A Report to the Barton Springs/Edwards Aquifer Conservation District

Methodology for Estimating Landscape Irrigation Demand

Review and Recommendations

Dennis Pittenger

April 2014 – Final Report

Executive Summary

Landscape water use in Texas is estimated to be about 46% of all water used in urban areas of the State. It is likely to increase due to population growth and lifestyle preferences of urban and suburban dwellers. In order to implement effective landscape water management practices and conservation policies, it is necessary to estimate accurately landscape water requirements and corresponding irrigation demand. This report centers on the background and presentation of a recommended science-based methodology for estimating landscape irrigation demand. It also provides brief reviews of background topics and various approaches used to estimate landscape water and irrigation requirements, including the District's current methodology of calculating estimated landscape irrigation demand.

Evapotranspiration (ET) is a measurement of the total amount of water lost to the atmosphere by a planted area due the processes of evaporation of water from the soil and transpiration of water by plants. The term is a combination of the words "evaporation" and transpiration". Under identical weather conditions, different plants have different ET rates and thus different water requirements because of their physiology and dissimilar response to weather. A value known as reference ET (ETo) is calculated from weather data to reflect the effects of climate and weather on plant water use among locations. Adjustments to ETo, known as plant factors (PF) or crop coefficients (Kc), are needed to estimate the water demand or water requirements (ET) of specific crops and landscape plants. These PF's or Kc's are usually fractions, and account for plant morphology, crop physiology, and irrigation management.

The ETo algorithm was developed for agriculture; the product of ETo multiplied by a crop-specific fractional adjustment factor estimates the depth of water that crop requires. The ETo adjustment factors for landscape plants are termed a "plant factor" (PF). Widely accepted, research-based average PF's for warm-season and cool-season grasses in their growing seasons are 0.6 and 0.8, respectively, when grown as general lawn areas with the expectation of simply providing adequate appearance. Studies on water requirements of trees, shrubs, and groundcover plant species has found these plant types require about 50-70% of ETo during their growing season in order to provide acceptable landscape appearance and function.

There are multiple methods and approaches for estimating water requirements of landscapes, but not all are scientifically sound and defensible. A climate-based approach relying on local ETo data and reliable PF's can provide reasonable and rational water requirement estimates because it recognizes the fact that plant water demand is in large part a function of the local climate. Localized ETo data from a reliable source provides the climatic reference basis for estimating the amount of water plants require. A source or means of estimating reliable PF's is also essential. There are only a few scientific and reliable sources of PF's for landscape plants. The most widely vetted, complete yet simple source of PF's is found in the Draft ANSI/ASABE Standard S623.

BS/EACD Current Irrigation Demand Methodology

The current methodology used by the District incorporates a soil water balance that factors in monthly average precipitation, runoff, infiltrated rainfall, ETo, and an estimated leaching requirement based on the salt tolerance of bermudagrass and aquifer water quality data. In the end, the computations provide an estimated landscape irrigation requirement reported as the "actual water demand of the crop (alfalfa) and an application rate that will only allow for maximum volume necessary to satisfy this demand." While the approach includes a climate basis factor (ETo) and the data sources for its variables are authoritative, overall it appears to produce generous estimates of landscape irrigation demand and it does not incorporate application of recent science in landscape plant water requirements.

Recommended Methodology for Estimating Landscape Water Requirements and Irrigation Demand of Established Landscapes

Landscapes are complex mixes of plants making it difficult to arrive at a single algorithm that produces accurate irrigation demand estimates for all possible situations. The recommended methodology is somewhat more complex than the current methodology, but its results are more accurate and defensible estimates of landscape irrigation need. It recognizes that a process for estimating landscape irrigation demand involves a balance of simplicity and complexity in calculations.

There are a few procedural options available to District staff that increase the amount of detailed information required from water permit holders but might also increase the complexity and accuracy of irrigation demand calculations produces by the new methodology. District staff will need to evaluate if the time and effort needed to exercise options that increase the complexity of required information and calculations is justified.

The methodology relies on available science-based information on landscape plant water requirements to establish the PF's needed to adjust ETo. It will likely produce lower estimates of irrigation demand than the current methodology used by the District. A table of recommended PF's for categories of landscape plant types is provided in the report body. The District is advised to follow future revisions to the PF's listed in the Draft ANSI/ASABE Standard S623 and incorporate any local scientifically derived PF's that become available.

The recommended algorithm for estimating landscape water requirement and irrigation demand is:

$$\text{Irrigation Demand in Gallons} = \sum \left[(\text{ETo} \times \text{PF}_{1\text{-x}})_{\text{J-D}} - (\text{P} \times 0.5)_{\text{J-D}} \times \text{LA}_{1\text{-x}}\right] \times 0.623 \div \text{DU} \times \text{LR}_{\text{ES,T}}$$

where:

- ETo is the historic average monthly ETo in inches.
- PF is the plant factor for the plant categories, 1 to x, for each month, January through December.
- P is the historic average precipitation in inches for each month January through December.
- $LA_{1\text{-}x}$ is the landscape area devoted to a respective plant category, 1 through x, in square feet.
- 0.623 is the factor to convert units to gallons.
- DU is the distribution uniformity of irrigation application, assumed 0.7.
- $LR_{ES,T}$ is the leaching requirement needed only for waters taken from the Trinity portions of the aquifer or those with similar salinity levels. This variable is not included when irrigation water is from other District sources of higher quality. The LR is calculated as follows:

$$\text{LR} = \frac{\text{EC of water}}{(5 \times \text{EC desired in soil}) - \text{EC of water}} + 1.0$$

Results from the algorithm can be converted to other units as follows:

- Acre-Feet = Gallons ÷ 325,853.
- Acre-Inches = Gallons ÷ 27,154.

Importantly, the algorithm can be used to develop a spreadsheet that automates the multiple calculations needed to derive estimated irrigation demand. A layout with columns for each independent calculation step similar to the Excel calculator in the District's current methodology might work well.

The recommended methodology is highly applicable for estimating irrigation demand of general landscapes. It can be applied to sports fields and golf courses, but its results may not be precise enough for high-end athletic surfaces. The methodology does not apply to any plant production operations, such as nurseries, greenhouses, sod farms, or commercial farms.

Introduction

Landscape water use in Texas is estimated to be about 46% of all water used in urban areas of the State (Cabrera et al., 2013). It is likely to increase due to population growth and lifestyle preferences of urban and suburban dwellers. Landscape water conservation is important to assure there is an adequate supply of water for all uses now and in the future. In order to implement effective landscape water management practices and conservation policies, it is necessary to estimate accurately landscape water requirements and corresponding irrigation demand.

This report centers on the background and presentation of a recommended science-based methodology for estimating landscape irrigation demand. In addition, it includes brief reviews of the science concerning landscape plant water use and landscape irrigation demand estimation, various approaches used to estimate landscape water and irrigation requirements, and the District's current method of calculating estimated landscape irrigation demand. A short list of recommended landscape irrigation best management practices (BMP's) for the District to consider incorporating into User Conservation Plans concludes the report's discussion sections. The report is extensively annotated with citations from the Bibliography, although there are non-cited references in the Bibliography that provide additional information and background on topics and disciplines related to landscape water requirements and irrigation management.

Purpose of Report and Disclaimer

The information in this report is based on science and research related to landscape plant water requirements plus related disciplines. Information supplied by the BS/EACD, which is believed to be accurate and reliable, was also reviewed and considered. The purpose of the report is to provide background analysis and information along with options rather than a prescription for the BS/EACD to consider in revising their methodology for estimating landscape irrigation demand. Staff of the BS/EACD must assess and modify as necessary the options and recommendations provided in this report to assure any new methodology or policies adopted related to estimating landscape irrigation demand are appropriate. Thus, BS/EACD is responsible for the impact of any methodology or policies adopted based on this report.

Water Requirements of Landscape Plants: *the Science*

Evapotranspiration (ET) is a measurement of the total amount of water lost to the atmosphere by a planted area due the processes of evaporation of water from the soil and transpiration of water by plants. The term is a combination of the words "evaporation" and transpiration". Under identical weather conditions, different plants have different ET rates and thus different water requirements because of their physiology and dissimilar response to weather. A value known as reference ET (ETo) is calculated from weather data to reflect the effects of climate and weather on plant water use among locations (Allen et al., 1998 and 2005). Reference ET is synonymous with the term potential evapotranspiration (PET). Use of ETo standardizes and simplifies the calculation of ET rates for individual plants and crops among locations. It is defined as the water used by a cool-season grass growing four inches tall and provided unlimited water (well-watered conditions) (Allen et al. 2005). Thus, cool-season grass is the reference crop, and adjustments to its water use (ETo), known as plant factors (PF) or crop coefficients (Kc), are needed to estimate the water demand or water requirements (ET) of specific crops and landscape plants growing in the same geographic area that given ETo values are calculated. These PF's or Kc's are usually fractions, and, for crops and some landscape plants, research has determined they vary with stage of plant growth or season of the year. Whereas ETo accounts for weather variation, the PF or Kc factors account for plant morphology, crop physiology, and irrigation management.

Many urban water purveyors and jurisdictions along with landscape management professionals have adopted the use of ETo to estimate landscape water demand and determine climate-based water budgets and irrigation schedules (St. Hilaire et al., 2008). Calculating accurate ETo-based plant water requirement estimates, water budgets and irrigation schedules requires multiplying ETo by a reliable adjustment factor (AF). A general estimate of a landscape's water requirement or water budget for a given time period can be calculated as:

Water Requirement or Budget (gal.) = ETo (in.) × Adjustment Factor × Landscape Area (sq. ft.) × 0.623.

The ETo value provides an estimate of the climatic influence on plant water demand and the Adjustment Factor, normally a fraction or decimal, is a crop coefficient (Kc) or plant factor (PF) that corrects the ETo value to account for the specific water demand of the plants present (Allen et al., 1998, 2005). In some jurisdictions, the Adjustment Factor is pre-set to establish a maximum water budget or water allowance for a site. The value, 0.623, is the factor that converts water depth in inches per square foot to water volume in gallons.

There are few comprehensive sources of scientific, quantitative estimates of landscape plants' water requirements as a percentage of ETo to employ as adjustment factors in algorithms like those above. The widely-referenced publication, Water Use Classification of Landscape Species (WUCOLS) (Costello and Jones, 2000 and 2014), is not research-based and has not been confirmed by scientific field research. Its data have been found to be unreliable in many instances, and thus they give the user a false sense of precision. It is also California-centric, which limits its application significantly. Most other popular and widely available lists of plant water needs or water use categories are similarly unscientific.

However, over the past 20 years or so there has been considerable research on water requirements of landscape plants and their water use physiology. The following is a brief summary of the pertinent findings of this science.

Landscape Plant Factors (PF)

The ETo algorithm was developed for agriculture; the product of ETo multiplied by a species-specific fractional adjustment factor estimates the depth of water a specific crop requires. However, the algorithm of ETo multiplied by a species-specific fractional adjustment has limited accuracy in estimating water needs of urban landscapes. Typical urban landscapes violate the standard conditions in which the relationship of ETo and Kc is defined and estimated. The ETo × Kc calculation assumes the following standard conditions for a hypothetical cool-season turfgrass surface: a uniform plant canopy that is connected to the atmosphere, plants' water use is tightly synchronized to ETo, and uniformly adequate soil water conditions (Allen, et al., 1998, 2005). The algorithm is not robust enough to account for the spatially and biologically complex mixes of turfgrass, woody, and herbaceous plant types in urban landscapes. (Shaw and Pittenger, 2004; St. Hilaire et al, 2008). These plant types differ in canopy architecture, plant physiology, and leaf size in ways that do not conform to the standard conditions under which ETo is defined.

Water requirements of many non-turf landscape plant species are not tightly synchronized to ETo and may respond non-linearly to weather factors used to estimate ETo (Choudhury and Montieth 1986). Also, unlike agricultural crops, urban landscape plants are grown for their aesthetic appearance and functional value that can be achieved over a range of water amounts, rather than being grown for optimum growth and yield based on precise water amounts as percentages of ETo. Water requirements of non-turf landscape plants are effectively defined as the percentage of ETo required to maintain their acceptable appearance and intended landscape function (Beeson, 2012, Pittenger et al., 2001, 2002; Pittenger et al., 2009; Shaw and Pittenger, 2004; Staats and Klett, 1995; Sun et al, 2012). Thus, ETo adjustment factors for landscape plants define the minimum amount of water a plant needs to maintain acceptable aesthetic appearance and expected function (e.g. shade, green foliage, screening element) rather than the amount of water the plant uses or requires for optimum growth and yield. Such an adjustment factor is properly termed a "plant factor" (PF) rather than a "crop coefficient" (Kc) because of the emphasis on plant appearance rather than optimum growth and yield.

Nevertheless, the approach of estimating landscape plants' water requirements as a percent of ETo using PF as an adjustment is relatively accurate and effective in estimating landscape water requirements. This approach is rational, reasonable, scientific, and climate-based (Kjelgren, et al., 2000; Snyder and Eching, 2006). Understanding the limitations of the ETo x PF, however, is crucial to apply this approach successfully to estimate landscape plants' water requirements and to estimate landscape irrigation requirements for the range of landscape plant types.

<u>Turfgrass</u>

Estimating water requirements of turfgrass as a fraction of ETo (ETo × Kc or PF) is a demonstrated highly effective tool in estimating water requirements and managing irrigation because turfgrass swards closely mimic the standard conditions of ETo estimation (Richardson et al., 2012; Devitt et al., 1992; Gibeault et al., 1985). However, providing a single PF value for all turfgrass is difficult due to the variation among grass species, cultivars, climates, as well as the intended usage and maintenance regime of the turfgrass area. Widely accepted research-based average PF's for warm-season and cool-season grasses are 0.6 and 0.8, respectively, when grown as general lawn areas with the expectation of simply providing adequate appearance (American Society of Agricultural and Biological Engineers, 2013). In situations where optimum growth of turfgrass is needed, such as in sports fields and the play areas of golf courses, the ETo adjustment factor may be higher because there is a need for optimum growth to recover from wear that results for the intense activity the turf receives.

<u>Trees, Shrubs, Groundcovers</u>

The ETo x PF approach can be successful for landscape tree, shrub, and groundcover species in landscape settings, but a tree PF comes with more variability (Costello et al., 2005; Pannkuk et al. 2010, Pittenger et al., 2002, 2009). A common finding among these studies is that trees, shrubs, and groundcover plant species growing in arid climates with a relatively dry growing season typically require water in the amount of about 50% of ETo during their growing season in order to provide acceptable appearance and function. This plant factor of

50% incorporates the variable response to climate of many tree, shrub, and groundcover species, and potentially mild water stress that does not affect plant appearance and performance. A plant factor of 70% of ETo has been determined to be more appropriate for woody plants and groundcovers growing in humid climates with relatively high summer rainfall, or plants native to wet habitats (usually including riparian species grown in arid climates).

Often trees in urban landscape settings are not in dense forest stands where much of a tree's crown is buffered by adjacent trees. The greater crown exposure and ventilation by wind means that an isolated tree is not buffered from climatic factors and responds non linearly to ETo and actually can reduce their water loss in some species (Daudet et al., 1999; Goldberg and Bernhofer, 2008; Jarvis and McNaughton, 1986). This response is analogous to an electrical circuit breaker that stops the flow of electricity when the system exceeds a set threshold. It is most pronounced in regions where the air is very dry (high ETo) during the growing season and the species can reduce transpiration at high ETo (Schulz, 2003; Tardeiu and Simmoneau, 1998). For isolated urban trees (i.e. those growing with no other plant material or tree canopies in close proximity), the plant's transpiring leaf area controls the volume of water required, so the ETo x PF approach must be modified to include an estimate of the tree's transpiring leaf area (Devitt et al., 1994; Montague et al., 2004). A procedure for this calculation is described in the Draft ANSI/ASABE Standard S623: Determining Landscape Plant Water Requirements (American Society of Agricultural and Biological Engineers, 2013).

Methods for Estimating Landscape Water and Irrigation Requirements

There are multiple methods and approaches for estimating water requirements of landscapes. A climate-based approach can provide reasonable and rational water requirement estimates because it recognizes the fact that plant water demand is in large part a function of the local climate. Localized ETo data from a reliable source provides the climatic reference basis for estimating the amount of water plants require. A source that calculates ETo using the ASCE standardized reference evapotranspiration equation (Allen et al., 2005) is the accepted standard, but other historical or real-time sources of ETo data can provide sufficiently reliable data to estimate landscape water requirements. As discussed earlier, estimating plant water requirements using ETo requires multiplying the ETo value by an adjustment factor, known as a crop coefficient (Kc) or a plant factor (PF), that accounts for plants' particular water needs. Thus, a source or means of estimating reliable plant adjustment factors is essential. Many local jurisdictions and water purveyors in various states have adopted landscape water conservation ordinances or have implemented landscape design and irrigation budgeting programs that employ a variety of ETo-based methods for estimating landscape water and irrigation requirements. For the scope of this report, the following methods were reviewed.

<u>California's State Model Water Efficient Landscape Ordinance</u>

The Model Water Efficient Landscape Ordinance (MWELO) developed by the State of California (California Department of Water Resources, 2009) is a notable example of a prescriptive approach for estimating landscape water requirements, establishing maximum landscape water budgets for all new landscapes meeting minimum size criteria, and standardizing certain landscape development practices and irrigation hardware. All California counties and cities were required to adopt either the MWELO or their own equally effective local landscape water conservation ordinance in 2010. Among other requirements for site development and irrigation system hardware, the ordinance mandates an arbitrary maximum landscape water budget based on a site's landscape area and a fixed 70% of local ETo, plus an additional water allowance (100% of ETo) for certain defined special landscape areas. Essentially, new landscapes meeting the size criteria must be designed, through the combination of plant selection and irrigation efficiency, to perform acceptably with no more than 70% of ETo (the maximum water budget) provided as irrigation. Optionally, local agencies may also require consideration of effective precipitation when a site's maximum water budget is calculated. In such instances, 25% of annual precipitation (the amount of precipitation deemed effective) is subtracted from annual ETo when calculating a maximum water budget.

To determine that a site design does not exceed it maximum water budget, one must estimate the water requirements of the plantings, and if irrigation is necessary, this must calculated for each irrigation zone and the irrigation efficiency (i.e distribution uniformity) must be factored in as well. The designated, though not mandated, source of PF's for use in the algorithms in the ordinance is the Water Use Classification of Landscape Species (WUCOLS) (Costello and Jones, 2000, 2014) data base, which has significant reliability and credibility limitations discussed earlier.

The MWELO approach to estimating landscape water requirements is centered on prescribing landscape development practices and certain irrigation hardware as well as ensuring that landscape irrigation demand does not exceed 70% of ETo. It uses a relatively complex and, when WUCOLS data are integrated in equations, unscientific method to estimate landscape plant water requirements and corresponding irrigation needs.

<u>The Landscape Coefficient Method</u>

This method substitutes a so-called landscape coefficient (K_L) in place of a PF or Kc value to adjust ETo for estimating a landscape's water requirement or water budget (Costello and Jones, 2000). The equation for a given period is:

$$\text{Gallons of Water} = \text{ETo} \times K_L \times \text{Landscape Area} \times 0.623.$$

The K_L must be calculated separately with the following equation: $K_L = K_s \times K_{mc} \times K_d$,
where:

- K_s is a plant species factor to account for the variability in water requirements among landscape plant species and is assumed by the user or taken from an accepted reference.
- K_{mc} is a microclimate factor, usually ranging from 0.5-1.4, assigned by the user to account for the presence of extreme meteorological conditions in a landscape (e.g. extreme reflected heat, persistent windy conditions, shade).
- K_d is a density factor, usually ranging from 0.5-1.3, assigned by the user to account for the presumed influence of layered canopies or closeness of plant groupings.

The intent of this method is to capture the influences of a landscape's microclimate(s) and variable plant canopy densities in addition to the plant species response to climate. However, as pointed out by Pittenger and Shaw

(2013), the method possesses significant technical problems and limitations. It does not reliably estimate landscape water requirements, so it gives one a false sense of precision in its calculations. Although the K_L theory was conceived over 20 years ago and was updated more recently (Costello, 1991; Costello and Jones, 2000), it has never been scientifically verified that the values produced by the K_L equation adjust ETo to reflect the amount of water landscape plants require to provide acceptable appearance and function. In fact, research in landscape plant water needs and plant ecology over the past 20 years or so indicates that using K_L to adjust ETo can add unscientific complexity that does not result in greater accuracy in estimating the amount of water a landscape requires to provide acceptable performance and function (Pittenger and Shaw, 2013).

<u>Estimating Crop Irrigation Volumes for the Tindal Limestone Aquifer – Katherine, Australia</u>
The method provides a defensible, straightforward, and accurate means of estimating monthly water requirements and irrigation volumes for an assortment of annual and perennial agricultural crops grown in the region. It is science based and uses historic local ETo values derived from evaporation pan data, historic rainfall data, monthly Kc's reflecting differences in seasons or crop development stages, and an adjustment for irrigation system efficiency. Although the authors note the accuracy of the approach suffers from the lack of science-based Kc's for all crops, the need to improve the ETo data, and the difficulty in accurately assessing effective rainfall, this method is a good general model for use in agricultural production settings.

<u>City of Austin Water's Alternative Irrigation Compliance Pilot Program</u>
The method described in this program establishes quarterly site water budgets based on 70-year historic ETo data for the Austin area from Texas A&M Agrilife Extension Service (2014), monthly Kc's for warm-season grass, an adjustment factor for desired turfgrass performance (Qf), and the specific irrigated area (Austin Water, no date). The general equation is:

$$\text{Water Budget (gal.)} = \text{ETo} \times \text{Kc} \times \text{Qf} \times \text{Sq. Ft. Irrigated} \times 0.623.$$

The algorithm represents a simple and relatively sound scientific approach, with the exception of the user-assigned values of the adjustment factor for desired "turfgrass quality" (Qf), which can range from 0.4 (very high stress) to 1.0 (no stress), but is mandated to be set at 0.8 or lower. The science base to support synchronization between a given Qf value and a level of turf performance is not given and such a relationship has not been reported otherwise. In essence, the water users are allowed no more than 80% of ETo. Forcing users to recognize that plant water requirements are in part driven by expectations of plant performance is commendable, but incorporating an ETo adjustment factor value in this manner can create complexity with limited benefit.

<u>SLIDE – Simplified Landscape Irrigation Demand Estimation</u>
A small consortium of academic experts on landscape water needs drafted and proposed this approach to estimating the irrigation and total water demand of established landscapes in 2012 (Pittenger, 2012), though has not been scientifically published. It is based on the interpretations and common findings of field research studies related to landscape plant water requirements and plant water-use physiology completed by the consortium and many others over the past several years. The principal premises of SLIDE are:

- PF's of established landscape plants can be accurately estimated by assigning individual species into a general plant-type category.

- Total landscape water requirements can be accurately and easily estimated by weighting the area devoted to each plant category.

The plant type categories and their respective PF's proposed in the draft of SLIDE are:

- Turfgrass – 0.6 for good performance and 0.4 for minimum soil coverage of warm-season species, 0.8 for good performance and 0.6 for minimum soil coverage of cool-season species.
- Trees, shrubs, groundcovers, woody vines – 0.5-0.6, possibly 0.7 for humid climates.
- Annual and perennial flowering/foliage plants – 0.7-0.8.
- Very drought tolerant plants and landscape areas with low performance expectations – 0.3-0.4.

The SLIDE equation for estimating the water demand of an established landscape is:

$$\text{Water Demand (gal.)} = \sum (PF_{\text{category 1}} \times LA_1) + (PF_{\text{category 2}} \times LA_2) + (PF_{\text{category 3}} \times LA_3), \text{ etc.} \times 0.623$$

Where:

ETo = reference evapotranspiration,

PF = plant factor for a given plant type category,

LA = sq. ft. landscape devoted to plants of a given plant category, and

0.623 = converts ETo inches of water to volume of water in gallons [gal. ÷ (in. x sq. ft.)].

Furthermore, SLIDE recognizes the research findings that:

- Landscape plants are usually capable of using more water than they need in order to provide acceptable performance and function.
- The ETo × PF concept has limited accuracy in landscapes due to the biological physical complexities of these systems, and adding other ETo-adjustment factors to an equation does little to improve its accuracy.
- Most species tolerate moderate managed drought and can provide acceptable performance over a range of PF's.

The SLIDE approach to estimating landscape water requirements is relatively simple, and scientifically based and defensible.

<u>ANSI/ASABE Draft Standard S623: Determining Landscape Plant Water Requirements</u>

The standard is among the simplest and broadly applicable methods in use, and it is the most scientifically defensible method described. It describes a methodology to estimate total plant water requirements of permanently installed established landscape plant materials. It is designed to provide a standardized, science-based, defensible, simple and accurate approach for estimating landscape water requirements that can be applied anywhere in the United States. It estimates the minimum water requirements for acceptable plant appearance and function. It does not address production of plant material or plants used in sports fields or golf courses.

The content of this new standard is based on the SLIDE concepts reviewed above. Its content is an update and expansion of the original SLIDE draft reported by Pittenger et al. (2012). It follows SLIDE's general approach of estimating PF's by categorizing plants and then weighting the landscape area devoted to each plant category. The plant type categories and their PF's for acceptable landscape appearance and function as they appear in the current draft standard are:

- Cool-season Turf (Kentucky bluegrass, tall fescue, ryegrass) 0.8
- Warm-season Turf (bermudagrass, zoysiagrass, St. Augustinegrass) 0.6
- Herbaceous Perennials and Annual Flowers/Bedding Plants 0.8
- Woody Plants (trees, shrubs, groundcovers, vines) – humid areas 0.7
- Woody Plants (trees, shrubs, groundcovers, vines) – arid areas 0.5

Currently, the technical committee that is writing the standard is working on a possible revision of the PF for the Herbaceous Perennials and Annual Flowers category; it is recognized that a PF of 0.8 for the herbaceous perennial plants is probably too high, but there is limited research to suggest what a lower, more accurate value should be. The standard is scheduled to undergo a second public review and comment period prior to its final revisions and adoption anticipated in mid- to late-2014.

BS/EACD Current Irrigation Demand Methodology: *Review and Recommendations*

The current methodology used by the District (Barton Springs/Edwards Aquifer Conservation District, no date) incorporates a soil water balance approach calculated using an algorithm adopted from Texas Land Disposal of Sewage Sludge Guidelines (Texas Commission on Environmental Quality, 1990) that factors in monthly average precipitation (NOAA, Camp Mabry), runoff (USDA, 1990), infiltrated rainfall, ETo (McDaniels, 1960; Mercier and Brown, 1992), and an estimated leaching requirement based on the salt tolerance of bermudagrass (Texas Commission on Environmental Quality, 1990) and aquifer water quality data. In the end, the computations provide an estimated landscape irrigation requirement reported as the "actual water demand of the crop (alfalfa) and an application rate that will only allow for maximum volume necessary to satisfy this demand." While the approach includes a climate basis factor (ETo) and the data sources for its variables are authoritative, overall it appears to produce generous estimates of landscape irrigation demand and it does not incorporate application of recent science in landscape plant water requirements.

Evapotranspiration Estimation

The use of ET or ETo data enables one to estimate water requirements of landscape plants based on the influence of weather and climate. The current methodology cites the use of historic ET data ("climate index" data) published by McDaniels (1960) and it is unclear if the revision of this data by Mercier (1992) has been adopted. Regardless, there are newer and more scientifically accepted ETo data sources available that more precisely relate the influence of local climate on plant water use. It is recommended that monthly historic ETo data for the Austin area from the Texas ET Network (Texas A&M AgriLife Extension, 2014) be used going forward to estimate landscape water requirements. The Texas ET Network uses the standardized ASCE Penman-Monteith method (Allen, et al., 2005) to calculate ETo from weather station data, which is the most widely, scientifically accepted equation. Current and historical ETo data calculated by the Texas ET Network at various locations is available via the Web at http://texaset.tamu.edu. This standardized ETo calculation provides a means for estimating climatic influence on plant water use, and importantly, it facilitates the sharing and use of PF's and Kc's developed in various locations. Using this source of data also facilitates a transition to the use of real-time ETo and real-time water budgeting should the District or irrigators desire to do so in the future.

Plant Material Coefficient

The plant related ETo adjustment factor used in the current methodology is for perennial grass that is in turn estimated to be 90% of the water required for alfalfa production as reported by McDaniels (1960). However, the currently used alfalfa-based ETo adjustment factor is not as appropriate or defensible for estimating landscape water requirements as are the more recent science-based estimated PF's for landscape plant categories reviewed earlier in this report. Going forward, PF's representing landscape and turfgrass plants should be used to adjust ETo. The PF's described in the ANSI/ASABE Draft Standard S623 (American Society of Agricultural and Biological Engineers, 2013) are the most current, broadly applicable, and scientifically vetted available, so it is recommended that they serve as the basis for PF's with the following modifications:

- Woody Plants PF should be 0.6 because the Austin area climate is intermediate to the humid (PF 0.7) and arid (PF 0.5) regions described in the Standard.
- Warm-season turfgrass PF should adjust monthly according to Texas A&M AgriLife Extension (2014).
- Herbaceous Perennials PF should be 0.7 because it is judged this value more accurately estimates the water requirements of plants in this category in light of the current discussions among the technical committee developing the Standard's content.
- The PF of mixed landscape plantings should use the PF of the plant material in the mix that has the highest PF or be the average of PF's in the mix.
- Incorporate or adapt any local, scientifically derived PF's for turfgrass or landscape plants that are or become available.

Reported PF data from Fipps (2014), Green (2005), Meyer et al. (1985), Snyder (2014), and Texas A&M AgriLife Extension (2014) are recommended to fill gaps and provide added localization of PF data.

Precipitation, Infiltration, Runoff, Soil Water Balance

The current methodology includes an accounting for effective rainfall and, based on the example provided in the Irrigation Demand Calculation Methodology (Barton Springs/Edwards Aquifer Conservation District, no date), it estimates an amount of average rainfall that effectively enters the soil and plants' root zone. When infiltrated rainfall is less than average ET for any month, the amount of irrigation needed to make up the difference is calculated. When summed for all months, the estimated annual irrigation demand permitted in the example provided is about 59% of ET. In light of the PF's estimated for many landscape plant categories described earlier, the amount of water provided by the current method seems generous.

In reality, annual precipitation can vary widely from the historic average amount, and individual events can vary considerably in intensity and amount across the District's service area. These characteristics make it difficult to accurately estimate or predict how much precipitation will effectively meet plant water needs in any single month or year. It also appears that much of Texas, including Austin, may be in a similar long-term drought and high ET pattern as the one described by Mercier (1992) and McDaniels (1960). Precipitation reduces the irrigation demand, but since it occurs with great variability, it is important that calculations used to predict landscape irrigation requirements avoid grossly over or under estimating the actual precipitation beneficial to landscape plants. After discussing these considerations with District staff, some accounting of precipitation influence on irrigation demand is imperative, but it is reasonable to be somewhat conservative when accounting for effective precipitation. It is recommended to assume 50% of average monthly precipitation is beneficial to plants in any month for estimating landscape irrigation demand. The recommended source of average precipitation data for Austin is provided by the Texas ET Network (Texas A&M AgriLife Extension, 2014).

The infiltration and runoff parameters in the current methodology add complexity to the estimations of landscape water and irrigation demand but they do not necessarily add additional accuracy to them. These parameters are important to the hydrology of natural settings. However, they are less predictable in urban and suburban settings because of the inherent spatial variability in soils due in large part to the fact that urban soils are typically altered physically during development. Their topographies and properties often no longer correspond closely to those predicted from surveys made prior to the area's development. The value of these parameters in calculating irrigation demand is judged to be relatively minor. Infiltration and runoff potential are more of a concern in irrigation scheduling and management in urban and suburban landscapes. It is thus recommended for these variables to be omitted from future methods of estimating landscape water and irrigation demand.

<u>Allowance for Irrigation Inefficiency</u>

The current methodology adds an adjustment or buffer of 15% to the estimated irrigation demand to account for irrigation system inefficiencies. An allowance for irrigation system and/or management inefficiencies is commonly applied when calculating landscape irrigation requirements. For landscapes, the measured distribution uniformity (DU) of the irrigation system is the most common measurement of efficiency used for this purpose. It reveals how uniformly irrigation water is applied over an area. The DU is reported as a decimal or percentage that is used to calculate how much additional water is needed in order for all of a planted area to receive the required minimum amount of water. Its values cannot exceed 1.0 (100%) and are essentially always less than that because no irrigation system applies water in perfectly uniform fashion. The estimated irrigation requirement of the area is calculated, then that value is divided by the site's DU, which increases the amount of applied water needed to assure all the irrigated area receives at least the estimated irrigation required. Keeping DU as high as possible (i. e. as close to 1.0 or 100%) results in more efficient irrigation application and minimizes the amount of irrigation needed to meet a landscape's water requirement.

The District's current 15% allowance for irrigation system inefficiency relates to a DU of about 0.87, which is very high for landscape irrigation and is normally achieved only with drip or low-volume emitting irrigation systems (Irrigation Association, personal communication). Overhead spray and sprinkler systems used in landscapes can achieve DU's of 0.7-0.8 (Green, 2005), although DU's typically are much lower, about 0.5-0.6, in many residential and commercial landscapes. Drip irrigation systems can produce much higher DU's but they are not as widely used for general landscape irrigation unless a high DU value is desired by the water user or mandated by a water purveyor or ordinance. However, assuming a relatively high DU (or a small inefficiency allowance) when estimating irrigation demand or water budgets recognizes that irrigation is an imperfect activity, yet it encourages water conservation and innovation in irrigation systems and their management. For these reasons, it is recommended that a DU of 0.7 be factored into calculations that provide estimated landscape irrigation demand. The DU value can be adjusted in the future as irrigation technology advances or as the District requires to promote water conservation.

Water Quality/Leaching Requirement

A leaching requirement is currently included on the methodology. It is based on the salt tolerance of bermudagrass and is calculated by the method prescribed in 30 TAC Chapter 309, Subchapter C - Section 309.20 (Texas Commission on Environmental Quality, 1990). For the calculations in the methodology, the salinity of water managed by the District is set at an average 0.55 mmhos/cm and the salt tolerance of bermudagrass is assumed ECe of 10.0 mmhos/cm in the soil.

The recent analysis of aquifer waters provided by the District indicates water quality varies according to the portion of the aquifer that water is extracted from (Table 2, Hunt et al., 2009). This data shows that all aquifer waters have relatively high bicarbonate concentrations so they are likely to increase soil pH, create unsightly deposits on landscape plant foliage from overhead irrigation, and create deposits in irrigation systems. However, only waters from the Trinity portions of the aquifer should pose serious salinity problems for landscape plants.

Reported average water salinity levels (ECw) in samples from aquifer areas other than the Trinity portions showed low to moderate salinity levels for growing landscape plants. Although many non-turf landscape plant species are less salt tolerant than bermudagrass and other turfgrasses, the reported salinity levels of these waters are low enough and average precipitation is high enough that leaching is not recommended generally when they are used for irrigation (Farnham et al., 1993; Fipps, 2003; Queensland Government 2012a, 2012b; Tanji et al., 2007). However, highly salt-sensitive plant species might be adversely affected with these waters if rainfall is much less than normal over a period of a year or more. These special circumstances would require some leaching, or more effectively, highly salt-sensitive plants should simply be avoided.

Conversely, waters from the Trinity portions showed average salinity levels that are moderate to high for growing landscape plants, so these waters could create salinity problems for many landscape plant species (Farnham et al., 1993; Fipps, 2003; Harivandi, et al., 2008; Queensland Government 2012a, 2012b; Shaw, 1993; Tanji et al., 2007). Leaching is required if waters from either the Trinity portions are used for irrigation. It is recommended to calculate a leaching requirement that maintains soil ECe ≤ 4.0 dS/m (4,000 mS/cm or 4.0 mmhos/cm) for non-turf plants. When irrigating high-value plants, literature should be consulted to determine if a leaching requirement greater than the recommended one might be more appropriate (see: Farnham et al., 1993; Fipps, 2003; Harivandi, et al., 2008; Shaw, 1993; Tanji et al., 2007). For turfgrasses (Harivandi, et al., 2008), the leaching requirement should be calculated to maintain

- ECe < 6.0 dS/m for perennial ryegrass, creeping bentgrass, zoysiagrass, and tall fescue.
- ECe < 10.0 dS/m for bermudagrass and St. Augustinegrass.

In addition, salt-sensitive plant species and those with a low tolerance to irrigation water with ECw > 1.5 dS/m should not be planted where waters from Trinity portions of the aquifer are used for irrigation. It is recommended to avoid irrigating with any water that has an average ECw > 2.0 dS/m (2,000 mS/cm or 2.0 mmhos/cm).

Recommended Methodology for Estimating Landscape Water Requirements and Irrigation Demand of Established Landscapes

Landscapes are complex mixes of plants making it difficult to arrive at a single algorithm that produces accurate irrigation demand estimates for all possible situations. The recommended methodology is somewhat more complex than the current methodology, but its results are more accurate and defensible estimates of landscape irrigation need. It recognizes that a process for estimating landscape irrigation demand involves a balance of simplicity and complexity in calculations. Simplistic equations require little information or time to compute but often provide inaccurate results, while extremely complex equations that incorporate numerous factors increase time and effort to gather input data and compute but may only improve accuracy of results marginally.

There are procedural options available to District staff that increase the amount of detailed information required from water permit holders but might also increase the complexity and accuracy of irrigation demand calculations produced by the new methodology. District staff will need to evaluate if the time and effort needed to exercise options that increase the complexity of required information and calculations is justified. These issues are discussed in more detail later in this section.

The recommended methodology will likely produce lower estimates of irrigation demand than the current methodology used by the District. It relies on the available science-based information on landscape plant water requirements to establish the plant factors needed to adjust ETo. The science is limited, especially for non-turf plants, and it does not provide monthly or seasonal plant factors for all categories of landscape plants. However, it identifies categories of plant types according to their water requirements, which greatly simplifies the selection of accurate plant factors needed in calculations. The District is advised to follow future revisions to the plant factors listed in the Draft ANSI/ASABE Standard S623 (American Society of Agricultural and Biological Engineers, 2013) and revise Table 1 below accordingly. Any local scientifically derived PF's should also be incorporated in Table 1 as they become available.

The general recommended algorithm for estimating landscape water requirement and irrigation demand is:

$$\text{Irrigation Demand in Gallons} = \sum \left[(\text{ETo} \times \text{PF}_{1\text{-x}})_{\text{J-D}} - (\text{P} \times 0.5)_{\text{J-D}} \times \text{LA}_{1\text{-x}} \right] \times 0.623 \div \text{DU} \times \text{LR}_{\text{ES,T}}$$

where:

- ETo is the historic average monthly ETo in inches.
- PF is the plant factor for the plant categories, 1 to x, for each month, January through December, irrigated independently in different zones in a landscape (hydrozones) or it is an average of plant factors when plants with dissimilar PF's are irrigated together or when the breakdown of total landscape are devoted to plants with dissimilar PF's is unavailable.

- P is the historic average precipitation in inches for each month January through December.
- $LA_{1\text{-}x}$ is the landscape area devoted to a respective plant category, 1 through x, in square feet.
- 0.623 is the factor to convert units to gallons.
- DU is the distribution uniformity of irrigation application, assumed 0.7.
- $LR_{ES,T}$ is the leaching requirement needed only for water taken from the Trinity portions of the aquifer or those with similar salinity levels. This variable is not included when irrigation water is from other District sources of higher quality. The LR is calculated as follows (Ayers and Westcot, 1985; Harivandi, et al., 2008):

$$\mathrm{LR} = \frac{\text{EC of water}}{(5\ \times \text{EC desired in soil}) - \text{EC of water}} + 1.0$$

Results from the algorithm can be converted to other units as follows:

- Acre-Feet = Gallons ÷ 325,853.
- Acre-Inches = Gallons ÷ 27,154.

<u>Procedures</u>

Values for recommended PF's for plant material categories, historic average ETo, and average precipitation, are provided in the tables below. The algorithm calculates estimated monthly water requirements of each plant category in a landscape, subtracts effective monthly rainfall to derive estimated monthly irrigation demand for each plant category, sums the irrigation demands, adds an allowance for uniformity of irrigation application, and converts units to yield gallons of irrigation demand per year.

Note in Table 1 the category "Mixed Plantings", which represents situations where plants from various categories are interplanted and irrigated simultaneously or where the plant categories are grouped in discrete beds or zones according to PF but there are no data on the square footage devoted specifically to each plant category represented in the overall landscape mix. In these circumstances, it is simplest and safest to assume the PF is that of the plant type in the mix with highest PF. Alternatively, one could assume equal space devoted to each of the plant categories in the mix, equally divide the total square feet of the mix among the categories, then calculate the average PF of the plant categories present. Either of these options reduces precision in the estimated water requirement and irrigation demand of the landscape portion identified as a "mix".

In situations where shade trees are planted within a turf area, there is no need to factor in the water requirement of the trees. Their demand will be accounted for in the water demand estimate for the turf. When plant canopy (turf, trees, shrubs, etc.) shades at least 75% of the soil, water use is at its maximum and at the rate of the plant creating most of the canopy cover in a given area. Adding layers of canopy does not significantly increase the area's water use.

Importantly, the algorithm can be used to develop a spreadsheet that automates the multiple calculations needed to derive estimated irrigation demand. A layout with columns for each independent calculation step similar to the Excel calculator in the District's current methodology might work well. The basic calculations are:

1. Multiply monthly ETo by the PF's for the plant categories in the landscape and for each month of the year. This is the estimated water requirement in inches of the plant category for each month. If plant-category specific square footage figures are not available (e.g. there is 6,000 sq. ft. of mixed landscape beds with native plants, shrubs, perennials), one can either
    a. assume the PF is that of the plant type in the mix with highest PF, or
    b. calculate an average PF for the area ($[PF_1 + PF_2 + PF_3] \div 3$),
2. Calculate estimated effective precipitation by multiplying average monthly precipitation by 0.5 (i.e. calculate 50% of precipitation).
3. Subtract the monthly effective precipitation from the monthly plant water requirement calculated in #1. Results that are negative values are recorded as zero. This is the estimated amount of irrigation, in inches, each plant category will need in order to maintain acceptable landscape appearance and function.
4. For each plant category, multiply the inches of irrigation required by the square feet of each plant category. See #1 for guidance where plant-category specific square footage is not available.
5. Sum the products calculated in #4 and multiply it by 0.623.
6. Divide the product from #5 by 0.7. This is the annual irrigation demand for the landscape including an allowance for irrigation efficiency for water sources other than Trinity areas. For irrigation water taken, from Trinity portions of the aquifer, got to the next step.
7. Calculate a leaching fraction (LF) as described above, then multiply LF by the product calculated in #6. The answer is the total irrigation demand for users of the Trinity and other aquifer waters with high salinity.

The following example scenarios provided by District staff illustrate how the irrigation demand algorithm is applied to typical irrigation user categories.

<u>Example Residential Landscape Scenario</u>
Given:

- 13,432 sq. ft. (0.308 acres) of warm-season turf.
- 4,398 sq. ft. (0.1009 acres) of mixed landscape beds (native plants, shrubs, perennials).
- 30 small trees/large shrubs.

Reasonable Assumptions:

- All plants are established.
- Irrigation water is high quality so no leaching is required.
- The mixed landscape beds are interplantings of native plants, shrubs, and perennials so that they are irrigated simultaneously and are irrigated to satisfy the needs of the plant category in the mix with the highest irrigation demand so that these plant types receive adequate irrigation.
- The 30 small trees/large shrubs are 6-8 feet in diameter now but will be about 20 ft. in diameter when mature. In addition, 10 of the small trees/large shrubs are planted within a turf area, 10 are isolated individual plants with several feet between them and are mulched, and 10 are planted outside of turf as

a tall, 20-ft. wide screening element where much of their canopies will be in contact and at least 75% of the soil surface devoted to these plant will be covered by their canopies when they mature.

- Irrigation demand for the eventual mature landscape is needed (i.e. when small trees/large shrubs reach mature size).

Steps:

1. Identify plant categories present and their PF using Table 1.
    a. General Lawns, Golf Rough & Fairway (warm-season turfgrass): use monthly PF.
    b. Mixed Plantings (mixed landscape beds): Perennials have highest PF, so PF = 0.7.
    c. 10 small trees/large shrubs planted in turf area: no PF assigned and no irrigation demand estimated. (Plants' irrigation demand met by lawn irrigation.)
    d. 10 small trees/large shrubs, isolated plants: PF = 0.6
    e. 10 small trees/large shrubs, screen: PF = 0.6.
2. Define square footage devoted to each plant category from step 1.
    a. General lawn = 13,432.
    b. Mixed landscape beds = 4,398.
    c. Small trees/large shrubs planted in turf area = 0.
    d. 10 small trees/large shrubs, isolated plants: estimate irrigation requirement for expected mature diameter of 20 ft.
        i. Estimate mature canopy square footage as this determines potential irrigation requirement of landscape.
        ii. $Canopy\ Sq.Ft. = \pi \times r^2$ = 3.14 × (10 × 10) = 314 sf. per tree = 3,140 sf. for all 10 trees.
    e. 10 small trees/large shrubs, grown as a screen: calculate area occupied by mature plant canopies as this determines potential irrigation requirement of landscape.
        i. $Canopy\ Sq.Ft. = Length\ \times Width\ of\ planting$ = (20 ft. × 20) × 10 trees = 4,000 sf.
3. Calculate monthly water requirement as ETo_{month} × PF for each plant category for each month using data in Table 2.
4. Subtract 50% of average monthly rainfall (Table 3) from each monthly water requirement. This is the monthly irrigation demand.
5. Sum the monthly irrigation demand for each plant category and then multiply each sum by the square footage devoted to the respective plant category as defined in step 2.
    Lawn = 15.36 in. × 13,432 sf.
    Mixed Landscape Beds = 23.64 in. × 4,398 sf.
    Isolated Trees = 17.93 in.×3,140 sf.
    Tree Screen = 17.93 × 4,000 sf.
6. Sum all the values calculated in step 5: 206,316 + 103,969 + 53,000 + 71,720 **= 435,005.**
7. Multiply the result in step 6 by 0.623 to convert the units to gallons: 435,005× 0.623 = **271,008 gal.**
8. Divide the result in step 7 by 0.7 to account for irrigation distribution uniformity being less than perfect 271,008 ÷ 0.7**<u>= 387,154 gallons is the annual estimated irrigation demand</u>**.
9. Convert gallons to other desired units.
    a. Acre-Foot = Gallons ÷ 325,853, therefore:
    387,154 gal. ÷ 325,853 **<u>= 1.2 Acre-Feet is the annual irrigation demand for the landscape.</u>**

Example Golf Course Scenario

Estimating irrigation needs of golf courses requires estimation of square footage devoted to the different use and management elements (greens, tees, fairways, rough, practice range) found in a typical golf course because the intensity of management and expected turf performance vary among these elements and influence greatly by the amount of available soil water. It is recommended to use the average percentages of golf course acres devoted to specific elements that are found in Table 4 unless the District can obtain specific data from each golf course permitted for water use.

Given:

- 4,573,800 sq. ft. (105 acres; includes greens, tees, fairway, roughs, and driving range) of warm-season turf, over-seed with cool-season winter rye in fall.
- 1,306,800 sq ft (30 acres) of mixed landscape beds (native plants, shrubs, perennials) (Mixed Planting #1).
- 43,560 sq ft (1 acre) of annual flowers and ground cover (Mixed Planting #2).

Reasonable Assumptions:

- All plants are established, with the exception of the overseeded turfgrass areas.
- Irrigation water is high quality so no leaching is required.
- Overseeding covers all greens, tees, and fairways, and overseeding begins about October.
- Monthly PF's will be used for plant materials where available.
- The breakdown of golf course acres (square footage) by the use and management elements is as described in Table 4 below.
- The square footage of mixed landscape beds is equally divided among plant categories listed in the particular mix.

Steps:

1. Identify plant categories present and their PF using Table 1.
   a. Overseeded General Lawns and Golf Fairways: use monthly PF.
   b. Overseeded Golf Greens and Tees: use monthly PF.
   c. General Lawns, Golf Rough and Fairway (warm-season turfgrass): use monthly PF.
   d. Mixed Planting #1 of native plant, shrubs, perennials: calculate average PF of 0.5 as ([0.3 +0.6 + 0.7] ÷ 3 = 5.3.
   e. Mixed Planting #2 of annual flowers and groundcover: calculate average PF of 0.7 as ([0.8 + 0.6] ÷ 2 = 0.7.

2. Define square footage devoted to each plant category from step 1. Use Table 4 to estimate square feet of golf course's 105 acres devoted to each element.
   a. Overseeded fairways = 1,600,830 sf.
   b. Overseeded greens and tees = 228,690 sf.
   c. Rough = 2,744,280 sf.
   d. Mixed Planting #1 = 1,306,800 sf.

    e. Mixed Planting #2 = 43,560 sf.

3. Calculate monthly water requirement as ETo_{month} × PF for each plant category for each month using data in Table 2.
4. Subtract 50% of average monthly rainfall (Table 3) from each monthly water requirement. This is the monthly irrigation demand. Note that plant categories with PF's less than 0.6 have no irrigation requirement in some months because assumed precipitation (50% of average) meets or exceeds the water requirements (calculations not shown due to space considerations).
5. Sum the monthly irrigation demand for each plant category and then multiply each sum by the square footage devoted to the respective plant category that was defined in step 2.

    Tees and Greens: 27.9 in. × 228,690 sf. = 6,380,451
    Fairways = 21.67 in. × 1,600,830 sf. = 34,689,986
    Rough = 15.36 in. × 2,744,280 sf. = 42,152,140
    Mixed Planting #1 = 12.0 in × 1,306,800 sf. = 15,681,600
    Mixed Planting #2 = 23.64 × 43,560 sf. = 1,029,758

6. Sum all the values calculated in step 5 **= 99,933,935.**
7. Multiply the result in step 6 by 0.623 to convert the units to gallons **= 62,258,841 gal.**
8. Divide the result in step 7 by 0.7 to account for irrigation distribution uniformity being less than perfect **<u>= 88,941,201 gallons is the annual estimated irrigation demand</u>**.
9. Convert gallons to other desired units.

    a. Acre-Foot = Gallons ÷ 325,853, therefore:
    88,452,720 gal. ÷ 325,853 **<u>= 273 Acre-Feet is the annual irrigation demand for all 136 acres.</u>**

<u>Recommendations and Considerations for Information Required from Permittees</u>

- Define the square feet devoted to each of the plant type categories listed in Table 1. Rather than accepting "mixed landscape beds with annual flowers, perennials and shrubs" for instance, request the square feet dedicated to each of the plant categories in Table 1. Also, confirm whether plants with identical PF's can be irrigated independent of plants with different PF's. If plants from different PF categories are irrigated together, then one has the "mixed landscape planting" dilemma of setting a meaningful PF discussed above. Having this information will improve accuracy of irrigation demand estimates and will often benefit the applicant.
- Encourage or require that plants be grouped and irrigated in the landscape according to their water requirements according to the categories in Table 1. This is known as "hydrozoning". It makes irrigation management and estimating landscape irrigation demand more efficient, effective and accurate. When plants with different water requirements are mixed and irrigated by a common irrigation station or valve, some compromise is required when estimating and managing required irrigation.
- There is no need to differentiate whether woody plants are evergreen or deciduous or whether perennials have a dormancy period because there is no scientific information to determine different monthly or seasonal PF's for these plant categories.
- New plantings of non-turf landscape plants usually require more water than the PF's listed in Table 1, which is for established plants. Consider providing a PF of 0.9 for 3-6 months after new landscape areas

are planted if users can document the plantings. Turfgrass establishment typically requires at least 100% of ETo (PF ≥ 1.0) for a 4-8 weeks. Turf establishment could also be a situation where users could request additional water.

- When trees are listed as a plant type, determine if they are:
  - within a turf area.
  - mixed with other non-turf plants and what those plant categories are.
  - planted as isolated plants with perhaps mulch or bare soil around them but no other trees or plants growing under or around them.
- There is no need to estimate tree canopy diameter in mixed plantings of trees, groundcover, and/or shrubs. The PF is 0.6 for the square footage occupied by the entire plant mix.
- When trees are growing among plants from other PF categories from Table 1, the PF of the mix is most accurately set at the highest PF category in the mix. (see discussion above regarding trees in turfgrass plantings).
- Water requirements of isolated, immature trees will increase as their canopies expand to mature size. Water users can be asked to supply updated plant size estimates periodically, or the irrigation demand can be estimated assuming tree's mature size from the beginning. The latter would require some assumptions of mature tree canopy size based on the user's description, such as small trees = up to 10 ft. diameter, medium trees = 10-20 ft. diameter, and large trees = diameter more than 20 ft., or similar categories that are more appropriate.

Limitations of the Recommended Methodology

The recommended methodology for estimating irrigation demand is highly applicable to general landscapes. It can be applied to sports fields and golf courses, but its results may not be precise enough for high-end athletic facilities since there are no Kc's or PF's reported for these that the author is aware of. The methodology does not apply to any plant production operations, such as nurseries, greenhouses, sod farms, or commercial farms. There are sophisticated algorithms for many of these commodities that are beyond the scope of this report.

The Scope of Work for this report identified "ornamental plant production nurseries" as an irrigation use category to include in determining reasonable irrigation demand calculations. Based on the author's personal knowledge of ornamental production systems, and after reviewing the scientific literature on ornamental plant water requirements and assessing the variation in water quality for various waters in the aquifer, it became obvious that deriving an irrigation demand calculator for this potential irrigation user category would be very complicated and very different from a calculator for landscape irrigation demand. Developing a calculator for this user category requires a separate project, equal in scale to this one, and so it was deemed beyond the scope of this report.

Table 1. Recommended Plant Factor (PF) for Categories of Established Landscape and Garden Plants[z].

Plant Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
General Lawns, Golf Rough & Fairway - *Warm-season Turfgrass*	0.1	0.3	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.3	0.1
Sports Fields; Golf Greens & Tees - *Warm-season Turfgrass*	0.4	0.4	0.6	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.5	0.4
Overseeded General Lawns & Golf Fairways	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.6	0.6	0.8	.08	0.8
Overseeded Golf Greens & Tees	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8
General Lawns, Golf Rough & Fairway - *Cool-season Turfgrass*	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sports Fields, Golf Greens & Tees - *Cool-season Turfgrass*	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Annual Flowers	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Groundcovers	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Trees	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Shrubs	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Herbaceous Perennials	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Native Plants	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Vegetable Gardens	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Home Orchard *Deciduous*	0.1	0.3	0.6	0.7	0.8	1.0	1.0	1.0	1.0	0.8	0.3	0.1
Home Orchard *Evergreen*	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Mixed Plantings *Non-turf*	*PF is that of the plant category present with the highest PF, or the average PF of the plant categories present*											

[z]*Adapted from:* American Society of Agricultural and Biological Engineers, 2013; Austin Water, n.d.; Fipps, 2014; Green, 2005; Meyer et al., 1985; Snyder, 2014; Texas A&M AgriLife Extension, 2014. Values do not apply to any plant production operations, such as nurseries, greenhouses, sod farms, or commercial farms.

Table 2. Average ETo (inches) for Austin, TX[z].

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Austin	2.27	2.72	4.34	5.27	6.39	7.15	7.22	7.25	5.57	4.38	2.74	2.21	**57.51**

[z]Texas A&M AgriLife Extension, 2014.

Table 3. Average Precipitation (inches) for Austin, TX[z].

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Austin	2.11	2.41	2.05	3.01	4.38	3.46	2.05	2.23	3.38	3.35	2.28	2.46	**33.16**

[z]Texas A&M AgriLife Extension, 2014.

Table 4. Average Percentage of Golf Course Acres Devoted to Specific Elements[z].

Fairways	Greens and Tees	Rough (incl. Practice Range)
35	5	60

[z]Adapted from: Green, 2005; United States EPA, 2005.

Recommended Best Management Practices for Residential and Commercial Irrigation

The following irrigation Best Management Practices (BMP's) are recommended to maximize irrigation efficiency and effectiveness in residential and commercial landscapes. They are intended to supplement the practices the District currently requires of permittees as listed in User Conservation Plan, Form UCP-IRG (Barton Springs/Edwards Aquifer Conservation District, 2012).

- Design landscapes and irrigation systems so that plants with complimentary water requirements can be irrigated separately from plants with different water requirements.
- Limit irrigation frequency and apply enough water at each irrigation to rewet most of the plants' root zones.
- Avoid runoff. Implement cycle and soak irrigation scheduling. Deeper irrigation requires longer runtimes. Divide total required runtimes into multiple irrigation cycles about one hour apart on each irrigation day. For example, if 18-20 minutes of total runtime is needed to apply the desired amount of water, then then schedule 3 cycles that are 6 or 7 minutes each and about an hour apart.
- Design, maintain, and or retrofit the irrigation system so that it applies water uniformly. Spray and sprinkler systems should strive to have a distribution uniformity (DU) greater than 70%, and drip irrigation systems should have a DU of at least 85%.
- Adjust base irrigation schedules monthly.
- During drought, prioritize available irrigation to plants that are most difficult to replace and/or are most valuable to the landscape.

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