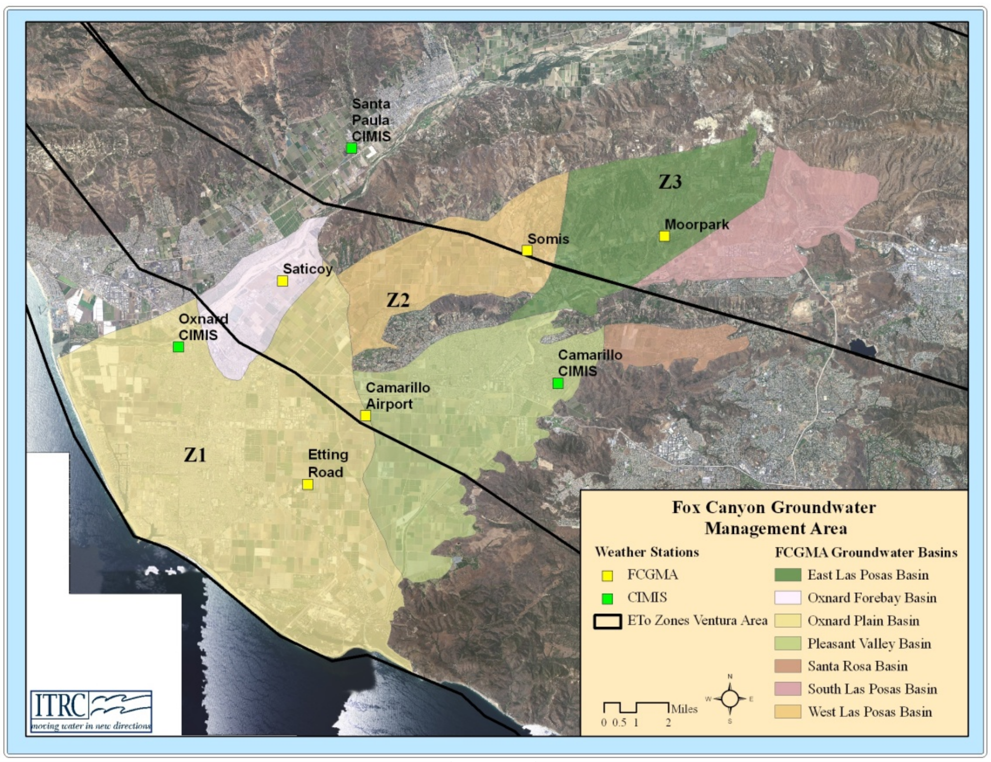
moving water in new directions

Fox Canyon Groundwater Management Agency

Evaluation of Strengths and Weaknesses of the Existing FCGMA IE Program and Specific Suggestions for Improvement

Final Task 2.2

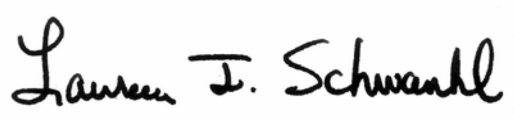


IRRIGATION TRAINING AND RESEARCH CENTER

Fox Canyon Groundwater Management Agency

November 22, 2010

IRRIGATION TRAINING AND RESEARCH CENTER



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Irrigation Training and Research Center
November 22, 2010

TASK 2.2 – SUMMARY OF FINDINGS

The Irrigation Training and Research Center (ITRC), at California Polytechnic State University, San Luis Obispo (Cal Poly), with support from the University of California Cooperative Extension in Ventura County, was tasked by Fox Canyon Groundwater Management Agency (FCGMA) with evaluating their "Irrigation Efficiency Extraction Allocation" program. This Task 2.2 report is a continuation of the Task 2.1 report.

- **Task 2.1 –** Analysis and annual plant required water values for crops in the FCGMA
- **Task 2.2 –** Evaluation of strengths and weaknesses of the existing FCGMA IE program and specific suggestions for improvement

Task 2.1 focused on irrigation water required by the crop to meet crop evapotranspiration demand. In this Task 2.2 report, irrigation water requirements for other crop management purposes are investigated and a Total Irrigation Allowance value is proposed. The Total Irrigation Allowance incorporates irrigation water to meet evapotranspiration demand, salinity leaching, and distribution uniformity.

This Task 2.2 report addresses the following items:

1. Modifications to Task 2.1 were incorporated into this report to include comments raised at the September 22, 2010 FCGMA Board of Directors meeting by board members and the public. The main modification involved increasing the number of crop categories from 21 to 24 (**Appendix E**).
   a. To account for avocado orchards that were less than full canopy cover because they were recently planted or thinned, this report includes three categories for avocados: 20% Cover, 50% Cover, and 70% (full) Cover.
   b. An additional category was added for blueberries that have less than full canopy coverage. There are now two categories for blueberries: 50% Cover and 70% (full) Cover.
2. Irrigation water concerns for crop management:
   a. Salinity leaching is important in FCGMA because of the relatively high salt content of the groundwater used for irrigation and the sensitivity of many crops grown in the region. ITRC evaluated groundwater quality data provided by FCGMA by basin and found average electrical conductivity values of the water (EC_w) ranged from approximately 1.0-1.8 dS/m by basin. Utilizing an overall EC_w value of 1.8 dS/m, the recommended leaching requirements (LR) by crop are shown in **Appendix A**. As more information is gathered on different water sources and their EC_w values, the issue of salinity management may need to be revisited and fine-tuned.
   b. Distribution uniformity is an important component of required irrigation application. System evaluations in the late 1980's and early 1990's showed distribution uniformities around 0.65 in Ventura County. More recent evaluations on a limited number of acres in Ventura County showed an improved DU of 0.78. Another factor of irrigation efficiency is localized deep percolation that is found using drip and microspray irrigation. A reasonable value for DU and localized deep percolation given the irrigation systems utilized in FCGMA is 0.8.

c. Irrigation for frost protection can be effective. After examining application amounts provided in the grower interviews, it appears 0.5 inches per frost protection event is likely typical. The total annual requirements will be dependent on the number of frost events per year.

d. Santa Ana winds are common in fall and early spring in FCGMA. Evaluations of weather station data at the Camarillo CIMIS station indicated that the higher temperatures and lower relative humidity was accounted for in the weather data and the grass reference evapotranspiration (ET_o). Therefore, ITRC does not recommend adding additional allocation to meet Santa Ana conditions since increased requirements are accounted for in the growing period ET_{iw} values.

e. Greenhouses and tunnels affect a crop's micro-climate. By blocking outgoing long wave radiation and reflecting it back, energy is increased. However, incidental incoming shortwave radiation is partially blocked as well, so the initial energy in the greenhouse/tunnel can be lower than outside. In addition, higher relative humidity and lower wind speeds tend to result in lower evapotranspiration rates (discussed in main body of report). However, since precipitation cannot reach the soil surface, crops grown in greenhouses/tunnels require more irrigation water. These factors were incorporated into the growing period ET_{iw} values for raspberries grown in tunnels and miscellaneous vegetable crops (spring, summer, and fall) grown in greenhouses. It is important to note that it was beyond the scope of this project to perform a research study to determine crop evapotranspiration in greenhouses. Such a study would be extensive and long-term, but is recommended as part of future research at FCGMA.

f. Flow meter accuracy seems to be very good in FCGMA. The average percent error for the 578 flow meter tests was 0.27%. Ninety-eight percent of these flow meters measured discharge within +/-6% of actual. To reduce the possibility of reporting errors, it is recommended that FCGMA require photos of flow meter totalizer readings at the beginning and end of the calendar year.

g. Vegetative acreage accounting is critical for accurate irrigation allowance computation. Orchard age, continuous harvesting and planting, and fallowing land between crops must be taken into account when determining irrigation allowance. It is recommended that growers provide aerial photos of their cropped fields to determine orchard canopy cover and identify roads and buildings. These can be obtained from online mapping services (e.g., Google and Yahoo maps). These aerials are not taken every year but should be only 2-3 years old.

3. The proposed irrigation allowance index is a simple ratio of actual applied water to irrigation allowance. An index value less than or equal to 1.0 is good, indicating the grower is applying less than or equal to the allowance. Values greater than 1.0 indicate an application greater than allowance and should be investigated.

   a. Irrigation allowance combines growing period ET_{iw}, salinity leaching requirement, and distribution uniformity for three zones for three precipitation year types (typical, dry, and wet). The ET_o data from local weather stations will be used as a check to ensure that ET_o is not significantly different from long-term averages and to provide information on precipitation year type. Because of site conditions at the current FCGMA weather stations, it is currently recommended that CIMIS stations located within each proposed ET_o Zone be used as primary source of weather information with one FCGMA weather station in each zone used as a backup. The total Irrigation

Allowance, discussed in *"Proposed Irrigation Allowance/Index Program"* section, shown in **Table S1** is computed as:

$$\text{Irrigation Allowance} = \frac{\mathit{Growing\ Period\ ET_{iw}}}{(\text{DU} + \text{Localized Deep Perc. on Drip}) \times (1 - \text{LR})}$$

Where,

DU + Localized Deep Percolation on Drip = 0.8

LR = Leaching requirement (**Appendix A**)

<u>The irrigation allowance values shown in this report are best estimates based on existing available information. In the future, these values may need to be revised with updated information.</u>

Table S1. Recommended Option 1 Annual Irrigation Water Allowance for the three ET_o zones proposed by ITRC. Includes water for salinity leaching and non-uniformity of distribution and localized deep percolation from drip systems.

	Annual Irrigation Allowance* (Inches)								
	Oxnard (Z1)			Camarillo (Z2)			Santa Paula (Z3)		
	Typical	Dry	Wet	Typical	Dry	Wet	Typical	Dry	Wet
Crop Category	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Avocado - 20% Cover	22	25	21	25	28	23	28	30	25
Avocado - 50% Cover	32	36	30	37	41	33	40	44	37
Avocado - 70% Cover	44	49	42	50	56	48	54	61	52
Blueberries - 50% Cover	32	33	31	36	37	35	39	41	38
Blueberries - 70% Cover	44	46	42	49	52	47	54	57	52
Celery - Fall	12	13	10	13	14	12	14	16	13
Celery - Spring	20	21	18	23	24	20	25	26	22
Citrus - 20% Cover	23	25	21	26	29	24	28	31	26
Citrus - 50% Cover	31	32	28	35	36	32	38	40	35
Citrus - 70% Cover	41	43	38	47	48	43	51	53	47
Lima Beans	12	13	12	14	15	14	15	16	15
Misc. Veg Greenhouse - Fall	10	10	10	11	11	11	13	13	13
Misc. Veg Greenhouse - Spr	16	16	16	18	18	18	20	20	20
Misc. Veg Greenhouse - Summer	15	15	15	17	17	17	18	18	18
Misc. Veg Single Crop - Fall	11	12	9	12	14	11	13	15	12
Misc. Veg Single Crop - Spr	19	20	18	21	23	20	23	25	22
Misc. Veg Single Crop - Summer	24	25	23	27	28	26	29	30	29
Nursery Container	53	56	51	60	64	58	66	69	63
Nursery - Flowers	54	56	52	62	63	59	67	69	64
Raspberries - Tunneled	54	54	54	61	61	61	67	67	67
Sod	48	51	47	54	57	53	59	63	58
Strawberries - Main Season	29	30	29	33	33	32	36	37	35
Strawberries - Summer	15	15	15	17	17	17	19	19	19
Tomatoes – Peppers (Summer)	27	27	26	31	31	30	34	34	32

*add 0.5 inches per frost event.

b. The "year type" range was selected by examining annual precipitation and crop effective precipitation from the modeling. There is significant variability in effective precipitation even with similar annual precipitation amounts, but the general trends are outlined in **Table S2**. For more information about the year type determinations, refer to the *"Option 1: Specific Annual Irrigation Allowance Amount"* section in the main body of this report.

Table S2. Year type precipitation amounts

Year Type	Precipitation Range (inches)
Typical	11 – 17
Dry	<11
Wet	>17

c. For comparison, **Table S3** shows the ITRC irrigation allowance in the three proposed ET_o zones for a typical year and the nearby FCGMA weather station normalized allowed water from 2009. Since FCGMA incorporates irrigation efficiency components, such as distribution uniformity, into the evaluation of the "Irrigation Efficiency" values by allowing the IE to be 80% or above, the values of ITRC allowance and FCGMA allowed water are not directly comparable. To normalize the values, the FCGMA published allowed water values by crop category were divided by 80%.

Table S3. Comparison of ITRC irrigation allowance with FCGMA allowed water (normalized by dividing FCGMA published values by 80%) by proposed ET_o zone

	Comparison of ITRC Typical Year Irrigation Allowance compared to Normalized 2009 FCGMA Allowance (divided FCGMA published allowed water by 80%) for nearby weather stations					
	Oxnard (Z1)		**Camarillo (Z2)**		**Santa Paula (Z3)**	
Crop	ITRC Allowance (in)	FCGMA Etting Road Allowed norm. (in)	ITRC Allowance (in)	FCGMA Camarillo Air. Allowed norm. (in)	ITRC Allowance (in)	FCGMA Moorpark Allowed norm. (in)
Avocado - 20% Cover	22	47	25	45	28	54
Avocado - 50% Cover	32	47	37	45	40	54
Avocado - 70% Cover	44	47	50	45	54	54
Blueberries - 50% Cover	32	52	36	50	39	61
Blueberries - 70% Cover	44	52	49	50	54	61
Celery – Fall	32	52	36	50	39	61
Celery – Spring						
Citrus - 20% Cover	23	47	26	44	28	54
Citrus - 50% Cover	31	47	35	45	38	54
Citrus - 70% Cover	41	47	47	45	51	54
Lima Beans	12	47	14	45	15	54
Misc. Veg Greenhouse – Fall	41	51	46	48	50	60
Misc. Veg Greenhouse – Spr						
Misc. Veg Greenhouse – Summer						
Misc. Veg Single Crop – Fall	53	52	60	48	66	60
Misc. Veg Single Crop – Spr						
Misc. Veg Single Crop – Summer						
Nursery Container	53	51	60	49	66	60
Nursery – Flowers	54	52	62	50	67	61
Raspberries – Tunneled	54	52	61	50	67	61
Sod	48	52	54	50	59	61
Strawberries – Main Season	29	52	33	50	36	61
Strawberries – Summer	15	52	17	50	19	61
Tomatoes – Peppers (Summer)	27	51	31	49	34	60

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DEFINITION OF KEY TERMS

Actual Applied Water	Flow meter totalized flow from all water sources
DU	Distribution uniformity, or, the measure of uniformity with which irrigation water is distributed to different portions of the field
DU_{lq}	Distribution uniformity of the low quarter
EC_e	Soil salinity
EC_w	Salinity of irrigation water
Effective precipitation	Net precipitation after losses by evaporation and deep percolation
ET_o	Grass reference evapotranspiration computed using the 2005 ASCE Standardized Penman-Monteith equation from weather data collected at special weather stations
ET_c	Total crop and soil evapotranspiration from precipitation and irrigation water. ITRC typically reserves this notation for the total evaporation and transpiration that occurs on a field throughout a calendar year. ET_c includes portions of the year when the soil is bare for annual crops or when deciduous orchards are dormant.
ET_{iw}	Crop evapotranspiration of irrigation water during the growing period only
FCGMA Allowable Water	Computed using annual local ET_o values from 5 FCGMA weather stations. Assumes an annual crop coefficient of 1.0 for three crop categories: orchards (avocado, lemon, orange), strawberry/celery/sod, and vegetable crops. The difference between the crop categories is the computed effective precipitation.
Irrigation Allowance	Volume of allowed water for specific year types for crop total allowed water from appropriate crop categories, based on average actual vegetative acres
IE	Irrigation efficiency, which is defined as the volume of irrigation water beneficially used divided by the volume of irrigation water applied minus the change in water storage
K_c	Crop coefficient
K_t	Total allowance coefficient
LR	Leaching requirement
Threshold EC_e	Sensitivity of a crop to salinity

FOX CANYON GROUNDWATER MANAGEMENT AGENCY
TASK 2.2

Overview

The Fox Canyon Groundwater Management Agency (FCGMA) manages groundwater extraction in a portion of Ventura County through allocation of groundwater resources. Municipal/industrial allocation is set; however, agricultural extraction allocations under the current irrigation efficiency program ("Irrigation Efficiency Extraction Allocation") vary by year as a function of crop type, acreage, and weather.

The Irrigation Training and Research Center (ITRC), at California Polytechnic State University, San Luis Obispo (Cal Poly), with support from the University of California Cooperative Extension in Ventura County, was tasked with evaluating the "Irrigation Efficiency Extraction Allocation" program. This report examines the "Irrigation Efficiency Extraction Allocation" procedure. The first portion of this report provides a summary of the work conducted as part of Task 2.1 and an overview of the existing FCGMA IE Extraction Allocation program. The *"Recommendations"* section systematically evaluates issues pertaining to crop and management irrigation water requirements. In the final portion of this document, specific proposed procedures to improve the allocation program will be discussed.

Geographic Boundaries

The Fox Canyon Groundwater Management Area is located in the southern portion of Ventura County. Agriculturally irrigated acreage in FCGMA is estimated to be approximately 51,000 acres. There are seven groundwater basins in FCGMA. **Figure 1** shows a map of the agency boundaries and the groundwater basins.

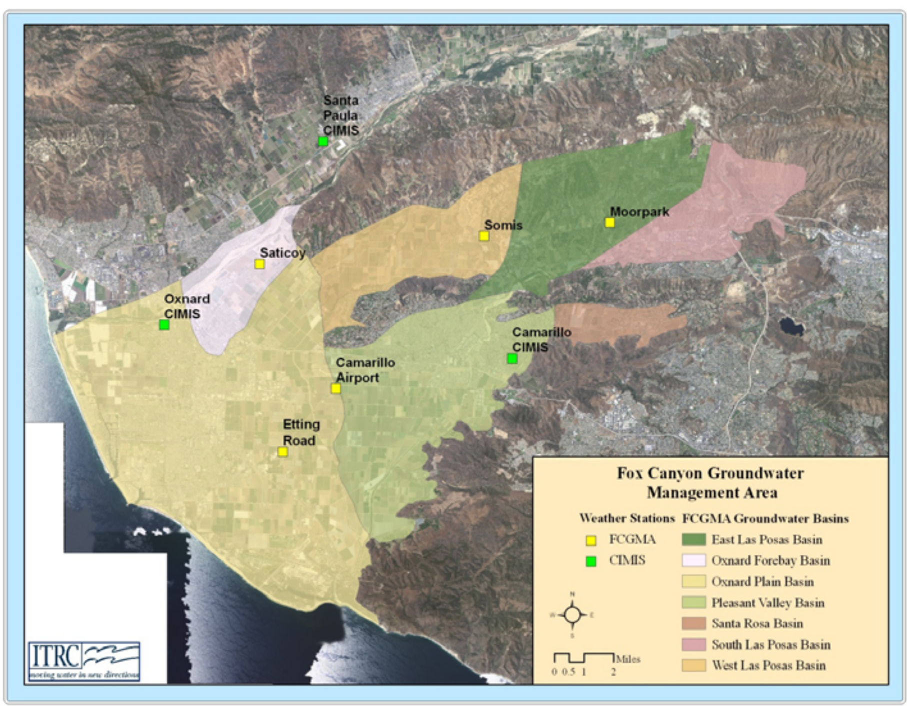

Figure 1. FCGMA boundaries and weather station locations

Description of Work Completed for Task 2.1

For complete details about Task 2.1, please refer to the Task 2.1 final report. The main findings of Task 2.1 were:

1) Weather stations used for computing grass reference evapotranspiration in FCGMA were examined. In general, the quality of weather data collected by the five FCGMA weather stations prior to 2007 can be considered poor to very poor. Since 2007 the quality of data has improved significantly, but the site conditions at the five FCGMA stations do not currently adhere to the recommended standard site conditions for computing grass reference evapotranspiration (ET_o). However, there are three DWR CIMIS stations in or near FCGMA that provide satisfactory data. **Appendix C** contains the recommended quality control program and weather station site conditions.

2) Examining the ET_o data throughout the region, ITRC recommended FCGMA use only three ET_o zones. These zones are loosely based on the DWR ET_o zone map, and would allow the agency to abandon one or two existing stations and invest more into the quality of the existing stations. For each zone there are one or two FCGMA weather stations and one CIMIS station, which provides some level of redundancy. ITRC also recommended a weather data quality control program that would involve comparing solar radiation measurements to clear sky potential solar radiation computations.

3) Because of the relatively low confidence in historical FCGMA weather station ET_o data, corrected data from the Camarillo CIMIS station was used for crop evapotranspiration modeling. ITRC recommended 24 crop categories (as opposed to the current five categories) to improve estimates of crop evapotranspiration (ET_c). While some of these categories include the same crop, they differentiate planting and harvest dates for some annual crops and recently planted versus mature orchards. Effective precipitation was also computed on a monthly basis. Significant variability was found based on crop growth stage and the amount and duration of the precipitation events.

4) FCGMA Allowed Water estimates were compared to modeled crop growing period evapotranspiration.

Existing Irrigation Efficiency Extraction Allocation Program

For Task 2.2, the existing Irrigation Efficiency Extraction Allocation Program was examined for strengths and weaknesses.

Strengths

1. The existing program attempts to account for spatial and temporal variability by using weather stations that collect real-time data that are spread throughout the agency.
2. The simplicity of the program should be noted. The grower forms and equations are easy to follow and simple to complete.
3. There is an attempt to compute effective precipitation using daily data.

Weaknesses

1. FCGMA attempts to account for spatial and temporal variability with limited success. Historically, the weather data collected at the five FCGMA weather stations has been very poor. Since the new station equipment was installed in 2006 the quality has improved at most stations; however, their site conditions remain very poor.

2. The program may be too simple to really be effective. Within the simplification there are numerous assumptions that have a tendency to overestimate what grower water requirements might be. Two examples are:
   - A grower that only grows one vegetable crop per year has the same water allocation as a grower that grows three vegetable crops.
   - A citrus orchard with young trees with leaves that cover only 20% of the ground surface is allocated the same amount as a mature orchard with leaves that cover 70% of the ground surface.

3. The effective precipitation is likely overestimated since the algorithm used does not make any attempt to compute actual crop evapotranspiration, account for irrigation in the soil moisture, or differentiate water destinations at the time of precipitation events. This will result in the algorithm computing a drier soil than what actually exists, which translates into an overly large effective precipitation value. Effective precipitation is very difficult to compute using any method, and while the current methodology is logical, there is not sufficient information to ensure accuracy.

Current Computation of FCGMA Allowable Water

The FCGMA allowable water values are determined on an annual basis utilizing grass reference evapotranspiration (ET_o) computed at five private weather stations owned and operated by a private consultant (InvestmentSignals Inc.) for FCGMA. This ET_o is summed annually and is then reduced by an "effective precipitation" value based on the annual precipitation measured at each station for three crop categories (the FCGMA program shows five crop categories; however, the allowable water values for avocado, lemons, and oranges are the same). This allocation is computed after the year is over and compared to the actual amount of water applied to each particular crop by growers. As shown in the bottom of **Figure 2**, the ratio of applied water to FCGMA allowed water is termed "Irrigation Efficiency" and is used to evaluate and potentially penalize users if it is below a certain value (80%).

Fox Canyon Groundwater Management Agency
2009 Eto, Effective Rainfall & Allowed Water for Various Crops
(All values in Inches or Feet, unless otherwise noted)

Station	Total Eto	Total Rain	Total Effective Rain					Total Allowed Water *(Acre-Inches or Acre-Feet)*				
			Avocados	Lemons	Oranges	Straw/Sod /Celery	Veges	Avocados	Lemons	Oranges	Straw/Sod /Celery	Veges
Moorpark Total	53.10	10.81	9.96	9.96	9.96	4.09	4.84	43.14" or 3.595'	43.14" or 3.595'	43.14" or 3.595'	49.01" or 4.084'	48.26" or 4.022'
Somis Total	50.34	8.07	8.00	8.00	8.00	4.16	4.67	42.34" or 3.528'	42.34" or 3.528'	42.34" or 3.528'	46.18" or 3.848'	45.66" or 3.805'
Saticoy Total	45.04	11.53	9.34	9.34	9.34	3.89	4.67	35.70" or 2.975'	35.70" or 2.975'	35.70" or 2.975'	41.15" or 3.429'	40.36" or 3.363'
Etting Rd Total	46.23	8.76	8.59	8.59	8.59	4.61	5.11	37.64" or 3.137'	37.64" or 3.137'	37.64" or 3.137'	41.62" or 3.468'	41.12" or 3.427'
Camarillo Airport Total	44.13	8.45	8.09	8.09	8.09	3.83	4.57	36.04" or 3.003'	36.04" or 3.003'	36.04" or 3.003'	40.30" or 3.358'	39.56" or 3.297'

$$\text{Irrigation Efficiency} = \frac{(\text{Allowed Water}^{**}) \times (\text{No. of Acres Irrigated})}{\text{Water Applied}} \times 100$$

** The allowed water for a particular crop is the total Eto for 2009 times a coefficient (Kc) of 1.0 less adjustments for effective rainfall

Note: Differences in Total Allowed Water values are due to negative allowed water in rainy periods.

Figure 2. Example of FCGMA Allowable Water table for 2009

FCGMA water allocation is computed as a function of annual ET_o computed at one of the five FCGMA weather stations. Growers should select the closest weather station when computing the allocation. The weather station data and site quality was evaluated in Task 2.1. The effective precipitation is discussed in the next section. The total water allocation per crop provided as a depth is multiplied by the acreage of each crop. This acreage is reported by the grower along with maps showing the area of interest.

The grower must also report the volume of water applied on all of their agricultural land from each water source. Ideally, growers obtain this from flow meter readings at the beginning and end of each calendar year. However, some growers may have several sources of water in addition to direct groundwater pumping, including surface water, groundwater from another grower, and water provided by a water purveyor.

Current Computation of Effective Precipitation

InvestmentSignals Inc. currently tracks precipitation and computed ET_o at each weather station to estimate the effective precipitation. The current methodology that is used to compute effective precipitation is:

$$AWr_i = AWr_{i-1} - (ET_{o,i} * K_c) + P_i$$

If $AWr_i > TAWr$
    $Eff.\ P = AWr_i - TAWr$
    $AWr_i = TAWr$
Else
    $Eff.\ P_i = P_i$
End If

Where,

AWr_i = Root zone available water on day i
AWr_{i-1} = Root zone available water on the previous day
$ET_{o,i}$ = Grass reference evapotranspiration at the end of day i
P_i = Precipitation on day i
$TAWr$ = Total water holding capacity of the soil for the entire crop root zone
$Eff.\ P_i$ = Effective precipitation on day i

Basically, the algorithm examines daily information on precipitation, ET_o along with an assumed root zone depth, and total available water holding capacity of that root zone. If the initial computation of AWr_i is greater than the possible water storage in the root zone ($TAWr$), then the effective precipitation must be less than the total precipitation. This means that some of the precipitation could be lost to surface runoff or deep percolation below the root zone. In the cases of smaller precipitation events when AWr_i is less than $TAWr$, the algorithm assumes the total amount of precipitation will be effective.

The annual effective precipitation seen previously in **Figure 2** is computed by summing the daily effective precipitation values over the year. The three crop categories show some variability likely due to the difference in root zone depth impacting $TAWr$.

Irrigation Efficiency and Distribution Uniformity

FCGMA uses the term "irrigation efficiency" in the allocation program. Irrigation efficiency is often used as a buzzword or very generally by people who really do not understand the term. However, irrigation efficiency has a specific meaning and can be formulated into a standard equation. It should be noted that the existing FCGMA Irrigation Efficiency Allocation procedure does not follow the technical standard established to compute irrigation efficiency (IE).

The technical definition of IE[1] is:

$$IE = \frac{Vol. of\ Irrigation\ Water\ Beneficially\ Used}{Vol. of\ irrigation\ water\ applied - Change\ in\ RZ\ water\ storage} \times 100\%$$

This precise definition of IE places a maximum limit on the IE value at 100% since the beneficial use of irrigation water is limited to the irrigation water applied assuming the timeframes are the same. However, even approaching a value of 100% on a field scale would be technically impossible based on the constraints of irrigation systems and scheduling.

[1] Burt, C. M., A. J. Clemmens, T. S. Strelkoff, K. H. Solomon, R. D. Bliesner, L. A. Hardy, T. A. Howell and D. E. Eisenhauer (1997). "Irrigation Performance Measures: Efficiency and Uniformity." *Journal of Irrigation and Drainage Engineering*, 123(6), 423-442.

The volume of irrigation water beneficially used as it pertains to FCGMA would include applied irrigation water…

…that evaporates from the soil or plant surface and is transpired by the crop (actual growing period ET_{iw})
…for soil preparation (and seed germination)
…used for frost protection
…used to leach salts below the root zone

The total volume of irrigation water applied incorporates the beneficial uses listed above plus non-beneficial uses that include irrigation water that…

…deep percolates below the root zone due to distribution uniformity
…deep percolates below the root zone due to over-irrigation
…runs off the field (minimal with irrigation methods used in FCGMA)

More general descriptions of beneficial and non-beneficial uses can be found in Burt et al (1997). One weakness of using IE as an indicator is that IE can be high with under-irrigation. Under-irrigation will lead to increased crop water stress and reduced evapotranspiration, resulting in decreased yields (and possibly increased salinity buildup in the root zone).

In order to determine the volume of water beneficially used, a detailed water balance study would typically be conducted where the FAO-56 soil water balance model would determine soil and crop evapotranspiration of irrigation water by evaluating possible water stress and incorporating field conditions such as bare spots and decreased vigor. The goal of this type of analysis would be to determine crop growing period evapotranspiration of irrigation water on average over the entire area. Some fields for a given crop would use more and some less.

In contrast, the analysis that was conducted in Task 2.1 was to model crops assuming little to no water stress and does not incorporate bare spots or decreased vigor due to stresses, since it would be inappropriate to determine an allocation using evapotranspiration values that would lead to decreased yields. Therefore, the actual field evapotranspiration of irrigation water should be less than or equal to the values estimated in Task 2.1.

Since the volume of irrigation water beneficially used in the IE equation is not computed, the IE indicator is not appropriate for the FCGMA evaluation of allocation. An alternative method is presented in the *"Proposed Irrigation Allowance Program"* section of this report.

A key component that will make up the basis of the irrigation allowance program and is incorporated into the non-beneficial uses is deep percolation due to distribution uniformity (DU). DU is defined as "the measure of the uniformity with which irrigation water is distributed to different portions of a field" (Burt et al, 1997). There are technical aspects of how DU is computed that are beyond the scope of this report, but low-quarter DU (DU_{lq}) is the most appropriate and widely accepted method of computing DU (see Burt et al, 1997 for more details). DU_{lq} is typically represented as a ratio (0-1) to differentiate it from IE.

<u>Distribution Uniformity in Ventura County</u>

It is impossible to have perfect irrigation water distribution on a field scale with any irrigation method. Drip and microspray irrigation have the potential for higher distribution uniformity compared to alternative methods if designed, installed, and managed appropriately. Properly designed and managed furrow, border strip, and sprinkler irrigation techniques can also result in good distribution uniformity.

In Ventura County, the Ventura County Resource Conservation District (VCRCD) has had programs (mobile irrigation labs) where growers can voluntarily have their irrigation systems evaluated. Results from irrigation evaluations primarily in orchards conducted between 1985 and 1992 were summarized and published by Little et al (1993)[2]. The results are shown in **Figure 3** (distribution uniformity is DU_{lq} and shown as a percentage instead of a ratio).

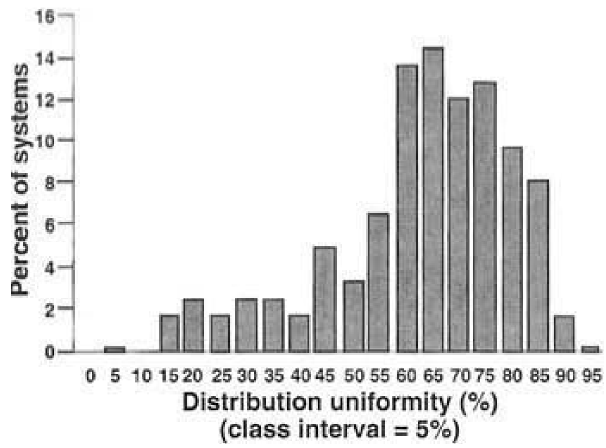

Figure 3. Histogram of distribution uniformities (DU_{lq}) (%) measured by VCRCD from approximately 1985 through 1992
(figure from Little et al, 1993)

Table 1 shows the DU_{lq} (as a percentage) for orchards under different irrigation methods in Ventura compared with other regions in California measured between 1985 and 1992 (Little et al., 1993).

[2] Little G, Hills D, Hanson B. (1993). "Uniformity in pressurized irrigation systems depends on design, installation". *California Agriculture*. 47(3):18-21.

Table 1. Average DU_{lq} (as a percentage) from measurements between 1985 and 1992 for different regions throughout California
(from Little et al, 1993)

Location	System type	No.	Area	DU	Area-weighted DU
			ac	.... %	
Ventura	Drip	12	260.5	54.8	55.7
	Micro-spray	113	3,036.3	67.1	67.1
	Sprinkler	4	101.0	58.8	67.2
Total/avg.		129	3,397.8	65.0	66.3
Pond-Shafter-Wasco	Drip	4	988.0	77.5	81.7
	Micro-spray	12	608.0	76.6	79.6
	Sprinkler	9	530.0	84.6	84.1
Total/avg.		25	2,126.0	79.6	82.6
Riverside-Corona	Drip	15	475.5	82.0	79.7
	Micro-spray	27	668.0	75.5	75.1
	Sprinkler	0	—	—	—
Total/avg.		42	1,143.5	77.8	75.9
Mission	Drip	0	—	—	—
	Micro-spray	12	123.8	70.6	70.7
	Sprinkler	0	—	—	—
Total/avg.		12	123.8	70.6	70.7
Coachella	Drip	25	1,296.0	76.3	74.6
	Micro-spray	25	1,839.4	77.8	76.7
	Sprinkler	0	—	—	—
Total/avg.		50	3,135.4	77.1	74.7
Totals	Drip	56	3,171.0	74.1	75.0
	Micro-spray	189	6,169.2	70.0	72.3
	Sprinkler	13	586.0	75.1	82.5
	Total/avg	258	9,926.2	71.0	73.8

(table from Little et al. 1993)

More recent data has been obtained from VCRCD with the results shown in **Table 2**. These evaluations have been conducted since the end of 2008. The average overall DU_{lq} is weighted based on total acres. The results indicate that improvements to DU have been made since the late 1980's and early 1990's.

Table 2. Average DU_{lq} measured and provided by VCRCD in 2009 and 2010 on drip and microspray irrigation systems in Ventura County

System Type	No. of Evaluations	Total Area (acres)	DU_{lq}
Drip	4	196	0.75
Microspray	16	282	0.81
Total / Wt. Avg.	20	478	0.78

Incorporating localized deep percolation with drip/microspray and the measured DU_{lq}, a combined value of 0.8 is reasonable in FCGMA. Overall this value is considered "Good" by most field level standards and is achievable with proper irrigation system design, installation, and management.

RECOMMENDATIONS

The main body of this report summarizes the results of each portion of the evaluation. The appendices provide more detailed explanations and data related to each portion.

Proposed ET_o Zones

The three ET_o zones recommended in Task 2.1 are shown in **Figure 4**. These zones are loosely based on the DWR ET_o zone map. This zoning would allow the agency to abandon one or two existing stations and invest more into the quality of the existing stations. For each zone there would be one or two FCGMA weather stations and one CIMIS station, which provides some level of redundancy in case of a failure or error at the other station in the zone. The recommended combination of stations for each zone using existing sites is:

- Zone 1 (Z1) – Oxnard CIMIS and FCGMA Etting Road Station
- Zone 2 (Z2) – Camarillo CIMIS and FCGMA Camarillo Airport Station
- Zone 3 (Z3) – Santa Paula CIMIS and FCGMA Moorpark Station

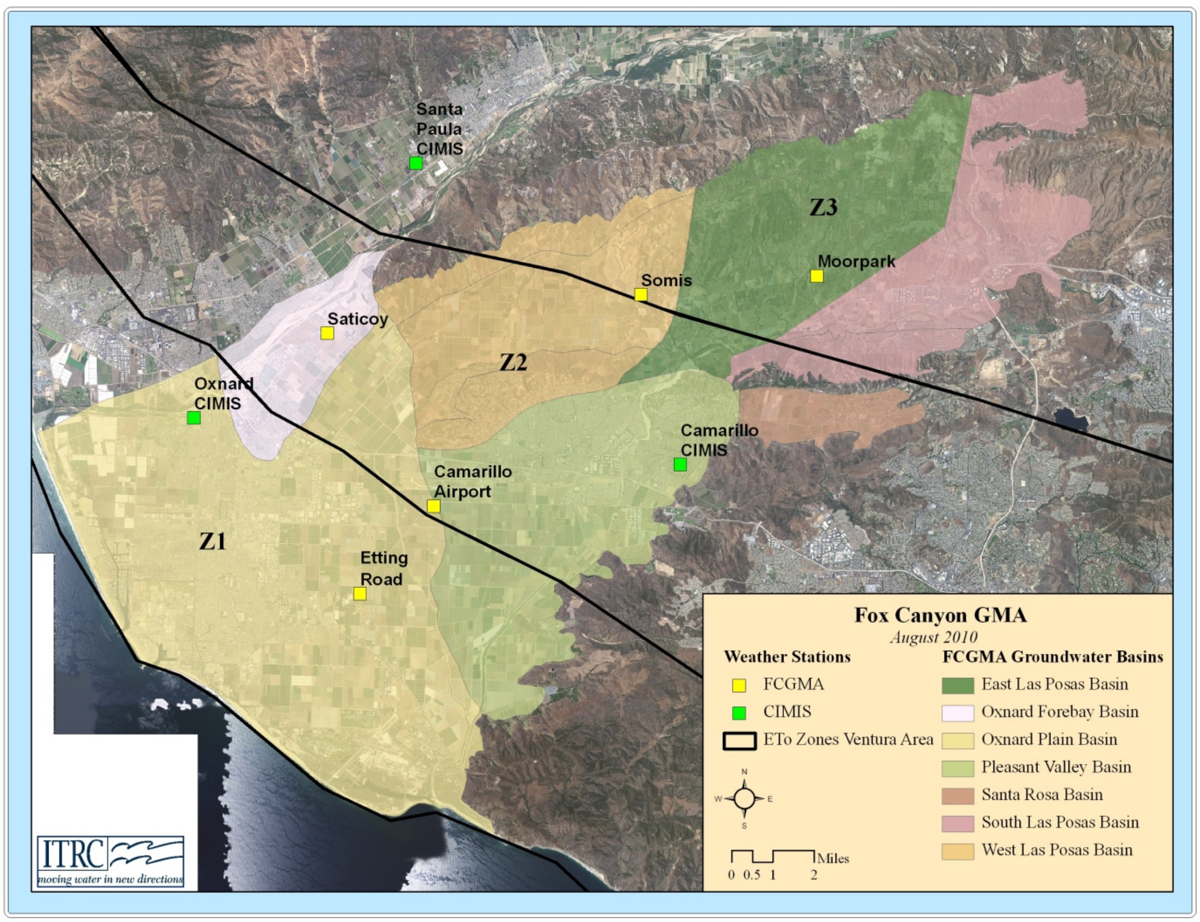

Figure 4. Possible ET_o zones for FCGMA and weather station locations

Irrigation Water Requirement Components

In Task 2.1, ITRC modeled 21 cropping scenarios to estimate the amount of irrigation water the crops require. Based on comments from the FCGMA board members, ITRC increased the number of crop categories to 24 to account for avocado and blueberries with different percent canopy cover.

As outlined in Task 2.1, total crop water requirements are met through irrigation and effective precipitation. Effective precipitation is discussed in **Appendix D**. Irrigation water could be required for other management purposes such as salinity leaching and frost protection. Several of these factors are discussed on the following pages.

Salinity Leaching Requirements

Salts are imported into irrigated agriculture through irrigation water applications. Salts become concentrated in the upper soil profile due to the evapotranspiration (*ET*) process, whereby water is removed from the soil through evaporation and plant transpiration, and the salts from the water are left behind in the soil. Soil salinity is usually expressed as the electrical conductivity of an extract of a saturated paste of the soil (EC_e). Irrigation water salinity is expressed as the electrical conductivity of water (EC_w).

Groundwater quality information was provided to ITRC by FCGMA staff dating back to the 1950's. A portion of the groundwater well samples contained salinity information that included EC_w. The salinity data by well from 2005-2009 were organized and summarized by groundwater basin. **Figure 5** shows the average EC_w in each groundwater basin from 2005-2009. **Appendix A** provides more detailed information on the statistics of these values including the number of samples and minimum and maximum EC_w of the groundwater samples. Because of the limited sampling wells in some of the groundwater basins, and the variability of salinity within basins, a relatively high average EC_w value was selected equal to 1.8 dS/m for all of FCGMA. In some cases surface water may be currently utilized and in the future recycled water with lower salinity levels may be used. Therefore, the average EC_w value of 1.8 dS/m is likely a conservative value. A comparison of different EC_w values on a sample of crop leaching requirements is shown in **Appendix A**.

The amount of salts in the soil tolerated by a specific crop depends on the type of crop as well as the interactions between soil fertility, climate, irrigation method, growth stage, and other environmental stresses. Research has determined crop sensitivity to salinity, which is typically represented as "Threshold EC_e." A fundamental reality is that on a long-term basis the amount of salts removed by leaching must be equal to or greater than the salts imported with irrigation water in order for crop production to be sustainable. A certain amount of deep percolation from irrigation water and/or rainfall is required to maintain acceptable levels of soil salinity by leaching salts from the root zone. The portion of deep percolation that can be considered a "beneficial use" of imported irrigation water is the quantity that is necessary to keep soil salinity levels below the crop-specific threshold levels, to prevent a decline in yields.

Threshold EC_e values for each crop are shown in **Appendix A**. These values vary from sensitive crops such as avocados, which have threshold EC_e = 1.3 dS/m (deciSiemens per meter), to more tolerant sod, which has EC_e = 4.0 dS/m. In general, however, most of the crops in FCGMA are relatively sensitive to salinity.

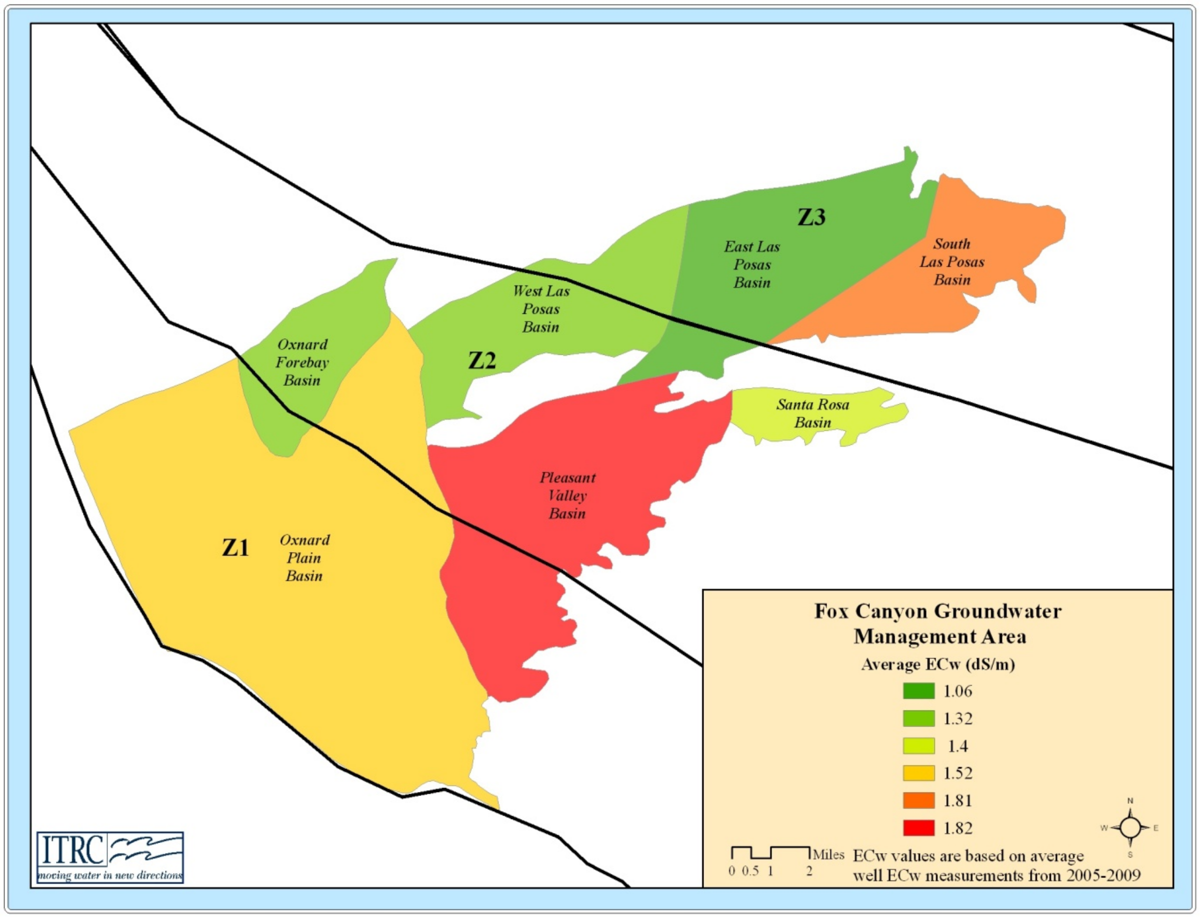

Figure 5. 2005-2009 average electrical conductivity of groundwater samples by groundwater basin

The high levels of EC_w measured in the groundwater along with low values of threshold EC_e for some crops would indicate that there should be a significant amount of leaching to maintain soil salinities below the threshold EC_e using the traditional leaching requirement formula. However, this formula is <u>not</u> applicable for daily management of most drip irrigation because it assumes that there is uniform vertical movement of water through the root zone, with corresponding uniformly distributed deep percolation to remove salt (Burt and Styles, 2007[3], Hanson et al., 2009[4]). Instead, it must be understood that salt with drip/micro needs to be removed by reclamation leaching (sprinklers).

Farmers of strawberries and various produce crops, grown under drip irrigation, often use sprinklers as a pre-planting reclamation practice to remove accumulated salt. If the sprinklers apply water to bare soil (not to plastic-covered soil), the volume of water per

[3] Burt, C.M. and S.W. Styles. 2007. *Drip and Micro Irrigation Design and Management*. Irrigation Training and Research Center, Cal Poly. San Luis Obispo, CA. ISBN 978-0-9643634-4-1. 391 p.

[4] Hanson, B.R. D.E. May, J. Simunek, J.W. Hopmans, and R.B. Hutmacher. 2009. Drip Irrigation Provides the Salinity Control Needed for Profitable Irrigation of Tomatoes in the San Joaquin Valley. *California Agriculture*. 63(3):131-136.

season needed for reclamation leaching with sprinklers is similar to the volume of water needed for leaching requirement (LR) practices if sprinklers were used throughout the growing season.

In addition, the interaction between non-uniformity of applied irrigation water and salinity leaching is another factor to consider. As previously discussed, applied irrigation water distribution uniformity (DU) is imperfect – some portions of the field will receive more water than others. It is important to understand that one point in the field is receiving more or less water than others. The portions that receive more water will have more deep percolation below the root zone, which will leach salts.

The traditional LR approach assumes that the areas receiving more or less water remains consistent from irrigation to irrigation and season to season. This is typical for furrow and border irrigation regimes that have the same field slope, high/low points, and consistent flow rates and irrigation durations. The result is that a significant amount of water must be applied to an entire field to leach salts (to meet the LR) in the portion that consistently receives the lowest amounts of irrigation (where the salt is building up because of a low leaching fraction).

As discussed in **Appendix A**, the areas of the field receiving more or less water does not remain constant for row crops that are sprinkler or drip-irrigated or use some combination of the two. The locations of the furrows, and consequently the locations of the sprinkler laterals and drip tape, changes from crop to crop. Some significant factors in the DU such as emitter plugging and emitter and sprinkler manufacturer variability are random and will change spatially from crop to crop.

Precipitation that infiltrates the soil and moves past the root zone can also contribute to the leaching requirement (LR). Examination of the ITRC soil water balance model used in Task 2.1 indicated that approximately 2-3 inches of precipitation on an annual basis percolates below the root zone during a typical precipitation year.

Summary of Principles

Reclamation Leaching – Occasional salinity leaching using high amounts of water over a short period of time to reduce an accumulated salinity in the soil. This should be completed using several irrigation events spaced closely together (within 1-2 weeks to minimize surface runoff), typically conducted in the fall or winter when there is low ET_o. The amount of water needed for reclamation leaching is approximately equal to that needed for seasonal LR.

Incorporating LR into daily management – The additional water required to meet the LR is applied during each irrigation so that salts are continuously leached, and the EC_e remains fairly constant. Some types of drip irrigation are incapable of removing the salt, because of the way water moves in the soil under emitters.

Inconsistent non-uniformity from growing season to growing season means that the locations of the field receiving more or less water can change and be somewhat self-compensating in terms of leaching needs. Therefore, for some crop/irrigation strategies a portion of the LR can be met through normal irrigation practices.

Each of the factors discussed was used to determine a recommended LR for crops in FCGMA. The equation to compute leaching requirement (LR) is shown in **Appendix A** along with threshold EC_e values for major crops grown in Ventura County. The leaching requirements in **Appendix A** are only estimates. The issues with salinity in irrigation water in FCGMA should continue to be monitored and leaching requirements may need to be fine-tuned in the future. This will be especially true as water sources change in future years.

Frost Protection

When protecting crops against frost, growers have a variety of methods to choose from, including wind, heaters, and irrigation application. Irrigation application can be effective for protecting against frost during mild frost scenarios. The reason for this is that water releases heat while it is cooling at a rate of 1 calorie per gram of water per degree Celsius. The major benefit occurs as the water changes state from liquid to solid, at which point 79 calories per gram of water are released. The heat that is released from the water warms the plant canopy, reducing the potential for frost damage. However, the irrigation system must continue operating during the period of freezing temperatures (6 to 12 hours).

The amount of water required for frost protection is related to the number of frost events per year and the application amounts of the irrigation systems. Most orchards in FCGMA utilize microsprayers or drip irrigation. Row crops may utilize sprinklers or drip or both. From the grower interviews conducted by Dr. Ben Faber, U.C. Extension Ventura County, application amounts were provided for citrus orchards and a number of strawberry growers stated that they leave sprinklers in the field for frost protection.

Microsprayers and drip systems have lower application rates compared with sprinklers. In **Appendix B**, the application rates of different systems from the grower interviews were investigated with assumptions on how much would be applied for an assumed 10-hour system run time per frost event. For drip/micro systems the applications varied from 0.3 to 0.6 inches per event for typical systems. For sprinklers the application amount would be 1.2-1.4 inches per event assuming 10 hours of continuous application. However, it would be more likely that sprinklers (and drip/micro systems) would be run intermittently on any one portion of a field because of limited system supply (irrigation would be rotated to different blocks within the field or farm). ITRC estimates that a reasonable application per frost event would be 0.5 inches/event for all irrigation methods.

The number of days with minimum temperatures at or below 0° C (32° F) varied from 0 to 13 depending on CIMIS weather station location. On average there were two events in FCGMA ET_o Zones 1 and 2 and seven events in Zone 3 (**Appendix B**). It should be noted that microclimates in fields can have lower temperatures than would be measured at these weather stations. Many growers have thermometers in their fields to account for microclimate differences.

Santa Ana Winds

Santa Ana (a.k.a. santana) winds are a meteorological phenomenon that occurs in southern California consisting of high winds blowing warm, dry air from the Great Basin of Nevada and Utah typically in the fall and winter months. The Santa Ana winds come from the northeast towards the ocean (off-shore winds) affecting regions from Ventura County to Baja

California. Growers understand the need for increased irrigation during the fall and winter because crops will require more water due to the warm, dry air and high winds.

The goal of this analysis was to determine whether this increase in crop water needs is accounted for in the grass reference evapotranspiration (ET_o) values computed using local weather parameters. **Table 7** shows the 2000-2009 average monthly ET_o and weather parameters from the Camarillo CIMIS station. The Santa Ana wind timeframe can be seen with the minimum daily relative humidity being the lowest from January-March and October-December, coinciding with the primary wind direction out of the northeast. The maximum daily temperatures during October and November are similar to those in early summer. The average monthly ET_o does show some drop-off in early fall even with the high temperatures and low relative humidity due to the decrease in incoming solar radiation.

Table 3. Key 2000-2009 average monthly weather parameters from the Camarillo CIMIS station

Month	Average Monthly ET_o	Average Daily Max. Temperature	Average Daily Min. Relative Humidity	Average Daily Wind Speed	Primary Wind Direction
	inches/month	Deg. F	%	mph	
January	2.5	68	40	3.6	Northeast
February	2.6	67	45	3.4	Northeast
March	3.7	69	49	3.3	Northeast
April	4.2	69	52	3.4	Southeast
May	4.7	72	59	3.1	Southeast
June	4.9	75	62	3.2	Southeast
July	5.5	79	61	3.1	Southeast
August	5.0	79	60	3.0	Southeast
September	4.1	79	56	2.9	Southeast
October	3.2	75	52	3.0	Northeast
November	2.7	72	42	3.1	Northeast
December	2.3	67	41	3.3	Northeast

While the ET_o does drop off in October and November it is likely that this decrease would not be as significant as it would be if there were no Santa Ana conditions. In addition, the magnitude of Santa Ana conditions varies year by year. This can be seen in **Figure 6**, which shows daily ET_o from the Camarillo CIMIS station for 2007 and 2008. These years were selected because of the noteworthy Santa Ana conditions in the region, which played a significant role in the October 2007 and November 2008 wildfires. These are compared to 2009, which has a weaker Santa Ana condition.

In 2007 and 2008 the daily ET_o increases significantly during the Santa Ana timeframe. It is very clear from the relatively high ET_o values in October and November of 2008 that Santa Ana winds impacted the ET_o.

There are some special circumstances where additional irrigation may be necessary above the ET_o. Since strawberries can be transplanted in early fall, with the lack of established roots with young plants, additional water would be required to maintain a healthy crop. Similarly, any young crop with a lack of established roots could have the same irrigation needs. However, these additional applications, while greater than actual crop evapotranspiration requirements during that timeframe, could be used for salinity leaching or stored in the root zone to be used by the crop in the future.

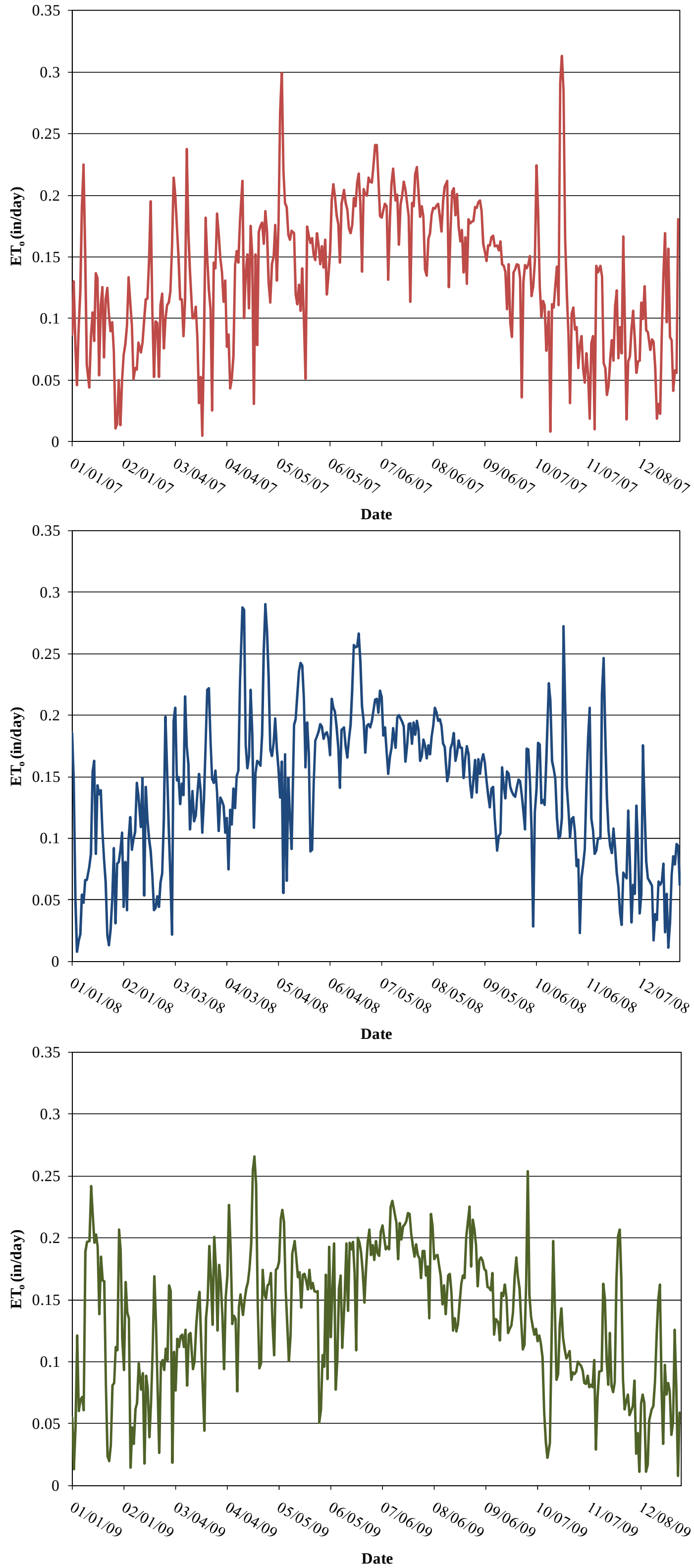

Figure 6. Daily *ET$_o$* for 2007 (top), 2008 (middle), and 2009 (bottom) from the Camarillo CIMIS station

Greenhouse and Tunnel Considerations

Greenhouses and tunnels (hoophouses) require special attention because there is limited information on water use under these growing conditions. The environment inside of these systems is different than the reference condition used to compute ET_o. Crop coefficients used as the basis of computing crop evapotranspiration are determined based on ET_o and a crop growing outdoors.

The climate inside of a greenhouse or tunnel has some major differences in attributes. Temperature is generally higher in the system because it does not allow long wave radiation to leave. This means that the total energy available to the plant is higher than an outdoor system, creating a potential for increased evapotranspiration. However, other key factors that impact evapotranspiration such as relative humidity and wind must also be considered. The relative humidity inside of the greenhouse/tunnel is higher and there is no wind to decrease the evapotranspiration rate. In addition, some research has indicated that incoming solar radiation is actually lower in indoor than outdoor situations[5]. It was outside the scope of this report to evaluate specific greenhouses and tunnels in FCGMA to determine actual evapotranspiration rates. This would require a significant long-term study, which is proposed in the *"Recommended Future Work"* section of this report. Crop evapotranspiration from crops grown in greenhouses and tunnels was estimated based on best currently available information[5].

For greenhouses, research has indicated that evapotranspiration rates are somewhat lower overall compared to the same crop grown outdoors[5]. This was accounted for in the ITRC evapotranspiration estimates. However, since rainfall cannot reach the soil in a greenhouse, there is no effective precipitation. Therefore, in the computation of growing period ET_{iw}, no effective precipitation was included for greenhouses or tunnels.

The only crop category analyzed in greenhouses was "miscellaneous vegetable crops" grown in fall, winter, and spring. If a vegetable crop such as tomatoes is grown year-round in greenhouse conditions, the irrigation allowance for all three crop categories should be combined for the total Irrigation Allowance.

Raspberries were the only crop evaluated in tunnel conditions. Miscellaneous vegetable crops were evaluated under both greenhouse and normal field conditions. Crops evaluated under greenhouse conditions are identified as greenhouse crops in **Table S1** and **Table 4**. More detailed analysis may be required in the future that focuses on greenhouse growing conditions to fine-tune evapotranspiration demands in these situations.

Flow Meter Accuracy

In 2007 and 2008 a flow meter evaluation was completed on primarily agricultural well flow meters throughout FCGMA. The results of the evaluation were provided by FCGMA staff. A total of 578 flow meter tests provided information on accuracy. Of these approximately 6 were for domestic use only. A histogram analysis showing the number of wells within

[5] Fernandes, C.; Cora, J.E. and Araujo, J. 2003. Reference evapotranspiration estimation inside greenhouses. *Sci. agric*. vol.60, n.3, pp. 591-594 . Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-90162003000300027&lng=en&nrm=iso

ranges of percent error is shown in **Figure 7**. There were two outliers that are not shown in the figure: one meter that had a percent error of -73% and another that showed a percent error of 112%. These meters were noted as being replaced. Percent error is computed as:

$$Percent\ Error = \frac{(Meter\ Flow - Actual\ Flow)}{Actual\ Flow} \times 100\%$$

As shown in **Figure 7**, nearly 98% of the 576 flow meters tested were within +/-6% of the actual flow and nearly 64% of the flow meters were within +/-3% of the actual flow. These results should be very encouraging to growers and FCGMA.

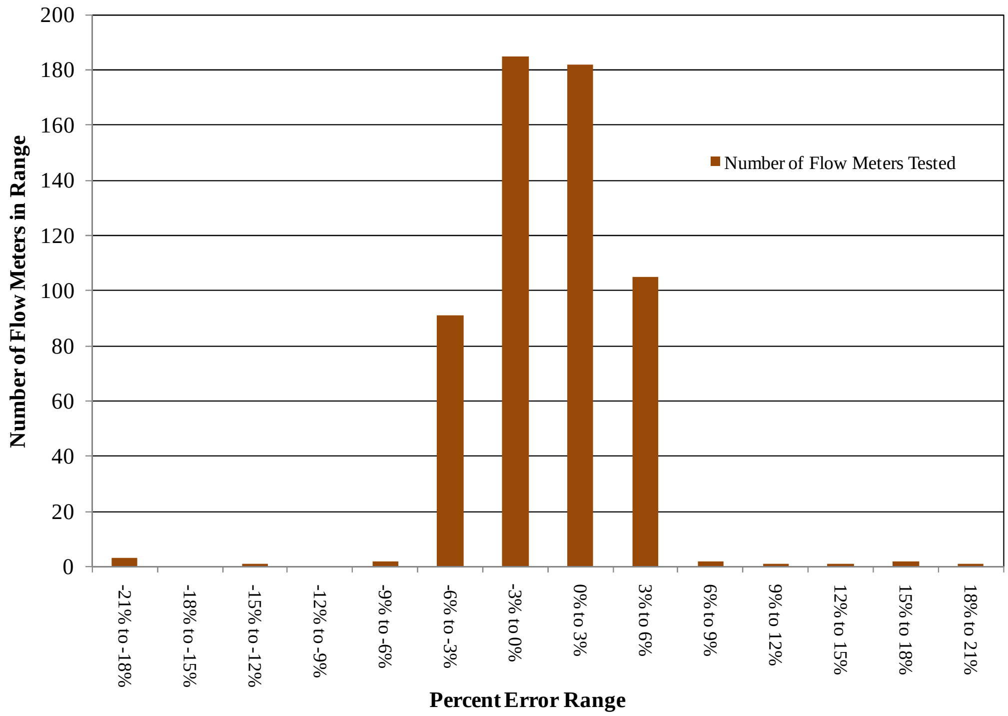

Figure 7. Histogram analysis showing the number of flow meter tests within a range of flow meter percent errors

It is the responsibility of growers within FCGMA to report the total volume of water pumped from each well. Every flow meter should have a totalizer in addition to instantaneous flow measurement. The totalizer is similar to the odometer for a car. The totalizer, which typically reads in acre-feet, sums the total discharge that has moved through the flow meter. A common source of error in the reporting of volume of water applied involves transposing numbers or misreading values.

In order to minimize the chance of reporting errors, ITRC recommends that FCGMA request photos of the flow meter totalizer readings at the beginning and end of each calendar year. The total volume pumped would be the difference between the two totalized values from the image. Of course, the totalized volume at the end of one year should be the same as the totalized volume at the beginning of the next.

Planted Acreage and Canopy Coverage Impacts

Planted crop acreage is a difficult value to precisely determine given crop growing strategies in FCGMA. There are two important components of crop acreage that will have an impact on FCGMA allowable irrigation water:

1) Actual planted acreage
2) Canopy cover

Planted crop acreage is currently reported by growers. If FCGMA follows the recommendations in this report, where 24 crop categories will be used instead of the three under the existing program, growers will be responsible for tracking and reporting more detailed information on planted acreage and orchard canopy coverage. The benefit is that the allocation should more closely match what a grower actually needs.

As an example, during 2009, one avocado grower applied approximately 1 acre-foot/acre on average and was allocated over 3.5 acre-feet per acre (AF/A). In this case, the grower's FCGMA IE for 2009 was over 300%. By viewing a portion of the applicant's planted acreage via an aerial photo (**Figure 8**), it becomes apparent that the avocado orchard had been planted relatively recently, resulting in small trees with approximately 20% canopy cover. Utilizing ITRC's "Avocado - 20% Cover" category, the allocated water would have been approximately 1.9 AF/A (does not include water required to meet DU). This value is much closer to the actual applied than the current calculation of 3.5 AF/A.

Figure 8. 2009 aerial photo image of a recently planted avocado orchard

The crop acreage reported by growers should not include areas with buildings, roads, or open areas not used for actually growing crops. **Figure 8** shows local roads and buildings that are common in agricultural areas (it should be noted that the grower's reported acreage was less than the APN acreage in the previous example, indicating that they accounted or attempted to account for some of the non-agricultural acreage. A detailed evaluation was not conducted).

Row crop acreage in FCGMA, as with many coastal areas in California, can be difficult to accurately assess. Cropped acreage is different than field acreage because there may be multiple crops grown on a field throughout a year. For example, there could be three vegetable crops grown throughout a year on a 20-acre field. In this example there are 60 cropped acres and 20 field acres. In the existing FCGMA IE program, a grower would report 20 acres and use a per-acre allocation assuming a crop was on the field throughout the year. However, some growers may only grow two crops per year depending on the crop.

Nurseries and sod farms pose yet another set of issues. In most cases there is a crop on a portion of a field, nursery, or greenhouse all year. However, because of continual harvesting/planting, at any time only a portion of the area might be vegetated. The actual vegetative acreage will change during the year. Therefore, ITRC did not attempt to evaluate this in the growing period ET_{iw} values for these crops. It will be the responsibility of the grower to report annual average vegetative acreage to account for this. An additional option would be to scale the growing period ET_{iw} values down based on an assumed percent of vegetative acreage during the year. However, at this point there is insufficient information on nurseries, sod farms, and greenhouses to make this adjustment. More detailed analysis could be conducted in the future examining the actual vegetative acreage on a sample of sod farms and nurseries at different times of the year.

Proposed Irrigation Allowance/Index Program

This report has suggested a number of improvements that could provide a more accurate determination of allowable water to growers for FCGMA. Under the existing FCGMA IE Allocation program, weather data from a series of weather stations is used as a broad estimate of allocation. In this report, ITRC systematically determined estimates of irrigation water requirements:

1. Crop evapotranspiration needs using 24 crop categories
2. Salinity leaching
3. Frost protection
4. Reasonable distribution uniformity

In the next section these components will be combined to determine the total irrigation water allowance. The final portion of this report will discuss a proposed alternative to the existing FCGMA IE indicator that is currently used. As previously discussed the existing IE indicator is not computed using the standard irrigation efficiency equation. The proposed Irrigation Allowance Index will be a ratio of actual application to total irrigation allowance.

Total Irrigation Water Allowance

The total irrigation water allowance will incorporate effective precipitation, salinity leaching, frost protection, and distribution uniformity. Effective precipitation varies by precipitation year and can vary within a year depending on the magnitude of individual events and when the events occur. Three options are shown to compute the Annual Irrigation Allowance.

Option 1: Specific Annual Irrigation Allowance Amount (Recommended)

Because this is such a complicated issue, ITRC is proposing to simplify the procedure by using a specific value of growing period ET_{iw} for each crop category for three year types (typical, dry, and wet) in the three ET_o zones previously discussed (only the year type will change in this option). The values incorporate the average ET_o in each zone measured by each primary CIMIS weather station (implications are discussed in the "*Comparison of Options*" section). The average ET_o used for **Table S1** values by ET_o Zone were:

Zone 1 ET_o = 42.6 inches (average of corrected Oxnard CIMIS ET_o, 2002-2009)
Zone 2 ET_o = 48.2 inches (average of corrected Camarillo CIMIS ET_o, 2001-2009)
Zone 3 ET_o = 52.6 inches (average of corrected Santa Paula CIMIS ET_o, 2006-2009)

Precipitation year types were examined using data collected at all FCGMA weather stations and CIMIS stations from 2000-2009 (data shown in the Task 2.1 report). From this information the average annual precipitation in the region was approximately 14 inches ranging from approximately 5 inches to over 26 inches per year at specific weather stations. Examining the effective precipitation in Zone 2 (using Camarillo CIMIS data) shown in **Appendix D**, the precipitation range for each year type was selected where the volume of effective precipitation was similar. Representative years were used to determine the allowance values in **Table S1**; 2004, 2005, and 2007 were utilized as representative typical, wet, and dry years, respectively. The ranges selected are shown in **Table S2**. It is possible that different year types could be selected for different ET_o zones in the same year.

The values in **Table S1** show the proposed Total Irrigation Water Allowance for each crop category, ET_o zone, and for three precipitation years. These values include water for salinity leaching and to overcome non-uniformity of irrigation uniformity (DU + Local deep percolation for drip = 0.8). <u>Frost protection water was not included because this can vary significantly by year and some growers may use other methods for frost protection</u>.

$$Irrigation\ Allowance\ =\ \frac{Growing\ Period\ ET_{iw}}{(\mathrm{DU} + \mathrm{Localized\ Deep\ Perc.\ on\ Drip}) \times (1 - \mathrm{LR})}$$

Annual Irrigation Allowance values shown in **Table S1** vary by year type more significantly for crops that are growing during the fall, winter, and spring when precipitation occurs. During wet years there is more effective precipitation, which translates to a lower allowance compared to dry years. The differences are consistent with modeled effective precipitation values from 2001-2009 shown in **Appendix E** by crop for proposed ET_o Zone 2 (Camarillo CIMIS). During summer growing periods, the effective precipitation is minimal and there is little difference between year type allowance values. Other factors that impact effective precipitation include root zone depth, timing of precipitation events, and precipitation duration. For example, sod has lower effective precipitation than avocado because sod has a shallow root zone not capable of storing significant precipitation. During wet years when there are heavy events occurring over a short duration much of this precipitation will run off the field or move below the root zone.

The values in **Table S1** are not directly comparable to the existing FCGMA Allowable Water because the existing FCGMA program accounts for distribution uniformity by allowing growers to have an "IE" as low as 80%. While the allowances in the table vary by year for most crops, summer crops, crops in tunnels, and greenhouses either show minimal or no variation. This is caused by limited precipitation during the summer and the assumption that greenhouses/tunnels do not allow precipitation to reach the soil.

<u>Option 2: Using a Regional Allowance Coefficient (K_t)</u>

Modeling of the crops in FCGMA indicated that while the total evapotranspiration demand by crops varied by ET_o zone because of weather (ET_o), a consistent coefficient could be developed by crop and water year between all three zones. This coefficient is similar to a crop coefficient except that it incorporates the total irrigation allowance by including salinity leaching requirements and water needed for imperfect distribution uniformity. This novel coefficient is termed the Total Allowance Coefficient (K_t) shown in **Table 4** for each precipitation year type.

As mentioned, the K_t is similar throughout FCGMA and only varies by crop and precipitation year type. To account for differing weather conditions the K_t is multiplied by the <u>annual</u> measured ET_o at the weather stations in each ET_o zone.

$$Irrigation\ Allowance = K_t \times Zone\ ET_o$$

The benefit of using the regional allowance coefficient (K_t) as opposed to the specific annual irrigation allowance amount shown in **Table S1** is that annual variability in ET_o can be accounted for by using weather station-measured ET_o in each zone. However, the second option is somewhat more complex for the growers making the computations.

Table 4. Option 2 basin-wide annual irrigation allowance coefficient (K_t) by crop

	Basin Wide Annual Allowance Coefficient (K_t)		
	Typical	Dry	Wet
Crop	K_t	K_t	K_t
Avocado - 20% Cover	0.53	0.58	0.48
Avocado - 50% Cover	0.76	0.84	0.69
Avocado - 70% Cover	1.03	1.15	0.99
Blueberries - 50% Cover	0.74	0.77	0.73
Blueberries - 70% Cover	1.03	1.08	0.98
Celery - Fall	0.27	0.30	0.25
Celery - Spring	0.47	0.50	0.42
Citrus - 20% Cover	0.53	0.59	0.50
Citrus - 50% Cover	0.72	0.76	0.67
Citrus - 70% Cover	0.97	1.01	0.89
Lima Beans	0.29	0.30	0.29
Misc. Veg Greenhouse - Fall	0.24	0.24	0.24
Misc. Veg Greenhouse - Spr	0.37	0.37	0.37
Misc. Veg Greenhouse - Summer	0.34	0.34	0.34
Misc. Veg Single Crop - Fall	0.25	0.29	0.22
Misc. Veg Single Crop - Spr	0.44	0.47	0.41
Misc. Veg Single Crop - Summer	0.56	0.57	0.55
Nursery Container	1.25	1.32	1.19
Nursery - Flowers	1.28	1.30	1.22
Raspberries - Tunnel	1.26	1.26	1.26
Sod	1.13	1.19	1.11
Strawberries - Main Season	0.69	0.69	0.67
Strawberries - Summer	0.35	0.35	0.35
Tomatoes - Peppers	0.64	0.64	0.61

<u>Option 3: Computing Annual Allowance Each Year</u>

The annual growing period ET_{iw} was computed using daily weather data and cropping information fed into a daily soil water balance model based on the Modified ITRC/FAO-56 dual crop coefficient approach discussed in the Task 2.1 Report prepared by ITRC for

FCGMA. A third option for computing the annual irrigation allowance is to utilize daily weather data collected from stations in each of the three zones and running the model at the end of the each year.

The Modified ITRC/FAO-56 soil water balance model is complicated and requires oversight by an irrigation expert. The weather data requires intensive quality control procedures and the model setup, operation, and data analysis are time-consuming. These factors make this option the most expensive.

Comparison of Options

Each of the three options has benefits and costs.

- Option 1 provides simplicity and clarity in implementation combined with detailed information regarding irrigation requirement components. However, since average ET_o values were used to develop the values in **Table S1**, the annual variability in ET_o is not taken into account. There is an assumption that ET_o in future years will be similar to the average ET_o used to compute the values. The annual ET_o varied at each ET_o zone by:
    - Zone 1 ET_o = 40.4 – 46.7 inches (corrected Oxnard CIMIS ET_o, 2002-2009)
    - Zone 2 ET_o = 47.2 – 51.1 inches (corrected Camarillo CIMIS ET_o, 2001-2009)
    - Zone 3 ET_o = 50.8 – 55.8 inches (corrected Santa Paula CIMIS ET_o, 2006-2009)

  Given the issues with the current FCGMA weather data, utilizing an average ET_o value even with the variability in CIMIS ET_o over the referenced timeframe should be an improvement. However, if concerns exist Option 2 can be utilized to account for actual annual ET_o.

- Option 2 provides the ability to account for annual variability in ET_o with added complexity in computations. This option requires accurate ET_o data, which makes quality control of weather parameters essential.

- Option 3 is significantly more complex than the other two options. This option requires that an irrigation expert be contracted to set up and run the soil water balance model annually.

Considering these factors, Option 1 is currently recommended.

Weather Station Data Requirements

Correct weather data is essential for all three options; however, only Options 2 and 3 require the ET_o as a direct input for the Annual Irrigation Allowance. Accurate precipitation is important for all three options so that the correct year type can be selected.

It is recommended that weather stations continue to be utilized in the three proposed ET_o zones regardless of which Irrigation Allowance computation option is selected. With the current FCGMA weather station siting issues, it is recommended that the CIMIS stations be utilized as the primary source of weather data with the FCGMA stations as backup. The

ASCE standardized ET_o equation should be used to compute grass reference ET_o at all weather stations (discussed in the Task 2.1 report).

- Zone 1 (Z1) – Oxnard CIMIS and FCGMA Etting Road Station
- Zone 2 (Z2) – Camarillo CIMIS and FCGMA Camarillo Airport Station
- Zone 3 (Z3) – Santa Paula CIMIS and FCGMA Moorpark Station

The precipitation data collected at these stations should be used for precipitation year type selection. The precipitation values collected by the two stations in each zone should be compared to ensure consistency. If there is a significant difference between stations in a region, precipitation data at all six stations should be compared. While there could be some variability in precipitation within FCGMA, trends should exist. For example, if five stations show precipitation values between 14 inches and 16 inches and one station shows 5 inches, the 5 inches should not be used. Additionally, Ventura County Watershed Protection Agency has a network of precipitation gauges that can also be used either as a primary source of rainfall measurements if FCGMA personnel have more confidence in these stations or as an additional check on the precipitation values from the CIMIS and FCGMA weather stations. ITRC did not evaluate the Ventura County Watershed Protection Agency precipitation data as part of this study.

Another issue that could occur is if two stations in one zone have similar precipitation values but on either side of the year type break point (say a reading that is 9.5 inches at one station and 10.5 inches at another). It is recommended that the dryer year type be selected in these cases, which will result in a higher irrigation allowance in that zone. It is unknown which precipitation value is correct; both could be true depending on spatial precipitation variability. It is possible that between zones different precipitation year types could be selected.

Proposed Irrigation Allowance Index

The proposed irrigation allowance index has been formulated to conform to industry standards and for ease of analysis. The index is computed as a ratio to differentiate it from some type of efficiency computation, which it is not. The proposed Irrigation Index is computed as:

$$Irrigation\ Allowance\ Index = \frac{Actual\ Applied\ Water}{Annual\ Irrigation\ Allowance}$$

Where,

Actual Applied Water = Flow meter totalized actual total applied from all water sources

Irrigation Allowance = Volume of annual irrigation allowance for specific year types for appropriate crop categories computed using average actual vegetative acres

An index of 1.0 or below is good. It means that the applied water is equal to or less than the Irrigation Allowance. If the Index is greater than 1.0, the grower is applying more water than the allowance and the cause should be investigated.

Recommended Future Work

1. Provide quality control of the recommended irrigation allowance program for the first year of implementation. This will supply FCGMA personnel with direct feedback as the program is implemented and as questions and concerns arise.

2. Modify the crop categories with grower and FCGMA personnel feedback.

3. Correct the growing period ET_{iw} by rerunning the Modified ITRC/FAO 56 model based on grower feedback. This would likely take place in the summer of 2011 so that modifications could be incorporated by the end of the year.

4. Evaluate evapotranspiration of crops grown in greenhouses. There is currently a lack of good information on evapotranspiration rates in greenhouses. Recommended research could involve directly measuring water vapor leaving greenhouses through vents by measuring airflow and relative humidity. While greenhouse operations are not standard, this type of study would be a step forward from existing information.

5. ITRC has started a remote sensing program where satellite images are utilized to compute crop evapotranspiration. Mapping Evapotranspiration at High Resolution (METRIC) utilizes LandSAT 5 thermal imaging to compute instantaneous evapotranspiration at satellite overpass times. The LandSAT 5 passes over a region once every 16 days. Given the complexities in agricultural operations in FCGMA, it could be beneficial to utilize METRIC to examine actual evapotranspiration in the region. This information could be used as an analytical check of the modeled ET_c values from the soil water balance model used as the basis for the irrigation allowance. In addition, METRIC ET_c could be useful in other situations, such as when looking at regional water balances for groundwater hydrology investigations. Important points to note are:
    - The satellite information would not be useful for greenhouses and tunnels since emitted radiation is blocked.
    - However, differences in canopy coverage and planted versus total field acreage would be accounted for.
    - METRIC requires an intensive evaluation. Most likely, 8-10 images would have to be processed for each year evaluated.

Appendix A
Salinity Management

Estimating Irrigation Requirement for Salinity Leaching

The groundwater pumped in FCGMA and used for irrigation contains salts of varying concentrations. These salts become concentrated in the upper soil profile due to the evapotranspiration (*ET*) process, whereby water is removed from the soil through evaporation and plant transpiration, and the salts from the water are left behind in the soil. Soil salinity is usually expressed as the electrical conductivity of an extract of a saturated paste of the soil (EC_e).

For any particular crop, when soil salinity reaches a certain level the yield begins to decline. Each crop has a "crop salt tolerance", which is the degree of salinity that a plant can withstand for a certain yield response under optimal conditions. The maximum salinity level that can be tolerated with no yield reduction is termed the "salinity threshold" (threshold EC_e).

The quantity of salts in soil tolerated by a specific crop depends on the type of crop as well as the interactions between soil fertility, climate, irrigation method, growth stage, and other environmental stresses. The threshold EC_e is also dependent upon the soil moisture condition – a plant growing in a continuously moist soil can withstand a higher EC_e than one in a dry soil, or than one in a soil that experiences shifts between wet and dry.

However, a fundamental reality is that on a long-term basis the amount of salts removed by leaching (deep percolation of water through and beyond the root zone) must be equal to or greater than the salts imported with irrigation water in order for crop production to be sustainable. A certain amount of deep percolation from irrigation water and/or rainfall is required to maintain acceptable levels of soil salinity by leaching salts from the root zone. The portion of deep percolation that can be considered a "beneficial use" of imported irrigation water is the quantity that is necessary to keep soil salinity levels below the crop-specific threshold levels, to prevent a decline in yields.

The leaching requirement (*LR*) increases with both the salinity of the irrigation water being applied (EC_w) and the sensitivity of the crop to salts.

The leaching requirement (LR) value (which is a decimal) is commonly used to estimate the gross irrigation water to apply as:

$$Gross\ to\ apply = \frac{ET\ requirement - ET\ supplied\ by\ rain}{\frac{Irrigation\ Efficiency}{100} \times (1 - LR)}$$

To estimate the leaching requirement, both the crop's threshold EC_e and the salinity of the irrigation water (EC_w) must be known or estimated. The percentage of irrigation water necessary for leaching to maintain desired salinities (e.g., below the threshold EC_e for 100% yield potential) with the standard formula is calculated as follows:

$$LR = \frac{EC_w}{[5 \times EC_e] - EC_w}$$

However, this formula is not applicable for daily management of most drip irrigation because it assumes that there is uniform vertical movement of water through the root zone, with corresponding uniformly distributed deep percolation to remove salt[1,2]. Instead, it must be understood that salt with drip/micro needs to be removed either by reclamation leaching (sprinklers) or by rainfall deep percolation.

Farmers of strawberries and various produce crops, grown under drip irrigation, often use sprinklers as a pre-planting reclamation practice to remove accumulated salinity. If the sprinklers apply water to bare soil (not to plastic-covered soil), the volume of water per season needed for reclamation leaching with sprinklers is similar to the volume of water needed for leaching requirement (LR) practices if sprinklers were used throughout the growing season.

Another issue to consider involves the interaction between non-uniformity of applied irrigation water and salinity leaching. The applied irrigation water distribution uniformity (DU) is imperfect – some portions of the field will receive more water than others. (DU is discussed in more detail in the main report.)

Because of non-uniformity of irrigation application, a significant portion of a field, say 50% or greater, may have enough deep percolation from normal irrigations to meet the leaching requirement – without applying any additional water for salt control. So the incorporation of the LR in the "gross to apply" formula above is intended to supply enough leaching water from the driest points in the field.

The ratio of applied water that leaches below the root zone to the total applied water that infiltrates the soil at a point is termed the leaching fraction (LF). While the leaching requirement (LR) is one value computed for a field, the LF at every point of the field is different because of non-uniformity.

$$LF = \frac{Inches\ of\ deep\ percolation}{Total\ applied\ water}$$

The traditional LR approach found in salinity literature and formulas (such as the "gross to apply" formula above) assumes that the spatial locations of the points receiving more or less water remains consistent from irrigation to irrigation and from season to season. This is typical for furrow and border irrigation regimes that have the same field slope, high/low points, and consistent flow rates and irrigation durations. The result is that a significant amount of water must be applied to an entire field to leach salts (to meet the LR) in the

[1] Burt, C.M. and S.W. Styles. 2007. *Drip and Micro Irrigation Design and Management.* Irrigation Training and Research Center, Cal Poly. San Luis Obispo, CA. ISBN 978-0-9643634-4-1. 391 p.

[2] Hanson, B.R. D.E. May, J. Simunek, J.W. Hopmans, and R.B. Hutmacher. 2009. *Drip Irrigation Provides the Salinity Control Needed for Profitable Irrigation of Tomatoes in the San Joaquin Valley.* California Agriculture. 63(3):131-136.

portion that consistently receives the lowest amounts of irrigation (where the salt is building up because of a low leaching fraction).

However, for microspray, sprinkler, drip, and combination sprinkler/drip irrigation this is not the case.

For *row crops using only sprinklers*:

- The furrows are not established in exactly the same location or the same size for subsequent growing seasons. Therefore, a sprinkler lateral is placed at a different location relative to the beds for each growing season. This means the sprinkler overlap pattern onto the soil changes from year to year.
- Wind direction and magnitude change throughout a season, impacting sprinkler overlap patterns.
- Because non-uniformity of the sprinkler overlap patterns is by far the greatest component of non-uniformity for solid set sprinklers, the shifting of the overlap pattern over time means that what was the dry spot one season may be the wet spot the next season. Therefore, over the course of multiple seasons, the uniformity of leaching will be better than the uniformity of irrigation for just one season. This in turn means that less "extra" water is needed to satisfy the LR because normal non-uniformity will provide much of the needed deep percolation.

For *combination sprinkler/drip*:

- The sprinkler portion will have the same impact as listed above for row crops using only sprinklers.
- With drip tape, approximately 50% of the non-uniformity is due to plugging and manufacturing variability. Manufacturing variability means that no two new emitters are exactly the same, and therefore some emitters will have higher discharge compared to others even when they are new. This is a random occurrence. Emitter plugging is also somewhat random in spatial occurrence. This randomness means that the locations of portions of the field receiving more or less water will change between growing seasons.
- The DU of the sprinkler system likely does not coincide with the drip DU. Sprinkler overlap uniformity may cause a portion of the field to have a lower leaching fraction, yet when drip is used later in the season, the same area may receive more water and thus have a higher leaching fraction.

For *microspray and drip on orchards*:

- Assuming the emitter spacing remains the same for many years, the salinity buildup would not be random because pressure and manufacturing variability will remain consistent throughout a field. Therefore, a more traditional salinity management regime will be necessary where the water needed for leaching is met using a series of closely spaced annual leaching events (reclamation leaching).
- The first 12 years of avocado orchard establishment are a special case. Typically, avocados are initially planted in high density of 100 trees per acre. Throughout the first 12 years or so the orchard undergoes two thinning events where trees are removed and the emitters around the remaining trees are reorganized (43 trees per acre remain based on recommendations in the U.C. Cooperative Extension Avocado Handbook). During

this timeframe the reorganization of emitters would impact the location of high salinity areas around the trees and likely reduce the high salinity concentrations in the root zone. However, this presents some special challenges in FCGMA, because when emitters are moved they may flush accumulated soil salt directly into the root zone, and cause serious plant damage. Therefore, a reclamation leaching should take place before this reorganization occurs.

Summary of Principles

Reclamation Leaching – Occasional salinity leaching using high amounts of water over a short period of time to reduce an accumulated salinity in the soil. This should be completed using several irrigation events spaced closely together (within 1 or 2 weeks to minimize surface runoff), typically in the fall or winter when there is low ET_o. The amount of water needed for reclamation leaching is approximately equal to that needed for seasonal LR.

Incorporating LR into daily management – The additional water required to meet the LR is applied during each irrigation so that salts are continuously leached, and the EC_e remains fairly constant. Some types of drip irrigation are incapable of removing the salt, because of the way water moves in the soil under emitters.

Inconsistent non-uniformity from growing season to growing season means that the locations of the field receiving more or less water can change and be somewhat self-compensating in terms of leaching needs. Therefore, for some crop/irrigation strategies a portion of the LR can be met through normal irrigation practices.

These principles are incorporated into the adjusted leaching requirement discussed in proceeding sections.

Irrigation Water Salinity (EC_w) in FCGMA

FCGMA provided water quality samples from wells throughout the management area from the 1950's through the end of 2009. A portion of the nearly 10,000 water quality samples included electrical conductivity of the irrigation water (EC_w) measurements. Focusing on samples from 2005 through 2009, the EC_w data was summarized by well in each groundwater basin. The average EC_w for each groundwater basin is shown in **Table A-1** and **Figure A-1**.

Table A-1. Average EC_w of groundwater samples by groundwater basin in FCGMA

	Groundwater Basin						
Description	Arroyo Santa Rosa	Las Posas - East	Las Posas - South	Las Posas - West	Oxnard Plain Forebay	Oxnard Plain Pressure	Pleasant Valley
Number of wells sampled	11	12	3	7	19	55	12
Average EC_w within basin, dS/m	**1.4**	**1.1**	**1.8**	**1.3**	**1.3**	**1.5**	**1.8**
Maximum EC_w, dS/m	1.7	2.2	1.9	1.8	1.6	7.5	2.9
Minimum EC_w, dS/m	0.9	0.4	1.7	0.9	1.1	0.7	1.1

The average EC_w values throughout FCGMA of 1.1 to 1.8 dS/m are relatively high. General water quality guidelines would classify water in this range as having “increasing problems.” However, the extent of the problems depends on the individual crop salinity tolerance. Examining the EC_w values in **Table A-1**, an EC_w value of 1.8 dS/m was used for the salinity management analysis for all of FCGMA.

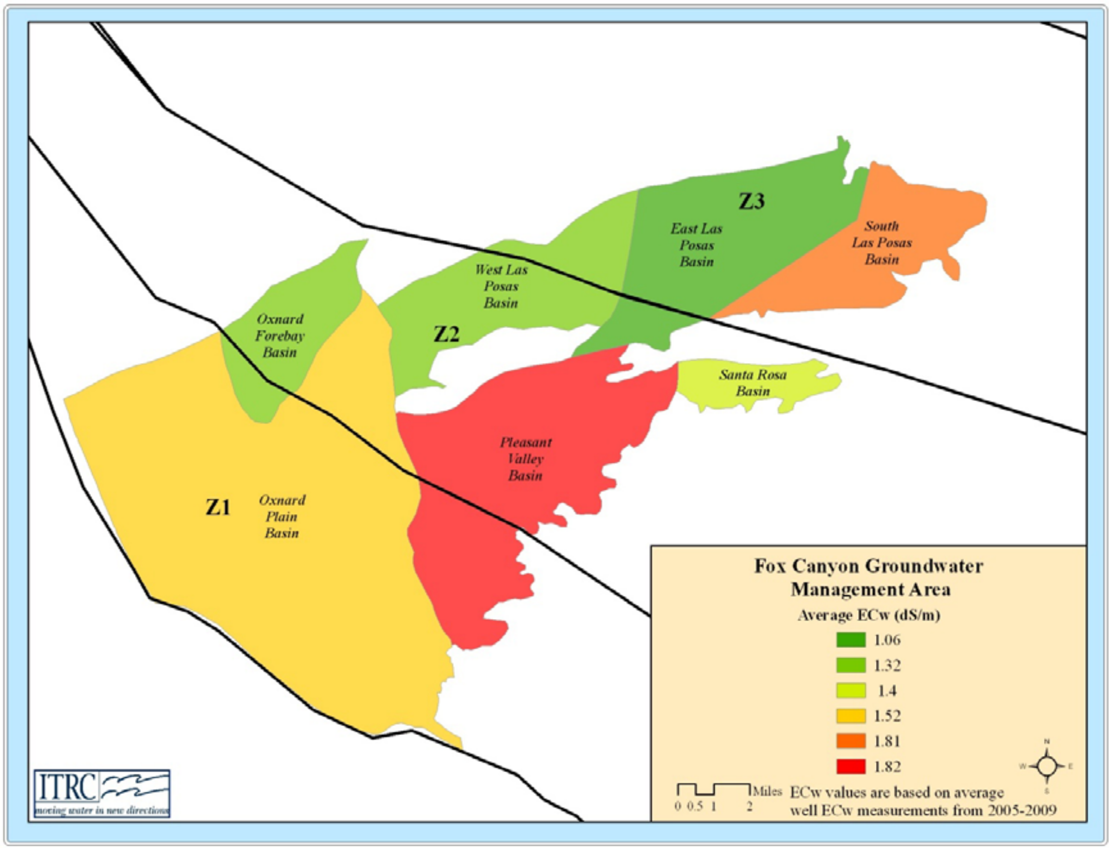

Figure A-1. 2005-2009 average electrical conductivity of groundwater samples by groundwater basin

Crop Salinity Tolerance (Salinity Threshold)

There has been significant work on estimating threshold soil salinity (EC_e) for agricultural crops throughout the world. A larger crop threshold EC_e indicates that the crop is more tolerant to soil water salinity. For example, a crop that would be considered salt tolerant among grain crops is barley, which has a threshold EC_e of 8 dS/m. **Table A-2** summarizes the threshold EC_e values for the major crops in FCGMA.[3] The threshold EC_e values shown in **Table A-2** indicate a low tolerance to salts for the vast majority of crops in FCGMA. Published values for strawberries, tomatoes, and peppers have been replaced by slightly higher numbers, as explained below the table.

[3] Refer to Tanji, K.K. 1990. *Agricultural Salinity Assessment and Management.* ASCE Manual No. 71. Water Quality Technical Comm. of the Irrig. and Drainage Div., ASCE. New York, NY. and
Khan, M. Ajmal; Weber, Darrell J. (Eds.) *Ecophysiology of High Salinity Tolerant Plants*. Christy T. Carter and Catherine M. Grieve. Salt Tolerance of Floriculture Crops. Ch. 19, p. 279-287

Table A-2. Threshold soil salinity values for crops in FCGMA

Crop	Threshold EC_e dS/m
Avocado	**1.3**
Blueberries	**1.5**
Raspberries	**1.5**
Celery	**1.8**
Citrus	**1.7**
Lima Beans	**1.5**
Misc. Vegetables	**1.3**
Nursery Container	**3.5**
Nursery – Flowers	**3**
Sod	**4**
Strawberries	***2.0***
Tomatoes – Peppers	***3.5***

Strawberries and Soil Salinity

Strawberries are a special case. In FCGMA, the soil salinities (EC_e) for strawberry root zones are typically in the range of 3-4 dS/m without showing apparent damage to the strawberries. This higher-than-published salinity tolerance is similar to what has been encountered with processing tomatoes on drip irrigation in the San Joaquin Valley.

Based on actual practices in FCGMA, the strawberry threshold EC_e has been modified from 1.0 dS/m, to 2.0 dS/m. The tomato and pepper threshold EC_e has been modified from 2.5 dS/m to 3.5 dS/m based on research by Blaine Hanson from U.C. Davis.

Salinity Leaching, Localized Leaching, and Irrigation Efficiency

Tables A-3 shows the recommended adjusted leaching requirement (LR) for FCGMA by crop using an agency average EC_w of 1.8 dS/m. The adjusted leaching requirement factors in the contribution of precipitation (average precipitation year) and the inconsistent DU from year to year on crops that use drip and sprinklers (discussed in a previous section).

Precipitation percolating below the root zone can contribute toward meeting a portion of this leaching requirement during years of average-to-high precipitation (except where plastic mulch, tunnels, and greenhouses are used). Examining the ITRC soil water balance model for annual crops, it is estimated that 2-3 inches of precipitation percolate below the root zone, contributing to the leaching requirement during average years.

To account for the variations in precipitation effectiveness, plus specific irrigation practices, the original formula of:

$$Gross\ to\ apply = \frac{ET\ requirement - ET\ supplied\ by\ rain}{\frac{Irrigation\ Efficiency}{100} \times (1 - LR)}$$

was modified for FCGMA as:

$$Gross\ to\ apply = \frac{ET\ requirement - ET\ supplied\ by\ rain}{\frac{Irrigation\ Efficiency}{100} \times (1 - adjusted\ LR)}$$

where:

$$Adjusted\,LR = \frac{EC_w}{[5 \times EC_e] - EC_w} \times Adjustment\ Factor$$

The "Adjustment Factor" perhaps more correctly should have been presented as an adjustment to the "Irrigation Efficiency", but it was applied here to the LR so that the focus would remain on salinity control. The Adjustment Factors ranged from the 1.0 for container nursery where outside soil is brought in with the containers and salinity does not build up year after year but standard leaching practices are needed to maintain a constant EC_e, to the 0.65 (reduced LR by 35%) for strawberries, where plastic mulch prevents precipitation from contributing to the LR, but the use of sprinkler and drip impact the leaching due to random distribution uniformity factors as previously discussed.

It is important to understand that most of the published information/research on threshold salinities and leaching practices used older irrigation methods and different crop varieties. Therefore, we simply do not know for sure if a leaching requirement should be 0.30 or 0.25, given a specific crop variety, irrigation water salinity, and irrigation practices. While ITRC believes that **Table A-3** provides reasonable numbers, it will be important to monitor soil salinities and crop responses to fine-tune the recommendations in the future.

Table A-3. **Recommended** Adjusted Leaching Requirement (LR) for crops in FCGMA using an overall average EC_w = 1.8 dS/m

Crop	*Threshold* EC_e, (dS/m)	Adjusted Leaching Requirement (LR), (0-1)
Avocado	**1.3**	**0.19**
Blueberries-Raspberries	**1.5**	**0.16**
Celery	**1.8**	**0.13**
Citrus	**1.7**	**0.16**
Lima Beans	**1.5**	**0.13**
Misc. Vegetables	**1.3**	**0.15**
Nursery Container	**3.5**	**0.10**
Nursery-Flowers	**3**	**0.08**
Sod	**4**	**0.05**
Strawberries	**2.0**	**0.14**
Tomatoes – Peppers	**3.5**	**0.06**

An EC_w of 1.8 dS/m results in a larger leaching requirement than using a lower value. **Figure A-2** compares three example crop net leaching requirements using 3 different EC_w values (1.0, 1.5, and 1.8 dS/m). Since the net leaching requirement is a function of growing period ET_{iw} as well as the threshold EC_e and EC_w, the magnitude of difference between the example crops varies. For avocados there is approximately 3.3 inches of difference between an EC_w of 1.0 and 1.8 dS/m. This difference is significantly less for the other two crops.

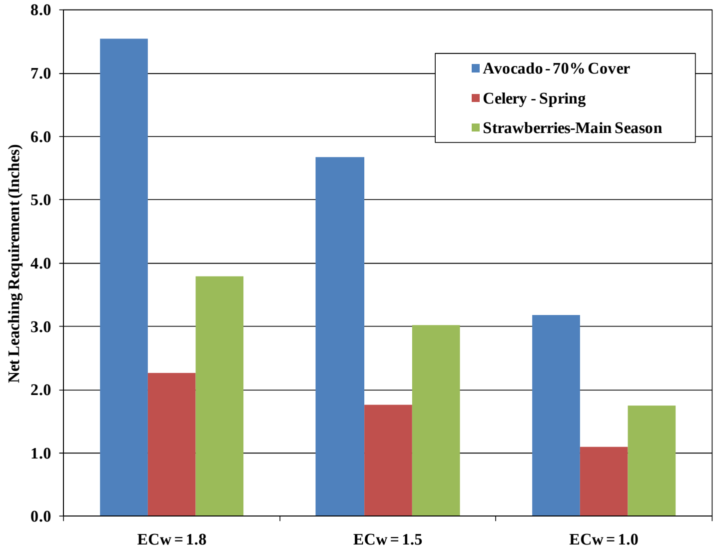

Figure A-2. Comparison of net leaching requirement (inches) for three crops with three different EC_w values for a typical year in ET_o Zone 2.

Example computation for water allowance incorporating salinity management

The amount of water needed specifically for salt removal from agricultural fields is estimated as follows:

Step 1. The "LR" is computed. For example, for main season strawberries:

Threshold EC_e = 2.0 dS/m
Salinity of irrigation water (EC_w) = 1.8 dS/m as FCGMA average

$$Adjusted\ LR = \frac{EC_w}{[5 \times EC_e] - EC_w} \times Adjustment\ Factor$$

$$= \frac{1.8}{(5 \times 2.0) - 1.8} \times 0.65$$

= 0.14

Step 2. The gross water needed for irrigation, including non-uniformity and localized deep percolation on drip – but not yet accounting for salinity control – is computed. "Localized deep percolation" refers to the inevitable deep percolation that occurs directly under an emitter if drip-irrigated plants are irrigated to have no ET stress. This deep percolation will indeed remove some of the salt that is applied, but because most of the water flow is sideways, most of the salt is not leached out but rather accumulates on the sides of the wetted pattern. This localized deep percolation is most pronounced when there are individual emitters with wetted patterns that do not overlap. It is least pronounced with microsprinklers, and with very dense emitter spacing (such as can occur sometimes with tape), both cases of which can sometimes wet large amounts of surface area and therefore result in a more uniform vertical movement of water from the soil surface, downwards.

Main season strawberry ET_{iw} (typical year Zone 2) = 22.8 inches
ET_{iw} = (ET requirement – ET supplied by rain)
Factor to account for DU and Localized Deep Percolation on drip = 0.8

$$\text{Gross required (not including salt control)} = \frac{ET_{iw}}{\text{Factor to account for DU and Localized Deep Perc. on Drip}}$$

$$= \frac{22.8\ inches}{0.8}$$

$$= 28.5\ inches$$

<u>Step 3.</u> The gross water needed for irrigation, including non-uniformity, localized deep percolation on drip, <u>and</u> accounting for salinity control, is computed.

Salinity Leaching Requirement (LR) for strawberries = 0.14

$$\text{Gross to Apply (including salt control)} = \frac{ET_{iw}}{(\text{Factor to account for DU and Localized Deep Perc. on Drip}) \times (1 - \text{LR})}$$

$$= \frac{22.8\ inches}{0.8 \times (1 - 0.14)}$$

$$= 33.1\ inches$$

<u>Step 4.</u> The amount of water needed to manage soil salinity is determined.

Value from Step 3 (gross water) – Value from Step 2 (gross for everything except salinity control)

= 33.1 *inches* – 28.5 *inches*

= 4.6 *inches* of water needed to manage soil salinity

The 4.6 inches of water should be applied as a reclamation leaching event, meaning it should be applied over a short period of time in a single or several closely spaced irrigation events. Care should be taken to prevent surface runoff. If sprinklers are used, the plastic mulch should not be on the field during this reclamation leaching event.

Appendix B
Irrigation for Frost Protection

When protecting crops against frost, growers have a variety of methods to choose from, including wind, heaters, and irrigation application. Irrigation application can be effective for protecting against frost during mild frost scenarios. The reason for this is that water releases heat while it is cooling at a rate of 1 calorie per gram of water per degree Celsius. The major benefit occurs as the water changes state from liquid to solid, at which point 79 calories per gram of water are released. The heat that is released from the water warms the plant canopy, reducing the potential for frost damage. However, the irrigation system must continue operating during the period of freezing temperatures (6 to 12 hours).

The goal of this analysis was to determine reasonable application amounts during a freeze. Citrus, avocado, strawberries, and some vegetable crops are sensitive to frost. The majority of the growers interviewed by Dr. Ben Faber from the Ventura County UC Cooperative Extension utilize drip and microspray on orchards and a combination of sprinkler and drip on row crops for irrigation. A number of survey participants stated that the sprinkler systems are often left in the row crop fields for frost protection.

An examination of weather data from FCGMA and CIMIS weather stations on an hourly basis revealed that freezing events typically lasted between 6 and 12 consecutive hours in this area. For this analysis, a freeze event duration of 10 hours was assumed. The number of freeze events by CIMIS weather stations is shown in **Table B-1**.

Table B-1. Number of days with temperatures at or below 0° Celsius (32° Fahrenheit) measured at CIMIS stations in FCGMA

	Days with minimum temperature at or below 0° C		
Year	**Oxnard CIMIS**	**Camarillo CIMIS**	**Santa Paula CIMIS**
2000		1	
2001	1	3	
2002	5	3	
2003	1	3	
2004	3	2	
2005	2	2	
2006	1	2	5
2007	1	4	13
2008	2	1	4
2009	1	0	7
Average	**1.9**	**2.1**	**7.3**

Actual application rates will vary depending on the irrigation system design. It is typically recommended, with overhead sprinklers, that an application rate of 0.12-0.14 inches per hour be applied for appropriate frost protection. Assuming this is similar for row crop frost protection, approximately 1.2-1.4 inches of water would be needed per 10-hour frost event using sprinklers. However, since there is a typically not sufficient water supply to apply water over an entire field or farm at the same time, applications would likely be rotated throughout the protection area. A single portion of a field may only receive irrigation by sprinklers for one-third or less of the 10-hour frost event.

The application rates are lower for drip and microspray used in avocado and citrus orchards. The exercise on the following page examines different application rates and tree spacings based on answers provided in the grower survey. According to the survey, the grower would likely apply between 0.2 and 0.9 inches per frost event, assuming the drip/microspray systems were running for the entire 10-hour frost event. Since the tree spacing was not provided for the maximum application per tree scenario, the 0.9 inches per event may be an overestimate. In all likelihood, the **irrigation application for frost protection using sprinkler, drip, or microspray would likely be below 0.5 inches per event**.

Note: In addition to the continuous frost protection just described, water applications may be used prior to a frost event to wet the ground surface to a depth of 1 foot, to provide a heat buffer. Depending on the soil moisture and soil type it could take anywhere from 0.5 to 1.5 inches of applied water to wet the top 1 foot of the soil profile.

Frost Protection using Irrigation in Orchards

Assumptions

Growers must anticipate a freeze using a forecast
If the daily minimum temperature is below 1° C, frost protection may be implemented

Flow rates (drip and microspray)

From UCCE grower surveys – flow rate per tree varied

Citrus

Minimum	6	gph/tree
Maximum	18	gph/tree

Avocado

Minimum	18	gph/tree
Maximum	32	gph/tree

Area

Citrus	140	trees per acre (stated)
	311	ft^2 per tree (16x20ft spacing) estimated

Mature Avocado

40’ x 40’ tree spacing

1600 ft^2 per tree

Assumed hours of operation for frost protection

10 hours

Estimated inches of frost protection water per event

inches = (GPM*96.3*hours per event))/(Area)

Citrus

Minimum	**0.31**	inches/event	
Maximum	**0.93**	inches/event	(unusual)

Mature Avocado

Minimum	**0.18**	inches/event
Maximum	**0.32**	inches/event

Less than 0.5 inches per event is reasonable

Appendix C
ET_o Weather Station Quality Control and Siting

The following document on reference evapotranspiration (ET_{ref}) weather station siting and quality control is from the American Society of Civil Engineers (ASCE) Technical Committee on Evapotranspiration in Irrigation and Hydrology of the Environmental and Water Resources Institute (EWRI).

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To: Managers of Agricultural Weather Networks and Associated Weather Data Systems
From: Technical Committee on Evapotranspiration in Irrigation and Hydrology of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE)
Date: 1 April, 2009

Subject: Quality Assessment and Control of Automated Weather Data

This memorandum discusses the following topics:

- The need for high quality weather data for calculating reference evapotranspiration (ET_{ref})
- Encouragement to your network to test the visually based QA/QC processes proposed by ASCE-EWRI (2005) for adoption by your QA/QC system
- Encouragement to your network to provide public access to final sets of QA/QC'd weather data to leverage QA/QC efforts and to promote economic efficiency
- To call your attention to the ASCE-EWRI (2005) standardization for the calculation of reference evapotranspiration

In 2005 the American Society of Civil Engineers – Environmental and Water Resources Institute (ASCE-EWRI) published "*The ASCE Standardized Reference Evapotranspiration Equation*[1]" that describes standardized calculation procedures for determining reference evapotranspiration (ET_{ref}). The basis of the standardized ET_{ref} equation and definition is the ASCE Penman-Monteith (ASCE-PM) method. Standardized calculations were recommended for vapor pressure and net radiation determination and for wind speed adjustment. A major impetus for the ASCE report was to improve consistency and quality of calculated ET_{ref} and to provide guidelines on assessing weather data integrity. Reference ET and associated estimates of crop ET are coming under increasing scrutiny in the American courts during water rights cases. The integrity of weather data that form the basis of ET_{ref} calculations is increasingly required to "pass muster."

[1] *The ASCE Standardized Reference Evapotranspiration Equation.* Allen, R.G., I.A. Walter, R.L. Elliott, T.A. Howell, D. Itenfisu, M.E. Jensen, and R.L. Snyder.(eds), Am. Soc. Civ. Engrs., 216 p. ISBN 078440805X. Available at: http://www.asce.org/bookstore/book.cfm?book=5430

State employees and private consultants routinely invest considerable time and expense in identifying and correcting errors and bias in weather data sets. Too often, each side of a water case applies duplicative efforts to QA/QC the same data sets. These efforts are typically repeated by other users of data, including hydrologists, planners and ground-water modelers, constituting large expenditures of financial resources. Application approaches and quality of final data sets vary widely.

ASCE-EWRI (2005) recommended procedures for visual assessment of solar radiation, humidity and wind speed data (appendices D and E). The procedures are straightforward and are intended to streamline and speed QA/QC processes to insure and produce high quality and representative weather data for use in calculating reference ET[2]. *The ASCE-EWRI Committee on Evapotranspiration in Irrigation and Hydrology (ASCE-EWRI-ET) encourages your network to test these QA/QC processes and to consider them to complement other QA/QC means employed by your automated weather data management system.*

Many automated weather station network systems (AWSN) measure the primary variables affecting ET: solar radiation, air temperature, wind speed and humidity, and therefore provide relatively complete data for calculating reference ET. Because the quality and accuracy of the ET_{ref} calculation is dependent on the quality of the weather data, it is important that the weather data are subjected to a QA/QC process that goes beyond checking of over- or underruns of data extremes relative to established thresholds. It is important that significant over or under measurement or calibration of sensors be rectified. Many AWSN employ QC procedures that compare incoming data against relevant physical extremes (for example, insuring that relative humidity ≤ 100%); some use statistical techniques to identify extreme or anomalous values; others compare data among neighboring stations. Some networks flag questionable data while other networks replace questionable data with estimated values. Often, however, these QC procedures are rather broad or coarse, so that products of the QC procedures do not necessarily exhibit data having low measurement bias. This is a primary concern of the *ASCE-EWRI-ET* Committee.

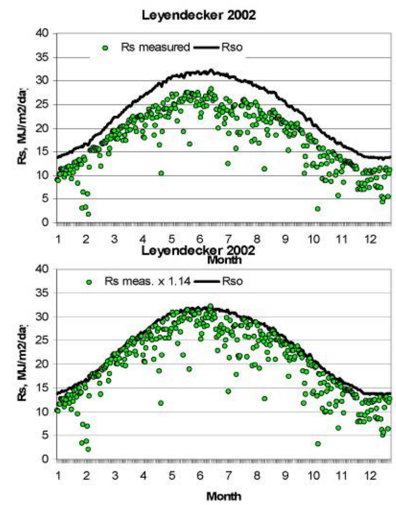
Our sister professional society, the *ASABE*, recently adopted Engineering Practice 505: "*Measurement and Reporting Practices for Automatic Agricultural Weather Stations*" (ASAE, 2004). This standard provides specifications for sensor accuracy, resolution, placement and monitoring, as well as intervals and procedures for sensor maintenance and calibration. The *ASCE-EWRI-ET* Committee supports EP 505 and encourages its use in designing, establishing, locating, and operating AWS networks. The visual data screening and calibration procedures of ASCE (2005) complement EP 505 by providing operational processes for identifying and correcting biased weather data. These procedures are described in Appendix D of ASCE (2005) and are briefly noted in the following paragraphs.

Visual screening of weather data is supported and recommended by *ASCE-EWRI-ET* because it can readily involve the human brain's processing and determination of 'reasonableness' of data in the context of impacts of environmental factors and with implicit comparison to physically known ranges and constraints. In addition, plotted data are conducive to rapid scanning and input by the human.

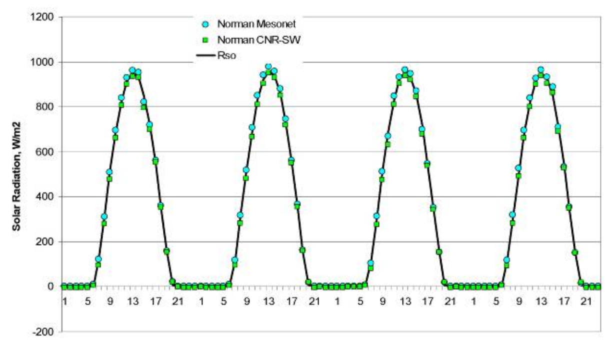
[2] An early journal paper summarizing the primary processes in the ASCE-EWRI (2005) visual QA/QC procedure is Allen, R.G. 1996. Assessing Integrity of Weather Data for use in Reference Evapotranspiration Estimation. *J. Irrigation and Drainage Engrg.*, ASCE. Vol 122 (2):97-106. A recent summary of the ASCE-EWRI method, including current calibration coefficients for clear sky solar radiation is Allen, R.G. 2008. Quality Assessment of Weather Data and Micrometeological Flux - Impacts on Evapotranspiration Calculation. *J. Agricult. Meteorology* 64(4):191-204.

Solar radiation data, R_s, can be visually screened by plotting measurements against estimates of R_s for clear sky conditions (R_{so}) for hourly or daily timesteps. R_{so} can be readily estimated from Appendix D of ASCE-EWRI (2005) using calculation procedures that include the influence of sun angle, atmospheric thickness (represented by atmospheric pressure), and water content of the atmosphere (estimated from near surface humidity data). When evaluating daily data sets, measured R_s and computed R_{so} can be plotted against the day of the year for one month or one year at a time. Hourly R_s and computed R_{so} data can be plotted against time of day for rapid scanning and assessment of R_s.[3]

A rapid visual review of the R_s -- R_{so} plots provides indication of whether measured R_s "bumps" up against the clear sky envelope of R_{so} on what appear to be cloud-free days for daily data or during cloud-free hours for hourly data. R_s will fall below the R_{so} curve on cloudy or hazy days. If these "upper" values of measured R_s lie routinely above or below the computed R_{so} curve by more than 3 to 5%, then the operator is encouraged to scrutinize the data more closely, to consider impacts of maintenance and calibration of the R_s sensor and datalogging system on the R_s data. Improper calibration, incorrect coefficient, leveling errors, the presence of contaminants on the sensor (e.g., dust, salt, or bird droppings), and electrical problems can cause R_s to deviate from R_{so} on clear days.

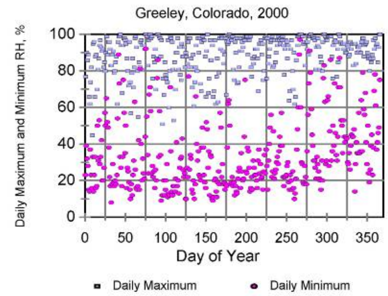


Values of R_s that are consistently above or below R_{so} on clear days can often be adjusted by dividing R_s by the average value of R_s/R_{so} for clear periods. Often, a consistent multiplier can be applied over extended periods when the cause of low or high R_s readings stems from miscalibration of the sensor. An example of visual screening of daily R_s data over one year and results of applying a 14% upward correction to the data is shown in the figure above for Leyendecker, NM. The figure to the right shows hourly solar radiation from two collocated sensors at a Norman, OK Mesonet plotted vs. the R_{so} curve on clear days, where one sensor followed the R_{so} curve relatively closely and the second sensor (CNR) averaged a few percent above the curve. Plots of R_s against the R_{so} curve also provides means to assess the accuracy of the datalogger clock, especially with older data sets.

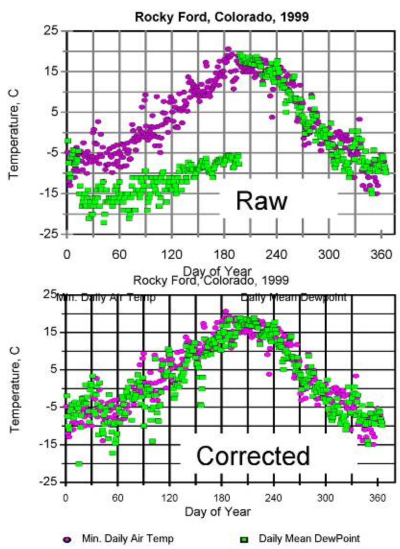


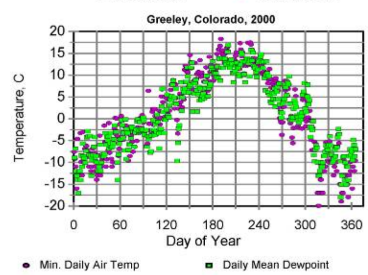
[3]The visual comparisons are often the only available means to assess historical data. For current data collection, a second, dual sensor is encouraged in the case of solar radiation, wind speed, RH and temperature, either mounted permanently or only periodically, to provide redundancy in measurements or to assist in external calibration.

Humidity and air temperature data can be screened to identify questionable or erroneous data. The screening process requires that the user has a sense of reasonable vs unreasonable values. For example, mid-afternoon relative humidity (RH) values chronically lower than 5 to 10% in arid regions and chronically lower than 30% in subhumid regions are uncommon and may indicate problems with the sensor[4]. Similarly, RH values in excess of 100% do not occur in the natural environment and generally indicate that the sensor is out of calibration. The accuracy of most modern-day electronic RH sensors is within +/- 5% RH (ASABE EP505); thus, recorded RH values in excess of 105% suggest the need for correction. Correction of RH data can generally be done using proportional adjustment of all data based on a multiplier and/or offset. The use and magnitude of the multiplier or offset can be based on visual analysis of daily maximum and minimum RH over a period of months. They may also be determined by co-comparison of data among weather stations in the same subregion.



Humidity data can be visually assessed in the form of RH or in the form of a computed dew-point temperature (T_{dew}), or both. T_{dew}, and vapor pressure, e_a, are typically calculated from RH and air temperature, T. Error and bias in RH and T will affect T_{dew} and e_a. Values for daily average and early morning T_{dew} can be compared with daily minimum air temperature (T_{min}). In humid regions, the T_{dew} measurement will typically approach T_{min} most days. Exceptions occur on days that feature a change in air mass (e.g., frontal passage). T_{dew} may approach T_{min} in arid and semiarid environments if nighttime winds are light and measurements are made over a surface exhibiting behavior similar to the reference definition (i.e., sufficient evaporation to cause evaporative cooling). It is not uncommon in arid and semiarid regions to have T_{dew} 2 to 5 ^oC lower than T_{min} under reference conditions, but well below T_{min} if the measurement site is subject to local dryness. If daily average T_{dew} regularly exceeds T_{min}, then the humidity sensor may be out of calibration. Such data should be examined closely and possibly adjusted prior to use. The example plots of daily maximum and minimum



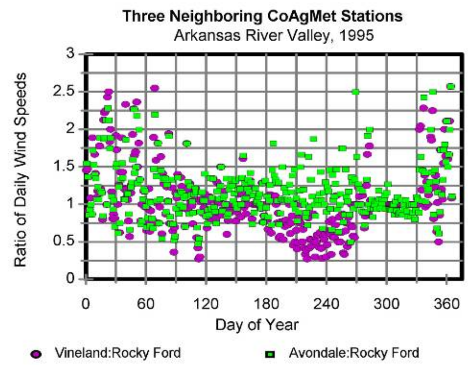


[4] The QA/QC recommendations given in ASCE-EWRI apply primarily to agricultural weather stations and other weather stations whose data are used to calculate reference evapotranspiration that is characteristic of well-watered environments. The ASCE-EWRI ET Committee recognizes that some weather station networks focus on collection of ambient weather data in natural settings. In those situations, air temperature levels may exceed and humidity levels may be lower than those expected in conditioned agricultural settings.

RH and T_{min} and T_{dew} for Greeley, Colorado, above right, show expected ranges, extremes and relationships.

In the case of the humidity data for Rocky Ford, Colorado, above left, a faulty calibration coefficient on RH caused extreme undermeasurement of RH and therefore undercalculation of e_a and T_{dew}. Data were corrected by multiplying the RH measurements over the first half of 1999 by a constant correction factor. The result of the correction on T_{dew} is shown in the bottom figure. In cases where humidity data irreparable, T_{dew} can be estimated from T_{min} using procedures suggested in Appendices D and E of ASCE-EWRI (2005).

Some precautions with scanning RH data are the tendency for some sensors to exhibit a break in calibration slope when RH > 90% (B. Nef, Campbell Sci., pers. commun., 2008).



Assessment of wind speed data generally requires comparisons between wind speed measured at two or more locations. However, a gust factor (ratio of instantaneous maximum to mean daily wind speed can serve as a useful index. Gust factors can increase as contamination increases the friction in bearings. Wind speed at nearby locations are generally related and ratios of wind speed from the two locations is expected to remain relatively constant over time. Plotting ratios over time can identify problems with anemometers or environment. Sudden and consistent changes in ratios often indicate a failed anemometer; gradual change in ratios can indicate growing contamination in bearings or effects of tall vegetation in the immediate vicinity of one of the stations (such as occurred at Vineland, Colorado in the figure above, where the 2 m anemometer was located next to field corn). When possible, the *ASCE-EWRI-ET* Committee recommends that anemometers be located at 3 m above the ground surface to reduce the impacts of surrounding vegetation on reducing wind speed. Wind speed data at the 3 m height can be adjusted to the standard 2 m height for use in standardized ET_{ref} equations using accepted adjustment procedures.

Data flagging and Reporting of Corrected Data. The *ASCE-EWRI-ET* Committee suggests that two sets of weather data (the original (or "raw") and corrected) be housed and made available to users. The nonaltered original data are valuable for assessing the nature and magnitudes of data correction. Some type of "flagging" procedure should be employed to clearly identify data that have been corrected or estimated. In addition, 'meta-data' describing the nature of corrections should be contained within the corrected data archives or be made available as readily assessable reports.

We encourage each network to produce the flagged and corrected weather data sets (as a second data set) to promote economic efficiency, where the data QA/QC and correction is done one time and by a knowledgeable, experienced and trained staff person. This consolidation and centralization of QA/QC will reduce the large number of duplicative corrections by individual data users as is often the case. The *ASCE-EWRI-ET* Committee recognizes that implementation of QA/QC processes may require additional network program funding. However, in the case of State resources, this can constitute an efficient expenditure of public monies, due to the reduction of State resources invested in multiplicative, repetitive data QA/QC by a variety data users (for studies often funded by the State), where the QA/QC is often done by users having insufficient background.

Station Siting. For purposes of calculating ET_{ref}, meteorological data should be measured over and downwind of vegetation that approximates the (well-watered) reference surface. This is important because the standardized ET_{ref} equation was developed for use with meteorological data collected primarily over and downwind of dense, fully transpiring grass or similar vegetation exhibiting behavior similar to the defined reference surface condition. Feedback between and conditioning of the boundary layer exists above an evaporating surface, so that evaporation at the surface impacts temperature and humidity of the air layer above. Studies in southern Idaho by Burman et al. (1975)[5] illustrated how the lower level of the atmosphere changes when going from desert to a patchwork of irrigated and non-irrigated fields. Humidity, temperature and wind speed variables change when entering an irrigated field surrounded by dry or poorly irrigated fields. It is important, when making calculations of ET_{sz}, that weather measurements are accurate and that the weather measurements reflect an environment that conditions the boundary layer as defined by the reference surface.

Ideally, weather stations used to calculate reference ET for agricultural water management and water rights issues should be centered within large, nearly level expanses of uniform vegetation that are supplied with sufficient water through precipitation and/or irrigation to support ET near maximum levels. The preferred vegetation for the site is clipped grass. However, alfalfa or a grass-legume pasture maintained at a height of less than 0.5 m can serve as an effective vegetation. Meteorological measurements made over other short, green, actively transpiring crops will approach reference measurements, provided canopy cover exceeds approximately 70%. A station may be located outside the periphery of a vegetated field provided the station is downwind of the conditioning field during important daytime hours and that vegetation is shorter than about 0.5 m so as to not impact the wind measurement. In an ideal setting, the well-watered vegetation extends at least 100 m in all directions from the weather station. However, it is recognized that frequently such a weather station site is not available, and that often some nonvegetated areas or roadways will be present near the station.

Failure of a weather station site to meet the definition of a reference condition described above does not preclude use of the data for estimation of ET_{ref}. However, data from such a station should be examined carefully, and may, in some cases, require adjustment to humidity or temperature data to make the data more representative of reference conditions (ASCE-EWRI 2005).

The ASCE Standardized Penman-Monteith Reference Evapotranspiration Equation. During the past decade, for convenience and reproducibility, the reference surface has been expressed as a hypothetical surface having specific characteristics (Smith et al., 1991; 1996[6]; ASCE, 1996[7]; FAO-56,

[5] Burman, R.D., Wright, J.L., and Jensen, M.E. 1975. "Changes in climate and estimated evaporation across a large irrigated area in Idaho." *Trans. ASAE* 18(6):1089-1093.

[6] Smith, M., Allen, R., Monteith, J., Perrier, A., Pereira, L. and Segeren, A. 1991. Report of the expert consultation on procedures for revision of FAO guidelines for crop water requirements. UN-FAO, Rome, Italy, 54 p.
Smith, M., Allen, R.G., and Pereira, L. (1996). "Revised FAO methodology for crop water requiremens." pp. 116-123. In: C.R. Camp, E.J. Sadler, and R.E. Yoder (eds). *Evapotranspiration and Irrigation Scheduling*. Proc., Int'l. Conf., San Antonio, TX, Nov., 1184 pp.

[7] Allen, R.G., Pruitt, W.O., Businger, J.A., Fritschen, L.J., Jensen, M.E., and Quinn, F.H. (1996). Evaporation and Transpiration. Chap. 4, pp. 125-252 In: Wootton et al. (Task Com.), *ASCE Handbook of Hydrology*, 2nd ed" Am. Soc. Civ. Engrs., New York, NY., 784 pp.

1998[8]; ASCE-EWRI, 2005[1]). ASCE-EWRI (2005) defined the standardized reference evapotranspiration as the ET rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation. ASCE-EWRI (2005) established two standardized surfaces to serve the needs of the agricultural and landscape communities and to provide for continuity with past reference ET usage. The ASCE Penman-Monteith (ASCE-PM) equation of ASCE Manual 70[9] was used to represent the standardized surfaces of clipped, cool-season grass (short reference) and full-cover alfalfa (tall reference).

The standardization recommended by ASCE-EWRI (2005) follows commonly used procedures for calculating vapor pressure terms, net radiation, and soil heat flux. The standardization applies the ASCE-PM equation for both reference surfaces using a single equation having fixed constants and standardized computational procedures. The computational procedures were intended to be relatively simple to apply, readily understandable, supported by existing and historical data, technically defensible, and accepted by science and engineering communities. The standardized equation has been investigated over a wide range of locations and climates across the United States. The *ASCE-EWRI-ET* Committee encourages the use of the standardized ET_{ref} equation and procedure in AWS network archives when possible to represent reference ET for the establishment of reproducible and universally transferable ET estimates, climatic description, and derived crop and landscape coefficients.

The ASCE standardized PM method is intended to complement, rather than to replace, other methods currently employed within AWSN for estimating ET_{ref}. The *ASCE-EWRI-ET* Committee recommends application of the standardized reference ET equation and calculation procedures to bring commonality to the calculation of reference ET among AWSN and to provide a standardized basis for determining or transferring crop coefficients for agricultural and landscape use.

The ASCE-EWRI (2005) report[1] includes all necessary calculation equations and information to apply the standardized ASCE Penman-Monteith equation for the grass and alfalfa references. The *ASCE-EWRI-ET* Committee is comprised of 30 professionals involved in ET application and research and represents more than 10 states spanning the US continent. The committee welcomes your comments, feedback and suggestions[10].

This letter is posted as a pdf file that can be downloaded from
www.kimberly.uidaho.edu/water/asceewri/index.html
Pdf copies of the main text of the ASCE-EWRI (2005) report and Appendices D and E describing visual QA/QC of weather data are also available from that site.

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[8] Allen, R.G., Pereira, L.S., Raes, D. and Smith M., (1998). *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*. Irrig. and Drain. Paper No. 56, United Nations Food and Agriculture Organization,. Rome, Italy, 300 pp.

[9] Jensen, M.E., Burman, R.D. and Allen, R.G. (1990). *Evapotranspiration and Irrigation Water Requirements.* ASCE Manuals and Reports on Engineering Practice, No 70, 350 pp.

[10] Current officers of the ASCE-EWRI Technical Committee on Evapotranspiration in Irrigation and Hydrology are: Michael Dukes, Univ. of Florida, Chair; Suat Irmak, Univ. Nebraska, Vice-Chair; Thomas Ley, Colorado Division of Water Resources, Secretary. Mail contact: Dr. Michael Dukes, Agricultural and Biological Engineering Dept.; 107 Frazier Rogers Hall; PO Box 110570; Gainesville, FL 32611; email: mddukes@ufl.edu; tel: (352) 392-1864 x107; fax: (352) 392-4092

Appendix D
Effective Precipitation

Effective precipitation is generally a complicated value to estimate precisely, especially when trying to generalize the value based on monthly or annual precipitation values. Effective precipitation can vary significantly from one year to another even with similar annual precipitation amounts because it depends on when the precipitation occurred and the magnitude of the precipitation events.

The FAO 56 dual crop coefficient soil water balance model that was utilized in Task 2.1 has the capability to partition the amount of evaporation and transpiration from precipitation and irrigation water. The 2009 FCGMA reported effective precipitation estimated using Camarillo Airport weather data is shown in **Table D-1** (from **Figure 2** in the main report). The 2001-2009 modeled effective precipitation by crop is shown in **Table D-2** based on the Camarillo CIMIS weather data.

Table D-1. FCGMA reported total effective precipitation reported by crop category using Camarillo Airport weather data compared to ITRC modeled effective precipitation for 2009

Crop Category	2009 FCGMA Reported Effective Precipitation Camarillo Airport (inches)	2009 ITRC Modeled Eff. P Camarillo CIMIS (inches)
Avocado, Lemons, Oranges	8.1	7.3
Strawberries, Sod, Celery	3.8	2.6
Vegetables	4.6	4.9

The summer crops in **Table D-2** have very little effective precipitation because there is very little if any rainfall during the late spring, summer, and early fall. Because of the crop rotations common in Ventura County it was assumed that there is very little if any precipitation carryover from the winter into the summer growing season. A winter crop would likely have been planted that would have utilized that precipitation. For greenhouses and tunnels it was assumed that there would be no effective precipitation since that water could not reach the soil. Because strawberries utilize plastic mulch, it was assumed that only a small portion of the precipitation would be effective (maximum of 25%).

Table D-2. Modeled effective precipitation in inches and as a percent of total precipitation for the Camarillo CIMIS weather station by crop

Camarillo CIMIS Weather	2001	2002	2003	2004	2005	2006	2007	2008	2009
Annual Precipitation (Inches)	16.8	5.1	7.6	14.9	25.9	14.3	5.3	10.9	10.5

	Growing Season Effective Precipitation (Inches)								
Crop	2001	2002	2003	2004	2005	2006	2007	2008	2009
Avocado - 20% Cover	10.1	3.8	6.7	6.3	10.0	10.3	4.3	6.5	6.3
Avocado - 50% Cover	10.5	4.2	5.5	7.8	10.2	10.4	4.4	6.7	6.8
Avocado - 70% Cover	11.8	3.3	5.7	8.7	10.1	10.1	4.6	7.4	7.3
Blueberries - 50% Cover	8.5	3.7	5.8	5.9	8.5	9.2	3.9	5.5	5.0
Blueberries - 70% Cover	8.7	3.8	5.3	6.5	8.0	8.5	3.4	5.5	4.2
Celery - Fall	2.7	1.9	1.2	3.2	1.7	1.5	0.6	1.9	1.9
Celery - Spring	3.0	0.6	2.6	2.4	4.5	5.5	1.7	2.5	1.9
Citrus - 20% Cover	10.0	4.0	6.3	7.0	10.0	9.9	4.4	6.6	6.0
Citrus - 50% Cover	10.4	4.1	6.4	6.7	10.2	9.6	4.4	7.1	6.7
Citrus - 70% Cover	10.7	4.1	5.5	8.7	9.7	10.0	4.7	6.9	7.2
Lima Beans	0.0	0.1	0.6	0.0	0.0	1.2	0.0	0.0	0.1
Misc. Veg Greenhouse - Fall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Misc. Veg Greenhouse - Spr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Misc. Veg Greenhouse - Summer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Misc. Veg Single Crop - Fall	3.8	0.8	1.4	3.0	2.0	1.2	0.5	1.6	2.4
Misc. Veg Single Crop - Spr	3.4	0.9	3.0	1.8	4.1	5.0	2.6	2.5	2.4
Misc. Veg Single Crop - Summer	0.3	0.1	1.3	0.0	0.8	1.1	0.3	0.0	0.1
Nursery Container	6.3	2.7	4.4	5.2	6.5	7.3	3.6	4.8	4.2
Nursery - Flowers	7.4	2.9	4.4	5.2	6.8	7.0	3.3	4.7	3.7
Raspberries - Tunnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sod	6.8	3.2	4.9	6.2	7.3	8.2	3.7	4.7	4.8
Strawberries - Main Season	3.9	1.3	1.9	3.7	4.1	3.6	1.3	2.7	2.6
Strawberries - Summer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tomatoes - Peppers (Summer)	0.4	0.1	0.3	1.9	0.9	0.8	0.4	0.5	0.8

	Growing Season Effective Precipitation (%)								
Crop	2001	2002	2003	2004	2005	2006	2007	2008	2009
Avocado - 20% Cover	60	75	88	43	39	72	82	59	60
Avocado - 50% Cover	62	82	73	52	40	73	84	61	65
Avocado - 70% Cover	70	64	76	58	39	71	87	67	69
Blueberries - 50% Cover	51	73	76	40	33	64	74	50	47
Blueberries - 70% Cover	52	74	70	44	31	60	64	50	40
Celery - Fall	16	37	16	21	6	11	11	17	18
Celery - Spring	18	12	35	16	17	38	32	23	18
Citrus - 20% Cover	60	78	83	47	39	69	83	60	58
Citrus - 50% Cover	62	80	85	45	39	67	84	65	64
Citrus - 70% Cover	64	81	73	58	38	70	90	63	68
Lima Beans	0	2	7	0	0	8	0	0	1
Misc. Veg Greenhouse - Fall	0	0	0	0	0	0	0	0	0
Misc. Veg Greenhouse - Spr	0	0	0	0	0	0	0	0	0
Misc. Veg Greenhouse - Summer	0	0	0	0	0	0	0	0	0
Misc. Veg Single Crop - Fall	23	16	18	20	8	9	10	15	23
Misc. Veg Single Crop - Spr	20	17	39	12	16	35	49	23	22
Misc. Veg Single Crop - Summer	2	2	18	0	3	8	6	0	1
Nursery Container	38	53	57	35	25	51	68	44	40
Nursery - Flowers	44	57	58	35	26	49	62	43	36
Raspberries - Tunnel	0	0	0	0	0	0	0	0	0
Sod	40	62	64	41	28	57	71	43	46
Strawberries - Main Season	23	25	25	25	16	25	24	25	25
Strawberries - Summer	0	0	0	0	0	0	1	0	0
Tomatoes - Peppers (Summer)	2	2	3	12	3	5	8	4	8

Appendix E
Task 2.1 Updated Growing Period ET_{iw} Values

Based on comments from the FCGMA Board of Directors and active participants, modifications were made to the growing period ET_{iw} tables reported in the Task 2.1 final report. Major concerns addressed included adding additional canopy coverage categories for avocados and blueberries to incorporate young or recently thinned orchards. The ITRC soil water balance model discussed in the final Task 2.1 report was run with these additional categories. The effective precipitation values in **Appendix D** coincide with these growing period ET_{iw} values. For the year type, modeled data for 2004 was utilized as a representative typical year, 2005 as a representative wet year, and 2007 as a representative dry year. The ET_{iw} values in **Table E-1** were normalized by average ET_o in each region to account for annual ET_o variability. For example, the representative wet year could have a higher ET_o than a typical or dry year, which would cause the growing period ET_{iw} to be larger where it should be lower. Normalizing by average ET_o for each region (shown in the main report) accounts for this variability.

Table E-1. Growing period ET_{iw} values on an annual basis for typical, dry, and wet years.

	Oxnard (Z1)			Camarillo (Z2)			Santa Paula (Z3)		
	Typical	Dry	Wet	Typical	Dry	Wet	Typical	Dry	Wet
Crop	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)	ET_{iw} (inches)
Avocado - 20% Cover	15	16	13	16	18	15	18	20	17
Avocado - 50% Cover	21	23	19	24	26	22	26	29	24
Avocado - 70% Cover	28	32	27	32	36	31	35	39	34
Blueberries - 50% Cover	21	22	21	24	25	24	26	27	26
Blueberries - 70% Cover	29	31	28	33	35	32	36	38	35
Celery - Fall	8	9	7	9	10	8	10	11	9
Celery - Spring	14	15	13	16	17	14	17	18	16
Citrus - 20% Cover	15	17	14	17	19	16	19	21	18
Citrus - 50% Cover	21	22	19	23	24	22	25	27	24
Citrus - 70% Cover	28	29	26	31	32	29	34	35	32
Lima Beans	9	9	9	10	10	10	11	11	11
Misc. Veg Greenhouse - Fall	7	7	7	8	8	8	9	9	9
Misc. Veg Greenhouse - Spr	11	11	11	12	12	12	13	13	13
Misc. Veg Greenhouse - Summer	10	10	10	11	11	11	12	12	12
Misc. Veg Single Crop - Fall	7	8	6	8	9	7	9	10	8
Misc. Veg Single Crop - Spr	13	14	12	14	15	13	16	17	15
Misc. Veg Single Crop - Summer	16	17	16	18	19	18	20	21	19
Nursery Container	38	41	37	43	46	41	47	50	45
Nursery - Flowers	40	41	38	45	46	43	49	51	47
Raspberries - Tunnel	36	36	36	41	41	41	45	45	45
Sod	37	39	36	41	44	40	45	48	44
Strawberries - Main Season	20	20	20	23	23	22	25	25	24
Strawberries - Summer	10	10	10	12	12	12	13	13	13
Tomatoes - Peppers	19	19	18	21	21	20	23	23	22