again after a number of Senators raised concerns about delaying the review and revision process.

In addition, several pieces of legislation that had been introduced to "streamline" the process for developing and implementing marine water desalination or brackish groundwater desalination projects and/or aquifer storage and recovery (ASR) projects did not make it through the process. Although many environmental groups believe that desalination and ASR projects increasingly are going to be part of our water supply and indeed have positive appeal compared to other infrastructure projects (for example, surface water reservoirs), they are concerned about taking away important authority from state agencies and/or groundwater management districts to oversee and permit these projects in a responsible manner. These proposed bills were characterized by many as "not ready for prime time." But desalination is still on the front burner for discussion. Due to the passage of House Concurrent Resolution 59 (Hunter/Lucio), a joint interim study of "water desalination" should get underway in the fall of 2013.

Conclusion

The general session of the 83rd Texas Legislature was a "water session" in many respects. Although it may be remembered most for the establishment of funding for state water plan projects (assuming the voters ratify the proposed constitutional amendment), there were many other significant legislative actions on water, and those actions indicate that our state officials are looking at water much more seriously than perhaps ever before. The drought conditions of recent years — continuing and intensifying in a large portion of Texas in the summer of 2013 — have driven home the point that our state cannot afford to waste our precious water resources. Moreover, the shrinking surface water reservoirs in many parts of Texas and indeed the number of bone-dry reservoirs in West Texas are stark reminders that water infrastructure alone will not address our water problems. The 83rd Texas Legislature is to be commended for tackling the infrastructure funding issue and taking important steps forward on water conservation and management. But there are many river miles ahead of us in reaching a comprehensive solution to our state's water issues.

83RD TEXAS LEGISLATIVE WRAP-UP

By Stacey A. Steinbach Texas Alliance of Groundwater Districts

Unlike in previous sessions, it was no surprise when the 83rd Legislative Regular Session was inundated with water bills, particularly when it came to water infrastructure financing. Certainly, the largest water issue during 2013 — and one of the biggest overall this session — was providing a mechanism for adequately funding the state water plan. Through the passage of 2 bills and 1 resolution, Texas Legislators took an important, even revolutionary step, toward meeting the long-term water needs of the state. As my colleagues in this collaboration for Texas Water Journal have adeptly explained the substance of that legislation in their own columns, I will focus on other bills from the 83rd session that may affect groundwater use and management.

From the groundwater management perspective, the "beginning" (the bill filing deadline) and end of session painted very different pictures. Of the 150-plus bills tracked by the Texas Alliance of Groundwater Districts (TAGD), nearly 2 dozen would have significantly impacted groundwater conservation district (GCD) operations and authorities in this state. In prospect, those bills loomed as large as bills filed during the 82nd Legislative Session, when groundwater ownership, the Texas Water Development Board (TWDB) sunset review, and an overhaul of the desired future conditions (DFC) process was on the agenda. Even still, and despite efforts of legislators, staffers, and stakeholders to reach consensus, almost all of the groundwater bills filed this session failed to make it to *Sine Die*. In fact, just 2 housekeeping-type groundwater bills made it to the Governor: Senate Bill (SB) 1282, extending the deadline for proposing the next round of DFCs to May 1, 2016, and House Bill (HB) 1563, increasing the maximum fees of office for a GCD board member from $150/day to $250/day (with the annual cap remaining at $9,000).

What Didn't Pass

With so few groundwater bills that passed and so many that garnered attention, it is likely that what didn't pass this session is just as important — if not more so — than what did pass. These bills covered a myriad of notable issues, including brackish groundwater utilization, aquifer storage, groundwater use reporting requirements, long-term permitting, well construction standards and enforcement, DFC appeals, and hydraulic fracturing. Of these, bills related to brackish groundwater, long-term permitting, and hydraulic fracturing received a great deal of stakeholder attention and gained momentum at some point in one or both chambers. Perhaps more than in previous sessions, there also seemed to be multiple, competing bills filed on these 3 subjects, each with a different approach or philosophy.

Groundwater and Hydraulic Fracturing

Like many states, gas exploration and development in Texas has increased dramatically over the past 10 years. Of TAGD-member GCDs with hydraulic fracturing in their jurisdictions, half are experiencing significant activity and nearly three-fourths are observing impacts to groundwater as a result of fracturing activities. But recently, a debate has emerged over a GCD's ability to require a permit for groundwater withdrawals related to hydraulic fracturing. Though some GCDs require permits without difficulty, others waive permit requirements out of concerns related to varying interpretations of the exemption described in Texas Water Code § 36.117(b)(2).

A look at the plain language and legislative history of this section supports the notion that the exemption language was not intended to encompass continuing oil and gas operations, of which hydraulic fracturing is a non-conventional example. But because the exemption language was adopted before the hydraulic fracturing boom in this state, these operations are not specifically addressed, and the exemption's applicability is being inferred in various ways. Ultimately, an interpretation that withdrawals related to fracturing activities are exempt from permit requirements creates a situation where these significant users of groundwater are exempted from regulatory requirements that all other significant users of groundwater must follow. This interpretation results in a greater regulatory burden for some users — agriculture, municipal, industry — and not others.

Three bills aimed to resolve the confusion this session, and 1 bill, SB 873, passed the Senate after being amended on the floor to include language to address oil and gas industry concerns. That bill would have expressly authorized a GCD to require a permit for oil- and gas-related groundwater withdrawals, while at the same time incorporating an "interim permit" concept to ensure that operations would not be delayed during the permitting process. Though the bill failed to move in the House, it likely presents a positive starting point for resolution of this issue during the next session.

Long-Term Permitting

Questions related to long-term groundwater permitting continue to garner attention at the Legislature. With the recent drought, water-supply certainty is more important than ever, and a few large water providers have been pushing for a statewide requirement for long-term or automatically renewed permits (though some GCDs already incorporate such concepts in their rules). Proposed solutions during the

83rd session ranged from 30-year operational permits for transporters to automatic permit renewals with proportional cutbacks when "conditions" change. Though stakeholders could generally agree with the latter approach, they could not reach consensus in fully defining the changed "conditions" and other details related to implementing cutbacks.

A GCD's mandate to balance private property rights, the highest practicable level of groundwater production, and conservation of the aquifer necessitates some flexibility for GCDs in managing this subsurface resource, especially in light of the court opinion in *Edwards Aquifer Authority v. Day*. All parties agree that no GCD can guarantee a certain level of groundwater availability for 30 years into the future and that arbitrary cutbacks should be (and already are) prohibited. Finding specific language that satisfies the needs of long-term groundwater investors and adequately addresses a GCD's local needs in accordance with statutory requirements has been challenging.

"Brackish" Groundwater

The groundwater issue that received the most attention during this session was brackish groundwater utilization, including desalination and aquifer storage and recovery. Early versions of filed bills would have essentially deregulated groundwater with a total dissolved solids (TDS) level of 1,000 parts per million (ppm) or more in order to promote its treatment and use.

Many GCDs had concerns with such a management strategy for numerous reasons; the most significant being that "brackish" groundwater is often hydrologically connected to other sources of groundwater. Production of such water may cause freshwater levels to drop or actually affect the quality of freshwater as the hydraulic pressure regimes change. Another important concern was that in some areas of the state, groundwater now being used without advanced desalination treatment and being managed by GCDs would be considered "brackish" under such a definition and therefore could no longer be managed by the GCD. Additionally, because a TDS concentration cannot be determined until after a well is drilled, and even then the concentration can fluctuate over the life of the well, a bright-line numerical definition creates a "chicken and egg" scenario that actually inhibits the certainty that most parties are seeking.

Legislators, staffers, and stakeholders worked hard on this issue during the session and though no legislation passed, all came to agree that hydrological connection to currently used sources of groundwater is a more important demarcation than an arbitrary TDS level that has different significance in different parts of the state. One bill, HB 2578, as amended, would have incorporated concepts of "brackish groundwater production zones" to be identified by the Texas Water Development Board (TWDB), with the assistance of GCDs and other stakeholders. In those areas, GCDs would be required to issue permits with 30-year permit terms and unlimited production, unless the GCD could show that cutbacks were necessary to respond to a significant change in aquifer levels or adverse effects to water quality. Though the bill didn't address all stakeholder concerns, the concept of identifiable, "distinct" brackish groundwater zones based on scientific research likely makes for a good launching point for stakeholder discussions during the interim. The upside to this issue is that there is a consensus among all stakeholders that use of brackish groundwater needs to be incorporated as a new water supply strategy wherever feasible.

What Did Pass

In addition to the bills/resolution related to funding the state water plan and the bills that amended the DFC proposal deadline and increased maximum fees of office for a GCD board member, the following bills passed during the 83rd Legislature may impact groundwater management. This list is not intended to be exhaustive and merely provides a starting point for legislative research by interested individuals.

New GCDs

- SB 1835 extends the deadline for the confirmation election for the Calhoun County GCD to December 31, 2016 and authorizes a tax if approved by voters.
- SB 980 creates the Reeves County GCD and authorizes a tax, subject to voter approval before December 31, 2018.
- SB 1840 creates the Deep East Texas GCD (consisting of Shelby, San Augustine, and Sabine Counties) and authorizes a tax, subject to voter approval before September 1, 2015.

Water Conservation/Drought

- HB 252 requires a retail public utility and any of its wholesalers to notify the Texas Commission on Environmental Quality (TCEQ) when they reasonably believe that less than 180 days of water is available.
- HB 857 requires retail public utilities serving more than 3,300 connections *or* receiving financial assistance from the TWDB to conduct an annual water loss audit (other retail public utilities are still on a 5-year schedule).
- HB 1461 requires retail public utilities to provide notification of water loss to customers after each water loss audit.
- HB 3604 requires utilities to implement water conservation plans *and* drought contingency plans when a

disaster emergency is declared due to drought.

- HB 3605 requires the TWDB to review a utility's compliance with its water conservation plan when considering financial assistance applications from retail public utilities serving more than 3,300 customers.
- SB 1 provides appropriations for water conservation grants, including $1.5 million per year for 2 years to the Agricultural Water Conservation Grant Program to be used for grants to GCDs that require meters in order to offset half the costs to well owners of installing those meters.
- SB 198 prohibits a homeowners' association from prohibiting xeriscaping, though the association can require plans to be pre-approved.
- SB 654 clarifies that a municipality may bring a civil action for enforcement of an ordinance relating to water conservation.
- SB 662 adds representatives of the Public Utility Commission of Texas and Electric Reliability Council of Texas to the Drought Preparedness Council.

Open Meetings/Open Records

- HB 2414 provides specifications for general videoconferencing meetings.
- SB 293 authorizes a "water district" covering 3 or more counties to hold a meeting via telephone or videoconference if it is a special called meeting, immediate action is required, and a quorum at 1 location would be difficult to obtain.
- SB 471 authorizes the use of electronic recorders for the official recording of open meetings.
- SB 984 provides specifications for videoconference meetings when the government entity is statewide or covers 3 or more counties.
- SB 1297 allows public officials to communicate between meetings on Internet message boards maintained by the governmental body and visible to the public.
- SB 983 provides for an "in camera" review of information at issue in a public information lawsuit.
- SB 1368 defines public information as it relates to contracts between non-government entities and government entities.

Looking Ahead

If the number and scope of unsuccessful bills during the 83rd Texas Legislative session are any indication, 2015 will be a busy year for those interested in groundwater management. During the interim, stakeholders should continue the work they started on many of these issues with the goal of coming to the Capitol with some consensus language for consideration during the 84th Legislative session.

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Public attitudes toward water management and drought in Texas

James W. Stoutenborough[1], Arnold Vedlitz[2*]

Abstract: Water management in Texas is increasingly salient as the population grows, water supplies continue to be taxed and the planet continues to warm, resulting in more severe, widespread, and frequent droughts in the state. Public support, though, is often essential for governments to enact large-scale projects, like those that may be needed to tackle water management issues. Given the challenges facing the state of Texas, surprisingly few studies explore public attitudes, preferences, and risk assessments about water-related resource allocations. Will the public act to direct or limit the actions of its elected officials on water issues? Is the public ready to consider policies, regulations, and expenditures concerning the potential impacts of increased drought frequency on Texas water resources? We report the results of 2 public opinion surveys of the citizens of Texas that focused on water management and drought issues. We found that the public is willing to support government efforts to manage water, but not if these efforts negatively affect the environment or agriculture.

Keywords: water management, drought issues, public attitudes, risk assessments, Texas drought

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As the planet continues to warm, Texans will need to adapt to their changing environment. In addition to problems such as rising sea levels and more extreme weather events, scientists predict many parts of the world are more likely to experience longer, more intense droughts (e.g. IPCC 2007). Vast expanses of Texas are included in these drought zones (e.g. Banner et al. 2010; Seager et al. 2007; Yu et al. 2006). Complicating things, the aquifer that Texas draws much of its water from, the High Plains Aquifer, has decreased by 27% in the last half century (Lubick 2004). Consequently, droughts have the potential to radically alter the way of life for Texans.

The Texas government will need to become more involved in water management. However, public support is often a necessary ingredient for political action. Studies consistently find that policy-maker decision-making tends to mirror the preferences of the public (e.g. Burstein 2010). If the public does not support a policy, it is very difficult for elected officials to find the will to act.

Understanding public attitudes toward an issue is an indispensable step toward legislating it. However, there are surprisingly few studies that explore public attitudes toward water issues. Will Texans act to constrain the actions of their elected officials? Are Texans ready to consider policies, regulations, and expenditures that address their water supply?

In this paper, we report the results of 2 recent public opinion surveys that focused on water management and drought issues in Texas. First, we describe our survey. Second, we place water issues in their appropriate context. Third, we explore general water views. Fourth, we investigate drought attitudes. Fifth, we survey attitudes toward government response to these issues. Finally, we discuss the implications of this project.

RESEARCH METHODS

We conducted 2 public opinion surveys of adults in Texas. The first survey was administered from 21 February 2013 to 12 March 2013 and resulted in 410 completed surveys for a 49.4% completion rate. The second survey, with identical questions, was in the field from 2 April 2013 through 16 April 2013 and resulted in a total of 412 completions for a completion rate of 38.6%. Both surveys were administered online by GfK (formerly Knowledge Networks). The 2 samples were drawn from KnowledgePanel®, a probability-based web panel designed to be representative of Texas for adults age 18 and over. Descriptive statistics for the demographic characteristics of the samples can be found in Appendix A. The median survey completion time was 27 minutes. Because there were no major water-related emergencies between the 2 surveys, we report the pooled results to simplify the presentation[1].

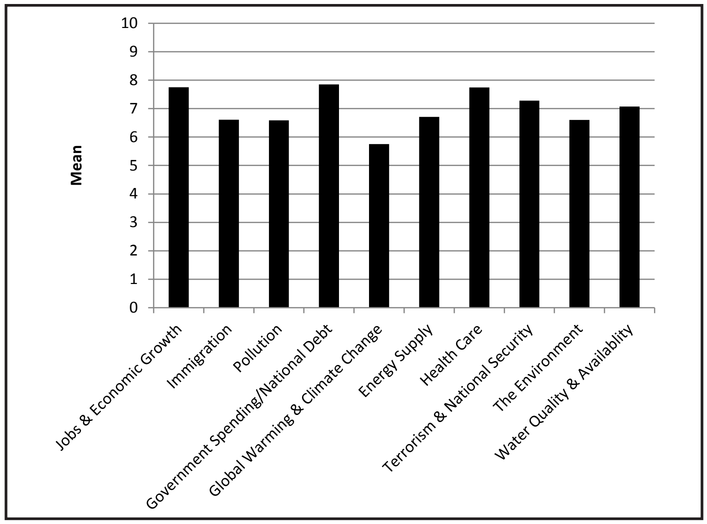

Figure 1. Comparing public concern for water quality and availability against other issue domains.

RESULTS

Comparing water to other issue domains

To understand attitudes on an issue, it is important to place them in their appropriate context. Texans may not view water issues as important in relation to other issues. If so, all of the subsequent opinions and attitudes should receive a lower priority. Without proper context, it is difficult to discern what these attitudes mean and whether policy-makers should act on them.

We used 2 methods to contextualize water issues in Texas. First, respondents were asked to identify their level of concern for different issue domains[2]. The mean levels of concern for each of the issues are illustrated in Figure 1. We found 5 issue domains — jobs and economic growth, government spending/national debt, health care, terrorism and national security, and water quality and availability — weigh most heavily on the public with a mean concern greater than 7. Water quality and availability is the fifth most concerning issue. On average, the public would rate water issues a 7.07 on this scale. Texans are more concerned than not about water issues, and they are

[1] The Texas Legislature was acting on several water-related policies during this time, which generated some press. However, it is unclear if this coverage was out of the ordinary or if it became salient to the lay person. To ensure this was not a concern, we conducted T-Tests for several questions, none of which identified a significant difference between the means of the two samples. Additionally, a Texas Tribune poll indicates that, when compared to other important issues, water was a lower priority than the others (Blank and Henson 2013), which suggests that these legislative activities may not have been particularly salient or at least that they are not dominating the public's attention.

[2] The scaling for all of the survey questions is from lowest to highest. Specific question wording can be found in Appendix B.

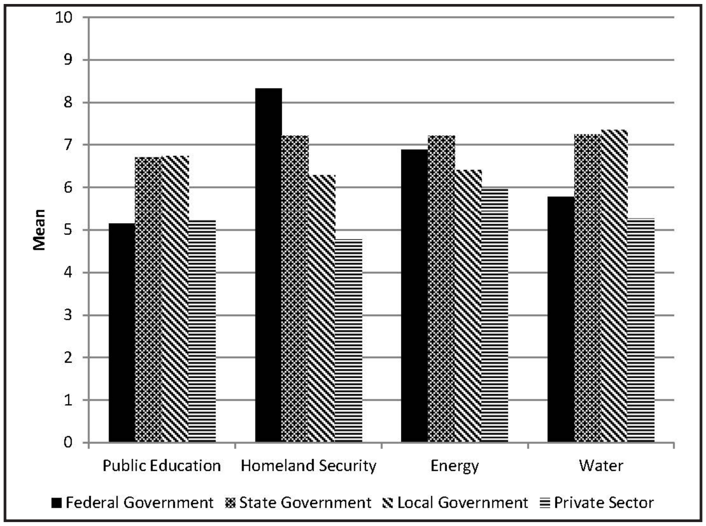

Figure 2. Comparing perceptions of responsibility for water policy against other policy domains.

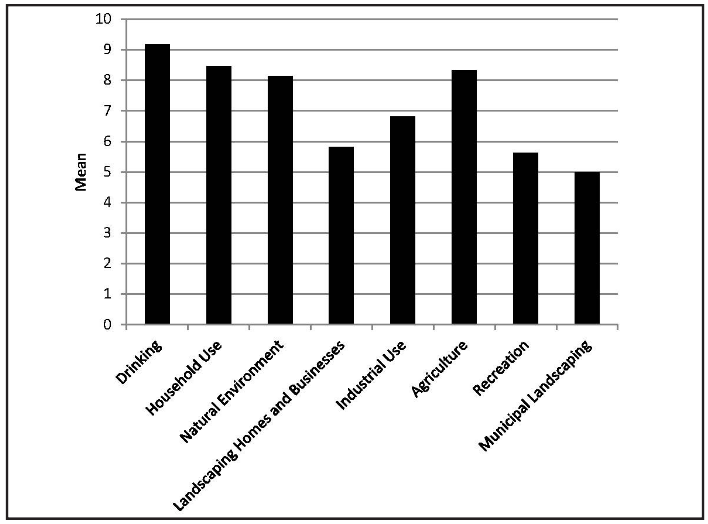

Figure 3. Public views on the importance of various water uses.

generally more concerned about water than many of the other issues, which suggests that water quality and availability is an important issue[3].

The second manner of comparing water to other issues relates to perceptions of responsibility. Who is responsible for handling a given policy domain? In our federal system, there are realistically only 4 types of institutions that can manage a major public issue — the federal government, state governments, local governments, or the private sector. We asked respondents to indicate how responsible each institution was for handling 4 policy domains: public education, homeland security, energy, and water. As presented in Figure 2, we found that water policy is believed to be the responsibility of state and local governments[4]. This distribution resembles that found with public education where the federal government and private sector are expected to take a back seat to state and local institutions. This distribution differs from homeland security where responsibility begins with the federal government and decreases with each lower level of government. Respondents generally prefer the state to handle energy issues, but barely more so than the federal government. However, energy policy represents the most clustered distribution with the smallest difference between the most responsible institution and the least responsible. This differs from water policy, where state and local governments are clearly favored. Overall, this suggests that attitudes concerning water issues are most applicable to state and local governments.

General water perceptions

Preconceived notions and general attitudes will influence perspectives toward water management and drought. By understanding what Texans generally think about these issues, we will be able to interpret better their more specific attitudes. We began with an examination of water use. Does the public find certain water uses to be more important than others? We asked respondents about 8 water uses, which are presented in Figure 3. The most important uses of water are drinking, household use, natural environment, and agriculture. Conversely, industrial use, recreation, and landscaping uses are of lower importance. Municipal landscaping is viewed as the least important use of water and is the only use that is in the lower half of the scale.

We asked respondents about water availability and their willingness to conserve water. The results can be found in Table 1. We found that Texans are generally not optimistic about their current and future water needs, as both have means in the lower half of the scale (mean less than 2.0). However, they are less pessimistic about their current water needs than their long-term needs. Though the public does not believe that the economy is more important than the environment in water

[3] This interpretation differs from those drawn from the Texas Tribune poll (Blank and Henson 2013). The difference lies in the different approaches to the questions used in these interpretations. The Texas Tribune question forced respondents to identify the most important issue facing Texas and did not allow a respondent to indicate whether any other issues are important or not. Our question allowed a respondent to indicate importance through their level of concern for each of the issues. However, we are unable to definitively say that any one is the single most important issue because that is not what we asked, just as the Texas Tribune poll did not ascertain whether any other issues were important, and if so, how important because that is not what their question asked.

[4] While some areas of water policy are the responsibility of quasi-state entities, like river authorities, we were primarily concerned with the public's overall expectation for water policy.

Table 1. Public perceptions of water availability and willingness to conserve water.

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree	Mean
Water conservation for fish/wildlife habitat and economic growth are equally important	2.48	10.41	32.34	45.60	9.17	2.48
There is enough water in my state to meet current needs	9.05	26.02	29.99	30.86	4.09	1.94
Cities should be able to divert water from rural areas if they need more water	6.08	24.57	42.18	23.45	3.72	1.94
In water planning, the economy is more important than the environment	8.67	28.87	39.28	18.96	4.21	1.81
Household water restrictions should be voluntary rather than mandated by the government	10.79	32.88	33.00	16.50	6.82	1.75
There is enough water in my state to meet future needs	13.37	31.68	34.03	18.07	2.85	1.65
I am willing to conserve water under extreme drought conditions	0.99	0.74	9.75	43.58	44.94	3.30
I am willing to conserve water to lower my water bill	1.24	2.22	16.69	58.47	21.38	2.96
I am willing to conserve water to protect the environment	1.85	2.22	20.27	54.64	21.01	2.90
I am willing to conserve water for agricultural uses	1.00	3.61	25.37	53.61	16.42	2.80
I am willing to conserve water for industrial uses	3.71	18.94	45.92	26.86	4.58	2.09
Making efforts to conserve water is inconvenient	12.38	42.08	25.12	18.44	1.98	1.55
The issues related to the conservation and availability of water do not affect me	31.72	39.03	21.69	5.82	1.73	1.06

Values are percentages, except the mean. The mean is calculated using a coding scheme from 0 (strongly disagree) to 4 (strongly agree). A 2.0 represents the midpoint of the scale.

planning, it generally believes that fish and wildlife habitats and the economy are of equal importance. Respondents also disagree with cities diverting water from rural areas, even when in need. This suggests that the public would much rather conserve water than risk hurting agriculture.

Will Texans conserve water, and under what conditions will they do so? Also in Table 1, we found that the respondents recognize that issues related to water availability affect them personally, which suggests saliency. On average, the public prefers government mandates of water restrictions over hoping individuals will act responsibly through voluntary measures, even though most people believe that conservation is convenient[5]. We also found that when framed in different manners, the public is willing to conserve water. Specifically, on average, Texans will conserve to lower their water bill, protect the environment, for agricultural uses, and under extreme drought conditions. Texans are almost evenly divided on conserving for industrial uses, with respondents barely more likely to conserve than not.

Finally, we asked respondents to identify what they believe to be the most important water-related issue. The results are illustrated in Figure 4. We found that 67.33% indicated that they believe water quantity, or drought, is the most important issue. 18.81% believe water distribution, or providing enough water, is the most important issue. Finally, 13.86% consider water quality/pollution as the most important issue. Clearly, the public is more concerned about water quantity than distribution or quality.

Drought options

With water attitudes in their appropriate context, we turn to public drought perceptions. Given the likelihood of increased frequency and intensity (e.g. IPCC 2007), droughts are likely to be a greater water management concern to the people of

[5] The midpoint of the scale is a 2.0. Values lower than this indicates that the public is, on average, less agreeable to the option. Values higher suggest that, on average, the public is more agreeable.

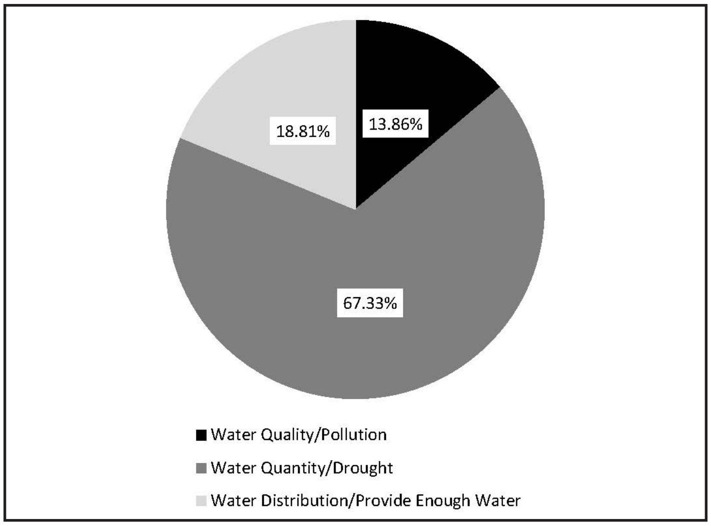

Figure 4. The most important water related issues.

Texas. Texas officials have 2 basic options — be proactive or reactive. Since governments can be constrained by a lack of public support, understanding public attitudes and beliefs with regards to droughts is important.

An informed citizenry is a necessary step toward gaining public support on the issue. Studies indicate that knowledge is an essential component of problem-solving (e.g. Hmelo-Silver 2004). Additionally, Ostrom (2007) argues that imperfect information increases the likelihood of selecting improper strategies to solve problems.

We asked respondents their level of agreement with potential causes of droughts or water shortages, which are found in Table 2. On average, Texans agree that all 5 of these potential causes are likely responsible for drought conditions or water shortages in Texas. The public is most convinced about the impact of short-term changes to rainfall.

We also wanted to know if attitudes reflected those outlined by the Intergovernmental Panel on Climate Change (2007). Do Texans believe droughts are becoming more common and more severe? Table 3 presents the results of this assessment. The majority of Texans believes droughts are occurring more frequently, while a slim majority believes they are as severe as they have always been. However, a substantial minority, 45.29%, believes droughts are more severe. Less than 5% of Texans believe droughts are less severe or less frequent.

Several water-related risks have been linked to droughts (NDMC 2013). Does the public recognize the likelihood of these risks? We asked respondents to evaluate the likelihood

Table 2. Public perceptions of the cause of droughts or water shortages

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree	Mean
Short-term changes in annual rainfall levels	0.99	2.41	11.61	51.42	33.57	3.14
Increased demand from water users	1.70	7.66	26.10	51.63	12.91	2.66
Climate change	7.40	9.25	25.46	38.69	19.20	2.53
Inadequate management of water resources	1.99	11.51	39.49	37.50	9.52	2.41
Overuse of water	2.27	14.63	32.67	41.05	9.38	2.40

Values are percentages, except the mean. The mean is calculated using a coding scheme from 0 (strongly disagree) to 4 (strongly agree). A 2.0 represents the midpoint of the scale.

Table 3. Public perceptions on drought occurrence and severity

	Less	Same	More	Mean
Are droughts in your region becoming more common, less common, or continuing to occur at the same rate?	2.28	42.88	54.84	1.52
Are droughts in your region becoming more severe, less severe, or continuing to occur with the same severity?	3.57	51.14	45.29	1.41

Values are percentages, except the mean. The mean is calculated using a coding scheme from 0 (Less) to 2 (More). A 1.0 represents the midpoint of the scale..

Table 4. Perceptions of the likelihood of drought risks.

	Very unlikely	Somewhat unlikely	Unsure	Somewhat likely	Very likely	Mean
Increased food prices	2.23	2.36	16.50	41.69	37.22	3.09
Increased water costs	2.22	1.73	17.31	41.66	37.08	3.09
Increased fires	2.73	4.22	22.08	38.21	32.75	2.94
Increased water-user conflicts	2.48	3.22	32.71	39.53	22.06	2.75
Damage to animal and plant species	3.95	7.65	27.28	37.04	24.07	2.69
Loss of recreational activities	4.09	8.80	35.69	33.71	17.72	2.52
Disruption of water supplies	3.95	10.62	35.56	32.72	17.16	2.48
Reduced water quality	5.82	11.76	40.10	26.49	15.84	2.34

Values are percentages, except the mean. The mean is calculated using a coding scheme from 0 (very unlikely) to 4 (very likely). A 2.0 represents the midpoint of the scale.

of 8 risks, which can be found in Table 4. We found that the public is, on average, likely to recognize the possibility of each of these risks during drought conditions. Risk perceptions are strongest for increased food prices, water costs, and fires. While still perceived as more likely than not, Texans report the threat to water quality as the least likely of these risks.

Government response to drought

Since water is typically distributed through public utilities, it is the government's responsibility to prepare for and/or respond to drought conditions to ensure an adequate supply of water. Given the decreasing supply of water and increasing demand, governments are facing some potentially costly investments to secure long-term water security (see EPA 2002). If public support is a necessary component for government action, what actions will the public support? The first step toward understanding the public's preferences for government response is to determine which water use should be the first to conserve. As illustrated in Figure 5, a slim plurality, 32.51%, believe that cities should be the first to reduce water use. This reflects the results in Figure 3, which found that municipal water uses are the least important. In a close second, 32.39% think that they, themselves, should be the first to reduce. Interestingly, the difference between first and third is only 1.23%, as 31.28% of Texans believe industry should be the first to reduce. Finally, consistent with previous question batteries, only 3.82% think that agriculture should be the first to reduce its water use. With

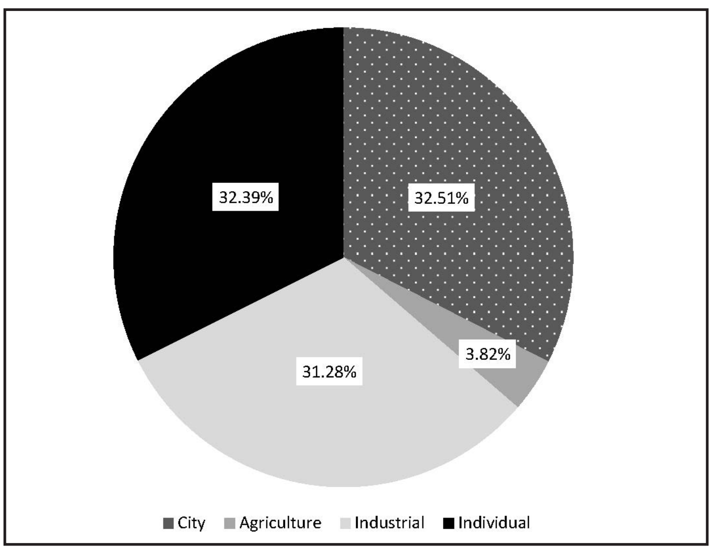

Figure 5. Which water use should be reduced first?

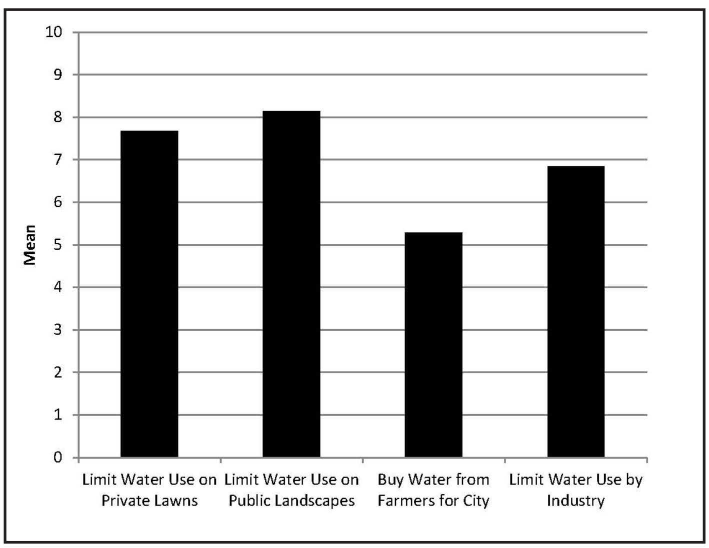

Figure 6. Favorability of short term drought strategies by cities.

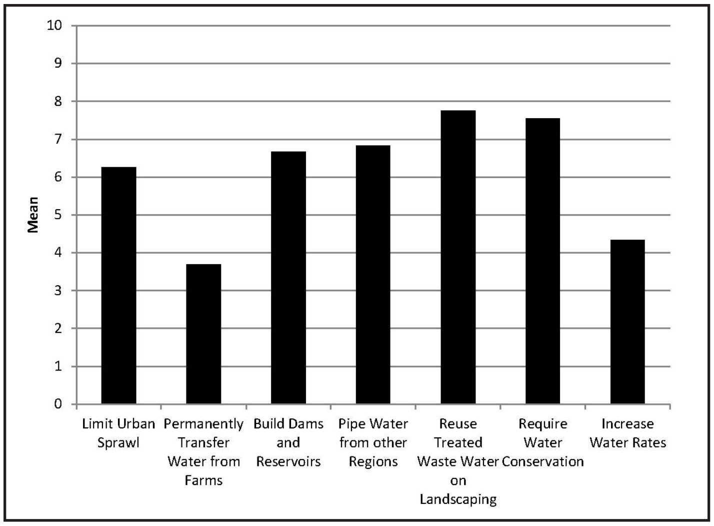

Figure 7. Favorability of future drought strategies by cities.

the exception of agriculture, Texans are evenly divided as to who should be the first to reduce water use.

Cities often have limited available options when facing a drought. We wanted to understand what actions the public would support in response to a short-term drought. Figure 6 presents the public's favorability toward potential strategies. Not surprisingly, the public is generally in favor of limiting the use of water on private and public lawns. This is also consistent with what we found in Figure 3. Texans also favor limiting water use by industry. Even in short term situations, the public is less favorable toward diverting water from agriculture to use in a city.

Cities also have the ability to prepare for droughts. However, these projects are often costly, and it is not clear the extent to which the public would support these projects[6]. Public support for future drought strategies is found in Figure 7. Texans are generally supportive of all of these long-term strategies except permanently transferring water from farms to cities and increasing water rates. Respondents are most supportive of reusing treated waste water on landscaping as an alternative to using fresh water. Texans are generally supportive of the city requiring water conservation[7] and limiting urban sprawl[8]. The public also supports building more dams and reservoirs and investing in water pipelines from other regions of the country.

The above strategies were framed in terms of a city's response to droughts. It is possible some respondents may not favor cities taking on these responsibilities, but may be supportive if other governmental units were overseeing these projects. Therefore, we decided to frame various strategies in terms of policy options, but we did not associate them with any particular level of government except for one that is framed with the national government.

The policy battery results can be found in Table 5. Generally, the public is supportive of all the policy alternatives. The public most strongly supports policies that would build infrastructure to support water demands and protect some water resources to preserve wildlife and fishery habitats. There is also strong support for policies that require lawn watering using reclaimed/reused water instead of drinking water, that conduct campaigns for voluntary water conservation, that give tax incentives for the installation of water-saving equipment, and that require low water-use landscaping. The public is also more supportive than not for providing tax cuts to companies to reduce their water use, requiring mandatory water conservation, and developing a comprehensive national plan for allocating water across state borders. The public is consistent in its

[6] Not all of these projects are costly. For instance, the cost associated with raising water prices and conservation is limited. However, the cost of investing in infrastructure projects can be quite large. The EPA (2002) predicts that cities will need to invest more than $274 billion between 2000 and 2019 to ensure adequate levels of drinking water, and this does not include the estimated $388 billion needed for clean water. These numbers will only increase as the population continues to increase, and as the public migrates to arid or semi-arid areas, including Texas, where the supply of water is already stressed.

[7] We are unable to determine if the respondent presumed conservation was related to long-term efforts such as retrofitting toilets or short-term drought-related efforts such as limiting water use for landscaping.

[8] Urban sprawl results in greater residential water use per capita when compared to urban users. New residential developments tend to be lower in density, which means larger lawns and the increased availability for space that would allow private swimming pools, resulting in a greater demand for water for these areas to keep the larger lawns green and the pools full than the demand in more densely populated areas. The EPA (2013) estimates that approximately 30% of a household's water use is for outdoor uses, such as watering lawns and gardens. Since more densely populated areas do not have large lawns or gardens, the majority of this water use is occurring in less dense areas, such as suburbs and exurbs. Limiting sprawl encourages greater population density, which decreases extraneous water uses. Moreover, Southwestern states, including Texas, already have residential water-use levels that exceed the rest of the nation (EPA 2006), and sprawl will exacerbate this.

Table 5. Public support for water policy proposals

	Strongly oppose	Oppose	Unsure	Support	Strongly support	Mean
Build infrastructure (dams, reservoirs, pipelines) to support water demands during a drought	1.13	2.02	29.35	47.61	19.90	2.83
Protect some water resources to preserve wildlife and fishery habitats	2.02	3.16	23.23	53.03	18.56	2.82
Give tax incentives for the installation of water-saving equipment	3.03	5.30	23.86	49.37	18.43	2.74
Require that lawn watering use reclaimed/reused water instead of drinking water	2.28	6.32	26.42	44.12	20.86	2.74
Conduct campaigns for voluntary water conservation	2.42	5.47	25.45	50.89	15.78	2.72
Require low water-use landscaping	3.68	6.21	23.07	48.92	18.12	2.71
Provide state tax cuts to companies that reduce their water use	3.68	7.73	32.45	45.88	10.27	2.51
Require mandatory water conservation	3.94	11.44	31.51	38.88	14.23	2.48
Develop a comprehensive national plan for allocating water across state borders	6.58	9.37	39.11	33.80	11.14	2.33

Values are percentages, except the mean. The mean is calculated using a coding scheme from 0 (strongly oppose) to 4 (strongly support). A 2.0 represents the midpoint of the scale.

belief that the federal government is less responsible than state or local governments, as the proposal of the national plan is the least supported policy option in the battery, which is reflected in the largest rate of "unsure" and "strongly oppose" responses.

DISCUSSION

We began this project by trying to better understand Texans' attitudes toward water management and droughts. Due to the shortage of public opinion on this issue, we wanted to report the results of our public opinion surveys of the people of Texas to the larger Texas research community. We believe that the data presented here can be helpful for government practitioners and researchers, and that there are several important implications.

First, Texans are generally supportive of government efforts to manage water resources during a drought and to implement plans that reduce the impact of future droughts. We found quite a bit of support for government policies and action. We anticipate that the public most likely believes that these actions will be carried out by the state or local governments (Figure 2).

Second, we found that the public consistently supports efforts so long as these efforts do not negatively affect agriculture. As presented in Figure 5, agriculture is the last place the public wants to look for water supply savings. The evidence suggests that the public recognizes that disruptions in the water supply will likely increase the cost of food (Table 4) (e.g. Fannin 2011; Trostle 2008) and is much more willing to accept the costs of conserving water than burden agriculture (Figure 5). The consistency of these findings throughout the survey indicates that these are strong beliefs.

Third, we found a similar pattern with the environment. The public identifies the natural environment as the fourth most important use of water (Figure 3). The public also believes that fish and wildlife habitats are just as important as the economy (Table 1). Respondents were highly likely to agree or strongly agree (75.65%) that they would conserve water to protect the environment (Table 1). The public recognizes that droughts are likely to damage animal and plant species (Table 4). Additionally, 71.59% of Texans would support or strongly support a policy that would protect water resources to preserve wildlife and fishery habitats. Clearly, the public wants to protect the environment from water shortage issues.

We found conflict in opinions between the environment and infrastructure investment. It is possible several camps could exist here. Many of the infrastructure projects certainly would influence the environment in a negative manner. From the disruption of natural streamflow to the destruction of habitats, the creation of a reservoir has many large ecological implications (e.g. McCully 2001). Although we are unable to determine this from our survey, we suspect that this is more a reflection of the public's lack of understanding about what is involved in the creation of a reservoir. On the other hand, the recycling of waste water for irrigation would have 2 impacts.

First, and arguably a positive impact, the waste water would not be reintroduced to fresh water supplies, which would decrease the amount of chemicals and other foreign bodies in rivers and streams. Second, it is unclear the extent to which this recycling would impact water levels downstream. If the treated waste water is no longer pumped into the streams or pumped at a much lower rate, will this cause streams to dry because demand would be greater than supply? Conversely, if recycled water is being used for irrigation purposes, this would decrease the demand on natural streamflow, which would potentially decrease the potential negative trade off. Additional research is needed to answer these questions.

Fourth, we were not sure how the public would respond to the use of recycled water due to the potential "gross" factor associated with waste water. We found that the public is quite supportive and see this as one of the best ways to limit the impact of future droughts (Figure 7). While our questions focus on using the recycled water for irrigation, it is unclear if the public would support using this water for potable uses.

Finally, it appears that the public will generally be supportive of government action to reduce the impact of droughts. However, the government may need to explain why a given action is necessary (Table 1). The public will act if it is in response to a severe drought. Given the consistency in these responses, it is also possible that in non-drought conditions the public's desire to protect the environment and agriculture will cause it to support water management projects so long as the projects are framed in this manner. However, efforts to take advantage of these general dispositions will likely need to be more specific than what is often found during non-drought conditions. The legislative environment looks favorable for Texas officials since many Texans already believe droughts are more severe and more frequent. The question is whether the Legislature is able to corral this base support.

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APPENDIX A

Appendix Table 1: Descriptive statistics

	Survey 1	Survey 2	Combined
Gender			
Male	51.71	55.58	53.65
Female	48.29	44.42	46.35
Education			
Less than high school	10.49	7.04	8.76
High school	28.05	30.58	29.32
Some college	31.46	30.83	31.14
Bachelor's degree or higher	30.00	31.55	30.78
Race			
White	56.59	56.55	56.57
Black	10.00	10.92	10.46
Hispanic	26.59	27.43	27.01
Multiracial	4.63	2.67	3.65
Other	2.20	2.43	2.31
Age			
18-24	6.10	5.58	5.84
25-34	10.24	17.96	14.11
35-44	14.63	14.32	14.48
45-54	20.73	20.15	20.44
55-64	25.37	17.48	21.41
65-74	16.83	17.48	17.15
75+	6.10	7.04	6.57
Income			
Less than $15,000	12.68	9.95	11.31
$15,000 – $29,999	12.93	13.35	13.14
$30,000 – $49,999	19.76	22.09	20.92
$50,000 – $74,999	19.51	19.17	19.34
$75,000 – $99,999	13.66	13.11	13.38
$100,000 – $149,999	14.63	14.08	14.36
More than $150,000	6.83	8.26	7.54
Party identification			
Democrat	34.35	35.25	34.80
Republican	34.61	36.25	35.44
Independent	31.04	28.50	29.76
Number of observations	410	412	822

All values are percentages.

APPENDIX B

Appendix Table 2: Variable definitions

	Question wording	n
Figure 1		
Battery prompt	"On a scale from 0 to 10, with 0 indicating not at all concerned and 10 indicating extremely concerned, how concerned are you about each of the following issues?"	
Jobs & economic growth	"Jobs and economic growth"	815
Immigration	"Immigration"	815
Pollution	"Pollution"	810
Government spending & national debt	"Government spending/national debt"	817
Global warming & climate change	"Global warming and climate change"	818
Energy supply	"Energy supply"	814
Health care	"Health care"	814
Terrorism & national security	"Terrorism and national security"	817
The environment	"The environment"	815
Water quality & availability	"Water quality and availability"	816
Figure 2		
Public education battery prompt	"Different levels of government claim responsibility for specific policy areas. Using the following 0 to 10 scale with 0 being Not at all Responsible and 10 being Completely Responsible please indicate which group you believe should be responsible for managing public education policy."	
Federal government	"Federal government"	809
State government	"State government"	809
Local government	"Local government"	810
Private sector	"Private sector"	809
Homeland security battery prompt	"Different levels of government claim responsibility for specific policy areas. Using the following 0 to 10 scale with 0 being Not at all Responsible and 10 being Completely Responsible please indicate which group you believe should be responsible for managing homeland security policy."	
Federal government	"Federal government"	797
State government	"State government"	791
Local government	"Local government"	791
Private sector	"Private sector"	789
Energy battery prompt	"Different levels of government claim responsibility for specific policy areas. Using the following 0 to 10 scale with 0 being Not at all Responsible and 10 being Completely Responsible please indicate which group you believe should be responsible for managing energy policy."	
Federal government	"Federal government"	805
State government	"State government"	805
Local government	"Local government"	805
Private sector	"Private sector"	805

Appendix Table 2 (cont.)

	Question wording	n
Water battery prompt	"Different levels of government claim responsibility for specific policy areas. Using the following 0 to 10 scale with 0 being Not at all Responsible and 10 being Completely Responsible please indicate which group you believe should be responsible for managing water policy."	
Federal government	"Federal government"	804
State government	"State government"	809
Local government	"Local government"	805
Private sector	"Private sector"	806
Figure 3		
Battery prompt	"On a scale from 0 to 10, with 0 indicating Not at all Important and 10 indicating Extremely Important, rate how important each of the following water uses is to you?"	
Drinking	"Water for drinking"	812
Household use	"Water for household use (e.g. showers, laundry, and toilets)"	813
Natural environment	"Water for the natural environment such as fish and wildlife habitat"	811
Private landscaping	"Water for landscaping homes and businesses"	807
Industrial use	"Water for industrial use (e.g. manufacturing, mining and energy generation)"	815
Agriculture	"Water for agriculture (e.g., crops and livestock)"	811
Recreation	"Water for recreation (e.g., pools and boating)"	811
Municipal landscaping	"Water for municipal landscaping (e.g., parks and golf courses)"	811
Table 1		
Battery prompt	"Please indicate whether you Strongly Disagree, Disagree, Neither Disagree Nor Agree, Agree, or Strongly Agree with each of the following statements."	
Water to meet current needs	"There is enough water in my state to meet current needs."	807
Water to meet future needs	"There is enough water in my state to meet future needs."	808
Economy vs. environment	"In water planning, the economy is more important than the environment."	807
Fish/wildlife vs. economy	"Water conservation for fish/wildlife habitat and economic growth are equally important."	807
Cities divert from rural areas	"Cities should be able to divert water from rural areas if they need more water."	806
Conservation affects me	"The issues related to the conservation and availability of water do not affect me."	807
Voluntary conservation	"Household water restrictions should be voluntary rather than mandated by the government."	806
Conserve: inconvenient	"Making efforts to conserve water is inconvenient."	808
Conserve: lower water bill	"I am willing to conserve water to lower my water bill."	809
Conserve: environment	"I am willing to conserve water to protect the environment."	809
Conserve: industrial use	"I am willing to conserve water for industrial uses."	808
Conserve: agriculture	"I am willing to conserve water for agricultural uses."	804
Conserve: drought conditions	"I am willing to conserve water under extreme drought conditions."	810
Figure 4		
Most important water issue	"What do you think is the most important water related issue in your state?" 1) "Water Quality/Pollution;" 2) "Water Quantity/Drought in areas;" 3) "Water Distribution/Provide enough water to all users"	808

Appendix Table 2 (cont.)

	Question wording	n
Figure 2		
Battery prompt	Indicate whether you Strongly Disagree, Disagree, Neither Disagree Nor Agree, Agree, or Strongly Agree that each of the following has been a cause of drought or water shortage in your region.	
Annual rainfall	"Short-term changes in annual rainfall levels"	706
Overuse of water	"Overuse of water"	704
Inadequate management	"Inadequate management of water resources"	704
Increased demand	"Increased demand from water users"	705
Climate change	"Climate change"	703
Table 3		
Drought frequency	"Are droughts in your region becoming more common, less common, or continuing to occur at the same rate?"	702
Drought severity	"Are droughts in your region becoming more severe, less severe, or continuing to occur with the same severity?"	700
Table 4		
Battery prompt	"How likely are the following drought impacts to occur in your region in the next five years?" Very Unlikely, Somewhat Unlikely, Unsure, Somewhat Likely, or Very Likely	
Disruption of water supply	"Disruption of water supply"	810
Increased food prices	"Increased food prices"	806
Increased water costs	"Increased water costs"	809
Loss of recreational activities	"Loss of recreational activities"	807
Damage to animals & plants	"Damage to animal and plant species"	810
Reduced water quality	"Reduced water quality"	808
Increased fires	"Increased fires"	806
Increased water-use conflicts	"Increased water-use conflicts"	807
Figure 5		
Which use should be reduced first	"Which of the following water uses should be reduced first to lessen the impacts of drought?" 1) "City use;" 2) "Agricultural use;" 3) "Industrial use;" or 4) "Individual use"	812
Figure 6		
Battery prompt	"During times when water availability is limited due to a short-term drought (lasting less than two years), a city may adopt several strategies to ensure it has enough water. Please rate the strategies that a city might consider on a scale of 0 to 10 with 0 being Not Favored by you and 10 being Highly Favored by you."	
Limit use on private lawns	"Limiting water use on private lawns"	812
Limit use on public lawns	"Limiting water use on public landscapes"	811
Buy water from farmers	"Buying water from farmers to use in cities"	810
Limit water use by industry	"Limiting water use by industry"	810
Figure 7		
Battery prompt	"Increasing population means that cities will need more water for the long run (more than ten years in the future). Listed below are several possible strategies that a city might consider to ensure adequate water supplies in the future. Please rate the strategies on a scale of 0 to 10 with 0 being Not Favored by you and 10 being Highly Favored by you."	
Transfer water from farms	"Permanently transferring water from farms to the city"	809

Appendix Table 2 (cont.)

	Question wording	n
Build dams & reservoirs	"Building dams and reservoirs"	808
Pipe water	"Constructing pipelines to bring water from other regions"	807
Reuse treated waste water	"Reusing treated waste water on lawns and landscapes"	809
Require conservation	"Requiring water conservation"	805
Limit urban sprawl	"Limiting urban sprawl"	805
Increase water rates	"Increasing water rates"	808
Table 5		
Battery prompt	"A number of policy options have been proposed to manage water resources. Please indicate whether you Strongly Oppose, Oppose, Support, or Strongly Support each of the following options." Respondents were also allowed to choose "Unsure."	
Build infrastructure	"Build infrastructure (dams, reservoirs, pipelines) to support water demands during a drought"	794
Voluntary conservation	"Conduct campaigns for voluntary water conservation"	786
Require conservation	"Require mandatory water conservation"	787
Tax incentives	"Give tax incentives for the installation of water-saving equipment"	792
Comprehensive national plan	"Develop a comprehensive national plan for allocating water across state borders"	790
State tax cuts	"Provide state tax cuts to companies that reduce their water use"	789
Low water-use landscaping	"Require low water-use landscaping"	789
Protect wildlife & fish habitat	"Protect some water resources to preserve wildlife and fishery habitats"	792
Reuse treated waste water	"Require that lawn watering use reclaimed/reused water instead of drinking water"	791

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Freshwater inflow requirements for the Nueces Delta, Texas: *Spartina alterniflora* as an indicator of ecosystem condition

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Abstract: Estuarine wetlands and salt marshes are fundamentally driven by variations in freshwater inflow. However, many estuaries have been subject to a heavily modified hydrology due to flood protection engineering and the construction of upstream dams for municipal water supply. Assessment of the impacts of these activities on the health of estuarine wetlands has traditionally focused on tracking the abundance of economically important shellfish and finfish species. In this study, we examine fluctuations in the abundance of selected salt marsh plants and use this information to develop estimates of freshwater inflow needs. The impact of freshwater inflow events on 3 common emergent plants in the Nueces River Delta (*Spartina alterniflora*, *Borrichia frutescens*, *Salicornia virginica*) was determined from long-term monitoring of permanent census plots. Of the 3 species examined, *Spartina alterniflora* was determined to be the best indicator species because its abundance most closely tracked variations in freshwater inflow. For example, under low salinity conditions *S. alterniflora* cover approached 66%. However, when salinities exceeded 25‰, *S. alterniflora* cover declined rapidly. Our results provide clear evidence that the presence or absence of key plant indicator species (in this case *S. alterniflora*) is reflective of overall estuarine hydrological condition over time scales exceeding 6 months.
Keywords: *Spartina alterniflora*, freshwater inflow, Nueces Delta

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Terms used in paper

Short name or acronym	Descriptive name
Bayesian change point analysis	BCPA
canonical correspondence analysis	CCA
non-metric multidimensional scaling	NMDS

INTRODUCTION

Estuarine wetlands and salt marshes are fundamentally sustained by variations in freshwater inflow. The frequency, duration, and seasonal distribution of these "freshets" often determine the physiochemical characteristics of both aquatic and sedimentary wetland environments (Zedler 1983; Mitsch and Gosselink 2007). Environmental characteristics such as nutrient concentration and salinity are regulated by freshwater inflow events and ultimately restrict the distribution and abundance of estuarine organisms (Adams 1963; Alexander and Dunton 2002; Mitsch and Gosselink 2007). The relative impact of freshets within a particular estuary is dependent on the tidal regime, precipitation frequency, geomorphology, and water residence time (Solis and Powell 1999; Brock 2001). Small freshwater inflow events are capable of flushing estuaries with small water volumes and large tidal ranges. However, the waters within microtidal semi-arid estuaries exhibit long residence times and require large freshwater inflow events to effectively flush accumulated salts and nutrients from sediments (Solis and Powell 1999).

The Nueces Estuary, near Corpus Christi, Texas, represents one of the largest, driest, and least flushed estuaries along the Gulf of Mexico (Solis and Powell 1999). Although large freshwater inflow events are relatively rare in this system, their occurrence significantly impacts physiochemical characteristics and biological communities (BOR 2000; Alexander and Dunton 2002; Powell et al. 2002; Montagna et al. 2009). Freshwater inflow events in the Nueces Estuary are subject to a high degree of interannual and interdecadal variability. Increased freshwater inflow during wet years increases the abundance and physiological condition of emergent vegetation, ichthyoplankton, and benthic infauna (Montagna et al. 2002; Forbes and Dunton 2006; Tolan 2007). In contrast, salinity stress and moisture deficits common during dry years results in the decreased abundance and altered community structure of resident estuarine organisms (Forbes and Dunton 2006; Montagna et al. 2009).

The construction of upstream reservoirs, intended to increase municipal water supplies, has resulted in significant alterations to the Nueces Estuary (BOR 2000). Several environmental impact assessments followed the construction of the Lake Corpus Christi (1958) and Choke Canyon (1982) reservoirs (BOR 1975; TDWR 1982; Pulich et al. 2002). These studies were intended to document the impact of reservoir development on downstream ecosystems and estimate future freshwater inflow needs. Estimation of freshwater needs in the Nueces Estuary is confounded by extreme interannual variations in freshwater supply coupled with dramatic hydrologic changes to the watershed resulting from reservoir construction. Freshwater inflows to the Nueces Delta have decreased by approximately 99% relative to pre-reservoir conditions (BOR 2000).

The freshwater inflow management targets of particular estuaries are often determined by the physiological requirements of several "focal" or "indicator" species (TDWR 1982; Longley 1994; Doering et al. 2002; Pulich et al. 2002; Richter et al. 2003; BBEST 2011). These indicator species are selected because they are either economically important or particularly sensitive to environmental conditions (Dale and Beyeler 2001; Doering et al. 2002). Following the identification of an indicator species, field observations are used to determine its critical salinity threshold. After the salinity tolerances of a suite of indicator species have been determined, they are related to freshwater supply and used to estimate specific inflow requirements. In this study, we consider the inflow requirement in a management context. The inflow requirement is not the level below which the system is fundamentally altered and permanent loss of species occurs but rather the level below which the relative abundance of species within the vegetation community ceases to resemble that of a typical estuarine system.

It is important to note that, in this study, the term "indicator species" refers to a *condition* indicator rather than a *composition* indicator. While a composition indicator is used as a proxy for a distinct species assemblage, condition indicators are used as a proxy for a distinct set of environmental conditions (Zacharias and Roff 2001). Condition indicators are selected for their ability to track fluctuations in environmental conditions and can be used to monitor changes in habitat quality as a result of management practices (Zacharias and Roff 2001). This is consistent with many conservation programs, which seek to limit their focus to maintaining representative habitats rather than maximizing specific productivity or biodiversity metrics (Palmer et al. 1997; Mitsch and Gosselink 2007). It should be noted that tracking the abundance of a limited number of indicator species provides only a rough measure of ecosystem health. There is little ongoing assessment of ecosystem function or species interactions (ter Braak and Prentice 1988; Palmer et al. 1997). These limitations are partially addressed through the selection of a suite of indicator species. The use of multiple condition indicators is assumed to account for unknown environmental variables as well as potential dependency among species (ter Braak and Prentice 1988).

Invertebrates, such as the blue crab (*Callinectes sapidus*) and commercially important fish species such as the Atlantic croaker (*Micropogonias undulatus*), are often used as indicators of estuarine ecosystem condition (Powell et al. 2002; BBEST 2011). The use of these species as indicators is only possible because of intensive monitoring programs (e.g. Texas Parks and Wildlife Fishery-Independent Monitoring Program, Pulich et al. 2002, Buzan et al. 2009). However, it is currently unclear whether these species provide a reliable representation of environmental conditions because they experience high population variability, incur losses due to fishing pressure, and are subject to seasonal migration (Dale and Beyeler 2001; Powell et al. 2002).

In contrast to nekton species, vascular marsh plants are immobile and are not normally subject to harvesting pressures. In estuaries, plant zonation and distribution is largely controlled by soil porewater conditions rather than tidal creek water (Bertness et al. 1992). Because porewaters have longer residence times, rooted plants reflect environmental conditions over longer time scales. Few studies have examined the utility of vascular plants as estuarine indicators. However, submerged vascular plants have been used as condition indicators to estimate freshwater inflow needs in Florida (Doering et al. 2002). Although emergent plants are infrequently used to estimate freshwater inflow needs within Texas estuaries, they satisfy established criteria for use as indicator species (Dale and Beyeler 2001) and have been developed as indicators of ecosystem condition in Georgia (White and Alber 2009).

The objective of this study was to evaluate the utility of emergent plants as indicators of ecosystem condition and freshwater inflow requirements for the Nueces River Delta, Texas. The response of the overall plant community to variations in freshwater inflow was used to determine whether the plant community exhibited a consistent response to hydroclimatic periods. Next, the response of individual plant species to freshwater inflow events was addressed by 1) determining the salinity tolerance of potential indicator species and 2) deriving the relationship between freshwater inflow and porewater salinity. This study specifically investigated the hypothesis that smooth cordgrass (*Spartina alterniflora*) abundance reflects variations in freshwater inflow and subsequent variations in porewater salinity. We examine *S. alterniflora* individuals that were present as a result of natural processes and not the product of restoration activities. Our salinity tolerance determinations for emergent plants improves on earlier studies, which were generally limited to time periods of less than 3 years and in some cases were established from only a single survey (Penfound and Hathaway 1938; Adams 1963; Webb 1983).

METHODS

This study was conducted in the Nueces River Delta (27° 51' N, 97° 31' W) located in the Northwestern Gulf of Mexico. The delta is comprised of an expansive complex of tidal flats bisected by a tidal creek network (Figure 1). The low marsh plant assemblage is dominated by ox-eye daisy (*Borrichia frutescens*), glasswort (*Salicornia virginica*), and saltwort (*Batis maritima*). Tidal creeks are fringed with stands of smooth cordgrass (*S. alterniflora*) and high marsh areas are dominated by expansive gulf cordgrass (*Spartina spartinae*) meadows (Rasser 2009).

Hydrography

The Nueces Delta is located within a semi-arid region of low average annual precipitation (76 centimeters per year). Dry conditions persist throughout most of the year except follow-

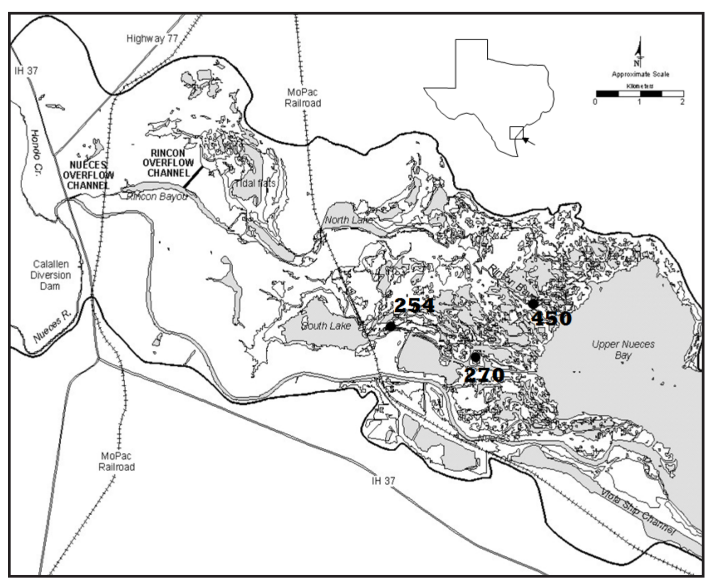

Figure 1: Location of sampling stations in the Nueces Delta.

ing rare tropical storm events that develop in late summer. The hydroclimatic regime has a marked seasonal pattern due to the pulsed nature of freshwater inflows (Figure 2) which inundate the Delta when flows in the Nueces River exceed approximately 2.16 x 10^6 cubic meters per day (Montagna et al. 2009). When flows fail to exceed this threshold, Nueces River discharge moderates wetland salinities indirectly by lowering the salinity of Nueces Bay. Freshwater inflows to the Nueces Estuary over the past 20 years (1990–2011) exhibit highly variable patterns (Figure 2). During the study, the Delta experienced both extremely dry conditions during the period from 2008 to 2011 and extremely wet conditions during the period from 2002 to 2005. Freshwater inflows were high during the study period relative to the past 20 years, but relatively low compared to historic levels (BOR 2000). Wet and dry periods were identified using a simple statistical analysis of Nueces River flows throughout the study period (1999–2011). Dry periods were defined as years with inflows below the median (Table 1). Although direct precipitation can potentially affect environmental conditions in the Delta (Dunton et al. 2001), it was not included in the analysis of dry periods because there was no consistent relationship between precipitation and salinity.

Vegetation and porewater monitoring

The abundance and distribution of emergent plants was monitored quarterly over a 12-year period from 1999 to 2011 at 3 sites in the low marsh. The resulting dataset documents observed changes in seasonal plant community composition and coverage in response to changes in soil porewater characteristics. The abundance of emergent plants for this time period was estimated from percent cover data collected within 0.25-square-meter quadrats (percent cover data was used as a

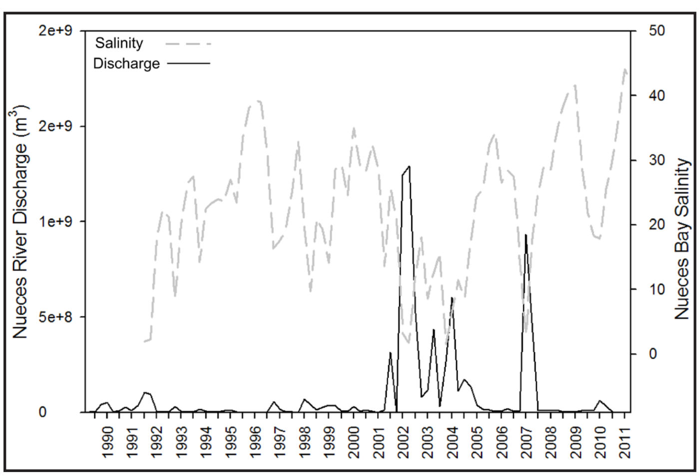

Figure 2: Long-term trends in Nueces River discharge and Nueces Bay salinity (1990–2011).

proxy for abundance). Measurements were taken at 2-meter intervals along 6 parallel 10-meter transects (30 quadrats per site) at each of the 3 sites (Figure 1). Soil characteristics were obtained by extracting water from soil cores (2.5 centimeters diameter x 10 centimeters length) by centrifugation. The extracted water was analyzed for salinity using a handheld refractometer (Reichert Scientific Instruments, Buffalo, NY) and porewater ammonium (NH_4+) using standard colorimetric techniques (Parsons et al. 1984). Separate soil cores were collected for determination of soil moisture. Cores were transferred to the laboratory in sealed containers and dried to a constant weight in a 60 °C oven. The soil moisture content was calculated as the change in weight following drying and standardized to initial wet weight. Variations in porewater salinity and corresponding vegetation characteristics were evaluated with respect to freshwater inflow (Nueces River, USGS 2011).

Identification of indicator species

Several vegetation species were evaluated as potential indicators of ecosystem condition, including *B. frutesecens*, *S. virginica*, and *S. alterniflora*. Indicator species were ultimately selected based upon documentation of their sensitivity to stress, ease of assessment, and known population distribution (Dale and Beyeler 2001). Although all 3 species were evaluated, we regarded *S. virginica* and *B. frutescens* as unlikely candidates because *S. virginica* is relatively insensitive to salinity stress (Forbes et al. 2008; Rasser 2009) and *B. frutescens* is primarily found at higher marsh elevations. Literature surveys and preliminary analysis suggested that *S. alterniflora* was a strong indicator species candidate (Webb 1983). The salinity tolerance of indicator species was estimated by comparing vegetation abundance data against corresponding porewater salinity measurements. Determination of freshwater inflow needs was calculated from the relationship between freshwater inflow and porewater salinity targets modeled as an exponential decay function.

Statistical analysis

The relationship between vegetation cover and environmental variables was examined using canonical correspondence analysis (CCA). The CCA procedure begins by regressing a chi-square vegetation matrix on a set of environmental variables. The importance of specific environmental variables is assessed by calculating their correlation with a projected vegetation matrix (the result of eigen-analysis). For this study, CCA was performed on a species-environment matrix that included quarterly measurements of vegetation cover versus corresponding measurements of environmental variables porewater salinity, porewater NH_4+, soil moisture, and

Table 1: Gauged freshwater inflows to the Nueces Estuary via the Nueces River (USGS gauge #08211500) and estimated annual freshwater inflow needs. Numbers for this study were calculated based on historical attainment of a 25-porewater salinity target for vigorous *Spartina alterniflora* growth in the Nueces Delta. Estimates are reported as the average or median inflow observed or estimated among specified years.

Inflow type	Sampling method	Freshwater inflow (m^3y^{-1})	Date range	Source
Gauged	Average	7.87×10^7	1990–1998	This study
	Average	5.57×10^8	1999–2011	
	Median	1.18×10^8	1999–2011	
Estimated need	Average	4.98×10^8	1962–1976	TDWR 1982
	Average	1.12×10^8	1995–present	BOR 2000
	Average	1.71×10^8	1978–1997	Pulich et al. 2002
	Range	$2.20–3.69 \times 10^8$	1999–2011	This study

distance to nearest tidal creek). Vegetation cover data was left unstandardized in order to retain information on the species-environment relationship (Kenkel 2006). Non-metric multidimensional scaling (NMDS), based on a Bray-Curtis similarity index, was used to evaluate changes in the vegetation community with respect to hydroclimatic periods. Vegetation data was log (x +1) transformed prior to NMDS in order to normalize the data. The salinity tolerance of potential indicator species was evaluated using field observations, values reported in the literature, and Bayesian change point analysis (BCPA). BCPA was performed in order to estimate probable salinity thresholds beyond which vegetation cover is reduced. The procedure starts by partitioning the data into segments such that *S. alterniflora* cover is approximately constant within segments. Next, the probability of all possible partitions of the data is evaluated based on those that minimize the with-in group sum of squares while maximizing the between group sum of squares. Finally, a probability distribution is constructed by averaging over all the partitions (Barry and Hartigan 1993). All statistical analyses were carried out in the R statistical program (version 3.0.1). Both CCA and NMDS analyses were carried out using the *vegan* package (Okansen et al. 2007). BCPA was performed using the *bcp* package (Erdman and Emerson 2007).

RESULTS

Climate and hydrology

Freshwater inflows to the Nueces Estuary exhibited significant variation throughout the study period and were characterized by distinct wet and dry periods (Figure 2). There were 3 periods with measurable freshwater inflow in 2002–2004, 2007, and 2010. These relatively wet periods were preceded by extended dry periods in 1999–2001, 2005–2006, and 2008–2009 (Figure 2). The end of the study period in 2011 was characterized by an exceptional drought period (see National Climate Data Center, http://www.ncdc.noaa.gov/sotc/drought/2011/). Average annual freshwater inflow to the Nueces Estuary was 5.57×10^8 cubic meters per year over the course of the study period (Table 1). Porewater salinity was lower during wet periods when large freshwater inflow events flushed soils of accumulated salts (Figure 3). During dry periods and in the absence of freshwater inflow, porewater salinity was often elevated to values several times that of standard seawater (Figure 3). In the creekbank areas where *S. alterniflora* was present, porewater salinity was nearly equivalent to the salinity of nearby tidal creeks (Figure 4).

Hydrologic impacts on emergent plants

Hydrology clearly influenced the plant community of the Nueces River Delta (Figure 5, 7). The first 2 CCA ordination axes explained 92% of the variance for emergent plant cover (Table 2). However, the first axis had considerably greater explanatory power (77.9%) than the second axis (14.1%). The first axis was negatively correlated with soil moisture and positively correlated with porewater salinity. This suggests that species' habitat is separated primarily according to soil moisture and porewater salinity (Table 2). While *S. alterniflora* cover was most common in brackish water-logged sediments, *B. frutescens* cover dominated well-drained saline sediments (Figure 8). The

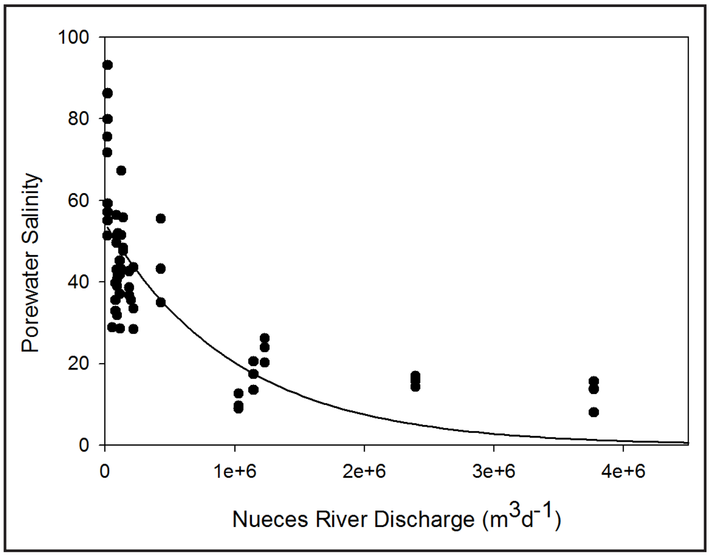

Figure 3: Relationship between freshwater inflow (Nueces River: USGS #08211500) and porewater salinity along the creek bank in the low marsh. Regression curve is a best fit line for an exponential decay function ($y = 54.39\ e^{(-9.89e-7)x}$, $R^2 = 0.63$). A salinity target of 25 yields a freshwater inflow target of approximately $7.86 \times 10^5\ m^3d^{-1}$.

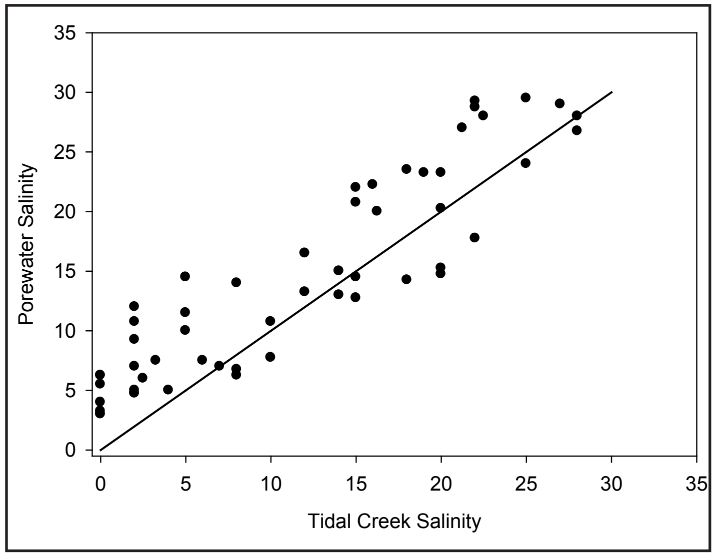

Figure 4: Corresponding measurements of porewater and tidal creek salinity in relation to their theoretical one-to-one relationship (solid line, y=x). The similarity between the areas suggests that emergent plants, which are affected by variations in porewater salinity, are likely to reflect general conditions in the estuary.

composition of vegetation communities immediately following major freshwater inflow events was highly variable (Figure 6). However, *S. alterniflora* was consistently more abundant following freshwater inflow events. Vegetation communities during dry periods were characterized by an abundance of *S. virginica*. Analysis of percent cover data provided evidence of a distinct vegetation assemblage corresponding with identified dry periods (Figure 5). We used non-metric multidimensional scaling of emergent plants according to site and time period in order to test if this vegetation assemblage is unique to dry periods (Figure 6). We found a distinct clustering according to the hydroclimatic periods. For example, almost all (94%) of dry period assemblages at site 254 fell within the same similarity envelope (Figure 6). Likewise, dry period assemblages at site 450 and 270 were also found within the same similarity envelope (73% and 38% respectively). The lack of dry period clustering at site 270 can be attributed to massive disturbance caused by a flooding event in 2002. This flood event eroded almost 4 m from the creekbank and permanently changed the community from a mixed vegetation assemblage to one dominated primarily by *B. frutescens* (Dunton, unpublished data). As a result, early dry period assemblages (1999–2002) at this site are not comparable to post-flood assemblages. The fixed plot design used in this study enabled us to track changes in the plant community over time but did not enable us to examine and quantify spatial variation.

Estimation of Freshwater Inflow Requirements

Although freshwater inflows were concentrated in the summer season, there was no consistent relationship between time of year (season) and standing coverage of *S. alterniflora*. The abundance of *S. alterniflora* fluctuated from a minimum cover near 0% (Spring 2009) to a maximum cover of approximately 66% (Summer 2004, Figure 7). Spatial variations in *S. alterniflora* cover were evident among study sites. The site with the highest cover, site 270, is close to Nueces Bay and has the lowest topographic relief. In contrast, the site with the

Table 2: Results of Canonical Correspondence Analysis.

Constraining variables	Axis 1	Axis 2
Porewater salinity	0.59	-0.45
Porewater ammonium	-0.01	0.34
Soil moisture	-0.94	0.27
Distance to tidal creek	0.40	0.37
Distance to Nueces Bay	0.59	0.64
% Variance explained	**77.93**	**14.08**

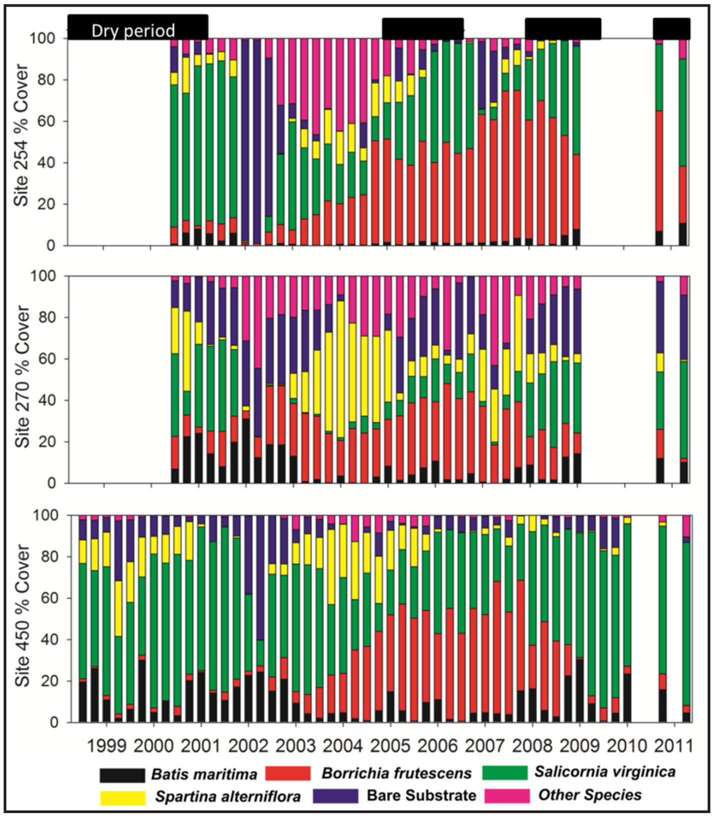

Figure 5: Quarterly percent cover of emergent plants at selected sites in the Nueces River Delta for the period 1999–2011. Shaded boxes at top indicate the occurrence of dry periods. Dry periods were defined as years with inflows below the median.

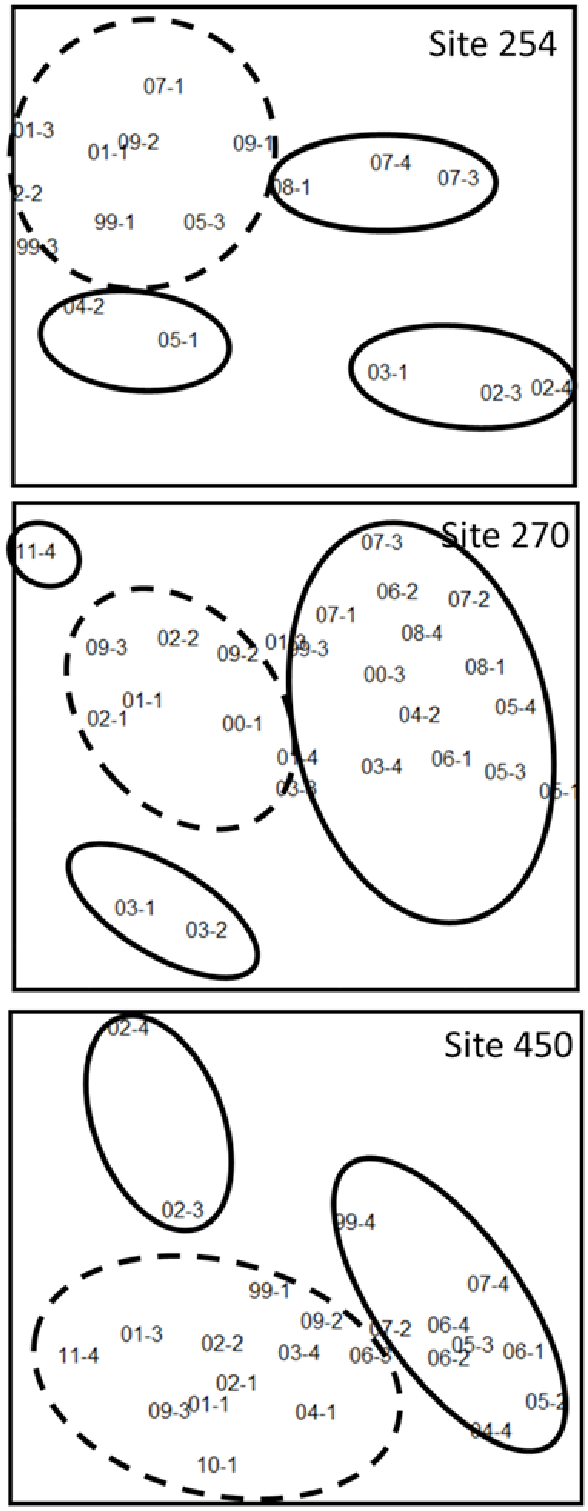

Figure 6: Non-metric multidimensional scaling ordination of emergent plant communities averaged by station and quarterly sampling date formatted as YY-Quarter. For example, Winter 2000 is denoted by 00-1. Similarity clusters are defined at 60% similarity by the Bray-Curtis method. Clusters are outlined to show corresponding dry period (dashed circles) and wet period (non-dashed circles) vegetation assemblages. Only selected sampling dates are shown in order to reduce label overlap and increase readability.

lowest maximum cover, site 254, has a pronounced creekbank levee (Rasser 2009). The salinity tolerance of potential indicator species was determined for *S. alterniflora*, *B. frutescens*, and S. *virginica* based on changes in percent cover in relation to porewater salinity (Figure 8). Consistent with our hypothesis, fluctuations in *S. alterniflora* cover were clearly related to porewater salinity and freshwater inflow. Porewater salinities exceeding 25‰ resulted in dramatic declines in *S. alterniflora* cover (Figure 7). There were only 2 outliers where *S. alterniflora* coverage was substantial (>25%) and salinity exceeded 25‰ (Figure 8). These outliers were associated with the lagged response of plants to rapid increases in salinity during the onset of a dry period in 2005. Occasionally, we observed low cover despite favorably low salinities (Figure 9). These observations are likely associated with disturbance caused by flooding events such as channel bank scouring. Figure 8 combines data from multiple sites. Low cover data points (relatively speaking) may occur because of site-specific differences in available habitat due to differences in slope, drainage, or sediment characteristics (Table 2).

The observed relationship between porewater salinity and freshwater inflow was investigated with respect to *S. alterni-*

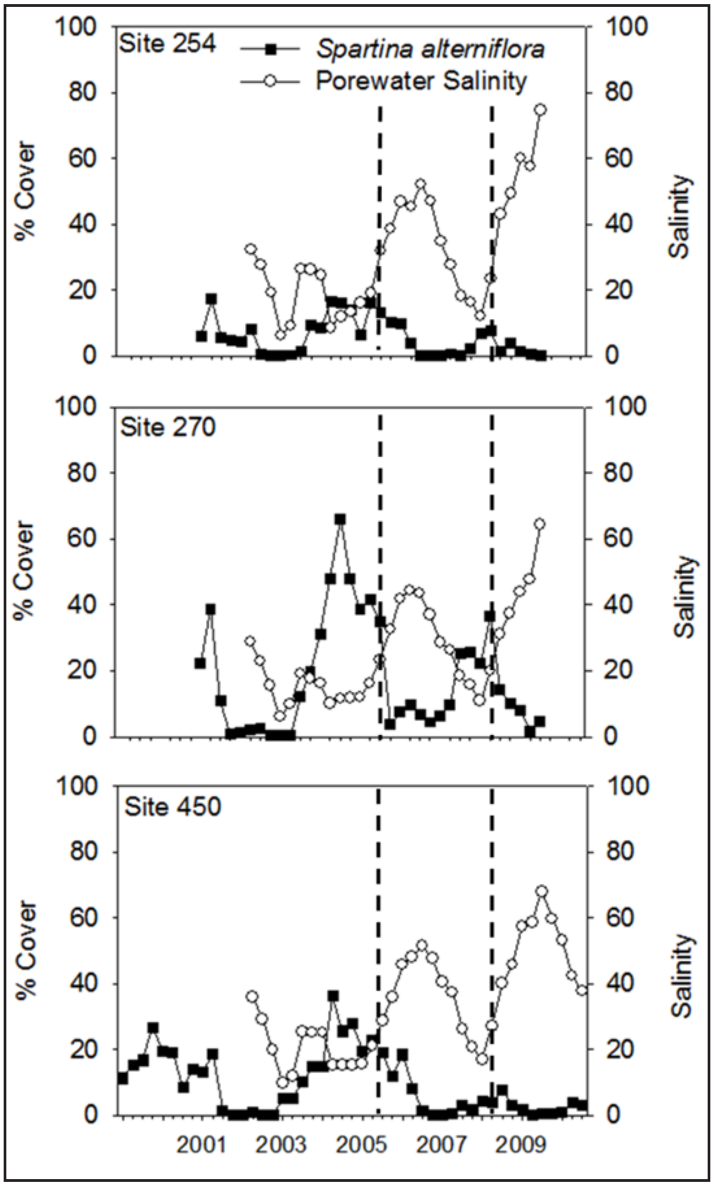

Figure 7: Porewater salinity (white circles) and percent cover of *Spartina alterniflora* (black squares) along the creek bank in the low marsh. Dashed black lines illustrate how the timing of porewater salinities exceeding 25‰ correspond with declines of *S. alterniflora* abundance.

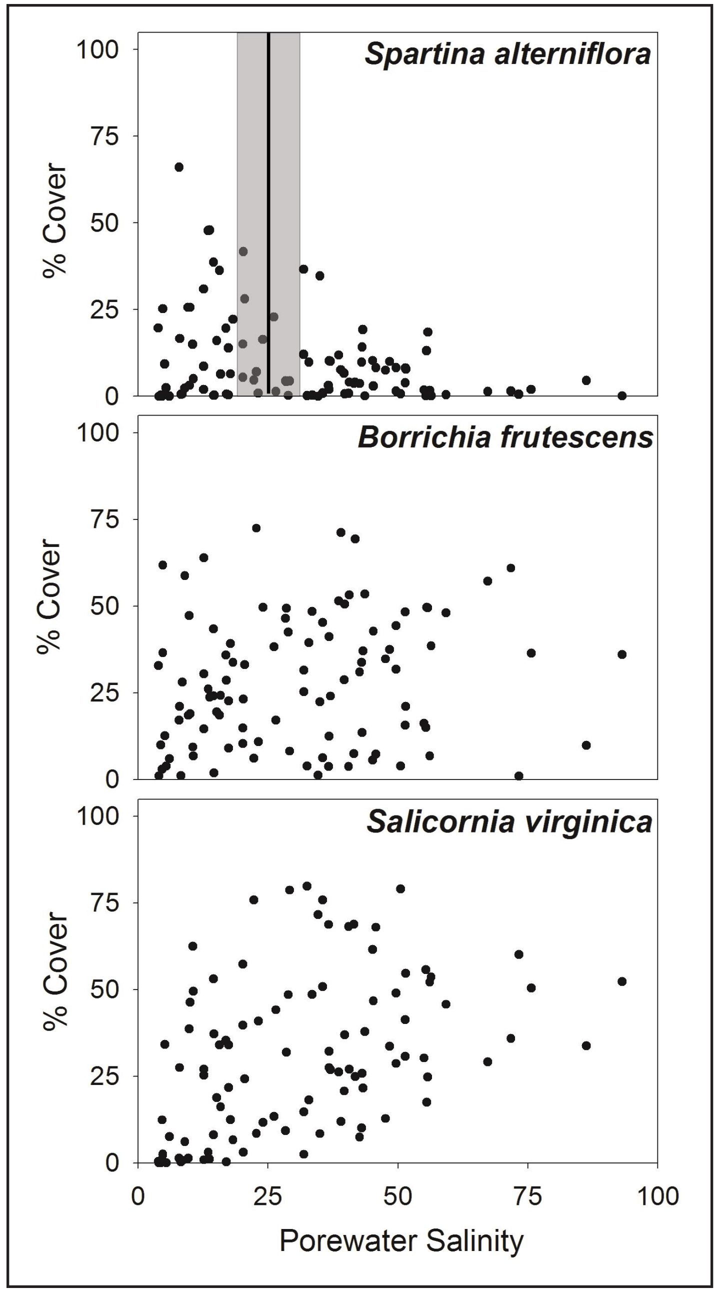

Figure 8: Percent cover of individual plant species (*S. alterniflora*, *B. frutescens*, and *S. virginica*) relative to variations in porewater salinity. The salinity tolerance of *S. alterniflora* was estimated at 25‰ by visual inspection of Figure 7 along with Bayesian breakpoint analysis (vertical line). The uncertainty of this threshold (±5‰) was estimated from published literature values (Webb 1983, Bertness 1991) and Bayesian change point analysis (shaded box).

flora abundance. An exponential decay fit to this relationship provided a means to estimate freshwater inflow corresponding to a given salinity target. This study determined that achieving a porewater salinity target of 25‰ requires a Nueces River discharge of approximately 2.87 x 10^8 cubic meters per year (Table 1). However, this value can be expressed as a range between 2.2 x 10^8 and 3.7 x 10^8 m x 10^8 cubic meters per year owing to the range of probable change points we identified and uncertainties associated with published salinity tolerance values for *S. alterniflora* between 20–30‰ (Webb 1983, Bertness 1991).

DISCUSSION

Vegetation Response to Freshwater Inflow

Freshwater inflow events impact the Nueces Estuary by flushing salts, delivering nutrients, and distributing sediments

(BOR 2000). The most dramatic of these effects is the flushing of salts following large magnitude freshwater inflow events. For example, flooding in 2002 caused extensive freshening of Nueces Bay, dropping salinity values from near standard seawater (35%) to values typical of freshwater and brackish systems (Figure 2). Previous studies have shown that the emergent plant community is responsive to variations in salinity and freshwater inflow (BOR 2000; Alexander and Dunton 2002; Forbes and Dunton 2006). However, this study is unique in that it considers both the wettest period (2002–2004) and the driest period (2008–2009) since reservoir construction. Our results demonstrate that the vegetation community typical of dry periods is distinct from that of wet periods (Figure 6). In addition, communities observed during early dry periods (1999–2001) reappeared subsequently in the later dry period (2008–2011). These dry period communities were characterized by a high abundance of *S. virginica* and a low abundance of *S. alterniflora* (Figure 5, 7). The time required for the reappearance of dry period assemblages was related to the magnitude of freshwater inflow events during the preceding wet period. High freshwater inflows during 2002–2004, the wettest period during this study, extended the period between the reemergence of dry period vegetation communities (Figure 5, 6). Our results are consistent with previous studies regarding the response of the plant community to salinity and freshwater inflow (Forbes and Dunton 2006).

Large magnitude events, such as floods, are known to cause wholesale reorganization of the vegetation community (Forbes and Dunton 2006). The NMDS analysis from this study confirms a consistent reorganization of the plant community following flood disturbances (Figure 6). This finding is important because the use of emergent vegetation as indicators of ecosystem condition is predicated on the assumption that community structure is predictable under a given set of hydroclimatic conditions. Vegetation communities, in this study, followed a predictable trajectory. First, bare areas were created following large inflow events and were initially colonized by stress-intolerant species such as *S. alterniflora* and *Sueda maritima* (see 2002–2004, Figure 5). Next, in the absence of freshwater inflow, these individuals were eventually replaced by the moderately stress-tolerant *B. frutescens*. Finally, the onset of drought conditions encouraged the replacement of all other species by the stress-tolerant *S. virginica* (see 2008–2011, Figure 5). Our observation that *S. virginica* abundance increases during drought periods is consistent with a study by Forbes and Dunton (2006) that demonstrated the displacement *S. virginica* by *B. frutescens* following freshwater inflow events. In addition, a variety of studies determined that *S. virginica* is resilient to extreme environmental stress (Zedler 1983; Forbes and Dunton 2006; Rasser 2009).

Management of Freshwater Inflows

Reduced freshwater inflows, due to hydroclimatic variability and reservoir construction, prompted legislative mandates calling for ecological assessments of Texas estuaries with the purpose of determining freshwater inflow requirements (TDWR 1982; BBEST 2011). Although studies have utilized numerous methods to derive hydrologic data output, nearly all ecological studies concerning freshwater inflow have used the physiological (salinity) tolerance of indicator species to set inflow bounds (Powell et al. 2002). These tolerances are typically determined from simple correlation analyses (Figure 8) or habitat suitability indexes using a suite of environmentally sensitive or economically important indicator species (Doering et al. 2002). As a result, effective management and allocation of freshwater for the ecological benefit of estuarine wetlands requires detailed knowledge of the physiological tolerances of resident organisms. In many cases, these are estimated from limited and expensive field surveys. This study demonstrates that emergent marsh plants respond predictably to environmental conditions and provide valuable information regarding the ecological condition of estuaries. Salt marsh plants are valued as a substrate stabilizer, a contributor to food webs, and a refuge for a variety of nekton species including fish, invertebrates, and migratory birds (Henley and Rauschuber 1981; Zedler and Kercher 2005). Given that they are also inexpensive to survey, they make ideal candidates to be included in a suite of indicator species.

S. alterniflora is the only emergent plant species considered in this study that consistently reflects environmental conditions in tidal creeks (Figure 4, 8), exhibits a salinity tolerance similar to other faunal estuarine indicator species (BBEST 2011), and provides an ecologically important habitat (Kneib 2003). Our results show that the coverage of *S. alterniflora* is related to variations in porewater salinity (Figure 8). Field observations indicated that the cover of this species was substantially reduced at salinities exceeding 25‰. A study by Webb (1983) also found that porewater salinities exceeding 25‰ resulted in significant reductions in density, height, and standing biomass. However, there is considerable uncertainty associated with this threshold. Previous studies have found that the salinity tolerance of *S. alterniflora* is between 20‰ and 30‰, and our change point analysis found that probable change points were centered on 25‰ within the 15–35‰ interval (Bertness et al. 1991). Although we focus on salinity in this study, it is important to recognize that cover of a single species at any given point in time is a function of many different factors. The plant cover data presented in the study are affected by variables not explicitly considered here. Chief among these are antecedent conditions and site specific environmental differences. We use instantaneous salinity and cover measurements gathered from 3 different sites in order to define the relationship between emergent plant species and salinity (Figure 7). Low cover values in Figure 7 may occur even at low salinity because of antecedent flooding or because the creek bank slope, drainage, or sediment characteristics prevent peak abundance (high cover). Given that this study utilizes data from field surveys rather than greenhouse plantings, changes in *S. alterniflora* cover were aligned with changes in salinity with remarkable consistency.

Integrative studies by BBEST (2011) and TDWR (1982) found that the freshwater inflow needs of *S. alterniflora* are nearly identical to that of other common indicator species such as the blue crab (*Callinectes sapidus*), Atlantic croaker (*Micopogonias undulates*), and eastern oyster (*Crassostrea virginica*). Therefore, one would expect that the abundance of *S. alterniflora* serves as a reasonable proxy for the abundance of these higher trophic level organisms. *S. alterniflora* stands represent a unique habitat because it is the only species found at the lowest exposed elevations in the Nueces Delta. Cover of this species is limited to the areas directly adjacent to creekbanks that fall within the range of daily tidal variation (Rasser 2009). Under stressful environmental conditions, *S. alterniflora* habitat is converted to open water habitat. This conversion represents the loss of a unique habitat as *S. alterniflora* is known to promote nekton density and production (Whaley and Minello 2002; Kneib 2003). In the Nueces Delta, the benefits of *S. alterniflora* cover to higher trophic level organisms likely occur indirectly through the provision of habitat rather than direct carbon assimilation (Wallace 2011).

Although numerous studies have examined the freshwater inflow needs of the Nueces Estuary, no study has yet produced a comprehensive comparison of inflow estimates from diverse methodologies and time periods. Previous estimates of freshwater inflow needs in the Nueces Delta vary widely from annual inflows of only 1.12×10^8 to 4.98×10^8 cubic meters per year (Table 1). Estimated freshwater inflow needs have varied among studies because of historical reservoir development, differing analytical methods, and time scales. Early studies estimating freshwater inflow requirements of the Nueces Estuary, prior to reservoir development, determined that adequate ecosystem function is achieved at annual inflows of 4.98×10^8 cubic meters per year (TDWR 1982). Subsequent estimates following reservoir construction were much lower (1.71×10^8 cubic meters per year, Pulich et al. 2002; 1.12×10^8 cubic meters per year, BOR 2000). A study by BOR (1975), predating reservoir construction, determined that average annual inflows from 1972 to 1975 were 5.07×10^8 cubic meters per year. This is well above the average annual inflows observed throughout this study period and clearly not realistic given increasing municipal water demand and upstream reservoir construction. However, more recent estimates by Pulich et al. (2002) and Bureau of Reclamation (2000) barely exceed median observed inflows and may underestimate actual inflow needs (Table 2). Our estimate, based on the abundance of *S. alterniflora,* falls between historically high estimates and recent low estimates at a conservative 3.13×10^8 cubic meters per year (Table 1). Achieving such annual freshwater inflows requires less than the average annual inflow observed during the study period (Table 1). Although Nueces River flows exceeded our estimated freshwater inflow requirements in 5 of the 11 years encompassed by this study (1999–2011), they only exceeded this target 6 years between 1990 and 2011 (Figure 2, USGS 2011).

We primarily focused on annual and interannual patterns in freshwater inflow because it is consistent with municipal water management strategies discussed in previous studies (BOR 2000, Pulich et al. 2002). However, there are likely important variations in freshwater inflow on time scales not explicitly considered in our analyses. Analysis of historic freshwater inflow patterns suggests that decadal variations in freshwater inflow may be occurring (BOR 2000). For example, while observed annual freshwater inflows regularly exceeded our inflow requirement estimates listed in Table 1, they were met in only 1 year between 1990 and 2000 (USGS 2011). It is also likely that seasonal inflow patterns are important given that seedling germination mostly occurs in the spring (Alexander and Dunton 2002). Furthermore, previous studies have found evidence that seedlings exhibit different physiological tolerances to environmental stress than adult plants (Shumway and Bertness 1992). In the Nueces Delta, Alexander and Dunton (2002) found that seed germination and expansion of *Salicornia bigelovii* was facilitated by freshwater input. Water managers tasked with resolving conflicts between municipal use and ecological benefits should consider altering the timing of freshwater inflows to coincide with critical germination periods of *S. alterniflora.* Future research should assess the impacts of freshwater inflow timing on *S. alterniflora* abundance. Greater knowledge of the importance of inflow timing is required before our recommendations can be applied in a management context.

Future Impacts

The overall extent of emergent salt marsh plants in the Nueces Delta is likely to shrink as a result of continued decreases in freshwater inflow concurrent with more erratic and possibly decreasing precipitation due to global climate change (Forbes and Dunton 2006). Ward and Valdes (1995) evaluated the impact of global climate change on Texas water resources relative to a scenario characterized by a 2 °C increase in temperature and a 5% decrease in precipitation. Based on this scenario, Ward and Valdes (1995) projected a 35% decrease in freshwater inflow to Texas estuaries. Our results suggest that if droughts become longer and more frequent, *S. virginica* will likely replace *S. alterniflora* and make up a greater proportion of the overall community. This has important implications for the ecological health of the Nueces Delta and provision of ecosystem services. Since the rooting depth of *S. virginica* is much shallower than the rooting depth of *S. alterniflora*, this shift would decrease the ability of vegetation to provide sediment stabilization. Changes in the plant community of the Nueces Delta may provide a forecast of future changes in wetter, more northerly estuaries (Kirwan et al. 2009). Future monitoring efforts in these estuaries should focus on northward latitudinal shifts in *S. alterniflora* in response to freshwater inflow and global climate change.

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