# Landscape Irrigation System Evaluation and Management

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## Contents

# Preface

This publication presents practical information and field procedures for evaluating landscape irrigation hardware performance and determining irrigation schedules. These guidelines will enable the user to develop a superior irrigation management program that will optimize plant growth and health without wasting water. Emphasis is given to water conservation strategies that are effective during periods of restricted water use.

Green Industry personnel, at all levels of experience and training, should be able to understand and implement the information. The authors have avoided the use of technical jargon where possible. The main body of the handbook describes the overall procedures and the appendices contain formulae and other reference information.

Field evaluations and scheduling techniques require an irrigator to have a basic knowledge of water measurement calculations. The necessary calculations can be performed with either a hand-held calculator or with a computer, utilizing software or web-based irrigation management programs. While both calculators and computers will provide the same useful solutions, the computer programs offer time savings and a printed irrigation schedule useful for controller programming. Irrigation scheduling web sites and software sources are listed in Appendix F.

This publication is a working revision of *Landscape Irrigation System Evaluation and Scheduling for Southern California*, written by David A. Shaw and Paul F. Zellman. The publication supplements information presented at U.C. Cooperative Extension classroom and field demonstration sessions.



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# Landscape Irrigation Management - An Overview

The goal of good irrigation management in the landscape is to supply the plant materials with the correct amount of water at the proper time. In areas where water costs are high, supplies are limited, and there is demand for high quality turf and landscapes, the irrigation manager must maintain irrigation systems for peak performance and make careful decisions on when and how much to irrigate.

Effective landscape irrigation involves the following concepts:

1. Irrigation systems should be designed, installed, and maintained to **distribute water as uniformly** as possible. Precise irrigation scheduling is of little value if systems have a low uniformity.

2. To assure adequate irrigation of all areas, the irrigation system should be operated long enough to **apply a depth of water equal to the water use of the landscape** plus extra to compensate for the non-uniformity of the system and leaching requirements.

3. The irrigation system should be designed, maintained, and operated to **avoid runoff**.

To address these concepts, the irrigation manager or auditor must assess the system hardware, the water requirements of the plant material, and the irrigation management. Irrigation hardware performance is defined in practical terms by the system precipitation rate and distribution uniformity. Precipitation rates are used to calculate station run times and may indicate runoff potential. Distribution uniformity values provide the irrigator with an indication of how evenly water is applied to the landscape. Landscape water use estimates are derived from reference evapotranspiration (ETo) information and crop coefficient (Kc) values.

The overall procedure to develop landscape irrigation schedules consists of the following steps:

I. Perform a **"walk-through" inspection** of each station within the irrigation system and make necessary repairs.

II. Determine the **precipitation rate** and **distribution uniformity** of irrigation systems using volumetric measurements or catch can tests.

III. Determine the **water needs** of landscape plant materials using local weather and plant water use information available from the University of California, Department of Water Resources CIMIS program, local water districts, and related agencies;

IV. Calculate station **run times** to meet the water needs of the landscape.

V. Decide the **frequency of irrigation** and if **"cycling"** is necessary.

VI. Verify the irrigation schedule with **field observations** and adjust if necessary.

# The "Walk-Through" System Inspection

The purpose of the "walk-through" inspection is to identify readily apparent problems with the irrigation system that will reduce system performance and overall irrigation efficiency. It consists of a visual inspection of the system components including sprinklers, piping, control system, the zoning of stations, and the health of the plant material.

The *IRRIGATION SYSTEM INSPECTION CHECKLIST*, found in Appendix A, is used to conveniently record problems found during the "walk-through" inspection. Information on the location, contact person, and evaluator is located at the top of the checklist, followed by sections on irrigation control system inspection, station-by-station system inspection, and space for specific remarks. Appendix A contains a detailed description of each of the items encountered on the CHECKLIST. For large systems several copies of the form may be required. Irrigation managers may wish to modify the form for adaptation to specific situations.

The walk-through inspection should become a regular part of an irrigator's normal routine. Many controller manufacturers provide a convenient "two minute test" program that can be run to facilitate the visual inspection of each valve station. Obvious and easily made repairs and adjustments should be performed before conducting field tests to determine precipitation rates and uniformity.

# Irrigation System Precipitation Rates and Distribution Uniformity

Once the "walk-through" inspection is completed and the necessary repairs have been made, the performance of the system can be evaluated by determining the Precipitation Rate (PR) and Distribution Uniformity (DU). The PR is the rate at which water is delivered to the landscaped area and is measured in inches per hour. The DU is an easily calculated statistic, which indicates the amount of variation in the precipitation rate of the system. PR and DU are the two most important irrigation system performance characteristics used to calculate station run times and indicate how evenly water is applied to all areas of the landscape.

The fieldwork to determine irrigation performance can be either a brief, simple procedure or a complete, full inspection of all the irrigation system stations and hardware. An irrigation manager should not always assume that stations which appear similar have the same PR and DU. Extrapolating single station inspections to the entire facility can lead to gross errors in scheduling unless nozzle size and operating pressure (both of which govern head output), and spacing between heads is field verified to be the same. Likewise, the actual PR and DU of newly installed systems should be field verified and not assumed to be those in the catalogue or design specifications. It is recommended that all newly installed or upgraded systems be evaluated to assess baseline performance characteristics.

**PRECIPITATION RATES**

There are several methods of calculating precipitation rates: Measurement of system flow rate and area irrigated; measurements of head output and spacing; and catch can tests. In addition, PR can be estimated in the design stages of a project from design criteria (pressure, flow, spacing, etc.) and manufacturer's performance data for the equipment used. Data collection forms and formulae used for system inspections are in Appendices B and H.

**Flow and Area Irrigated Method**

Gross precipitation rates in inches per hour can be determined from the system flow rate and area irrigated using the following formula:

$$\text{PR (In/Hr)} = \frac{\text{GPM} \times 96.3}{\text{Landscape Area in square feet}}$$

This method is convenient, especially if a meter is present and the landscaped area can be easily measured. It is also useful for situations where the landscaped area and irrigated area are not equal. Trees in irrigated planters or median strips, for example, may develop a large canopy relative to a small irrigated area. The flow/area method provides a gross PR value and can also be used to verify PR values from head measurements or catch can tests but provides no information on irrigation uniformity.

**Head Output and Spacing Method**

The average Precipitation Rate (PR), expressed as inches of water per hour, can be determined for any type of irrigation system by measuring the output of the sprinkler, spray head, or drip emitter and average spacing between the heads or emitters.

Field measurement of most single stream sprinkler and emitter outputs, expressed as gallons per minute (GPM) or gallons per hour (GPH), is relatively simple and requires only a few tools: collection buckets and short pieces of 3/4" hose. Accurate measurement of multi-stream rotors and spray head sprinklers may be difficult. Drip emitter flow rates can be measured and converted to GPH using 35mm film canisters and Appendix Table x. The formula for calculating the average PR is:

$$\text{PR (In/Hr)} = \frac{\text{Average GPM per head} \times 96.3}{\text{Average head spacing in square feet}}$$

Another method of calculating the average PR using head output is the use of performance charts. Irrigation equipment manufacturers provide performance charts for each of their sprinkler and emitter types, which list output values at various operation pressures. Most performance charts also list a calculated precipitation rate for square and triangular spacings under idealized conditions. While the use of performance charts may be quick and useful during project planning, field verification of the information is recommended to provide an accurate measurement of actual PR.

**DISTRIBUTION UNIFORMITY (DU)**

Distribution uniformity (DU) of an irrigation system describes how evenly water is applied over the irrigated area. DU estimates the maximum efficiency of an irrigation system and greatly influences the total amount of water that must be applied to the landscape area in order to assure that the all plants receive the minimum water they need.

DU values for spray head, mini-sprinkler, and drip systems used to irrigate trees and shrubs, are calculated from measurements of head output. For these systems, the DU is often referred to as Emission Uniformity (EU). DU values for systems which irrigate turf, ground covers, potted plants, or large areas containing small individual plants cannot be calculated nor accurately estimated from either the measurement of head output or the use of sprinkler/emitter performance charts. For these irrigation systems, the DU is determined from a catch can test.

In landscape irrigation, a DU value is usually calculated for each irrigation valve as the ratio of the lowest one-fourth of the head outputs or catches to the overall average head output or catch within the irrigation valve. This is known as the low quarter DU ($DU_{LQ}$). Using $DU_{LQ}$ increases runtime dramatically in systems with a low DU. The irrigation industry has recently moved toward calculating DU using the lowest 50% of the catches, which results in a lower runtime multiplier. The rationale for this is applied irrigation water moves laterally as well as down in the soil and the DU is actually higher than what a $DU_{LQ}$ estimates. Therefore, the $DU_{LQ}$ underestimates the actual DU and over adjusts the runtime.

## CATCH CAN TESTS

Catch can tests are a fast and accurate way to evaluate the PR and DU of sprinkler systems irrigating turfgrass, potted plants, and ground cover areas. These tests involve setting out catch cans (containers) and running the systems long enough to collect measurable amounts of water in the cans.

CATCH CAN SELECTION AND MEASUREMENTS: A variety of containers make suitable catch cans including plastic drinking cups, coffee mugs, and soup, tuna or cat food cans. Rain gauges provide convenient depth measurement but are somewhat cumbersome and expensive. Conical catch cans with graduations marked on the sides are also handy, but are substantially more expensive. Regardless of the container selected, it is best to use a set of similar containers.

The water within a catch can may be measured as a **depth of water** in inches or **volume of water** in milliliters. If the depth of water in each can is to be measured, each can should have straight sides and a flat bottom. It is more precise to measure the volume of water collected in a catch can than to measure the depth of water collected. Pouring the water collected into a graduated cylinder allows rapid and precise measurement of the catch volume. When measuring water volumes, the diameter or area of the catch can opening should be recorded and be the same for all cans.

SET OUT CATCH CANS: The objective of the catch can test layout is to obtain a representative sample of the true precipitation rate and distribution uniformity of the sprinkler irrigation system. If a sprinkler system is truly 100% uniform, then only one catch can could be placed anywhere within the sprinkler pattern with equal results. Common sense indicates that the use of more than one catch can will provide greater confidence in the accuracy of the test. Since no system is 100% uniform, it is recommended that at least 40 similar cans be used spaced five to ten feet apart to achieve accurate results. The layout of the containers can be a grid, radial, or even random pattern. A grid layout lends to easy catch data collection and identification of problem areas or sprinklers. See Appendix C for sample can layouts for a variety of irrigation designs and sprinkler station overlaps.

RUN THE SYSTEM: After the catch cans are laid out, run the irrigation station(s) until a measurable amount of water is caught. It is best to perform catch can tests in the morning when wind is minimal. Some areas may require that two or more valve stations be operated to completely overlap the test site. For a 3.5 inch diameter catch can, one should expect to catch between 20 and 80 milliliters. The test run time may range from 10 minutes (high PR greater than 1.5"/hr) to 90 minutes (low PR less than 0.4"/hr.). While the sprinklers are running, periodically observe the amounts of water caught. Use this time to observe sprinkler rotation, operating pressure, and verify repair of items identified on the checklist.

Some turf managers choose to layout catch cans in the early evening prior to running a typical irrigation cycle during the night and early morning hours. This method provides the best duplication of actual field irrigation conditions that may affect PR and DU (e.g. wind, pump and sprinkler operation pressures, etc.), but makes verification of controller run times and proper sprinkler operation difficult for most managers.

RECORD VOLUMES AND TIMES: Record the individual catch can volumes, preferably in milliliters, and the station(s) test run time in minutes. If there is a controller, a stopwatch should be used to verify the accuracy of the controller clock. The stopwatch time should be used to determine the true system PR if inaccuracies exist. If the controller clock is consistently slow or fast, run times can be adjusted accordingly. The controller should be replaced if the clock is erratic (sometimes slow, sometimes fast).

ANALYZE DATA: Data tabulation and calculation of PR and DU are performed as follows:
• Identify the Low Quarter (25% of the cans that caught the lowest amounts of water);
• Calculate the average catch and the average of the low quarter;
• Calculate the DU by dividing the low quarter catch by the average catch;
• Determine the PR from the average of all catch volumes and area of the catch can opening.

**Data collection forms and formulae used for system inspections are in Appendix B.**

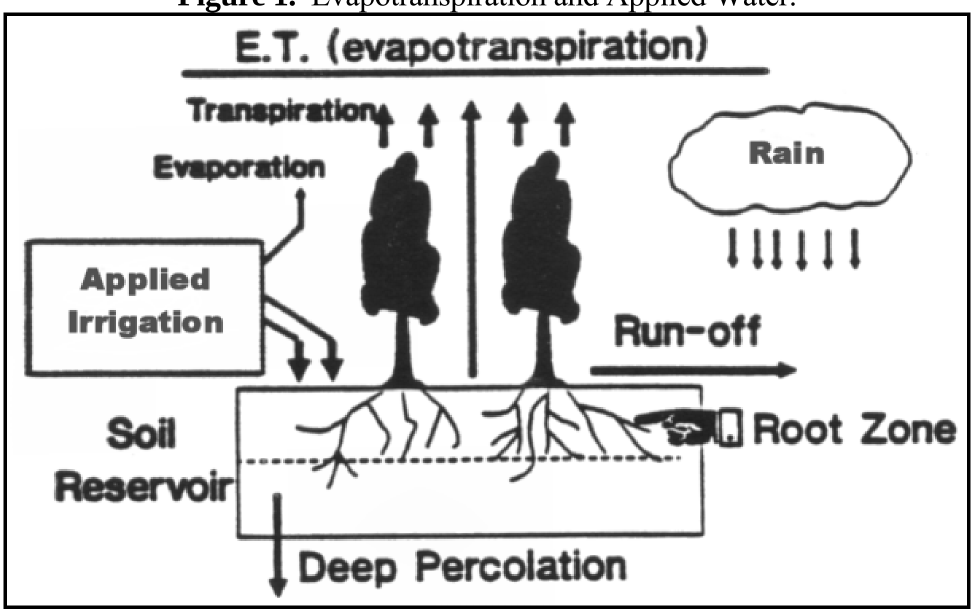
# Water Use of Turfgrass and Landscape Plant Materials

In the landscape, water is transpired by plants and evaporated from the soil. This process is defined as evapotranspiration or **ET**. ET is usually expressed as the quantity of water in inches, millimeters, or gallons that needs to be replaced in order for the plant materials to maintain optimal growth and aesthetic appearance.

The physiology and structure of a plant, its location in the landscape, and weather conditions are the primary factors affecting ET. For example, when growing under the same conditions, bluegrass uses more water than English ivy. Similarly, more water would have to be applied to both bluegrass and English ivy growing in the desert region of Palm Springs than to the same plants growing at the coast in Long Beach because of the hotter and drier conditions found in the desert.

The primary climatic factors that affect ET are solar radiation, air temperature, relative humidity, and wind speed. Studies of pasture water use and weather data have led to the development of relationships for predicting ET from climatic factors and weather data. Generally, as sunlight, temperature, and wind increase and as relative humidity decreases, ET increases.

**Figure 1.** Evapotranspiration and Applied Water.




California has developed a statewide system of computer operated driven weather stations to generate ET values on a daily basis through the California Irrigation Management Information System (CIMIS). Since it would be too cumbersome and complex to generate ET values for the thousands of different kinds of plants grown in California, each weather station generates only one ET value per day. This one daily value is called **real-time reference evapotranspiration** (ETo) because it and represents the water use of a standard pasture (the reference plant) and is derived from current weather date (real-time data). This standard pasture grass is tall fescue, mowed at four to six inches in height, and maintained in optimal, non-stressed condition. ETo data from CIMIS is calculated from hourly average data from weather station sensors using a modified Penman equation. ETo provides a good estimate of the daily water use of the pasture grass in inches and indicates the impact of local climate on plant water use. The CIMS stations and their data output are managed by the California Department of Water Resources.

**Historical ETo** or average values of ETo have been determined for most areas of California from evaporation, solar radiation, and temperature records. The historical ETo information is of great value in predicting plant water use for determining generalized irrigation schedules. One can irrigate fairly accurately using historic ETo data, but remember that these guidelines are averages and actual daily data can vary significantly from a 30 or 40-year average. For example, historic ETo for a day in February in Oceanside is 0.09 inches. However, on February 14, 1992 the real-time ETo was 0.04 inches and on February 23, 1992 the real-time ETo soared to 0.20 inches.

Thus, ETo information is available as historical data, based on 30 to 40 year averages or as real-time data from CIMIS or on-site weather stations. Real-time ETo data are useful for weekly updating of generalized irrigation schedules. Historical ETo values for locations in Southern California and sources of CIMIS real-time data are given in Appendices E and G, respectively.

Water needs of plants vary by individual species and their location in the landscape. Most landscape plants such as turfgrass, groundcovers, shrubs and trees need less water than ETo (reference ET) which the estimated water use of the standard pasture, thus, their water needs are expressed as a percentage of ETo. This percentage of ETo is often called a crop coefficient ($K_C$), plant factor (PF), or landscape coefficient ($K_L$). The relationship is:

**ETo x Kc = Plant ET**

For example, to perform optimally, bermudagrass needs about 60% of the water that the standard pasture needs. Thus, if we knew that ETo for a day was 0.20 inches, then bermudagrass would need 0.20 inches times 0.60, or 0.12 inches of water. Although ETo varies from one climate zone to another, the percentage of it used for a given species (or the crop coefficient) does not change. Crop coefficients are dimensionless numbers usually ranging from 0.1 to 1.2.

The concept of using the ETo standard to estimate a crop's water needs through a crop coefficient was initially derived by agricultural crop scientists to estimate the water requirements of large tracts of field and orchard crops. Thus, the scientific application of ETo to calculate crop coefficients assumes the plant material of interest is:

- ♦ well-watered with soil moisture unlimited at all times.
- ♦ growing vigorously.
- ♦ forming a uniform, nearly continuous canopy that functions as a single big leaf.
- ♦ grown with the goal of optimum growth and development and yield.
- ♦ using water in direct proportion to the rate of ETo.

Crop coefficients (Kc values) and plant factors are developed by determining the water use of a given species or crop and comparing it to ETo over the same time period. There are several methods used to estimate crop water use by measuring:

- applied water to the crop and estimating application losses;.
- the weight of water lost from the crop using lysimeters or weighing devices;.
- water flux from the crop canopy to the atmosphere (aerodynamics);).
- water flow through plant stems or tree trunks;.
- water lost through a combination of these methods.

In addition, the crop condition and performance is are evaluated in terms of yield, growth, appearance, or other parameters. Then a relationship between water use and ETo and the performance of the crop is developed and the Kc value is determined for the crop.

### Kc Values for Turfgrass

Lawns and other turfgrass plantings closely match the ETo assumptions noted above, so crop coefficients have been scientifically determined that represent the water needed by common turfgrass species to perform optimally (Table 1). The annual Kc averages are commonly used for irrigation scheduling, but monthly values generate irrigation schedules that more precisely match turfgrass needs.

**Table1.** Crop coefficients (Kc) for cool-season and warm- season turfgrasses in California [1].

| Month | Cool Season[2.] | Warm Season[3.] |
|---|---|---|
| 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*** |

1. Meyer et al. 1985. Irrigation of turfgrass below replacement of evapotranspiration as a means of water conservation: determining crop coefficient of turfgrasses, pp. 357-364 in: F. Lemaire (ed.) Proc. 5th Intl. Turfgrass Res. Conf., Avignon, France, July 1985. INRA Publications, Versailles, France.
2. Species include tall fescue, ryegrass, bentgrass, and Kentucky bluegrass.
3. Species include bermudagrass, zoysiagrass, and St. Augustinegrass.

## Kc Values for Landscapes

Reliable research-based data on landscape water needs is extremely limited primarily 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. Many landscape plantings also violate the above assumptions of the relationship between ETo and a plant's Kc. Mixed plantings of groundcover, shrub, and tree species create variations in the plant canopy and shading that prevent the overall planting from functioning as a single big leaf, soil water content is not always at optimum levels, and the plants are not usually grown with optimum growth, development, and yield as the goal. Expectations of landscape plant performance are simply acceptable appearance and function, which are much less stringent than optimum growth, development, and yield. Also, research in plant physiology has revealed that water use of some woody landscape plants does not increase proportionally as ETo increases throughout the day especially when site conditions are harsh, such as when trees are planted within paved parking lots. Some species actually use less water in harsh situations because their stomata close naturally when water is limited. Altogether, these factors severely limit the ability of the ETo equation to accurately reflect a landscape's water requirement and make it impossible to determine a precise crop coefficient for each landscape plant species. Since landscape plants do not conform to the scientifically accepted assumptions of calculating crop coefficients, the ETo standard has been used to determine ranges in percentage of ETo or plant factors for several species in which they will provide minimally acceptable performance and function, not necessarily optimum growth. The research findings show that many universally used species maintain their aesthetic and functional value when irrigated within a range of 18% to 80% of ETo (see Table 2). These numbers are useful in estimating water budgets and irrigation schedules for landscapes even though the precise water use of the plants has not been quantified.

Field research on non-turf landscape plants' minimum water requirements is limited to several commonly used groundcover, tree, and shrub species. There is very little research-based water requirement data for California native plants when they are used in planned landscapes. Few information sources offer quantitative estimates of landscape plants' water requirements, and most of those that do, including the widely-referenced publication, *Water Use Classification of Landscape Plants* (or *WUCOLS)*, are *not* based on scientific field research. While there is limited information on landscape plant water needs, We do know from the available scientific data that most landscape species, including turfgrass, require an amount of water that is less than ETo to provide acceptable performance during most of the year.

For the many landscape species with unknown water requirements, it is currently recommended to set initial irrigation schedules at 50% ETo for established non-turf landscape plantings. Adjustment of the Kc is the easiest way to handle differences in aspect, shade, microclimate, plant densities, stress, and irrigation frequency. In other words, it may be necessary for landscape water managers to adjust Kc values depending on site conditions and the amount of water stress desired. For example, the Kc may need to be adjusted for plantings subjected to partial shade from a building (lower Kc), excessive wind (higher Kc), or heat from a nearby street or parking lot (higher Kc). Plant performance must be evaluated and irrigation increased or decreased in increments of about 10% ETo until the desired level of performance is attained with the least amount of water. Intervals between irrigation of woody landscape plant materials can usually be greatly extended from fall through winter.

The Calculating a landscape coefficient ($K_L$) method is another method of estimating a landscape's water requirement popular theory used to adjustment Kc values for local conditions that involves assigning additional microclimate, density, and species factors to a landscape. While useful in generating numbers needed for irrigation scheduling computer programs and for predicting landscape ET, it is based on theory with little supporting research. The theory does not address or account for plant stress or minimum irrigation requirements which greatly influence a landscape's water need. While the $K_L$ methodology can be used for irrigation scheduling, a user may find that the additional estimations and necessary calculations do not necessarily result in a more refined estimate of the landscape water needs than using the plant factors discussed above.

To summarize the overall process of estimating a landscape's irrigation need, we use ET information to determine the approximate amount of water that specific plants require for desired quality. With this information and the irrigation system precipitation rate and uniformity, we determine how long to run irrigation systems (Figure 1). The next step is to decide the irrigation frequency.

**Table 2.** Irrigation amount required (as percent of ETo) for selected landscape groundcovers and shrubs to provide acceptable landscape performance after establishment. [z]

| **Scientific Name** | **Common Name** | **% ETo** |
|---|---|---|
| *Arbutus unedo* 'Compacta' | Compact strawberry tree | 18 - 36 |
| *Arctostaphylos uva-ursi* 'Pacific Mist' | Bearberry | 18 - 36 |
| *Artemisia* 'Powis Castle' | Wormwood | 0 - 36 [y, w] |
| *Baccharis pilularis* 'Twin peaks' | Twin Peaks coyote bush | 20 |
| *Calliandra haematocephala* | Pink powder puff | 18 - 36 |
| *Cassia artemisioides* | Feathery cassia | 0 - 36 [y, x] |
| *Cistus x purpureus* | Orchid spot rock rose | 0 - 36 [y] |
| *Correa alba* 'Ivory Bells' | White Australian correa | 18 - 36 |
| *Drosanthemum hispidum* | Pink iceplant | 20 |
| *Echium fastuosum* | Pride of Madeira | 0 - 36 [y] |
| *Escallonia x exoniensis* 'Fradessii' | Frades escallonia | 18 - 36 |
| *Galvezia speciosa* | Bush snapdragon | 0 - 36 [y, x] |
| *Gazania rigens v.leucolaena*'Y.Cascade' | 'Yellow Cascade' trailing gazania | 50 - 80 |
| *Grevillea* 'Noelii' | Noel grevillea | 0 - 36 [y] |
| *Hedera helix* 'Needlepoint' | Needlepoint English ivy | 20 - 30 |
| *Heteromeles arbutifolia* | Toyon | 0 - 36 [y] |
| *Hibiscus rosa-sinensis* | Rose of China | 40 - 60 |
| *Lantana montevidensis* | Trailing lantana | 18 - 36 |
| *Leptospermum scoparium* | New Zealand tea tree | 18 - 36 |
| *Leucophyllum frutescens* 'Green Cloud' | 'Green Cloud' Texas ranger | 0 - 36 [y, x] |
| *Ligustrum japonicum* 'Texanum' | Texas privet | 40 - 60 |
| *Myoporum 'Pacificum'* | Prostrate myoporum | 0 - 36 [y] |
| *Otatea acuminata* | Mexican bamboo | 18 - 36 |
| *Phormium tenax* | New Zealand flax | 18 - 36 |
| *Pittosporum tobira* | Mock orange | 18 - 36 |
| *Potentilla tabernaemontanii* | Spring cinquefoil | 70 - 80 |
| *Prunus caroliniana* | Carolina laurel cherry | 0 - 36 [y] |
| *Pyracantha koidzumii* 'Santa Cruz' | 'Santa Cruz' firethorn | 0 - 36 [y] |
| *Rhaphiolepis indica* | Indian hawthorn | 18 - 36 |
| *Teucrium chamaedrys* | Germander | 18 - 36 |
| *Vinca major* | Periwinkle; myrtle | 30 - 40 |
| *Westringia rosamarinaformis* | Rosemary bush | 18 - 36 |
| *Xylosma congestum* | Shiny xylosma | 18 - 36 |

[z] References:

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

[y] Acceptable landscape performance with no summer irrigation shown only at the immediate coast. Inland plantings may require summer irrigation up to the maximum amount listed.

[x] Species typically provides unacceptable landscape performance in summer and fall months irrespective of irrigation amount.

[w] Requires renovation approximately every 3 years to maintain acceptable performance.

# Irrigation Schedules

Irrigation scheduling consists of determining how long and how often to run the system.

## Station Run Times

Individual station run times are determined from both plant water use estimates (ET) and the system PR and DU using either a hand-held calculator or the U.C. scheduling software (TURFIMP) on a daily, weekly, or monthly basis. Virtually all irrigation scheduling calculations and software use the following information:

1) The Precipitation Rate (PR) of the irrigation system in inches/hour.

2) The Distribution Uniformity (DU) of the irrigation system. The DU is used as an estimate of the irrigation efficiency (IE). DU will account for the losses due to non-uniformity of irrigation. IE accounts for uniformity, runoff, and deep percolation losses. If runoff is minimal and the average depth of water applied to the low quarter is equal to the landscape water use, then DU is a viable estimate of IE.

3) Historical or Real Time Evapotranspiration (ETo) Information.

4) Crop Coefficient (Kc) Values.

The following formula is used by both computer software and hand calculations to calculate irrigation run times from the above information:

$$^{*}\text{RUN TIME (minutes)} = \frac{\text{ETo} \times \text{Kc} \times 60}{\text{PR} \times \text{DU}}$$

Run time for successive days can be determined by adding daily run times or using the cumulative ETo value. Run time per week can be determined by using the average daily ETo multiplied by 7 days per week. For example:

$$^{*}\text{DAILY RUN TIME} = \frac{.18 \text{ in/day} \times .50 \times 60}{.75 \text{ in/hr} \times .80} = 9.0 \text{ minutes/day}$$

$$^{*}\text{WEEKLY RUN TIME} = \frac{(.18 \text{ in/day} \times 7 \text{ days}) \times .50 \times 60}{.75 \text{ in/hr} \times .80} = 63 \text{ minutes/week}$$

* **WARNING!!** It is necessary to use the correct units. PR is in inches per hour, ETo is in inches per day, and DU and Kc are expressed as decimal values rather than percentages.

## Irrigation Frequency

Since we can calculate the approximate amount of water that plants need on a daily basis, we could simply apply that amount everyday. However, under most conditions applying rather small amounts of water on a daily basis is an inefficient and unsound horticultural practice. A more practical and effective method is to wait a period of time, usually several days, and then apply the accumulated amount.

The following factors should be considered in determining irrigation frequency.

**Factors Which Restrict Scheduling Flexibility:**

Mandated Irrigation Days and/or Hours
Limited Water Supply
Cultural or Maintenance Practices
Sports or Other Activities
High Wind Conditions

**Factors Which Necessitate Frequent Irrigation:**

High Plant Water Use Rates
Shallow Rooting Depth
Sandy Soils with Low Water Holding Capacity
High Runoff Potential Due to Slope or Compaction
Poor Infiltration Rate Due to Compaction or Clay Soils

**Factors Which Allow Less Frequent Irrigation:**

Low ET Rates or Presence of Rainfall, Dew, or Fog
Deep Roots and High Root Density
Plants with Ability to Tolerate Drought
No Runoff Problems
Acceptable Quality or Site Use under Reduced Irrigation

Field observation of plant material quality, rooting depth, water penetration, soil type, and estimates of available water holding capacity will help irrigators determine irrigation frequencies. Often a field estimate of soil moisture status or plant water stress is used for deciding when to irrigate and ET data are used to determine the amount of water or run time. Where site conditions limit the infiltration rate, runoff will determine the longest possible station run time. Multiple cycles should be programmed if additional run time is required for water to penetrate to a desired depth in the soil.

There are at least three common methods used to decide **when** to irrigate: a "**Flexible Method**" based on an estimated value of root zone soil moisture depletion; a fixed day "**Calendar Method**" to accommodate weekly cultural practices and site use activities; and **Soil Moisture Sensors**. Many irrigation controllers provide programming functions for all three methods using a seven or fourteen day calendar, "skip day" features, and sensor inputs. Each method is acceptable as long as the proper amount is applied and runoff is minimal.

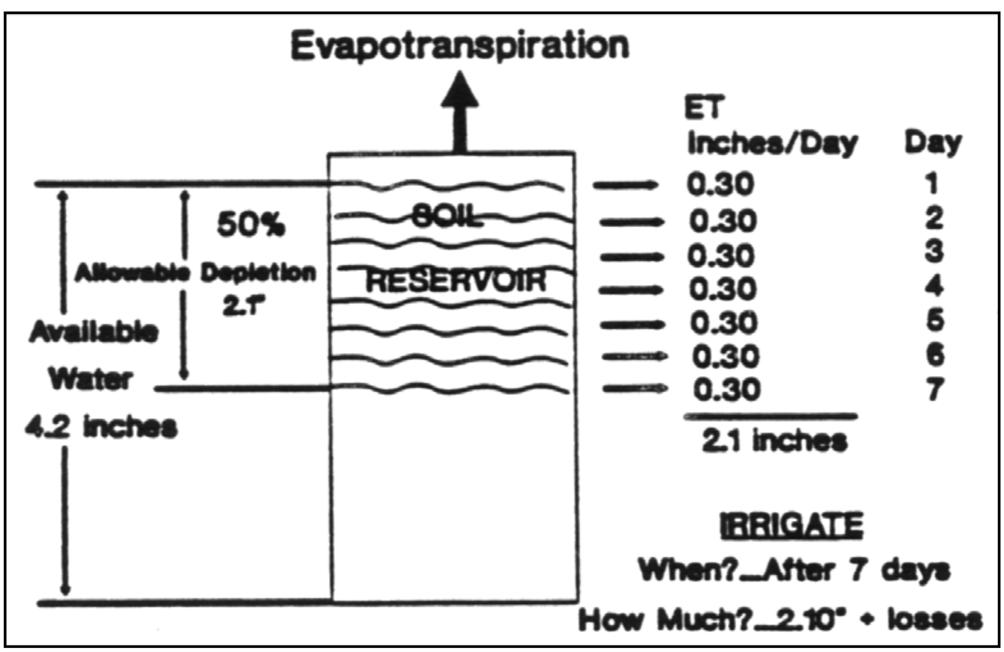
**Soil Moisture Depletion or Flexible Method:**

Using the Flexible Method, the run time per irrigation stays the same and irrigation frequency varies during the year. Irrigation frequency is derived from an estimate of the allowable soil moisture depletion and daily plant water use.

The soil moisture status and allowable depletion in inches of water is easily determined by the "feel method", a simple technique involving field observations and a soil probe or shovel. Soil probes also provide information on actual rooting depth of plants, wetted depth, and type(s) of soil. Appendix D describes in detail the technique for the "feel method" of soil moisture measurement and charts for estimating Soil Available Water Holding Capacity in inches of water. A general rule of thumb is to irrigate when 50% of the available water is depleted.

Irrigation frequency is determined by summing the daily plant water use values (ETo x Kc) until the total water use equals the desired soil moisture depletion (Figure 2). Rainfall and fog may contribute to soil moisture and their effect can only be assessed by field observation.

Figure 2. Soil Moisture Depletion (Flexible) Method.



**Calendar Method**:

Using the Calendar Method, irrigation frequency is fixed to specific days of the week that accommodate overall site activities. Consequently, the run time per irrigation varies during the year. The Calendar Method is described by the following steps. First, determine the minutes of **run time per week**. Second, determine the number of irrigation **days per week**. Third, calculate **run time per day**:

$$\text{Run Time per Irrigation Day} = \frac{\text{Minutes per Week}}{\text{Irrigation Days per Week}}$$

Fourth, **observe if runoff occurs**. If so, divide the run time into multiple cycles. If the soils at your site permit a high precipitation rate, you may only need one cycle per irrigation day.

**Soil Moisture Sensors:**

Soil moisture sensors are sometimes used to govern landscape irrigation by indicating when to start and stop irrigating. It is very important that these sensors be located in the active root zone and be properly calibrated for the site specific soil conditions. A timely maintenance and physical monitoring program should also be in place to verify sensor readings. When using soil moisture sensors, irrigation uniformity remains a critical and important factor and ET information plays a limited role in water management. However, an irrigation schedule may be developed based on historical ETo data and sensors used to shut down the system when water is not needed.

## Centralized and Smart Irrigation Controllers

Irrigation control systems that automatically operate valve stations have been utilized by the agriculture and landscape industries for a number of years. These systems adjust irrigation by sensing soil moisture, condition of plant materials, weather or environmental data, or a combination of information. Simple systems have utilized a device to interrupt the controller to valve circuit, allowing the system to operate only when the switch is closed. The switch circuitry can be based on a direct electrical measurement (as in a capacitance sensor or gypsum block soil moisture sensor) or electrical interpretation of a sensing device (like a tensiometer, scale, or pressure sensor). The switch/interrupt technology also includes the use of wind sensors, light or motion sensors, or flow sensors incorporated into the controller to override the irrigation schedule.

Advances in the electronics industry, especially in communications and computers, have had great impacts on the irrigation industry. Control system technology now available can not only schedule and operate irrigation valves, but can record operation times and water amounts, incorporate data from an onsite weather station, and coordinate pumps and control flow using sensors, as well as allow for operation from remote location via radio or telephone. Computer systems and sophisticated software interfaced with valve control and sensor reading capabilities offer the irrigation manager a high degree of control capabilities. This technology, often referred to as "Central Control Systems", allows precise management of large irrigation systems with considerable labor savings. Central control systems are used for large or expansive facilities, such as large parks, transportation corridors, and golf courses that can afford the expense and have trained personnel to manage the system. Until recently, these systems have been too expensive to be suitable for residential and small commercial use.

Irrigation controllers that set and adjust water application in response to changes in the weather are now available at competitive prices for residential and commercial use. They offer many potential benefits to a landscape manager. These devices are commonly termed "smart", "ET", "weather-sensing", or "weather-based" irrigation controllers, and the technology is collectively referred to by the irrigation industry as Smart Water Application Technology, or *SWAT*. The devices automate the use of historical or real-time reference evapotranspiration (ETo) data or other environmental parameters correlated with evapotranspiration (ET) and plant water demand. While any standard automatic irrigation controller can be set to apply ETo-based schedules, the new SWAT products allow input of precipitation rates, plant material type, and climatic information for estimating landscape ET. In this way, SWAT devices reduce or eliminate the laborious and sometimes complicated runtime calculations required to set a controller to implement real-time ETo-based irrigation budgets and schedules. Irrigation runtimes and water amounts are automatically adjusted for seasonal changes in weather based on ET data stored within the controller or on localized sensor readings or ETo data downloaded periodically from a support service. Some of the newer controllers adjust irrigation frequency and cycling based on input of soil type and slope of the site.

In theory, the use of one of these devices simplifies and improves accuracy of landscape irrigation scheduling resulting and results in measurable water conservation. Other benefits include reducing runoff and impacts on environmental water quality as well as reducing visits to re-set irrigation controllers. The use of the "smart" device also takes because it automatically and accurately schedules weather-based irrigation to various landscape plantings thereby taking irrigation management decisions out of inexperienced peoples' hands, reducing the human error factor, reducing visits to re-set irrigation controllers, and minimizing runoff. In practice, users report variable experiences in how easy these devices are to set up and how well they achieve the goals of improved water management and conservation.

Although there have been several studies on the performance of various SWAT devices, few of them provide scientific analysis of a product's or technology's performance or reference water used (or water saved) objectively to plant performance. A controlled study in 2003 by U.C. Cooperative Extension involving three SWAT products demonstrated variation in their abilities to irrigate accurately and effectively cool-season turfgrass, trees/shrubs, and annual flowers. Overall findings and conclusions from the study were:

- Use of weather-sensing controllers does not assure landscape water conservation or acceptable landscape plant performance.

- Greater complexity and technicality of required setup information does not necessarily result in more accurate, water-conserving irrigation schedules.

- Adoption of SWAT will not eliminate human interaction in landscape irrigation management.

- Weather-sensing controllers will likely require professional monitoring and follow-up adjustment of their initial irrigation schedules.

New SWAT products are being introduced regularly, and it is possible may be that the best technology or product has yet to emerge. Available information indicates that SWAT products can potentially reduce/decrease human errors in making calculations, and reduce or eliminate the need to update controller programming with weather changes, and automate irrigation cycling as a tool for preventing runoff. However, even though precision control may be gained by using a SWAT controller, their accuracy and performance are typically dependent on the quality and accuracy of the user-supplied set up information about the irrigation system and the plant material in each valve station. Most importantly, to realize the potential benefits, the irrigation delivery system, including filters, valves, water lines, and sprinklers or other emission devices must be well-designed, installed properly, and meticulously maintained.

In addition to cost and other important parameters, consumers should consider the following before purchasing a SWAT product:

- What type and amount of technical information about the landscape and irrigation system to be managed are needed to set up this product? Am I qualified to develop and supply this data?

- How does the product use the set up information to calculate irrigation amounts and schedules? Does this approach make sense horticulturally?

- How user friendly is the interface?

## Meeting Water Budgets and Setting Priorities

City and county government codes as well as water agencies often require commercial properties and large landscape sites to develop and adopt a landscape water budget. The water budget may be used to set water allocations and the price per unit of water used.

In many jurisdictions, a first step in establishing a water budget is to determine a site's *Maximum Applied Water Allowance* (MAWA). It is the maximum amount of irrigation water that can be allocated to the site and is calculated as

**MAWA = ETo × AF ×LA × 0.62**

where,

MAWA = maximum applied water allowance in gallons per unit of time (year, month, week);
ETo = historic or real-time reference ET in inches per unit of time;
AF = ETo adjustment factor, which varies but is commonly 0.8 or 1.0;
LA = landscaped area in square feet; and,
0.62 = factor for conversion to gallons from inches per square foot.

Since there are 748 gallons per 100 cubic feet, the MAWA can be converted to billing units of hundred cubic feet (CCF) of water as follows:

**CCF = MAWA ÷ 748**.

A hypothetical MAWA calculation for a landscape project is offered below.
*Project site:* Business park with a landscaped area of 50,000 sq. ft. in Riverside, CA.

Annual MAWA = ETo/yr × AF × LA × 0.62
= 56.2 in/yr × 0.8 × 50,000 sq ft × 0.62
= 1,393,760 gal/yr
= 1,393,760 ÷ 748 gal/CCF = 1,863 CCF per year.

The actual *Water Budget* (in inches) for a hydrozone or landscaped area is the estimated amount of water required to maintain the plant material taking into account the uniformity of the irrigation system. It is calculated as

**Hydrozone Water Budget = (ETo × PF) ÷ DU**

where,

Water Budget = water required in inches per unit of time (year, month, week);
ETo = historic or real-time reference ET in inches per unit of time;
PF = plant factor, or crop coefficient (Kc);
LA = landscaped area in square feet; and,
DU = distribution uniformity of the irrigation system.

Water budgets can be converted to billing units for comparison to the MAWA by the following equation:

**CCF = (Water Budget in inches × LA × 0.62) ÷ 748**.

Since the irrigation manager distributes water in different amounts to different plant materials, a water budget for a landscaped site is commonly determined by calculating the water budget for each irrigation station or hydrozone within the site, and then summing them for entire landscaped area. A site's total water budget should not exceed its MAWA.

During a drought or for other reasons, a site's water allocations (MAWA) can be reduced, so irrigation managers need to make adjustments and set priorities for watering landscape areas to ensure the water allocation is not exceeded. This is achieved by determining the types of plant materials and their respective areas (square footage) or their proportion of the total landscaped area represented in each irrigation station or hydrozone. Then a water budget can be developed and/or modified for each area, so that the total applied water does not exceed the allocation. The following examples illustrate how a water budget is calculated and then how priority setting is done.

***Commercial landscape #1*:**
10,000 sq ft during July and the water district has allocated 5.0 inches (100% ETo) of water. This landscape is 50% cool season turfgrass, 10% bedding/color plants, and 40% woody shrubs. The DU for these areas is 70% (0.7) for the turfgrass, 60% (0.6) for the bedding plants and 80% (0.8) for the shrubs. For illustration, assume a Kc value of 0.8 for the turfgrass, a PF of 1.0 for the bedding plants, and a PF of 0.5 for the shrubs. The water needed for each area is calculated by multiplying its percent of the total area and then summing the area calculations to find out how close the budget is to the allocation:

Turfgrass inches = (ETo x Kc)/DU = (5.0 x 0.8)/0.7 = 5.7 inches x 50% = 2.9 inches.
Bedding inches = (ETo x PF)/DU = (5.0 x 1.0)/0.6 = 8.3 inches x 10% = 0.8 inches.
Shrubs inches == (ETo x PF)/DU = (5.0 x 0.5)/0.8 = 3.1 inches x 40% = 1.2 inches.

The total budget is 4.9 inches, which is within the allocation.

***Commercial landscape # 2*:**
10,000 sq ft during July and the water district has allocated 5.0 inches (100% ETo) of water. The landscape is 100% cool season turfgrass and the DU is 70% (0.7), the Kc is 0.8 inches. The amount of water needed is:

Inches needed for July = (ETo x Kc)/DU = (5.0 x 0.8)/0.7 = 5.7 inches

Clearly, a 100% cool season turfgrass landscape will require more water than the allocation. The landscape manager has the option to exceed the allocation, improve DU and IE, and/or under-irrigate areas of the turf. The manger might also recommend re-designing a portion of the landscape to reduce the total water needs of the site.

This approach is somewhat iterative in that the variables can be adjusted for each hydrozone until the total water budget is within the MAWA. In this way the irrigation manager can set priorities and indicate which areas may sustain reduced irrigation (by using lower Kc or PF values) to offset areas needing more water. In addition, it may help set priorities for irrigation system hardware changes to increase uniformity or efficiency.

# Conclusion

As with all irrigation practices, observations of plant response, soil moisture measurements, and the judgment of the irrigation manager will help verify the irrigation schedule. These field observations are critical for the irrigation manager to determine WHEN to water and to make adjustments to the irrigation system. The ET scheduling methodology results in an approximation of HOW MUCH water to apply. Modifications of the Kc values or system performance data and subsequent recalculation of the run times is necessary to fine tune the irrigation schedule. Historical ("normal year") ETo data, useful in predicting landscape irrigation schedules, can be updated with "real time" ETo data from CIMIS or from an on-site weather station to improve the precision of the schedule, especially if weather is different from "normal".

High quality, efficient landscape irrigation systems are the product of good design, quality hardware, professional installation and timely maintenance. Each component within the system is dependent on the others for success. The failure of any one component may be the demise of the entire system. Truly efficient landscape irrigation management combines high quality irrigation systems with knowledgeable people performing proper scheduling and monitoring activities.

High quality irrigation systems under good management result in quality landscape performance as well as water conservation. If water restrictions are imposed by water districts or jurisdictions, the irrigation manager must set priorities to balance conservation and landscape quality. The first priority is to repair and adjust the irrigation systems to eliminate runoff and maximize uniformity and efficiency. This practice alone can often save significant amounts of water. The next step is to improve scheduling, followed by deficit irrigation strategies or cessation of water applications if needed. Finally, replacement of plant materials with more drought tolerant species may be necessary to meet long term water conservation goals. However, species replacement is usually not recommended during drought events due to water needed for landscape establishment. These conservation strategies, together with prioritizing areas and actions for landscape facilities, will guarantee the highest landscape quality with the least amount of water.

In conclusion, this publication provides tools for irrigation system inspection and determination of system run times to meet landscape water use. The use of these tools in combination with field observation and the judgment of the irrigation manager will provide a superior irrigation management program.

# Appendix A.

# The "Walk-Through" Irrigation System Evaluation and Checklist

# IRRIGATION SYSTEM EVALUATION CHECKLIST

LOCATION: ______________________ EVALUATOR: ______________________ Page ___ of ____
ADDRESS: ______________________ TELEPHONE: ______________________
CONTACT PERSON: ______________________ DATE: ______________________
TELEPHONE: ______________________ TIME SPENT: ______________________

**IRRIGATION CONTROL SYSTEM EVALUATION:**

1.) Controller Type: ______________________ No. of Stations: ______ No. of Programs: ____
2.) Valve Conditions: (Circle) GOOD NOT WORKING LEAKING BAD SOLENOID REMARKS: ______________________
3.) Wiring Conditions: (Circle) GOOD BROKEN POOR CONNECTIONS REMARKS: ______________________
4.) Backflow Prevention: YES NO
5.) Soil Moisture Sensor: YES NO Station # _____
6.) Rainfall Sensor: YES NO
7.) Pressure Regulator: YES NO MULTI
8.) Manifold Pressure: _______ PSI

**STATION BY STATION SYSTEM EVALUATION:** (✓) indicates problem observed

| STATION # | SYSTEM TYPE: Sprinkler, Mini Sprinkler, Shrub Heads, Bubbler, Drip | PLANT TYPE: Warm Season Turf, Cool Season Turf, Trees, Shrubs, Bedding Plants, Drought Tolerant? | NOT ZONED FOR PLANT REQ | NOT ZONED FOR EXPOSURE | OBVIOUS OVER-WATERING | OBVIOUS UNDER-WATERING | PONDING NEAR PLANT TRUNKS | MULCH NEEDED | SOIL COMPACTION | EXCESS TURFGRASS THATCH | BROKEN COMPONENTS | HEADS/NOZZLES NOT SIMILAR | SPACING UNEVEN | PRECIP RATES NOT MATCHED | SPRAY PATTERN BLOCKED | SPRAY MISDIRECTED/OVERSPRAY | WRONG PATTERNS: 1/4-1/2-FULL | SUNKEN HEADS | HEADS NOT VERTICAL | HEADS NOT TURNING | CLOGGED NOZZLES/EMITTERS | WORN NOZZLES/EMITTERS | UNEQUAL DISCHARGE RATES | UNEQUAL PRESSURES | LOW HEAD DRAINAGE | |
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**REMARKS:**

FORM ISE-1 PREPARED BY THE UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION - PRINTED WITH ASSISTANCE FROM THE METROPOLITAN WATER DISTRICT

# Appendix A.

# The "Walk-Through" Irrigation System Evaluation and Checklist

The purpose of the "walk-through" evaluation is to identify apparent problems with the irrigation system that will affect the performance and overall efficiency of irrigation. It consists of an evaluation of the control system, zoning of stations, health of the plant material, and physical condition of the system components. Often, conditions conducive to "water wasting" can be easily identified through this procedure. Once the evaluation is complete and the necessary repairs performed, the precipitation rate and uniformity of the system can be determined for use in irrigation scheduling.

The *IRRIGATION SYSTEM EVALUATION CHECKLIST* is used to record problems found during the "walk-through" evaluation. For large systems more than one form may be required. Information on the location, contact person, and evaluator is at the top of the checklist, followed by sections on ***irrigation control system evaluation, station by station system evaluation***, and space for specific ***remarks***.

## IRRIGATION CONTROL SYSTEM EVALUATION

This section is used primarily for identification of the controller or time clock, the number of stations, condition and presence of control system components. If no controller is used write in ***MANUAL***. Ideally, the irrigation manager should have the ability to program each station or valve independently with regard to day, start time, run time, and number of repeat cycles. However, many controllers are designed with one or several "programs" which designate the start time and day of irrigation. The operator sets the program start time and irrigation days, and then selects which stations are to be run with that program and inputs the run time for each station. On the checklist, write in the number of available programs or ***IND*** for independently operated stations.

**Valve Conditions:** Valves should be operational and not leaking. Faulty valves can be identified under remarks.

**Wiring Conditions:** Wiring is inspected for visible breaks, poor connections, or broken insulation. If a valve is not functioning and wiring is suspected, the wiring voltages should be checked and repaired by a qualified professional.

**Backflow Prevention:** Backflow prevention devices are required to prevent the contamination of domestic water supplies. Either a check valve, anti-siphon valve, pressure vacuum breaker, or reduced pressure backflow prevention device must be present.

**Soil Moisture Sensor:** Soil moisture sensors are becoming more popular for use in scheduling irrigations. Most read either soil moisture tension or electrical resistance which can be related to soil moisture tension. The sensors can be read manually or they can be wired into the controller to override irrigation programs and allow watering only when needed. Placement of the sensors is crucial for proper operation. They should be placed at a location in the plant's root zone which is under the influence of the irrigation system. Sensor depth of four to six inches is adequate for turf and shrubs. Sensors may be placed deeper (up to 24 inches or more) for shrubs and trees depending on the depth of rooting and water penetration.

**Rainfall Sensor:** A rain gauge or sensor is used to monitor rainfall and if integrated into the controller, to inactivate programmed irrigations when rainfall is adequate.

**Pressure Regulators:** A pressure regulator in often needed to reduce water supply line pressure to that needed for proper irrigation system operation. Sprinkler systems are run at pressures ranging from 25 to 85 PSI depending on the type of sprinkler and system used. For drip and low volume systems the pressure is usually reduced to 10 to 25 PSI. Indications that the pressure is too high include excessive atomization, fogging, and misting from sprinkler nozzles and the physical "blowing-up" of system components. Indications of low pressure include inadequate break-up of sprinkler spray patterns and the uneven discharge rates from sprinklers or emitters. More than one pressure regulator is needed if both sprinkler and drip systems are used. In addition, if topography varies greatly, pressure regulators can be installed on individual lines to assure equal pressure and even distribution of water at different elevations.

## STATION BY STATION SYSTEM EVALUATION:

This section is used to identify specific problems with each station or zone of the irrigation system. A check mark indicates the problem and specific remarks should be made in the remarks section. The first five columns indicate the **Station Number, System Type, Plant Type** and whether the station and system is **adequately zoned** for the plant type, water requirements, and exposure. Problems can include: the mixing of types of systems on the same station or line; mixing of plant types with vastly different water requirements; one station waters both sunny and shady areas; inappropriate type of system for the plant material present.

The next six columns are for observed plant and soil problems related to water management. Plant health, disease problems, brown spots in turf areas, salt damage to leaves, as well as the presence of moss, salt crust, or the ponding of water can be indications of **Over-watering or Under-watering**.

**Ponding of water around plant trunks** creates conditions favorable to root rotting organisms. Water should drain away from the trunk or crown area. **Mulch** is used to cool soil, add aesthetic value, and prevent excessive evaporation from soil surfaces. Mulch materials include organic material such as wood or bark chips, and inorganic materials such as plastic and rock. Mulch layers are usually two to three inches thick. Although mulches are beneficial, irrigations need to penetrate mulch layers and into the soil to be effective. In addition, excessive mulch against plant trunks can be conducive to root rot.

**Soil Compaction and Excessive Turfgrass Thatch** reduce the infiltration rate of water into the soil resulting in runoff or ponding of water. For existing turf areas, aeration, dethatching or vertical mowing, and reduction of traffic are options to help eliminate or lessen runoff.

**PHYSICAL PROBLEMS WITH THE IRRIGATION SYSTEM:**

**Broken Components** and **Heads or Nozzles Not Similar** and **Uneven Spacing** are the most common problems with irrigation systems. Uneven spacing and different heads or nozzle sizes on the same system lead to uniformity problems. When water is not applied uniformly, wet and dry spots develop. Since the irrigator will operate the system long enough to irrigate the dry areas, the wet areas get over-watered.

**Precipitation Rates** should be **Matched** between sprinklers and between different sprinkler patterns (1/4, 1/2, 3/4, and Full circle) to provide uniform water application. A 1/4 head should discharge 25% of the water that a full circle does, a 1/2 head 50%, etc. If the precipitation rates are not matched, different patterns should be on different valves with different run times.

**Spray Pattern Blocked, Spray Misdirected, Wrong Spray Pattern, Sunken Heads, Heads Not Vertical, Heads Not Turning, Clogged Heads or Emitters, Worn Heads or Emitters, Unequal Pressures** are all conditions, which lead to poor distribution of water or **Unequal Discharge Rates**.

**Low Head Drainage** occurs when water drains out the lines (at the lowest heads) after the system is turned off. In-line check valves or the use of sprinklers with internal anti-drainage features will prevent low head drainage.

**************************

# Appendix B.

# Data Collection Forms

# and

# Formulae Used For Calculation of

# Distribution Uniformity and

# Precipitation Rates

# SPRINKLER EVALUATION DATA SHEET

Location: ____________________________________________ Evaluator: _______________

Controller: ___________________ Station: __________________ Date: __________________

Computer Filename: _____________ TEST RESULTS: PR = _____ In/Hr DU= _______ %

CATCH CAN TEST: Catch Can Diameter: _____________ inches

Volume or Depth Units: ML OZ MM IN (Circle)

TEST RUN TIME: Actual ____ min. Controller ____ min.

Did Runoff Occur? Yes/No After _______ Minutes

Wind Direction
Relative to Test

X = Sprinkler Location

List Pressures in PSI

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SPRAY HEAD, BUBBLER, MINI-SPRINKLER, OR DRIP EVALUATION DATA SHEET

Location: ________________________________ Evaluator: ______________________

Controller: ____________________ Station: ______________ Date: _______________

Computer Filename: ____________________ (8 Character Filename)

Sprinkler/Emitter Type: _____________________________________________________

Manufacturer/Model/Orifice Type: ______________________________________________

Spacing: _______ Ft. x ______ Ft. Number/Plant: ________

Volume Unites: ML or Gallons Test Time: ___________ Seconds

| Emitter Number | Volume Measured | Pressure PSI | Emitter Number | Volume Measured | Pressure PSI |
|---|---|---|---|---|---|
| 1 | | | 21 | | |
| 2 | | | 22 | | |
| 3 | | | 23 | | |
| 4 | | | 24 | | |
| 5 | | | 25 | | |
| 6 | | | 26 | | |
| 7 | | | 27 | | |
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| 9 | | | 29 | | |
| 10 | | | 30 | | |
| 11 | | | 31 | | |
| 12 | | | 32 | | |
| 13 | | | 33 | | |
| 14 | | | 34 | | |
| 15 | | | 35 | | |
| 16 | | | 36 | | |
| 17 | | | 37 | | |
| 18 | | | 38 | | |
| 19 | | | 39 | | |
| 20 | | | 40 | | |

Average: _____________ Low Quarter Average: _________________

DU = Low Quarter Average ÷ Average = ___________

PR = _________Inches/Hour

Application Rate Calculations:

# Appendix B.

# Calculation of Distribution Uniformity and Precipitation Rates

## CATCH CAN TEST ANALYSES FOR TURF/GROUNDCOVER SPRINKLER SYSTEMS

The Distribution Uniformity (DU) is one of the best and most commonly used measures of uniformity. To calculate the DU from the catch can data, first determine the average catch by adding all catch values and then dividing by the number of catches. Next determine the average of the lowest 25% of the catches (low quarter). For example, if there were 40 catches, for the average catch: sum all 40 values then divide by 40. For the average of the low quarter: sum the 10 lowest catches and divide by 10.

The DU is then calculated by dividing the average of the low quarter by the average catch.

$$\text{DU} = \frac{\text{Average of the Low Quarter}}{\text{Average of All Catches}}$$

The Average Precipitation Rate (PR) in inches per hour is determined from the Average Catch, the test time, and the area of the catch can using one of the following formulae. **The formula you use depends on how the water was measured.**

1. Water measured in Milliliters (ML)
   Area of the catch can opening in Square Inches

$$\text{PR (In/Hr)} = \frac{\text{Average Catch in ML} \times 3.66}{\text{Catch Can Area in Square Inches} \times \text{Test Time in Minutes}}$$

2. Water measured in Milliliters (ML)
   Area of the catch can opening in Square Centimeters

$$\text{PR (In/Hr)} = \frac{\text{Average Catch in ML} \times 23.6}{\text{Catch Can Area in Square Centimeters} \times \text{Test Time in Minutes}}$$

3. Water measured in Ounces
   Area of the catch can opening in Square Inches

$$PR\ (In/Hr) = \frac{\text{Average catch in Ounces} \times 108.3}{\text{Catch Can Area in Square Inches} \times \text{Test Time in Minutes}}$$

4. Water depth measured in Inches
   Catch can with straight sides (area not needed)

$$PR\ (In/Hr) = \frac{\text{Average depth in Inches} \times 60}{\text{Test Time in Minutes}}$$

5. Water depth measured in Millimeters
   Catch can with straight sides (area not needed)

$$PR\ (In/Hr) = \frac{\text{Average depth in Millimeters} \times 2.36}{\text{Test Time in Minutes}}$$

**VOLUMETRIC ANALYSES OF SPRAY HEAD, MINI-SPRINKLER, AND DRIP SYSTEMS USED FOR TREES AND SHRUBS**

The Precipitation Rate and Uniformity of small spray head, mini-sprinkler, or drip systems are determined by measuring the output and spacing of the heads or by measuring the mainline flow and the area irrigated. Uniformity of output from each head is important and the Distribution Uniformity (sometimes referred to as Emission Uniformity) is calculated from the head output values. Since these systems are used to irrigate plants, which have extensive root systems, complete coverage of the soil is not as critical as with turfgrass and other groundcovers.

Measure the head or emitter spacing or the total number of heads and the entire area of the system. Measure the output using a container suitable for the flow of your sprinklers or emitters. A hose and bucket or a graduated cylinder and flow director work well for shrub heads. A small graduated cylinder or a 35 MM film canister work well for drip emitters. Use a stopwatch to determine the rate of flow (i.e. Gallons per minute, milliliters per second, or liters per minute) or the time it takes to fill a specific volume. For easy analysis, convert measured values to gallons per minute (GPM) or gallons per hour (GPH). For drip calculations, 63 ml per minute equals one gallon per hour.

Data analysis for these systems is performed in the same manner as with turfgrass sprinkler systems. The DU is also a commonly used measure of uniformity among heads or emitters. It is easily calculated by dividing the Average of the Low Quarter by the Average measured output.

$$\text{DU} = \frac{\text{Average of the Low Quarter}}{\text{Average of All Measurements}}$$

The Average Precipitation Rate (PR) in inches per hour is determined from the average output, the test time, and the head or emitter spacing using one of the following formulae. **The formula you use depends on how the water was measured.**

1. Gallons Per Minute (GPM) per head
   Head spacing in Square Feet

$$\text{PR (In/Hr)} = \frac{\text{Average GPM} \times 96.3}{\text{Spacing in Square Feet}}$$

2. Gallons Per Hour (GPH) per emitter
   Emitter Spacing in Square Feet

$$\text{PR (In/Hr)} = \frac{\text{GPH per Emitter}}{0.6234 \times \text{Emitter Spacing in Square Feet}}$$

Alternatively, readings from a flow meter in the main line and area irrigated can be used to determine the PR. However, the Distribution or Emission Uniformity will need to be determined by measuring head output or pressures.

3. Mainline flow in Gallons per minute (GPM)
   or Total number of heads x GPM per head
   or Total GPM output of all heads
   Total Area irrigated in Square Feet

$$\text{PR (In/Hr)} = \frac{\text{Total GPM} \times 96.3}{\text{Total Area Irrigated in Square Feet}}$$

# Appendix C.

# Catch Can Layout Designs

The objective of the catch can test layout is to obtain a representative sample of the true application rate and distribution uniformity of the sprinkler irrigation system. If a sprinkler system was truly 100% uniform, then only one catch can could be placed anywhere within the sprinkler pattern with equal results. Since no system is 100% uniform, additional cans (usually 40 or more cans) need to be used to achieve accurate results. The layout of the containers can be a grid, radial, or even random pattern. A grid layout lends to easy catch data collection and identification of problem areas or sprinklers.

There are many approaches to catch can layout ranging from simple to complex. For example:

- *Sunset Magazine* - five coffee mugs in a straight line;
- Department of Water Resources - a container next to each sprinkler and containers placed midway between sprinklers;
- Merriam and Keller - "...at least 24 containers on a grid having a spacing not to exceed 10' x 10'. The grid should be laid out to cover two adjacent areas between three sprinklers";
- Ideal Layout - entire irrigated surface covered by catch cans, one can touching its many neighboring cans.

Do not always assume that stations which appear similar have the same PR and DU. When extrapolating catch can test data to other stations, it is important to verify the likeness of nozzle size, head spacing and operating pressures. We recommend that catch can tests be performed on all newly installed or upgraded systems to assess baseline performance characteristics.

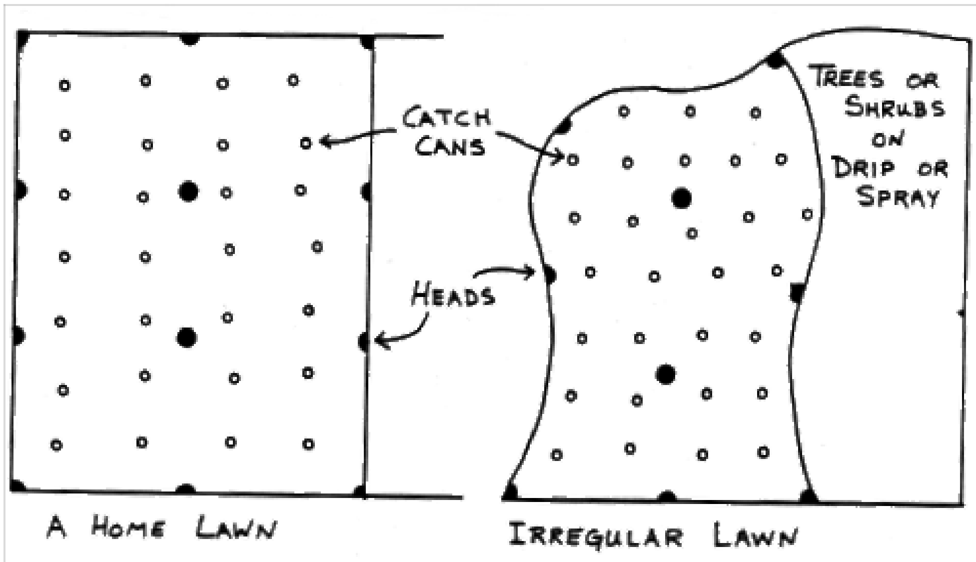
The following designs are examples of how an evaluator may test various situations.

### Design I. The "Single" Valve Station Layout

Often small turf and groundcover areas are irrigated from one valve station with a mix of full, half, and quarter circle sprinkler patterns (a home lawn, for example). Ideally, the **precipitation rates should be matched** between sprinklers and between different sprinkler patterns to provide uniform water application. A 1/4 head should discharge 25% of the water that a full circle does, a 1/2 head 50%, etc. For matched precipitation rates, it is best to set out the catch cans in a grid or random pattern over the entire area irrigated (Figure 1) and proceed with the test.

If the precipitation rates are not matched, uniformity is reduced unless each different pattern is placed on a different valve and run times are adjusted accordingly. If different sprinkler patterns are not matched but are separately valved, run each valve in proportion to the sprinkler pattern. Run full circles until a measurable amount of water is collected, then run half circles for half the test run time, quarter circles for one quarter the time, etc. Then record the catch volumes.

Figure 1. Single Valve Station Layout Examples.

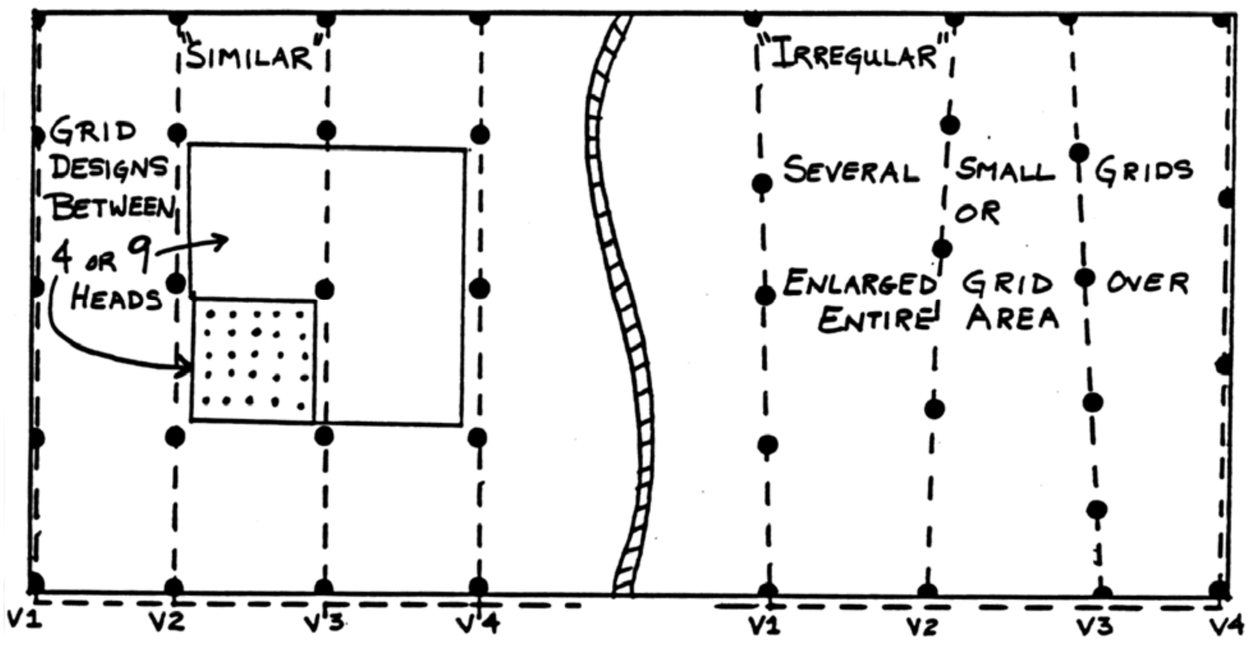



**Design II. The "Sports Field" Layout**

Large turf facilities often have separate valves for each lateral supply line traversing the field. For this situation, verification of similar sprinkler output (or pressure and nozzle size) and uniform spacing is necessary. If sprinklers and spacings are similar, then the test can be performed in a representative area of the field between four, six, or nine sprinklers. A grid pattern can be used with approximately 10 feet between cans (Figure 2). Test run time should be equal for overlapping stations. As in Design I above, be aware of matched versus un-matched stations.

If sprinkler output and spacing are not similar, several grid designs or an enlarged grid design may be used to test the majority of the area. The drawback to using enlarged grid designs, where cans are spaced 20, 30, of more feet apart, is that each can represents a much greater area and raises the potential for error. The evaluator must determine if the test is representative of the true PR and DU.

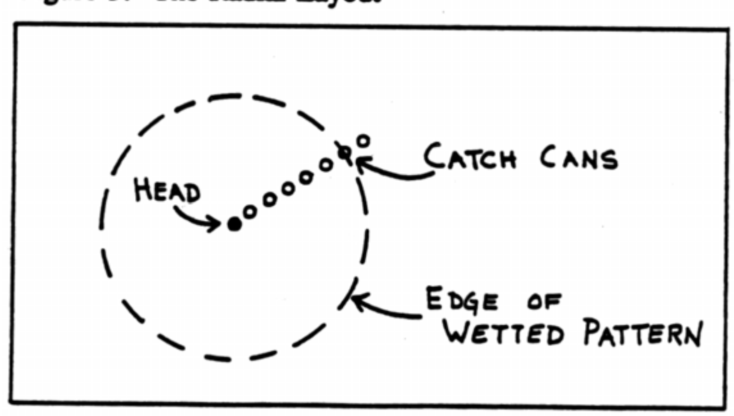
Figure 2. "Sports Field" Layout Examples.




**Design III. The Radial Layout**

The radial layout is where catch cans are placed in a line, two feet or less apart, starting from a single sprinkler to the edge of the sprinkler pattern (Figure 3). This radial layout is often used by manufacturers to determine how water is distributed from a single sprinkler (the sprinkler "profile"). Together with volumetric output, this information is used by manufacturers to develop precipitation rate and uniformity charts for various sprinkler spacings and pressures. However, the method is useful in some field situations: with isolated, valve-in-head sprinklers; where heads and spacings are mixed intentionally and overlaps must be determined; or where overlap from other stations needs to be excluded.

Figure 3. The Radial Layout



# Appendix D.
# Irrigation Efficiency and Uniformity

Irrigation efficiency (IE) is a term used to describe how effectively water was applied to a crop or landscape. Numerically, IE is expressed as a decimal or percentage of the water applied that was used beneficially compared to the total applied water. The formula is often written:

IE = Amount of water used beneficially / Total water applied

This will result in a decimal fraction since it is less than 1.0 and multiplying by 100 will give the number as a percentage of the total applied water. While IE is usually estimated on a per irrigation basis, average irrigation efficiency can be estimated for several irrigation events or over a given time period such a month or even an irrigation season. The total applied water is usually determined from a meter reading, water bill, or by measuring the rate of flow and area irrigated. Beneficial use includes water used for ET, leaching of salts, frost control, and cultural practices. The difference between the total water applied and that used beneficially is the amount of water lost during application. Losses include leaks in the system, runoff, and water the percolates through the root zone and beyond the reach of plant root systems. Since the total applied minus the losses equal the beneficial water applied, an estimate of the losses could be used to determine the beneficial water applied by subtraction. Unfortunately, runoff and deep percolation are very difficult to measure. Therefore, estimates of landscape ET are often used to estimate the beneficial amount of water. Hence, IE is usually an estimate as well.

Confidence in estimates: Of all the values used to calculate IE, the most precise number is usually the amount of applied water since it is determined from a meter reading or flow measurement. If runoff is negligible and the irrigation is uniform, then the efficiency is about equal to the uniformity of the irrigation system. If water does not percolate through the root zone and runoff is negligible, then the IE can approach 100%. However, portions of the irrigated area will be under-irrigated and plant health may suffer.

How can I get my IE to 100%? This is accomplished by either under-irrigation or by collection of runoff and percolation water and reusing that water on another crop. This is common in nursery operations where runoff is reapplied to a crop that can adjust for water stress and extra salinity in the irrigation water.

IE is a function of the irrigation delivery system and the management or control system. For example, if the uniformity of the irrigation system is high (say 90%) and the right amount of water is being applied at the right time and runoff is minimal, then the IE would be high (about 90%). If the manager under-irrigates, then the IE actually goes up towards 100%, unless irrigations are so light that water does not penetrate into the soil. Conversely, if the manager over-irrigates, then IE goes down because percolation and/or runoff is increased.

IE is maximized by maintaining good irrigation system uniformity and providing accurate scheduling for the landscape. Further increased IE can be achieved precariously through under-irrigation or by collection and reuse of excess water applied.

# Evaluating Irrigation System Uniformity and Efficiency

The purpose of this section is to define commonly used terms and give you practical guidance in the evaluation of irrigation systems. Irrigation evaluations can be brief or in depth. Results can be simple and easy to understand or complex, with lots of numbers and confusing analyses. The following terms are often used to describe irrigation systems:

**Irrigation Efficiency (IE)**

Irrigation Efficiency = 100 x (Amount of water used beneficially / Total amount applied)

What is "beneficial" water? Largely, this is the water held in the root zone for plant use. However, this definition can be expanded to include the water applied for environmental modification (misting, cooling, or frost control) and leaching of salts. Runoff, while usually considered wasted, could also be considered beneficial if it is reused downstream.

Both system hardware and management affect irrigation efficiency. Rarely can a grower attain high IE with a system that cannot distribute water uniformly to the crop. On the other hand, the best irrigation system with high uniformity under poor management can also result in poor efficiency.

Irrigation efficiency can be estimated in a number of ways. IE can be calculated on a per irrigation event basis, a per crop basis, or a monthly, seasonal, or yearly basis. The gross amount of water applied can usually be estimated with some degree of accuracy. The net amount (or beneficial water) is usually calculated by subtracting runoff and deep percolation estimates from the gross amount. Unfortunately, these estimates are difficult to obtain with any great precision. Soil moisture measurements and evapotranspiration (ET) rates of the crop can also be utilized to improve the precision of IE estimations.

**Irrigation System Uniformity (DU, CU)**

Uniformity is the term used to describe how evenly water is applied to a crop. It is an important factor especially when irrigating small plants (turfgrass) or plants in pots because the roots of these crops are contained (or limited in expanse) and the system must have the capability to irrigate each plant. In tree and shrub areas, while uniformity is needed over generalized areas, it is not necessary to irrigate each square foot of soil equally because these plants have roots that can explore considerable volumes of soil.

Uniformity, unlike IE, can be measured using catch cans and other volumetric containers. Catch can tests are the used to estimate the DU of systems used to irrigate turfgrass areas or containerized pots. For drip systems, one of the easiest methods for estimating DU is to measure emitter output with a 35mm film canister. These canisters (provided by Kodak, Fuji and others) will hold about 35 ML of water. A 1.0 gallon per hour (GPH) emitter will fill the canister in 33.3 seconds. The relationship is GPH = 33.29/# seconds. The following table can be used for quick conversions.

| Estimating Drip Emitter Output with a Film Canister and Stopwatch | | | | | |
|---|---|---|---|---|---|
| **# Seconds** | **GPH** | **# Seconds** | **GPH** | **# Seconds** | **GPH** |
| **10** | **3.33** | **24** | **1.39** | **45** | **0.74** |
| **12** | **2.77** | **26** | **1.28** | **50** | **0.67** |
| **14** | **2.38** | **28** | **1.19** | **55** | **0.61** |
| **16** | **2.08** | **30** | **1.11** | **60** | **0.55** |
| **18** | **1.85** | **32** | **1.04** | **70** | **0.48** |
| **20** | **1.66** | **35** | **0.95** | **80** | **0.42** |
| **22** | **1.51** | **40** | **0.83** | **90** | **0.37** |

**Distribution Uniformity (DU)** is probably the most common uniformity statistic because it is easy to calculate. After making 20 or so measurements and converting to gallons per hour, the mean (average) is calculated by adding the measured amounts and dividing by the number of measurements. Then the 25% of the measurements which are the smallest are identified and averaged. This is called the average of the 'low quarter'. If you used 20 measurements total, the low quarter consists of the five smallest measurements. Then the DU is calculated as:

DU = 100 x (Average of the LQ / Average of All)

Other uniformity statistics include the Christiansen's Coefficient of Uniformity (CU) and the Scheduling Coefficient. 1/DU will provide a good estimate of the amount of extra water necessary to provide adequate irrigation to all plants.

The film canister method will provide a good estimate of the uniformity of a system while it is running. However, if supply lines are drained or if there is significant time between when the first and last plant to receive irrigation, then it is best to use larger containers and sample the system output over successive irrigation cycles. This may change your initial estimate of DU.

**Evaluation Procedures (How to collect and cook your numbers):**

There is certainly no one way to perform an irrigation evaluation. However, there are some guidelines and some factors that must be taken into account. Irrigation evaluators have developed many unique methods for obtaining good numbers.

1. **Make note of the type of equipment…. Yep, that means everything… Map?**
2. **What is the crop? Where are the roots?**
3. **Turn on the system and look for leaks and obvious problems.**
4. **Take some volumetric measurements for uniformity and rate calculations.**
5. **Make your calculations and determine results.**
6. **If uniformity is poor, WHY?**
7. **If necessary, take pressure or spacing measurements.**
8. **Fix problems and re-test.**

**Remember that a system evaluation or audit is the best way to determine the precipitation rate and distribution uniformity of any irrigation system. This information is then used in the irrigation scheduling process.**

# Appendix E. - Available Soil Moisture

Available soil moisture is soil moisture that can be used by plants. The upper limit of available soil moisture is the **field capacity** defined as the soil moisture at which deep percolation ceases. The lower limit is the **wilting point** defined as the soil moisture at which plants wilt permanently.

Figure 1 illustrates the differences in soil moisture between field capacity and wilting point. At field capacity, the illustration shows considerable water in the soil (indicated by the dark areas in the figure). No deep percolation occurs, indicated by the lack of water in the pan. Soil moisture contents greater than the field capacity result in **deep percolation**, indicated by the water in the pan beneath the saturated soil. At wilting point, little soil moisture exists, indicated by the lack of dark areas. Plants are unable to extract water at soil moisture contents less than wilting point.

Available soil moisture depends on soil texture. Sandy soils have less available soil moisture than clay soils. Figure 2 shows the available soil moisture (illustrated by the water levels in the buckets) for coarser soils, such as sands or sandy loams, can range between 0.5 to 1.5 inches per foot, while that of fine-textured soils, clay loams or clays, can range between 1.75 to 2.25 inches per foot.

Allowing a plant to use all of the available moisture is not recommended. Plants that have used all of the available water will have reduced plant vigor and health. Plant vigor reduction can be prevented by irrigating when an allowable soil moisture depletion has occurred. For many landscape plants, this allowable soil moisture depletion is about 50 percent of the available soil moisture. The feel or appearance of soil can provide a good indication of the soil moisture status (Figure 3.)

Figure 1. Soil Moisture

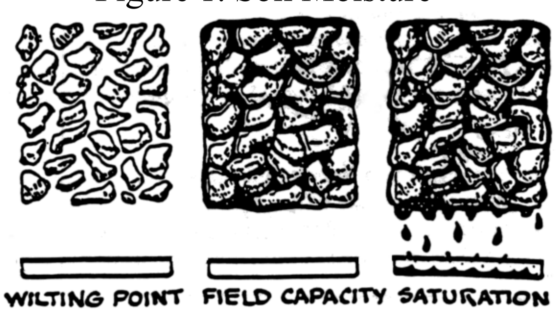



Figure 2. Water Holding Capacities of Soils

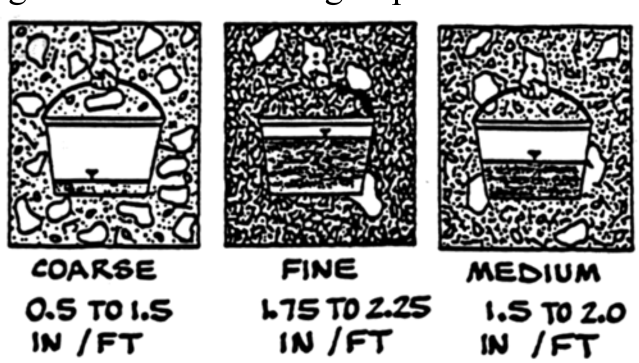


Figure 3. Soil Moisture, Appearance, and Description Chart. (From *Goldhamer and Snyder 1989. Irrigation Scheduling. U.C. Publication 21454*)

| **Available water*** | **Feel or appearance of Soil~** | | | |
|---|---|---|---|---|
| | **Sand** | **Sandy Loam** | **Loam/Silt Loam** | **Clay Loam/Clay** |
| Above Field Capacity | Free water appears when soil is bounced in hand | Free water is released with kneading | Free water can be squeezed out | Puddles; free water forms on surface |
| 100% (Field Capacity) | Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand (1.0) | Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Makes short ribbon. (1.5) | Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 1 inch. (2.0) | Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 2 inches. (2.5) |
| 75-100% | Tends to stick together slightly, sometimes forms a weak ball with pressure. (0.5 to 0.8) | Quite dark. Forms weak ball, breaks easily. Will not stick. (1.2 to 1.5) | Dark color. Forms a ball, is very pilable, sticks readily if high in clay. (1.5 to 2.0) | Dark color. Easily ribbons out between fingers, has sticky feeling. (1.9 to 2.5) |
| 50-75% | Appears to be dry, will not form a ball with pressure. (0.5 to 0.8) | Fairly dark. Tends to ball with pressure but seldom holds together. (0.8 to 1.2) | Fairly dark. Forms a ball, somewhat plastic, will sometimes stick slightly with pressure. (1.0 to 1.5) | Fairly dark. Forms a ball, ribbons out between thumb and forefinger. (1.2 to 1.9) |
| 25-50% | Appears to be dry, will not form a ball with pressure. (0.2 to 0.5) | Light colored. Appears to be dry, will not form a ball. (0.4 to 0.8) | Light colored. Somewhat crumbly, but holds together with pressure. (1.0 to 1.5) | Slightly dark. Somewhat pliable, will ball under pressure. (0.5 to 1.2) |
| 0-25% (0% is permanent wilting) | Dry, loose, single-grained, flows through fingers. (0 to 0.2) | Very slight color. Dry, loose, flows through fingers. (0 to 0.4) | Slight color. Powdery, dry, sometimes slightly crusted, but easily broken down into powdery condition. (0 to 0.5) | Slight color. Head, baked, cracked, sometinmes has loose crumbs on surface. (0 to 0.8) |
| Source: Adapted from Merriam (1950) and Hansen, Israelsen, and Stringham (1960). | | | | |
| * Available water is the difference between field capacity and permanent wilting point. | | | | |
| ~ Numbers in parentheses are available water contents expressed as inches of water per foot of soil depth. | | | | |

# Appendix F. Reference Evapotranspiration for Southern California

## TABLE I. Eto IN INCHES PER MONTH

| LOCATION | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOS ANGELES COUNTY | | | | | | | | | | | | | |
| *CLAREMONT/CHINO* | 2.2 | 2.9 | 3.9 | 4.7 | 5.5 | 6.5 | 7.3 | 7.3 | 5.9 | 4.1 | 2.6 | 2.0 | 54.9 |
| *CHATSWORTH/SAN FERNANDO* | 2.0 | 2.6 | 3.7 | 4.7 | 5.5 | 5.9 | 7.3 | 6.7 | 5.3 | 3.9 | 2.6 | 2.0 | 52.2 |
| *LANCASTER* | 2.2 | 3.1 | 4.6 | 5.9 | 8.5 | 9.4 | 11.0 | 9.8 | 7.1 | 4.6 | 2.8 | 1.7 | 70.8 |
| *LONGBEACH* | 2.2 | 2.6 | 3.4 | 3.5 | 4.9 | 4.7 | 5.5 | 4.9 | 4.1 | 3.4 | 2.4 | 2.0 | 43.6 |
| *LOS ANGELES/HOLLYWOOD* | 2.2 | 2.6 | 3.7 | 4.7 | 5.5 | 5.9 | 6.1 | 6.1 | 5.3 | 3.9 | 2.6 | 2.0 | 50.6 |
| ORANGE COUNTY | | | | | | | | | | | | | |
| *IRVINE* | 2.2 | 2.6 | 3.7 | 4.1 | 4.9 | 5.3 | 6.1 | 5.5 | 4.7 | 3.7 | 2.4 | 2.0 | 47.1 |
| *LAGUNA BEACH/NEWPORT* | 2.2 | 2.6 | 3.4 | 3.5 | 4.3 | 4.7 | 4.9 | 4.9 | 4.1 | 3.4 | 2.4 | 2.0 | 42.4 |
| *YORBA LINDA* | 2.2 | 2.9 | 3.9 | 4.7 | 5.5 | 6.5 | 7.3 | 6.7 | 5.3 | 3.9 | 2.6 | 2.0 | 53.5 |
| RIVERSIDE COUNTY | | | | | | | | | | | | | |
| *COACHELLA* | 2.9 | 4.0 | 6.1 | 8.3 | 10.4 | 11.8 | 12.2 | 9.8 | 8.9 | 6.1 | 3.8 | 2.4 | 86.6 |
| *TEMECULA* | 2.0 | 2.6 | 3.9 | 4.7 | 6.1 | 7.1 | 7.3 | 7.3 | 5.9 | 3.9 | 2.6 | 2.0 | 55.4 |
| *RIVERSIDE* | 2.2 | 2.9 | 3.9 | 4.1 | 6.1 | 7.1 | 7.9 | 7.3 | 5.9 | 4.1 | 2.6 | 2.0 | 56.2 |
| SAN BERNARDINO COUNTY | | | | | | | | | | | | | |
| *BARSTOW* | 2.4 | 3.5 | 5.6 | 7.7 | 10.4 | 11.8 | 12.2 | 11.0 | 8.3 | 5.6 | 3.3 | 2.0 | 83.8 |
| *CRESTLINE* | 1.5 | 1.8 | 3.4 | 4.1 | 5.5 | 6.5 | 7.9 | 7.3 | 5.3 | 3.4 | 2.4 | 1.7 | 50.8 |
| *SAN BERNARDINO* | 2.0 | 2.6 | 3.9 | 4.7 | 5.5 | 7.1 | 7.9 | 7.3 | 5.9 | 4.1 | 2.6 | 2.0 | 55.7 |
| *VICTORVILLE* | 2.2 | 3.1 | 4.6 | 6.5 | 9.8 | 10.6 | 11.0 | 9.8 | 7.1 | 5.1 | 2.8 | 2.0 | 74.6 |
| SAN DIEGO COUNTY | | | | | | | | | | | | | |
| *CHULA VISTA* | 2.2 | 2.7 | 3.4 | 3.8 | 4.9 | 4.7 | 5.5 | 4.9 | 4.5 | 3.4 | 2.4 | 2.0 | 44.4 |
| *ESCONDIDO* | 2.1 | 2.8 | 3.8 | 4.7 | 5.6 | 6.7 | 6.8 | 6.5 | 5.4 | 3.8 | 2.5 | 2.0 | 52.7 |
| *FALLBROOK* | 2.1 | 2.7 | 3.8 | 4.7 | 5.6 | 6.7 | 6.8 | 6.5 | 5.4 | 3.8 | 2.5 | 2.0 | 52.6 |
| *OCEANSIDE* | 2.2 | 2.7 | 3.4 | 3.7 | 4.9 | 4.7 | 4.9 | 5.1 | 4.1 | 3.3 | 2.4 | 2.0 | 43.4 |
| *PINE VALLEY* | 1.5 | 2.4 | 3.8 | 5.1 | 6.0 | 7.0 | 7.8 | 7.3 | 6.0 | 4.0 | 2.2 | 1.7 | 54.8 |
| *RAMONA* | 2.1 | 2.5 | 4.0 | 4.7 | 5.6 | 6.5 | 7.3 | 7.0 | 5.6 | 3.9 | 2.5 | 1.7 | 53.4 |
| *SAN DIEGO* | 2.2 | 2.5 | 3.3 | 3.8 | 4.9 | 4.6 | 5.1 | 4.9 | 4.5 | 3.4 | 2.4 | 2.0 | 43.6 |
| *SANTEE* | 2.1 | 2.7 | 3.7 | 4.7 | 5.7 | 7.6 | 6.8 | 6.2 | 5.4 | 3.8 | 2.6 | 2.0 | 53.3 |
| *WARNER SPRINGS* | 1.6 | 2.7 | 3.7 | 4.7 | 5.7 | 7.6 | 8.3 | 7.7 | 6.3 | 4.0 | 2.5 | 1.5 | 56.3 |
| VENTURA COUNTY | | | | | | | | | | | | | |
| *VENTURA* | 2.2 | 2.6 | 3.2 | 4.1 | 4.9 | 4.7 | 5.5 | 4.9 | 4.1 | 3.4 | 2.4 | 2.0 | 44.0 |

Data interpreted and converted from Eto maps in the publication:
Pruitt, W.O., E. Fereres, K. Kaita, and R.L. Snyder. 1987. Reference evapotranspiration (Eto) for California. U.C. Bulletin 1922. 14pp + 12 plates.

## TABLE II. Eto IN INCHES PER DAY

| LOCATION | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOS ANGELES COUNTY | | | | | | | | | | | | |
| *CLAREMONT/CHINO* | 0.07 | 0.10 | 0.13 | 0.16 | 0.18 | 0.22 | 0.24 | 0.24 | 0.20 | 0.13 | 0.09 | 0.06 |
| *CHATSWORTH/SAN FERNANDO* | 0.06 | 0.09 | 0.12 | 0.16 | 0.18 | 0.20 | 0.24 | 0.22 | 0.18 | 0.13 | 0.09 | 0.06 |
| *LANCASTER* | 0.07 | 0.11 | 0.15 | 0.20 | 0.28 | 0.31 | 0.35 | 0.31 | 0.24 | 0.15 | 0.09 | 0.06 |
| *LONGBEACH* | 0.07 | 0.09 | 0.11 | 0.12 | 0.16 | 0.16 | 0.18 | 0.16 | 0.14 | 0.11 | 0.08 | 0.06 |
| *LOS ANGELES/HOLLYWOOD 0* | 0.07 | 0.09 | 0.12 | 0.16 | 0.18 | 0.20 | 0.20 | 0.20 | 0.18 | 0.13 | 0.09 | 0.06 |
| ORANGE COUNTY | | | | | | | | | | | | |
| *IRVINE* | 0.07 | 0.09 | 0.12 | 0.14 | 0.16 | 0.18 | 0.20 | 0.18 | 0.16 | 0.12 | 0.08 | 0.06 |
| *LAGUNA BEACH/NEWPORT* | 0.07 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.16 | 0.16 | 0.14 | 0.11 | 0.08 | 0.06 |
| *YORBA LINDA* | 0.07 | 0.10 | 0.13 | 0.16 | 0.18 | 0.22 | 0.24 | 0.22 | 0.18 | 0.13 | 0.09 | 0.06 |
| RIVERSIDE COUNTY | | | | | | | | | | | | |
| *COACHELLA* | 0.09 | 0.14 | 0.20 | 0.28 | 0.33 | 0.39 | 0.39 | 0.31 | 0.30 | 0.20 | 0.13 | 0.08 |
| *TEMECULA* | 0.06 | 0.09 | 0.13 | 0.16 | 0.20 | 0.24 | 0.24 | 0.24 | 0.20 | 0.13 | 0.09 | 0.06 |
| *RIVERSIDE* | 0.07 | 0.10 | 0.13 | 0.14 | 0.20 | 0.24 | 0.26 | 0.24 | 0.20 | 0.13 | 0.09 | 0.06 |
| SAN BERNARDINO COUNTY | | | | | | | | | | | | |
| *BARSTOW* | 0.08 | 0.13 | 0.18 | 0.26 | 0.33 | 0.39 | 0.39 | 0.35 | 0.28 | 0.18 | 0.11 | 0.06 |
| *CRESTLINE* | 0.05 | 0.06 | 0.11 | 0.14 | 0.18 | 0.22 | 0.26 | 0.24 | 0.18 | 0.11 | 0.08 | 0.06 |
| *SAN BERNARDINO* | 0.06 | 0.09 | 0.13 | 0.16 | 0.18 | 0.24 | 0.26 | 0.24 | 0.20 | 0.13 | 0.09 | 0.06 |
| *VICTORVILLE* | 0.07 | 0.11 | 0.15 | 0.22 | 0.31 | 0.35 | 0.35 | 0.31 | 0.24 | 0.17 | 0.09 | 0.06 |
| SAN DIEGO COUNTY | | | | | | | | | | | | |
| *CHULA VISTA* | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.16 | 0.18 | 0.16 | 0.15 | 0.11 | 0.08 | 0.06 |
| *ESCONDIDO* | 0.07 | 0.10 | 0.12 | 0.16 | 0.18 | 0.21 | 0.22 | 0.21 | 0.18 | 0.12 | 0.08 | 0.06 |
| *FALLBROOK* | 0.07 | 0.09 | 0.12 | 0.16 | 0.18 | 0.21 | 0.22 | 0.21 | 0.18 | 0.12 | 0.08 | 0.06 |
| *OCEANSIDE* | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.16 | 0.16 | 0.17 | 0.14 | 0.11 | 0.08 | 0.06 |
| *PINE VALLEY* | 0.05 | 0.06 | 0.09 | 0.14 | 0.18 | 0.23 | 0.26 | 0.24 | 0.20 | 0.13 | 0.08 | 0.05 |
| *RAMONA* | 0.07 | 0.09 | 0.13 | 0.16 | 0.18 | 0.22 | 0.24 | 0.22 | 0.19 | 0.13 | 0.09 | 0.06 |
| *SAN DIEGO* | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.16 | 0.17 | 0.16 | 0.15 | 0.11 | 0.08 | 0.06 |
| *SANTEE* | 0.08 | 0.09 | 0.12 | 0.15 | 0.18 | 0.21 | 0.22 | 0.20 | 0.18 | 0.12 | 0.08 | 0.06 |
| *WARNER SPRINGS* | 0.05 | 0.08 | 0.12 | 0.16 | 0.19 | 0.25 | 0.27 | 0.25 | 0.21 | 0.13 | 0.08 | 0.05 |
| VENTURA COUNTY | | | | | | | | | | | | |
| *VENTURA* | 0.07 | 0.09 | 0.10 | 0.14 | 0.16 | 0.16 | 0.18 | 0.16 | 0.14 | 0.11 | 0.08 | 0.06 |

Data interpreted and converted from Eto maps in the publication:
Pruitt, W.O., E. Fereres, K. Kaita, and R.L. Snyder. 1987. Reference evapotranspiration (Eto) for California. U.C. Bulletin 1922.

# Appendix G

## Conversion Factors, Formulas, and Reference Numbers

1 inch water = 0.62 gallons per square foot
1 Acre Foot = 325,851 Gallons
1 Acre Inch = 27,154 Gallons
1 Gallon water = 8.3 pounds
1 Gallon water = 3.785 litres

To convert inches of water applied to an area to gallons of water applied:

Gallons applied = inches of water applied × sq. ft. of area irrigated × 0.623 gal/sq. ft.

To convert gallons of water applied to an area to inches of water applied:

Inches applied = × (sq. ft. of area irrigated × 0.623 gal/sq. ft.) ÷ gallons of water applied

CCF = 100 cubic feet water = 748 gallons (this is a standard billing unit for most urban water agencies)

Precipitation Rate in./hr. = (GPM × 96.3) ÷ sq. ft. of irrigated area

# Appendix H.

# Reference Materials and Sources of Information

**University of California Agricultural Publications:** (Available at U.C. Cooperative Extension Offices or by mail order from ANR Publications, University of California, 6701 San Pablo Avenue, Oakland, CA 94608-1239).

Irrigation Scheduling - Publication 21454

Basic Irrigation Scheduling - Leaflet 21199

Turfgrass Water Conservation - Publication 21405

Reference Evapotranspiration for California - Bulletin 1922

Determining Daily Reference Evapotranspiration - Leaflet 21426

Using Reference Evapotranspiration and Crop Coefficients to Estimate Crop Evapotranspiration: Agronomic Crops, Grasses and Vegetable Crops - Leaflet 21427
Trees and Vines - Leaflet 21428

Turfgrass Irrigation Scheduling - Leaflet 21492

Evaluating Turfgrass Sprinkler Irrigation Systems - Leaflet # 21503

Farm Irrigation System Evaluation: A Guide for Management.
1978. J.L. Meriam and J. Keller.

Landscape Water Management Handbook. DWR Office of Water Conservation. 1987.
R.E. Walker and G.J. Kah

**CIMIS Information:** DWR Office of Water Conservation
P.O. Box 942836
Sacramento, CA 94236-0001

CIMIS information may also be available locally through U.C. Cooperative Extension, Resource Conservation Districts, and Water District Offices.

## Useful Internet Web Sites For Irrigation And Water Policy Information

**California Dept. of Water Resources Sites:**

- CIMIS Program general information, technical resources and contacts: http://www.cimis.water.ca.gov/
- DWR, Water Use Efficiency Office's urban water management, landscape water use and other water conservation and efficiency program activities and information resources: http://wwwdpla.water.ca.gov/urban/

**California Urban Water Conservation Council (CUWCC)**

- background information on the structure and operation of the Council, details of the MOU and Best Management Practices (BMPs) that members agree to abide by are available in PDF; information regarding public policy and technical aspects of urban water management is posted to assist water managers and water agencies implement BMP's
- http://www.cuwcc.org/home.html

**University of California Sites:**

- Dr. Richard Snyder's U. C. Davis weather and irrigation scheduling information site: http://lawr.ucdavis.edu/coopextn/biometeorology/index.htm
- Dennis Pittenger's U.C. Riverside web page with landscape management information: http://plantbiology.ucr.edu/coop/ (scroll to "Dennis Pittenger" link).

**U.S. Bur. Reclamation** report: *Weather-based Technologies for Residential Irrigation Scheduling:* http://www.usbr.gov/pmts/tech_services (search for "ET Controllers")

**Irvine Ranch Water Disrtict's** water conservation information and help page, including copies of surveys and studies related to water use and conservation within their service area: http://www.irwd.com/Conservation/Conservation.html

**Irrigation Association:** http://www.Irrigation.org

# IRRIGATION SYSTEM EVALUATION CHECKLIST

LOCATION: ______________________ EVALUATOR: ______________________ Page ___ of ___
ADDRESS: ______________________ TELEPHONE: ______________________
CONTACT PERSON: ______________________ DATE: ______________________
TELEPHONE: ______________________ TIME SPENT: ______________________

**IRRIGATION CONTROL SYSTEM EVALUATION:**

1.) Controller Type: ______________________ No. of Stations: ______ No. of Programs: ____
2.) Valve Conditions: (Circle) GOOD NOT WORKING LEAKING BAD SOLENOID REMARKS: ______________________
3.) Wiring Conditions: (Circle) GOOD BROKEN POOR CONNECTIONS REMARKS: ______________________
4.) Backflow Prevention: YES NO
5.) Soil Moisture Sensor: YES NO Station # _____
6.) Rainfall Sensor: YES NO
7.) Pressure Regulator: YES NO MULTI
8.) Manifold Pressure: ______ PSI

**STATION BY STATION SYSTEM EVALUATION:** (✓) indicates problem observed

| STATION # | SYSTEM TYPE: Sprinkler, Mini Sprinkler, Shrub Heads, Bubbler, Drip | PLANT TYPE: Warm Season Turf, Cool Season Turf, Trees, Shrubs, Bedding Plants, Drought Tolerant? | NOT ZONED FOR PLANT REQ | NOT ZONED FOR EXPOSURE | OBVIOUS OVER-WATERING | OBVIOUS UNDER-WATERING | PONDING NEAR PLANT TRUNKS | MULCH NEEDED | SOIL COMPACTION | EXCESS TURFGRASS THATCH | BROKEN COMPONENTS | HEADS/NOZZLES NOT SIMILAR | SPACING UNEVEN | PRECIP RATES NOT MATCHED | SPRAY PATTERN BLOCKED | SPRAY MISDIRECTED/OVERSPRAY | WRONG PATTERNS: 1/4-1/2-FULL | SUNKEN HEADS | HEADS NOT VERTICAL | HEADS NOT TURNING | CLOGGED NOZZLES/EMITTERS | WORN NOZZLES/EMITTERS | UNEQUAL DISCHARGE RATES | UNEQUAL PRESSURES | LOW HEAD DRAINAGE |
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**REMARKS:**

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FORM ISE-1 PREPARED BY THE UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION - PRINTED WITH ASSISTANCE FROM THE METROPOLITAN WATER DISTRICT

SPRINKLER EVALUATION DATA SHEET

Location: ______________________________________________ Evaluator: _______________

Controller: ___________________ Station: __________________ Date: __________________

Computer Filename: _____________ TEST RESULTS: PR = _____ In/Hr DU= ______ %

CATCH CAN TEST: Catch Can Diameter: _____________ inches

Volume or Depth Units: ML OZ MM IN (Circle)

TEST RUN TIME: Actual ____ min. Controller ____ min.

Did Runoff Occur? Yes/No After _______ Minutes

Wind Direction
Relative to Test

X = Sprinkler Location

List Pressures in PSI

| | | | | | | | | | | | |
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SPRAY HEAD, BUBBLER, MINI-SPRINKLER, OR DRIP EVALUATION DATA SHEET

Location: ________________________________ Evaluator: ______________________

Controller: ____________________ Station: ______________ Date: _______________

Computer Filename: ____________________ (8 Character Filename)

Sprinkler/Emitter Type: _____________________________________________________

Manufacturer/Model/Orifice Type: _______________________________________________

Spacing: _______ Ft. x ______ Ft. Number/Plant: ________

Volume Unites: ML or Gallons Test Time: ___________ Seconds

| Emitter Number | Volume Measured | Pressure PSI | Emitter Number | Volume Measured | Pressure PSI |
|---|---|---|---|---|---|
| 1 | | | 21 | | |
| 2 | | | 22 | | |
| 3 | | | 23 | | |
| 4 | | | 24 | | |
| 5 | | | 25 | | |
| 6 | | | 26 | | |
| 7 | | | 27 | | |
| 8 | | | 28 | | |
| 9 | | | 29 | | |
| 10 | | | 30 | | |
| 11 | | | 31 | | |
| 12 | | | 32 | | |
| 13 | | | 33 | | |
| 14 | | | 34 | | |
| 15 | | | 35 | | |
| 16 | | | 36 | | |
| 17 | | | 37 | | |
| 18 | | | 38 | | |
| 19 | | | 39 | | |
| 20 | | | 40 | | |

Average: _____________ Low Quarter Average: ________________

DU = Low Quarter Average ÷ Average = ___________

PR = _________Inches/Hour

Application Rate Calculations: