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An online, peer-reviewed journal
published in cooperation with the
Texas Water Resources Institute

TEXAS WATER JOURNAL

Volume 4, Number 2
2013

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Volume 4, Number 2
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ISSN 2160-5319

texaswaterjournal.org

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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

Texas Water Resources Institute
Texas Water Journal
Volume 4, Number 2, Pages 14–27

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

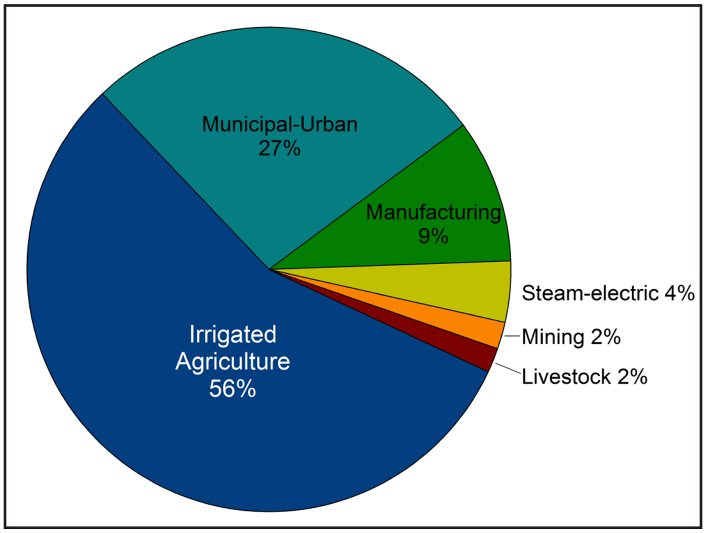

Figure 1. Relative water demand projected in 2010 for various activities in Texas (Drawn from data in the 2012 state water plan; TWDB 2012).

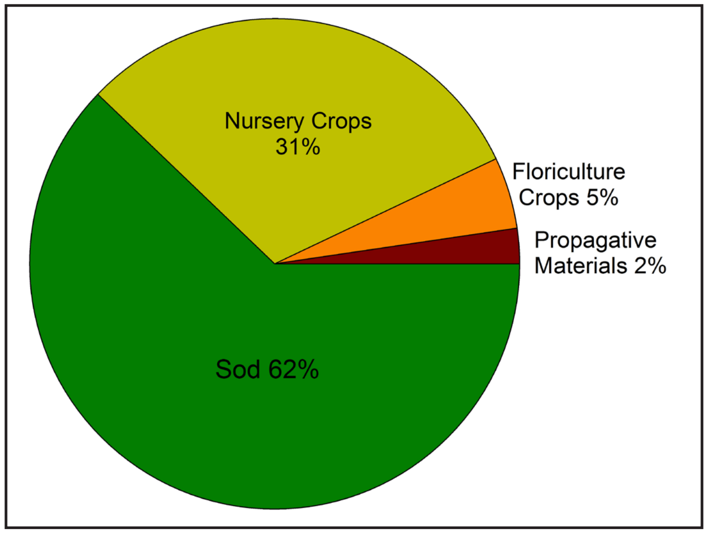

Figure 2. Relative distribution of the area devoted to the production of ornamental commodities and sod in Texas (From data in 2007 Census of Agriculture; NASS 2009).

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

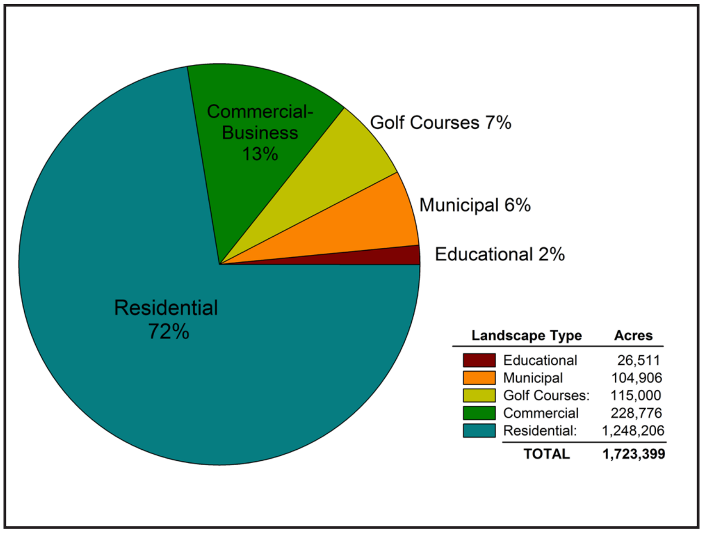

Figure 3. Distribution of the urban landscape (and lawn) area in Texas, including golf courses.

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.

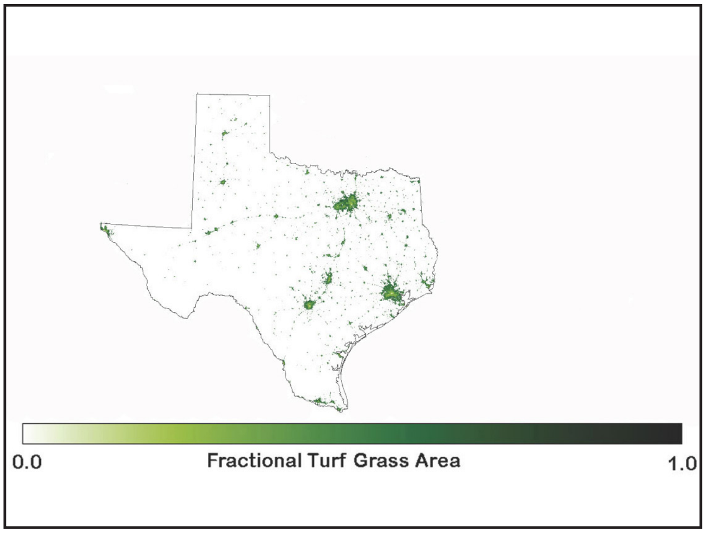

Figure 4. Geographical distribution of the turf and tree surface area (i.e. urban landscapes) in Texas, estimated from relationships between impervious and vegetated surfaces in high-resolution satellite photography tiles (Illustration adapted from Milesi et al. 2005).

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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