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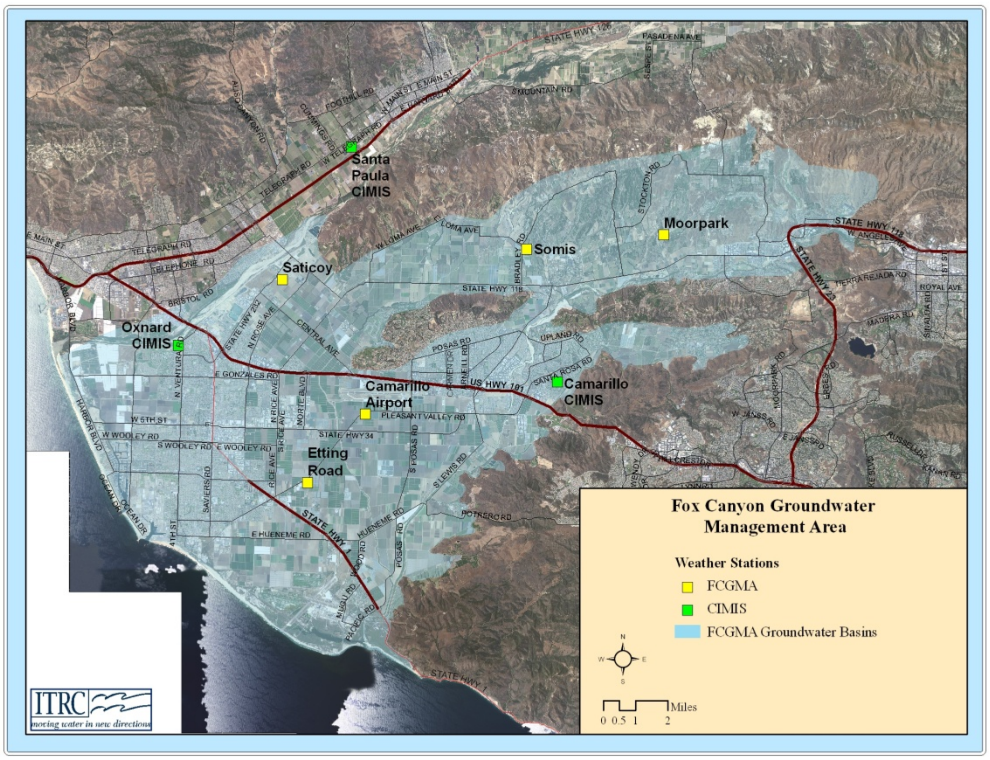
Fox Canyon Groundwater Management Agency
Analysis and Annual Plant Required Water Values for Crops within the FCGMA

Task 2.1



Fox Canyon Groundwater Management Agency

September 8, 2010

IRRIGATION TRAINING AND RESEARCH CENTER

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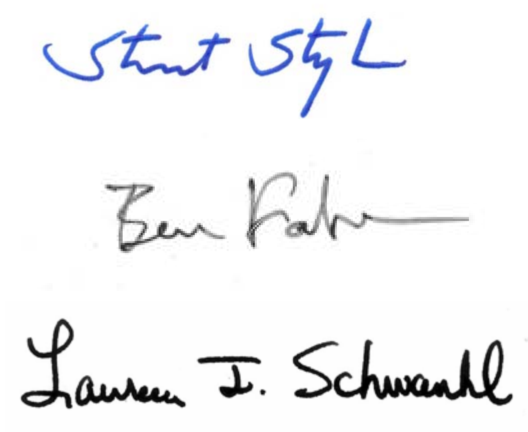

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SUMMARY OF FINDINGS

This report examines the water required to meet crop evapotranspiration for major crops in the Fox Canyon Groundwater Management Area (FCGMA). **The crop evapotranspiration values presented in this report do not include water requirements for farm and irrigation management such as frost protection, distribution uniformity, salinity leaching, etc. Those requirements will be examined in Task 2.2.** The main findings of this portion of the study (Task 2.1) are:

1) For weather stations used for computing grass reference evapotranspiration in FCGMA:
    a. The quality of weather data collected by the five FCGMA weather stations prior to 2007 (prior to the installation of the new equipment) can be considered poor to very poor. Since 2007 the quality of data has improved significantly.
    b. The site conditions at the five FCGMA stations do not adhere to the recommended standard site conditions for computing grass reference evapotranspiration (ET_o).
    c. The combination of (a) and (b) have resulted in very little confidence in historical weather and ET_o data from the five FCGMA stations prior to the installation of new weather station equipment in 2006. While the confidence in data quality has improved with the new equipment (2007 to present) there continue to be issues with weather station site conditions at the FCGMA weather stations.
    d. There are three California Department of Water Resources CIMIS stations in or near FCGMA. While ITRC found some errors in solar radiation measurements at the Camarillo and Santa Paula CIMIS stations, overall the data quality and site conditions are better at these stations.
    e. Precipitation data seems to be good at all of the stations with the exception of the Oxnard CIMIS station data in 2002. In recent years, rainfall has varied from very wet in 2005, dry in 2007 and 2009, and in 2006 and 2008 precipitation amounts were near the 10-year average.
2) Examining the ET_o data throughout the region, ITRC recommends FCGMA use only three ET_o zones. These zones are loosely based on the DWR ET_o zone map. This 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 in case of a failure at one of the stations.
    a. Zone 1: Coastal – Use Oxnard CIMIS as primary and Etting Road as secondary
    b. Zone 2: Mid – Use Camarillo CIMIS as primary and Camarillo Airport as secondary
    c. Zone 3: Inland – Use Santa Paula CIMIS as the primary and Moorpark as secondary
    d. A weather data quality control program that would involve comparing solar radiation measurements to clear sky potential solar radiation computations should be maintained for both FCGMA stations and CIMIS stations on a monthly basis

utilizing protocols detailed in FAO-56* to ensure proper sensor calibration. If errors are found at CIMIS stations, DWR should be contacted and the data corrected as described in FAO-56. Errors found at FCGMA stations should be reported by the consultant at least on a monthly basis.

3) Crop evapotranspiration modeling:

   a. Because of the relatively low confidence in historical FCGMA weather station ET_o data, the corrected data from the Camarillo CIMIS station was used for crop evapotranspiration modeling. The Oxnard and Santa Paula CIMIS stations were installed more recently, so long-term modeling was not possible.

   b. The FCGMA "Irrigation Efficiency Extraction Allocation" currently relies on annual water use estimates for five crop categories. ITRC recommends 21 crop 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.

   c. Utilizing 21 crop categories increases the resolution of ET_c estimates; however, it does not cover every cropping scenario. Depending on the actual planting and harvest date a crop may use more or less water than estimated in this report. Crop coefficients generated from the crop evapotranspiration modeling were used to compute crop evapotranspiration from other regions in FCGMA for 2009 using ET_o data from the Oxnard and Santa Paula CIMIS stations.

   d. Effective precipitation was computed on a monthly basis. There is significant variability based on crop growth stage and the amount and duration of the precipitation events. This will be investigated further as part of Task 2.2.

4) Comparison of FCGMA Allowed Water estimates and modeled crop growing period evapotranspiration.

   a. Because of the numerous cropping scenarios the comparison should be viewed with caution. Modeled crop growing period evapotranspiration values (counting for effective precipitation – ET_{gpiw}) using the Oxnard, Camarillo, and Santa Paula CIMIS stations were compared to FCGMA Allowed Water at nearby stations in 2009.

   b. Theoretically, the FCGMA Allowed Water accounts for water required for crop management practices such as salinity leaching, frost protection, and Santa Ana wind management. These values will be investigated as part of Task 2.2.

   c. Crops that had similar ET_{gpiw} and Allowed Water values:
      - Mature Avocados and Citrus
      - Sod
      - Blueberries and Raspberries

   d. Crops that had lower ET_{gpiw} compared to Allowed Water values:
      - Vegetables and Strawberries

* Refer to *Crop Evapotranspiration; Guidelines for Computing Crop Water Requirements – FAO 56* (Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations, Rome. ISBN 92-5-104219-5. 300 p.) Online at: http://www.fao.org/docrep/x0490e/x0490e00.htm.

- Immature Citrus

e. Crops that had higher ET_{gpiw} compared to Allowed Water values:
   - Container Nursery
   - Flowers
   - It was assumed that the rate of evapotranspiration was continuous throughout the year for these crops. These are continuously harvested and replanted. An alternative strategy may be necessary to assess water requirements such as adjusting the number of actual irrigated acres.

5) Issues affecting irrigation efficiency such as irrigation system distribution uniformity will be examined in Task 2.2.

6) The daily soil water balance model used by ITRC to examine ET_{gpiw} in FCGMA is too complicated to be used on a real-time or even annual basis to assess "allowable" water. As part of Task 2.2, alternative methods will be examined to develop an appropriate plan that can be implemented effectively by FCGMA. The values in this report will be used as the basis for that plan.

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DEFINITION OF KEY TERMS

ASCE P-M	2005 ASCE Standardized Penman-Monteith equation
ET_o	Grass reference evapotranspiration computed using the ASCE P-M 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_{gp}	Crop and soil evapotranspiration from precipitation and irrigation water during the growing season (between the planting and final crop harvest where vegetation is removed or tilled into the soil). For deciduous orchards the growing period is from the break of dormancy in the spring to dormancy in the fall or winter. ET_{gp} does not include evaporation during the off-season. For evergreen crops the ET_{gp} is equal to the ET_c.
ET_{gpiw}	Crop evapotranspiration of irrigation water during the growing period only. The ET_{gpiw} value is nearly equal to ET_{iw} since most of the irrigations will occur during the crop growing period. The difference between these values is the resulting evaporation from pre-irrigations or salinity leaching irrigations. The reason for separating ET_{iw} and ET_{gpiw} is that the leaching requirement will be presented as a separate required water value as part of Task 2.2. Growers can decide when to apply this water (pre- or post-harvest, during a single event or multiple events, etc.).
ET_{iw}	Crop evapotranspiration of irrigation water only. The effective precipitation is removed from ET_c, resulting in ET_{iw}. ET_{iw} includes evaporation due to irrigation that may occur outside of the growing period for leaching salts, pre-irrigation, and soil preparation. The water stored in the root zone after these types of events and utilized by the crop after planting is included in ET_{iw}.
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.
Growing period K_c	The crop coefficient computed as the monthly modeled ET_{gp} divided by the monthly ET_o.
K_{cb}	Basal crop coefficient
K_e	Soil water evaporation coefficient
K_s	Stress reduction coefficient
RH	Relative humidity
Rs	Daily solar radiation
Rso	Clear sky maximum solar radiation

FOX CANYON GROUNDWATER MANAGEMENT AGENCY
TASK 2.1

Purpose and 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 irrigation efficiency program can vary by year as a function of crop type, acreage, and weather. Currently, agricultural allocations are determined through the "Irrigation Efficiency Extraction Allocation" procedure. Utilizing grass reference evapotranspiration (ET_o) computed at five private weather stations owned and operated by a private consultant for FCGMA, this ET_o is summed annually and is then reduced by an "effective precipitation" value based on the annual precipitation measured for five crop categories. This allocation is computed after the year is over and compared to the actual amount of water applied to each particular crop by growers. The ratio of applied water to FCGMA allocation is termed "Irrigation Efficiency" and is used to evaluate and potentially penalize users if it is below a certain value (80%).

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 is the first of two reports that will be submitted to FCGMA, and will discuss:

- FCGMA weather station data quality and ET_o computation
- FCGMA weather station siting
- CIMIS station weather data quality and siting
- Spatial variability in ET_o for the possibility of using ET_o zones
- Survey of 25 growers to determine agronomic practices used throughout FCGMA so that crop evapotranspiration requirements can be computed
- Estimates of crop evapotranspiration requirements in FCGMA
- Estimates of effective rainfall contributing to crop evapotranspiration

The second report will examine the "Irrigation Efficiency Extraction Allocation" procedure and will provide recommendations towards improvement. Along with recommended improvements, the second report (Task 2.2) will also address water requirements for leaching of salts, distribution uniformity, and other management practices (pre-irrigation, germination/transplant irrigations, Santa Ana winds, etc.).

Study Approach

The combined consumptive process of water movement from the soil surface by *evaporation* and by the crop as *transpiration* is referred to as *evapotranspiration* (*ET*). *ET* is normally expressed in terms of depth (inches) per unit time (hour, day, month or year). The rate of *ET* expresses the amount of water lost (or consumed) by a crop in units of water depth over an extensive surface. Many factors affect *ET* rates of irrigated crops, including: weather parameters such as solar radiation, air temperature, humidity and wind speed; crop characteristics such as crop type, density and stage of growth; management; and environmental aspects such as soil type, nutrient availability, salinity, aeration of the root zone, etc.

The general procedure involves computing the *ET* for a reference crop such as grass (termed ET_o) and then multiplying this value by an empirical crop coefficient (K_c) for a specific crop to produce an estimate of consumptive use on a daily, monthly or annual basis. To compute *ET* accurately for this study, the dual crop coefficient method was used following the standard procedures in FAO-56.[2] The dual crop coefficient approach utilizes a daily soil water balance to determine the crop coefficient. The model starts with a basal crop coefficient (K_{cb}), which is what a crop could use assuming a dry soil surface (no evaporation) and no crop stress due to lack of water. The K_{cb} varies depending on crop conditions in the field and is adjusted on a daily basis depending on modeled soil and crop conditions. For example, in cases where precipitation or irrigation has occurred recently the crop coefficient is adjusted up because of increased evaporation from the soil and plant surface. The crop coefficient may be adjusted down when soil moisture is below an optimal level, such as just prior to an irrigation event because of water stress. This is discussed in more detail in **Appendix D**.

The modeling approach has an added benefit of tracking evaporation from precipitation and irrigation events separately so that effective precipitation can be estimated. The *ET* computed for individual crops for a complete growing season relies on specific local datasets for precipitation, and corrected ET_o values in addition to the dual crop coefficient method and cropping strategies, as discussed in **Appendix D**.

Task 2.1 was split into key parts with the final goal of accurately estimating historical crop *ET* requirements in FCGMA. The first portion of the study was to obtain and evaluate key weather parameters from the five FCGMA weather stations as well as the three CIMIS weather stations in Ventura County. As part of this analysis, the computational method used to calculate ET_o at the FCGMA stations was evaluated by recalculating ET_o using a standard equation and comparing the results.

In order to accurately model *ET*, information on crop management must be input into the model. Surveys of 25 growers in FCGMA were conducted by Dr. Ben Faber at the U.C. Cooperative Extension in Ventura County (full survey responses are included in **Appendix E**). Information on planting and harvest dates, irrigation practices, and crop rotations were collected for input into the model.

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[2] Refer to *Crop Evapotranspiration; Guidelines for Computing Crop Water Requirements – FAO 56* (Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Irrigation and Drainage Paper No. 56. Food and Agriculture Organization of the United Nations, Rome. ISBN 92-5-104219-5. 300 p.)

Using corrected ET_o data, published information on potential evapotranspiration rate, rooting depth, crop height, etc., and information gathered from the surveys, the daily soil water balance model based on the dual crop coefficient method was used following the standard procedures in FAO-56 to compute ET.

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.

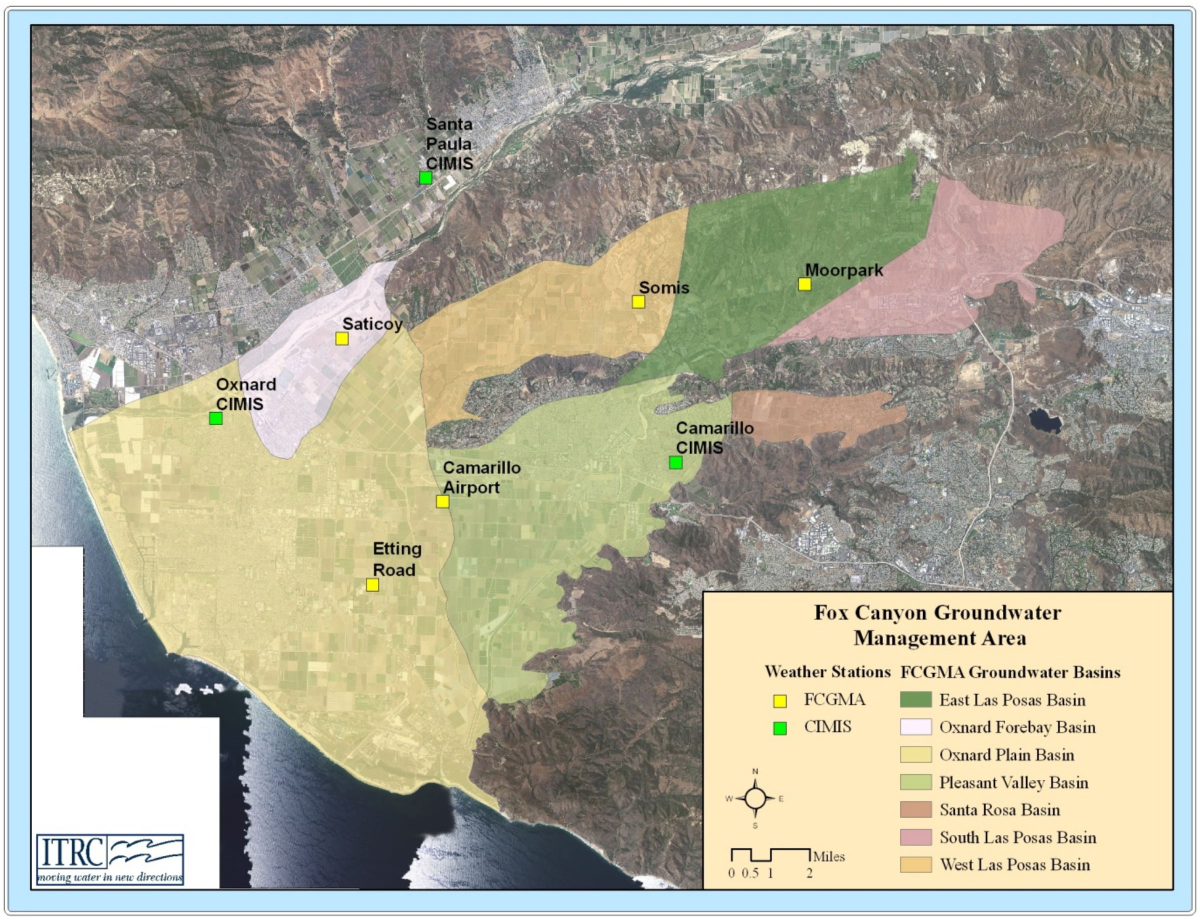

Figure 1. FCGMA boundaries and weather station locations

EVALUATION

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.

Weather Station Data Evaluation

Currently, FCGMA utilizes five privately owned weather stations within the management area (shown in **Figure 1**) to provide grass reference evapotranspiration (ET_o) information for the *Irrigation Efficiency Extraction Allocation* program. A private consultant has been contracted to manage these weather stations for the agency. Over the past decade, management and equipment at each site has changed. A summary of what changes have occurred since 2000 is listed below:

- Through the end of 2001, Peek Electronics managed the weather stations.
- From 2002 through 2006, DST operated the weather stations for FCGMA.
- During 2006, the new Campbell Scientific weather stations were installed at each site and InvestmentSignals (ISS) (formally Peek Electronics) took over control of the weather stations.
- There are 3 additional CIMIS stations in Ventura County that have come online in or near FCGMA boundaries (**Figure 1**).

Raw weather data was provided by David Peek, CEO of InvestmentSignals (ISS), from the five weather stations used by FCGMA. Mr. Peek was very coorperative providing data and background information instrumental for this evaluation. Raw weather data was also collected from CIMIS weather stations within Ventura County. A total of eight weather stations were analyzed with data from 2000 through 2009. The stations are listed in **Table 1**.

Table 1. FCGMA and CIMIS weather station information

Station Name or Location	Installation of New Equipment	North Latitude (deg,min,sec)	West Latitude (deg,min,sec)	Elevation (ft. above msl)	Township and Range
Camarillo Airport	4/1/2006	34° 12' 15"	119° 05' 40"	54 feet	1N/21W-04D
Etting Road	5/1/2006	34° 10' 22"	119° 07' 30"	30 feet	1N/21W-18C
Moorpark	8/1/2006	34° 17' 16"	118° 56' 02"	494 feet	2N/20W-01E
Saticoy	7/1/2006	34° 15' 51"	119° 08' 28"	124 feet	2N/22W-12N
Somis	8/1/2006	34° 16' 48"	119° 00' 30"	460 feet	2N/20W-06R
Camarillo CIMIS (#152)	2000	34° 13' 14"	118° 59' 25"	130 feet	
Oxnard CIMIS (#156)	2001	34° 14' 00"	119° 11' 49"	48 feet	
Santa Paula CIMIS (#198)	2005	34° 19' 29"	119° 06' 18"	218 feet	

Grass reference evapotranspiration (ET_o) is computed based on weather parameters including temperature, relative humidity, solar radiation, and wind speed. Using these measurements and assumptions based on a standard reference crop an equation is utilized to compute ET_o. Typically, a Penman-Monteith equation is used for the computation although there are a number of forms of this equation and others that can be selected. The equation used is discussed further in **Appendix B**. Currently, the most widely recommended and utilized ET_o equation is the 2005 ASCE Standardized Equation.[3] ET_o can be computed on an hourly, sub-hourly, or daily basis; however, it is typically held that hourly or sub-hourly computations provide a better estimate than daily computations. The evaluation of weather station data and computation is split into three parts:

1. Evaluation of two key weather parameters; solar radiation (*Rs*), and relative humidity (*RH*) (**Appendix A**).
2. Correction of any errors in these parameters and computation of ET_o using the corrected data.
3. Comparison of the equation currently used to compute ET_o with the 2005 ASCE Standardized ET_o equation (**Appendix B**).

Weather data and computed ET_o was obtained from the current weather station consultant (ISS) for the five FCGMA stations from 2000-2009. Because of the change in weather station management and equipment, ISS only had daily historical data from 2000 until the new stations were installed in 2006. Therefore, parts 1 and 2 of the evaluation were conducted with daily values and part 3 was examined only using data from the new weather station equipment with data provided by ISS every half-hour. The goal of part 3 was to compare the equation used by ISS with the 2005 ASCE Standardized ET_o equation. Since ISS currently computes ET_o on a half-hourly basis, the same half-hourly raw weather data was required as an input to the ASCE Standardized ET_o equation for proper comparison.

Weather data and computed ET_o were also obtained from the three local CIMIS stations on a daily basis since the time that the stations were started to conduct the same evaluations.

Solar Radiation and Relative Humidity

An in-depth quality control check was conducted on the daily solar radiation (*Rs*) and relative humidity (*RH*) data. Solar radiation is obtained from a pyranometer installed at each station. Pyranometers should be cleaned and calibrated regularly to ensure correct readings. The *Rs* data is a significant factor in the reference evapotranspiration calculation; therefore, it is extremely important to ensure correct data.

Solar radiation data was checked against the "maximum potential solar radiation on a clear day" (*Rso*). *Rso* is a theoretical value that is calculated based on the weather station's elevation, latitude, and the day of the year as described in FAO-56. On a completely clear day, the measured weather station solar radiation (*Rs*) data should be approximately equal to the *Rso* value for that day.

[3] Refer to ASCE-EWRI, 2005. *The ASCE Standardized Reference Evapotranspiration Equation*. Technical Committee report to the Environmental and Water Resources Institute of the American Society of Civil Engineers from the Task Committee on Standardization of Reference Evapotranspiration. ASCE-EWRI, Reston, VA 173 pp.

Figure 2 shows an example of the daily *Rs* compared to the *Rso* values from 2000 to 2009. A comprehensive set of comparisons for all eight stations from 2000 through 2009 can be found in **Appendix A**. **Figure 2** indicates significant problems with the quality of weather station-measured solar radiation especially from 2000-2003, as seen in the radiation data that appears above the maximum potential radiation line. These anomalies were consistent at each of the five FCGMA stations. From 2004 until the new stations were installed in 2006 there was some improvement but overall the solar radiation data quality was relatively poor. Since the installation of the new equipment, the data quality continues to be poor. However, there do seem to be some active attempts at correcting this data.

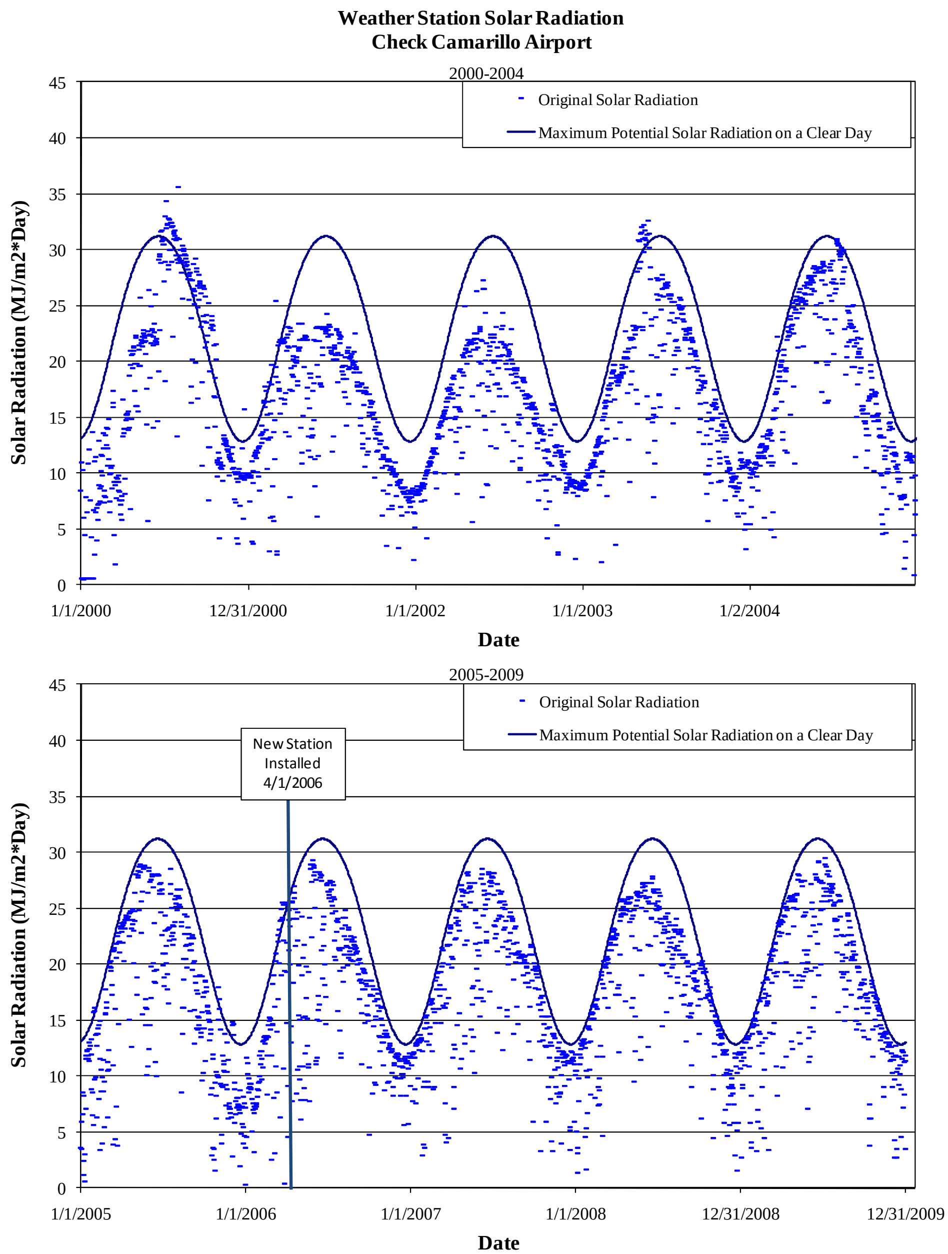

Figure 2. Raw daily solar radiation compared to *Rso* at the FCGMA Camarillo Airport weather station from 2000-2009

Once the errors were identified in the solar radiation data during this study, corrections were made as shown in **Figure 3**. Typically, errors in the solar radiation data are related to calibration or something covering the pyranometer. The pyranometer should be cleaned on a monthly basis by the consultant or entity managing the weather station. If the measured *Rs* data continues to differ from the *Rso*, the pyranometer should be recalibrated or replaced. There will be periods of foggy/cloudy days where *Rs* is less than *Rso*. However, there should be some clear days during a period of several weeks where the *Rs* values should closely match the *Rso* curve.

For this historical solar radiation analysis, a correction factor was applied so that the solar radiation more closely matched the maximum potential solar radiation with a clear sky. The corrected values are shown as light blue in **Figure 3**.

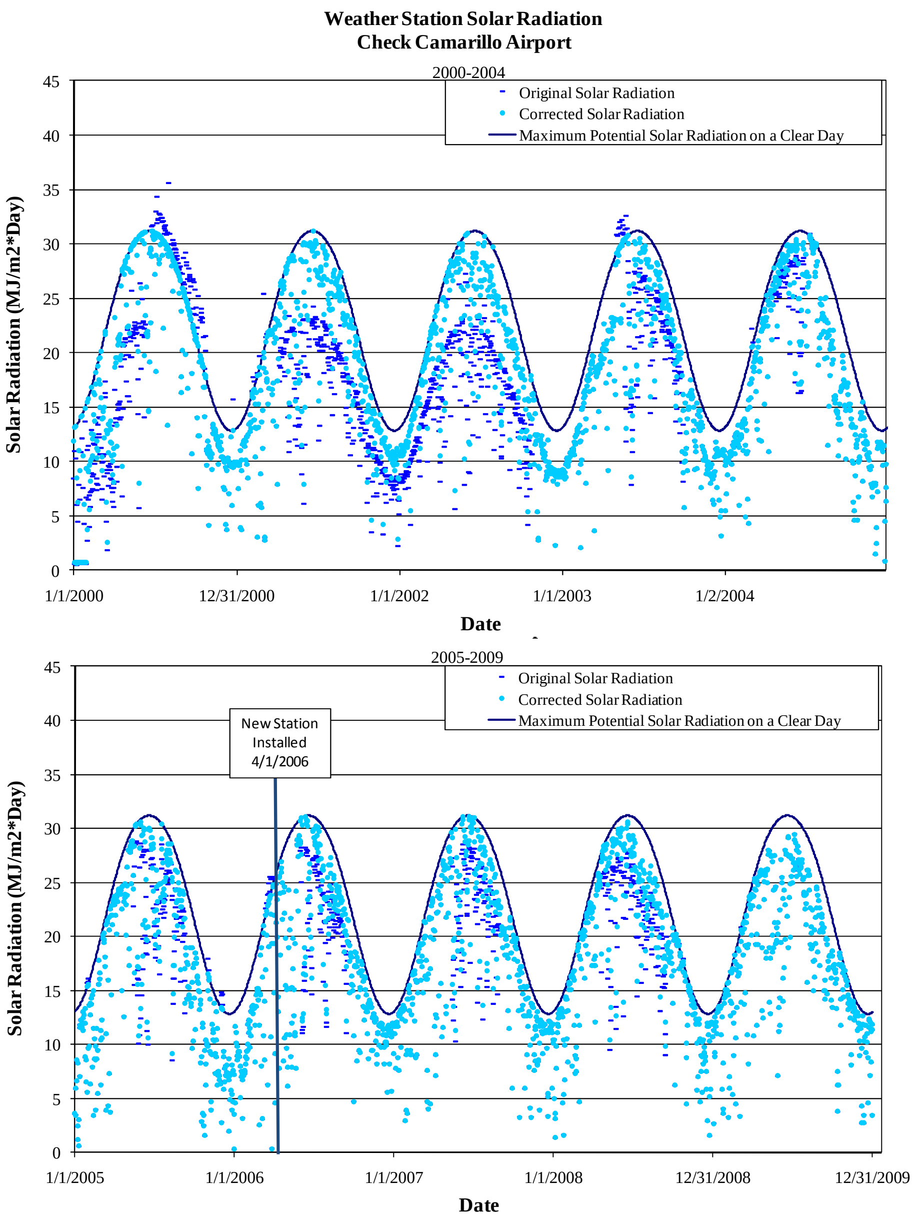

Figure 3. Corrected daily solar radiation compared at the FCGMA Camarillo Airport weather station from 2000-2009

Measured solar radiation errors were not limited to FCGMA weather stations. Problems were also identified at the Camarillo and Santa Paula CIMIS stations for significant periods of time. The magnitude of error was not as significant at the CIMIS stations but did warrant correction (refer to **Appendix A**).

Relative humidity (*RH*) data was also evaluated for anomalies. If there are major calibration issues with the sensors they can be seen by plotting long term daily average *RH* data. During this evaluation two of the FCGMA weather stations (Etting Road and Saticoy) showed anomalies during a portion of the analysis period. The relative humidity (*RH*) data for these two stations are shown in **Figure 4** with brackets showing the anomalies.

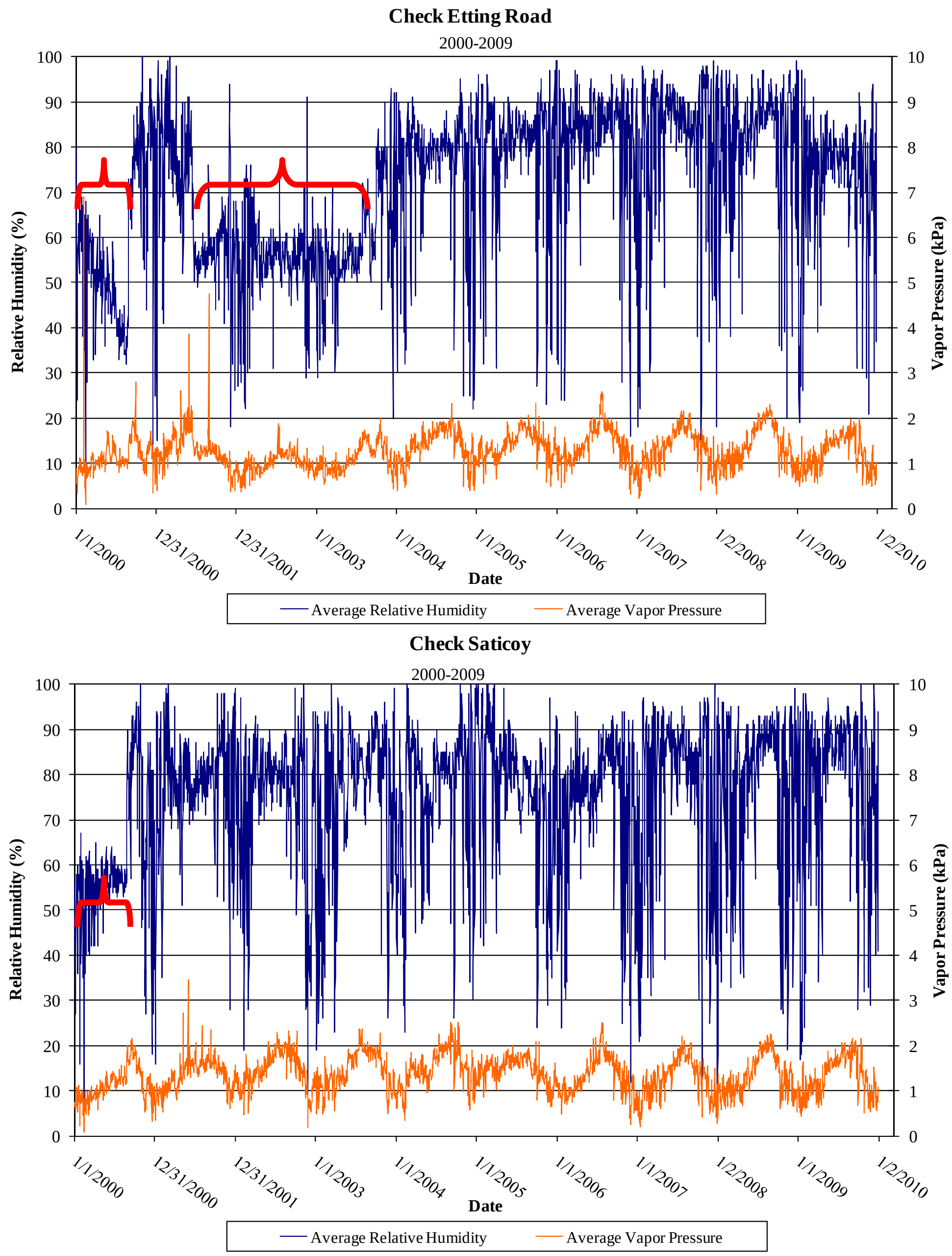

Figure 4. Etting Road and Saticoy *RH* data with anomalies for 2000-2009

A comparison of monthly wind speed collected at FCGMA and CIMIS stations can be found in **Appendix A**. From this analysis, wind speed seems to be significantly different (lower) at Moorpark and Somis compared to the other sites. With Santa Ana wind conditions it would seem that wind speed should be higher at these sites. This could be related to the location of the stations, or it could be caused by improper siting of the weather stations, which is discussed later.

Recomputed ET_o Comparison

In **Table 2**, the annual ET_o is presented for each station from 2000-2009. The "original ET_o" is the original published value. The "recomputed ET_o" is computed with corrected solar radiation and relative humidity data (when necessary) on a daily basis using the ASCE Standardized grass reference evapotranspiration (ASCE P-M ET_o). Color coding in **Table 2** indicates the company managing the stations. Percent difference is shown in the right-hand column. **Table 3** shows the "recomputed ET_o" from the CIMIS stations. It should be noted that for the FCGMA comparisons, the recomputed ET_o was calculated using daily weather parameters. Therefore, some differences (5-7%) between the original and recomputed values will exist.

Obvious errors in ET_o can be seen from 2000-2003 at the FCGMA weather stations. The recomputed ET_o is significantly less than the original. Since the solar radiation was corrected upward, the recomputed ET_o should be higher. However, this is not the case. The overall magnitude of the original ET_o during this time frame at all FCGMA stations is much higher than it should be. Values in the 60 inch per year range are typical in the high desert but not in coastal regions. There is likely an error in the fundamental computation of ET_o during this time frame.

From 2004-2006 there is some improvement in station quality but there were still some issues with solar radiation data. There is some problem with the weather data from Moorpark and Somis from 2004 through 2006 that cannot be pinpointed.

The magnitude and inconsistency in the ET_o data from FCGMA weather stations prior to installation of the new equipment leads ITRC to have low confidence in data from these stations prior to 2007. Therefore, the remainder of the crop evapotranspiration evaluation was accomplished using corrected data from the Camarillo CIMIS station, which has been the longest running CIMIS station in the region during the evaluation time frame.

The difference between corrected and uncorrected data at the CIMIS stations was much less significant during the evaluation period. The Camarillo CIMIS station seemed to underestimate ET_o by 5-6% throughout the study period, which can be directly attributed to the under-reporting of *Rs* values at that site.

Table 2. Original published annual ET_o compared to recomputed ET_o based on corrected weather parameters using the ASCE Standard ET_o equation

	Camarillo Airport		
	Original ET_o	Recomputed ET_o	
Year	Inches	Inches	Percent Difference
2000	68.2	47.5	-30%
2001	63.2	48.1	-24%
2002	67.5	50.9	-25%
2003	48.6	46.9	-3%
2004	49.3	43.9	-11%
2005	42.2	39.2	-7%
2006	41.6	43.1	3%
2007	43.8	48.7	11%
2008	45.0	50.2	12%
2009	44.1	47.2	7%

	Etting Road		
	Original ET_o	Recomputed ET_o	
Year	Inches	Inches	Percent Difference
2000	62.2	39.8	-36%
2001	63.2	48.2	-24%
2002	69.8	45.4	-35%
2003	40.1	42.8	7%
2004	48.7	42.3	-13%
2005	42.0	38.1	-9%
2006	39.8	40.2	1%
2007	39.1	42.5	9%
2008	40.3	43.5	8%
2009	46.2	48.5	5%

	Moorpark		
	Original ET_o	Recomputed ET_o	
Year	Inches	Inches	Percent Difference
2000	55.3	39.6	-28%
2001	64.1	49.5	-23%
2002	65.7	47.6	-28%
2003	50.3	43.3	-14%
2004	51.5	38.4	-25%
2005	45.7	38.6	-15%
2006	44.0	41.8	-5%
2007	46.8	48.1	3%
2008	48.3	49.8	3%
2009	53.1	49.8	-6%

Table 2 (continued). Original published annual ET_o compared to recomputed ET_o based on corrected weather parameters using the ASCE Standard ET_o equation

	Saticoy		
	Original ET_o	**Recomputed ET_o**	
Year	**Inches**	**Inches**	**Percent Difference**
2000	64.3	44.4	-31%
2001	59.6	42.4	-29%
2002	64.5	45.6	-29%
2003	47.4	46.1	-3%
2004	55.7	47.4	-15%
2005	44.9	41.6	-7%
2006	43.2	45.1	4%
2007	42.7	47.2	11%
2008	44.1	49.2	12%
2009	45.0	49.1	9%

	Somis		
	Original ET_o	**Recomputed ET_o**	
Year	**Inches**	**Inches**	**Percent Difference**
2000	60.2	43.2	-28%
2001	54.9	41.9	-24%
2002	61.5	41.8	-32%
2003	49.7	43.1	-13%
2004	52.3	41.4	-21%
2005	44.2	36.4	-18%
2006	43.8	37.4	-15%
2007	45.8	42.2	-8%
2008	44.6	43.2	-3%
2009	50.3	43.6	-13%

(purple)	Weather stations managed by Peek Electronics
(green)	Weather stations managed by DST
(blue)	Weather stations managed by ISS (with new stations)

Table 3. Recomputed annual CIMIS ET_o

Camarillo

	Original ET_o	Recomputed ET_o	Percent Difference
Year	Inches	Inches	Inches
2001	42.1	44.2	5.2%
2002	46.0	48.0	4.5%
2003	45.6	47.7	4.6%
2004	47.6	49.8	4.6%
2005	44.5	47.3	6.1%
2006	44.4	47.2	6.2%
2007	46.1	49.0	6.2%
2008	48.1	51.1	6.1%
2009	46.6	49.4	5.9%

Oxnard

	Original ET_o	Recomputed ET_o	Percent Difference
Year	Inches	Inches	Inches
2001			
2002	40.5	40.4	-0.3%
2003	41.2	42.1	2.2%
2004	43.0	43.1	0.3%
2005	40.9	40.8	-0.1%
2006	41.7	41.7	-0.1%
2007	42.7	42.6	-0.2%
2008	43.8	43.8	-0.1%
2009	46.8	46.7	-0.1%

Santa Paula

	Original ET_o	Recomputed ET_o	Percent Difference
Year	Inches	Inches	Inches
2001			
2002			
2003			
2004			
2005			
2006	49.0	50.8	3.6%
2007	49.9	51.6	3.4%
2008	54.2	55.8	2.9%
2009	53.0	52.9	-0.1%

ET_o Computation

The third part of the weather data quality control analysis was to evaluate the equation utilized to compute ET_o. As previously mentioned, there are numerous equations available to compute ET_o from weather parameters. In 1998 and again in 2005 attempts were made to establish a standard equation by the Food and Agricultural Organization (FAO) and American Society of Civil Engineers (ASCE), respectively. Currently, the most widely used equation is the 2005 ASCE Standardized equation (the 1998 FAO 56 equation and 2005 ASCE Standardized equation are essentially the same for grass reference ET_o). The 2005 ASCE Standardized equation is one of two equations used by CIMIS to compute ET_o. CIMIS also uses its own equation to compute ET_o. When obtaining data from CIMIS, the value simply shown as ET_o is computed from the CIMIS equation and that shown as P-M ET_o is computed using the ASCE Standardized equation. ITRC recommends using the ASCE Standardized equation.

This portion of the evaluation is limited to comparing ET_o computed by FCGMA weather stations and using the ASCE Standardized equation using the same weather parameters. Since FCGMA stations compute ET_o every half-hour and sum that data on a daily basis, half-hour weather data obtained from ISS for 2008 and 2009 was input into the ASCE Standardized equation for direct comparison. So that a direct comparison could be made, raw, uncorrected weather parameters were used for this analysis. Therefore, ET_o values shown in this section and **Appendix B** may have errors in solar radiation data and should not be used other than for comparison in this analysis.

The results of the evaluation are shown in **Figure 5** and in **Appendix B**. Overall there is between a 1% and 7% difference in annual ET_o for 2008 and 2009 between the computational methods. Other than Somis, the ET_o computed using the ASCE standardized equation is slightly higher than the original reported by the FCGMA. Some of this difference could be attributed to rounding of weather parameters during the transfer of data or computational process.

Overall, there do not seem to be any major issues with the computational method used at FCGMA since the installation of new weather station equipment in mid-2006. It is recommended that ISS review the ET_o equation that is used and ensure that it conforms to the ASCE Standardized equation (refer to **Appendix B**). ISS should also implement a quality control program on the solar radiation data measured at each station as described in FAO-56. The site conditions at each weather station are a separate issue that will be discussed in a later section.

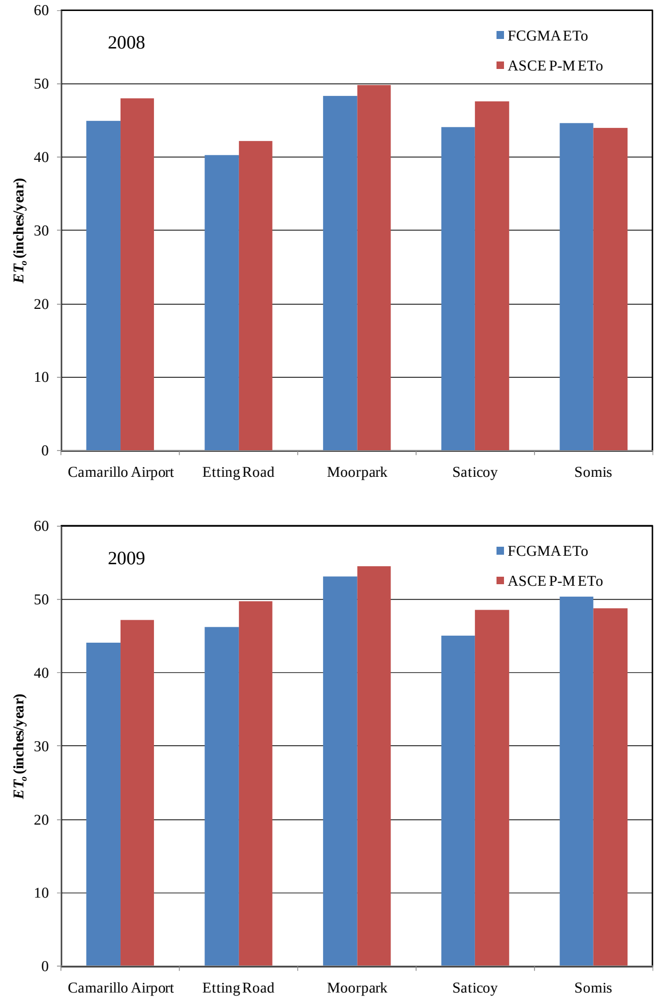

Figure 5. Comparison of 2008 and 2009 annual uncorrected ET_o from FCGMA stations to that computed using ASCE Standardized equation with the same half-hourly data

Crop Evapotranspiration Modeling

A computer model (termed the "Modified ITRC/FAO-56 Model"), was used to compute daily/monthly/annual crop and soil evapotranspiration (ET_c) for different crop and climatic conditions using reference evapotranspiration data from the Camarillo CIMIS station. Full details about the model, which calculates the crop coefficient (K_c) on a daily basis, are outlined in **Appendix D**. A total of 21 crop situations were modeled.

Data for the crop parameters such as general planting and harvest dates, irrigation practices and methods required to accurately estimate crop water needs were gathered through twenty-five interviews with representative growers carried out by Dr. Ben Faber from the University of California Cooperative Extension in Ventura County (**Appendix E**). The results of the interviews were compiled and analyzed in order to develop representative datasets for each crop parameter.

ET_o Data for Model

Because of the lack of confidence in historical FCGMA weather station ET_o, the only station in the region with data throughout our analysis period was the Camarillo CIMIS station. Therefore, corrected daily ET_o and weather data was used from the Camarillo CIMIS station to model crops from 2001 through 2009.

The monthly crop coefficients generated through the daily modeling can then be used to estimate crop evapotranspiration in Zones 1 and 3 for recent years using the CIMIS data from the Santa Paula and Oxnard sites.

Table 4. Annual corrected Camarillo CIMIS ET_o used for the crop evapotranspiration modeling

	Recomputed
Year	**Inches**
2001	44.2
2002	48.0
2003	47.7
2004	49.8
2005	47.3
2006	47.2
2007	49.0
2008	51.1
2009	49.4

Crop Growing Period Evapotranspiration

Utilizing the daily soil water balance model, **Table 5** shows the computed crop evapotranspiration based on the Camarillo CIMIS station's corrected ET_o during the crop growing periods (ET_{gp}) averaged from 2001 through 2009. ET_{gp} by month for each year examined is shown in **Appendix D**.

Table 6 shows the estimated crop coefficients (K_c) computed from 2001 through 2009 during the growing period. For more details about the values shown in these two tables, refer to **Appendix D**.

Note: Values in Tables 5 and 6 do not account for management water requirements such as salinity leaching, frost protection, and Santa Ana wind management, which will be fully detailed in the Task 2.2 report (October 2010).

Table 5. 2001-2009 average estimated monthly growing period crop evapotranspiration (ET_{gp}) using the Camarillo CIMIS reference ET_o and precipitation

Average	**Camarillo CIMIS ET_{gp} (inches)**												
Crop	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Total**
Avocado	3.0	3.1	3.9	3.8	3.9	3.9	4.3	3.9	3.1	2.7	2.4	2.1	40.1
Blueberries	2.0	2.3	2.8	3.4	4.4	5.2	5.9	5.4	4.3	3.3	2.6	2.1	43.6
Raspberries – Tunnel	2.0	2.3	2.8	3.4	4.4	5.2	5.9	5.4	4.3	3.3	2.6	2.1	43.6
Celery – Fall									1.9	2.9	3.0	2.5	10.3
Celery – Spring	1.2	2.4	4.1	4.7	5.1								17.5
Citrus – 20% Cover	2.3	2.5	2.7	2.4	2.2	2.0	2.1	2.0	1.6	1.6	1.7	1.7	24.7
Citrus – 50% Cover	2.5	2.8	3.2	3.0	2.8	2.6	2.9	2.6	2.1	2.0	1.9	1.9	30.4
Citrus – 70% Cover	2.9	3.0	3.8	3.7	3.7	3.6	4.0	3.7	3.0	2.6	2.3	2.1	38.4
Lima Beans					1.4	3.0	5.3	0.6					10.3
Misc. Veg Greenhouse – Fall								0.7	1.4	2.3	2.0	1.2	7.7
Misc. Veg Greenhouse – Spr	0.5	2.0	2.9	3.2	2.0								10.7
Misc. Veg Greenhouse – Summer				0.7	2.7	3.3	3.5						10.2
Misc. Veg Single Crop – Fall								1.2	1.5	3.1	2.7	1.4	9.9
Misc. Veg Single Crop – Spr	1.0	1.9	3.7	4.3	2.7								13.6
Misc. Veg Single Crop – Summer				1.2	4.0	5.4	5.6						16.2
Nursery Container	3.2	3.4	4.6	5.0	5.5	5.7	6.3	5.8	4.7	3.7	3.2	2.6	53.8
Nursery – Flowers	3.3	3.4	4.6	5.0	5.4	5.5	6.1	5.5	4.5	3.6	3.1	2.6	52.5
Sod	3.1	3.3	4.3	4.5	4.8	4.8	5.4	4.9	4.0	3.3	2.9	2.5	47.7
Strawberries – Main Season	2.7	2.9	3.7	3.9	4.2	2.3			0.0	2.2	1.7	2.0	25.6
Strawberries – Summer							4.0	4.1	3.0				11.0
Tomatoes – Peppers					1.2	1.3	4.4	5.8	4.7	3.4	0.3		21.1

Table 6. 2001-2009 average estimated monthly growing period crop coefficient (K_c) using the Camarillo CIMIS reference ET_o and precipitation

Average	**Growing Period Crop Coefficients (K_c)**												
Crop	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Average**
Avocado	1.1	1.1	1.0	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.9	1.0	0.9
Blueberries	0.7	0.8	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
Raspberries – Tunnel	0.7	0.8	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9
Celery – Fall									0.4	0.8	1.1	1.1	0.9
Celery – Spring	0.4	0.8	1.0	1.1	1.0								0.9
Citrus – 20% Cover	0.8	0.9	0.7	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.8	0.6
Citrus – 50% Cover	0.9	1.0	0.8	0.7	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.9	0.7
Citrus – 70% Cover	1.0	1.1	1.0	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	1.0	0.8
Lima Beans					0.3	0.6	0.9	0.1					0.5
Misc. Veg Greenhouse – Fall								0.1	0.3	0.7	0.7	0.6	0.5
Misc. Veg Greenhouse – Spr	0.2	0.7	0.8	0.7	0.4								0.6
Misc. Veg Greenhouse – Summer				0.2	0.6	0.6	0.6						0.5
Misc. Veg Single Crop – Fall								0.2	0.4	0.9	1.0	0.6	0.6
Misc. Veg Single Crop – Spr	0.4	0.7	0.9	1.0	0.5								0.7
Misc. Veg Single Crop – Summer				0.3	0.8	1.0	1.0						0.8
Nursery Container	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.1
Nursery – Flowers	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.1
Sod	1.1	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.1	1.0
Strawberries – Main Season	1.0	1.0	0.9	0.9	0.8	0.4			0.0	0.7	0.6	0.9	0.7
Strawberries – Summer							0.7	0.8	0.7				0.7
Tomatoes – Peppers					0.2	0.2	0.7	1.1	1.1	1.0	0.1		0.6

Precipitation

Table 7 shows the precipitation measurements at each station, including the precipitation measured at a National Climate Data Center (NCDC) station in Santa Paula (the lower portion of the table shows a comparison between the average precipitation from all stations and the annual precipitation collected at each station). There can be significant differences between precipitation measurements throughout an area; however, there should be some consistency between years. For example, in 2002 all measurement stations had low precipitation values except for the Oxnard CIMIS station.

In general, the precipitation values seem to be good for all stations except for the Oxnard CIMIS station in 2002.

Table 7. Precipitation data from weather stations in Ventura County

	Camarillo Airport	Etting Road	Moorpark	Saticoy	Somis	Camarillo CIMIS	Oxnard CIMIS	Santa Paula CIMIS	Santa Paula NCDC	Average
Year	**Inches**	**Inches**	**Inches**	**Inches**	**Inches**	**Inches**	**Inches**	**Inches**	**Inches**	**inches**
2000	10.8	12.3	10.9	12.1	12.1				19.1	12.9
2001	15.0	20.7	15.9	23.4	20.0	16.8			26.5	19.8
2002	7.5	8.6	6.8	8.5	9.8	5.1	32.8		11.5	8.2*
2003	11.6	13.2	9.7	14.6	11.9	7.6	11.7		14.1	11.8
2004	12.9	15.0	16.9	14.5	20.3	14.9	13.9		19.3	15.9
2005	16.3	21.6	30.9	23.1	33.5	25.9	21.8		38.7	26.5
2006	11.3	11.6	13.2	9.1	17.1	14.3	13.8	15.5	15.5	13.5
2007	6.8	7.4	6.8	7.9	8.7	5.3	7.7	7.4	8.7	7.4
2008	13.2	13.6	14.7	14.9	15.5	10.9	13.9	15.0	15.4	14.1
2009	8.5	8.8	10.8	11.5	8.1	10.5	7.1	10.8	10.5	9.6
									Average	**14.0***

Percent difference between station precipitation and the average of all stations

	Camarillo Airport	Etting Road	Moorpark	Saticoy	Somis	Camarillo CIMIS	Oxnard CIMIS	Santa Paula CIMIS	Santa Paula NCDC
Year	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
2000	-16%	-5%	-15%	-6%	-6%				48%
2001	-24%	5%	-20%	18%	1%	-15%			34%
2002	-9%	4%	-18%	3%	19%	-38%	298%		39%
2003	-2%	12%	-17%	24%	1%	-36%	-1%		19%
2004	-19%	-6%	6%	-9%	27%	-7%	-13%		21%
2005	-38%	-18%	17%	-13%	27%	-2%	-18%		46%
2006	-16%	-14%	-2%	-33%	27%	6%	2%	15%	15%
2007	-8%	0%	-8%	7%	17%	-29%	4%	0%	18%
2008	-6%	-4%	4%	5%	10%	-23%	-2%	6%	9%
2009	-12%	-9%	13%	20%	-16%	9%	-26%	12%	9%

*Averages do not include Oxnard CIMIS precipitation for 2002.

Effective Precipitation

The amount of precipitation that is utilized by a crop can be difficult to assess because it varies depending on when it occurs, duration of occurrence, and amount. If a large amount occurs over a short period of time the percent that is effective towards crop evapotranspiration will be relatively low.

The following table shows the monthly effective precipitation for the 2009 modeled crop scenarios with the maximum effective precipitation set to 90%. It is assumed that 90% is the maximum effective precipitation since some will evaporate into the atmosphere without contribution to the crop. These effective precipitation values were determined through the daily soil water balance model. The destinations of precipitation include “non-effective” uses such as surface runoff and deep percolation below the crop root zone, as well as “effective” uses such as evaporation from the soil and plant surface and soil root zone storage where it can be utilized by the crop. The amount of effective precipitation will depend on the amount of precipitation during an event combined with the daily soil moisture at the time of the event, which is tracked using the model.

Table 8. Monthly percent effective precipitation for 2009 computed from the evapotranspiration modeling using Camarillo CIMIS data

	2009 Modeled Percent Effective Precipitation using Camarillo CIMIS Data											
Crop	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly Precipitation (Inches)	0.47	4.97	0.41	0.02	0.01	0.07				1.21		3.34
Avocado	90%	32%	90%	90%	90%	90%				90%		54%
Blueberries	90%	32%	90%	90%	90%	90%				37%		41%
Raspberries – Tunnel												
Celery – Fall										74%		31%
Celery – Spring		31%	90%	90%	40%							
Citrus – 20% Cover	90%	46%	90%	90%	50%	90%				79%		57%
Citrus – 50% Cover	90%	55%	90%	90%	90%	90%				90%		61%
Citrus – 70% Cover	90%	60%	90%	90%	90%	90%				90%		67%
Lima Beans						90%						
Misc. Veg Greenhouse – Fall												
Misc. Veg Greenhouse – Spr												
Misc. Veg Greenhouse – Summer												
Misc. Veg Single Crop – Fall										85%		40%
Misc. Veg Single Crop – Spr	90%	31%	90%	90%	40%							
Misc. Veg Single Crop – Summer				15%	90%	90%						
Nursery Container	90%	26%	90%	90%	50%	90%				65%		37%
Nursery – Flowers	90%	26%	90%	90%	90%	90%				54%		28%
Sod	90%	37%	90%	90%	90%	90%				68%		38%
Strawberries – Main Season	25%	25%	25%	25%	25%	25%				25%		25%
Strawberries – Summer												
Tomatoes – Peppers						90%				62%		

The effective precipitation values in **Table 8** show monthly variability due to precipitation amounts. For example, in February of 2009 the percent effective precipitation was low because the precipitation was high and mostly occurred early in the month. In most cases over 50% of the precipitation either deep percolated below the root zone or ran off the surface. In March, the effective precipitation increased to 90% because of the relatively insignificant amount of precipitation (0.40 inches) that occurred over three very small events spread throughout the month.

The benefit of using a daily soil water balance model that tracks actual soil moisture storage over multiple seasons is the accuracy in estimating historical effective precipitation. It is incredibly difficult to estimate effective precipitation by some empirical method based on monthly or annual total precipitation without knowing what is occurring in the soil root zone.

Utilizing the monthly effective precipitation values from **Table 8,** the crop coefficients from **Table 7**, and the monthly corrected ET_o for Oxnard and Santa Paula CIMIS stations, the crop growing period evapotranspiration of irrigation water (ET_{gpiw}) was computed. The ET_{gpiw} for all three stations is shown in **Table 9**. Since there were different precipitation amounts measured at each station, the amount of effective precipitation also varied. For this reason, the ET_{gpiw} from Oxnard is similar to that from Camarillo.

Table 9. 2009 comparison of modeled ET_{gpiw} using ET_o data from the three CIMIS weather station (does not account for water required for management purposes)

	Oxnard (Z1)	Camarillo (Z2)	Santa Paula (Z3)
Crop	ET_{gpiw}	ET_{gpiw}	ET_{gpiw}
Avocado	35.6	35.4	37.4
Blueberries	38.3	39.3	41.9
Raspberries – Tunnel	41.3	43.5	46.6
Celery – Fall	10.8	8.7	9.6
Celery – Spring	14.8	16.1	17.4
Citrus – 20% Cover	19.2	18.0	19.3
Citrus – 50% Cover	24.7	23.7	25.4
Citrus – 70% Cover	32.4	31.7	34.1
Lima Beans	9.2	10.2	10.3
Misc. Veg Greenhouse – Fall	8.5	8.0	9.4
Misc. Veg Greenhouse – Spr	9.9	10.7	11.3
Misc. Veg Greenhouse – Summer	8.7	9.6	9.8
Misc. Veg Single Crop – Fall	10.0	7.8	8.4
Misc. Veg Single Crop – Spr	11.1	11.9	12.9
Misc. Veg Single Crop – Summer	14.0	15.5	15.7
Nursery Container	49.4	50.8	53.9
Nursery – Flowers	48.6	50.1	53.3
Sod	43.3	44.1	47.0
Strawberries – Main Season	23.2	23.2	25.6
Strawberries – Summer	10.1	11.3	11.6
Tomatoes – Peppers	20.0	20.5	21.1

The annual ET_{gpiw} is shown and compared against the FCGMA Allowed Water for sites near the CIMIS stations (**Table 10**). **It should be noted that this is a rough comparison since the ET_{gpiw} does not account for water required for management purposes such as salinity leaching, Santa Ana wind management, distribution uniformity, and frost protection.** In addition, some crops are shown for a single season and the FCGMA Allowed Water values are based on annual ET_o amounts. For example, lima beans may be grown between a spring and fall celery crop. In that case the ET_{gpiw} from the three crop scenarios should be combined. Several cropping scenarios in **Table 10** were combined (such as Misc. Veg. fall, spring, and summer) to compare the modeled ET_{gpiw} to the FCGMA Allowed Water.

Table 10. 2009 comparison of modeled crop water use and FCGMA allowed water from sites within each zone (Inches). ET_{gpiw} does not account for water required for management purposes

	Oxnard (Z1)		Camarillo (Z2)		Santa Paula (Z3)	
	Modeled	FCGMA Etting Road	Modeled	FCGMA Cam. Airport	Modeled	FCGMA Moorpark
Crop	ET_{gpiw}	Allowed Water	ET_{gpiw}	Allowed Water	ET_{gpiw}	Allowed Water
Avocado	35.6	37.6	35.4	36.0	37.4	43.1
Blueberries	38.3	41.6	39.3	40.3	41.9	49.0
Raspberries – Tunnel	41.3	41.6	43.5	40.3	46.6	49.0
Celery – Fall + Celery – Spring	25.6	41.6	24.8	40.3	27.0	49.0
Citrus – 20% Cover	19.2	37.6	18.0	36.0	19.3	43.1
Citrus – 50% Cover	24.7	37.6	23.7	36.0	25.4	43.1
Citrus – 70% Cover	32.4	37.6	31.7	36.0	34.1	43.1
Lima Beans (Single Crop)	9.2	41.1	10.2	39.6	10.3	48.3
Misc. Veg Greenhouse – Fall + Misc. Veg Greenhouse – Spr + Misc. Veg Greenhouse – Summer	27.1	41.1	28.3	39.6	30.5	48.3
Misc. Veg Single Crop – Fall + Misc. Veg Single Crop – Spr + Misc. Veg Single Crop – Summer	35.2	41.6	35.2	39.6	36.9	48.3
Nursery Container	49.4	41.6	50.8	40.3	53.9	49.0
Nursery – Flowers	48.6	41.6	50.1	40.3	53.3	49.0
Sod	43.3	41.6	44.1	40.3	47.0	49.0
Strawberries – Main Season +	23.2	41.6	23.2	40.3	25.6	49.0
Strawberries – Summer	10.1	41.6	11.3	40.3	11.6	49.0
Tomatoes – Peppers	20.0	41.1	20.5	39.6	21.1	48.3

Nursery and sod crops show higher water requirements than FCGMA Allowed Water. Caution should be taken when examining these values since the crop model assumes full spatial coverage of an area. In fact, nursery and sod are continually harvested and replanted. At any given time a certain percentage of a sod field or nursery ground may not have any crop. An assessment of actual planted area in these situations has not been made.

WEATHER STATION SITING

Weather data that is used to compute ET_o should be obtained from appropriately sited weather stations. There are specific assumptions built into the ET_o equations based on the site conditions where the data is collected. Improperly sited stations can cause significant errors in ET_o computations. Grass reference evapotranspiration (ET_o) computations should be made from weather data measured over and downwind of vegetation similar to the reference surface (grass). The surface should be well-watered and maintained. The site should be free of wind obstructions within a 50 to 100 yard radius. Discussion of appropriate site conditions can be found in Appendix D of ASCE-EWRI 2005[4] and on the CIMIS website at: wwwcimis.water.ca.gov/cimis/infoStnSiting.jsp.

Figures 6 and **7** show images of FCGMA and CIMIS weather stations. Complete image sets of each weather station taken facing in the four cardinal directions are shown in **Appendix C**.

Figure 6. Photos of FCGMA weather stations – Camarillo Airport (top left), Etting Road (top right), Moorpark (middle left), Saticoy (middle right), and Somis (bottom)

[4] Refer to ASCE-EWRI, 2005. *The ASCE Standardized Reference Evapotranspiration Equation*. Technical Committee report to the Environmental and Water Resources Institute of the American Society of Civil Engineers from the Task Committee on Standardization of Reference Evapotranspiration. ASCE-EWRI, Reston, VA 173 pp.

Figure 7. Photos of CIMIS weather stations – Oxnard (top left), Santa Paula (top right), Camarillo (bottom)

The majority of the FCGMA weather station sites are not sited according to standard conditions. Some are still near irrigated agricultural areas so the chance of gross errors in ET_o are not likely (site influences on Temp and RH parameters). However:

- The fallow area around the Saticoy station could cause errors with key weather parameters.
- Wind could be influenced by trees and structures close to the stations at Camarillo Airport, Moorpark, and Somis.

It is difficult and expensive to site weather stations appropriately. Many CIMIS weather stations are in irrigated pastures because there is vegetation year-round and the height of the vegetation is similar to grass. There does not seem to be any significant amount of irrigated pasture in FCGMA service area, so this is not an option.

CIMIS also uses golf courses because the grass is well-maintained. However, trees and houses throughout a golf course can also impact wind velocity measurement accuracy. From the site investigations of the three CIMIS stations, there do not seem to be major wind obstructions within the allotted 50 to 100 yards from the sites.

ITRC recommends that FCGMA investigate alternative sites for the existing FCGMA weather stations free of wind obstructions and surrounded by relatively short-growing irrigated agriculture (i.e., not orchards). It is preferable to invest in a few sites with good site conditions. Discussion of appropriate site conditions can be found in Appendix D of ASCE-EWRI 2005[5]

Coastal Effects of ET_o and Recommended ET_o Zones

The effects of fog and cooler summer temperatures can have a significant effect on ET_o. With cooler temperatures and coastal fog, ET_o is lower near the coastal regions and increases with distance away from the coast. A study presented in California DWR Bulletin 113-3[6] in 1974 showed the effects of evaporation from Class A evaporation pans located in irrigated pasture for several Central Coast valleys (**Figure 8**). The DWR study indicates that the "coastal" effect impacts evaporation (which correlates with ET_o) within approximately 15-20 miles of the coast.

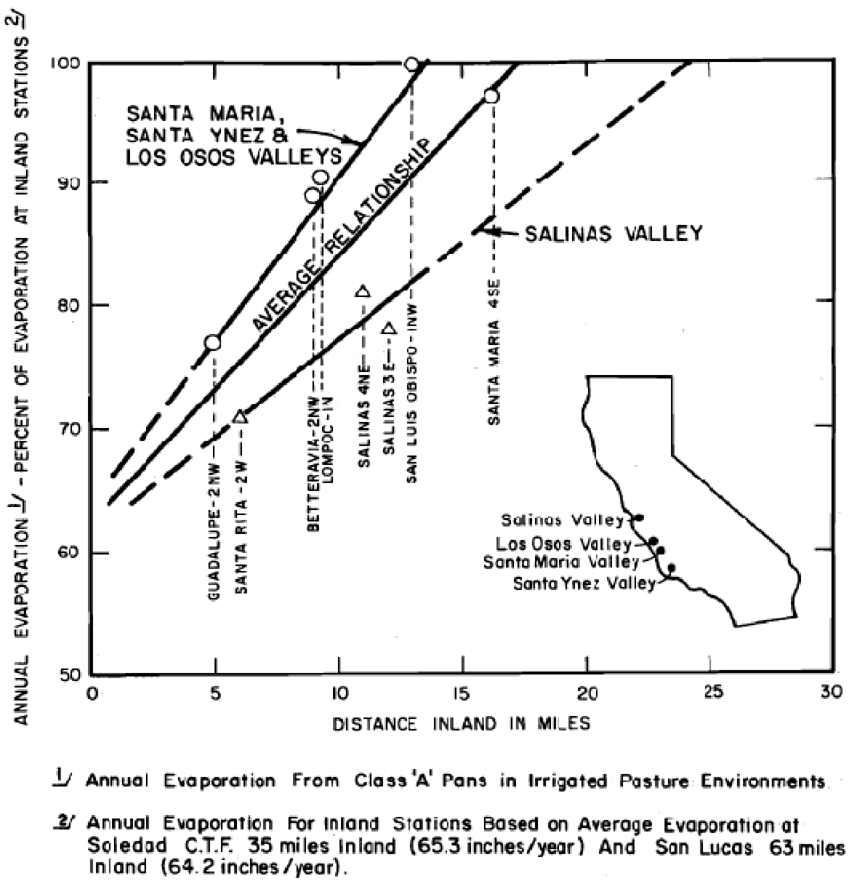

Figure 8. Relationship between annual evaporation as a percent of inland evaporation and distance from the ocean for eight Class A evaporation pans along the central coast (DWR 1974)

[5] Refer to ASCE-EWRI, 2005. *The ASCE Standardized Reference Evapotranspiration Equation*. Technical Committee report to the Environmental and Water Resources Institute of the American Society of Civil Engineers from the Task Committee on Standardization of Reference Evapotranspiration. ASCE-EWRI, Reston, VA 173 pp.
[6] DWR. 1974. Vegetative Water Use, 1974. State of California Department of Water Resources Bulletin 113-3

Using a similar relationship for FCGMA, the annual recomputed ET_o values from 2007 through 2009 were averaged for the eight stations and plotted against their distances from the ocean (**Figure 9**). Excluding the FCGMA Somis and Moorpark stations, a linear relationship can be drawn, similar to those in **Figure 8**. There are problems with the weather data from Moorpark and Somis, resulting in lower ET_o values (either data quality that cannot be pinpointed or station siting).

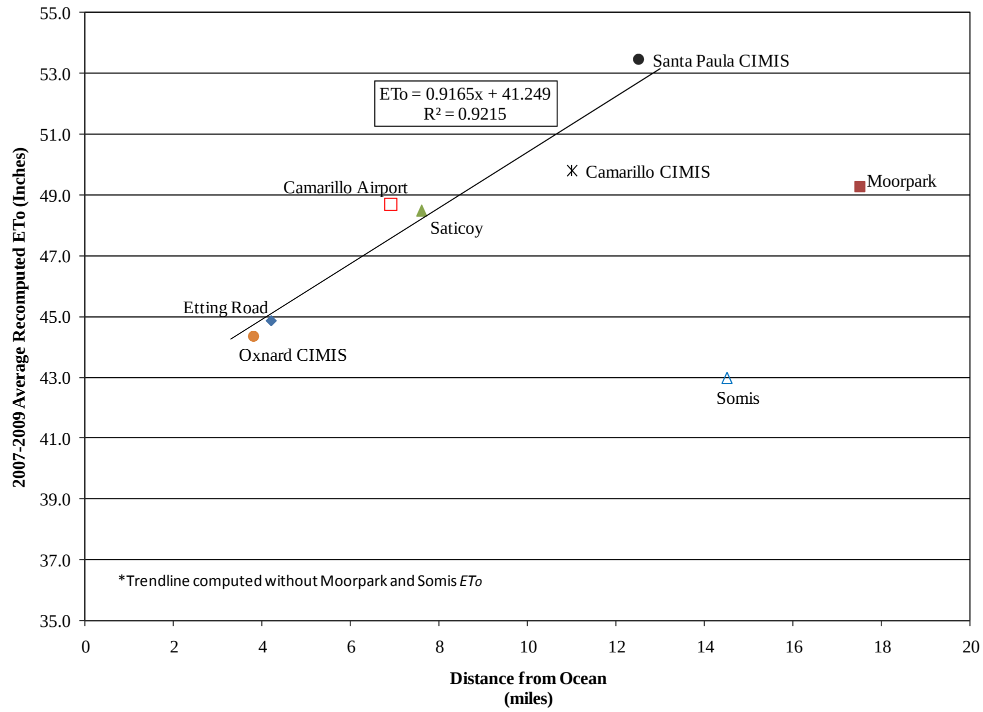

Figure 9. Relationship between 2007-2009 average annual recomputed ET_o and distance from ocean for the 8 weather stations in the coastal region of Ventura County

The relationship between ET_o and distance from the ocean confirms the need for multiple weather stations or zones in FCGMA. ITRC recommends using three ET_o zones with boundaries at different distances from the ocean to account for these coastal effects.

The three ET_o zones recommended are shown in **Figure 10**. These zones are loosely based on the DWR ET_o zone map, which indicates coastal effects similar to those seen in **Figure 9**. This zoning would allow the agency to abandon one or two existing stations and invest more into the quality of the existing stations. One station that seems to consistently provide poor data is Somis. 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

If more appropriate site conditions can be established for any of the FCGMA stations, the recommended combination of stations listed above should be revisited.

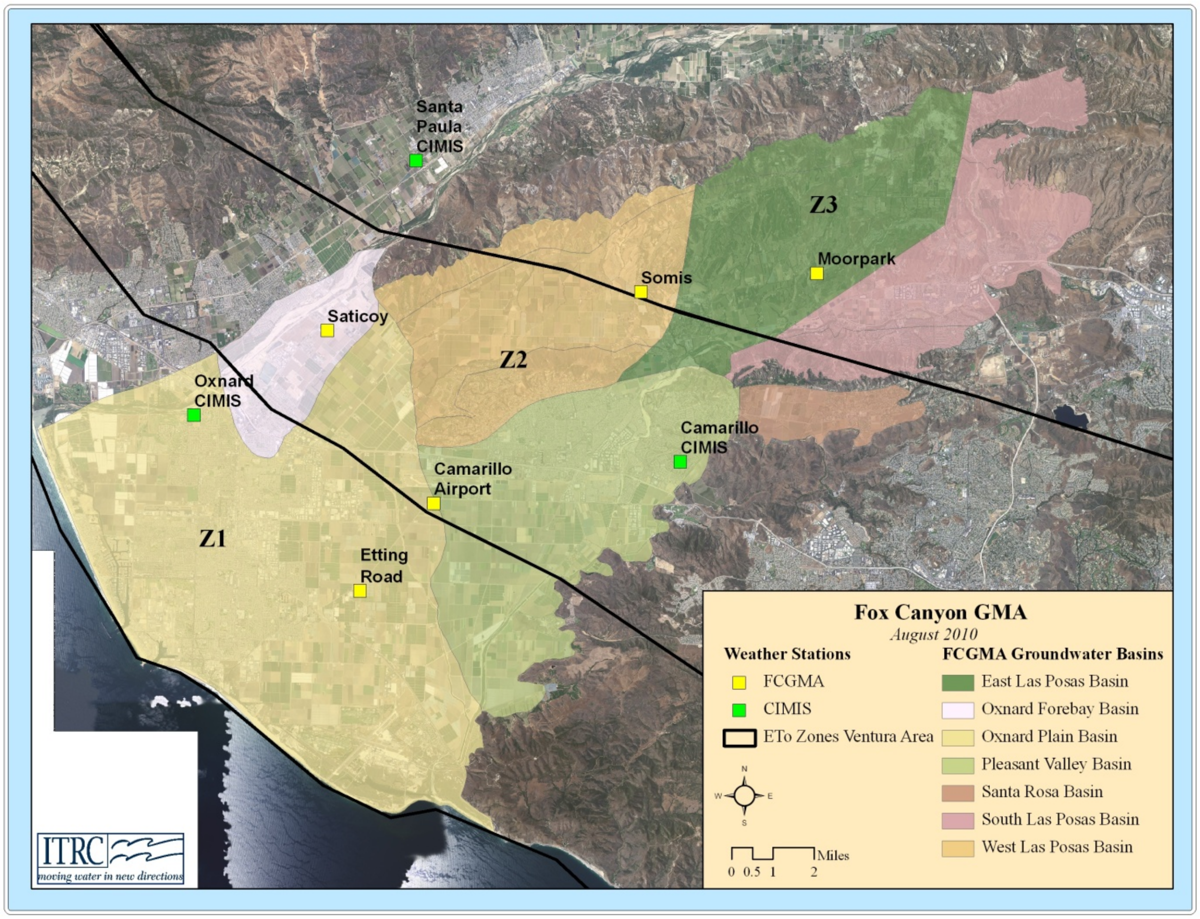

Figure 10. Possible ET_o zones for FCGMA and weather station locations