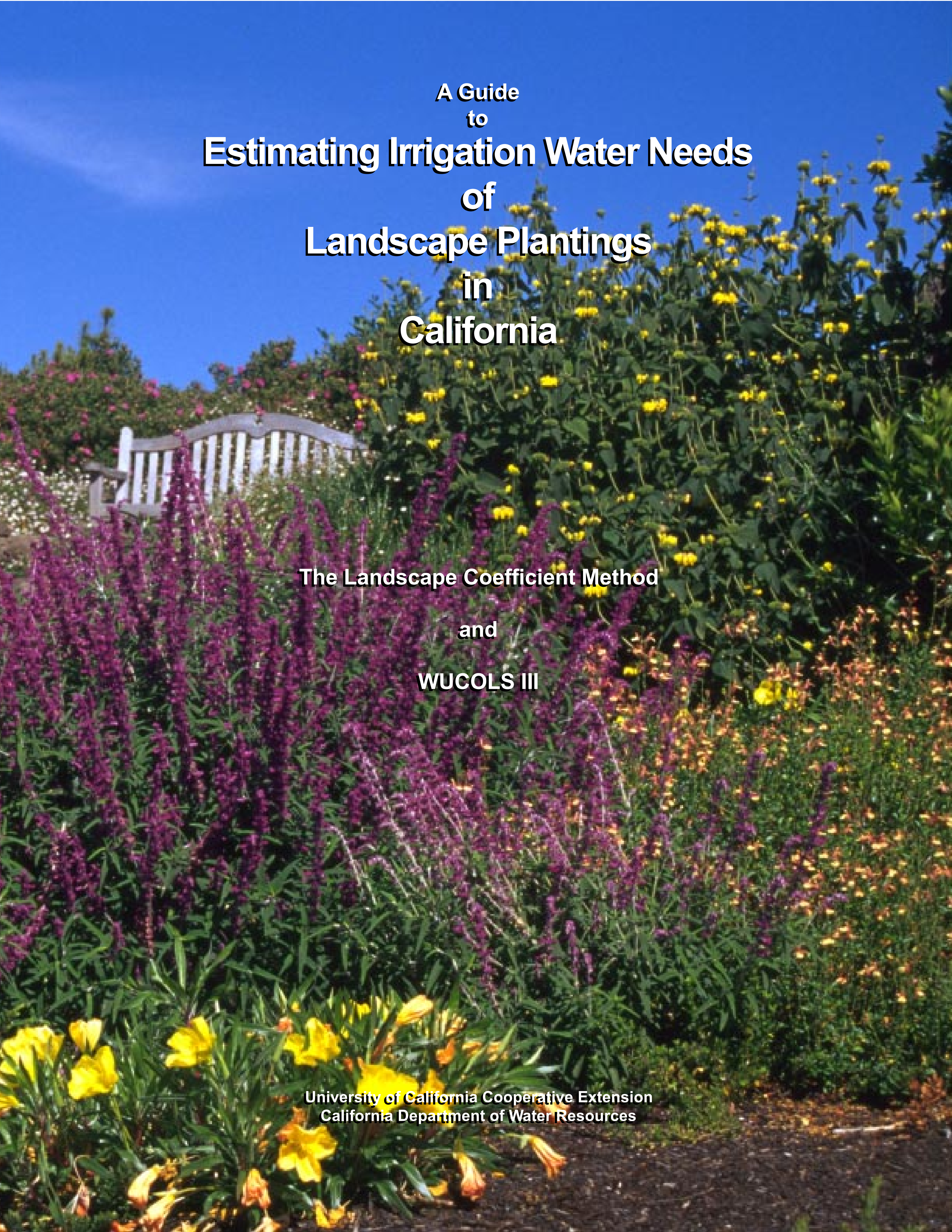
A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California

The Landscape Coefficient Method

and

WUCOLS III



University of California Cooperative Extension
California Department of Water Resources

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Photography: L.R. Costello and K.S. Jones, University of California Cooperative Extension
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to

Estimating Irrigation Water Needs of Landscape Plantings in California

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and

WUCOLS III*

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

University of California Cooperative Extension
California Department of Water Resources

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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*

- L.R. Costello, University of California Cooperative Extension
- 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 water 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.

Contents

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.

L. R. Costello, Environmental Horticulture Advisor
University of California Cooperative Extension

N. P. Matheny, Horticultural Consultant
HortScience, Inc.

J. R. Clark, Horticultural Consultant
HortScience, Inc.

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 managers, 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 calculated. This formula (referred to as the ET_c formula) is written as follows:

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 Table1).

$$ET_c = K_c \times ET_o$$

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_o) 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 evapotranspiration (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:

ET_o = 0.18 inches per day x 31 days = 5.58 inches (average for July in Monterey)
K_c = 0.8 (midseason value for grapes)

$ET_c = Kc \times ET_o$
ET_c = 0.8 x 5.58 = 4.46 inches

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:

$$ET_L = K_L \times ET_o$$

Landscape Evapotranspiration =
Landscape Coefficient x Reference Evapotranspiration

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 inches for August in Fresno

$ET_L = K_L \times ET_o$
$ET_L = 0.2 \times 7.1 = 1.42$ 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 (Levitt 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.

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

Example: A landscape manager in Pasadena is attempting to determine the water requirements of a large planting of Algerian ivy. In using the ET_L 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.)

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
Potentilla tabernaemontani	0.5 - 0.75
Sedum acre	0.25
Cerastium tomentosum	0.25
Liquidambar styraciflua	0.20
Quercus ilex	0.20
Ficus microcarpa nitida	0.20
Hedera helix ‘Neddlepoint’	0.20
Drosanthemum hispidum	0.20
Gazania hybrida	0.25-0.50
Vinca major	0.30
Baccharis pilularis	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, irrrigation was withdrawn from this planting of star jasmine (*Trachelospermum jasminioides*) 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.

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.

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 k_d category .

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_d = 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.

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

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

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_d = 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_d 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_d 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).

"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.

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.

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.

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).

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 exposed 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.

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.

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 areas 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 similar 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.

Chapter 3—
Using the Landscape Coefficient Formula

The landscape coefficient formula was introduced in Chapter 2, and the three factors which determine its value were discussed. Now these factors are used to calculate values for the landscape coefficient. A series of field cases show the range of values that can be determined for K_L. In Chapter 4, calculations using the landscape coefficient in the ET_L formula are presented.

Using the information presented in Chapter 2, values for the landscape coefficient can be calculated. The following cases show how the landscape coefficient is used for a variety of species, density, and microclimate conditions. Species factor values will be taken from the WUCOLS list, while density and microclimate values are based on the planting and site conditions described. For quick reference, the following table gives values for each factor.

Landscape Coefficient Factors

	Species	Density	Microclimate
High	0.7 - 0.9	1.1 - 1.3	1.1 - 1.4
Mod./Ave.	0.4 - 0.6	1.0	1.0
Low	0.1 - 0.3	0.5 - 0.9	0.5 - 0.9
Very Low	< 0.1		

Case 1—A large, mature planting of star jasmine in a park in San Jose. It is in full sun and has little wind exposure.

$$k_s = 0.5$$
$$k_d = 1.0$$
$$k_{mc} = 1.0$$
$$K_L = 0.5 \times 1.0 \times 1.0 = 0.5$$

Analysis: Star jasmine is classified as moderate in the WUCOLS list (moderate range = 0.4 to 0.6) and a midrange k_s value of 0.5 is assigned. Since the planting is mature it will be considered full (i.e., canopy cover = 100%), and being of one vegetation type, it is classified as an average density and k_d is 1.0. The microclimate is similar to reference evapotranspiration conditions (full sun, open area, no extraordinary winds) and, therefore, is classified as average and k_{mc} is 1.0.

Case 2—A mixed planting of dwarf coyote brush, Pfitzer juniper, oleander, purple hopseed, and olive in an office park in Los Angeles. The planting is full, exposed to sun all day, but not to extraordinary winds.

$$k_s = 0.2$$
$$k_d = 1.2$$
$$k_{mc} = 1.0$$
$$K_L = 0.2 \times 1.2 \times 1.0 = 0.24$$

Analysis: All species are classified as low in the WUCOLS list and are assigned a midrange value of 0.2. Canopy cover is 100%, and since all three vegetation types occur, this is classified as a high density planting and a k_d value of 1.2 is assigned. The microclimate is average and a value of 1.0 is assigned.

Case 3—A mature planting of rockrose, star jasmine, and dichondra in an amusement park in Sacramento. The planting is in full sun and atypical winds are infrequent.

$$k_s = 0.8$$
$$k_d = 1.0$$
$$k_{mc} = 1.0$$
$$K_L = 0.8 \times 1.0 \times 1.0 = 0.8$$

Analysis: Species in this planting are in three different WUCOLS categories: low (rockrose), moderate (star jasmine), and high (dichondra). To maintain the dichondra in good condition, a k_s value of 0.8 is needed. This means, however, that both the rockrose and star jasmine will receive more water than they need. Obviously this is not a water-efficient planting. Both the density and microclimate conditions are average and were assigned values of 1.0.

Case 4—A widely-spaced planting of camellia on a university campus in San Francisco. Canopy cover of the planting is 40% to 50%. A 4-inch mulch covers the ground throughout the planting. It is in full sun and no extraordinary winds occur.

$$k_s = 0.5$$
$$k_d = 0.5$$
$$k_{mc} = 1.0$$
$$K_L = 0.5 \times 0.5 \times 1.0 = 0.25$$

Analysis: Camellia is classified as moderate in the WUCOLS list and is assigned a midrange value of 0.5. This is a low density planting of a single species and a k_d value of 0.5 is assigned. The microclimate is average and given a value of 1.0.

Case 5—A planting of leatherleaf mahonia and Burford holly in an office park in Pasadena. The planting is full, but shaded in the afternoon by an adjacent building. The building also blocks afternoon winds typical for the area.

$$k_s = 0.5$$
$$k_d = 1.0$$
$$k_{mc} = 0.6$$
$$K_L = 0.5 \times 1.0 \times 0.6 = 0.30$$

Analysis: Both species are classified as moderate in the WUCOLS list and are assigned a midrange value of 0.5. The canopy cover is full and since only one vegetation type occurs, it is classified as average density. Since the building shades the planting and protects it from wind, the microclimate is low and a k_{mc} value of 0.6 is assigned.

Case 6—A mixed planting of sweetgum, *Rhaphiolepis* sp., Wheeler's dwarf pittosporum, Raywood ash, and English ivy at a zoo in San Diego. The planting is mature (canopy cover is 100%), in full sun, and exposed to continual strong winds not typical for the area (i.e., windier than the reference ET location).

$$k_s = 0.5$$
$$k_d = 1.2$$
$$k_{mc} = 1.3$$
$$K_L = 0.5 \times 1.2 \times 1.3 = 0.78$$

Analysis: All species in this planting are classified as moderate in the WUCOLS list and are assigned a midrange value of 0.5. Since the canopy cover is 100% and all three vegetation types occur, this is a high density planting and a k_d of 1.2 is assigned. Since the site is atypically windy for the area, the microclimate is classified as high and a k_{mc} of 1.3 is assigned.

Case 7—A new planting of rockrose, manzanita, pink melaleuca, and bushy yate along a freeway in Monterey County. All plants are 5-gallon container stock, planted in full sun, and are not exposed to extraordinary winds. Canopy cover is 20 to 30%. A 4-inch layer of mulch covers the ground throughout the planting.

$$k_s = 0.2$$
$$k_d = 0.5$$
$$k_{mc} = 1.0$$
$$K_L = 0.2 \times 0.5 \times 1.0 = 0.1$$

Analysis: All species in this planting are classified as low in the WUCOLS list and a midrange value of 0.2 is given. Since this is a new planting and canopy cover is not full, it is placed in a low density category and assigned a k_d value of 0.5. The microclimate is average and assigned a value of 1.0. (See Chapter 8 for information on irrigating new plantings.)

These field examples should provide an understanding of how values for each of the landscape coefficient factors are assigned and used. In addition, an appreciation for the diversity of species, differences in vegetation density, and variation in microclimates which exist in landscapes should be realized. In many cases, there will be a different landscape coefficient for each irrigation zone.

For discussions of the following special planting cases, refer to Chapter 8:

- New Plantings
- Trees in Turf
- Individual Specimens
- Vines
- Herbaceous Plants

Landscapes vary considerably in species composition, vegetation density and microclimates.

Chapter 4—
Using the Landscape Coefficient to Estimate Landscape Evapotranspiration

The landscape coefficient and reference evapotranspiration now are used to estimate landscape evapotranspiration for the plantings described in Chapter 3. This chapter completes the process used to produce estimates of landscape water loss. Subsequent chapters discuss how to use estimates of ET_L to calculate total irrigation water needs and how to apply this information in landscape management programs.

In Chapter 3, seven landscape planting cases were described and used for landscape coefficient calculations. These cases will be used here to calculate landscape evapotranspiration with the ET_L formula. The ET_L formula was described in Chapter 2 and is presented here for quick reference:

$$ET_L = K_L \times ET_o$$

Landscape Evapotranspiration =
Landscape Coefficient x Reference Evapotranspiration

For each case, reference evapotranspiration (ET_o) values will be taken from Appendix A. All are normal year average values for the month of July for the respective locations.

Case 1— $K_L = 0.5$
ET_o for San Jose = 7.44 inches

$ET_L = 0.5 \times 7.44 = 3.72$ inches

Case 2— $K_L = 0.24$
ET_o for Los Angeles = 6.5 inches

$ET_L = 0.24 \times 6.5 = 1.56$ inches

Case 3— $K_L = 0.8$
ET_o for Sacramento = 8.6 inches

$ET_L = 0.8 \times 8.6 = 6.88$ inches

Case 4— $K_L = 0.25$
ET_o for San Francisco = 4.9 inches

$ET_L = 0.25 \times 4.9 = 1.22$ inches

Case 5— $K_L = 0.30$
ET_o for Pasadena = 7.4 inches

$ET_L = 0.30 \times 7.4 = 2.22$ inches

Case 6— $K_L = 0.78$
ET_o for San Diego = 5.8 inches

$ET_L = 0.78 \times 5.8 = 4.59$ inches

Case 7— $K_L = 0.1$
ET_o for Monterey = 5.5 inches

$ET_L = 0.1 \times 5.5 = 0.55$ inches

These calculations show that landscape irrigation water needs vary substantially. Estimates range from 0.55 inches to 6.88 inches—more than a 12-fold difference.

The two factors used to determine ET_L, the landscape coefficient and reference evapotranspiration, are solely responsible for producing these differences in water loss estimates. For plantings in the same location (i.e., where the same ET_o values will be used), the differences will arise solely from the landscape coefficient. To produce useful estimates of water loss, therefore, it is important to carefully determine the value of K_L.

Even though the ET_L formula has given an estimate of water loss from a landscape, the total amount of irrigation water needed has not been determined. The total amount is calculated from two factors: ET_L and irrigation efficiency. The following chapter discusses irrigation efficiency and shows how it is used to determine the total amount of water to apply.

Chapter 5—
Irrigation Efficiency and Calculating the Total Amount of Water to Apply


Not all water applied to landscapes is used by plants. Some is lost due to runoff, windspray, or deep percolation. Irrigation efficiency losses need to be included in water budget calculations.

The first four chapters have described the process for estimating plant water needs. To calculate the total amount of water to apply, irrigation efficiency needs to be addressed. This chapter introduces the formula for calculating total water needs and discusses the irrigation efficiency factor. How this information applies to irrigation management is discussed in Chapter 6.

The ET_L formula calculates the amount of irrigation water needed to meet the needs of plants. This is not the total amount of water needed to apply, however. Since every irrigation system is inefficient to some degree, the landscape will require water in excess of that estimated by ET_L. In this chapter, irrigation efficiency will be discussed and then used to calculate the total amount of water to apply.

Irrigation Efficiency

Efficiency can be defined as the beneficial use of applied water (by plants). The following formula is used to calculate irrigation efficiency:

$$\text{Irrigation Efficiency (\%)} = \frac{\text{Beneficially Used Water}}{\text{Total Water Applied}} \times 100$$

An efficiency of 100% would mean that all applied water was used by the planting. This rarely occurs. Consequently, irrigation efficiency is less than 100% in virtually all cases and additional water should be applied to account for efficiency losses.

A determination of irrigation efficiency (IE) for **landscape plantings** is challenging. As yet, a standard method has not been established. The approach used for turf irrigation, distribution uniformity (DU), is not appropriate for most landscape plantings.

Three approaches are considered here: calculation, estimation, and goal setting. Each method has **significant** limitations, and are presented here only as possible options to consider.

Calculation

To calculate irrigation efficiency, values for ET_L and TWA are needed. In landscapes, beneficially used water is the equivalent of ET_L (the amount of water estimated to be needed by a planting). This is calculated as described in Chapter 4. The total water applied can be determined by operating an irrigation system for a scheduled cycle and measuring the total water used (usually read from a water meter). The following example shows a typical calculation:

ET_L = 4 inches (calculated using the ET_L formula)
TWA = 5 inches (measured)

$$IE = \frac{ET_L}{TWA} \times 100 = 80\%$$

In the above example, the system has an 80% efficiency, or 8 out of every 10 gallons of applied water is used beneficially by the planting. Two gallons are lost, perhaps to runoff, evaporation, leakage, or wind spray. To supply 8 gallons of water means that a total of 10 gallons needs to be applied.

This approach has limited application for two reasons:

1. it requires a water meter to measure the amount of water applied, and
2. it may include efficiency losses associated with poor scheduling.

It assumes that applied water is close to optimum for the landscape plants and the system operating capabilities. It may be, however, that inefficiencies are linked to the operating schedule. For example, the irrigation duration may be too long for the planting.

Estimation

In cases where the total water applied cannot be measured, then irrigation efficiency may be estimated. Estimates are based on an assessment of the design and performance of the irrigation system. A system which is well designed and operated can have an efficiency range of 80% to 90%. Poorly designed and operated systems may have efficiencies of less than 50%. A representative range of efficiencies for landscape systems is proposed here to be from 65% to 90%.

Estimating is a subjective process where two assessments of the same system can vary widely. The utility of an estimate will be related to the knowledge and experience of the estimator.

Goal Setting

Irrigation efficiency values may also be based on a design and/or management goal. For instance, a new landscape may be designed to achieve an irrigation efficiency of 90%. Or, an existing landscape may be managed to achieve an irrigation efficiency of 85%. Both values represent efficiency goals. These efficiency values are then used to estimate the total water needed to achieve the goal. This approach is useful for water budgeting purposes, but does not provide a useful estimate of actual system performance.

All three of these methods are highly approximate. Until a standard method of measuring landscape irrigation efficiency is determined, however, they provide some guidance.

Total Water Applied

Regardless of the method used to determine irrigation efficiency, the total amount of water needed for a landscape planting is calculated using the following formula:

$$TWA = \frac{ET_L}{IE}$$

$$\text{Total Water Applied} = \frac{\text{Landscape Evapotranspiration}}{\text{Irrigation Efficiency}}$$

The following are examples of calculations using irrigation efficiency and landscape evapotranspiration to determine the total water to apply. The first three cases presented in Chapters 3 and 4 will be used. An irrigation efficiency value of 70% is assigned for each case.

Case 1— ET_L = 3.72 inches
IE = 70% or 0.7

$$TWA = \frac{3.72}{0.7} = 5.31 \text{ inches}$$

(see Case 1 in Chapter 4)

Case 2— ET_L = 1.56 inches
IE = 70% or 0.7

$$TWA = \frac{1.56}{0.7} = 2.22 \text{ inches}$$

Case 3— ET_L = 6.88 inches
IE = 70% or 0.7

$$TWA = \frac{6.88}{0.7} = 9.8 \text{ inches}$$

It is clear from these calculations that irrigation efficiency plays a very large role in determining the total amount of water to apply. Water added to account for efficiency losses ranges from 0.67 inches to 2.88 inches.

If the efficiency of the system is greater or less than 70%, the total water applied will vary accordingly. The magnitude of this effect can be seen in the following calculations where IE values from 30% to 90% are used. The ET_L value from the first sample calculation (3.72 inches) is used in each case.

@ 30% IE, $TWA = \frac{3.72}{0.3} = 12.4$ inches

@ 60% IE, $TWA = \frac{3.72}{0.6} = 6.2$ inches

@ 90% IE, $TWA = \frac{3.72}{0.9} = 4.1$ inches

These calculations indicate that for the same landscape plants, at the same location, and under identical environmental conditions, the total amount of water applied varies from 4.1 inches to 12.4 inches, due solely to irrigation efficiency differences. Clearly, the IE factor needs to be addressed very carefully when planning and managing landscapes.

Chapter 6— Putting It All Together: A Worksheet for Calculations

Chapters 1 through 5 have introduced a number of formulas and numbers that are used to estimate landscape water needs. This chapter puts all the equations together to show the calculation process. Subsequent chapters discuss considerations for applying estimates and special planting situations.

Three steps are needed to estimate irrigation water needs of a planting:

1. calculate the landscape coefficient,

2. calculate landscape evapotranspiration, and

3. calculate the total water applied.

These steps are combined in a worksheet format on the following page. After the worksheet, an example is given to show how it is used, followed by a discussion of converting units from inches of water to gallons.

Converting Inches to Gallons

Landscape evapotranspiration (ET_L) and total water applied (TWA) values have been given in units of inches. Frequently, it is of interest to know how many gallons of water are needed. Inches of water can be converted to gallons by using: 1) a conversion factor, and 2) a measure of the area to be irrigated.

1) The conversion factor, 0.62, can be used to convert inches-of-water-per-square-foot to gallons. A volume that is one-foot long, one-foot wide, and one-inch deep contains 0.62 gallons of water. This means that there are 0.62 gallons of water in a square-foot-inch. (There are 325,851 gallons in an acre-foot of water.)

2) The area to be irrigated needs to be measured. To use the conversion factor, units of square-feet are required.

With the area and the conversion factor, gallons of water can be calculated using the following formula:

Estimated water in gallons = estimated water in inches x area (square feet) x 0.62

Example: It was determined that 2.11 inches of water was needed for a groundcover planting. Let's say the planting covers 5,000 square feet.

To convert inches to gallons:

Gallons = 2.11 inches x 5,000 sq. ft. x 0.62 = 6,541

It is estimated that 6,541 gallons of water are needed to maintain the 5,000 square feet of groundcover.

Worksheet for Estimating Landscape Water Needs

Step 1: Calculate the Landscape Coefficient (K_L)

K_L formula: $K_L = k_s \times k_d \times k_{mc}$ .... k_s = species factor
k_d = density factor
k_{mc} = microclimate factor

k_s = _______ (range = 0.1-0.9) (see WUCOLS list for values)

k_d = _______ (range = 0.5-1.3) (see Chapter 2)

k_{mc} = ______ (range = 0.5-1.4) (see Chapter 2)

K_L = ______ x ______ x ______ = ______ .
(k_s) (k_d) (k_{mc})

Step 2. Calculate Landscape Evapotranspiration (ET_L)

ET_L formula: $ET_L = K_L \times ET_o$ .... K_L = landscape coefficient
ET_o = reference evapotranspiration

K_L = _______ (calculated in Step 1)

ET_o = ______ inches (listed in Appendix A for month and location)

ET_L = ______ x ______ = ______ inches.
(K_L) (ET_o)

Step 3. Calculate the Total Water to Apply (TWA)

TWA formula: $TWA = \frac{ET_L}{IE}$ .... ET_L = landscape evapotranspiration
IE = irrigation efficiency

ET_L = _______ (calculated in Step 2)

IE = ________ (measured, estimated, or set) (see Chapter 5)

$TWA = \frac{ET_L}{IE}$ = _______ inches

Worksheet Example

A landscape manager in San Bernardino is interested in estimating water requirements for a large planting of African daisy (*Osteospermum fruticosum*) for the month of July. The planting is in an open area and is not exposed to extraordinary winds for the area. The manager estimates that irrigation efficiency is 70% and, using the work-sheet, follows the three steps (see below).

Step 1. $K_L = k_s \times k_d \times k_{mc}$

k_s = 0.2 (from WUCOLS list)
k_d = 1.0 (complete canopy cover and one vegetation type)
k_{mc} = 1.0 (open area, no extraordinary winds)

$K_L = 0.2 \times 1.0 \times 1.0 = 0.2$

Step 2. $ET_L = K_L \times ET_o$

K_L = 0.2 (from Step 1)
ET_o = 7.4 inches (for July in San Bernardino) (see Appendix A)

ET_L = 0.2 x 7.4 = 1.48 inches

Step 3. $TWA = \frac{ET_L}{IE}$

ET_L = 1.48 inches (from Step 2)
IE = 0.7 (70% irrigation efficiency estimated by landscape manager)

$TWA = \frac{1.48 \text{ inches}}{0.7} = 2.11 \text{ inches}$

(To convert 2.11 inches of water to gallons, see "Inches to Gallons".)

The landscape manager has estimated that the groundcover will need 2.11 inches of water for the month of July. Using this estimate, the manager can develop an irrigation schedule. Other factors may need to be considered before deciding if this estimate is appropriate for the planting. Chapter 7 addresses these considerations.

Chapter 7—
Using Water Estimates in Landscape Planning and Management

Before water needs estimates are used for landscape planning and management purposes, a few points need to be considered. In Chapter 7, five special topics which are relevant to using estimates are addressed. The following chapter discusses some special planting situations.

The previous chapters have described how to estimate irrigation water needs for landscape plantings. These estimates can be used in landscape planning and management to:

- develop water budgets for planned or existing landscapes,
- assist in the design of landscapes to meet irrigation goals,
- assist in designing and managing effective hydrozones,
- help in the determination of irrigation system efficiency (i.e., along with measurements of total water use), and
- serve as an auditing tool by providing assessments of the amount of water landscapes need compared to that actually being used.

When using landscape water estimates for these purposes, however, a few considerations are important to note. These are discussed briefly under the following special topics headings.

Field Adjustments

The landscape coefficient method provides **estimates** of water needs, not exact values. Consequently, adjustments likely are needed in the field. If plants are showing signs of water stress, then an upward adjustment will be needed. Conversely, when it appears that too much water is being applied, then a downward adjustment is warranted. It is strongly recommended that when irrigation water estimates are implemented in the field that they be followed by careful monitoring.

Irrigation Schedules

An estimate of water needs is the first step in developing an irrigation schedule. Irrigation frequency, duration, and cycles also need to be determined to create a schedule. These are determined from the soil infiltration rate, rooting depth, sprinkler application rate, allowable depletion amounts, and soil water holding capacity. Each of these factors needs to be evaluated to determine how frequently to irrigate, how long to irrigate at any one time, and how many irrigation cycles are needed.

Soil Evaporation

Water loss may occur from the soil as well as from plants. This is most common when ground shading is less than 100% and a mulch is not present. The rate of evaporative water loss from soils depends on soil wetness, texture, structure, and density. When soil evaporation contributes to landscape water losses, water estimates should be increased by 10% to 20%. With sufficient mulching, however, bare soil surfaces will not be a source of water loss.

Salts and Leaching Fractions

When soil salt concentrations are sufficiently high to cause plant injury, the application of water in excess of that needed to meet plant needs is necessary. This process is called "leaching" and the percentage of applied water used to move salts below the root zone is called the "leaching fraction". For example, if 100 gallons of water is applied, and 25 gallons percolated below the root zone to remove salts, this would be a 25% leaching fraction. The leaching fraction needed for a landscape will depend on soil salt concentrations, tolerable levels, depth of the root zone, and soil physical properties. To determine an appropriate leaching fraction, it is recommended that managers consult with a qualified soil laboratory. The leaching fraction will add water to that needed for plants (ET_L), and the total water applied (TWA) will increase.

Reclaimed Water

The use of reclaimed water in landscape irrigation is becoming more common. Reclaimed water varies in quality, however, depending on the source and treatment process. Some reclaimed water is of high quality with little potential to injure plants. In other cases, reclaimed water may be of low quality, containing injurious levels of salts or specific elements. When irrigating with reclaimed water, planners and managers will need to assess and monitor water quality. Some upward adjustments in water estimates may be needed to reduce plant injury potential with low quality water. Consult a qualified laboratory when making such adjustments.

When irrigating with reclaimed water, planners and managers will need to monitor water quality. When irrigating with low quality reclaimed water, upward adjustments in water budgets may be needed to reduce the potential of plant injury.

Chapter 8—
Special Planting Situations

Although the application of the landscape coefficient method has been described for many landscape cases, there are some special planting situations that require further consideration. These cases are described in Chapter 8. This concludes the process of making water needs estimates for landscape plantings. Remember, the appendices contain important reference information to use in calculations.

New plantings, trees in turf, individual plants, vines, and herbaceous plants represent special cases which require further consideration in making water needs estimates. All are common elements of landscapes.

New Plantings

In terms of irrigation water needs, the key differences between new and mature plantings are in density factor assignments and irrigation efficiency. Typically, canopy cover is substantially less in a new planting and the lowest k_d value, 0.5, is appropriate. Irrigation efficiency is also typically low for new plantings.

New landscape plantings require special consideration. The actual amount of water needed to maintain health and appearance in new plants is lower than that needed for established plantings (mainly because the density factor is low). However, irrigation efficiency losses are usually very high in new plantings, and the total amount of water needed may be equivalent to that of established plantings.

A landscape coefficient (K_L) calculation for a new planting was made in "Using the Landscape Coefficient Formula" (Chapter 3, example 7). In the example, a k_d value of 0.5 was used which produced a K_L of 0.1 (k_s = 0.2, k_{mc} = 1.0).

Based on experience, it may be thought that irrigating a new planting at one tenth of reference evapotranspiration is insufficient. Generally, landscape managers believe that new plantings need even more water than mature plantings. When irrigation efficiency (IE) is considered, however, the amount of water needed increases substantially. Indeed, it is because of very low efficiencies when irrigating new plantings that the total amount of water is much greater than that needed solely for the plants.

A sample calculation helps to show the role of irrigation efficiency in new planting irrigation. Using example 7, ET_L = 0.1 for a new planting in Monterey

County in July. The total amount of water needed is calculated using the TWA formula:

$$TWA = \frac{ET_L}{IE}$$

Selecting an irrigation efficiency of 10%,

$$TWA = \frac{0.1}{0.1} = 1.0 \text{ inch}$$

Ten times more water needs to be applied than that actually needed for the plants. This is based on a 10% irrigation efficiency for a new planting which is sprinkler irrigated. An IE of 10% is reasonable because most of the root mass of new plantings is confined to the rootball, with available water consisting of only that held in the rootball and, in some cases, a small volume of adjacent soil. Sprinklers deliver water to the entire planted area, not just the rootballs, so much of the water falls outside the usable area.

For instance, in a planting area of 100 sq. ft., only 10 sq. ft. may be occupied by rootball. Thus, if water is distributed uniformly, only 10% of the water applied falls in the root zone, which produces a 10% irrigation efficiency.

Irrigation efficiencies for some new plantings may be even less than 10%. If a planting is sparse and root zone occupies less than 10% of the irrigated area, and/or some of the water that lands on the rootball is lost to evaporation, percolation, or runoff, then IE may be less than 10%.

As roots develop into the adjacent soil, however, irrigation efficiency increases rapidly. For instance, if after one year, roots have developed into the adjacent soil to the point that half the planting area has some root mass, then water landing on half the area potentially may be absorbed by plants. In this case, irrigation efficiency has increased 5-fold to 50% (assuming no loss from runoff, evaporation, etc.).

It should be recognized that sprinkler irrigation of new plantings (i.e., of container grown plants) is not efficient. Other methods should be considered for water conservation purposes. Drip systems deliver water directly to rootballs and, therefore, have higher efficiency. Potentially, hand watering is also more water efficient than sprinkler irrigation, provided it is done carefully.

The water needs of most tree species planted in turf are generally met by the relatively high water needs of turf. Trees with relatively high water needs, such as these white alder (*Alnus rhombifolia*), should be used in turf areas.

As root development increases into the adjacent soil, sprinkler irrigation efficiency increases, while drip irrigation efficiency may actually decrease if emitters are not moved or supplemented to supply the larger root zone. Dual systems of both drip emitters and sprinklers may have the greatest potential for maximizing efficiency for new and developing plantings: the drip system being used for the new planting and the sprinklers employed once the root system has developed.

Trees in Turf

The water needs of most tree species planted in turf are generally met by the relatively high water needs of turf. Turf crop coefficients range from 0.6 (warm season species) to 0.8 (cool season species). This range is sufficient to satisfy the needs of all trees in the moderate, low, and very low WUCOLS categories. Trees in the high category may need supplemental water, particularly if they are planted in warm season turf. Trees in cool season turf are not likely to need supplemental water.

Aside from meeting total water needs, some other factors need to be considered regarding trees in turf:

1. ***Species Selection***. Not all tree species can be expected to perform well in turf. Species in the low and very low WUCOLS categories may be injured or killed by turf irrigation. Many species are adapted to dry summer conditions (e.g., oak species) and frequent irrigations associated with turf may result in root injury, typically from disease or poor aeration. Species selection is very important. When specifying trees in turf, species should be limited largely to those classified as "high" on the WUCOLS list. Species from the "moderate" category may be used in some cases, but there will be a greater potential for injury.

2. ***New Turf Around Established Trees***. When new turf (and associated irrigation) is installed around established trees, precautions are needed to avoid injury to the trees. This is particularly the case for trees that were not formerly irrigated. By supplying water to the root zone of established trees the potential for injury from disease or poor aeration increases substantially. Certain species (e.g., oaks) are more sensitive to such changes than other species. The root crown area is particularly sensitive and needs

In times when the water supply for turf becomes restricted (e.g., drought years), the water needs of trees in turf may not be met. These white birch (*Betula pendula*) died when water was withdrawn from the turf during a drought year. Notice that the juniper (*Juniperus sp.*) were not injured.

special consideration. To help ensure the survival of both the turf and trees in this situation, it is recommended that a certified arborist be consulted.

3. ***Drought Years***. In times when the water supply for turf becomes restricted (e.g., drought years), the water needs of trees in turf may not be met. During previous droughts in California, many trees in turf areas were severely injured or killed when water was withheld from turf. Frequently, the turf recovers when irrigation resumes, but the trees do not. It is very important to provide water directly to trees during such times.

4. ***Newly-Planted Trees***. Water supplied to meet turf needs is often not sufficient for newly planted trees in turf. Although turf irrigation is likely sufficient for most species once established, newly planted trees have special requirements. In most cases after planting, the roots of new trees are confined to the rootball, or a relatively small volume of soil. Much of the water supplied in turf irrigation (typically via sprinklers) does not rewet the rootball sufficiently. It is only the water that lands on the rootball that can be absorbed, and in most cases this is not adequate to meet the needs of the tree. As a result, many trees are very slow to develop in turf, and some are injured or killed. Supplemental water (delivered manually or by drip systems) are strongly recommended for trees in turf.

   In addition to special water needs, newly planted trees in turf also may be inhibited biologically by the turf. This is an effect known as "allelopathy," where one plant inhibits the development of another by the release of phytotoxic materials from its roots. Turf species are recognized as having allelopathic effects on young trees and, therefore, an area (2 ft. radius) around newly planted trees should be kept turf-free. Ideally mulch is applied to the soil surface in the turf-free zone to reduce evaporation and minimize the potential for mower or trimmer injury.

5. ***Shallow Rooting and Windthrow***. Turf irrigation typically supplies water to the surface 3 to 6 inches of soil, the active root zone for most turf species. Consequently, turf irrigations are relatively shallow and frequent (i.e., when compared to tree irrigation depths of 1 to 3 ft.). As a result, tree roots in turf areas tend to develop close to the soil surface. There has been some concern regarding the potential for reduced anchorage associated with shallow root systems of trees in turf. It is thought that large trees may have a higher potential for windthrow. Although this occurrence has been observed, there is no documentation to show that the potential for tree windthrow is higher in turf than elsewhere. Nevertheless, it is generally held that deep irrigations for trees in turf are beneficial. They not only increase the potential for root development deeper in the soil profile, but they also increase the size of the soil volume from which roots can extract water.

Individual Plants

To this point, the landscape coefficient method has been used to estimate water needs of plantings (i.e., groups of plants). It also can be used to estimate water needs of individual plants. The three factors (species, density, and microclimate) are used to determine a landscape coefficient as before. A few considerations apply for individual plants, however, and they are discussed for shrubs and trees separately.

Shrubs

k_s: Species factor values are found in the WUCOLS list.

k_d: For most shrubs, an average density factor of 1.0 will be appropriate. For very large shrubs, an upward adjustment to 1.1 may be warranted.

k_{mc}: In most cases, the microclimate factor would be assigned as discussed in Chapter 2.

Trees

k_s: Species factor values are found in the WUCOLS list.

k_d: For small trees (< 15 feet tall), an average density factor of 1.0 would be appropriate. For larger trees, an upward adjustment to 1.1 or 1.2 accounts for the increase in leaf area found in many canopies.

k_{mc}: In most cases, the microclimate factor would be assigned as discussed in Chapter 2. For large trees, however, an upward adjustment to 1.2 or 1.3 to account for wind flow through the canopy may be appropriate.

Example: The urban forester for the city of Modesto is interested in estimating water needs for a large Modesto ash tree located in a downtown city plaza for the month of July.

Water needs for individual trees or shcubs can be estimated using the landscape coefficient method. Species, density and microclimate factors all need to be considered.

First, the forester needs to assign values for each of the landscape coefficient factors. In the WUCOLS list *Fraxinus velutina* 'Modesto' is classified as "moderate" with a k_s value of 0.4. Since this is a large, dense tree, the forester uses a density factor value of 1.1. The microclimate in the plaza warrants a "high" microclimate factor value. In addition, the forester wants to adjust for wind flow through the canopy since no trees or buildings are nearby to attenuate the wind. The forester selects a k_{mc} value of 1.5. Using these values, a calculation of the landscape coefficient can be made.

$$K_L = k_s \times k_d \times k_{mc}$$
$$K_L = 0.4 \times 1.1 \times 1.5 = 0.66$$

A species factor range of 0.4 to 0.8 is suggested to be appropriate for most annual species.

With the landscape coefficient calculated, the landscape evapotranspiration formula is used to calculate ET_L:

$$ET_L = K_L \times ET_o$$
$$K_L = 0.66$$
$$ET_o = 8.0 \text{ inches (for July in Modesto)}$$
$$ET_L = 0.66 \times 8.0 \text{ inches} = 5.28 \text{ inches}$$

The urban forester has estimated that the tree needs 5.28 inches of water for the month of July to maintain good appearance, health, and growth. A further adjustment to this value is needed to account for irrigation efficiency (see Chapter 5).

An alternative method for estimating water loss from an individual tree is described in Lindsey and Bassuk (1991). This method uses leaf area index (LAI) to account for density differences in tree canopies.

Vines

Vines occur in many landscapes and need to be considered in water loss estimates. Vines can contribute substantial leaf area to a planting whether they occur on walls, trellises, arbors, poles, or on the ground. Water needs evaluations for many vine species are included in the WUCOLS list. Although the microclimate factor (k_{mc}) will not be affected by the presence of vines, the density factor (k_d) is affected. Vines add another vegetation type or tier (in some cases) to a landscape and, therefore, increase the vegetation density. They also may contribute to canopy cover. Upward adjustments in k_d are likely needed when vines are present. These can range from small increases (0.1) to large (0.3) depending on the amount of vegetation (leaf area) added.

Annuals

Estimates of water needs for plantings of annual species can be made using the landscape coefficient formula. As for woody plantings, values for K_L and ET_o are needed. ET_o values are obtained as described previously, while K_L needs to be calculated from the three factors, k_s, k_d, and k_{mc}. The microclimate factor, k_{mc}, is determined as before, and k_d will range from 0.5 to 1.0 depending on the fullness of the plantings. The species factor, k_s, is more difficult to determine as many species are not included in the WUCOLS list. Generally, the water requirements of annual plants are relatively high and a k_s range of 0.4 to 0.8 is suggested for most species. By assigning values for k_s, k_d, and k_{mc}, the landscape coefficient, K_L, can be calculated and an estimate of water needs (ET_L) is determined.