Draft
White Paper: Evapotranspiration Adjustment Factor.
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Prepared by Department of Water Resources staff in support of the updated Model Water Efficient Landscape Ordinance

1. Introduction.

The evapotranspiration adjustment factor (ETAF) is a coefficient that adjusts reference evapotranspiration (ETo) values based on a plant factor (PF) and irrigation efficiency (IE) and is used to calculate the maximum amount of water that can be applied to a landscape. ETo is a combination of evaporation and transpiration from standardized grass surfaces on which weather parameters are measured and ETo is then calculated. The plant factor includes effects of plant type, plant density, and microclimate on the water demand of a landscape. Irrigation efficiency is the amount of water that is beneficially used divided by the total amount of water applied. For purposes of this paper, however, IE is estimated from distribution uniformity (DU) and irrigation management efficiency (IME). DU is a measure of the uniformity of irrigation water that is applied to the landscape and theoretically ranges in value from zero to 100 percent. IME is an indicator of how well the irrigation water is being managed. ETAF, therefore, is determined by quantifying all of these factors and dividing the plant factor by IE to get ETAF (PF / IE = ETAF). This white paper is prepared to describe how the Department of Water Resources (DWR) , using the best available resources, updated the ETAF value in the Model Water Efficient Landscape Ordinance (the Ordinance).

2. Background.

In 1990, California was in a fourth consecutive year of drought and Assembly Bill 325, Water Conservation in Landscaping Act of 1990, was signed. This bill required DWR, by February 1, 1991, to appoint an advisory task force to work with the Department in drafting a model water efficient landscape ordinance. After holding public hearings, and based on recommendations of the task force, DWR adopted the State Model Ordinance in 1992. By January 1993, local agencies were required either to adopt a local water efficient landscape ordinance, adopt the state model water efficient landscape ordinance, or make a statement as to why the ordinance was not necessary. Prior to the Model Ordinance of 1992, local agencies were not required to adopt a landscape water conservation ordinance.

In 2001, a report by Western Policy Research (WPR) (Bamizai et al., 2001) concluded that nearly 90% of new development between 1992 and 1999 took place in agencies that had adopted a water efficient landscape ordinance. WPR also found deficiencies in AB 325 due to a lack of education about the ordinance, maintenance contractors rarely irrigating accurately, and that “maintenance” was the weakest link in the “design, installation, and maintenance” of water efficient landscape. The biggest problem that the researchers found, however, was the lack of irrigation monitoring or enforcement of the maximum applied water allowance in the field. Partly because of this report, Assembly Bill 2717 (AB 2717) was proposed to address some of the deficiencies of AB 325.

AB 2717 was passed in 2004 and requested the California Urban Water Conservation Council (CUWCC) to convene a stakeholder Task Force, comprised of public and private agencies, to evaluate and recommend proposals by December 31, 2005, for improving the efficiency of water use in new and existing urban irrigated landscapes in California. The Task Force adopted a comprehensive set of 43 recommendations for updating the State Model Ordinance pursuant to AB 325. The task force also recommended that DWR form a stakeholder work group with broad representation to study the ETAF as a part of updating the landscape model ordinance.

The existing State Model Water Efficient Landscape Ordinance, prepared through a consensus stakeholder process, established a water budget for new construction based on size of the landscape, reference evapotranspiration (ETo), and an ETAF with a specified plant mix. To be approved by the local Planning Department, new landscapes must be designed and installed to meet the water budget. The existing Model Ordinance utilizes a statewide plant factor of 0.5, representing a mix of 1/3 high, 1/3 moderate, 1/3 low water using plants. The irrigation efficiency for purposes of the ETAF in the existing ordinance is 0.625 (or 62.5%). The ETAF is then obtained by dividing the average plant factor of 0.5 by the average irrigation efficiency of 62.5%, resulting in an ETAF of 0.8.

The Task Force Recommendation 12 specifically states that “DWR should reduce the ET Adjustment Factor in the Model Ordinance by 2010 for new non-single – family development, based on the results of a three year study of new and established landscapes designed to meet a variety of ET Adjustment Factors and a mix of plant factors (including the 0.5 plant factor) and if the study cannot be funded to use the best other data available”. The Task Force’s Irrigation Work Group recommended reducing ETAF to 0.70 from its current value of 0.80 based on an expected increase in irrigation efficiency from 62.5% to 71%.

Governor Arnold Schwarzenegger signed the Water Conservation in Landscaping Act of 2006, Assembly Bill 1881 (AB 1881), on September 28, 2006. The bill charges the Department of Water Resources (DWR), among other things, to update the Model Water Efficient Landscape Ordinance. The Water Conservation in Landscaping Act (Laird, Chapter 559, Statutes of 2006) includes some of the recommendations by the Task Force. The 2006 Act requires DWR, no later than January 1, 2009, to update the model ordinance in accordance with the recommendations of the Task Force. The 2006 Act also requires the

California Energy Commission (CEC), in consultation with DWR, to adopt, by regulation, performance standards and labeling requirements for landscape irrigation equipment, including irrigation controllers, moisture sensors, emission devices, and valves to reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy or water. The 2006 Act also requires DWR, not later than January 31, 2011, to prepare and submit a report to the Legislature relating to the status of water efficient landscape ordinances adopted by local agencies and on the DWR's recommendation regarding the landscape water budget component that establishes the maximum amount of water to be applied through the irrigation system, based on climate, landscape size, irrigation efficiency, and plant needs (AB 1881, section 65595 (a)(2) and (B), section 65596 (b)). DWR is in the process of preparing the updated Model Water Efficient Landscape Ordinance in consultation with stakeholders and through the rule making process.

In 2007 DWR formed an ETAF Technical Advisory Committee (TAC) to receive input in developing an ETAF study project proposal and assist DWR in the development of a new water budget component for the updated Model Ordinance. The TAC members represented a wide diversity of interested parties. The TAC has met several times and reviewed DWR's scope of work for a project to be conducted statewide. DWR has initiated a contract with the University of California (UC) researchers to establish a comprehensive long-term study of new and established landscapes designed to meet a variety of ET Adjustment Factors and a mix of plant factors (including the 0.5 plant factor) in several locations state wide. The UC researchers have agreed, in principle, to participate in a limited number of study locations in the state and DWR is in negotiations to find other researchers to make the study more robust state wide.

DWR intends to adopt the updated Ordinance by January 2009, as required by the law. The long-term study, however, requires more time. Therefore, as recommended by the Landscape Task Force, DWR is using the best available data in order to establish an appropriate ETAF and to see if the ETAF can be lowered based upon improved landscape irrigation efficiency. DWR will continue working with UC and other researchers to pursue its long-term study of the ETAF and develop a more refined ETAF in the future. If it becomes necessary, DWR will begin a rule making process to revise its Model Ordinance.

DWR has been and will continue conducting a literature search for data and other information on landscape irrigation efficiency, distribution uniformity, and consulting with the ETAF TAC when necessary. The bulk of the information DWR obtained from the literature review regarding DU and IE was from irrigation audits of existing landscape systems. Some of the reviewed data and information are published in scientific journals and others are either in the process of publication or are collected by local agencies for internal use.

3. Findings.

The final report of AB 2717 Task Force cited that residential irrigation audits indicate very low DUs, with an average of 45 percent in a survey of 300 sites by Santa Clara Valley Water District and 55 percent by a consultant Chris Wilig (500 sites). Golf courses, on the other hand, are, generally, well maintained and managed with DUs of 75-90 percent, according to the report.

Irrigation Systems in the reviewed literatures were at least several years old and DUs for sprinkler systems were low ranging from 20 to 80 percent. The primary reasons cited for lower DUs were poor irrigation system design and installation, poor equipment selection, little or no maintenance, and inadequate management. In some cases, improvements in DUs and IEs were reported after making changes to the system. For example; simply replacing older nozzles with newer and upgraded nozzles (Zoldoske, 2003; and Mecham et al., 2004) resulted in efficiency improvements. Zoldoske (2003), also reported significant water savings in golf course studies but DU data was not presented. Mecham et al. (2004) found that rotor sprinklers generally had higher irrigation efficiency compared with fixed spray devices. Improvements in DU, emission uniformity (EU) water emission device uniformity, and IE has been reported at controlled study sites with manufacturer recommended design and testing criteria (Micker, 1996; Hla et al., 1998), further affirming that most of the problems that reduce IE can be overcome. Mecham (http://www.ncwcd.org/ims/ims_info/theeff1d.pdf), for example, used a well designed teaching and training field in Colorado and evaluated the effects of matched precipitation rate (MPR) nozzles and measured DUs ranging from 57% to 78%.

The reviewed literatures also indicated that the choice of landscape plants can influnce the amount of water used. It was shown, for example, that warm season turf can save as much as 20% water compared to the cool season species (Pittenger and Shaw, 2003; Ervin and Koski, 1998; Feldhake et al., 1983; Meyer and Gibeault, 1986; and Stewart et al., 2004). Many of these studies have also shown that using different irrigation treatments, with the right combination of irrigation frequency, cutting height, and fertilizer application, some warm season turf varieties can be irrigated at 60% of ETo and cool season varieties at 80% of ETo (Pittenger and Shaw, 2003; Bushman et al., 2007; Ervin and Koski, 1998; Brown et al., 2004; Feldhake et al., 1983; Meyer and Gibeault, 1986; and Devitt et al., 1992). Feldhake et al. (1983), for example, determined that a grass mowed at 5 cm had an ET rate of 13% higher than that mowed at 2 cm and that a nitrogen deficient treated grass used 14% less water than the adequately fertilized grass.

Some studies have further suggested the use of the low half distribution uniformity in irrigation scheduling rather than the low quarter distribution uniformity as is currently being practiced (Kissinger and Solomon, 2005; Kumar et al., 2006; Irrigation Association, 2005). These studies found that soil moisture has similar distribution uniformities to the low half DU of sprinklers mainly because the water redistributes laterally once it enters the soil. Use of the low half DU for irrigation scheduling results in higher values of DU and IE.

Other developments in landscape irrigation and maintenance that have significantly improved irrigation efficiency include advances in sprinkler technology (example, multi-stream, multi-trajectory rotating (MSMTR) sprinklers) and irrigation controllers (example, weather based irrigation controllers and soil moisture sensors). Several studies have shown that these new developments have increased irrigation efficiency (Solomon et al., 2006; Irvine Ranch Water District). Solomon et al. (2006) conducted over 50 field audits and observed that by converting from fixed spray to multi-stream, multi-trajectory rotating sprinklers, average DU changed from 44% to 67% after conversion. The improvement in DU ranged from a low of 4% to a high of 52%. A 2003 study by the Pacific Institute also estimates that California could reduce outdoor residential water use by 25% to 40% through improved landscape management practices and better application of available technology (Gleick et al., 2003).

Additional information was also obtained from various sources regarding landscape planning, design, installation, and maintenance practices that can save water (Hartin and McArthur, Irvine Ranch Water District, Coachella Valley Water District, Capistrano Water District, HydroPoint Data Systems, Inc., and Irrisoft). The information gathered from these groups indicated that newer technologies in emission devices and weather based irrigation controllers have improved irrigation system efficiency substantially. The data from these sources also included manufacturer's specifications and default IE values that the manufacturers of weather based irrigation controllers' use today.

Data supporting improved irrigation efficiency were also received from local water agencies from their dedicated metered landscape based on billing invoices. Most of these data illustrated that in real life scenarios landscapes were often being watered well below the current 80% of ETo (see appendix A for reference list and details). Data from these sources, however, did not specify what plant palettes were used.

San Diego County Water Agency, for example, has proposed a draft model ordinance with an ETAF factor of 0.7. The Coachella Valley Water District has adopted a more stringent approach with an ETAF of 0.5 by allowing a change in plant mix and a plant factor of less than 0.5. Weather based irrigation controller manufacturers use high IE values ranging from 70% – 90% as a default in scheduling irrigation. The following is an example of IEs from HydroPoint Data Systems, Inc. for the WeatherTRAK controller:

- Spray head = 70%
- Stream spray = 70%
- Stream rotors = 75%

- Full/Part/Mixed circle rotors = 80%
- Full/Part/Mixed circle impact = 85%
- Bubbler = 90%
- Drip emitter = 90%

4. Analysis.

The studies reviewed and the data collected from different sources demonstrate that existing landscape irrigation system design, maintenance, and management are often poor and result in low distribution uniformity and irrigation efficiency. The wide range of DUs and IEs observed by many investigators, and cited in this white paper, indicate that there are ample opportunities for irrigation improvements. The review process has clearly indicated that if the problems resulting in low DUs and IEs are corrected, landscapes can be irrigated more efficiently. There is also enough evidence to show that there have been major changes in irrigation technology, landscape design, and irrigation management in recent years and if applied, higher irrigation efficiency and water conservation can be achieved. Some of these developments include:

1. The increased use and acceptance of low volume irrigation systems in landscape irrigation;
2. Improved sprinkler systems, matched nozzles, and multi trajectory rotators;
3. Technological advances in irrigation controllers leading to improved irrigation management efficiency (example, weather-based irrigation controllers and soil moisture sensors);
4. Increased use and promotion of low water use native vegetation and xeriscaping;
5. Use of the low half distribution uniformity for sprinkler irrigation rather than the low quarter DU for irrigation scheduling;
6. Heightened public awareness of the significance of water conservation; and
7. Better understanding and management of soil properties and soil-plant-atmosphere interactions by landscape designers and managers.

Moreover, the California Energy Commission is required by the 2006 Act to establish performance standards and labeling requirements for landscape irrigation equipment, including but not limited to; irrigation controllers, moisture sensors, emission devices, and valves to reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy or water. The updated Model Ordinance will also require some specific measures (higher efficiency devices, irrigation controllers, irrigation audits, inspection, better irrigation system design and maintenance, use of water efficient plants, erosion and runoff control, etc.) that when incorporated into the landscape design, management, and maintenance will achieve irrigation efficiency greater than 62.5%, a value that is the basis for the ETAF factor of 0.8 in the existing model ordinance.

5. ETAF Value.

The minimum operational lower quarter distribution uniformities for spray, rotor, and drip/micro-spray cited by the Irrigation Association Best Management Practices Guidelines are 55%, 70%, and 80%, respectively. Based on the advances cited above, the findings from literature review, IA's minimum operational DUs, and with expectations of better landscape design, proper installation, improved management and maintenance in the future, landscape low quarter distribution uniformities of 62% for the high water use plants irrigated with spray heads and rotors and emission uniformities of 80% for the medium and low water use plants irrigated with drip and micro-spray systems are reasonable. In this white paper, the statewide average plant factor of 0.5 from the existing model ordinance is retained with the 1/3 high, 1/3 medium, and 1/3 low plant mix. Accordingly, ETAF calculations for a landscape with a 1/3 plant mix each of high, medium, and low water use plants is as follows:

For high water use plants irrigated with spray-heads and rotors, DUlq = 62%. For reasons discussed above, it is suggested that distribution uniformities of the low half be used for irrigation scheduling. The Irrigation Association uses the following equation to convert DUlq to DUlh:

$$DUlh = 38.6 + (0.614)(DUlq)$$

Kumar et al. (2006) verified the accuracy of this equation by simultaneously measuring distribution uniformities of the soil and the sprinklers. Therefore, the above equation is used here to convert DUlq to DUlh. DUlh for high water use plants with spray/rotor irrigation systems is 38.6+(0.614)(62) = 77%. For medium and low water use plants irrigated with drippers and micro-sprayers, emission uniformities, EU = 80% were used. Therefore, the average uniformity for the landscape is [(77 + 80 + 80) / 3] = 79%.

To calculate landscape irrigation efficiency, an Irrigation Management Efficiency (IME) needs to be determined. Zoldoske (2005) used an IME of 90% in calculating IE for the existing model ordinance. Although there have been technological advances since the existing model ordinance was adopted that have improved IME (example, ET controllers and soil moisture sensors), we preferred to retain 90% because we could not find published scientific data on updated IME values. Also, the Irrigation Association rates an IME of 90% as "very good". The irrigation efficiency for purposes of the model ordinance is therefore calculated as:

IE = (DU) (IME)

IE = (79)(90)/100 = 71%

Finally, the ET Adjustment factor is:

ETAF = Plant Factor/IE = (0.5/71)100 = 0.70.

Appendix A

Summary of Literatures Reviewed.

1. Bamizai, A., Perry, R., and C. Pryor. (2001) Water Efficient Landscape Ordinance (AB 325): A Statewide Implementation Review. Western Policy Research

2. Baum, M. C., Dukes, M.D., and Miller, G.L. (2005) "Analysis of Residential Uniformity". Journal of Irrigation and Drainage Engineering 131:4,336-341.

The following studies were referred to by Baum et al., 2005:

Utah (citing Aurasteh et al., 1984): DUlq = 0.30 for hand move and 0.37 for solid set in residential irrigation audits.

Georgia (citing Thomas et al., 2002): 24 percent over irrigation was discovered due to nozzle mismatch and poor management because of too high irrigation timing.

California (citing Pitts et al., 1996): mean DUlq for all systems was 0.64. Average DUlq for non-agricultural turfgrass sprinklers (residential lawns) was 0.49. Reasons for low DUlq were maintenance and faulty sprinkler heads, mixed equipment types in zones (spray and rotor), excessive pressure variations, and poor head-to-head coverage, listed in order of frequency.

Florida (citing Micker, 1996): average DUlq ranged from 0.38 in Lake County to 0.71 in South Dade. Minimum DUlqs ranged from 0.11 for Hillsborough to 0.40 for Fort Myers, whereas the maximum DUlqs ranged from 0.71 for Hillsborough to 0.89 for South Dade. Tests in Florida were conducted using Mobile Irrigation Labs (MIL).

The test for residential settings in Florida by Baum et al., 2005 showed the mean DUlq for the rotor zones was 0.49 and the mean DUlq for the sprays was 0.41. They also tested at a controlled site at the University of Florida and found that under ideal testing conditions (as recommended by manufacturers) the DUlq was 0.58 for rotary sprinklers and 0.53 for spray nozzles.

3. Brown, C.A., Devitt, D.A. and Morris, R. L., (2004) Water Use and Physiological Response of Tall Fescue to Water Deficit Irrigation in an Arid Environment. HortScience 39(2) 388-393.

Reducing leaching fraction (LF) and Irrigation (I) to ETo ratio with twice weekly irrigation schedule saved 20-47 percent of water for tall fescue. A loss in color and cover was observed when I/ETo ratio dropped below 0.80.
In Colorado (citing Fry and Butler, 1989) – color and cover ratings could be maintained while saving water at 75 percent and 100 percent ETo but loss in ratings occurred when irrigation were at 50 percent of ETo.

In Colorado (citing Ervin and Koski, 1998) – water could be conserved on tall fescue while maintaining acceptable turfgrass quality, if irrigation occurred every 3 days using a crop coefficient of 0.70.

4. Bushman, B.S. B. L. Waldron, J. G. Robins and K. B. Jensen (2007) Color and shoot regrowth of turf-type crested wheatgrass managed under deficit irrigation. Applied Turf Science. Doi:10.1094/ATS-2007-0418-01-RS

It was documented that it is possible to maintain an active green growth in crested wheat grass using weekly deficit irrigation levels greater than or equal to 60 percent ET replacement. Dormancy and unacceptable browning occurs in crested wheatgrass at irrigation of less than 60 percent ET replacement. They did not study, however, the effect of frequency and duration of irrigation interval. It should be noted that their ETo was estimated using the Hargreaves equation. Hargreaves equation has a good agreement with the Penman-Monteith equation on timely time steps such as this.

5. California Department of Water Resources. (2005) California Water Plan Update. Bulletin 160-05.

6. Capistrano Water District. Personal Communication

Of the 446 records with allocations in the original billing, 37 accounts went over their allocation; only 3 of those by more than 100 ccf, 369 accounts used less than 70 percent of allocation which was 96 percent of ETo. When the allocation is experimentally reduced to 70 percent of ETo, 75 accounts went over, but only 5 of these by more than 100 ccf. For 55 of these customers, the additional Tier 2 use was 50 ccf of less.

7. Carrow, R.N (2006) Can we maintain turf to customer satisfaction with less water? Agricultural Water Management 80:(1-3)117-131.

Citing several papers, Carrow 2005 documented landscape coefficient (K_L) for cool-season grasses as 0.70-0.95 and warm season grasses as 0.65-0.85 when the irrigation regime is 3-7 days between events. It was stated that as K_L values decreased below these general ranges using a similar irrigation schedule, turf performance rapidly declined. One way of reducing K_L while maintaining good quality turf was by irrigating more frequently. This avoided surface drying.

8. Coachella Valley Water District Personal Communication

Initially the inspections showed that 69 percent of the 16 sites were within their maximum water allowance. Thirty-one percent exceeded it. CVWD is looking at those sites that exceeded MAWA to determine why they were too high. On some sites, they are still in the establishment period. Some have landscaped more area than was approved for a particular meter. One specific site planted turf where it was not indicated on the plans.

The sites were plan checked under their older Ordinance 1302 which has an ET adjustment factor of 0.5.

9. Devitt, D.A., R.L.Morris and D.C. Brown. (1992) Evapotranspiration, Crop Coefficients, and Leaching Fractions of Irrigated Desert Turfgrass Systems. Agronomy Journal 84:717-723.

This research was conducted in southern Nevada on bermudagrass overseeded with perennial rye. The Penman combination equation was used to estimate ETo. A park site with similar soils, water quality, and grass species as two other golf courses used 29 percent less water due to less fertilizer application at the park site. Monthly Kc values ranged from as low as 0.43 in winter months to as high as 0.89 in summer months for the golf course sites. For the low management park site, it ranged from as low as 0.33 to as high as 0.60.

10. Ervin, E. H. and A.J. Koski. (1998) Drought Avoidance Aspects and Crop Coefficients of Kentucky Bluegrass and Tall Fescue Turfs in the Semiarid West. Crop Science 38:78-795

Using different irrigation treatments on Kentucky Blue Grass (KBG) and Tall Fescue (TF) in Colorado, the authors were able to determine crop coefficients that can be used to save water while maintaining the turf at an acceptable quality. The coefficients were 0.60-0.80 for KBG and 0.50-0.80 for TF. The reason for differences between the two was that TF has deeper roots hence extracting water from deeper layers during water shortage. It should be noted that the Kimberly-Penman equation was used to calculate reference evapotranspiration on alfalfa reference (ETr).

11. Feldhake, C.M., Danielson, R.E. and Butler,J.D. (1983) Turfgrass Evaporation, I. Factors Influencing Rate in Urban Environment. Agronomy Journal 75(5):824-830..

Warm season grasses used about 20 percent less water than cool-season grasses under identical management and microenvironment conditions. Grass mowed at 5 cm had an ET rate of 13 percent higher than that mowed at 2 cm. Nitrogen deficient treatment used 14 percent less water than the adequately fertilized grass. The research was conducted at Colorado State University.

12. Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G., Cushing, K.K., and A. Mann. (2003) Waste not, Want Not: The Potential for Urban Water Conservation in California. Pacific Institute.

13. Green, R. L. (2005) Trends in Golf Course Water Use and Regulation in California. Reports on Topical Issues. University of California, Riverside Turf Grass Research.
http://ucrturf.ucr.edu/topics/trends_in_golf_course_water_use.pdf

Discusses the feasibility of increasing irrigation efficiency and DU in golf courses and how regulators may set water budgets to be followed.

14. Hartin, J. and K. McArthur. (2007) Conserving Water and Improving Plant Health in Large Southern California Landscapes. Progress Report. 2004 Proposition 50 Water Use Efficiency Grant. Grant No. 4600004211

In early 2007 30 site visits were conducted by William Baker and Associates (subcontractor for UCCE) at parks, golf courses and school districts. These sites were surveyed; including a catch can test of distribution uniformity and precipitation rates. Several visits are planned for each site, with recommendations of improvements to be made after each visit.

Some of the types of irrigation issues discovered include: Poor DU due to uneven spacing of heads, unmatched precipitation rates, unmatched nozzles, too low pop-up, tilting, slow infiltration rate of soils.

A few sites were surveyed with exceptional efficiency rates, for example one golf course, had a DU Lq at 83 percent. Recommendations for high achieving sites were minimal and included items such as topdressing, aeration, checking pressure on non-conforming stations, etc.

Initial DU's for the 30 sites varied from 41 percent to 86 percent. 14 of the 30 sites had DU above 70 percent

Conclusions reached so far (no final report yet): many sites have low DU but with large potential for easy improvements (low tech, low cost) improvements such as cleaning filters, straightening alignment, resolving pressure. A few will need capital improvements such as equipment replacement and correcting improper spacing.

15. Hla, A.K. and P.M. Waller. Efficiency Analysis of Urban Microirrigation Systems in Phoenix Metropolitan Area. Presented at the1998 American Society of Engineers Annual International Meeting. Paper No. 982045. ASAE 2950 Niles Road. St. Joseph, MI 49085-9659 USA

This research was conducted in Phoenix, AZ to determine the operational effectiveness of microirrigation systems. It was concluded that drip irrigation is very inefficient and non-uniform in urban landscape irrigation in phoenix. The researchers estimated crop coefficients as 0.25 for low water-use desert adapted plants, 0.33 for semi-arid plants, and 0.5 for medium water-use plants. ETo rates were also estimated for summer (8 mm/d), spring (7 mm/d), winter (2 mm/d) and fall (5 mm/d). The average distribution uniformity (low quarter) for all zones was 18 percent. Reasons for low uniformity included improper number of emitters with respect to canopy area, degradation of emitters, differential rates of canopy growth, and failure to adjust the number of emitters as canopy diameter increases. In contrast, the distribution uniformity at the two control sites was 86 percent.

16. HydroPoint Data Systems, Inc., provider of WeatherTRAK. Personal Communication (2007)

Default settings for the WeatherTRACK weather based automated ET controller information on sprinkler efficiency:

- Spray head = 70 percent
- Stream spray = 70 percent
- Stream rotors = 75 percent
- Full/Part/Mixed circle rotors = 80 percent
- Full/Part/Mixed circle impact = 85 percent
- Bubbler = 90 percent
- Drip Emitter = 90 percent

17. Irrisoft. (2007) Personal Communication.

Irrisoft uses the IA's DU table to develop the default uniformity numbers. It also uses the DU lower half in scheduling and have found it to work very well.

18. Irvine Ranch Water District - Personal Communication

Systems installed prior to 1995 on public landscapes included 457 meters installed on 846.25 acres with an average of 30.01 inches of water/year (including effective precipitation) representing 64 percent of ETo as determined by CIMIS. The metered years included 2002 – 2007 Sept.

Systems installed prior to 1995 on private landscapes included 1858 meters installed on 293.77 acres with an average of 42.20 inches of water/year (including effective precipitation) representing 89 percent of ETo as determined by CIMIS. The metered years included 2002 – 2007 Sept.

Systems installed post 1995 on public landscapes included 230 meters installed on 870.04 acres with an average of 25.31 inches of water/year (including effective precipitation) representing 54 percent of ETo as determined by CIMIS. The metered years included 2002 – 2007 Sept.

19. Kissinger, J. and K.H. Solomon. Performance and Water Conservation Potential of Multi-Stream, Multi-Trajectory Rotating Sprinklers for Landscape Irrigation. Presented at 2006 American Society of Agricultural and Biological Engineers Annual Interantional Meeting, July 2006. Paper No. 062168

Over 50 field audits were presented comparing the performance of traditional fixed spray heads with multi-stream, multi-trajectory rotating (MSMTR) sprinklers. Distribution Uniformity (DU) and Run Time Multiplier (RTM) were used in the comparison. The following table was extracted from Solomon et al., 2006 and shows changes in DUlq due to conversion to MSMTR sprinklers.

Result	Range	Average	Median
Before conversion (fixed spray heads)	22-72	44	43
After conversion	46-88	67	67
Improvement due to conversion	4-52	23	23

20. Kumar, R., S. Mitra, and E. Vis. (2006) Comparison of Distribution Uniformities of Soil Moisture and Sprinkler Irrigation in Turfgrass. Final Report. California Landscape Contractors Association Environmental Research Funding Program. H:\CLCAFinalFiles2_06\CLCAFinal RPT3-17-06.

This project report was funded by the CLCA Environmental Research Funding Program and conducted in California. Soil moistures were measured using TDR and DU was measured using catch cans. On average (for 3 plots), the soil DUlq was 85 percent whereas the average DUlq for the catch cans was 70 percent. The researchers then calculated DUlh using two methods. Using the equation in Irrigation Association resulted in DUlh of 82 percent whereas calculating from the catch can data resulted in DUlh of 80 percent. In any case, DUlh was closer to the DUlq of the soil. It was estimated that using DUlh instead of DUlq for irrigation scheduling would result in 17 percent less water applied.

21. Little, G.E., Hills, D.J., and B.R.Hanson. (1993) Uniformity in Pressurized Irrigation Systems Depends on Design, Installation. California Agriculture May-June 47(3) 18-21.

Evaluated 258 agricultural irrigation systems by mobile Labs in 5 So. Cal. RCD's. Found average DU for drip to be 75 percent and micro spray 72 percent representing all types of terrain. The 13 sprinkler system on nonundulating terrain the average DU was 82 percent.

22. Mecham, B. Q. The effects of Matched Precipitation Rate Nozzles on DU , Northern Colorado Water Conservancy District, Loveland, Colorado. http://www.ncwcd.org/ims/ims_info/CaseStudy.pdf

Could not find any direct correlation to nozzle and better DU. Some zones do improve with MPR and others do not. Notes DU were ranged from 62 percent - 78 percent. DU is affected by many things; attention needs to be paid to design, proper installation, and adjustment of the head and maintenance.

23. Mecham, B.Q. (2004). A Summary Report of Performance Evaluations on Lawn Sprinkler Systems. Northern Colorado Water Conservancy District. http://www.ncwcd.org/ims/ims_info/SummaryEvaluationSprinklerSystems.pdf

Residential		Fixed Spray		Rotors	
Location	# of audits	Avg. DUlq, %	Range, %	Avg. DUlq, %	Range, %
Utah	4500	52		58	
Utah, USU	164	52	18-80	49	15-86
Colorado	973	53	20-89	54	19-92
Oregon	398	55*		54*	
Florida MIL	576	54	11-89		
U of FL case study	19	40		48	
California case study	19	41	16-54		
Commercial		Fixed Spray		Rotors	
Location	# of audits	Avg. DUlq, %	Range, %	Avg. DUlq, %	Range, %
Utah	166	55	7-82	55	8-84
Colorado	20	52	6-77	50	3-88
Arizona	7			41	20-56
Texas	6			58	27-79

*reflects the lower third distribution uniformity (usually, 3-9 percent higher than lower quarter, according to the author of the Oregon study).

These data were collected from 1999 through 2005.

24. Mecham, B. Q. and Boyd, R. (2004) Landscape Irrigation Efficiency of Nine Model Homes. Northern Colorado Water Conservancy District.. http://www.ncwcd.org/ims/ims_info/CaseStudy.pdf

Three model homes had traditional sprinklers and 3 had sub-surface drip irrigation. Initial DU was poor in sprinklers ranging 12-65 percent with an average of 40 percent. Took one yard and worked with existing system and increased DU from 35 percent to 50 percent. Took this same system and installed MP Rotator and achieved a 73 percent DU after tuning it. Paper also goes into detail about factors contributing to poor DU.

25. Meyer, J.L. and V.A. Gilbeault. (2006) Turfgrass Performance Under Reduced Irrigation. California Agriculture July-August 2006, pg. 19-20.

This research was conducted at the University of California South Coast Field Station, Irvine. It was found that there was no significant difference in cool-season grass performance between the 100 percent and 80 percent regimes (i.e., 100 percent of ETo and 80 percent of ETo). The 60 percent (0.6*ETo) regime significantly reduced the turf quality of the three cool-season grasses tested. Thirty-six percent less water was applied to the warm-season species than to the cool-season season species for acceptable turf quality.

26. **Miller, G.L., N. Pressler and M.D. Dukes.** 2003. How Uniform is Coverage from Your Irrigation System? Golf Course Management. August 2003. pp. 100-102.

Evaluated five golf courses in central Florida with an average DU of 57 percent for trees, 50 percent for fairways, and 60 percent for greens. Through retrofitting system to achieve average 70 percent DU needed head to head coverage adjusted pressure, nozzles breaks, improper tilt, size, & etc.

27. Pittenger, D. and D. Shaw. (2003) What We Know About Landscape Water Requirements. CO-HORT Summer 2003 vol. 5.2

Pittenger and Shaw have published the following table for crop coefficient (Kc) values of cool-season and warm-season turfgrasses. Note that the authors did not specify sources for these numbers. The cool-season species include tall fescue, ryegrass, bentgrass, and Kentucky bluegrass. The warm-season species include bermudagrass, zoysiagrass, and st. augustinegrass. Authors also documented that many universally used landscape species maintain their aesthetic and functional value when irrigated within a range of 20-80 percent of

ETo. For landscape species with unknown water requirements, they recommended setting initial irrigation schedules at 50 percent of ETo for established non-turf landscape plantings adjustments made as needed.

Month	Cool-Season	Warm-Season
January	0.61	0.55
February	0.64	0.54
March	0.75	0.76
April	1.04	0.72
May	0.95	0.79
June	0.88	0.68
July	0.94	0.71
August	0.86	0.71
September	0.74	0.62
October	0.75	0.54
November	0.69	0.58
December	0.60	0.55
Annual Average	0.80	0.60

28. Pitts, D., K. Peterson, g. Gilbert and R. Fastenau. (1996) Field Assessment of Irrigation System Performance. Applied Engineering in Agriculture. 12(3):307-313.

After conducting DU measurements on 385 irrigation system evaluations for agricultural and landscape irrigations in Santa Barbara and San Luis Obispo counties, they found that the mean DU for all systems was 64 percent. DU average for the 174 micro-irrigation (drip emitters and micro-sprayers) system evaluations was 70 percent. Commonly observed problem categories for micro-irrigation systems were emitter plugging, maintenance, and improper retro-fitting (e.g., mixed emitters).

The average DU for 37 turf irrigation systems was 49 percent. Over 40 percent of the turf irrigation systems evaluated had DUs less than 40 percent. The turf areas tested ranged from 0.4 to 12 ha (1 to 30 acre). The low DUs for turf irrigation systems were attributed to the following (in the order of frequency of occurrence): (1) maintenance, malfunctioning sprinkler heads, (2) mixed sprinklers, altered from original design, and (3) design problems, excessive pressure variations and insufficient sprinkler overlap. Many of the irrigators were unaware of turf ET and uncertain of the application rate, so irrigation scheduling was most frequently based on the turf's appearance.

29. Stewart, J. R., R. Kjelgren, P. G. Johnson and M. R. Kuhns. (2004) Soil-water-use Characteristics of Precision-irrigated Buffalograss and Kentucky Bluegrass. Online Applied Turfgrass Science doi: 1094/ATS-2004-1118-01-RS.

The research was conducted in Logan, Utah to characterize the relationship between foliage and air temperatures of buffalograss and Kentucky bluegrass under well-watered conditions and during a period without irrigation to determine the soil water content at the point of incipient water stress. Kentucky bluegrass reached incipient water stress when nearly 50 percent of the total water was depleted in its 0.6 m deep root zone. Buffalograss reached incipient water stress after 22 days of soil drying when it had depleted nearly 60 percent of soil water to a 0.9 m depth. Ninety-four percent of the Kentucky bluegrass root system was in the top 0.3 m of the soil compared to 62 percent for buffalograss. The average DU for the gear drive heads used to irrigate the study site was 63 percent across all 20 plots.

30. Waller, P. Tree and Shrub Irrigation.
http://ag.arizona.edu/abe/northernarizona/Tree_and_Shrub_Irrigation.html

Uses irrigation efficiency of 78 percent while discussing water use for some woody plants and the effects of droughts on irrigation scheduling.

31. Water Management Committee of the Irrigation Association. (2005) Landscape Irrigation Scheduling and Water Management. Irrigation Association.
http://www.irrigation.org/gov/pdf/IA_LISWM_MARCH_2005.pdf

32. Zoldoske, D.F. (2003) Improving Golf Course Irrigation Uniformity: a California Case Study. California Agricultural Technology Institute Publication No. 030901

Five golf courses participated for a time span of one year prior to nozzle change and one year afterwards in the study. Replacement nozzles were provided either as an upgrade by the manufacturer or by a third party vendor.

Calculated savings = 9 percent based on the calculated DUlq.

Gross annual water savings reported on the 18-hole course ranged from 55.5 acre feet to minus 22.8 acre feet. Average gross water savings per course was 16.6 ac-ft. The gross water savings was calculated as the annual water applied to the turf grass before the nozzle change less the annual water applied after the nozzle change.

Estimated total gross water savings for all the participants, without adjusting for useful rainfall, was 99.8 ac-ft of water, or 6.5 percent of applied water. Adjusting for useful rainfall, the estimated savings falls to 5.7 percent of the applied water.

There is a discussion about DU in the paper but no indication of measuring it at the study site.

33. Zoldoske, 2005. Review of Implications to Proposed Change of ET Adjustment Factor. Paper presented to the AB 2712 Landscape Task Force. http://www.cuwcc.org/Uploads/committee/ET_Adjustment_Calulation_Draft_3_05-08-05.pdf

Discussed the different components of ETAF and presented scenarios under which an ETAF of 0.7 can be achieved.