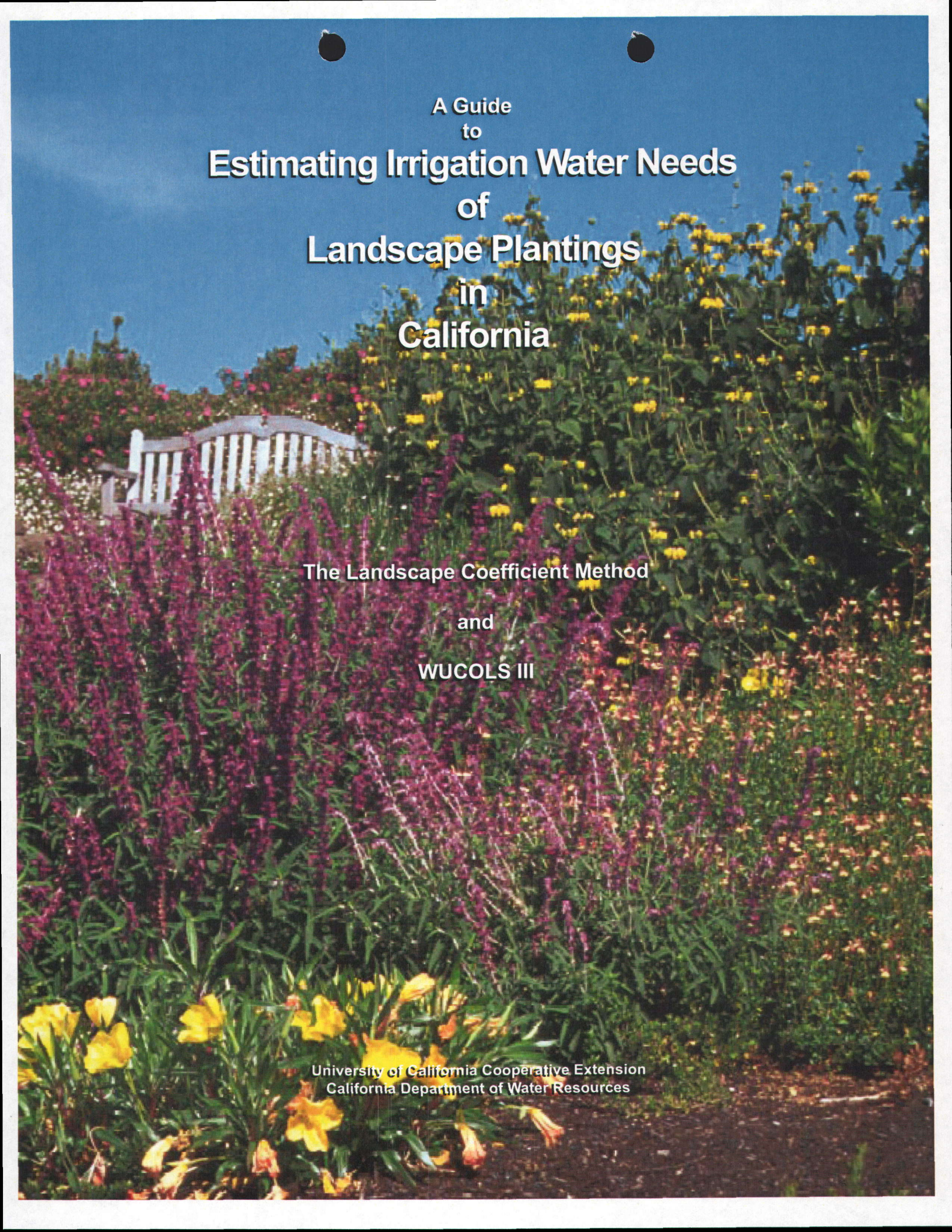


EXhibit Q

A vibrant garden scene with purple and yellow flowers, a wooden bench, and a blue sky. The text is overlaid on the image.

A Guide
to
**Estimating Irrigation Water Needs
of
Landscape Plantings
in
California**

The Landscape Coefficient Method
and
WUCOLS III

University of California Cooperative Extension
California Department of Water Resources



Cover photo: The Garden at Heather Farms, Walnut Creek, CA

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The Landscape Coefficient Method

and

WUCOLS III*

*WUCOLS is the acronym for Water Use Classifications of Landscape Species.

University of California Cooperative Extension
California Department of Water Resources

August 2000

Preface

This Guide consists of two parts, each formerly a separate publication:

Part 1—*Estimating the Irrigation Water Needs of Landscape Plantings in California: The Landscape Coefficient Method*

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- N.P. Matheny, HortScience, Inc., Pleasanton, CA
- J.R. Clark, HortScience Inc., Pleasanton, CA

Part 2—*WUCOLS III (Water Use Classification of Landscape Species)*

- L.R. Costello, University of California Cooperative Extension
- K.S. Jones, University of California Cooperative Extension

Part 1 describes a method for calculating landscape water needs, while Part 2 gives evaluations of wa-

ter needs for individual species. Used together, they provide the information needed to estimate irrigation water needs of landscape plantings.

Part 1 is a revision of *Estimating Water Requirements of Landscape Plants: The Landscape Coefficient Method*, 1991 (University of California ANR Leaflet No. 21493). Information presented in the original publication has been updated and expanded.

Part 2 represents the work of many individuals and was initiated and supported by the California Department of Water Resources. This third revision (WUCOLS III) includes many species not previously evaluated, as well as an update and reorganization of support information.

These two publications are companion documents and are intended to be used together.



Eschscholzia californica, California poppy

First-time readers are encouraged to carefully review both parts of this Guide before making estimates of landscape water needs.

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Part 1

The Landscape Coefficient Method

The Landscape Coefficient Method (LCM) describes a method of estimating irrigation needs of landscape plantings in California. It is intended as a guide for landscape professionals. It includes information that is based on research **and** on field experience (observation). Readers are advised that LCM calculations give **estimates** of water needs, not exact values, and adjustments to irrigation amounts may be needed in the field.

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Introduction

Part 1 leads you through the concepts, terms, and formulas needed to estimate irrigation water needs.

You will learn:

- the key formulas needed for calculations,
- the principal concepts that serve as a basis for calculations,
- how to use the methods in the field,
- how to use estimates in irrigation planning and management,
- where to find important numbers in reference tables, and
- considerations for special landscape situations.

Chapters

After providing background information on estimating water needs for agricultural crops and turf in Chapter 1, landscape needs are addressed in Chapter 2. The **landscape coefficient**, a key factor in the formula for estimating landscape water requirements, is introduced in Chapter 2. Subsequent chapters give examples of how to calculate and use the landscape coefficient. Chapter 5 addresses irrigation efficiency and gives examples of how it is used to determine total water needs. As a way of “putting it all together,” a worksheet which summarizes the process is provided in Chapter 6. Special topics are discussed in Chapters 7 and 8. The appendices provide further information.

Audience

All landscape professionals involved in the planning, installation, and maintenance of irrigated landscapes should find this information of value. This includes architects, planners, contractors, park man-

agers, gardeners, consultants, water suppliers, auditors, and students.

Importance

Estimates of landscape water needs are important for at least three reasons:

1. **Water Conservation.** Water is a limited natural resource. Efficient water use in urban landscapes contributes substantially to the conservation of this resource. Water use efficiency can be achieved by supplying only the amount of water sufficient to meet plant needs.



Applying only the amount of water landscape plants need to remain healthy and attractive is an efficient use of a natural resource.

2. **Economics.** Water costs continue to increase. By applying only that amount of water needed by landscapes, and avoiding excess use, money can be saved.
3. **Landscape Quality.** The potential for plant injury caused by water deficits or excess can be minimized by identifying and meeting plant needs.

Getting Started

First-time readers are encouraged to review the entire Guide prior to making water needs estimates. Field examples and a practice worksheet in Chapter 6 show how to use the information presented in previous chapters. Be sure to review the appendices; they contain important numbers for calculations.

Formulas and Numbers

Formulas and numbers are needed to calculate irrigation water requirements. Fortunately, the calculations needed here are simple and straightforward. They require only a basic understanding of mathematics. Once you have reviewed the examples and made some calculations on your own, you should have no difficulty. A worksheet with all the formulas and sample calculations is included in Chapter 6.

Chapter 1— Estimating Water Requirements for Crops and Turf

In agriculture, irrigation water requirements are well established for many crops. In urban landscapes, irrigation requirements have been determined for turfgrasses, but not for most landscape species. This chapter discusses the method used to estimate water requirements for agricultural crops and turfgrasses. Chapter 2 adapts this method for application to landscape plantings.

Water requirements for agricultural crops and turfgrasses have been established in laboratory and field studies by measuring plant water loss (evapotranspiration). The total amount of water lost during a specific period of time gives an estimate of the amount needed to be replaced by irrigation. Since growers and turf managers are not equipped to measure plant water loss in the field, a formula was developed which allows water loss to be calcu-



Water requirements of both cool and warm season turfgrasses have been established (see Table 1).



Water requirements of many agricultural crops have been established (see Table 1).

lated. This formula (referred to as the ET_c formula) is written as follows:

$$ET_c = K_c \times ET_o$$

Crop Evapotranspiration =
Crop Coefficient x Reference Evapotranspiration

This formula states that water loss from a crop (crop evapotranspiration, ET_c) equals the amount of water that evaporates from a 4- to 7-inch tall cool season grass growing in an open-field condition (reference evapotranspiration, ET_o) multiplied by a factor determined for the crop (crop coefficient, K_c).

Reference evapotranspiration (ET_o) is estimated from a Class A evaporation pan or from a specialized weather station. Normal year (historical) average values for many locations in California are found in Appendix A. Current daily ET_o values are available from the California Irrigation Management Information System (CIMIS) and can be accessed via the Internet (www.cimis.water.ca.gov) or by contacting the California Department of Water Resources (see Appendix D).



A specialized weather station (CIMIS station) or a Class A evaporation pan (background) can be used to determine reference evapotranspiration (ET_c) for a site. Daily CIMIS data is available online at www.cimis.water.ca.gov.

The **crop coefficient (K_c)** is determined from field research. Water loss from a crop is measured over an extended period of time. Water loss and estimated reference evapotranspiration are used to calculate K_c as follows:

$$K_c = \frac{ET_c}{ET_o}$$

As seen in the above equation, the crop coefficient (K_c) is simply the fraction of water lost from the crop relative to reference evapotranspiration. Typically, crop water loss is less than reference evapotranspiration and, therefore, the crop coefficient is

less than 1.0. For example, if water loss from corn was measured to be 4 inches in a month, and reference evapotranspiration for the same month was 8 inches, then the crop coefficient would be 0.5. Crop coefficients have been established for many crops and for turfgrasses. A sample of values is given in Table 1.

**Table 1—
Crop Coefficients for Various Crops and
Turfgrasses**

K_c values for agricultural crops typically change during the seasons: low values are for early season (March/April) or late season (September/October) and high values for midseason (May/June/July).

K _c values		
	Low	High
Deciduous orchard*	0.50	0.97
Deciduous orchard with cover crop**	0.98	1.27
Grape	0.06	0.80
Olive	0.58	0.80
Pistachio	0.04	1.12
Citrus	0.65	year-round
Turfgrass		
Cool season species	0.8	year-round
Warm season species	0.6	year-round

Source: UC Leaflet Nos. 21427 and 21428 (see references)

* Deciduous orchard includes apples, cherries, and walnuts

** When an active cover crop is present, K_c may increase by 25 to 80%.

In summary, an estimate of crop evapotranspiration is made from reference evapotranspiration and crop coefficient values. Estimates can be made for any location where reference evapotranspiration data exists and for any crop (or turfgrass) that has a crop coefficient.

Example: A grape grower in Monterey County wants to estimate how much water the vineyard may lose in the month of July. Using the ET_c formula, two numbers are needed: reference evapotranspi-

ration (ET_o) for July in Monterey and the crop coefficient (K_c) for grapes. July ET_o for Monterey can be found in Appendix A, and the K_c for grapes is listed in Table 1 (above). With the two values, the following computation is made:

$$\begin{aligned} ET_o &= 0.18 \text{ inches per day} \times 31 \text{ days} = 5.58 \\ &\text{inches (average for July in Monterey)} \\ K_c &= 0.8 \text{ (midseason value for grapes)} \\ \\ ET_c &= K_c \times ET_o \\ ET_c &= 0.8 \times 5.58 = 4.46 \text{ inches} \end{aligned}$$

The grower has estimated that 4.46 inches of water will be lost from the vineyard (via evapotranspiration) in the month of July. By using this ET_c estimate, the grower can calculate irrigation water requirements for the vineyard. (For an estimate of the total amount of water to apply, see Chapter 5).

The ET_c formula is the **key formula** for estimating water loss from crops and turfgrasses. A version of this formula will be used in Chapter 2 to estimate water loss for **landscape** plantings. It is recommended that you become familiar with the ET_c formula before continuing.

Chapter 2— Estimating Water Needs for Landscape Plantings

Two formulas are used to estimate water needs for landscape plantings:

- the landscape evapotranspiration formula and
- the landscape coefficient formula.

Both formulas are introduced here and then used in subsequent chapters to estimate water needs. The landscape coefficient was developed specifically for estimating **landscape** water needs and is the principal focus of Chapter 2.

The method used for estimating water needs for landscape plantings is basically the same as that used for crops and turfgrasses. The ET_c formula discussed in Chapter 1 is simply modified for application to landscapes. One key change, however, has been made: instead of using the crop coefficient (K_c), a landscape coefficient (K_L) has been substituted.

The Landscape Evapotranspiration Formula

Water needs of landscape plantings can be estimated using the landscape evapotranspiration formula:

$$ET_L = K_L \times ET_o$$

$$\begin{aligned} &\text{Landscape Evapotranspiration} = \\ &\text{Landscape Coefficient} \times \text{Reference Evapotranspiration} \end{aligned}$$

This formula (called the ET_L formula) states that water needs of a landscape planting (landscape

evapotranspiration, ET_L) is calculated by multiplying the landscape coefficient (K_L) and the reference evapotranspiration (ET_o).

As mentioned above, the ET_L formula is basically the same as the ET_c formula from Chapter 1, except that a landscape coefficient (K_L) has been substituted for the crop coefficient (K_c). This change is necessary because of important differences which exist between crop or turfgrass systems and landscape plantings (see “Why a Landscape Coefficient”).

The following is an example of a simple calculation using the landscape coefficient in the landscape evapotranspiration (ET_L) formula.

Example: A landscape architect wants to estimate water loss for the month of August from a large groundcover area being considered for a new commercial office park in Fresno. The architect looked up the reference evapotranspiration for August in Fresno (Appendix A) and found it to be 7.1 inches. The architect assigned a landscape coefficient value of 0.2. Using this information and the landscape evapotranspiration formula (ET_L formula), the architect makes the following calculations:

$$K_L = 0.2$$

$$ET_o = 7.1 \text{ inches for August in Fresno}$$

$$ET_L = K_L \times ET_o$$

$$ET_L = 0.2 \times 7.1 = 1.42 \text{ inches}$$

The architect estimates that the groundcover will need 1.4 inches in the month of August. (This is not the total amount of irrigation water needed, however, as irrigation efficiency needs to be considered. This topic is addressed in Chapter 5.)

In this example, a landscape coefficient was assigned. In actual practice, K_L needs to be calculated. The formula needed to calculate K_L is the heart of the landscape coefficient method and is the subject of the next discussion.

The Landscape Coefficient Formula

As the name implies, the landscape coefficient was derived specifically to estimate water loss from landscape plantings. It has the same function as the crop coefficient, but is not determined in the same way. Landscape coefficients are calculated from three factors: species, density, and microclimate. These factors are used in the landscape coefficient formula as follows:

$$K_L = K_s \times K_d \times K_{mc}$$

Landscape Coefficient =
species factor x density factor x microclimate factor

This formula (called the K_L formula) states that the landscape coefficient is the product of a species factor multiplied by a density factor and a microclimate factor. By assigning numeric values to each factor, a value for K_L can be determined. The landscape coefficient is then used in the ET_L formula, just as the crop coefficient is used in the ET_c formula.

Why a Landscape Coefficient?

Crop coefficients are used for agricultural crops and turfgrasses, so why not for landscape plantings? There are three key reasons why landscape coefficients are needed instead.

1. Unlike a crop or turfgrass, landscape plantings are typically composed of more than one **species**. Collections of species are commonly irrigated within a single irrigation zone, and the dif-

ET Rates and Plant Water Needs

Soil water availability plays a major role in controlling the rate of water loss from plants (ET rate). Many plants will lose water at a maximum rate as long as it is available. For example, some desert species have been found to maintain ET rates equivalent to temperate zone species when water is available. When soil moisture levels decrease, however, ET rates in desert species decline rapidly.

In landscape management, it is not the objective to supply all the water needed to maintain maximum ET rates. Rather, it is the intent to supply only a sufficient amount of water to maintain health, appearance and reasonable growth. Maximum ET rates are not required to do this.

The ET_L formula calculates the amount of water needed for health, appearance and growth, not the maximum amount that can be lost via evapotranspiration.



Some desert species, such as mesquite (*Prosopis glandulosa torreyana*), have been found to maintain ET rates equivalent to temperate zone species when water is available (Leviitt et al 1995). When soil moisture levels decrease, however, ET rates in desert species decline rapidly.



Unlike agricultural crops or turfgrass, landscape plantings are typically composed of many species. Collections of species are commonly irrigated within a single irrigation zone, and the different species within the irrigation zone may have widely different water needs. Using a crop coefficient for one species may not be appropriate for the other species.

ferent species within the irrigation zone may have widely different water needs. For example, a zone may be composed of hydrangea, rhododendron, alder, juniper, oleander, and olive. These species are commonly regarded as having quite different water needs and the selection of a crop coefficient appropriate for one species may not be appropriate for the other species. Crop coefficients suitable for landscapes need to include some consideration of the mixtures of species which occur in many plantings.

2. Vegetation **density** varies considerably in landscapes. Some plantings have many times more leaf area than others. For example, a landscape with trees, shrubs, and groundcover plants closely grouped into a small area will have much more leaf area than one with only widely spaced shrubs in the same-sized area. More leaf area typically means an increase in evapotranspiration (water loss) for the planting. As a result, a dense planting would be expected to lose a

greater amount of water than a sparse planting. To produce a reliable estimate of water loss, a coefficient for landscapes needs to account for such variation in vegetation density.

3. Many landscapes include a range of **microclimates**, from cool, shaded, protected areas to hot, sunny, windy areas. These variations in climate significantly affect plant water loss. Experiments in Seattle, Washington, found that a planting in a paved area can have 50%

greater water loss than a planting of the same species in a park setting. Other studies in California found that plants in shaded areas lost 50% less water than plants of the same species in an open field condition. This variation in water loss caused by microclimate needs to be accounted for in a coefficient used for landscape plantings.

Collectively, these factors make landscape plantings quite different from agricultural crops and turfgrasses, and they need to be taken into account when making water loss estimates for landscapes. The landscape coefficient was developed specifically to account for these differences.

The Landscape Coefficient Factors: Species, Density, and Microclimate

Three factors are used to determine the landscape coefficient:

- Species
- Density
- Microclimate

These factors are key elements of the landscape coefficient method and need to be understood fully before K_L and ET_L calculations are made. As well as describing each factor, the following sections give information on how to assign values to each.

Species Factor (k_s)

The species factor (k_s) is used to account for differences in species' water needs. In established landscapes, certain species are known to require relatively large amounts of water to maintain health and appearance (e.g., cherry, birch, alder, hydrangea, rhododendron), while others are known to need very little water (e.g., olive, oleander, hopseed, juniper).

This range in water needs is accounted for in the species factor.

Species factors range from 0.1 to 0.9 and are divided into four categories:

Very low	< 0.1
Low	0.1 - 0.3
Moderate	0.4 - 0.6
High	0.7 - 0.9

These species factor ranges apply regardless of vegetation type (tree, shrub, groundcover, vine, or herbaceous) and are based on water use studies for landscape species (Table 2) and applicable data from agricultural crops (Table 1).

An evaluation of plant water needs (based on field observations) has been completed for over 1,800 species. These values are presented in Part 2 (WUCOLS III). Species factor values can be found by looking up the species under consideration, and selecting an appropriate value from the category

Water: Needed for What?



In agricultural systems, water is applied to produce a crop. Whether it be tomatoes, beans, or apples, growers apply water to optimize yield and quality. In landscape systems, health, appearance, and growth are of greatest interest. Irrigation is managed to sustain plant defense systems, achieve desired canopy densities and color, generate desired growth, and produce flowers and fruit (in some species). Irrigation is not used to produce a harvestable crop in landscapes. Because of this difference between landscape and agricultural systems, landscapes typically can be managed at a level of irrigation lower than that needed for crop production.

range. The following is an example of using the WUCOLS list to select an appropriate k_s value.

Example: A landscape manager in Pasadena is attempting to determine the water requirements of a large planting of Algerian ivy. In using the ETL formula, the manager realizes a value for the species factor (k_s) is needed in order to calculate the landscape coefficient (K_L). Using the WUCOLS list (Part 2), the manager looks up Algerian ivy (*Hedera canariensis*) and finds it classified as “moderate” for the Pasadena area, which means that the value ranges from 0.4 to 0.6. Based on previous experience irrigating this species, a low range value of 0.4 for k_s is chosen and entered in the K_L formula. (If the manager had little or no experience with the species, a middle range value of 0.5 would be selected.)



Certain species, such as tree ferns (*Dicksonia antarctica* and *Cyathea cooperi*), require relatively large amounts of water to maintain health and appearance.

Although the above example is straightforward, the assignment of species factors to plantings can be difficult. Refer to “Assigning Species Factors to Plantings” for guidance in making k_s assignments.



Some species, such as flannel bush (*Fremontodendron* spp.), need very little irrigation water to maintain health and appearance.

**Table 2—
Irrigation Needs of Well-Established Landscape
Species Determined from Field Research**

Values are given as the minimum fraction of reference evapotranspiration needed to maintain acceptable appearance, health, and reasonable growth for the species. See Appendix D for complete references.

Plant Species	Fraction of ET _o
<i>Potentilla tabernaemontani</i>	0.5 - 0.75
<i>Sedum acre</i>	0.25
<i>Cerastium tomentosum</i>	0.25
<i>Liquidambar styraciflua</i>	0.20
<i>Quercus ilex</i>	0.20
<i>Ficus microcarpa nitida</i>	0.20
<i>Hedera helix</i> 'Neddlepoint'	0.20
<i>Drosanthemum hispidum</i>	0.20
<i>Gazania hybrida</i>	0.25-0.50
<i>Vinca major</i>	0.30
<i>Baccharis pilularis</i>	0.20

Reference: Staats and Klett; Hartin, et al; Pittenger, et al

Assigning Species Factors to Plantings

1. **For single-species plantings—**

When only one species occurs in the irrigation zone, use the k_s value assigned in the WUCOLS list. For example, coyote brush is assigned to the “low” category and has a k_s value from 0.1 to 0.3.

2. **For multiple-species plantings—**

a. When species have similar water needs: In well-planned hydrozones where species of similar water requirements are used, the selection of a k_s value is straightforward: simply select the category to which all

species are assigned and choose the appropriate value. For example, if all the species are in the moderate category, then a value from 0.4 to 0.6 is selected.

b. When species water needs are not similar: In cases where species with different water needs are planted in the same irrigation zone, then the species in the highest water-need category determine the k_s value. This assignment is required if all plants are to be retained without water stress injury. For example, if species in low, moderate, and high categories are planted in the same irrigation zone, then to avoid water stress injury to species in the high category, a k_s value from 0.7 to 0.9 would need to be selected. Unfortunately, this means that species in the moderate and low categories will receive more water than needed, which may result in injury.

Considering that plantings with mixed water needs are not water-efficient in most cases and



Plant injury may occur when species with different water needs are planted in a single irrigation zone. During a drought, irrigation was withdrawn from this planting of star jasmine (*Trachelospermum jasminoides*) and cotoneaster (*Cotoneaster* sp). Subsequently, star jasmine was severely injured, while cotoneaster was not visibly affected.

the incidence of plant injury may increase, some management options are worth considering:

- If only a small number or percentage of plants are in the high category, then the replacement of such plants with species with lower water needs would allow for the selection of a k_s in a lower range.
- If all plants are to be retained, but a level of appearance somewhat less than optimal is acceptable, then a k_s value from a lower range may be selected. For example, in the case where plants in the low, moderate, and high categories are in the same irrigation zone, a k_s value from the moderate range may be selected with the understanding that some injury to species in the high category may result.
- In cases where all plants are to be retained and no water stress injury is acceptable, then supplemental irrigation for species in the high category should be considered. Again using the case where species in low, moderate, and high categories are planted in the same irrigation zone, a k_s value from the moderate range may be selected for the planting, provided additional water is supplied to individual plants with higher water needs. This approach requires an adjustment to the irrigation system whereby additional sprinklers or emitters are used to deliver supplemental water to species with higher water requirements.



Certain species, such as these coast live oak (*Quercus agrifolia*), can maintain health and appearance without irrigation (after they become established). Such species are grouped in the “very low” category and are assigned a species factor of less than 0.1. Many California native species are in this category.

3. For species in the “very low” category—

It is important to remember that certain species can maintain health and appearance without irrigation after they become established. Such species are grouped in the “very low” category and are assigned a k_s of less than 0.1. Essentially this classification means that species in this group do not need to be irrigated unless winter rainfall is abnormally low. Accordingly, if no irrigation is supplied, then there is no need to calculate a landscape coefficient and a k_s value is not assigned. In low rainfall years, some irrigation may be needed, however, and a k_s value of 0.1 should be sufficient to maintain health and appearance in these species.

Density Factor (k_d)

The density factor is used in the landscape coefficient formula to account for differences in vegetation density among landscape plantings. Vegetation density is used here to refer to the collective leaf area of all plants in the landscape. Differences

in vegetation density, or leaf area, lead to differences in water loss.

The density factor ranges in value from 0.5 to 1.3. This range is separated into three categories:

Low	0.5 - 0.9
Average	1.0
High	1.1 - 1.3

Immature and sparsely planted landscapes typically have less leaf area than mature or densely planted landscapes, and thus lose less water. These plantings are assigned a k_d value in the low category. Plantings with mixtures of vegetation types (trees, shrubs, and groundcovers) typically have greater collective leaf areas than plantings with a single vegetation type, and thus will lose more water. These plantings are assigned a density factor value in the high category. Plantings which are full but are predominantly of one vegetation type, are assigned to the average category.

Example: The grounds manager of a college campus in San Diego wants to determine the landscape coefficient for a planting consisting of gazania groundcover and a few widely-spaced escallonia shrubs. Since the plants cover the ground surface completely, the planting is considered to be full. Based on these vegetation density characteristics (i.e., full and predominantly of one vegetation type), the manager determines that this is an average density planting and assigns a k_d value of 1.0.

Although this example might infer that the selection of the density factor is fairly simple, it can be difficult to determine. Vegetation density varies considerably and assigning density factors can be confusing. Many cases exist where plant spacing

and distribution is not uniform and where a mixture of vegetation types exist.

Unfortunately, a standardized system of evaluating vegetation density for landscapes does not exist. Nonetheless, limited information from agricultural systems (principally orchards) can be applied to landscapes. The following sections describe two terms, canopy cover and vegetation tiers, which when applied to landscape plantings provide some guidance in assessing vegetation density.

Canopy Cover

Canopy cover is defined as the percentage of ground surface within a planting which is shaded by the plant canopy (or, simply, percent ground shading). A planting with full canopy cover will shade 100% of the ground surface, while a 50% canopy cover will cast a shadow on 50% of the ground area. The higher the canopy cover the greater the density of vegetation on a surface area basis.

Most mature landscape plantings have a complete canopy cover, i.e., the trees, shrubs, and groundcovers shade 100% of the ground surface. New plantings, immature plantings, and widely-spaced plantings are examples of cases where the canopy cover is less than 100%.

Orchard data gives an indication of how canopy cover affects water loss. Studies show that water loss from orchards does not increase as canopy cover increases from 70% to 100%. Below 70% cover, however, orchard water loss declines.

Applying this information to landscapes, plantings of trees with a canopy cover of 70% to 100% constitutes a complete canopy cover condition, and

would be considered as average for density factor assessments. A tree planting with less than 70% canopy cover would be in the low category.

For plantings of shrubs and groundcovers, a canopy cover of 90% to 100% constitutes complete cover. This represents an average condition for density factor assessments, while less than 90% cover would be in the low category.

Vegetation Tiers

Canopy cover gives an assessment of vegetation density on an area basis, i.e., the percent ground area covered by vegetation describes the closeness or sparseness of plants in a planting. Another dimension needs to be considered for landscapes: the vertical dimension. Landscapes are frequently composed of plants of various heights: tall trees, low groundcovers, and shrubs somewhere in between. Due to the typical growth form of each vegetation type, "tiers" of vegetation result.

When combinations of these vegetation types occur in a planting they add a height element which will have an affect on water loss. In orchard plantings, for example, field research has shown that the addition of a cover crop increases evapotranspiration from 25% to 80% above a bare soil condition. In other words, adding a groundcover-like planting beneath orchard trees results in a substantial increase in water loss.

In landscapes, groundcovers and/or shrubs planted in the understory of trees are likely to have a similar effect on water loss as found in orchard settings. Additionally, by adding trees to a groundcover planting or shrubs to a tree-groundcover planting, an increase in water loss would be expected.

In most cases, the presence of vegetation tiers in landscapes constitutes a high density condition. For example, a planting with two or three tiers and complete canopy cover would be considered to be in the high ka category .



Landscapes are frequently composed of plants of various heights: trees, groundcovers, and shrubs. Due to the typical growth form of each vegetation type, "tiers" of vegetation result. Plantings with more than one tier are likely to lose more water than a planting with a single tier. Here, the trees and shrubs in the groundcover represent a higher water loss condition than if the groundcover occurred alone. The density factor accounts for differences in vegetation density.

Plantings with multiple tiers which do not have a complete canopy cover, however, may not constitute a high density condition. A new planting with trees, shrubs, and groundcovers, for example, has three vegetation tiers but canopy density is low. Although three tiers are present, this planting would be classified as low density.

Assigning Density Factor Values

Canopy cover and vegetation tiers are used to assess vegetation density for density factor assignments. Since it is very difficult to account for all the variation in vegetation density which occurs in landscapes, the following assignments are made simply as a guide to making reasonable assessments.

Average Density: $k_a = 1.0$

Plantings of one vegetation type: for trees, canopy cover of 70% to 100% constitutes an average condition. For shrubs or groundcovers, a canopy cover of 90% to 100% is considered to be an average condition.



Plantings of a single species, such as this iceplant groundcover (*Drosanthemum* sp), are considered to have average density ($k_a = 1.0$) when full (90 - 100% cover).



This mixed planting of Wheeler's pittosporum (*Pittosporum tobira* 'Wheeler's Dwarf'), Indian hawthorne (*Raphiolepis indica*), American sweetgum (*Liquidambar styraciflua*), and coast redwood (*Sequoia sempervirens*) is considered to be average density ($k_d = 1.0$). Trees are widely spaced through the sub-shrub/groundcover planting area.

Plantings of more than one vegetation type: for mixed vegetation types, an average density condition occurs when one vegetation type is predominant while another type occurs occasionally in the planting, and canopy cover for the predominant vegetation type is within the average density specifications outlined above. For example, a mature groundcover planting (greater than 90% canopy cover) which contains trees and/or shrubs that are widely spaced would be considered to be average density. Additionally, a grove of trees (greater than 70% canopy cover) which contains shrubs and/or groundcover plants which are widely spaced would constitute an average condition.

Low Density: $k_a = 0.5 - 0.9$

Low density plantings are characterized largely by canopy covers less than those specified for the average density condition. For instance, a tree planting with less than 70% canopy cover would be assigned a k_a value less than 1.0. The precise value assigned (between 0.5 and 0.9) would be based on the canopy cover assessment: a lower k_a value for a thinner canopy cover.

For shrubs and groundcovers, canopy cover less than 90% constitutes a density less than average and a k_d value less than 1.0 would be assigned.

Plantings with mixed vegetation types generally have greater canopy covers than those of a single type. For instance, a groundcover planting with canopy cover of 50% constitutes a low density condition and a k_d of 0.7 might be assigned. If an occasional tree occurs in the planting, then the principal effect is one of increasing canopy cover, and an upward adjustment in k_d to 0.8 or 0.9 would be warranted.

High Density: $k_d = 1.1 - 1.3$

When canopy cover is full for any vegetation type, then increases in density result from increases in the number of plants of other vegetation types. For example, by adding trees to a mature groundcover planting (groundcover canopy cover = 100%), an increase in vegetation density occurs. The addition of shrubs to the planting further increases the density. This mix of vegetation types creates a layering or tiering of vegetation which represents potential increases in water loss. Upward adjustments of k_d can be made to account for vegetation tiering. The highest density condition, where all three vegetation types occur in substantial numbers in a planting, would be assigned a k_d of 1.3. In plantings where lesser degrees of vegetation tiering occurs (e.g., a two-tiered planting), then a k_d value of 1.1 or 1.2 is appropriate.

Microclimate Factor (k_{mc})

Microclimates exist in every landscape and need to be considered in estimates of plant water loss. Features typical of urban landscapes (such as buildings and paving) influence temperature, wind speed, light intensity and humidity. These features vary considerably among landscapes, resulting in differences in microclimate. To account for these differences, a microclimate factor (k_{mc}) is used.

The microclimate factor ranges from 0.5 to 1.4, and is divided into three categories:

Low	0.5 - 0.9
Average	1.0
High	1.1 - 1.4

The microclimate factor is relatively easy to set. An “average” microclimate condition is equivalent to reference evapotranspiration conditions, i.e., an open-field setting without extraordinary winds or heat inputs atypical for the location. This microclimate is not substantially affected by nearby buildings, structures, pavements, slopes, or reflective surfaces. For example, plantings in a well-vegetated park which are not exposed to winds atypical of the area, would be assigned to the average microclimate category.



For shrubs and groundcovers, canopy cover less than 90% constitutes a density less than average ($k_d < 1.0$). This mixed planting would be assigned a low density value (0.5 - 0.9).



Plantings in a well-vegetated park, which are not exposed to winds atypical for the area, would be assigned to the average microclimate category ($k_{mc} = 1.0$). These conditions are similar to those used for reference evapotranspiration measurements (CIMIS stations).

In a “high” microclimate condition, site features increase evaporative conditions. Plantings surrounded by heat-absorbing surfaces, reflective surfaces, or exposed to particularly windy conditions would be assigned high values. For example, plantings in street medians, parking lots, next to southwest-facing walls of a building, or in “wind tunnel” areas would be assigned to the high category.



Plantings surrounded by heat-absorbing surfaces, reflective surfaces, or exposed to particularly windy conditions would be assigned a high microclimate value (1.1 - 1.4).

“Low” microclimate conditions are as common as high microclimate conditions. Plantings that are shaded for a substantial part of the day or are protected from winds typical to the area would be assigned low values. These include the north side of buildings, courtyards, under building overhangs, and on the north side of slopes.

The high and low microclimate categories have ranges of values. For example, the low category ranges from 0.5 to 0.9. The specific value assigned within a category will depend on an assessment of the degree to which the microclimate will affect plant water loss. For example, trees in a parking lot which are exposed to constant winds (atypical for the general area) will be assigned a higher value in the high category than if the location was not windy. Conversely, a courtyard planting in afternoon shade and protected from winds will be assigned a k_{mc} value in the low category, but less than that for a planting without afternoon shading.

Example: An irrigation consultant is estimating landscape water requirements for a large residential development. The buildings, parking lots,

walkways, and open areas at the site create substantially different microclimates within plantings. Starting with the open areas, he determines that conditions are quite similar to reference ET measurement sites and assigns them to the average category ($k_{mc} = 1.0$). Trees in the parking lot are exposed to heat from the asphalt pavement and reflected light from cars and are assigned to the high category. Since the parking lot is not ex-

posed to extraordinary winds, however, he chooses a midrange value of 1.2. Shrub and groundcover plantings on the northeast side of buildings are shaded for most of the day and are assigned to the low category. Being protected from winds typical of the area as well, they are given a k_{mc} value of 0.6, in the lower end of the range.

Assigning Microclimate Factor Values

Average Microclimate: $k_{mc} = 1.0$

Site conditions equivalent to those used for reference ET measurements represent an average microclimate. Reference ET is measured in an open-field setting which is not exposed to extraordinary winds or heat inputs from nearby buildings, structures, or vehicles. Plantings in similar conditions would be considered to be in an average microclimate. Plantings in park settings are most typically assigned to this category. Although some hardscape may exist, vegetation dominates the landscape. Large plantings of groundcover, groves of trees, and mixtures of shrubs, turf, and trees in relatively open ar-



Plantings that are shaded for a substantial part of the day, or are protected from winds typical to the area, are assigned low microclimate values (0.5 - 0.9). This planting on the northeast side of the office building is shaded for several hours each day.

reas represent examples of an average microclimate condition. Small parks with adjacent buildings, extensive hardscapes, or exposed to extraordinary winds would not be included in the average category.

Low Microclimate: $k_{mc} = 0.5 - 0.9$

Sites which are shaded or protected from winds typical to the area are considered to be in the low microclimate category (Costello et al. 1996). Features of the site modify the microclimate such that evaporative conditions are less than those found in the average microclimate. Plantings located on the north side or northeast side of buildings, shaded by overhead structures, or within courtyard settings are typically assigned a k_{mc} value in the low range. Plantings protected from winds by buildings, structures, or other vegetation also would be assigned to the low category. The specific value assigned for the microclimate factor will depend on the specific site conditions. For example, a planting in a courtyard which is shaded most of the day and protected from winds may be assigned a value of 0.6, while a simi-

lar planting which is located on the northeast side of a building may be assigned a value of 0.8.

High Microclimate: $k_{mc} = 1.1 - 1.4$

Sites which are exposed to direct winds atypical for the area, heat inputs from nearby sources, and/or reflected light would be considered to be in the high microclimate category. These features of the site increase evaporative conditions above those found in an average microclimate condition. Plantings located in medians, parking lots, or adjacent to south or southwest facing walls which are exposed to higher canopy temperatures than those found in a well-vegetated setting would be in the high category. Plantings in wind tunnel locations and those receiving reflected light from nearby windows, cars, or other reflective surfaces are also in high microclimate conditions. The specific value assigned will depend on the specific conditions. For example, a shrub planting located next to a southwest facing wall may be assigned a k_{mc} value of 1.2, while a similar planting next to a southwest wall which is composed of reflective glass and is exposed to extraordinary winds may be assigned a value of 1.4.

**Table 3—
Summary Table
Values for Landscape Coefficient Factors**

	High	Moderate	Low	Very Low
Species Factor* (k_s)	0.7-0.9	0.4-0.6	0.1-0.3	<0.1
Density (k_d)	1.1-1.3	1.0	0.5-0.9	
Microclimate (k_{mc})	1.1-1.4	1.0	0.5-0.9	

* Species factor values may change during the year, particularly for deciduous species. See Table 1 for seasonal changes in crop coefficients for agricultural crops.