16

# Urban Irrigation Challenges and Conservation

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## 1. Introduction

Urbanization has created landscapes occupied by diverse plant communities created for the enjoyment of society and the end user (Hope et al., 2003). There is a high demand for aesthetically pleasing urban landscapes. The expectations of the end user as well as the person paying for the installation and maintenance often determine the success of an urban landscape (Kjelgren et al. 2000). The loss of landscape elements, such as trees, shrubs, lawns etc. due to poor water management and drought could severely depress property values (St. Hilaire et al., 2008). Because of a lack of understanding about differences in plant communities as well as seasonal water demands, urban landscapes are often over-irrigated or under-irrigated.

Communities around the world face different water supply and demand issues based on climate-related differences in water use. For example, Ferguson (1987) reported that 40 to 70% of residential water use in the United States was for landscapes but urban water use in the Ebro basin in Spain was only 7% which was mainly in cases of drought (Salvador et al. 2011).

Because water is a critical component for establishing and maintaining landscape plants in the urban environment, imposing mandatory water restrictions without guidelines on improving water conservation can be detrimental. Because of their high visibility, urban landscapes are one of the first areas that water districts and government agencies regulate for water use (Devitt et al., 1995). Many factors such as soil type (Barnett, 1986), plant cultivar (Paine et al, 1992) and planting season (Welsh et al., 1991) can impact irrigation management strategies for establishment and plant growth. Important questions that need to be addressed to improve urban irrigation management are: 1) what is the composition of the landscape plant community, 2) how much water is needed to satisfy plant demand (baseline needs), and 3) how to uniformly deliver water to the landscape (De Pascale et al. 2011).

## 2. Challenges in the urban landscape

It is well documented that patterns of urban growth are closely connected to water use (Western Resource Advocates, 2010). For example, outdoor water use in the southwest ranged from 57.5 to 72.3% and accounted for over half of all residential water use (Western Resource Advocates, 2010). Many municipalities throughout the United States have started to regulate the amount of water that can be applied to landscape plants due to rapid urban population growth, droughts, and wasteful practices (Salamone, 2002; Thayer, 1982).

The challenge is to adequately irrigate urban landscapes and conserve water. When plants become stressed due to a lack of water, growth and development are decreased. Symptoms of water stress include wilting, yellowing or browning of leaves, leaf drop (abscission), decreased leaf size, decreased leaf number, and reduced photosynthesis (Fig 1) (Taiz and Zeiger, 2006).

Fig. 1. Viburnum (*Vibrunum odorotissimum*) and orange jasmine (*Murraya paniculata*) plants showing signs of water stress (yellowing/browning leaves, wilting, and leaf drop). Plants were grown in field plots at the University of Florida, Fort Lauderdale Research and Education Center, Davie, FL (Photos by K Moore)

Water consumption by urban landscapes will vary with climate (rainfall, solar radiation, relative humidity) as well with landscape cover, plant water loss patterns, and irrigation system application rates and uniformity. For example, parks and recreational areas typically have large areas covered with turfgrass while typical residential areas have mixtures of turf, woody ornamentals, herbaceous perennials, and annuals (Fig 2) (Limaye, 1996). Unlike agronomic crops that are valued based on yield, ornamental landscapes are a mixture of plant materials that are valued for their appearance. According to Kjelgren et al (2000) the amount of water applied to the landscape can be divided into three levels of usage: 1) water needed to meet baseline physiological needs, 2) water needed to compensate for irrigation system non-uniformity to ensure all plants receive baseline levels, and 3) water applied in excess of plant needs that could be conserved.

Fig. 2. Two pictures showing examples of common urban landscapes in south Florida. The first is a residential home with a mixture of turfgrass, trees, shrubs and other ornamentals while the second is an athletic field composed mainly of turfgrass. (Photos by K Moore)

### 2.1 Plant evapotranspiration

Depending on the location of the urban landscape, a variety of plant materials may be used to meet the aesthetic demands. Some plants are capable of acquiring more water or have high water-use efficiencies and will resist drought better (Taiz and Zeiger, 2006). For example, some plants possess $C_4$ and CAM modes of photosynthesis that allow them to survive in more arid climates (Taiz and Zeiger, 2006). Other plant adaptations that help regulate the demand for water include varying leaf size, leaf orientation, leaf coatings (waxes and hairs), and varying total leaf area (Taiz and Zeiger, 2006).

Evapotranspiration is a major component of the landscape water budget. Two processes are at work simultaneously. Evaporation of water or the conversion of liquid water to water vapor occurs from the soil. At the same time, water is lost from plant leaves to the atmosphere via the process of transpiration through leaf stomata. Evapotranspiration has been defined as the evaporation of water from a soil surface and transpiration of water from plant material (Allen et al. 2011; FAO, 2010). Several factors drive ET including solar radiation, temperature, relative humidity, and wind speed (ASCE-EWRI, 2005).

There are several methods for determining evapotranspiration rates. Actual evapotranspiration (AE, AET, and ETa) is measured by isolating the plant root zone and controlling the amount of water applied. Equipment such as lysimeters, pressure chambers, and tensiometers accurately record the amount of water lost from the soil and plant (Moore, 2008). Because of the expense of the equipment as well as the time commitment, most horticulturists rely on estimates made by computing potential ET rates (PET or ETp) and/or reference ET rates (ETo) that use weather data and mathematical equations rather than measuring AET (Moore, 2008). Reference ET is defined as the ET from a hypothetical reference crop with the characteristics of an actively growing, well-watered, dense green cool season grass of uniform height (ASCE-EWRI, 2005). Studies have shown that there is a strong relationship between actual ET and potential ET/reference ET.

Generalizations have been made about water use based on historical ET values for an area. This data can be used to schedule irrigation events as well as serve as a reference of water demand throughout the year. For example, the historical ET value in March in Fort Lauderdale Florida is approximately 0.13 inches. In general, ET rates tend to follow changes in humidity, wind speed, temperature, and solar radiation with minimum ET rates occurring in the cooler months and higher ET rates occurring in warmer months with higher solar radiation levels (Table 1) (Moore, 2008). Kjelgren et al. (2000) estimated landscape water use for cities in the United States by subtracting average winter water use from water use in April-September and then dividing by the total yearly water use. Cities varied from 9% of total in Atlanta to 48% in Salt Lake City (Kjelgren et al. 2000).

Unfortunately, standard ET definitions tend to be more relevant for turf but not trees, shrubs and other ornamentals in the landscape (St Hilaire et al., 2008). A more appropriate definition for water needs of non-turf species would be the percentage of ET required to maintain their appearance and intended function (Pittenger et al. 2001; Shaw and Pittinger, 2004). Furthermore, many non-turf species can maintain acceptable appearance at some level of moisture deficit (Kjelgren et al. 2000). For example, Montague et al. (2007) reported that shoot dry weight of *Lagerstroemia indica* 'Victor' (crape myrtle), *Spiraea* x *vanhouttei* (spiraea), and *Photinia* x *fraseri* (photinia) was greater for plants irrigated with high (100% reference ETO) and medium (75% reference ETO) irrigation than with low irrigation (50% reference ETO). However, they also reported that using organic mulch and irrigating plants at 50% reference ETO produced acceptable growth and appearance.

Scientists have been working to develop plant factors (PF) that they multiply with ET to define the minimum irrigation a plant needs to maintain acceptable appearance and function rather than optimum growth and yield (Pittenger et al, 2001; Shaw and Pittenger, 2004; Staats and Klett, 1995; Devitt et al, 1994; Montague et al., 2004). However, there are limitations to using PF and further work is needed. For example, a widely referenced publication containing a list of PF ranges for landscape species is based on non-research data (Costello and Jones, 2000).

| Month and year | Avg. Temp (°C) | RH (%) | Solar Radiation ( W/m²) | Average ET (in) |
|---|---|---|---|---|
| Jan-06 | 19.81 | 71 | 157 | 0.07 |
| Feb-06 | 18.69 | 70 | 192 | 0.09 |
| Mar-06 | 21.32 | 66 | 230 | 0.13 |
| Apr-06 | 24.29 | 66 | 263 | 0.16 |
| May-06 | 25.46 | 69 | 260 | 0.17 |
| Jun-06 | 27.35 | 74 | 225 | 0.17 |
| Jul-06 | 27.40 | 77 | 215 | 0.17 |
| Aug-06 | 27.87 | 76 | 210 | 0.18 |
| Sep-06 | 26.90 | 77 | 190 | 0.15 |
| Oct-06 | 25.48 | 70 | 197 | 0.11 |
| Nov-06 | 21.71 | 72 | 138 | 0.09 |
| Dec-06 | 22.72 | 75 | 116 | 0.08 |

Table 1. Average monthly temperature, relative humidity, solar radiation, and average monthly evapotranspiration (ET) rates in Fort Lauderdale FL as recorded by the Florida Automated Weather Network (http://fawn.ifas.ufl.edu/).

### 2.2 Irrigation uniformity

In other agriculture systems that require irrigation, irrigation efficiency is measured as the effectiveness of an irrigation system to deliver water to plants and the effectiveness of irrigation in increasing plant production (Haman et al. 2005). Irrigation efficiency is the ability to deliver water with a minimum of effort, waste, and expense and is an important component of irrigation scheduling and water budgets (De Pascale et al., 2011). For example, sprinkler systems used in container production tend to have irrigation efficiencies ranging from 15 to 50%, while micro irrigation systems (trickle and micro-spray) have average efficiencies ranging from 70 to 90% (Haman et al., 2005; Howell, 2003).

Unfortunately, there are a variety of irrigation systems used in urban landscapes that vary in application rate and uniformity. Application rates measure the rate of water applied to the soil in inches or mm per hour. For example, rotary sprinklers tend to have application rates of 0.25 to 0.50 inches per hour while spray heads tend to have application rates of 1 to 2 inches per hour (Bodle, 2003). Run-off and waste occur when application rates exceed the absorption capacity of the soil (Bodle, 2003).

Irrigation uniformity in the landscape is defined as the application of water to the landscape as evenly as possible (St. Hilaire et al., 2008; Kjelgren et al. 2000). Unfortunately, the amount of water applied in most urban landscapes is usually above baseline needs due to non-uniformity of application (Fig 3). For example, the application of more water to dry spots will result in over-irrigation in other parts of the landscape. The goal is to reduce the difference between minimum and maximum wetted areas (Zoldoske et al. 1994).

Fig. 3. This picture is an example of symptoms related to non-uniform irrigation of turf resulting in dry patches as well as green patches. (Photo by K Moore)

Collecting irrigation water in catch cans randomly placed in the irrigated area after running the system for a pre-determined length of time is a good method for determining application rates as well as uniformity. It is best to place open containers evenly in the radius of the throw of the sprinklers. A minimum catch-can reading of 3 mm in the driest catch can is suggested.

Application rate is determined by the average water levels in the catch cans as inches per hour or mm per hour. This is an indication of the water output for the irrigation system. A catch can test also can be used to determine uniformity (ASAE S398.1; American Society of Agricultural and Biological Engineers, 1985). There are three common ways of calculating water application uniformity: coefficient of uniformity (CU), distribution uniformity (DU), and scheduling coefficients (SC) (Burt et al., 1997). According to Zoldoske et al. (1994), the use of CU is the most referenced measure in agricultural irrigation. However, CU does not distinguish between over and under irrigated areas. Therefore, DU is more commonly used for landscape irrigation (St Hilaire et al., 2008). DU is calculated as the average depth of water in the driest 25% of cans divided by the average for all cans (St. Hilaire et al., 2008; Kjelgren et al. 2000). For example, a sprinkler system that applies the same depth of water over the entire coverage area would have a DU of 100% but if part of the areas receives half the average amount, then the DU would be 50% and twice the amount of water would be applied to the wetter areas (Goldhamer and Synder, 1989). The DU also will vary with the type of sprinkler head as well as field spacing. For example, Kjelgren et al. (2000) reported that the DU of impact/gear sprinklers for large turf areas was 90% while spray heads in small turf areas had a DU of 75%.

## 3. Irrigation and plant establishment

Most plants will require irrigation following planting into the landscape. There are varied recommendations on how much water and how often plants need to be watered during the establishment period in the urban landscape. Plants can become stressed when not properly irrigated during establishment. Adequate water is necessary to establish plants because they do not have sufficient root systems to compensate for the losses resulting from evapotranspiration (Barnett, 1986; Gilman et al., 1996; Montague et al., 2000). If irrigation is inadequate, root growth will be reduced (Balok and St. Hilaire, 2002; Witherspoon and Lumis, 1986) which will likely result in reduced vegetative (Shackel et al., 1997; Gilman and Beeson, 1996) and reproductive growth (Shackel et al., 1997). Drought symptoms will occur in plants not receiving sufficient irrigation including declining plant health and quality (Pittenger et al., 2001) and eventually plant death (Eakes et al., 1990).

Plants can die or grow poorly without irrigation immediately following planting (Geisler and Ferree, 1984). For example, research conducted at the University of Florida reported that *Psychotria nervosa* (wild coffee), *Murraya paniculata* 'Lakeview' (orange jasmine), and *Acalypha wilkesiana* (copperleaf) plants irrigated every 2 days with 3 L of water grew better than shrubs watered every 4 or 8 days with 3 L of water (Moore et al, 2009). However, after 52 weeks in the ground, rain fall events appeared to be sufficient to keep these shrubs alive and growing eliminating any initial effects from irrigation frequency.

### 3.1 Irrigation frequency

Irrigation frequency has been repeatedly reported to influence growth of trees and shrubs. A number of studies have reported that increased irrigation frequency corresponded to an increase in growth during establishment (Stabler and Martin, 2000; Marshall and Gilman, 1998; Gilman et al., 1996; Barnett, 1986). For example, red maple (*Acer rubrum* ) trees that were irrigated more frequently for 24 weeks had greater trunk diameter, height, and more root mass than trees watered less frequently for 24 weeks (Marshall and Gilman, 1998). Daily irrigation of *Ilex cornuta* 'Burford Nana' during establishment significantly increased shoot number, shoot: root ratios, and the percentage of roots originating from the top half of the root ball while less frequent irrigation promoted deeper rooting, but decreased shoot growth (Gilman et al., 1996). Harris and Gilman (1993) found greater regenerated root dry weight and root volume when *Ilex* x *attenuata* 'East Palatka' (holly) shrubs were watered more frequently. Gilman and Beeson (1996) also reported that trunk growth rate of 'East Palatka' holly slowed when irrigation frequency was reduced from daily to every 2 days. Knox and Zimet (1988) reported an increase in plant size and dry weight (*Myrica* and *Photinia*) when irrigation frequency increased but only for shrubs actively growing during the period of the study.

### 3.2 Irrigation volume

Irrigation volume appears to less critical to landscape establishment than irrigation frequency. Welsh et al. (1991) reported no significant changes in growth of *Photinia* x *fraseri* as a response to increased irrigation volume. Similarly, Gilman et al. (1998) reported that irrigation volume did not affect trunk diameter, crown spread, or height of live oak (*Quercus virginiana*) but trees that were irrigated infrequently grew more slowly than those irrigated more frequently. Paine et al. (1992) investigated the differences in growth of woody landscape plants that received the same total volume of water delivered at different irrigation frequencies. They reported that the irrigation treatments did not significantly affect plant size of *Rhamus* or *Photinia* plants but *Ceanothus* plants that were watered daily had less change in size than plants watered every 3rd or 7th day.

### 3.3 Planting season

Planting season has also been reported to influence woody plant establishment. For example, Harris and Bassuk (1994) reported that early spring/late fall transplant improved survival of *Quercus coccinea* (scarlet oak) and *Corylus colurna* compared to late spring/early fall transplant. A number of studies reported increased canopy growth (Harris et al., 1996; Dickinson and Whitcomb, 1981) and increased root growth (Hanson et al., 2004; Harris et al., 2002; Harris et al., 1996) in fall planted woody species compared with spring planted trees and shrubs. Fall planted trees and shrubs initiated roots earlier (Harris et al., 2002) and extended roots farther (Hanson et al., 2004; Harris et al., 1996) than woody plants established in other seasons. In addition, planting season may interact with irrigation frequency to affect establishment. Welsh et al. (1991) reported reduced canopy growth at increased irrigation frequencies when *Photinia* x *fraseri* was planted in the winter, but not when shrubs were established in the summer. Harris et al. (2002) reported that sugar maple (*Acer saccharum* 'Green Mountain') and northern red oak (*Quercus rubra* ) transplanted in the fall had more root growth than later fall or spring transplanted trees. They speculated that early root growth benefited the trees by providing amble roots to meet the higher water demand in the spring due to the developing canopies.

Shober et al. (2009) reported that viburnum could be transplanted year round in Florida, but it appears that in central and north central Florida plants grew better when transplanted in March (average ETp of 5.54 in Balm and 4.68 in Citra), while in south Florida viburnum plants grew better when transplanted in December (average ETp of 5.54 in Fort Lauderdale).

## 4. Water conservation

According to Gollehon and Quinby, (2006) 90% of total water use in the United States comes from renewable surface and ground water supplies. However, because of uneven distribution of water resources in the United States, droughts in different parts of the country might exacerbate supplies. When discussing water conservation it is important to distinguish between short term and long term conservation strategies (Kjelgren et al., 2000) Short-term conservation becomes important during drought periods when there is insufficient water to supply landscape irrigation with the understanding that normal consumption may resume after the emergency passes (Fig 4). However, long-term conservation occurs when supplies no longer support existing demands as well as future demands or when the cost of delivering water becomes prohibited (Kjelgren et a., 2000). There are several tools available for conserving water in the urban landscape such as low-water use landscapes, precision irrigation, and alternative water sources.


Fig. 4. This is an example of a short term conservation strategy as reflected by the sign over the road in Tamarac, Florida reading "Extreme drought, reduce your water use, no excuse." (Photo by K. Moore)

### 4.1 Water efficient landscapes

Proper selection of plant material that is considered 'water-efficient' is one technique for conserving water. It is well documented that a uniform sprinkler-irrigated landscape of herbaceous perennials and woody plants potentially uses less water than a turf landscape (Kjelgren et al., 2000). Trees, shrubs and perennials tend to respond to drought better than turfgrass because non-turf species tend to root more deeply and can maintain acceptable appearance under conditions of minor water stress. It also is possible to effectively use low-volume irrigation (drip or micro) on non-turf species that apply water to the root zone and reduce water loss from evaporation and runoff (Fig 5) (Dawson, 1993; Green and Clotheir, 1995; Kjelgren et a;., 2000). Mayer et al, (1999) reported that drip irrigation used 16% more water than homes that did not irrigate while homes with in-ground systems used 35% more water than homes with no irrigation.

Haley et al. (2007) compared residential water use in three different urban landscape situations in Central Florida. Treatment one consisted of an existing in-ground irrigation system and typical Florida landscape (75% turf, with common trees and shrubs used in the urban landscape) that was irrigated by the homeowner. Treatment two had a similar irrigation system and landscape design as treatment one but the time clock was adjusted seasonally to replace 60% of the historical ET. Treatment 3 was designed for optimal efficiency including minimized turfgrass (31%) that was irrigated on a separate zone from ornamentals (native plants) that were irrigated with micro-irrigation. They reported that treatment 1 used 149 mm/month while 2 used 105 mm/month and 3 used 74mm/month (Haley et al., 2007)

One of the biggest barriers to installing water-efficient landscapes is public perception about appearance or aesthetics (Hurd et al., 2006). According to a survey by Lockett et al. (2002), only 9% of respondents in Lubbock, TX felt water-conserving landscapes were aesthetically pleasing while 61% felt the opposite. Unfortunately, most individuals imagine water efficient landscapes as gravel landscapes interspersed with some drought tolerant plants (St Hilaire et al, 2008).

Fig. 5. Comparison of typical home irrigation versus the use of micro-irrigation at the base of the shrub or tree (Photos by K Moore)

### 4.2 Precision irrigation

Over-irrigation is wasteful and can cause run-off, flooding, and may carry away nutrients or other chemicals that could damage or pollute water resources. There are several useful tools available to improve irrigation application including rain sensors, soil moisture sensors, and evapotranspiration controllers (McCready and Dukes, 2011). For example, McCready et al. (2009) reported that water use was reduced by 7 to 30% using rain sensors, 0 to 74% using soil moisture sensors, and 25 to 62% using ET based sensors when compared to a typical time based irrigation set to irrigate 2 days a week.

Rain sensors or rain shut-off controllers will stop scheduled irrigation events when a specific amount of rainfall has occurred (Dukes and Haman, 2010). Benefits of using rain sensors include 1) water conservation, 2) reduced utility bills, 3) reduced wear on irrigation systems, 4) reduced disease damage, and 5) reduced pollution potential of surface and groundwater (Dukes and Haman, 2010). Carenas-Lailhacar et al. (2008) reported that treatments using rain sensors applied 34% less water than treatments without rain sensors while maintaining good turf quality. Haley and Dukes (2007) also reported that homes in Pinellas County Florida in 2006-2007 with rain sensors applied 19% less water than homes without rain sensors.

Another effective tool is the use of soil moisture sensors that recognize soil moisture levels to control irrigation events. Qualls et al. (2001) reported that the use of soil moisture sensors to control irrigation resulted in 193 mm less water used than the theoretical requirement. The most commonly used residential soil moisture sensors are bypass systems that have soil moisture threshold adjustments from dry to wet and will bypass a timed irrigation event if the soil moisture content is above the threshold. The threshold is adjustable but these types of sensors typically do not adjust the length of time of irrigation events, only whether the irrigation event occurs (Dukes, 2009). Cardenas-Lailhacar et al. (2008) reported water savings of 69 to 92% using three different SMS controllers. Other soil moisture sensors available are classified as on-demand controllers that begin irrigation at pre-determined low soil moisture thresholds and end irrigation at the high threshold. The difference between these controllers is that on-demand controllers begin and end irrigation events while by-pass controllers regulate whether schedule irrigation events on a time clock will occur.

Evapotranspiration controllers irrigate based on the calculated ET needs of the plant or landscape. Ideally they replace the water lost due to ET. There are several different types of ET controllers including standalone controllers, signal based controllers, and historical based controllers (Davis and Dukes, 2010). Stand alone controllers measure climatic variables (temperature and solar radiation) on site and then determine a cumulative daily ET value. Signal based controllers receive ET data from a wireless connection while historical ET controllers rely on historical ET information for the area (Davis and Dukes, 2010). Three ET controllers evaluated in southwest Florida by Davis et al. (2009) reported an averaged water savings of 43% over time-based irrigation without a rain sensor. Davis and Dukes (2010) reported that properly programmed ET controllers are more effective than manual irrigation scheduling because they can adjust to real-time weather and minimize over-watering.

In addition to using ET controllers, historical ET data can be used to manually control standard irrigation systems. For example, we know that in Fort Lauderdale Florida in March we tend to historically lose 0.13 inches of water a day, due to ET. If the application rate of an irrigation system is 2.10 inches per hour, it is possible to determine how long to run the irrigation system. In this example, the system would need to run for 3.7 minutes a day to replace the 0.13 inches of water lost per day.

0.13 inches/day X 1 hour/2.10 inches X 60 minutes/1 hour = 3.7 minutes/day

Because of different products available to schedule irrigation that vary in the technology and complexity, a testing protocol based on the soil water balance model was developed by the Irrigation Association (2008) titled Smart Water Application Technology (SWAT) protocol. SWAT is a national initiative to improve landscape water efficiency by applying water based on plant needs in order to reduce waste and runoff (St Hilaire et al., 2008; McCready and Dukes, 2011). McCready and Dukes (2001) compared the irrigation adequacy and scheduling efficiency of soil moisture sensors, ET controllers, and rain sensors over several 30-day periods to determine the amount of over irrigation and under irrigation for each technology based on the SWAT testing protocol. All controllers resulted in water conservation. However, they concluded that examining only one 30 day testing period as recommended in the SWAT testing protocol was not sufficient to capture the performance of an irrigation controller because values varied significantly (McCready and Dukes, 2011).

### 4.3 Alternative water sources

Although a more expensive alternative to other conservation practices, the use of reclaimed water from sewage effluent after treatment is a cheaper alternative for landscape irrigation than using other potable water sources (Postel, 1992). Waste water effects on field and forage crops, wetland plants, and forest ecosystems, have been the subject of numerous studies (Brister and Schultz, 1981; Day et al., 1981; Day and Tucker, 1977). However, studies conducted on the use of reclaimed waste water on the growth of ornamental plants have reported varying results (Yeager et al., 2009; Devitt et al., 2003; Gori et al., 2000; Parnell and Robinson, 1990; Fitzpatrick et al., 1986; Fitzpatrick, 1985; Parnell, 1988). For example, Fitzpatrick et al. (1986) reported that 4 out of 20 ornamental plant species tested had significantly increased growth when irrigated with treated waste water effluent while the other species showed no difference. They speculated that increased nutrient levels, especially nitrogen and phosphorus in sewage effluent might have contributed to increases in growth. Lubello et al. (2004) reported no difference in shoot dry weight of cypress (*Taxodium* spp.), juniper (*Juniperus* spp.), myrtle (*Myrtus* spp.), and *Weigela* spp. between well water and tertiary effluent irrigated plants but *Spiraea* spp. and *Arbutus* spp. shoot dry weight was less for plants irrigated with tertiary effluent. They suggested that there appeared to be no major limitation to using tertiary effluent as an irrigation source and that it had the added potential of serving as a source of fertilizer. Monitoring of nutrients in irrigation water is important when using reclaimed water. In general reclaimed water tends to have higher soluble salts and must be applied at higher volumes to provide leaching of salts from the soil (Hayes et al. 1990).

The use of waste water is not available in all states in the United State and in some states the costs of connecting to waste water is quite high. Most active waste water programs are used to irrigate golf courses, parks, and roadway medians where public acceptance is higher than in areas with greater contact with the general public (St Hilaire et al. 2008).

## 5. Conclusions

With rising water costs and limited water resources worldwide, it is imperative to continue to investigate conservation alternatives. It is evident that irrigation during plant establishment in the landscape is critical to survival. Research supports more frequent irrigation during establishment. Data also suggests that new landscape installations should be completed during times of lower evapotranspiration stress. After plants are established, irrigation is required to maintain acceptable aesthetic quality standards.

There are many choices available for urban landscape irrigation conservation. Research on using new and existing technologies have already resulted in reduce water consumption in the urban landscape and include the use of smart controllers. Research on low water use landscapes, grouping plants with like water needs, and alternative water sources have also resulted in reduced water consumption but these practices need further research.

## 6. References

American Society of Civil Engineers (ASCE-EWRI). 2005. The ASCE Standardized Reference Evapotranspiration Equation Report 0-7844-0805-X. ASCE *Task Force Committee on Standardization of Reference Evapotranspiration.* Reston, VA.

Allen, R. G.; Pereira, L.S.; Howell, T. A & Jensen, M.E. 2011. Evapotranspiration Information Reporting: I Factors Governing Measurement Accuracy. *Agricultural Water Management* 98:899-920.

American Society of Agricultural and Biological Engineers (ASAE). 1985 *ASAE S398. 1. Procedure for Sprinkler Testing and Performance Reporting* ASAE St Joseph, MI.

Balok, C.A. & Hilaire, R.S. 2002. Drought Responses among Seven Southwestern Landscape Tree Taxa. *Journal of the American Society for Horticulture Science*. 127:211-218.

Barnett, D. 1986. Root Growth and Water Use by Newly Transplanted Woody Landscape Plants. *The Public Garden*. 1:23-25

Bodle, M. (ed). 2003. *Water wise South Florida Landscapes*. South Florida Water Management District, West Palm Beach FL.

Burt, C.M.; Clemmens, A.J.; Strelkoff, T. S; Solomon, K. H.; Bliesner, R. D.; Hardy, L. A; Howell, T.A. & Eisenhauer, D.E. 1997. Irrigation Performance Measure: Efficiency and Uniformity. *Journal of Irrigation and Drainage Engineering* 123:423-442.

Brister, G.H. & Schultz, R.C. 1981. The Response of a Southern Appalachia Forest to Waste Water Irrigation. *Journal of Environmental Quality* 10(2):148-153

Cardenas-Lailhacar, B.; Dukes, M.D. & Miller, G.L. 2008. Sensor Based Automation of Irrigation on Bermudagrass During Wet Weather Conditions. *Journal of Irrigation and Drainage Engineering* 134(2):120-128.

Costello, L.R. &. Jones. K.S. 2000. *Water Use Classification of Landscape Plants (WUCOLS III)*. Retrieved from <http://www.owue.water.ca.gov/docs/wucols00.pdf>

Day, A.A. & Tucker, T. C. 1977. Effects of Treated Municipal Waste Water on Growth, Fiber, Protein, and Amino Acid Content of Sorghum Grain. *Journal of Environmental Quality* 6(3):325-327

Day, A.D; McFadyen, J.A; Tucker, T.C & Cluff, C.B. 1981. Effects of Municipal Waste Water on Yield and Quality of Cotton. *Journal of Environmental Quality* 10(1):47-49.

Davis, S.L. & Dukes, M.D. 2010. Irrigation Scheduling Performance by Evapotranspiration-based Controllers. *Agricultural Water Management* 98:19-28

Davis, S.L., Dukes, M.D. & Miller, G.L. 2009. Landscape Irrigation by Evapotranspiration-based Irrigation Controllers under Dry Conditions in Southwest Florida. *Agricultural Water Management* 96:1828-1836

Dawson, T.E. 1993. Hydraulic Lift and Waste Water Use by Plants – Implications for Water Balance, Performance, and Plant-Plant Interactions. *Oceologia* 95:565-574.

De Pascale, S; Costa, L.D.; Vallone, S., Barbiera, G. & Maggio, A. 2011. Increasing Water Use Efficiency in Vegetable Crop Production: From Plant to Irrigation Systems Efficiency. *HortTechnology* 21(3):301-308.

Devitt, D.A.; Morris, RA. & Neuman D.S. 2003. Impact of Water Treatment on Foliar Damage of Landscape Trees Sprinkle Irrigated with Reuse Water. *Journal of Environmental Horticulture* 21(2)82-88

Devitt, D.A., Neuman D.S., Bowman, D.C. & Morris, R.L. 1995. Water Use of Landscape Plants in an Arid Environment. *Journal of Arboriculture* 21:239-245.

Devitt, D.A.; Morris, R.A. & Bowman D.S. 1994. Evapotranspiration and Growth Response of Three Woody Ornamental Species Placed Under Varying Irrigation Regimes. *Journal of the American Society for Horticultural Science* 119:452-457.

Dickinson, S. & Whitcomb, C.E. 1981. Why Nurserymen Should Consider Fall Transplanting. *American Nurseryman* 153:11. 64-67.

Dukes, M.D. 2009. Smart Irrigation Controllers: What Makes an Irrigation Controller Smart? AE442. *Institute of Food and Agricultural Sciences,* University of Florida, Gainesville FL .Available from: <http://edis.ifas.ufl.edu>

Dukes, M.D. &. Haman, D.Z. 2010. Residential Irrigation System Rainfall Shutoff Devices ABE325. *Institute of Food and Agricultural Sciences,* University of Florida, Gainesville FL. Available from <http://edis.ifas.ufl.edu>

Eakes, D.J.; Gilliam, C.H; Ponder, H.G; Evans, C.E. & Marini M.E. 1990. Effect of Trickle Irrigation, Nitrogen Rate, and Method of Application on Field-grown 'Compacta' Japanese Holly. *Journal of Environmental Horticulture* 8:68-70.

Food and Agriculture Organization (FAO) of the United Nations Corporate Document Repository. 2010. Chapter 1 – Introduction to Evapotranspiration. *FAO Corporation* Available from <http://www.fao.org/docrep/X0490E/x0490e04.htm>

Ferguson, B.K. 1987. Water Conservation Methods in Urban Landscape Irrigation: An Exploratory Overview. *Water Resource Bulletin* 23:147-152.

Fitzpatrick, G.E. 1985. Container Production of Tropical Trees Using Sewage Effluent, Incinerator Ash and Sludge Compost. *Journal of Environmental Horticulture* 3(3):123-125.

Fitzpatrick, G. E.; Donselmann, H. & Carter N.S. 1986. Interactive Effects of Sewage Effluent Irrigation and Supplemental Fertilization on Container-grown Trees. *HortScience* 219(1):92-93

Geisler, D. & Ferree D.C. 1984. Response of Plants to Root Pruning. *Horticultural Review* 6:155-188.

Gilman, E.F. & Beeson R.C. 1996. Production Method Affects Tree Establishment in the Landscape. *Journal of Environmental Horticulture* 14:81-87.

Gilman, E.F.; Black, R.J. & Dehgan B. 1998. Irrigation Volume and Frequency and Tree Size Affect Establishment Rate. *Journal of Arboriculture* 24:1-9.

Gilman, E.F.; Yeager, T.H. & Weigle D. 1996. Fertilizer, Irrigation, and Root ball Slicing Affects Burford Holly Growth after Planting. *Journal of Environmental Horticulture* 14:105-110.

Gollehon, N. & Quinby, N. 2006. Irrigation Resources and Water Costs. Agricultural Resources and Environmental Indicators EIB-16. *U.S. Department of Agriculture Economic Research Services* Available from <www.ers.usda.gov/publications/arei/eib16/eib16_2-1.pdf>

Goldhamer, D. & Synder R. 1989. Irrigation Scheduling: A Guide to Efficient On-farm Water Management. *University of California Publication 21454*, Berkley, CA.

Gori, R.; Ferrini, F.; Nicese, F.P & Lubello C. 2000. Effect of Reclaimed Wastewater and Fertilization on Shoot and Root Growth, Leaf Parameters and Leaf Mineral Content on Three Potted Ornamental Shrubs. *Journal of Environmental Horticulture* 18(2):108-113.

Green, S.R. & Clothier, B.E. 1995. Root Water Uptake by Kiwifruit Vines Following Partial Wetting of the Root Zone. *Plant and Soil* 173:317-328.

Haley, M.B., Dukes, M.D. & Miller, G.L. 2007. Residential Irrigation Water Use in Central Florida. *Journal of Irrigation and Drainage Engineering* 133(5):427-434.

Haley, M.B. & Dukes M.D. 2007. Evaluation of Sensor Based Residential Irrigation Water Application. *ASABE Paper No 072251*, ASABE St Joseph, MI.

Haman, D.Z., Smajstria, A.G. & Pitts D.J. 2005. Efficiencies of Irrigation Systems Used in Florida Nurseries. BUL312 *Institute of Food and Agricultural Sciences*, University of Florida, Gainesville, FL Available from <http://edis.ifas.ufl.edu>

Hanson, A.; Harris, J.R. & Wright, R. 2004. Effects of Transplant Season and Container Size on Landscape Establishment of *Kalmia latifolia* L. *Journal of Environmental Horticulture* 22:133-138.

Harris, J.R. & Bassuk, N.L. 1994. Seasonal Effects on Transplantability of Scarlet Oak, Green Ash, and Turkish Hazelnut, and Tree Lilac. *Journal of Arboriculture* 20:310-317.

Harris, J.R. & Gilman, E.F. 1993. Production Methods Affects Growth and Post-transplant Establishment of 'East Palatka' Holly. *Journal of the American Society for Horticultural Science* 118:194-200.

Harris, J.R.; Fanelli, J. & Thrift P. 2002. Transplant Timing Affects Early Root System Regeneration of Sugar Maple and Northern Red Oak. *HortScience* 37:984-987.

Harris, J.R.; Knight P. & Fanelli J. 1996. Fall Transplanting Improves Establishment of Balled and Burlapped Fringe Tree (*Chionanthus virginicus* L.). *HortScience*. 31:1143-1145.

Hayes, A.; Mancino, C. & Pepper, I. 1990. Irrigation of Turfgrass with Secondary Sewage Effluent: I Soil and Leachate Water Quality. *Agronomy Journal* 82:939-943.

Hope, D.; Gries, C.; Zhu, W.; Fagan, W.F.; Redman, C.L.; Grimm, N.B.; Nelson, A.L.; Martin, C. &. Kinzig, A. 2003. Socioeconomics Drive Urban Plant Diversity. *Proceedings of the National Academy of Science* 100(15):8788-8792.

Howell, T. A. 2003. Irrigation Efficiency. *Encyclopedia of Soil Science*. Marcel Dekker, Inc. New York.

Hurd, B.; St. Hilaire, R. & White, J. 2006. Residential Landscapes, Homeowner Attitudes and Water-wise Choices in New Mexico. *HortTechnology* 16:241-246.

Irrigation Association. 2008. Smart Water Application Technology (SWAT) Turf and Landscape Irrigation Equipment Testing Protocol for Climatologically Based Controllers. 8th edition. *Irrigation Association* Falls Church, VA.

Kjelgren, R.; Rupp, L. & Kilgren D. 2000. Water Conservation in Urban Landscapes. *HortScience* 35(6):1037-1040.

Knox, G. W. & Zimet D. 1988. Water Use Efficiency of Four Species of Woody Ornamentals under North Florida Winter Conditions. *Proceedings of the Florida State Horticultural Society* 101:331-333.

Limaye, U. 1996. Analysis of Residential Water Demand Using Multispectral Videography and Other Electronic Databases. PhD Dissertation *Department of Biology and Irrigation Engineering at Utah State University*, Logan UT.

Lockett, L.; Montague, T.; McKenney C.; & Auld D. 2002. Assessing Public Opinion on Water Conservation and Water Conserving Landscapes in the Semiarid Southwestern United States. *HortTechnology* 12:392-396.

Lubello, C.; Gori, R.; Nicese, F.P. & Ferrini F. 2004. Municipal-treated Wastewater Reuse for Plant Nurseries Irrigation. *Water Research* 38:2939-2947

Marshall, M.D. & Gilman, E.F. 1998. Effects of Nursery Container Type on Root Growth and Landscape Establishment of *Acer rubrum* L *Journal of Environmental Horticulture* 16:55-59.

Mayer, P.W.; DeOreo, W.B.; Opitz, E.M.; Kiefer, J.C.; Davis, W.Y.; Dziegielewski, B. & Nelson, J.O.. 1999. Residential End Users of Water. *American Water Works Association Research Foundation*, Denver, CO.

McCready. M.S. & Dukes, M.D. 2011. Landscape Irrigation Scheduling Efficiency and Adequacy by Various Control Technologies. *Agricultural Water Management* 98:697-704.

McCready, Dukes, M.D. & Miller, G.L. 2009. Water Conservation Potential of Smart Irrigation Controller on St. Augustinegrass. *Agricultural Water Management* 96:1623-1632.

Moore, K.A. 2008. Following the Vapor Trail. *Ornamental Outlook*. Available from <www.ornamentaloutlook.com/nursery/index.php?storyid=105>

Moore, K.A.; Shober, A.L.; Gilman, E.F.; Wiese, C.; Scheiber, S.M; Paz, M. & Brennan M.M. 2009. Posttransplant Growth of Container Grown Wild coffee, Copperleaf and Orange Jasmine is Affected by Irrigation Frequency. *HortTechnology* 19(4):786-791.

Montague, T.; McKenney, C; Maurer, M. & Winn B. 2007. Influence of Irrigation Volume and Mulch on Establishment of Select Shrub Species. *Arboriculture & Urban Forestry* 33(3):202-209.

Montague, T.; Kjelgren, R.; Allen, R. & Webster D. 2004. Water Loss Estimates for Five Recently Transplanted Tree Species in a Semi-arid Climate. *Journal of Environmental Horticulture* 22:189-196.

Montague, T.; Kjelgren, R.; Allen, R. & Wester D. 2000. Water Loss Estimates for Five Recently Transplanted Landscape Tree Species in a Semi-arid Climate. *Journal of Environmental Horticulture* 22:189-196.

Paine, T.D.; Hanlon, C.C.; Pittenger, D.R.; Ferrin, D.M & Malinoski M.K. 1992. Consequences of Water and Nitrogen Management on Growth and Aesthetic Quality of Drought-tolerant Woody Landscape Plants. *Journal of Environmental Horticulture* 10:94-99.

Parnell, J. R. 1988. Irrigation of Landscape Ornamentals Using Reclaimed Water. *Proceedings of the Florida State Horticultural Society* 101:107-110.

Parnell, J. R. & Robinson, M LaRue. 1990. Reclaimed Water and Florida Natives. *Proceedings of the Florida State Horticultural Society* 103:377-379.

Postel, S. 1992. *Last Oasis: Facing Water Scarcity*. W.W. Norton Co. New York.

Qualls, R.J.; Scott, J.M. & DeOreo W.B. 2001. Soil Moisture Sensors for Urban Landscape Irrigation: Effectiveness and Reliability. *Journal of the American Water Resource Association* 37(3):547-559.

Pittenger, D.R.; Shaw, D.A.; Hodel D.R. & Holt D.B. 2001. Responses of Landscape Groundcovers to Minimum Irrigation. *Journal of Environmental Horticulture* 19:78-84.

St. Hilaire, R.; Arnold, M.A; Wilkerson D.C.;, Devitt, D. A.; Hurd, B.H.; Lesikar, B.J;. Lohr, V.I..; Martin, C.A.; McDonald, G.V.; Morris, R.L.; Pittenger, D.R.; Shaw D.A. &. Zoldoske D.F. 2008. Efficient Water Use in Residential Urban Landscapes. *HortScience* 43(7):2081-2092.

Salamone, D. 2002. A Drying Oasis Series: Florida Water Crisis Chapter 1. *Orlando Sentinel*. 03 Mar: A1.

Salvador, R. Baustista-Capetillo, C. & Playan, E. 2011. Irrigation Performance in Private Urban Landscapes: A Case Study in Zaragoza (Spain). *Landscape and Urban Planning* 100:302-311.

Shackel, K.A.; Ahmadi, H.; Biasi, W.; Buchner, R.; Goldhamer, D.; Gurusinghe, S.; Hasey, J.; Kester, D.; Krueger, B.; Lampinen, B.; McGourty, G.; Micke, W.; Mitcham, E.; Olson, B.; Pelletrau, K.; Philips, H.; Ramos, D.; Schwankl, L.; Sibbett, S;. Snyder, R.; Southwick, S.; Stevenson, M.; Thorpe, M.; Weinbaum, S. & Yeager J. 1997. Plant Water Status as an Index of Irrigation Need in Deciduous Fruit Trees. *HortTechnology* 7:23-29.

Shaw, D.A. & Pittenger, D.R. 2004. Performance of Landscape Ornamentals Given Irrigation Treatments Based on Reference Evapotranspiration. *Acta Horticulturae* 664:607-613.

Shober, A.L.; Moore, K.A; Wiese, C.; Scheiber, S.M.; Gilman, E.F.; Paz, M.; Brennan, M.M. & Vyapari, S. 2009. Posttransplant Irrigation Frequency Affects of Container-grown Sweet Viburnum in Three Hardiness Zones. *HortScience* 44(6):1683-1687.

Staats, D. & Klett, J.E. 1995. Water Conservation Potential and Quality of Non-turf Groundcovers, versus Kentucky Bluegrass Under Increasing Levels of Drought Stress. *Journal of Environmental Horticulture* 13:181-185.

Stabler, L.B. & Martin, C.A. 2000. Irrigation Regimens Differently Affect Growth and Water Use Efficiency of Two Southwest Landscape Plants. *Journal of Environmental Horticulture* 18:66-70.

Taiz, L & Zeiger E. 2006. *Plant Physiology 4th edition*. Sinauer Associates, Inc. Publishers Sunderland, Massachusetts

Thayer, R.L. 1982. Public Response to Water-conserving Landscapes. *HortScience.* 17:562-565.

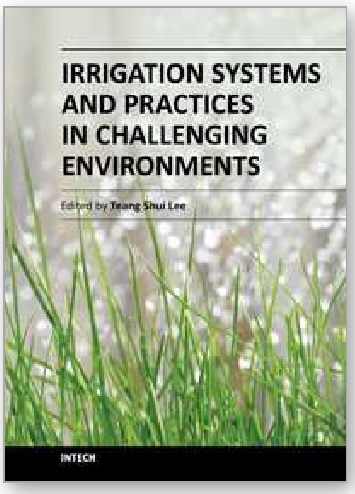
Western Resource Advocates. 2010. Urban Sprawl: Impacts on Urban Water Use Smart *Water: A Comparative Study of Urban Water Use Across the Southwest.* Available from: <www.westernresourceadvocates.org/media/pdf/SWChapter4.pdf>

Welsh, D.F.; Zajicek, J.M. & Lyons, Jr. C.G. 1991. Effect of Seasons and Irrigation Regimes on Plant Growth and Water-use of Container-grown *Photinia* x *fraseri*. *Journal of Environmental Horticulture.* 9:79-82.

Witherspoon, W.R. & Lumis, G.P. 1986. Root Regeneration of *Tilia cordata* Cultivars after Transplanting in Response to Root Exposure and Soil Moisture Levels. *Journal of Arboriculture* 12:165-168.

Yeager, T.; Larsen, C; von Merveldt, J. & Irani T. 2009. Use of Reclaimed Water for Irrigation in Container Nurseries ENH1119. *Institute of Food and Agricultural Sciences*, University of Florida, Gainesville, FL Available from <http://edis.ifas.ufl.edu>

Zoldoske, D.F.; Solomon, K.H. & Norum E.M. 1994. Uniformity Measurements for Turfgrass: What's Best? *Center for Irrigation Technology* November Irrigation Notes.

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The book Irrigation Systems and Practices in Challenging Environments is divided into two interesting sections, with the first section titled Agricultural Water Productivity in Stressed Environments, which consists of nine chapters technically crafted by experts in their own right in their fields of expertise. Topics range from effects of irrigation on the physiology of plants, deficit irrigation practices and the genetic manipulation, to creating drought tolerant variety and a host of interesting topics to cater for the those interested in the plant water soil atmosphere relationships and agronomic practices relevant in many challenging environments, more so with the onslaught of global warming, climate change and the accompanying agro-meteorological impacts. The second section, with eight chapters, deals with systems of irrigation practices around the world, covering different climate zones apart from showing casing practices for sustainable irrigation practices and more efficient ways of conveying irrigation waters - the life blood of agriculture, undoubtedly the most important sector in the world.