Making Sense of ET Adjustment Factors for Budgeting and Managing Landscape Irrigation

Proceedings of Irrigation Show and Education Conference. November 4-8, 2013, Austin, TX. pp. 369-379. Red Hook, NY: Curran Associates.

Dennis Pittenger and David Shaw

UC CE University *of* California
Agriculture and Natural Resources | Cooperative Extension

2013. Proc. of Irrigation Show and Education Conf., Nov. 4-8, 2013, Austin, TX, pp. 369-379. Red Hook, NY: Curran Associates.

Making Sense of ET Adjustment Factors for Budgeting and Managing Landscape Irrigation

Dennis Pittenger, Area Environmental Horticulturist
University of California Cooperative Extension
Los Angeles County/U.C. Riverside
U.C. Riverside Department of Botany and Plant Sciences
Riverside, CA 92521
dennis.pittenger@ucr.edu

David Shaw, Farm Advisor
University of California Cooperative Extension
San Diego County
151 E. Carmel Street
San Marcos, CA 92078

Abstract. *Landscape water budgeting and conservation are central to many urban development programs and codes, water purveyor delivery and pricing policies, and professional landscape irrigation management practices. These programs, policies, and practitioners often use various approaches to calculate and establish a site's water-conserving irrigation budget and irrigation schedules based in part on estimated local reference evapotranspiration (ET_o) data. These calculations can involve an assortment of ET_o adjustment factors associated with plant species, site characteristics, or other influences on how much water a landscape requires or should be allocated. Depending on the formula used, the adjustments to ET_o can be fixed, variable, or some combination. Science in landscape plant water requirements and plant ecology shows it is illogical to apply guesstimated user-selected ET_o adjustment factors for microclimate and plant density or to use a species-specific plant factor (PF) to adjust ET_o that are derived from non-scientific data bases. Rather, research shows that a distinct PF applies to each of the following plant type groups: turfgrass; trees, shrubs and groundcovers; annual flowers; herbaceous perennials; and desert plants. Except where there are microclimate influences that can be quantified scientifically to be significantly different from the location where ET_o is calculated, a landscape water requirement can be simply yet effectively estimated by applying just the appropriate research-based plant-type PF's, such as follows: Gallons of Water = ET_o (inches) × PF (fraction) × Landscape Area (square feet of plant type) × 0.62.*

Keywords: crop coefficient, evapotranspiration, plant factors, landscape coefficient, landscape water conservation, plant water requirements.

Background and Introduction

Many green building programs, water conservation programs, local development codes, and water conservation ordinances along with delivery and pricing policies of many water purveyors employ calculations using estimated local reference evapotranspiration (ET_o) data to establish climate-based maximum and conservation levels of landscape water requirements or allocations (California Department of Water Resources, 2009, 2010; Eastern Municipal Water District, 2013; U.S. Environmental Protection Agency, 2009, 2010; U.S. Green Building Council, 2009, 2013). Landscape water managers often follow a similar approach to estimate landscape water requirements, water budgets, or irrigation schedules for sites they oversee. Sometimes equations used by green building programs, development codes, and water purveyors to establish a maximum water allocation or water budget for a landscape use only arbitrary, predetermined ET_o adjustment factors of 0.45 to 1.0 (Eastern Municipal Water District, 2013; U.S. Green Building Council, 2013). More commonly, the formulae used by these entities and landscape water managers to derive landscape water requirements and budgets include the use of a plant factor (PF) or a crop coefficient (K_c) to adjust ET_o in order to account for the variability in water requirements among landscape plant species. Such an equation is:

$$\textbf{Gallons of Water} = ET_o \times PF \text{ or } K_c \times \textbf{Landscape Area} \times 0.62,$$

where:

- ET_o is inches of water for the time period of interest (day, week, month, year).
- PF or K_c are assumed by the user or taken from an accepted reference.
- Landscape Area is square feet of planted area.
- 0.62 is a unit conversion factor to result in gallons.

In many instances, the required equation goes further and substitutes a so-called landscape coefficient (K_L) in place of the PF or K_c value as a means of adjusting ET_o. The equation using K_L for calculating a water allocation, requirement, or budget of a landscape area for a given period of time is:

$$\textbf{Gallons of Water} = ET_o \times K_L \times \textbf{Landscape Area} \times 0.62.$$

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.

Although the K_L theory was conceived over 20 years ago and updated more recently (Costello, 1991; Costello et al., 2000), it has never been scientifically verified that the values produced by the K_L equation adjust ET_o to accurately and reliably 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 ET_o adds unscientific complexity that does not result in greater accuracy in estimating the amount of water a landscape requires to provide acceptable performance and function.

Plant Factors

Research has demonstrated that water requirements of landscape plants are effectively defined as the percentage of ET_o (Allen et al., 2005) required to maintain their acceptable appearance and intended landscape function (Pittenger et al., 2001; Shaw and Pittenger, 2004). The ET_o calculation assumes the following standard conditions for a hypothetical cool-season turfgrass reference surface: a uniform plant canopy growing in full sun that covers at least 75% of the soil surface and that governs how foliage connects to the atmosphere, uniformly adequate soil water, and plant water use that is tightly synchronized and linearly related with changes in ET_o (Allen et al., 2005). The ET_o algorithm was developed for agricultural crop production systems, and a crop's estimated requirement is the product of ET_o x a species-specific fraction that is the estimated depth of water the crop requires to provide optimum growth and yield. The species-specific fraction for this purpose is known as a crop coefficient (K_c), and it assumes all the standard conditions for calculating ET_o are present in the cropping system.

The ET_o x species-specific fraction algorithm has limited accuracy in estimating water needs of urban landscapes, however. The algorithm is not robust enough to account for the spatially and biologically complex mixes of turfgrass, woody, and herbaceous plants that comprise urban landscapes (St. Hilaire et al., 2008). These plant types differ in canopy architecture, plant structure, and leaf size in ways that do not conform to the standard conditions under which ET_o is calculated and defined. Water requirements of many non-turf landscape plant species are not tightly synchronized to ET_o and may respond non-linearly to climatic factors used to estimate ET_o (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 application amounts, rather than optimum growth and yield based on precise water application requirements.

Nevertheless, the approach of estimating landscape plants' water requirements as a percent of ET_o using an adjustment factor [plant factor (PF)] is rational, reasonable, scientific, and climate-based (Kjelgren et al., 2000; Snyder and Eching, 2006). This approach is sufficiently accurate and effective in estimating landscape water requirements based on a given plant palette. Understanding the limitations of ET_o x PF, however, is crucial to success when estimating landscape water requirements and managing landscape water for the range of different landscape plant types that occur.

Perhaps the mostly widely referenced source of species-specific PF values for landscape plants is the California-based Water Use Classifications of Landscape Species (WUCOLS) list (Costello and Jones, 2000), which refers to these values as a "species factor", K_s . The WUCOLS values for PF's range from <0.1 to 0.9, and it arbitrarily ranks PF values into ranges of high, medium, low, and very low water use. It is available online and provides a large number of specific PF's needed to fulfill the landscape water requirement and water budget calculations mandated in many water conservation ordinances in California (California Department of Water Resources, 2009, 2010). It also appears that PF's in WUCOLS are the basis for the PF data bases and ranges included in many other local and national green building and water conservation programs (Dukes, 2008; U.S. Environmental Protection Agency, 2009, 2010; U.S. Green Building Council, 2009, 2013). Unfortunately, the WUCOLS content is not scientific and is not research-based. The data can be unreliable when compared with research-based findings of landscape plant water needs (Martin et al., 2010; Oki and Reid, 2009; Pittenger et al., 2001, 2002, 2009; Shaw and Pittenger, 2004).

Turfgrass. Estimating water needs and managing irrigation of turfgrass as a percentage of ET_o (ET_o × PF) is a demonstrated effective approach because turfgrass swards closely mimic the standard conditions of ET_o estimation (Richardson et al., 2013; Devitt et al., 1992; Gibeault et al., 1990). Because turfgrass synchronizes well with ET_o and it is usually expected to have meaningful growth and yield (clippings), its species-specific water requirement as a fraction of ET_o is actually a K_c. The research findings indicate that the average K_c for cool-season turfgrass is 0.8 and the K_c for warm-season grasses is 0.6. These factors provide good quality general turf, but are not adequate for turf grown in sports fields or golf courses.

Trees, Shrubs, Groundcovers. The ET_o x PF approach has been shown to be an appropriate means of estimating water required ET_o by landscape groundcovers and shrubs to provide acceptable landscape performance (Beeson, 2012; Pittenger et al., 2001; Shaw and Pittenger, 2004; Staats and Klett, 1995; Sun et al., 2012). The approach can also be successful in estimating the amount of water required for landscape tree species to provide acceptable performance in most landscape settings, but a tree PF comes with somewhat less reliability (Costello et al., 2005; Pannkuk et al., 2010; Pittenger et al., 2002 and 2009).

A common finding among these studies is that tree, shrub, and groundcover species growing in arid climates with a relatively dry growing season (e.g. areas with Mediterranean climates and many portions of the southwestern and intermountain west U.S.) typically need water in the amount of about 50% of ET_o during the growing season in order to provide acceptable appearance and function. Thus, a PF of 0.5 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. However, a PF of 0.7 is more appropriate for woody plants and groundcovers growing in humid climates with relatively high summer rainfall, or for woody plants and groundcovers native to wet habitats (including riparian species in arid climates). Differences in water needs of an individual woody plant species in response to climate factors, particularly humid air, are less pronounced where sustained drought (plant-damaging water deficit) is not common and plant density is high (Jung et al., 2011).

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 so it responds non-linearly to ET_o (Daudet et al., 1999; Goldberg and Bernhofer, 2008; Jarvis and McNaughton, 1986). Somewhat analogous to an electrical circuit breaker, this response is most pronounced in regions where the air is very dry (high ET_o) during the growing season and plant species respond by reducing transpiration at high ET_o (Schulz, 2003; Tardeiu and Simmoneau, 1998). For isolated urban trees, the plant's transpiring leaf area controls the volume of water required, so the $ET_o \times PF \times$ Landscape Area approach must be modified to include an estimate of the transpiring leaf area (Devitt et al., 1994; Montague et al., 2004). In these situations, the plant factor of 0.5 or 0.7 still apply, but the procedure described below in "Landscapes with Incomplete Canopy Cover" should be followed to estimate water requirement of the landscape area.

Annual Flowers. Published scientific ET_o-based water requirement data is presently unavailable for annual flowering plant species. These plants have shallow root systems and are generally observed to have limited drought tolerance or resistance. Since they are expected to provide dramatic color and impeccable aesthetic appearance, a reasonable PF for their estimated water requirement is 0.8.

Herbaceous Perennials. Published scientific ET_o-based water requirement data is very limited for herbaceous perennial plants. Data available for a few herbaceous perennial plants is largely from species adapted to dry climates. It shows considerable variability among the few species evaluated, but it appears the species evaluated perform acceptably at 40-60% of ET_o (Oki and Reid, 2009; Reid et al, 2012; Sun et al, 2012). Since these species are usually expected to provide highly attractive flowering and/or foliage in the landscape, and most are adapted to mesic or moist habitats, a plant factor of 0.7 is reasonable for this plant group to assure performance expectations are met. See the discussions below for instances where an herbaceous perennial is a desert or native plant.

Desert Plants. There is no published scientific ET_o-based water requirement data for desert plants, and water requirements and PF's of desert plants are difficult to estimate. Most desert plants combine traits to reduce leaf temperature and stomatal opening that minimize transpiration, together with thick, evergreen leaves. Through various combinations of traits, these plants survive on very limited rainfall in their native climate, but they do not necessarily provide acceptable landscape appearance and function with this amount of water. The key to understanding desert plants is that most are perennials and shrubs, but few trees: the ecological answer is that trees have more leaves and so require more water than is available in desert habitats. A plant factor of 0.3 represents the estimated water required to ensure this plant group provides acceptable landscape performance.

Native Plants. Specifying a plant factor for native plants is difficult because native plants are by definition adapted to a specific region and climate. Published ET_o-based water requirement data for native plants is very limited and addresses largely plants native to Mediterranean (low summer rainfall) climates (Oki and Reid, 2009; Reid et al, 2012). Native perennial plants, regardless if they are woody or herbaceous, survive in landscapes with normal precipitation once they are established when grown in their native climate range. They may not provide acceptable landscape performance in such situations, however. Lacking significant data, it is reasonably estimated that PF's of native plants depend the plant type group presented above that a given species best fits.

Landscapes with Incomplete Canopy Cover. The $ET_o \times PF$ approach is most applicable in landscapes where plant canopy covers at least 75% ET_o of the soil surface and the plants are watered uniformly by irrigation or precipitation. In landscape plantings with less than 75% canopy coverage, such as newly planted landscapes where plant canopies are small and immature or established landscapes with widely-spaced isolated plant specimens, water needs become that of the individual plant, as discussed above. Plants in such landscapes are ideally drip irrigated based on volume of applied water rather than depth. The PF and uniform water application to the entire landscape area are less important than the size of the canopy (Beeson, 2010, 2012; Sun et al., 2012). These situations dictate estimating the canopy size (or total leaf area, which is difficult) of individual plants and then applying the appropriate PF.

The estimated PF for an irrigation zone or similar grouping of plants with similar water requirements and less than 75% canopy cover can be effectively adjusted by multiplying the PF by the percent canopy cover for the zone. Here, plant and landscape water requirements are estimated by multiplying the PF by the area of the crown projection of each plant to arrive at a volume of water:

$$\textbf{Gallons of Water} = ET_o \times PF \times (\text{Canopy Radius}^2 \times 3.14) \times 0.62.$$

Where the plants are widely spaced but have uniform canopy projections the average individual plant canopy cover area can be multiplied by the number of plants to obtain total canopy area.

Density Factor

A landscape density factor (K_d) included in the calculation of a K_L allows the user to apply a value usually from 0.5 to 1.3. To account for plantings that have incomplete canopies, a K_d value <1.0 is applied, and for plantings with layered or "closely spaced" canopies a K_d value >1.0 is applied (Costello et al., 2000; U.S. Environmental Protection Agency, 2009). The ET_o estimate assumes at least 75% canopy cover (closely spaced plant canopies), so applying a K_d value >1.0 is not defensible. When the canopy cover is <75%, ecological science supports following the approach outlined above under "Landscapes with Incomplete Canopy Cover" rather than applying a guesstimated ET_o adjustment via a K_d between 0.5 and 0.99. A layered landscape canopy, as when groundcover is grown under a tree canopy, does not significantly increase the water demand of the planting as the K_d adjustment in K_L presumes. This is because plant water use, and thus ET_o, are influenced most by the amount of solar radiation (sunlight) reaching the foliage and the exposure leaves have to the atmosphere; in layered canopies little light reaches understory foliage which is also highly buffered from the atmosphere, so the water use of the understory is negligible. Thus, K_d would not be >1.0 in these situations based on the ET_o algorithm and plant ecology principles.

Microclimate Factor

A landscape microclimate factor (K_{mc}) included in the calculation of a K_L allows the user to apply a value from 0.5 to 1.4 to account for plantings that experience extreme meteorological conditions, such as extreme reflected heat, persistent windy conditions, or shade (Costello et al., 2000; U.S. Environmental Protection Agency, 2009). Since an ET_o accounts for variations in meteorological factors affecting plant water use, applying an additional ET_o adjustment factor via K_{mc} is appropriate only in situations where one or more meteorological factors affecting a landscape are persistently and significantly different from those present at the location where ET_o is estimated. This could include constant daily high wind or continuous shade on a portion of a landscape cast by a tall building, for example.

There is no simple means for a user to effectively guesstimate a K_{mc} adjustment factor, however. The influence that microclimate conditions have on landscape plant water requirements can be empirically estimated over a considerable period of time. Alternatively, biometeorology principles and instrumentation can sometimes be employed to estimate the actual effect these extreme meteorological parameters have on ET_o, and then a specific adjustment can be made to the equation that calculates ET_o (R. L. Snyder, personal communication). Indeed, there are examples where use of meteorological instrumentation has been used to successfully modify ET_o estimates when locally persistent high wind conditions occur that are different than the wind occurring at the ET_o estimation site (R. L. Snyder, personal communication). This approach is scientifically valid and superior to applying a guesstimated K_{mc} of 0.5 to 1.4 and using the K_L equation to adjust ET_o. However, the actual effect certain extreme meteorological factors like reflected heat and shade actually have on the amount of water required by landscape plants to provide acceptable performance and function has not been determined scientifically, so the weighting of a microclimate adjustment to ET_o remains theoretical.

Conclusions

The ET_o algorithm has serious limitations in estimating the water requirements for non-turf landscape plants and entire mixed landscape plantings because it is not robust enough to account for the spatial and biological complexity that comes with urban landscapes. However, it is indefensible to apply arbitrary guesstimated adjustment factors K_{mc} and K_d to calculate a K_L, and/or adjust ET_o with a K_s or PF that is derived from non-scientific data bases such as WUCOLS. Such ET_o adjustment approaches are scientifically invalid, and they provide a false sense of precision and effectiveness while complicating the calculations for estimating landscape water requirements. Unfortunately, many of the green building and landscape water conservation programs and ordinances across the U.S. have adopted these approaches, so the merit and effectiveness of these measures in conserving water are questionable. Science in landscape plant water requirements and plant ecology suggest PF's for landscape plants are dependent primarily on what general plant type a given species fits, and ET_o can be simply and accurately adjusted to estimate landscape water requirements using these generalized plant-type PF's.

Acknowledgement

We thank Professor Roger Kjelgren, Utah State University Plants, Soils and Climate Department for providing valuable input to this paper.

References

Allen, R. G., I. A. Walter, R. L. Elliott, T. A. Howell, D. Itenfisu, M. E. Jensen, R. L. Snyder (eds.). 2005. ASCE standardized reference evapotranspiration equation. Reston, VA: American Society of Civil Engineers.

Beeson, R. C., Jr. 2010. Modeling actual evapotranspiration of *Viburnum odoratissimum* during production from rooted cuttings to market size plants in 11.4-L containers. HortScience 45:1260-1264.

Beeson, R. C., Jr. 2012. Development of a simple reference evapotranspiration model for irrigation of woody ornamentals. HortScience 47: PS 264-268.

California Department of Water Resources. 2009. Model Water Efficient Landscape Ordinance. Viewed June 17, 2013 at: http://www.water.ca.gov/wateruseefficiency/landscapeordinance.

California Department of Water Resources. 2010. Status of adoption of efficient landscape ordinances. Viewed June 17, 2013 at: http://www.water.ca.gov/wateruseefficiency/docs/LandscapOrdinanceReport_to_Leg-4-22-2011.pdf.

Choudhury, B. and J. Monteith. 1986. Implications of stomatal response to saturation deficit for the heat balance of vegetation. Agric. Meteor. 36:215-225.

Costello, L. R. 1991. Estimating water requirements of landscape plants: The landscape coefficient method. Oakland: University of California Division of Agriculture and Natural Resources Publication 21493.

Costello, L. R., J. R. Clark, and N. P. Matheny. 2000. Estimating irrigation water needs of landscape plantings in California: the landscape coefficient method. Sacramento: California Department of Water Resources. Available at: http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf.

Costello, L. R. and K. S. Jones. 2000. WUCOLS III (Water Use Classification of Landscape Species). Sacramento: California Department of Water Resources. Available at: http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf.

Costello, L. R., K. S. Jones, and D. D. McCreary. 2005. Irrigation effects on the growth of newly planted oaks (*Quercus* spp.) J. Arboriculture 31(2): 83-88.

Daudet, F. A., X. Le Roux, H. Sinoquet, and B. Adam. 1999. Wind speed and leaf boundary layer conductance variation within tree crown: Consequences on leaf-to-atmosphere coupling and tree functions. Agricultural and Forest Meteorology 97(3):171-185.

Devitt, D.A., R.L. Morris, and D.C. Bowman. 1992. Evapotranspiration, crop coefficients, and leaching fractions or irrigated desert turfgrass systems. Agron. J. 84:717-723.

Devitt, D.A., R.L. Morris, and D.C. Bowman. 1994. Evapotranspiration and growth response of three woody ornamental species placed under varying irrigation regimes. J. Amer. Soc. Hort. Sci. 119:452-457.

Dukes, M. D. 2008 (rev. 2012). LEED for homes: explanation of the landscape irrigation budget calculation for Florida. Gainesville: University of Florida Cooperative Extension Service, IFAS Publication AE441. Available at: http://edis.ifas.ufl.edu.

Eastern Municipal Water District. 2013. Water budgets and tiered rates. Viewed Sep. 3, 2013 at: www.emwd.org.

Gibeault, V.A., S.T. Cockerham, J.M. Henry, and J. Meyer. 1990. California turfgrass: It's use, water requirement and irrigation. Calif. Turfgrass Cult. 39:1-9.

Goldberg, V. and Bernhofer, C., 2008. Testing different decoupling coefficients with measurements and models of contrasting canopies and soil water conditions. Ann. Geophys. 26(7): 1977-1992.

Jarvis, P.G. and K. G. McNaughton. 1986. Stomatal control of transpiration: scaling up from leaf to region. In: A. MacFayden and E. D. Ford (eds.) Advances in ecological research 15:1-49. London: Academic Press.

Jung, E. Y., D. Otieno, B. Lee, J. H. Lim, S. K. Kang, M. W. T. Schmidt, J. Tenhunen. 2011. Up-scaling to stand transpiration of an Asian temperate mixed-deciduous forest from single tree sapflow measurements. Plant Ecology. 212:383-395.

Kjelgren, R., L. Rupp, and D. Kilgren. 2000. Water conservation in urban landscapes. HortScience 35:1037-1043.

Martin, E. C., U. Schuch, J. Subramani, and T. Mahato. 2010. Crop coefficients for Arizona landscape trees. Paper IRR10-9084, 5th National Decennial Irrigation Conf. Proc., 5-8 Dec. 2010, Phoenix Convention Center, Phoenix, AZ USA.

Montague. T., R. Kjelgren, R. Allen, and D. Webster. 2004. Water loss estimates for five recently transplanted tree species in a semi-arid climate. J. Environ. Hort. 22:189-196.

Oki, L. R. and K Reid. 2009. Irrigation and climate zone trial of UC Davis Arboretum All-Stars - 2008-2009. http://ccuh.ucdavis.edu/industry/arboretum/AllStars%20trials%20results_2008_2009_final.pdf. Viewed June 17, 2013.

Pannkuk, T. R., R. H. White, K. Steinke, J. A. Aitkenhead-Peterson, D. R. Chalmers, and J. C. Thomas. 2010. Landscape Coefficients for Single- and Mixed-species Landscapes. HortScience: 45:1529-1533.

Pittenger, D. R., D. A. Shaw, D. R. Hodel, and D. B. Holt. 2001. Responses of landscape groundcovers to minimum irrigation. J. Environmental Hort. 19(2):78-84.

Pittenger, D. R., W. E. Richie, and D. R. Hodel. 2002. Performance and quality of landscape tree species under two irrigation regimes 1996-2000. Final Report to Metropolitan Water District of Southern California. 92 pp.

Pittenger, D. R., A. James Downer, D. R. Hodel, and M. Mochizuki. 2009. Estimating water needs of landscape palms in Mediterranean climates. HortTechnology 19(4): 700-704.

Reid, K., L. R. Oki, D. W. Fujino, and E. Zagory. 2012. Final report: Sartoga Horticultural Research Endowment 2011-2012. http://ccuh.ucdavis.edu/industry/arboretum/2012results. Viewed June 17, 2013.

Richardson, M. D., D. E, Karcher, K. Hignight, and D. Hignight. 2012. Irrigation requirements of tall fescue and Kentucky bluegrass cultivars selected under acute drought stress. Applied Turfgrass Science Issue: May Pages: ATS-2012-0514-01-RS.

St. Hilaire, R., M. Arnold, D. C. Wilkerson, D. A. Devitt, B. H. Hurd, B. J. Lesikar, V. I. Lohr, C. A. Martin, G. V. McDonald, R. L. Morris, D. R. Pittenger, D. A. Shaw, and D. F. Zoldoske. 2008. Efficient water use in residential urban landscapes. HortScience 43: 2081-2092.

Schultz, H.R., 2003. Differences in hydraulic architecture account for near-isohydric and anisohydric behaviour of two field-grown *Vitis vinifera* L. cultivars during drought. Plant, Cell & Environment 26(8): 1393-1405.

Shaw, D. A. and D. R. Pittenger. 2004. Performance of landscape ornamentals given irrigation treatments based on reference evapotranspiration. In: Snyder, R. L. (ed.), Proc. IVth International Symposium on Irrigation of Horticultural Crops, Davis, CA, Sep. 1-6, 2003. ISHS Acta Hort. 664: 607-613.

Snyder, R. L. and S. Eching. 2006. Urban landscape evapotranspiration, Vol. 4 Reference Guide. In: California Water Plan Update 2005. Sacramento: California Department of Water Resources Bull. 160-05.

Staats, D. and J. Klett. 1995. Water conservation potential and quality of non-turf groundcovers versus Kentucky bluegrass under increasing levels of drought stress. J. Environ. Hort. 13:181-185.

Sun, H., K.J. Kopp, and R. Kjelgren. 2012. Water efficient urban landscapes – integrating different water use categorizations and plant types. HortScience 47(2):254-263.

Tardieu, F. and T. Simonneau. 1998. Variability among species of stomatal control under fluctuating soil water status and evaporative demand: modeling isohydric and anisohydric behaviours. Journal of Experimental Botany, 49 (Special Issue): 419-432.

U.S. Environmental Protection Agency. 2009. WaterSense water budget approach. Viewed Sep. 5, 2013 at: http://www.epa.gov/WaterSense/water_budget/.

U.S. Environmental Protection Agency. 2010. WaterSense water budget tool version 1.01. Viewed Sep. 5, 2013 at: http://www.epa.gov/WaterSense/water_budget/.

U.S. Green Building Council. 2009. LEED reference guide for green building operations and maintenance for institutional buildings. Washington, D.C.: U.S. Green Building Council. Viewed Sep. 5, 2013 at: http://www.gbci.org.

U.S. Green Building Council. 2013. LEED for Homes Rating System January 2008, Revised April 2013. http://www.usgbc.org/sites/default/files/LEED%20for%20Homes%20Rating%20System_updated%20April%202013.pdf. Viewed Sep. 5, 2013.