Investigation and Development of Methods to Determine Urban Landscape Irrigation for Planning and Permitting in Central Florida

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February 28, 2007

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1. Introduction

According to a turfgrass industry survey, 4.5 million acres of turf existed in Florida in 1991-92. Industry sales and services amounted to approximately $7 billion during that time (Hodges et al., 1994). In 2003, Morris estimated that there were 50 million acres of turf in the U.S., with approximately 67% found in home lawns Florida has the second largest withdrawal of ground water for public supply in the U.S. (Solley et al., 1998). Estimates in Florida indicate that 30-70% (FDEP, 2001) of residential per capita water use is for landscape water use. Landscapes ordinances and water conservation rebate programs from Texas, Arizona and California promote the use of drought resistance, water conserving species in urban landscapes and to reduce the amount of landscape area planted to turfgrass. However, little evidence is available to document the impacts of these ordinances and programs on reductions in water use (Havlak, 2003).

In agriculture, irrigation water requirements are well established for many crops. In urban landscapes, which are composed of diverse, disjointed spaces, irrigation requirements have been determined for turfgrasses but not for most landscape species (Costello et al., 2000). However, water requirements for urban landscapes is improving rapidly as several research groups have measured the water requirements of many new species of water conserving grasses (Brown, 2003). Landscape evapotranspiration (ET_L) can be estimated by multiplying the reference evapotranspiration (ET_o) and a “landscape coefficient” (K_L) factor that adjust for differences between the vegetation and the reference surface, in the so called Landscape Coefficient Methodology (LCM) (Costello et al., 2000). Another approach quite similar to the LCM but which includes an additional stress and evaporation coefficient is presented by Eching and Snyder (2005). The ET_L formula is basically the same as the ET_c formula, except that a landscape coefficient (K_L) has been substituted for the crop coefficient (K_c). Still, the LCM needs to be validated (Havlak, 2003).

At this time data do not exist in Florida for these types of systems to develop K_L factors that can be used with confidence for water permitting and planning. Furthermore, the scientific community is not in agreement if these factors can be developed and if so the best way to do so. Therefore, the objective of the present work is:

> To conduct a literature review of turfgrasses and ornamental plants, as well as methodologies available to construct a landscape coefficient to determine a landscape evapotranspiration

over heterogeneous communities of plants in urban areas in the South West Florida Water Management District (SWFWMD).

2. Turfgrass overview

The most recent estimation of the turf area in the USA was presented by Milesi et al. (2005). They reported a total turfgrass area estimated as 163,800 km^2 (+/- 35,850 km^2 for the upper and lower 95% confidence interval bounds), which include all residential, commercial, and institutional lawns, parks, golf courses, and athletic fields. The study was based on the distribution of urban areas from satellite and aerial imagery. If considering the upper 95% confidence interval bound, that would represent 199,679 km^2 and this estimate reasonably compares to the estimates of Morris (2003) if considering the upper confidence interval bound who estimated 50 million of acres (202,430 km^2) of turf in the U.S. on home lawns (66.7%), golf courses (20%), and sport fields, parks, playgrounds, cemeteries and highway roads (13.4%).

Turfgrass provides functional (i.e. soil erosion reduction, dust prevention, heat dissipation, wild habitat), recreational (i.e., low cost surfaces, physical and mental health) and aesthetic (i.e. beauty, quality of life, increased property values) benefits to society and the environment (Fender, 2006; King and Balogh, 2006). However, critics of grass maintain it not only wastes time, money and resources, but even worse, that efforts to grow grass results in environmental pollution. Critics recommend the total replacement with what are termed ‘native plants’ (Fender, 2006).

Turfgrasses have been utilized by humans to enhance their environment for more than 10 centuries and, for those individuals or group that debate the relative merits of any single landscape material, the complexity and comprehensiveness of these environmental benefits that improve our quality-of-life are just now being quantitatively documented through research (Beard and Green, 1994).

2.1 Turfgrass classification

Turfgrass breeding during the last 25 years had increased emphasis on developing new varieties which require less water, are more tolerant to heat, cold, or salinity stresses or improved disease or insect resistance. In the past 20 years, many new grasses have been tested (Kenna, 2006). In addition to the new varieties, effective screening techniques were developed for heat and cold hardiness, resistance to salinity, root length, tolerance to low clipping height, mowing, seed production, and drought tolerance.

Turfgrasses are classified into two groups based on their climatic adaptation: warm-season grasses, adapted to tropical and subtropical areas, and cool-season grasses which are adapted to temperate and sub-arctic climates (Huang, 2006). Warm-season grasses use significantly less water than cool-season species. Cool season grasses, on the other hand, are generally more susceptible to moisture stress than warm season grasses (Duble, 2006). Buffalograss, for example, can survive long periods of severe moisture stress, whereas bluegrass would be killed by the same conditions. This difference in water use derives from changes in the photosynthetic process that occurred in grasses evolving under hot, dry conditions. These changes, which include modifications to biochemical reactions and internal leaf anatomy, greatly enhance the photysynthetic efficiency of warm-season species and help reduce water use. Increased photosynthetic efficiency means that plants can maintain high levels of carbohydrate production and continue to grow even when stomates are partially closed. This partial closure of the stomates slows the plant’s water use. Cool-season grasses cannot maintain enough carbohydrate production to maintain growth unless their stomates are nearly wide open. When water is limited, transpiration rates are generally higher than those of warm-season grasses (Gibeault et al., 1989).

Cool-season grasses, which are used in lawns, sports fields, golf courses, and roadsides include *Festuca* L., *Poa* L., *Agrostis* L., and *Lolium* L. Warm-season turfgrasses include *Cynodon* L.C. Rich, *Buchloë* Engelm., *Zoysia* Willd., *Paspalum* L., *Eremochloa ophiuroides* [Munro] Hack. and *Stenotaphrum secundatum* [Walt.] Kuntze (Beard, 1994).

Next, we describe some turfgrass species that are grown throughout the southeastern USA for home lawns, golf courses, athletic fields, right-of-ways, and various other applications (Kenna, 2006; Busey, 2002; Trenholm and Unruh, 2002; Ruppert and Black, 1997):

St. Augustinegrass [*Stenotaphrum secundatum* (Walt) Kuntze]: St. Augustinegrass is a warm-season grass which some authors believe that this species is native from Africa (Kenna, 2006) or from both, the Gulf of Mexico and the Mediterranean (McCarty and Cisar, 1997). It is well adapted to the world’s warm, humid regions and, therefore, to a wide range of Florida conditions. It produces a dark to blue-green dense turf that is well adapted to most soils and climatic regions in Florida. Of all the warm season grasses, it is the least cold tolerant and has the coarsest leaf texture. It prefers well-drained, humid and fertile soils that are not exposed to long period of cold weather to produce an acceptable quality lawn.

Disadvantages: It recovers poorly from drought. There are shade tolerant cultivars existing (e.g. Seville, Delmar, Jade, and possibly Palmetto). It is susceptible to pest problems, like chinch bug, which is considered the major insect pest of this species. It wears poorly and some varieties are susceptible to cold damage.

Zoysiagrass (*Zoysia spp*.): Zoysiagrass is a warm-season grass that spreads by rhizomes and stolons to produce a very dense, wear-resistant turf. These grasses have been developed and are better adapted to a broader range of environmental conditions. It is believed that several species and varieties were introduced from the Orient to the United States. There are three major species of Zoysiagrass suitable for turf including Japanese lawngrass (*Z. japonica*), mascarenegrass (*Z. tenuifolia*), and manilagrass (*Z. matrella*). Their slow growth makes them difficult to establish; however, this can be a maintenance advantage because mowing is needed infrequently. Zoysiagrass is adapted to a wide variety of soils, has good tolerance to shade and salt spray, and provides a dense sod which reduces weed invasion. It is also stiff to the touch and offers more resistance than bermudagrass.

Disadvantages: Zoysiagrass is slow to establish because it must be propagated vegetatively. All zoysias form a heavy thatch which requires periodic renovation. There is a high fertility requirement and need for irrigations to maintain green color. These grasses are susceptible to nematodes, hunting billbugs and several diseases. It tends to be shallower rooting and is weakened when grown in soils low in potassium level.

Bahiagrass (*Paspalum notatum*): Bahiagrass is a warm-season grass that was introduced from Brazil in 1914 and used as a pasture grass on the poor sandy soils of the southeastern United States. The ability of bahiagrass to persist on infertile, dry soils and resistance to most pests has made it increasingly popular with homeowners. It can be grown from seed which is abundant and relatively inexpensive. It develops an extensive root system which makes them one of the most drought tolerant lawngrasses and it has fewer pest problems than any other Florida lawngrass. It is easily recognized by the characteristic "Y" shape of its seedhead, as well as its stoloniferous growth habit.

Disadvantages**:** Due to the tough leaves and stems, it is difficult to mow. It can be a very competitive and unsightly weed in highly maintained turf. It is not well suited for alkaline and saline soils.

Bermudagrass (*Cynodon dactylon*): Bermuda is a medium- to fine-textured warm- season turfgrass that spreads by rhizomes and stolons. Also called wiregrass, is planted throughout Florida primarily on golf courses, tennis courts and athletic fields. Bermudagrass is native to Africa where it thrived on fertile soils. Today, most of the bermudagrasses used for turf in Florida are hybrids of two different *Cynodon* species: *C. dactylon* and *C. transvaalensis*. It produces a vigorous, light to dark green, dense turf that is well adapted to most soils and climatic regions in Florida. It has excellent wear, drought and salt tolerance and is good choice for ocean front property, and it is competitive against weeds.

Disadvantages**:** Bermudagrass has a number of cultural and pest problems and therefore, will need a higher level of maintenance inputs than most other grasses and pesticides applications to control insects. In central and north Florida, bermudagrasses become dormant in cold weather. Overseeding in fall with ryegrass is a common practice to maintain year-round green color. Bermudagrasses have very poor shade tolerance and should not be grown underneath tree canopies or building overhangs. It can also be a very invasive and hard to control weed in some turf settings.

Centipedegrass [*Eremochloa ophiuroides* (Munro) Hack]: Centipedegrass is a warm-season turf that is adapted for use in low maintenance situation. It was introduced into the United States from southeastern Asia. It is well adapted to the climate and soils of central and northern Florida. It has a slow growing pattern, so it is not very competitive against weeds. It is adapted to heavy soils, performs poorly in deep sands (probably due to sting nematodes) but is adapted to infertile soils; maintenance requirements are low when compared to other turfgrasses. This grass is moderately shade-tolerant.

Disadvantages**:** Centipedegrass is highly susceptible to damage from nematodes. It exhibits iron chlorosis and produces a heavy thatch if over fertilized. It does not tolerate traffic, compaction, high pH, high salinity, excessive thatch, drought, or heavy shade.

Seashore paspalum (*Paspalum vaginatum*): Seashore paspalum is a warm-season grass that is native to tropical and sub-tropical regions world-wide. It was introduced into de United States around the world through maritime travel and it has since spread along coastal areas of the southeastern US, thriving in the salt-affected waters and environments of these areas.

This grass produces a high quality turfgrass with relatively low fertility inputs. While it has initially been marketed for golf course and athletic field use, it has good potential for use in the home lawn market as well. The advantages for use of seashore paspalum in a home lawn situation include: excellent tolerance to saline water, excellent wear tolerance, good tolerance to reduced water input, relatively low fertility inputs needed to produce a dense, dark green lawn, few insect disease problems in most environments, tolerates wide pH range, tolerates long periods of low light intensity and produces a dense root system.

<u>Disadvantages</u>: This grass has poor shade tolerance; it performs best when mowed at one to two inches; it is sensitive to many common herbicides and may be injured or killed by their use. Seashore paspalum tends to become thatchy, particularly when over fertilized and over-irrigated.

2.2 Importance of the root zone in turfgrasses

Grasses have a fibrous root system, composed primarily of fibrous roots after the first 6 to 8 weeks following germination and, although rooting depth of various grass species differs, the greatest proportion of roots generally occurs in the upper 12 cm of soil (DiPaola et al., 1982). However, it has been reported that warm-season grasses like ‘Tifway’ hybrid bermudagrass roots reached 75-cm soil depth compared with cool season grasses growing in 37-cm diameter PVC column lysimeters (Fagerness et al., 2004). In another study performed by Bowman et al. (2002), both “Tifway’ and common bermudagrasses and St. Augustinegrass reached 70 cm depth compared to other two warm-season grasses (Centipedegrass and both ‘Meyer’ and ‘Emeral’ Zoysiagrasses) growing on column lysimeters. These grasses were lightly irrigated twice daily during the first 4 weeks following planting. They also found that there were no significant differences in root length density (RLD) among species at the 5- and 18-cm depths (Table 1). At soil depths >30 cm, St. Augustinegrass and the bermudagrasses had significantly higher RLD than the other species; however, in all cases, over 80% of all roots were found in the top 30 cm of soil.

Table 1: Root length density with soil depth for six warm season grasses determined at conclusion of study (after Bowman et al., 2002).

	Root length density					
	Soil depth, cm (in)					
Species	4-6 (1.6-2.4)	17-19 (6.7-7.5)	29-31 (11-12)	42-44 (16-17.3)	54-56 (21– 22)	67-69 (26-7)
			cm cm^{-3}			
Centipedegrass	7.8	2.7	0.3d§	0.3c	0.0c	0.0
St. Augustinegrass	8.1	2.5	1.3bc	1.3ab	**0.9ab**	0.2
'Meyer' zoysiagrass	7.1	1.1	0.3d	0.1c	0.0c	0.0
'Emerald' zoysiagrass	7.7	2.0	0.8cd	0.4bc	0.0c	0.0
'Tyfway' bermudagrass	7.1	3.6	2.4a	1.7a	**1.3a**	0.2
Common bermudagrass	4.0	2.1	1.5bc	1.2ab	0.3c	0.0

§Values within a column followed by the same letter are not statistically different (LSD, P≤0.05).

2.2.1 Effect of irrigation treatments in rooting depth

Of most interest to turfgrass managers is the result of the irrigation treatments: turfgrass quality. In a study using warm-season grasses common bermudagrass, Centipedegrass, zoysiagrass and seashore paspalum, Huang et al. (1997) tested four soil moisture treatments: (i) control, water content in the entire soil profile kept at field capacity; (ii) upper 20-cm soil drying while the lower 40-cm segment was maintained at field capacity, (iii) upper 40-cm soil drying, while the lower 20-cm segment was kept at field capacity and (iv) a rewatering treatment. AP14 and PI paspalum (the former a Floridian ecotype), and TifBlair Centipedegrass produced higher total root length (TRL) in the entire soil profile. Rewatering caused further increases of the three previous ecotypes. TRL declined significantly with the soil drying treatments for Zoysiagrass and bermudagrass, but paspalum ecotypes were not affected by the treatments. Youngner et al. (1981) reported that for St. Augustinegrass and common bermudagrass, two warm-season grasses, neither quality nor rooting depth was affected by five irrigation treatments: (i) a control based on common practice; (ii) irrigation based on evapotranspiration from a pan, and (iii) three automatic irrigations activated by tensiometers at different settings. However, the cool-season grass experiment (using tall fescue and Kentucky bluegrass) quality was affected.

Some of the root characteristics associated with drought resistance included enhanced water uptake from deeper in the soil profile, root proliferation into deeper soil layers and persistent root growth in the drying surface soil (Huang et al., 1997). Other studies also recommended the use of infrequent irrigation for better turfgrass quality (Bennett and Doss, 1960; Zazueta et al., 2000), because excessive irrigation, which keeps the root system saturated with water, is also harmful to the lawn (Trenholm et al., 2001).

2.3 Evapotranspiration (ET), reference evapotranspiration (ET_o) and crop coefficient (K_c)

Definition: Evapotranspiration (ET) represents the loss of water from the earth's surface through the combined processes of evaporation (from soil and plant surfaces) and plant transpiration (i.e., internal evaporation). Reference evapotranspiration (ETref) is the rate at which readily available soil water is vaporized from specified vegetated surfaces (Jensen et al., 1990). Then, reference evapotranspiration is defined as the ET rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing and expanse of at least 100 m of the same or similar vegetation (Allen et al., 2005)

A large number of empirical methods have been developed over the last 50 years to estimate evapotranspiration from different climatic variables. Some of these methods are derived from the now well-known **Penman equation** (Penman, 1948) to determine evaporation from open water, bare soil and grass (now called evapotranspiration) based on a "combination" of an energy balance and an aerodynamic formula, given as:

$$\lambda E = [\Delta(R_n - G)] + (\gamma \lambda E_a) / (\Delta + \gamma) \tag{1}$$

where λE is the evaporative latent heat flux in MJ m^{-2} d^{-1}, Δ is the slope of the saturated vapor pressure curve [$\delta e^o / \delta T$, where e^o is saturated vapor pressure in kPa and T is the temperature in ^oC, usually taken as the daily mean air temperature], Rn is net radiation flux in MJ m^{-2} d^{-1}, G is sensible heat flux into the soil in MJ m^{-2} d^{-1}, γ is the psychrometric constant in kPa $^oC^{-1}$, and E_a is the vapor transport of flux in mm d^{-1} [1.0 mm d^{-1} = 1.0 kg m^{-2} d^{-1}]. Penman (1948) defined E as open water evaporation.

Various derivations of the Penman equation included a bulk surface resistance term (Monteith, 1965) and the resulting equation is now called the **Penman-Monteith equation**, which may be expressed for daily values as

$$\lambda ET_o = \{[\Delta (R_n - G)] + [86{,}400\ \rho_a C_p (e_s^o - e_a)]/r_{av}\} / \Delta + \gamma (1 + r_s/r_{av}) \tag{2}$$

where ρ_a is air density in kg m^{-3}, C_p is specific heat of dry air, e_s^o is mean saturated vapor pressure in kPa computed as the mean e^o at the daily minimum and maximum air temperature in ^oC, r_{av} is the bulk surface aerodynamic resistance for water vapor in s m^{-1}, e_a is the mean daily ambient vapor pressure in kPa and r_s is the canopy surface resistance in s m^{-1}.

Early in 1952, crop-water requirement studies were begun in Florida. A comparison of measured vs. computed water requirements for one year were reported by McCloud and Dunavin (1954) and a regression equation (3) was developed to express the relationship between measured water use and mean temperature:

$$\textbf{Potential daily water-use} = \mathbf{ETp = KW^{(T-32)}} \qquad \textbf{(3)}$$

where K = 0.01, W = 1.07, and T = mean temperature in F. These coefficients are relevant only to Gainesville, Florida (Mc Cloud, 1955).

Values from this empirical formula show fair agreement with values from other well-known formulas (Blaney and Criddle (1950); Tabor (1931) and Thornthwaite (1948)), in the lower temperature ranges – below 70 F. At higher temperatures, the exaggerated measured water-use rate disagrees with the estimated potential evapotranspiration (Augustin, 2000) using the previous mentioned methods, which may be caused by advective energy transfer from the area surrounding the tanks – an important factor to delineate in crop-water use studies (McCloud, 1955). The above formula showed a high correlation (r = 0.91, McCloud, 1955) between those predicted and measured water-use rates for Gainesville, Florida.

An updated equation was recommended by FAO 56 (Allen et al. 1998) with the **FAO-56 Penman-Monteith Equation**. Allen et al. (1998) simplified equation (2) by utilizing some assumed constant parameters for a clipped grass reference crop that is 0.12-m tall. In the context of this new standardization, reference evapotranspiration, it was assumed that the definition for the reference crop was “a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo value of 0.23” (Smith et al., 1992). The new equation is:

$$\mathbf{ET_o = \{[0.408\Delta\ (R_n - G)] + [\gamma\ 900/(T+273)\ U_2\ (e_s^o - e_a)]\}/\ \Delta + \gamma(\ 1 + 0.34\ U_2)} \qquad \textbf{(4)}$$

where ET_o is the reference evapotranspiration rate in mm d^{-1}, T is mean air temperature in ^oC, and U_2 is wind speed in m s^{-1} at 2 m above the ground (and RH or dew point and air temperature are assumed to be measured at 2 m above the ground, also). Equation 3 can be applied using hourly data if the constant value “900” is divided by 24 for the hours in a day and the R_n and G terms are expressed as MJ m^{-2} h^{-1}.

In 1999, the ASCE Environmental and Water Resources Institute Evapotranspiration in Irrigation and Hydrology Committee was asked by the Irrigation Association to propose one standardized equation for estimating the parameters to gain consistency and wider acceptance of ET models (Howell and Evett, 2006). The principal outcome was that TWO equations (one for a short crop named ET_{os} and another for a taller crop named ET_{rs}) were developed for daily (24 hr) and hourly time periods. **The ASCE-EWRI standardized reference ET equation** based on the FAO-56 Penman-Monteith equation (3) for a hypothetical crop is given as,

$$\mathbf{ET_{sz} = \{[0.408\ \Delta(R_n - G)] + [\gamma\ C_n /(T+273)\ U_2\ (e_s^o - e_a)]\}/\ \Delta + \gamma(1 + C_d\ U_2)} \quad \mathbf{(5)}$$

where ET_{sz} is the standardized reference evapotranspiration for a short reference crop (grass - ET_{os}) or a tall reference crop (alfalfa - ET_{rs}) in units based on the time step of mm d^{-1} for a 24-h day or mm h^{-1} for an hourly time step, C_n is the numerator constant for the reference crop type and time step and C_d is the denominator constant for the reference crop type and time step (see Table 2 for values of C_n and C_d)

Table 2: Values for C_n and C_d in Eq. 5 (after Allen et al., 2005).

Calculation time step	**Short reference crop ET_{os}**		**Tall reference crop, ET_{rs}**		**Units for ET_{os},ET_{rs}**	**Units for R_n and G**
	C_n	**C_d**	**C_n**	**C_d**		
Daily	900	0.34	1600	0.38	mm d^{-1}	MJ $m^{-2}d^{-1}$
Hourly, daytime	37	0.24	66	0.25	mm h^{-1}	MJ m^{-2} h^{-1}
Hourly, nighttime	37	0.96	66	1.7	mm h^{-1}	MJ m^{-2} h^{-1}

Reference evapotranspiration (ET) replaced the term potential ET. Reference evapotranspiration is defined as the ET rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation (Allen et al., 2005). The crop evapotranspiration (ET_c) under standard conditions is the evapotranspiration from disease-free, well fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions (Allen et al., 1998).

Crop coefficient (K_c)

The crop coefficients (K_c) are crop specific evapotranspiration values generated by research used with reference evapotranspiration data to estimate the crop's evapotranspiration requirement (ET_c). The Kc coefficient incorporates crop characteristics and averaged effects of evaporation from the soil (Allen et al., 1998). K_c is calculated by dividing ET_c/ET_o. Thus, using different ET_o equations will generate different K_c values, which is one reason the ASCE EWRI Standardized Reference ET methodology was developed (Allen et al., 2005). ET_c is calculated by multiplying the crop coefficient (K_c) by the reference evapotranspiration value (ET_o). Monthly coefficients can be averaged to yield quarterly, semi-annual, or annual crop coefficients (Richie et al., 1997), although averaging crop coefficients reduces monthly precision and turfgrass may be under-irrigated during stressful summer months. Since coefficients can vary substantially over short time periods, monthly averaged coefficients are normally used for irrigation scheduling (Carrow, 1995). Factors influencing crop coefficient for turfgrasses are seasonal canopy characteristics, rate of growth, and soil moisture stress that would cause coefficients to decrease, root growth and turf management practices (Gibeault et al., 1989; Carrow, 1995).

2.3.1 Evapotranspiration in turfgrasses

Water use of turfgrasses is the total amount of water required for growth and transpiration plus the amount of water lost from the soil surface (evaporation), but because the amount of water used for growth is so small, it is usually referred to as evapotranspiration (Huang, 2006; Augustin, 2000). Most of the water transpired through the plant moves through openings in the leaves called stomates. In actively growing turfgrasses, water continuity exists from the soil (roots), through the plant, to the leaves where evaporation occurs through the stomates. The primary benefit of transpiration is the cooling effect resulting from the evaporation process. In the absence of transpirational cooling, leaf temperatures can approach 130 F. In some locations with grasses such as bentgrass, transpirational cooling must be supplemented with syringing in midday to increase evaporative cooling on very hot, summer days. The amount of water lost through transpiration is a function of the rate of plant growth and several environmental factors – soil moisture, temperature, solar radiation, humidity and wind. Transpiration rates are higher in arid climates than in humid climates because of the greater water vapor deficit between the leaf and the atmosphere in dry air. Thus, transpiration losses may be as high as 0.4 inch of water per day in desert climates during summer months; whereas in humid climates under similar temperature conditions, the daily losses may be only 0.20 inch of water (Duble, 2006).

Turfgrass ET rates vary among species and cultivars within species. Inter- and intra-specific variations in ET rates can be explained by differences in stomatal characteristics, canopy configuration, growth rate and characteristics of the roots. ET rates also are influenced by environmental conditions (such as temperature, relative humidity, solar radiation, and wind, and edaphic factors such of soil temperature, water availability and soil texture) and cultural practices (mowing, irrigation, fertilization, use of antitranspirants, and plant growth regulators) (Huang and Fry, 2000). Increased mowing height and amount of top growth can be expected to increase evapotranspiration by increasing the roughness of the plant canopy surface, by increasing the capacity for absorbing advective heat and by increasing the root growth, which results in a greater soil water source to exploit (Kneebone et al., 1992). Most data on mowing height effect is observed with cool-season grasses. Within the warm-season grasses, Zoysiagrass, buffalograss and Centipedegrass showed increased ET rates at optimum heights of cut (Kim and Beard, 1984). Also, any cultural practice that increases leaf surface area, internode length and leaf extension (i.e. N fertilization), is expected to increase water use. Soil compaction may affect ET more than N source or N rates, since it may not allow the root system to function adequately due to the poor soil aeration, platy massive soil structure and low infiltration rates, which brings as a consequence a reduced water holding capacity of the soil (Huang, 2006)

The most commonly used cool- and warm-season turfgrass species have been categorized for ET rates (Beard and Kim, 1989) as shown in Table 3.

Table 3: Evapotranspiration rates of warm and cool-season turfgrasses commonly used in North America (after Beard and Kim, 1989).

Relative ranking	**ET Rate**		**Cool-season**	**Warm-season**
	(mm d^{-1})	**(in d^{-1})**		
Very low	< 6	< 0.24		Buffalo grass
Low	6 – 7	0.24 - 0.28		Bermudagrass hybrids Bluegrama

				Bermudagrass Centipedegrass Zoysiagrass
Medium	7 - 8.5	0.28– 0.33	Hard fescue Chewings fescue Red fescue	Bahiagrass Seashore paspalum St. Augustinegrass Zoysiagrass
High	8.5 - 10	0.33-0.39	Perennial ryegrass	
Very high	> 10	> 0.39	Tall fescue Creeping bentgrass Annual bluegrass Kentucky bluegrass Italian ryegrass	

Water use (ET) by turfgrasses is estimated with a correlation factor or crop coefficient K_c x ET_o = grass water use. This crop coefficient will exhibit considerable variation along the season which is due in part to plant cover, growth rate, root growth and stage of the plant development and turf management practices (Gibeault et al., 1989; Brown et al., 2001). An example of monthly K_c values for warm- and cool-season turfgrasses is given in Table 4 but if an annual average K_c is desired, 0.8 should be used for cool-season turfgrasses and 0.6 for warm-season turfgrasses (Gibeault et al., 1989). For this example, the Kc data for warm-season grasses include common and hybrid bermudagrasses, St. Augustinegrass, seashore paspalum, Zoysiagrass and kikuyugrass, which are used in the San Joaquin Valley, Southern California. Cool-season grasses include Kentucky bluegrass, perennial ryegrass, tall fescue, fine-leaved fescues in mixes, and specialty grasses such as creeping bentgrass, roughstalk bluegrass and annual ryegrass, which are used extensively in the northern part of California. Another factor contributing to the variation in K_c values is the differing computation procedures used by the various researchers to estimate ET_o. Recently, the FAO and ASCE have identified this disparity in ET_o computation procedures and have recommended using a standardized computation procedure based on the Penman-Monteith Equation to ensure uniform estimates of ET_o (Allen et al., 1998). Table 5 shows a summary of ET_o rates and K_c values for different turfgrass species using different methodologies at different locations in the U.S.A.

Table 4: Turfgrass crop coefficient (K_C) of warm- and cool-season grasses for all California (after Gibeault et al., 1989).

	K_C	
Month	**Warm**	**Cool**

Jan	0.55	0.61
Feb	0.54	0.64
Mar	0.76	0.75
Apr	0.72	1.04
May	0.79	0.95
Jun	0.68	0.88
Jul	0.71	0.94
Aug	0.71	0.86
Sep	0.62	0.74
Oct	0.54	0.75
Nov	0.58	0.69
Dec	0.55	0.60
Avg.	**0.64**	**0.79**

Table 5: Summary chart showing turfgrass species, mean daily evapotranspiration rate (ETo), average Kc, methodology used to determine ET and Kc and respective references.

Turfgrass species	ETo (mm d^{-1})	K_c	Study period length	Methodology	Reference/Location
Tifway bermudagrass	4.82/4.57*	0.67	First season: from 26 June to 10 Oct 1989 (data on the left) Second season: from 5/4/90 to 11/2/90 (data on the right)	For ET_c: TDR_s For K_c: Penman	Carrow, 1995/ Georgia
Common bermudagrass	4.88 /4.27 *	0.68			
Meyer zoysiagrass	4.64 /4.26 *	0.81			
Common centipedegrass	4.46 /4.47 *	0.85			
Raleigh St Augustinegrass	4.99 / 4.40 *	0.72			
Rebel II tall fescue	5.04 / 4.28 *	0.79			
Kentucky-31 tall fescue	4.41 / 4.56 *	0.82			
Merion Kentucky bluegrass	4.75 (a) 5.39 (b)	---- ----	First experiment: From 7/13/79 to 10/4/79.	Weighing lysimeter: [(a) 2 cm mowing height (b) 5 cm mowing height]	Feldhake et al.,1983 / Colorado
Merion Kentucky bluegrass	5.68	----	Second experiment: From 6/8/81 to 8/16/81.	Values are the average of two lysimeters	
Rebel tall fescue	5.81	----			
Tifway bermudagrass	4.53	----			
Common buffalograss	4.46				
Tifway bermudagrass (Jun-Sept) – Summer (3-yr avg) and Overseeded froghair ryegrass (Nov-May) – Winter (3-yr avg) (original data in mm y^{-1})	5.1**	0.80^a 0.83^b	Nov. 1994 to Sept. 1997. ^{a}Kc and ^{b}Kc for summer and winter, resp. (monthly average)	For ET_o: Penman-Monteith Equation.	Brown et al., 2001 Arizona
			Full sod treatment		
Tifway bermudagrass	2.9	---	1965	Non-weighing evapotranspirometers	Stewart et al., 1969
(original data in in y^{-1})	2.4	---	1966		
	2.9	---	1967		
			2/3 sod treatment		
	2.3	---	1965		

	2.2	---	1966		
	3.1	---	1967		
			1/3 sod treatment		
	1.8	---	1965		
	1.9	---	1966		
	3.1	---	1967		
Tifway bermudagrass			5-yr average (date not specified)	Non-weighing	
(original data in in y^{-1})	3.0	---	12 in depth to water table	evapotranspirometers	Stewart et al., 1967
	2.9	---	24 in depth to water table		
	2.9	---	36 in depth		
Warm-season grasses	----	0.65*	-----	Data available from California Irrigation Management System (CIMIS).	Gibeault et al., 1989. California.
Cool-season grasses	----	0.79*			
Tifway bermudagrass (summer)	4.08 (m)	----	1 year	$ET_c = K_c \times ET_o$	Brown, 2003
+ ryegrass (winter)	3.56 (n)				
(original data in mm y^{-1})			(m: high quality turf)		Arizona
ET value corresponds to ET_c			(n: acceptable quality turf)		

*See reference for detailed information.

** See reference for annual distribution of ET

3. Ornamental plants overview

Florida is ranked second nationally in the production of ornamental plants, which includes cut flowers, flowering potted plants, hanging baskets, potted foliage plants, cut foliage (cultivated greens, florists' greens), bedding and garden plants, and ornamental trees (Larson and Nesheim, 2000). They are vital in combating environmental pollution, helping keep the air supply fresh by trapping and filtering dust, removing carbon dioxide, and at same time releasing oxygen, lowering temperatures by shading and through evapotranspiration of water from their leaves (Black, 2003). Since landscape plant materials such as turf are being questioned for water use, Florida residents are following landscape watering restrictions, and native and/or drought-tolerant ornamental plants are being promoted due to their lower water needs in comparison to traditional lawns (Erickson et al., 2001; Park and Cisar, 2005).

The Southwest Florida Water Management District (SWFWMD) has developed a Plant Guide (Dawes, 2006) in order to help with the selection and placement of water-efficient landscape plants for this area of Florida. The guide contains information about 79 trees, 17 palms, 81 shrubs, 53 ground covers and 17 vines species, classified according to their environmental requirements, like temperature ranges and water requirements. No data on Kc values is shown, which makes the correct estimation of ETc difficult for each species. Water requirements are described as (1) oasis, meaning that plants require frequent irrigation; (2) drought tolerant plants, that occasionally need supplemental irrigation and (3) natural plants which can survive on normal rainfall. However, this is based on field observation which makes the classification subjective. Table 6 shows part of the extensive information about the drought-tolerant species that are described in the Guide.

Reliable research-based data on landscape plants' water needs is extremely limited. Few information sources offer quantitative estimates of landscape plant's water requirements, including the widely-referenced publication, Water Use Classification of Landscape Plants –**WUCOLS-** (Costello and Jones, 1999) which is not based on scientific field research. **WUCOLS** is a list intended as a guide to help landscape professional identify irrigation water needs of landscape species or for selecting species or to assist in developing irrigation schedules for existing landscapes. This guide provides irrigation water needs evaluation for over 1,900 species used in California landscapes, based on the observations and field experience of 41 landscape horticulturists in California. The Guide contains different sections which include background info needed to use the Guide effectively, like "categories of water needs", "plant types and "regions". Water needs categories assigned for each species were determined by consensus of the committee. These are: high "H" (70-90% ETo), moderate "M" (40 -60% ET_o), low "L" (10-30% ET_o) and very low (<10% ETo). Assignments were made for each of six regions in California: region 1: North-Central coast; region 2: central valleys; region 3: south coastal; region 4: south inland valleys and foot hills; region 5: high and intermediate desert; region 6: low desert. All of these regions are based on different climate zones in California. Each plant of the species list falls into one or more of the following vegetation types: trees (T), shrub (S), groundcovers (Gc), vines (V), perennial (P) and biennals (Bi). Cultivars with some exceptions are not mentioned. Turfgrasses were not evaluated by the committee, although **WUCOLS** includes a list of irrigation requirements for turfgrasses from the University of California ANR public 24191: Turfgrass ET map, central coast of California. However, this list has some limitations. It is also subjective (based on field observations rather than scientific data); it is a partial list since not all landscape species are included, and last, not all regions of California are included in the evaluations.

Field research on non-turf landscape plants' minimum water requirements is limited to several commonly used groundcover, tree and shrub species (Pittenger and Shaw, 2003). The little availability on landscape water needs' information is because there are hundreds of plant species to evaluate and the scientific process requires a great deal of resources to identify water requirements of an individual species. In addition, some species utilized for landscapes have the ability to maintain acceptable aesthetic quality under reduced irrigation (Pittenger et al., 2001). Table 7 shows a list of trees and shrubs most tolerant to dry areas.

Table 6. List of some drought-tolerant species for Southwest Florida (after Dawes, 2006).

Scientific name	**Common name**
Trees	
Acer rubrum	Red maple
Acer saccarum	Florida maple
Bauhinia variegata	Orchic tree
Bursera simaruba	Gumbo-limbo
Callistemon viminallis	Weeping bottlebrush
Callistemon rigidus	Upright botleebrush
Cersis canadensis	Redbud
Chionanthus verginicus	Fringe Tree
Citrus ccoalbidum	Citrus
Conocarpus erectus	Buttonwood
Delonix regia	Royal Poinciana
Diospyros kaki	Oriental persimmon
Ficus nitida	Rubber tree
Ilex decidua	Deciduous holly
Liriodendron tulipfera	Tulip tree
Platanus occidentalis	Sycamore
Sapium sebiferum	Chinese tallow tree
Vitex trifolia	Chaste Tree
Palms	
Acoelorrhaphe wrightii	Paurotis palm
Chrysalidocarpus lutescens	Areca palm
Phoenix roebelenii	Pygmi date palm
Rhapis excelsa	Rhapis/Lady palm
Shrubs	
Agave americana	Century plant
Aucuba japonica	Japanese aucuba
Bambusa spp	Bamboo
Camellia japonica	Camellia
Canna generalis	Canna Lily
Codiaeum variegatum	Croton
Ficus carica	Edible fig
Gardenia jasminoides	Gardenia
Illicium floridanum	Florida anise
Magnolia stellata	Star magnolia
Rhododendron spp.	Azalea
Viburnum odoratissimum	Sweet viburnum

Table 7. Trees and shrubs most tolerant to the Ohio dry areas (after Smith, 2006).

Scientific name	**Common name**
Trees	
Acer ginnala	Amur maple
Ailanthus altissima	Tree of Heaven*
Juniperus species	Juniper species
Koelreuteria paniculata	Rain tree
Maclura pomifera	Osage-orange*
Pinus virginiana	Virginia pine
Populus alba	White poplar*
Robinia species	Locust species
Sassafras albidum	Sassafras
Sophora japonica	Japanese pagoda tree
Ulmus pumila	Siberian elm*
Shrubs	
Berberis species	Barberry
Caragana species	Pea tree
Chaenomeles lagenaria	Flowering quince
Cornus racemosa	Gray dogwood
Cotinus coggygria	Smoke bush
Cytissus species	Broom species
Hamamelis virginiana	Common witch-hazel
Hypericum calycinum	Aaronsbeard St. Johnswort
Juniperus species	Juniper species
Kolkwitzia amabilis	Beautybush
Myrica species	Bayberry species
Rhamnus species	Buckthorn species
Rhus species	Sumac species
Ribes alpinum	Alpine currant
Rosa setigera	Prairie rose
Tamarix species	Tamarix
Viburnum lentago	Nannyberry viburnum
Yucca species	Adam’s needle

*****Not considered by most horticulturists to be the best tree selections for various reasons; however, in very dry sites they may be the only plants that thrive.

3.1 Evapotranspiration in ornamental plants

Few data on ornamental plants evapotranspiration and K_c values are reported in the literature for Florida. Studies from Park and Cisar (2005) and Park et al. (2005), show the water use from two contrasting landscapes: 1) a St. Augustinegrass turfgrass (TF) lawn and 2) a mixed species (MS) landscape, at theUniversity of Florida’s Fort Lauderdale Research and Education Center, FL. Table 8 shows the list of plant species used for the mixed species landscape. Working on eight test landscapes (5 m wide x 10 m long) on a 10% slope inclination and hydrologically isolated from the other landscapes, they found that the estimated ET using a water balance equation (Snyder et al., 1984) from the turfgrass landscape remained relatively the same over the 4-yr experimental period (between 822 to 949 mm y^{-1} or 32.4 to 37.4 inches y^{-1}), reflecting the complete canopy coverage since the turfgrass was installed as a sod. In contrast, water use increased approximately 30% from year one to year three in the mixed species landscape (9% annually; Table 9). The increasing ET from the mixed species landscape reflected its three-dimensional canopy. These results were compared to the McCloud equation (McCloud, 1955), whose results were greater than what was documented for both landscapes, since the landscapes were not maintained under well watered conditions and because the equation was designed for Gainesville conditions only. In addition, the development of the McCloud equation was done with above ground lysimeters which would bias the results higher than in ground measurements due to sensible heating and other on ideal factors. The high predicted ET values resulted in low Kc values. During the dry season, the average Kc values for the mixed species landscape (Kc = 0.67) were significantly different than the turfgrass landscape (Kc = 0.51), yet not during the wet season (Kc = 0.29 and 0.30 for MS and TG, respectively, $P>0.05$) (Table 10). The McCloud method, that estimates ET based on temperatures, performed the worst in a study comparing 14 methods to estimate ET in three locations in North Florida (Jacobs and Satty, 2001). In annually terms, this equation over-predicted ET by 1.04 % more than the ASCE PM-90, equation which was set as a reference. The resulting Kc values for the MS and TG treatments, during the wet season, are unrealistically low and not representative of any in this literature review and probably they are under-estimated due to the high ET values resulting from the McCloud formula.

Table 8: List of plant species using in treatment 'mixed species' (after Park et al., 2005)

Scientific name	**Common name**	**Florida native**
Liriope muscari (Dene.) Bailey 'evergreen giant'	Liriope	N
Lantana montevidensis (K. Spreng.) Briq.	Trailing lantana	N
Tripsacum floridana L. 'dwarf'	Dwarf Fakahatchee grass	Y
Zamia pumila L.	Coontie	Y
Ilex vomitoria Ait. 'schellings dwarf'	Dwarf yaupon holly	Y
Hamelia patens Jacq. 'compacta'	Firebush	Y
Galphimia gracilis Cav.	Thyrallis	N
Podocarpus macrophyllus (Thunb.) Sweet	Podocarpus	N
Myrcianthes fragans (Sw.) McVaugh	Simpon's stopper	Y

Myrica cerifera L. (small)	Wax myrtle	Y
Acoelorraphe wrightii (Griseb.& H. Wendl.) H.Wendl. ex Becc	Everglades palm	Y
Tabebuia heterophylla (DC.) Britt.	Pink trumpet-tree	N

Table 9: Water budget (mm y^{-1}) for the St. Augustinegrass turfgrass (TG) and mixed-species (MS) landscapes over the experimental period (Feb. 1999-April 2003) (after Park et al., 2005)

Year	**Rainfall**	**Irrigation**		**Percolate**		**ETc**	
		TG	**MS**	**TG**	**MS**	**TG**	**MS**
1	2054	964	881	2080	2240	909*	728
2	1394	233*	104	804*	555	822*	1000
3	1529	102	165	681	633	948	1060
4	1423	109*	254	655*	514	860*	1136

* Indicates significant differences for landscape type during the corresponding year at $P<0.05$.

Table 9: Treatment effect on wet and dry season Kc[§] values over the experimental period. MS = mixed species landscape. TG = turfgrass landscape (after Park et al., 2005).

	Year 1		**Year 2**		**Year 3**		**Year 4**	
Treatment	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
MS	0.27	0.31	0.50	0.31	0.15	0.72	0.25	1.34
TG	0.37	0.42	0.50	0.18	0.20	0.70	0.11	0.73
Significance	**	**	Ns	ns	ns	ns	ns	**

[§] Calculated by dividing the actual ET by the predicted ET based on McCloud method.

Erickson et al. (2001), also carried out an investigation at the University of Florida's Fort Lauderdale Research and Education Center, comparing nitrogen runoff and leaching between a turfgrass landscape (St. Augustinegrass) and an alternative residential landscape which included 12 different ornamental ground covers, shrubs, and trees (50% native from Florida). The ornamental species used were the same as those used in the two studies previously described (Table 8). Even when it was not the main objective of the paper, the estimates of ET were determined for each landscape treatment based on the rainfall, irrigation, and percolate data measured during the experiment. The mean dry season ET was estimated to be 43.7 and 21.2 mm mo^{-1}on the St. Augustinegrass and mixed-species, respectively, while the mean wet season ET was 104.5 mm mo^{-1} and 97.2 mm mo^{-1} on the respective landscapes. With these data, the estimated total annual ET for the turfgrass landscape would be 889 mm y^{-1} and for the ornamental landscape 710 mm y^{-1}.

In another study, the ET_c and K_c values of *Viburnum odoratissimum* (Ker.-gawl) grown in white and black multi-pot box system (MPBS) were measured in summer and fall on the campus of the University of Florida (Irmak, 2005). From a previous study

(Irmak et al., 2004) it was reported that the plants grown in the white MPBS had significantly higher growth rates and plant biomass production, since the black MPBS had heat induced stress caused by high root-zone temperatures. The measured ET_c ranged from 308 mm to 334 mm for the black and white MPBS plants, respectively, in summer; and from 346 to 351 mm for the black and white MPBS plants, respectively, in fall. The total growing period in the summer season was 13 weeks. The Kc of plants in the black and white MPBS ranged from 0.64 to 1.29 during that season. The fall season lasted 18 weeks and the Kc values for the black and white MPBS plants ranged from 0.55 to 1.68. For both treatments, the highest K_c values were obtained at the end of the growing season. The authors point out that these plants were not grown in a mixed landscape but separately grown for production purposes.

A study using *Viburnum odoratissimum* (Ker.-gawl), *Ligustrum japonicum* Thunb., and *Rhaphiolepsis indica* Lindl. Growing into 11.4-L containers for 6 months were irrigated under different irrigation regimes consisted of an 18-mm daily control and irrigation to saturation based on 20%, 40%, 60% and 80% deficits in plant available water (management allowed deficits – MAD) (Beeson, 2006). The results recommend 20%, 20% and 40% MAD for the previously mentioned woody ornamentals, respectively, for commercial production. The actual evapotranspiration for these results were 25% lower than the control conditions for *Viburnum odoratissimum* (Ker.-gawl) (124.8 vs 164.5 L); 28.9% higher than the control conditions for *Ligustrum japonicum* Thunb. (137.3 vs 106.8 L) and 10.4% higher than the control conditions for *Rhaphiolepsis indica* Lindl. (85.7 vs 77.6 L). The ET data is not expressed in standard units (mm y^{-1}) which make these results difficult to be compared.

4. Estimating water needs for landscape plantings

The irrigation requirements are well established for agricultural crops; however, in urban landscapes, irrigation requirements have been determined for turfgrasses but not for most landscape species. Landscape irrigation increases dramatically during summer months and contributes substantially to peak demand placed on municipal water supplies, and outdoor water use may account for 40 to 60% of residential water consumption (White et al., 2004). Estimates of landscape water needs are important to preserve water resources, to keep the landscape quality and to save money. Water is a limited natural resource that needs to be supplied according to the plant needs and so money can be saved since water costs continue to increase. The potential for plant injury caused by water deficits or excess can be minimized by identifying plant water needs (Costello et al., 2000).

The prediction of water use in landscapes with multiple plant species is still incipient and has just started (Havlak, 2003). There is a system of estimating irrigation water needs of landscapes, based on reference evapotranspiration (ET_o) and a landscape coefficient (K_L) which is a function of a species factor (k_s), microclimate factor (k_m) and a density factor (k_d) which has been developed and is currently being updated in California (Costello et al., 2000). However, this method includes information that is based on research and on field experience (observation) and readers are advised for some subjectivity in the method, and estimations of water needs are not exact values. Another methodology has been proposed by Eching and Snyder (2005) where the landscape coefficient (K_L) estimation considers a species (K_s), microclimate (K_{mc}), vegetation (K_v), stress (K_s) and an evaporation (K_e) factors. This method includes a computerized program called LIMP.XLS which is able to calculate ET_o rates, determine landscape coefficient (K_L) values, estimate landscape evapotranspiration (ET_L) and determine irrigation schedules at daily basis. Finally, White et al. (2004) proposed to find a relationship between ET_c and ET_o for a multiple plant species landscape to calculate a landscape coefficient for use in the development of residential water budgets.

4.1 The Landscape Coefficient Method

The Landscape Coefficient Method (LCM) describes a method of estimating irrigation needs of landscape plantings in California on a monthly basis. It is intended as a guide for landscape professionals and it includes information that is based on research and on field experience. Readers are advised that LCM calculations give estimates of water needs, not exact values, and adjustments to irrigation amounts may be needed in the field (Costello et al., 2000). Water needs of landscape plantings can be estimated using the landscape evapotranspiration formula:

$$\mathbf{ET_L = (K_L)\ (ET_o)} \tag{4}$$

where landscape evapotranspiration (ET_L) is equal to the landscape coefficient (K_L) times reference evapotranspiration (ET_o). The ET_L formula differs from the ET_c formula since the crop coefficient (K_C) has been substituted for the landscape coefficient (K_L). This change is necessary because of important differences which exist between crop or turfgrass systems and landscape plantings.

4.1.1. The landscape coefficient formula

Costello et al. (2000) point out the reasons why there must be a landscape coefficient: 1) because landscape plantings are typically composed of more than one species, 2) because vegetation density varies in landscapes and 3) because many landscapes include a range of microclimates. These factors make landscape plantings quite different from agricultural crops and turfgrasses and they need to be taken into account when making water loss estimates for landscapes. The landscape coefficient estimates water loss from landscape plantings and functions as the crop coefficient but not determined in the same way. Species, density and microclimate factors are used to calculate K_L.

$$K_L = (k_S)(k_d)(k_{mc}) \tag{5}$$

By assigning numeric values to each factor, a value of K_L can be determined. The selection of each numeric value will depend on the knowledge and gained experience of the landscape professional, which make the method largely subjective.

4.1.2. The landscape coefficient factors:

The species coefficient (k_S): This factor ranges from 0.1 to 0.9 and are divided into 4 categories, very low, low, moderate and high. These species factor ranges apply regardless of vegetation type (tree, shrub, herbaceous) and are based on water use studies, and from agricultural crops. Relative water need requirements for plants have been completed for over 1800 sp (see the water use classifications of landscape species - WUCOLS III- list).

The density coefficient (k_d): This factor is used in the landscape coefficient formula to account for differences in vegetation density among landscape plantings. This factor is separated into three categories: low (0.5–0.9), average (1.0) and high (1.1–1.3). Immature and sparsely planted landscapes, with less leaf area, are assigned a low category k_d value. Planting with mixtures of trees, shrubs and groundcovers are assigned a density factor value in the high category. Plantings which are full but are predominantly of one vegetation type are assigned to the average category.

The microclimate coefficient (k_{mc}): This factor ranges from 0.5 to 1.4 and is divided into three categories: low (0.5–0.9), average (1.0) and high (1.1–1.4). An ‘average’ microclimate condition is equivalent to reference ET conditions: open-field setting without extraordinary winds or heat inputs atypical for the location. In a ‘high’ microclimate condition, site features increase evaporative conditions (e.g. planting near streets medians, parking lots). ‘Low’ microclimate condition is common when plantings are shaded for a substantial part of the day or are protected from strong winds. These include the north side of buildings courtyards, under building overhangs, etc.

We wish to reiterate that these coefficients are for California only and that these factors were developed subjectively, whereas our study proposes to use quantitative methods to do so.

4.1.3. Irrigation efficiency and calculating the total amount of water to apply

The ET_L formula calculates the amount of irrigation water need to meet the needs of plants; however, this is not the total amount of water needed to apply. The landscape will require water in excess of that estimated by ET_L since every irrigation system is inefficient to some degree. The total amount or water needed for a landscape planting is calculated using the following formula, in spite of the method use to determine irrigation efficiency:

$$\mathbf{TWA = ET_L/IE} \qquad (6)$$

Where TWA = Total Water Applied, ET_L = Landscape Evapotranspiration and IE = Irrigation Efficiency. Just note that the IE factor needs to be addressed carefully when planning and managing landscapes.

4.2 The LIMP.XLS program (Eching and Snyder, 2005)

This program is able to calculate ET_o rates, determine landscape coefficient (K_L) values, estimate landscape evapotranspiration (ET_l) and determine irrigation schedules. Evapotranspiration from landscape vegetation is estimating by using a regional measure of evaporative demand (e.g. reference evapotranspiration), a microclimate coefficient (K_m) to adjust the ET_o for the "local" weather conditions, a vegetation coefficient (K_v) that accounts for the difference in ET between well watered vegetation and the local ET_o, a density coefficient (K_d) that adjusts the ET estimate for plant density, a stress (K_s) coefficient) that adjusts for reductions in ET due to water stress and an evaporation coefficient (K_e) that defines a baseline coefficient value. The coefficient (K_w) to estimate ET of a well-watered vegetated cover is estimated as:

$$\mathbf{K_w = (K_m)\ (K_v)\ (K_d)} \tag{7}$$

Then K_w is multiplied by a stress coefficient (K_s) to adjust for reductions in ET below that of well-watered vegetation. However, the evaporation coefficient (K_e) serves as a baseline, so the landscape coefficient is calculated as:

$$\mathbf{K_l = (K_w)\ (K_s),\ > K_e} \tag{8}$$

Then the landscape evapotranspiration (ET_l) for the vegetation in that location is calculated as:

$$\mathbf{ET_l = (ET_o)\ (K_l)} \tag{9}$$

The microclimate coefficient (K_m): It is the ratio between "local" over "regional" ET_o computed by LIMP by using the Penman-Monteith (Monteith, 1965) equation if solar radiation (MJ m^{-2} d^{-1}), air temperature (^oC), wind speed (m s^{-1}) and dew point temperature (^oC) are available data, or the Hargreaves-Samani (1982) is used if only temperature date are input in the model. A smooth curve fitting procedure is used to estimate daily K_m values for the year.

The vegetation coefficient (K_v): It represents well-watered vegetation with a full canopy and accounts for morphological and physiological differences between the vegetation and the reference surface (ET_o). ET_l is commonly estimated using $K_v = 0.8$.

The density coefficient (K_d): It is estimated by the following equation:

$$\mathbf{K_d = \sin [C_G\, \pi / (70)\, (2)]} \tag{10}$$

where C_G is the percentage of ground covered by green growing vegetation. It is assumed that this relationship accounts for differences in light interception by canopies with cover less than 70%. For canopies with more than 70% cover, $K_d = 1.0$.

The stress factor (K_S): It is used to reduce the ET rate of vegetation during dormant periods. A coefficient $K_S = 0$ would force ET = 0 and a $K_s = 1$ implies no reduction in ET.

The evaporation coefficient (K_e): It defines a baseline coefficient factor and it is used to estimate bare-soil evaporation as a function of ET_o and rainfall frequency based on the bare soil evaporation model (Stroosnijder, 1987) using the K_e model (originally called K_x) described by Snyder et al. (2000). The estimated soil evaporation (Es) is used to calculate a daily mean $K_e = E_s/ET_o$ value for bare soil for each month. The K_e is a baseline coefficient, so the K_l values must be greater than or equal to K_e (equation 11).

Then, the landscape coefficient K_l for estimating ET_L is computed as:

$$\mathbf{K_l = (K_m)\, (K_v)\, (K_d)\, (K_s)} \geq \mathbf{K}_e \tag{11}$$

The general conclusion is that the LIMP.XLS program can determine runtimes needed for irrigation of urban landscape vegetation using daily ET_o calculated from monthly climate data.

4.3 The methodology from the Texas Water Resources Institute, Texas A&M University (White et al., 2004)

This methodology allowed to determine 1) the relationship between ET_a and ET_o for a multiple plant species landscape, 2) use this relationship to calculate a landscape coefficient (L_c) for use in the development of residential water budgets, and 3) compare actual residential water use to residential water budgets for municipal water consumers for three years.

The methodology consisted to install 192 volumetric soil moisture sensors in 64 locations at 3 different depths (0 to 8, 8 to 16, and 16 to 24 inches) in a 9041 ft^2 landscape comprised of multiple plant species at the Texas A&M University Research and

Extension Center in Weslaco, Texas. The soil type was a fine sandy loam and the vegetation types included a St. Augustinegrass (*Stenotaphrum secundatum*), dwarf yaupon (*Ilex vomitoria nana*), ficus (*Ficus benjamina*), and rose (*Rosa sp.*)

The fertilization program was based on soil nutrient analyses and the turf was mowed weekly at 3 inches, and the trees and shrubs were pruned as needed. Supplemental irrigation was applied as plants began to wilt through an in-ground sprinkler irrigation system plus a drip irrigation line for the roses. Both systems were equipped with totalizing water meters. Actual evapotranspiration (ET_a) was determined by adding soil water loss from each of the three depths, while reference evapotranspiration (ET_o) was estimated by the Penman-Monteith equation and meteorological data from a Texas ET network. Landscape coefficients (L_c) were estimated from the daily average ratios of ET_a/ET_o and from using the slope of the linear regression of ET_a with ET_o for all days.

Water budgets for each residence were developed from estimates of landscape area, specific L_c values, and ET_o and precipitation from a Texas ET Network weather station. The monthly water budget for an L_c of 1.0 for each residence was estimated by:

$$\mathbf{MWB = 7{,}000\ g + \{LA\ ft^2 \times [(ET_o - precipitation) \times (27{,}154\ g/43{,}560\ ft^2)]\}} \quad (12)$$

where MWB is the monthly water budget (or predicted water use) in gallons, 7,000 is the base indoor use in gallons, LA is landscape area in square feet, ET_o is reference evapotranspiration in inches, precipitation is in inches, 43,560 is the square feet per acre, and 27,154 g is the gallons of water that covers an acre one inch deep. Monthly water budgets so derived were then compared with actual monthly water use for each residence. The main conclusion of this study was that the comparison of actual water used by residential municipal water customers in College Station, Texas with landscape water budget estimates demonstrated a potential savings of 24 to 34 millions gallons of water per year if all 800 customers had irrigated based on ET_o and an L_c of 1.0. Using ET_o combined with L_c has the potential to provide realistic water budgets for individual residential landscapes and greatly reduce landscape water use. Showing the amount of water that landscapes need, compared to how much water is actually applied to landscapes, will help utilities target their conservation efforts for maximum results.

5. Summary

This document presents a literature review of turfgrasses and ornamental plants in order to understand the methodologies to determine landscape evapotranspiration over heterogeneous communities of plants in urban areas.

Turfgrasses have been utilized by humans to enhance their environment for more than 10 centuries that provides functional, recreational and aesthetic benefits to society and the environment. The distribution of turf areas in the U.S. are approximately 66.7% on home lawns, 20% on golf courses and 13.4% on sport fields, parks, playgrounds and highway roads and according to the most recent estimation, the total area reaches approximately 40.5 million acres at the national level. Turfgrass areas have the potential to reduce “heat-island” effects, recharge groundwater more efficiently compared to asphalt-covered areas and have a psychological and physical effect on human beings. Knowing these facts would be extremely helpful for policy-makers to have access to the economic benefits resulting from the presence of turfgrass.

Turfgrasses are broadly classified into two groups based on their climatic adaptation: warm-season and cool-season. Warm-season turfgrasses are adapted to tropical and subtropical areas (e.g. bermudagrass, zoysiagrass, buffalograss, centipedegrass and St. Augustinegrass), while cool-season grasses mainly grow in temperate and cool areas (e.g. tall fescue, creeping bentgrass, perennial ryegrass and annual bluegrass). Cool season grasses are generally higher water users than warm season grasses. Typical water use rates (ET rates) range from 3 to 8 mm per day for cool season grasses and from 2 to 5 mm per day for warm season grasses under non-limiting soil moisture conditions. Water use (ET) by turfgrasses is estimated with a crop coefficient (K_c) multiplied by reference evapotranspiration (ET_o), which gives the turfgrass water use. Monthly K_c values for warm- and cool-season grasses have been reported in the literature. However, few data on ornamental plants evapotranspiration and K_c values are reported in the literature which is, in part, because nursery industry produces hundreds of species and cultivars of ornamental plants that are very diverse in their cultural practices and water requirements. Therefore, there is a need to develop methods for estimating K_c from more easily obtainable variables.

The irrigation requirements are well established for agricultural crops; however, in urban landscapes, irrigation requirements have been determined for turfgrasses but not for most landscape species. Landscape irrigation increases dramatically during summer months and contributes substantially to peak demand placed on municipal water supplies, and outdoor water use may account for 40 to 60% of residential water consumption. The prediction of water use in landscapes with multiple plant species is still incipient and has just started. There is a system of estimating irrigation water needs of landscapes, based on reference evapotranspiration (ET_o) and a landscape coefficient (K_L) which is a function of a species factor (k_s), microclimate factor (k_m) and a density factor (k_d) which has been developed and is currently being updated in California (Costello et al., 2000). However, this method includes information that is based on research and on field experience (observation) and readers are advised for some subjectivity in the method, and estimations of water needs are not exact values. Another methodology has been proposed by Eching and Snyder (2005) where the landscape coefficient (K_L) estimation considers a species (K_s), microclimate (K_{mc}), vegetation (K_v), stress (K_s) and an evaporation (K_e) factors. This method includes a computerized program called LIMP.XLS which is able to calculate ET_o rates, determine landscape coefficient (K_L) values, estimate landscape evapotranspiration (ET_L) and determine irrigation schedules at daily basis. Finally, White et al. (2004) proposed to find a relationship between ET_c and ET_o for a multiple plant species landscape to calculate a landscape coefficient for using in the development of residential water budgets.

To determine landscape irrigation requirements we propose a combined approach of determining turfgrass water requirements, selected ornamental water requirements, and a combination of turf and ornamentals in a mixed landscape. Turfgrass cultivars studied should consist of grasses common in landscapes or those gaining popularity. Since the wide variety of ornamental plants used in landscapes can not be studied in detail, it is proposed that select plants with moderate to high water needs be studied.

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