CALIFORNIA DEPARTMENT OF WATER RESOURCES

Advancement in Modeling Evapotranspiration for CalSim3 Model

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Acknowledgment

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- James Polsinelli - DWR
- Ruian Dhong – DWR
- Andy Draper – Stantec
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Motivation

- **Spatial ET Dataset:** To develop a **spatially distributed** evapotranspiration dataset for the CS3 domain and the CA state.
- **Long Term Dataset**: To create a **long-term** ET dataset (1922-2021) filling the limited historical range of high-resolution data.
- **Refine Spatial Handling:** To better account for the **irregular shapes** of modeling areas compared to data grids.
- **Ensure Consistency:** To bring **consistency** between different models like CS3, C2VSim etc.

Approach

Reference Crop Evapotranspiration (ETo) Update

ETo is the evapotranspiration rate from a reference surface under specific condition.

- Well-watered;
- The reference surface is a hypothetical grass reference crop with specific characteristics such as: Height - 0.12m;
- Surface Resistance: 70 s/m
- Albedo: 0.23

Crop Evapotranspiration (ETc) Update

- ETc represents the actual water use of a specific crop, taking into account factors like plant type, canopy cover, and soil moisture.
- Calculated by multiplying ETo by a crop coefficient (Kc), which reflects how the specific crop's water use differs from the reference grass.

Background

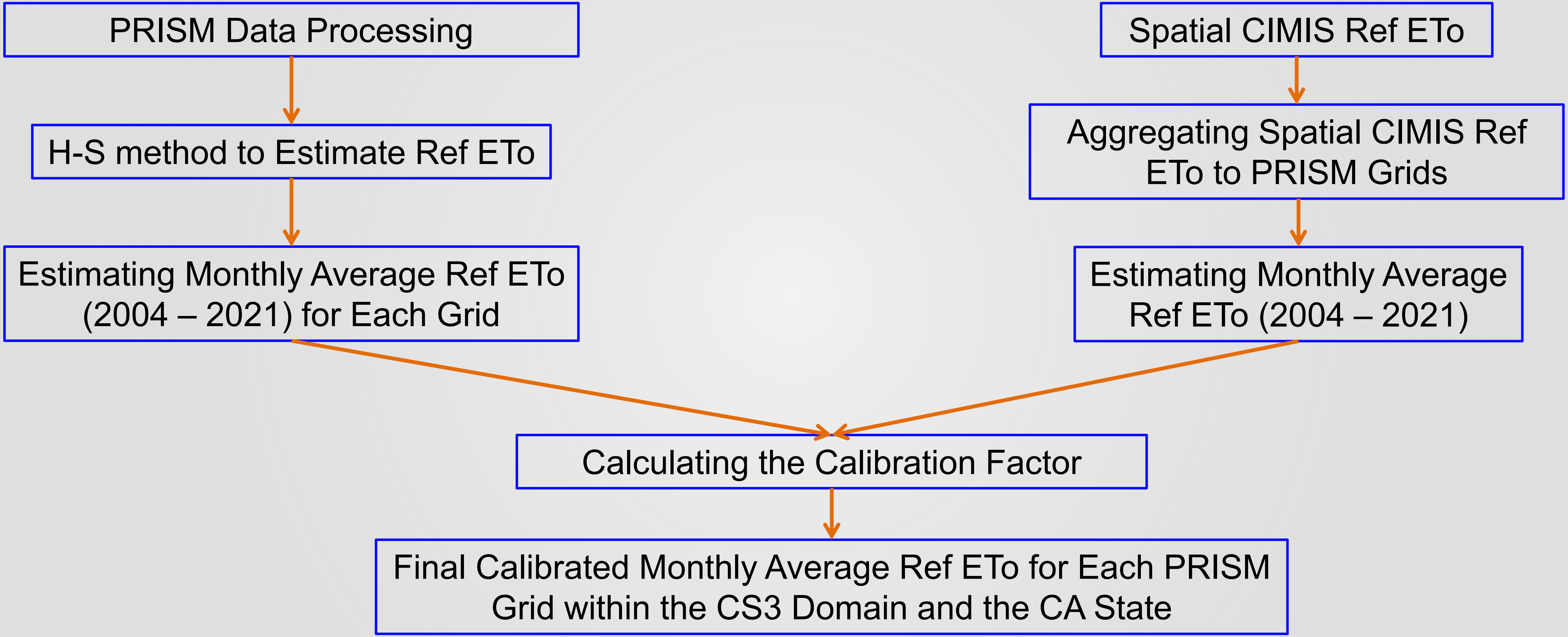
Development of Hargreaves-Samani based Ref ETo for CalSim3

1. Two (2) Factors Method with H-S Timeseries at CIMIS Stations
   a. Factor 1: Adjust Hargreaves-Samani (H-S) ETo vs CIMIS Penman-Monteith ETo.
   b. Factor 2: Spatial offset between WBA centroid and CIMIS station.
   c. H-S Timeseries at CIMIS Stations with the two calibration factors to represent WBA’s ETo.

2. One Factor Method with H-S Timeseries at WBAs
   a. Factor 1: Adjust Hargreaves-Samani (H-S) ETo vs CIMIS Penman-Monteith ETo.
   b. H-S Timeseries at WBAs with the calibration factor at the nearest CIMIS station to represent WBA’s ETo.

3. Spatial CIMIS Method with H-S Timeseries at PRISM Cells
   a. H-S Timeseries at all 4x4 km PRISM cells.
   b. Calibration factors at PRISM cells using spatial CIMIS dataset.
   c. Area averaged PRISM cell H-S Timeseries to present WBA’s ETo.

Methodology



Methodology

❑Step 01: PRISM Data Processing

- ❖ PRISM Tmax and Tmin data download.
- ❖ Data extraction.
- ❖ Grid selection – Defining area of interest for CS3 model domain and CA state.
- ❖ Data extraction for selected PRISM grids.

Methodology

❑Step 02: H – S Ref ETo Calculation

- ❖ Retrieves Tmax and Tmin for each grid.
- ❖ Computes monthly average Ra values.
- ❖ Uses the Hargreaves – Samani equation to estimate ETo

$$ETo = 0.0023.\mathrm{R}_a.(\mathrm{T}_{max} - \mathrm{T}_{min})^{0.5}.(\mathrm{T}_m + 17.8)$$

- ❖ Converting ETo from mm/day to inch/month.

Methodology

❑Step 03: Monthly Average ETo for PRISM Grid

- ❖ Calculating monthly average ETo for each PRISM grid for the period of January 2004 to December 2021.

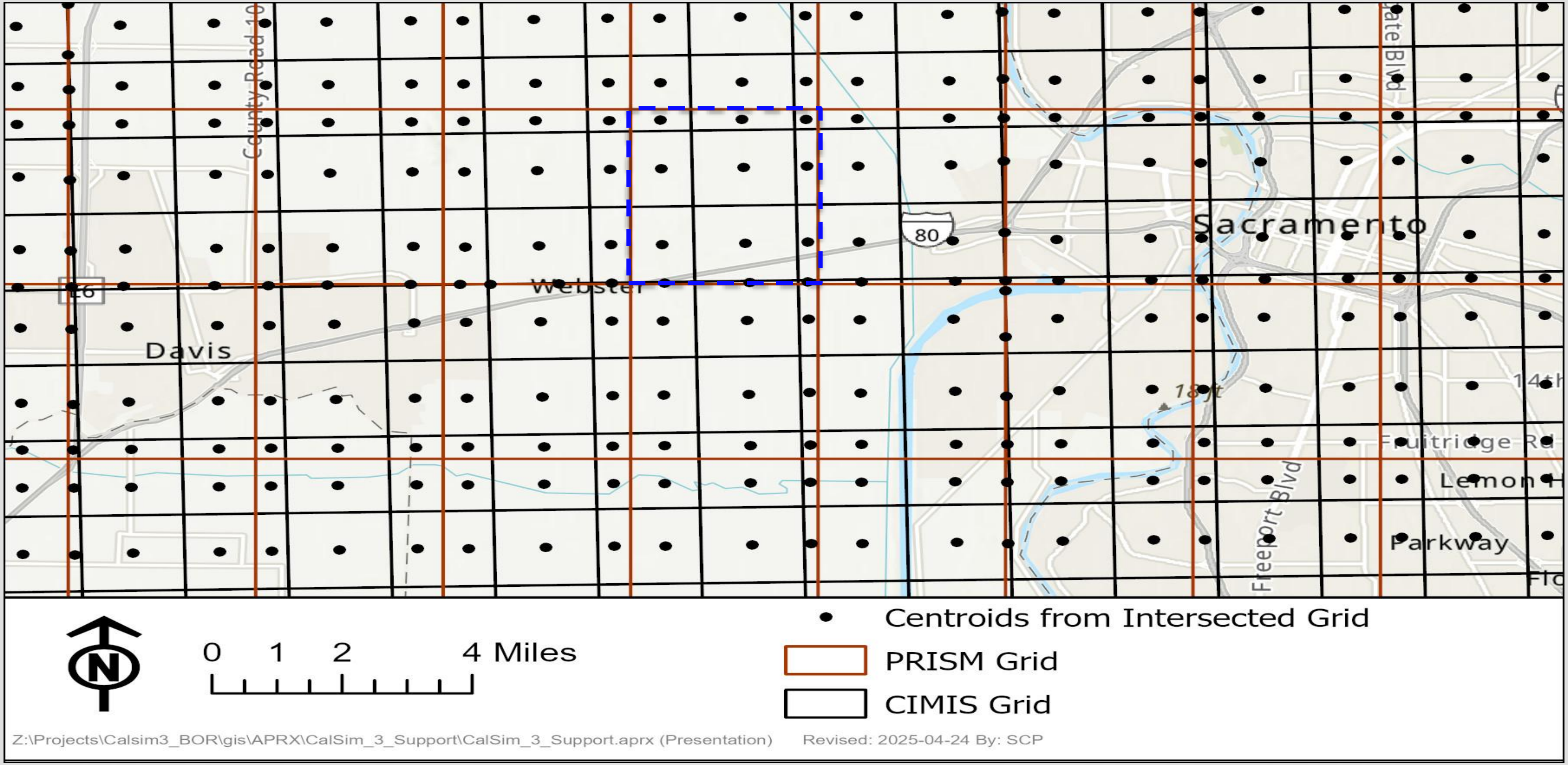
Methodology

❑Step 04: Spatial CIMIS ETo Data Processing

- ❖ Downloading Spatial CIMIS ETo data for the CA state
- ❖ Checking for missing dates.
- ❖ CIMIS grid creation
- ❖ PRISM grid creation
- ❖ Projecting coordinate system to UTM Zone 10N

Methodology

❑ Step 05: Aggregating Spatial CIMIS Ref ETo



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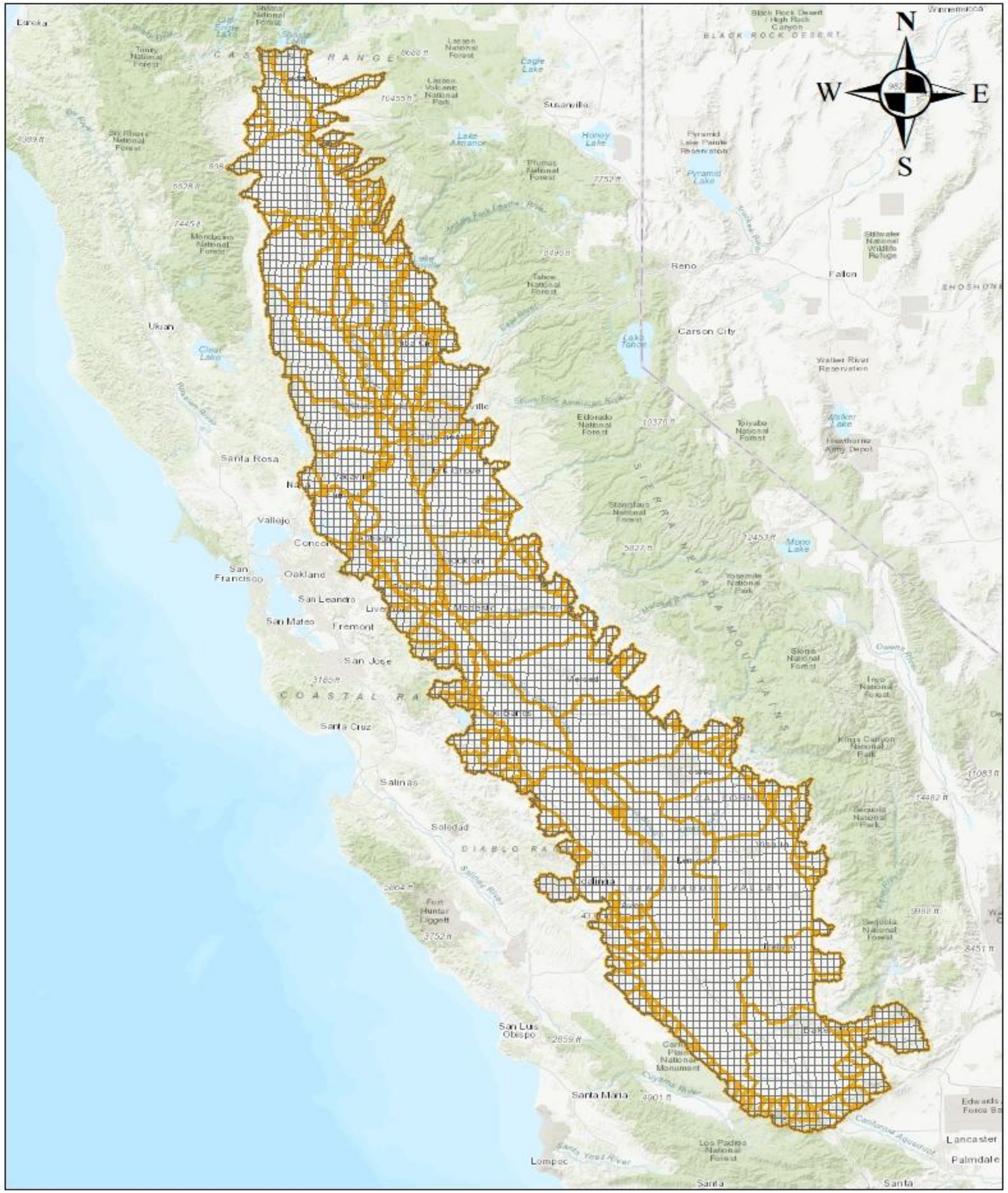
Methodology

❑Step 07: Calculating Calibration Factor

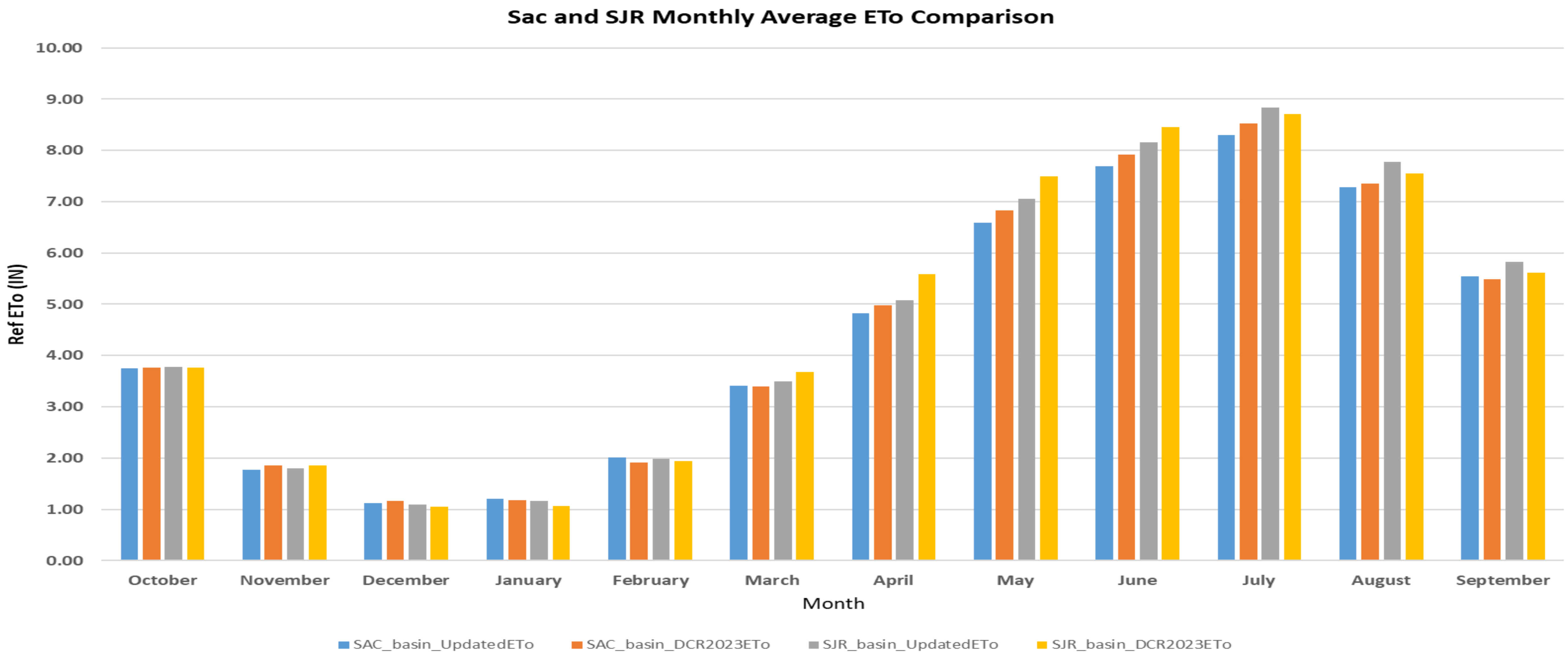
$$f_1(m, grid) = \frac{ET_{2004-2021}^{spatial\ CIMIS,grid}(m)}{ET_{\mathrm{HS}_{2004-2021}}^{PRISM,grid}(m)}$$

$$ETo^{PRISM\ Grid}(m, y) = f1(m).\,\mathrm{ETo_{HS}}^{PRISM\ Grid}(m, y)$$

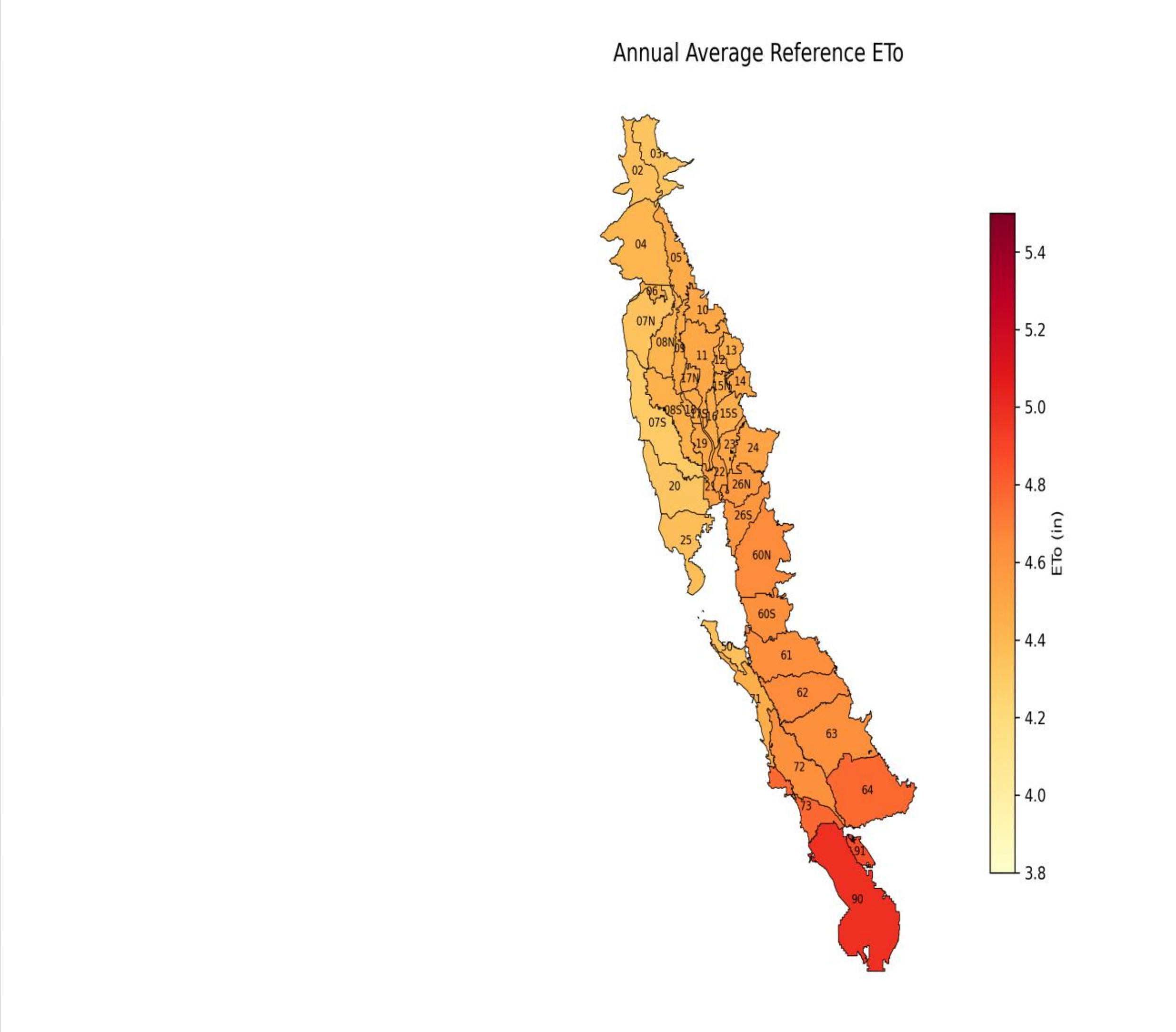
Spatial Average Ref ETo for CS3 Domain



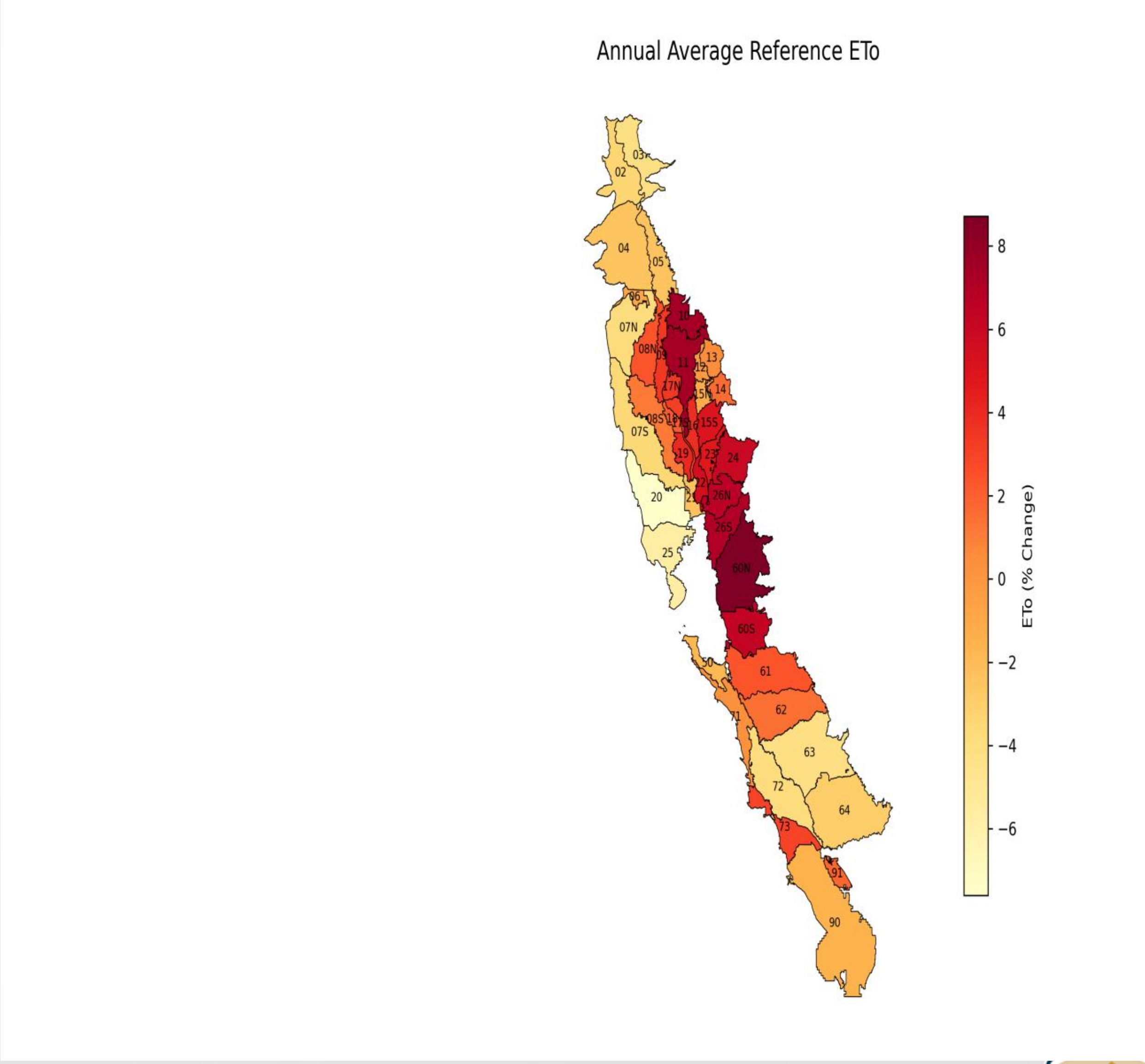
Ref ETo Comparison



Ref ETo Comparison



Updated Ref ETo



FAO-56 Single Crop Coefficient Method

$$ET_c = K_c \times ET_o$$

The calculation procedure for crop evapotranspiration, ETc, consists of:

1. Constructing the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and
   a) Identifying the crop growth stages, determining their lengths, and selecting the corresponding Kc coefficients;
   b) Adjusting the selected Kc coefficients for frequency of wetting or climatic conditions during the stage;

2. Calculating ETc as the product of ETo and Kc.

FAO-56 Single Crop Coefficient Method

$$ET_c = K_c \times ET_o$$

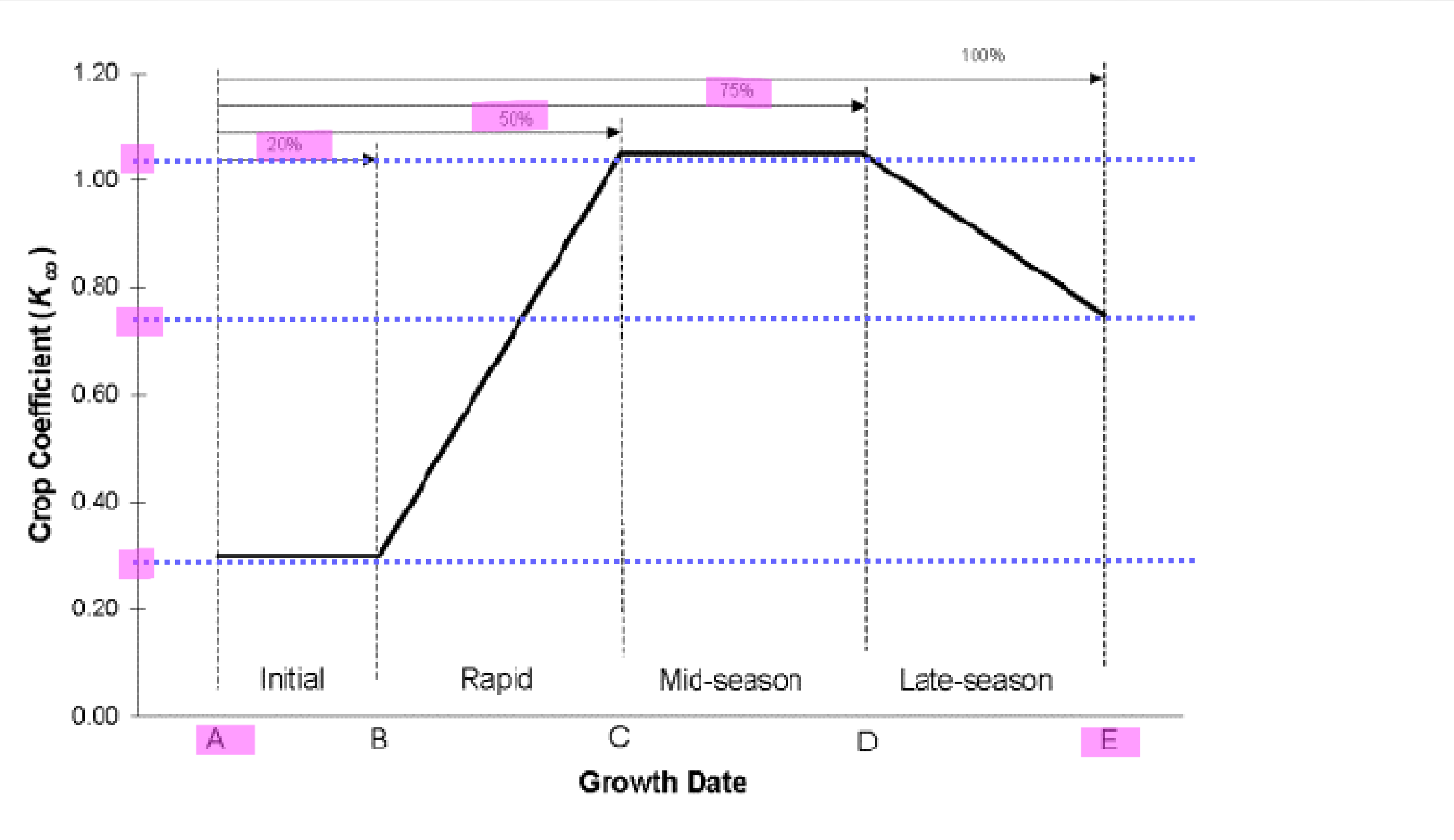


Figure 3. Hypothetical crop coefficient (K_c) curve for typical field and row crops showing the growth stages and percentages of the season from planting to critical growth dates.

= *CropRef.csv Input*

LUCI File Crop Information

- Crop information is from published sources that have been adjusted based on input from farm advisors, farmers, and DWR region office staff. LUCI files are named according to DAUCo and are organized by DWR Region Office.
- Previously 43 individual crops, now 47 crops with 112 different crop variations

DAU_Co:	3-digit DAU code underscore County name
Crop Cat. #	Crop identification number used in Cal-SIMETAW. This is the numeric portion of the crop ID in the Output files. Table 3 lists the crops and land uses associated with each crop ID.
Crop #	See Crop Cat. # above
Crop Name	Name of crop or land use
Crop Type	Crop type number
Growing Season	The Growing Season is defined with start and end dates: Begin Mon (month) and Begin Day, and End Mon and End Day. These correspond to points A and E on Figure 2.
Irrigation Frequency	The number of days between irrigation events during the initial growth period. 30 days is the default value.
Crop Coefficients	Crop coefficients KcB, KcC, KcD, KcE corresponding to dates B, C, D, and E shown on Figure 2
Percent Season	Defines points B, C, and D as a percentage of growing season from start of season, A. (Figure 2)
Root Depth (RDx)	Maximum effective rooting depth during growing season in millimeter (mm)
AD%	Allowable depletion (%); percent allowable depletion of soil water content between irrigation events.
Ground Shading	Ground cover percentage on date B, C, D, and E, which are used to account for immaturity effect on Kc values for tree and vine crops. Values of '70%' or greater indicate that the tree or vine crop is mature.

DAUCO:	1723											Percent of Season			Crop Coeffiecients			
Crop Cat	Crop No	Crop Name	Begin Mo	Begin Day	End Mon	End Day	Planted Area	Crop Type	RDx	AD	CF	A-B	A-C	A-D	KcB	KcC	KcD	KCE
#	#		#	#	#	#	acres	#	mm	%	%	#	#	#	#	#	#	#
1	1.08	Grain	11	1	5	15	69.48808684	1	1067	55	83	20	45	75	0.33	1.05	1.05	0.15
10	10.01	Pasture	10	1	9	30	82.21198246	2	610	60	77	25	50	75	0.95	0.95	0.95	0.95
10	10.06	Misc._grasses	10	1	9	30	2.534993389	2	610	60	77	11	22	92	0.95	0.95	0.95	0.95
10	10.12	PastureX	5	1	9	30	831.9427233	2	610	60	77	25	50	75	0.95	0.95	0.95	0.95
10	10.14	Misc._grassesX	5	1	9	30	3.801753873	2	610	60	77	11	22	92	0.95	0.95	0.95	0.95
16	16.251	Vegetables-Fall-1	10	1	12	15	3.814924795	1	610	35	80	33	67	92	0.8	0.9	0.9	0.9
16	16.26	Nursery	10	1	9	30	2.726285284	2	610	35	86	0	41	89	1.05	1.05	1.05	1.05
20	20.01	Grape	3	15	10	31	67.24826561	3	2000	40	86	0	25	75	0.45	0.8	0.8	0.35

PyCUP – CalSim3 Pre- Processing and Water Budget Areas (WBA)

LUCI File CSV files

Parameters:
By DAU-CO
By Crop

PyCUP Excel Input Tool

Produces PyCUP Input Files by WBA

Csh_CropTable.csv

Crop Category Weighting

CropRef.csv

Defines Kc Curve

Daily Data 1921-2021, Aggregated by WBA

ETo.csv

Precip.csv

Daily Data 1921-2021, Aggregated by WBA

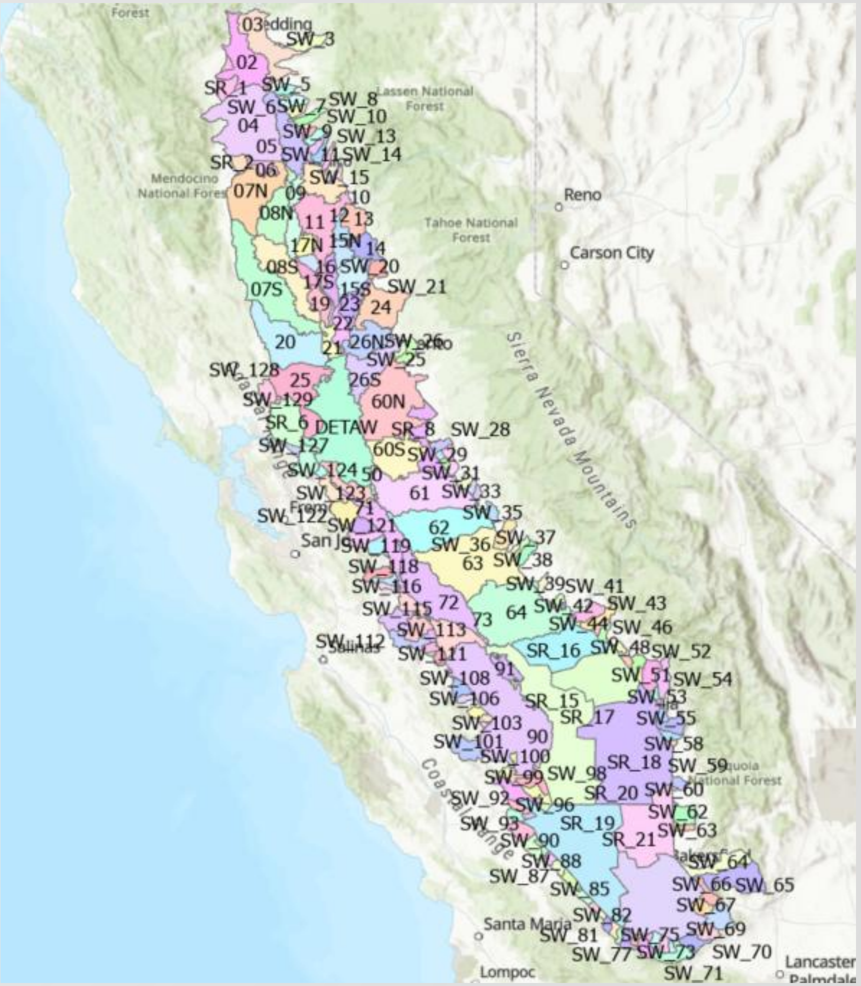
08_AbvCUPmodel_parrallel.py

PyCUP Script

PythonGenETc.dss

CalSimHydro

Determines Applied Water, Deep Percolation, Tailwater, etc. for CalSim3 Demand Unit Timeseries Inputs



ETc UTM10N Shape File (172 separate areas)

1. Correcting Kc – Immature Crops

- The following equation is used to adjust the mature K_c values (K_{cm}) as a function of percentage ground cover (C_g): $If\ \sin\left(\frac{C_g}{70}\frac{\pi}{2}\right) \geq 1.0\ then\ K_c = K_{cm}\ ;\ else\ \boldsymbol{K_c} = \boldsymbol{K_{cm}}\,[\boldsymbol{sin}\left(\frac{\boldsymbol{C_g}}{\boldsymbol{70}}\frac{\boldsymbol{\pi}}{\boldsymbol{2}}\right)]$

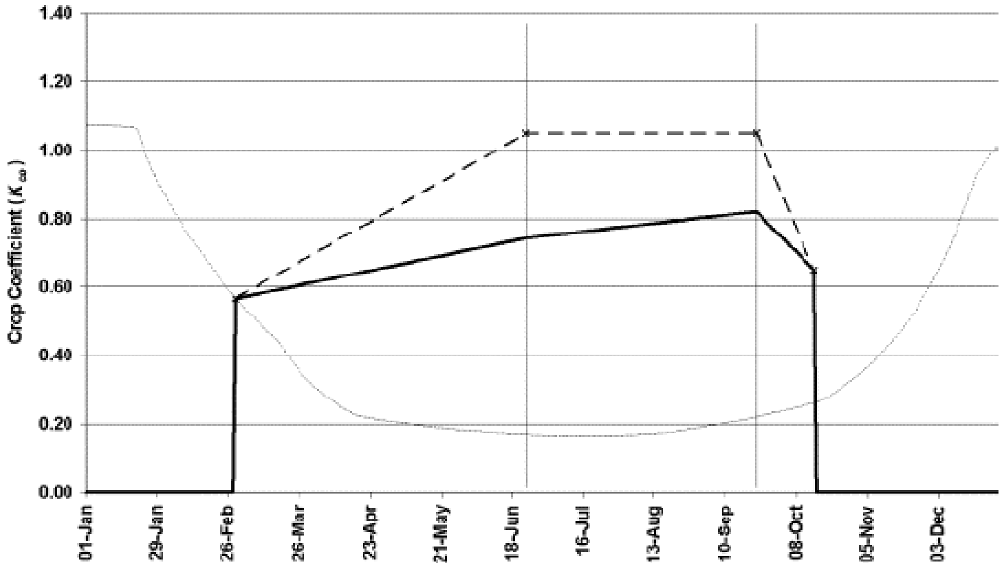


Figure 7. Crop coefficient curve for a stone fruit orchard grown near Fresno, California. The dashed line is for a clean cultivated, mature orchard and the solid line is for an immature orchard having C_g=35% and C_g=40% at the beginning and end of the midseason period. The dotted line is for bare soil evaporation.

2. Correcting Kc, initial - Bare Soil Evaporation

- A two-stage method for estimating soil evaporation presented by Stroonsnjider (1987) is used to estimate bare soil crop coefficients.
  - **Computed as a function of the daily ET_o rate and the days between rainfall.**
  - K_c not permitted to fall below the bare soil K_c.

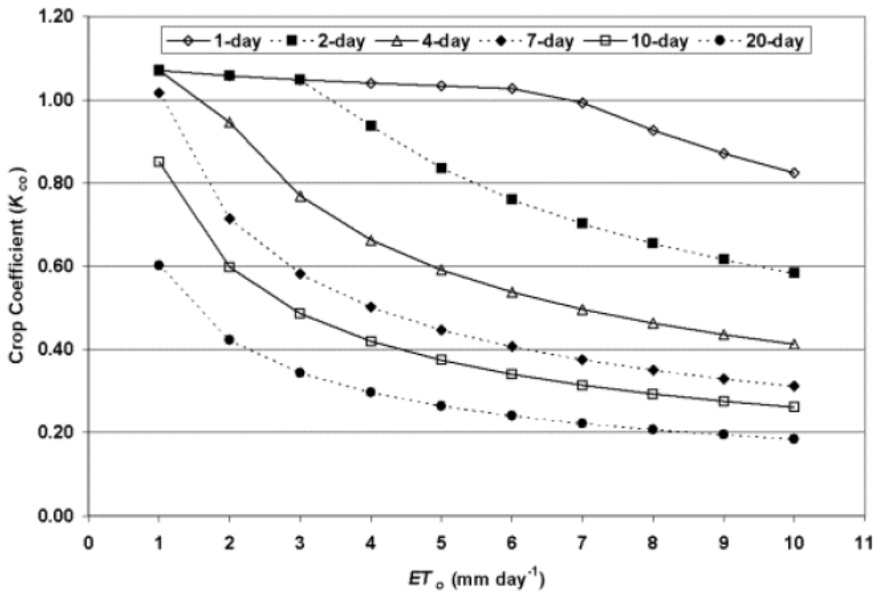


Figure 1. Crop coefficient (K_c) values for bare or near bare soil as a function of mean ET_o rate and wetting frequency in days by significant rainfall or irrigation using a soil hydraulic factor b =2.6.

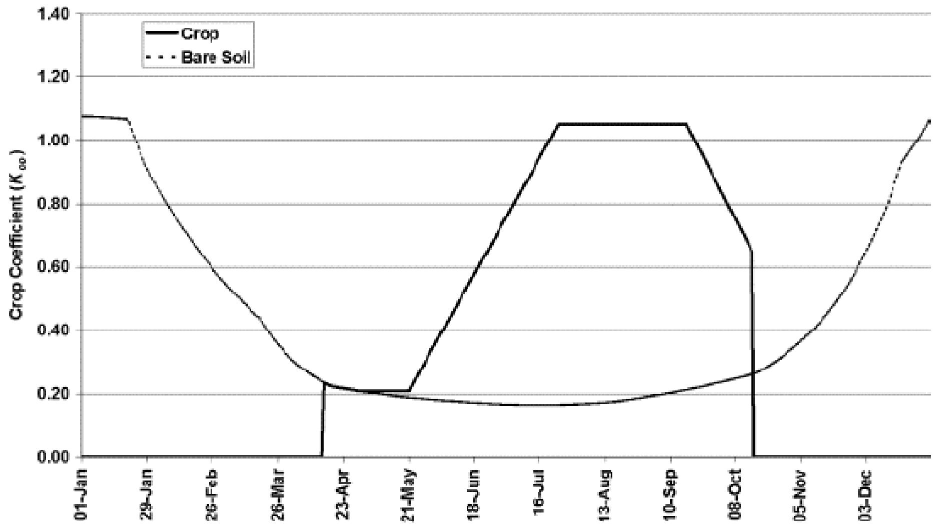
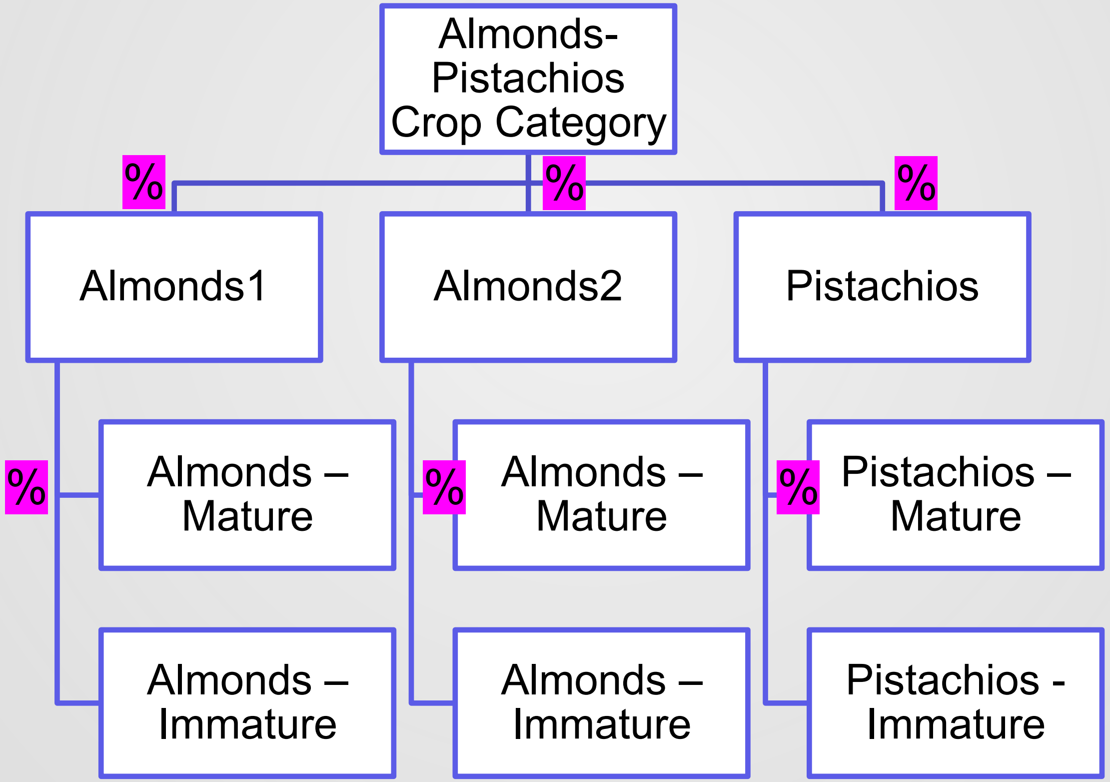


Figure 4. Crop coefficient curve, using a 30 day irrigation frequency during initial growth, for cotton grown near Fresno, California (solid line). Crop coefficient curve for bare soil (dotted line).

Crop Category Weighting by WBA

$$ET_{c,CC\ by\ WBA} = \sum w_{c,WBA} \times ET_{c,crop}$$



* *based on LUCI Data Land Use Acreage*

* *adjusted based in steady state/ historical land use assumption*

= csh_CropTable.csv Input

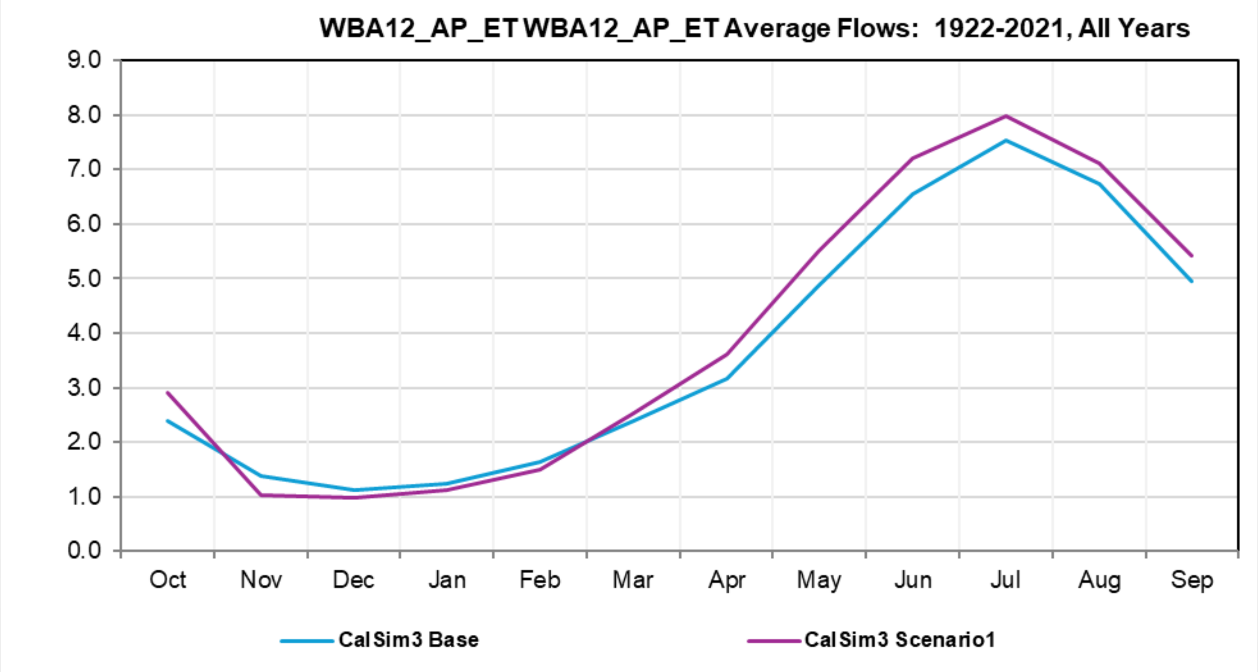
CalSim3 Average Annual ETc (in/year) by Crop Category and Water Budget Area – Non-Calibrated

	Alfalfa	Almond-Pistachios	Cotton	Corn	Cucurbits	Dry Bean	Field Crops (Misc.)	Grain	Native Vegetation	Onions-Garlic	Orchards	Pasture	Potatoes	Sugar Beets	Safflower	Subtropical Orchards	Tomato-Hand	Tomato-Machine	Truck Crops	Vineyards
WBA02	42.51	46.03	35.55	31.34	29.37	29.23	40.70	26.75	34.17	31.99	41.37	46.43	39.15	42.62	32.04	36.67	34.49	33.15	39.97	34.71
WBA03	42.48	44.18	35.66	31.53	29.60	29.44	40.73	27.10	34.32	32.23	41.25	46.37	39.26	42.69	32.11	41.37	34.64	33.31	36.25	34.76
WBA04	42.44	45.86	34.81	30.33	28.23	29.44	40.14	26.04	33.29	30.89	41.19	46.76	38.43	42.10	31.41	36.60	33.64	32.78	51.77	34.30
WBA05	43.07	46.50	35.31	30.75	28.63	29.84	40.15	22.87	33.75	31.29	41.79	47.47	39.02	42.72	31.86	41.77	34.08	33.26	51.99	34.84
WBA06	42.43	45.90	34.52	30.02	27.84	29.12	38.83	26.00	33.07	30.55	41.12	46.93	38.23	41.98	31.28	37.88	33.42	32.55	38.49	34.15
WBA07N	41.48	44.91	33.64	29.22	27.06	28.33	37.91	25.47	32.18	29.66	40.18	45.97	37.26	40.98	30.55	37.05	32.55	31.68	37.58	33.40
WBA07S	41.26	44.66	33.53	29.11	26.93	28.22	37.76	25.21	32.00	29.51	39.99	45.59	37.10	40.82	30.30	36.79	32.37	31.55	37.39	33.23
WBA08N	42.13	45.63	34.16	29.60	27.40	28.70	38.46	25.91	32.64	30.04	40.80	46.71	37.84	41.60	31.02	37.63	32.99	32.13	38.19	33.94
WBA08S	42.33	45.90	34.30	29.72	27.48	28.81	38.67	25.77	32.79	30.19	41.01	46.93	38.04	41.88	31.04	37.76	33.14	32.30	38.38	34.05
WBA09	42.86	46.57	34.92	30.30	28.09	29.39	37.64	24.17	33.38	30.80	41.53	47.42	38.67	42.45	31.59	39.85	33.71	32.88	44.32	34.59
WBA10	43.42	47.01	35.87	31.35	29.28	30.43	39.30	24.62	34.26	31.94	42.19	47.74	39.58	43.21	32.21	40.57	34.57	33.81	43.72	35.23
WBA11	43.24	46.53	35.51	30.91	28.73	29.78	36.64	19.94	33.90	31.43	43.02	47.68	39.24	42.97	31.93	40.99	34.23	32.76	52.36	35.79
WBA12	43.21	46.92	35.59	31.08	28.97	28.87	41.19	26.84	33.99	31.64	42.14	47.58	39.29	42.99	31.90	39.80	34.32	33.07	52.56	35.00
WBA13	43.35	47.01	36.09	31.69	29.66	29.50	41.49	27.06	34.46	32.29	42.34	47.50	39.77	43.35	32.20	36.80	34.78	33.61	52.40	35.26
WBA14	45.12	45.71	36.26	31.78	29.75	29.56	34.06	14.00	34.51	32.37	43.90	47.53	39.95	43.59	32.10	36.35	34.84	33.75	51.26	36.42
WBA15N	44.57	44.97	35.39	30.89	28.79	28.68	33.21	13.63	33.75	31.44	43.14	46.98	39.08	42.75	31.62	35.83	34.08	32.87	50.71	35.78
WBA15S	44.47	44.90	35.30	30.79	28.68	28.57	33.10	13.42	33.60	31.30	43.08	46.88	38.98	42.66	31.43	35.73	33.93	32.77	50.61	35.69
WBA16	42.54	44.86	35.13	30.55	28.41	27.44	30.83	13.60	33.46	31.06	43.80	47.30	38.83	42.57	31.43	35.56	33.79	32.24	52.20	35.66
WBA17N	42.63	44.84	34.96	30.38	28.19	27.26	30.68	13.65	33.43	30.90	43.75	47.48	38.74	42.54	31.56	35.65	33.77	32.05	52.43	35.65
WBA17S	42.59	44.89	35.00	30.38	28.14	27.23	30.66	13.44	33.39	30.84	43.81	47.42	38.75	42.56	31.47	35.61	33.73	32.08	52.36	35.67
WBA18	44.61	44.54	34.59	29.99	27.76	26.87	30.37	12.72	33.02	30.46	41.05	45.52	38.31	42.13	31.19	40.34	33.36	31.67	52.18	35.33
WBA19	44.97	45.07	35.15	30.51	28.27	27.36	30.88	12.73	33.51	31.00	41.60	45.88	38.90	42.70	31.53	41.72	33.85	32.21	50.38	35.76
WBA20	42.52	43.31	33.88	29.39	27.24	26.37	29.93	10.48	32.25	29.81	40.55	44.79	37.48	41.20	30.44	35.68	32.61	31.04	50.65	34.49
WBA21	44.46	45.59	35.49	30.74	28.47	27.84	32.53	15.96	33.77	31.22	42.41	46.88	39.30	43.17	31.69	37.16	34.10	32.74	53.12	35.92
WBA22	45.27	45.28	35.58	30.86	28.60	27.67	31.75	13.56	33.87	31.37	42.61	46.86	39.38	43.23	31.72	36.58	34.21	32.62	48.43	36.13
WBA23	44.97	45.36	35.56	30.94	28.75	27.79	31.25	13.55	33.84	31.45	42.49	46.24	39.32	43.09	31.64	35.92	34.18	32.67	51.09	35.98
WBA24	46.14	45.76	36.27	31.70	29.57	28.57	33.84	14.43	34.47	32.26	42.59	46.87	40.01	43.73	32.01	41.93	34.81	33.44	53.04	36.46
WBA25	44.06	43.80	34.09	29.53	27.36	26.44	29.77	12.92	32.41	29.92	40.88	46.28	37.73	41.49	30.61	36.69	32.76	31.21	50.84	34.80
WBA26N	46.20	46.16	36.32	31.62	29.40	28.42	31.88	13.48	34.55	32.18	43.14	48.52	40.15	43.97	32.18	38.49	34.89	33.39	53.28	36.65
WBA26S	46.37	46.32	36.38	31.59	29.37	28.37	31.86	13.36	34.56	32.16	43.27	48.71	40.21	44.07	32.19	38.62	34.90	33.40	53.51	36.74
WBA50	43.15	43.75	34.64	29.70	27.55	26.65	34.53	12.39	32.55	19.73	41.94	44.85	37.84	41.48	30.74	34.61	32.89	31.35	38.51	34.85
WBA60N	46.81	46.62	36.36	31.47	29.15	28.19	39.36	12.01	34.54	20.12	44.17	48.65	40.27	44.25	32.19	36.96	34.87	33.34	53.41	36.87
WBA60S	46.20	46.29	36.01	31.09	28.77	27.85	35.56	11.15	34.30	20.03	43.84	48.59	39.95	43.92	32.11	36.52	34.63	32.97	53.14	36.63
WBA61	46.26	46.29	35.88	30.93	28.57	27.68	35.45	11.01	34.21	19.98	43.82	48.67	39.83	43.87	32.08	36.53	34.54	32.81	53.25	36.61
WBA62	46.35	46.36	35.87	30.89	28.52	27.63	35.46	10.96	34.26	20.00	43.86	48.77	39.87	43.93	32.19	36.58	34.58	32.78	53.37	36.66
WBA63	46.14	46.08	35.60	30.63	28.24	27.37	35.22	10.75	34.05	19.80	43.58	48.57	39.63	43.71	32.01	36.37	34.37	32.52	53.17	36.40
WBA64	47.36	47.35	36.25	31.07	28.54	27.68	35.91	10.59	34.70	20.15	44.72	49.86	40.43	44.76	32.75	37.27	35.01	33.05	54.62	37.35
WBA71	44.31	43.83	33.57	28.80	26.57	25.69	33.15	10.74	31.95	19.33	41.40	46.65	37.29	41.23	30.32	34.95	32.30	30.58	51.09	34.63
WBA72	45.87	45.41	34.62	29.61	27.23	26.35	34.22	10.63	33.02	19.69	42.86	48.30	38.56	42.71	31.32	36.09	33.34	31.51	52.94	35.81
WBA73	47.07	46.19	34.90	29.62	27.23	26.28	34.39	10.61	33.08	19.78	43.54	49.61	38.85	43.16	31.40	36.96	33.39	31.65	54.43	36.26
WBA90	49.26	48.56	36.91	31.40	28.89	27.91	36.40	11.06	35.06	20.19	45.83	51.90	41.11	45.54	33.18	38.70	35.33	33.53	56.91	38.17
WBA91	48.39	48.40	37.18	31.87	29.36	28.42	36.76	10.94	35.49	20.07	45.75	50.94	41.43	45.76	33.46	38.10	35.77	33.91	55.79	38.19

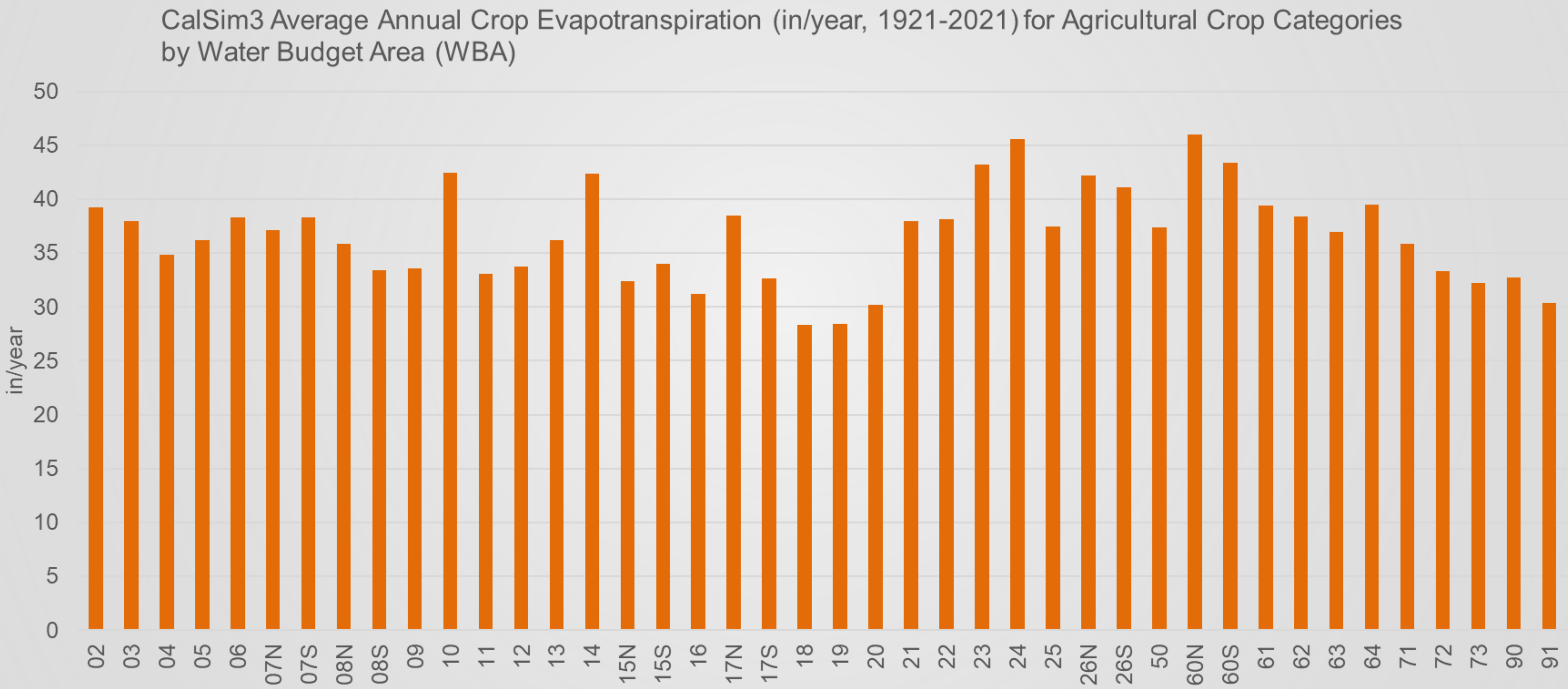
Ex: higher percentage of over winter crops in southern WBAs

Almonds-Pistachio Case Study

	CropType	Crop Name	perSeasonB	perSeasonC	perSeasonD	KcAB	KcCD	KcE	Planting Month	PlantingDay	HarvestMonth	HarvestDay	Growth Season Days	WBA02	WBA12	WBA22	WBA64
ET Update	3	Almonds	0	50	90	0.55	1.11	0.65	2	14	10	26	255	1	1		
	3	Almonds	0	50	90	0.55	1.11	0.65	3	15	10	31	230			0.93	0.9
	3	Almonds	0	50	90	0.55	1.11	0.65	3	10	10	20	224				0.1
	3	Pistachios	0	33	78	0.8	0.9	0.6	3	15	10	31	230			0.07	
LTO 21	3	Almonds	0	50	90	0.55	1.19	0.65	3	1	10	15	228	0.97	0.97	0.97	0.91
	3	Pistachio	0	33	78	0.70	1.14	0.50	3	1	11	26	270	0.03	0.03	0.03	0.09

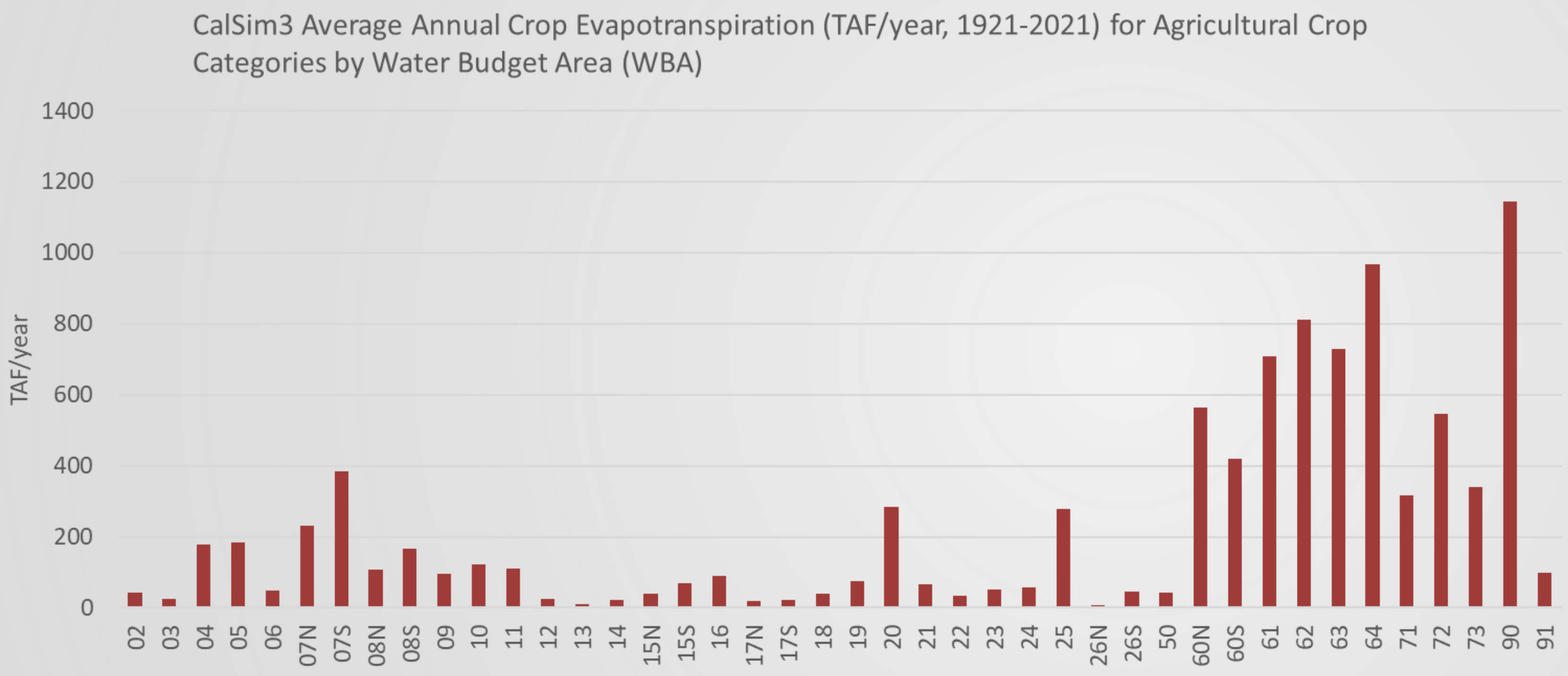


Crop Evapotranspiration

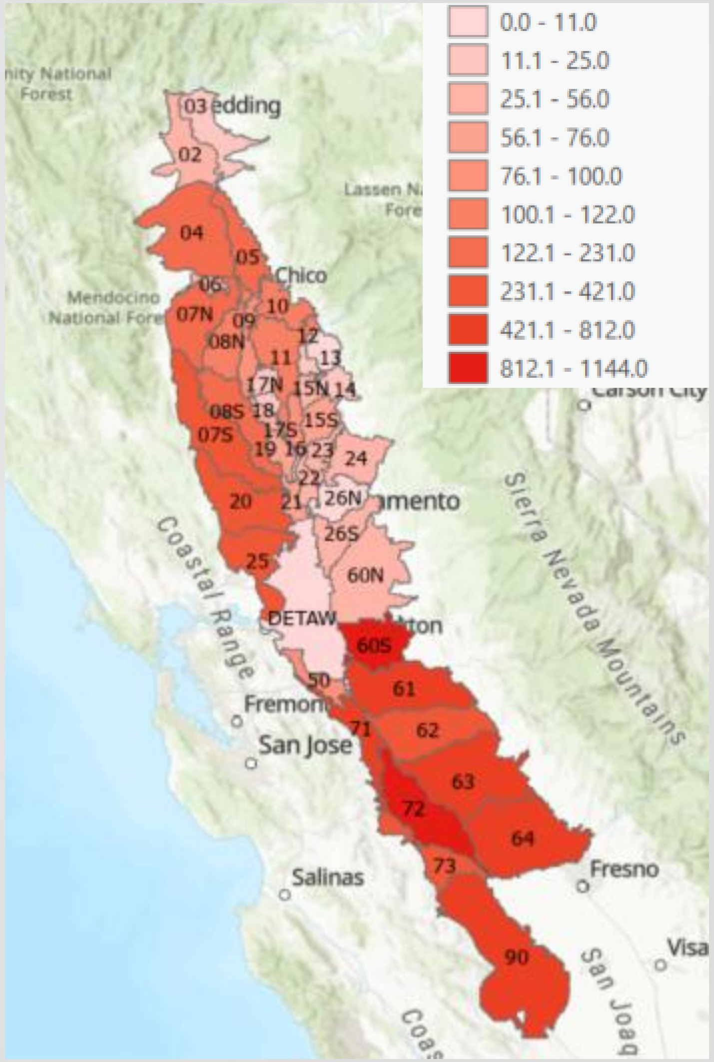


*Uncalibrated, Potential Crop Evapotranspiration

Volumetric Potential Crop Evapotranspiration



**Uncalibrated, Potential Crop Evapotranspiration, CalSim3 DCR 23 Land Use*



Conclusion

- Introduced grid-based, area-weighted approach for developing reference crop ET. Improves upon station-based correction method, preserving local variation.

- Updates long term reference evapotranspiration data and easy incorporation of climate change scenarios

- This method is flexible enough to enable the estimation of spatially averaged reference ETo for multiple defined spatial domain, including Water Budget Areas (WBAs), subregions (SRs), and small watersheds (SWs).

- Improves consistency across model inputs by using a common, gridded data source.