Temperature, Humidity, and Waterlogging Influences on Threshold EC

summary by C. Burt for USBR TWG
September 1993

PART I
Salinity-Temperature Interactions

General

Insufficient research has been done to determine "threshold ECe" values for many crops under the extremely hot conditions which are typical of Imperial Valley summers. Discussions of LR for salt-sensitive crops within IID have generally used salt tolerance values obtained in more moderate climates (often from the U.S. Salinity Lab in Riverside). During the last 10 years, the U.S. Salinity Lab has conducted its salinity trials at the Brawley research stations due to high ozone levels in Riverside, but the Imperial trials have only covered salt tolerant and new crops. The Lab has not been able to adequately evaluate salinity tolerances of salt sensitive crops because of the nature of the soils at the research station; it is too difficult to achieve the high leaching fractions necessary for such research (Maas, personal communication, 1993).

Although there is almost universal agreement that salt tolerances should be reduced at high temperatures, a literature search did not provide quantative answers regarding precise adjustment of salt tolerance data for high temperatures.

Research Results

Several researchers conclude that high temperatures exacerbate the negative effects of salinity on germination, growth and yields of many crops. The majority of work deals with germination and emergence, which is probably due to the simplicity of the measurements and procedures. "With the addition of NaCl, the maximum [lettuce] germination temperatures were lower, as indicated by germination percentages and rates (Coons et al. 1990)." Braun and Khan (1976) noted with lettuce seed germination that "high temperature and salinity appear to accentuate each other's effects. Thus, salinity, low osmotic potential, water deficit, and other soil related stresses may not be readily evident at low temperatures but may find expression at high temperatures."

Similar conclusions have been made regarding crambe germination: "The salinity levels at which a 50% reduction in germination occurred varied somewhat among temperatures. Germination was most tolerant at 20 and 25°C, slightly less tolerant at 10 and 15 °C and less tolerant at 30°C (Fowler 1991)." Hampson and Simpson (1989a) studied early growth of wheat and concluded that temperature stress on wheat germination showed no effect in the absence of salinity. "Temperature stress and salt or osmotic stress intensified each other, with tolerance to one stress being greatest when the other stress was low (Hampson and Simpson 1989a)." Concerning the salt-tolerant *Atriplex*, germination decreased with increasing temperature and salinity. Researchers concluded that there exists a "strong interaction between temperature and salinity level, with temperature and salinity acting synergistically to suppress germination disproportionately at the highest temperature and salinity levels (Mikhiel et al. 1992)."

Experiments with guar seeds resulted in the same conclusions: "In general, percent germination of the three cultivars was reduced with increasing salt concentrations and temperatures, except in the salt control, where there were no significant differences in germination among the different temperatures (Vinizky and Ray 1988)." Francois and Goodin (1972) studied sugar beet germination and stated that "when the temperature exceeds 25°C, an approximate 3 dS/m decrease in salinity must accompany each 5°C increase in temperature to prevent reduction in germination damage." They also noted that sugar beets germinated at 25-35°C had about half the germination rate as at 10-15°C, with about 3 dS/m salinity. At 10-15°C, there was almost no effect on germination due to increased salinity. In the Imperial Valley, soil temperatures are in the 40°C range during sugar beet planting time.

In addition, experiments have been conducted regarding crop growth and yield as a function of temperature and salinity. Exposure to heat during the bean flowering stage reduced yields significantly, but not as much as those exposed to heat during the entire experiment. In addition, pod yields were affected more than vegetative growth. This interaction with the environment was consistent for all salinity levels. "Bean grown in the cool, humid environment tolerated higher salt levels than those predicted from published tolerance data (Hoffman et al. 1978)."

In the case of aster, chrysanthemum, and kidney bean, combined effects of higher temperatures and increased salinity multiply the depressive effects to reduce growth (Lunt et al. 1960). In a field experiment in Torrey Pines, Riverside and Indio, the effect of temperature and salinity on several crops was studied over several years. Squash, tomatoes, onions, beans, sugar beets, cotton, garden beets, and carrots were depressed at a given salt concentration in Indio as compared to the Torrey Pines and Riverside plots. "The results obtained in this study show that most crops are injured by salt to a greater extent in warm than cool climates (Magistad et al. 1943)."

Growth reductions in wheat seedlings were attributed to the combined effects of salinity and temperature (Hampson and Simpson 1989b). Guggenheim and Waisel (1977) noted that Rhodes grass yields dramatically dropped with high temperatures, but it was not clear how to separate the temperature effects.

Humidity also affects salt effects on crops. Nieman and Poulsen (1967) conducted an experiment controlling for humidity and salinity with bean and cotton plants. Under the dry treatment, salinity decreased growth, reduced shoot water content, and deepened leaf color for both crops. Increased humidity consistently improved growth for both crops. "High humidity was most effective in this experiment [cotton]; it essentially abolished the effect of salinity. Under the humid regime the salt-treated plants were indistinguishable from the controls on the basis of appearance (Nieman and Poulsen 1967)." Rhoades (1990) states that "Climate is a major factor affecting salt tolerance. Most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. Yield is reduced more by salinity when humidity is low."

The following paragraph is extracted from page 266, Chapter 13 (Maas, author) of the 1990 ASCE Manual No. 71, Agricultural Salinity Assessment and Management. It summarizes the conclusions previously reported.

> Climate probably influences the response of plants to salinity as much as, if not more than, any other factor. Most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. Studies on several crops, including alfalfa, bean, beet, carrot, cotton, onion, squash, strawberry clover, salt grass, and tomato, have shown that salinity decreased yields more when these crops were grown at higher temperatures (Ahi and Powers 1938, Magistad et al. 1943, Hoffman and Rawlins 1970). Yields of many crops are also decreased more by

> salinity as relative humidity decreases. Experiments indicate that barley, bean, corn, cotton, onion and radish were more sensitive to salt at low humidity than at high humidity. The tolerances of beet and wheat were not greatly affected by humidity (Hoffman and Rawlins 1970, 1971; Hoffman et al. 1971; Nieman and Poulsen 1967)."

Conclusion on Temperatures

In summary, qualitative and limited quantative data support the theory that salt tolerance of many crops is reduced with high temperatures and low humidities. Not only are germination percentage and germination rates affected; but overall growth, quality and yield are negatively affected by the combined effects of high temperatures and salinity. It also seems that the relationship between the two factors is not additive. Rather, the negative effects are multiplied by each other.

PART II
Waterlogging

Waterlogging and temperature influences ion uptake of certain plants. In tomato plants with drained root zones, there were increased sodium ions in the leaves and increased chloride ions in the roots with increased temperatures. In waterlogged treatments, increased temperatures increased Cl^- in the roots. "The results show the direct importance of temperature of growth on the interaction between salinity and waterlogging. That temperature affects the magnitude of the response is seen in the differences occurring between the three temperatures and also between drained and waterlogged treatments at each of the three temperatures (West and Taylor 1980)."

The following paragraph is extracted from page 126, Chapter 6 of the 1990 ASCE Manual No. 71, Agricultural Salinity Assessment and Management:

> In irrigated agriculture under field conditions, surface irrigation, particularly on poorly drained land, can lead to an oxygen deficiency in the root zone of the soil (Meek et al. 1983). Since oxygen deficiency alone adversely affects the growth of most dryland species (Jackson and Drew 1984), the combined effects of salinity and oxygen deficiency would be expected to be particularly damaging. In corn, oxygen deficiency in the root medium under saline conditions led to a breakdown of Na^+ exclusion from the shoots and simultaneously inhibited K^+ transport (Drew

and Lauchli 1985). Oxygen deficiency in the root zone interacts with salinity relative to salt exclusion from the shoot in solution culture (Drew et al. 1988) and under field conditions (Barrett-Lennard 1986).

from page 165, Chapter 8 of the same Manual:

Salt tolerance in saline-drained conditions differs from that in saline-waterlogged conditions. Waterlogging in the root zone combined with salinity can be extremely hazardous. The loss of needed energy from oxidative metabolism disrupts energy-dependent ion uptake and exclusion and extrusion processes in root membranes. Salinity and waterlogging in the root zone greatly increase the uptake of salt (West 1978; West and Taylor 1984). Other important environmental factors that significantly interact with salinity include temperature, wind, humidity, light, and pollution....

References

Braun, J.W. and A.A. Khan. 1976. Alleviation of salinity and high temperature stress by plant growth regulators permeated into lettuce seeds via acetone. J. Amer. Soc. Hort. Sci. 101(6): 716-721.

Coons, J. M., R. O. Kuehl, and N. R. Simons. 1990. Tolerance of ten lettuce cultivars to high temperature combined with NaCl during germination. J. Amer. Soc. Hort. Sci. 115(6):1004-1007.

Fowler, J.L.. 1991. Interaction of salinity and temperature on the germination of crambe. Agron. J. 83:169-172.

Francois, L.E. and Goodin. 1972. Interaction of temperature and salinity on sugar beet germination. Agron. J. 64: 272-273.

Guggenheim, J. and Y. Waisel. 1977. Effects of salinity, temperature and nitrogen fertilization on growht and composition of rhodes grass. Plant and Soil 47: 431-440.

Hampson, C. R., and G. M. Simpson. 1989a. Effects of temperature, salt, and osmotic potential on early growth of wheat (*Triticum aestivum*). I. Germination. Can. J. Bot. 68: 524-528.

Hampson, C. R., and G. M. Simpson. 1989b. Effects of temperature, salt, and osmotic potential on early growth of wheat (*Triticum aestivum*). I. Early Seedling Growth. Can. J. Bot. 68: 524-528.

Hoffman, G. J., J. A. Hobes, Z. Hanscom. and E. V. Maas. 1978. Timing of environmental stress affects growth, water relations and salt tolerance of pinto bean. Trans. ASAE. 21:713-718.

Lunt, O. R., J. J. Oertli, and H. C. Kohl, Jr. 1960. Influence of environmental conditions on the salinity tolerance of several plant species. Proc. VIIth Intern. Cong. Soil Sci. 1:560-570.

Maas, E.V. 1993. Personal conversation. U.S. Salinity Laboratory.

Maas, E.V. and G. J. Hoffman. 1977. Crop salt tolerance -- current assessment. Journal of I&D Engineering, ASCE. 103(2): 115-134.

Magistad, O. C., A. D. Ayers, C. H. Wadleigh, and H. G. Gauch. 1943. Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Plant Physiology. 18:151-166.

Meek, B. D., T.J. Donovan, and L.E. Graham. 1986. Alfalfa stand losses from irrigation: influence of soil temperature, texture, and aeration status. Soil Sci. Soc. Am. J. 50:651-655.

Mikhiel, G. S., S. E. Meyer, and R. L. Pendleton. 1992. Variation in germination response to temperature and salinity in shrubby *Atriplex* species. J. Arid Env. 55:39-49.

Nieman, R. H. and L. L. Poulsen. 1967. Interactive effects of salinity and atmospheric humidity on the growth of bean and cotton plants. Bot. Gaz. 128(1):69-73.

Rhoades, J.D. 1990. Overview: Diagnosis of salinity problems and selection of control practices, Chapter 2 in Agricultural Salinity Assessment and Management (K. Tanji, ed.). ASCE Manual and Report on Engineering Practice No. 71. ASCE. New York, N.Y.

Vinizky, I. and D. T. Ray. 1988. Germination of guar seed under salt and temperature stress. J. Amer. Soc. Hort. Sci. 113(3):437-440.

West, D. W. and J. A. Taylor. 1980. The effect of temperature on salt uptake by tomato plants with diurnal and nocturnal waterlogging of salinized rootzones. Plant and Soil 56:113-121.

Date: Oct. 3, 1993

To: TWG members

From: Charles Burt

Re: Visit to CVWD by myself and Joe Lord on 9/30 and 10/1

Joe and I visited CVWD for five purposes:

1. Resolution of differences in turnout service area boundaries as reported by JM Lord, Inc. and Boyle
2. Estimation of the influence of the Salton Sea on the quantities of drainage water reported by CVWD, plus observations of drain flow measurement sites.
3. Investigation of the types of flows coming out of the drains which directly empty into the White River channel.
4. Investigation of information regarding pumping depths throughout CVWD.
5. Participation in meeting of managers and USBR on Friday morning.

This summary addresses these items. Joe has not had a chance to review this yet. I do not believe there will be any substantial changes recommended by him, as we discussed most of the items and saw the same things.

During Thursday, we were accompanied by Jim Weston, Assoc. Water Mgt. Spec. of the CVWD.

Item #1 - Acreage estimates.

Joe brought his maps showing the turnout service area, and I brought overlays which I obtained from Boyle Engineering that represented Boyle's efforts. We overlaid the two boundaries. The following should be noted:

- The Boyle boundaries were from an older map of the district distribution system.
- The JMLord boundaries were based on an aerial photo of 1992 crops and used the current CVWD distribution system map (updated March 18, 1986).

I believe the following can be stated based upon the quick comparison:

1. The Boyle report overestimated the area on about 3000 acres (comparing 1987 vs. 1992), as contrasted to JMLord, Inc.
2. The Boyle report did not include about 5300 agricultural acres included by JMLord, Inc. This difference is primarily due to the assumption by JMLord, Inc. (which I agree with, having looked at the maps) that although there are no turnouts directly supplying each 40 acres in the 5300 acre area, the water is probably moved throughout those acres by pipelines.
3. In addition, the JMLord, Inc. report includes about 1100 additional acres of golf courses. I am not sure how those acreages were used in the JMLord studies, but Joe can explain it.

From this quick comparison, it appears that the major differences in acreage are due to assumptions about fallow land and vegetable acreages.

Item #2 - Salton Sea direct contribution to the pumped drainage.

Joe has mentioned that some of the tile lines close to the Sea are drawing in water from the Salton Sea. We visited the cropped area next to the Sea to try to quantify this contribution.

On the western edge of the Salton Sea, there are 3 tile sump pumps. We visited each of those. On the eastern edge, there are an additional 12 sump pumps. We visited some of those. At each site, an estimate was made of the flow rates of the pumps or else observations of the water trajectory from a discharge pipe were made. The ground slope was also observed (but not measured), and it appears that within a few hundred feed to the Sea, the crop root zones are apparently above the level of the Sea.

A brief summary of each of the sumps visited is given below. Pictures were taken and are being developed.

Sump Pumps Near the Salton Sea

Sump Location	Flow rate Information	Approx. Continuous GPM	Other Information
Ave. 81.5 (West)	Similar to Grant 84	160	
Grant & 84 (West)	Cycles from 3/4 full to almost 0.0 on 1.5 min. cycle 6" pipe	160	
Grant So. of 84 (West)	Joe's estimate of flow rate. Continuous	200	Joe estimates 1 - 1.5% of the flow is from the Sea.
Hayes & 71 (East)	Full 4" pipe. 3.5' out at 12" drop. 3 min on, 9 min off	560/4 = 140	No apparent outlet from district subsurface drain system. However, water was boiling up at a point in the surface drain, indicating that the district outlet was buried.
Hayes 0.5 (East)	4" pipe. No flow for 7 min, 37 sec. Flow full for 1 min, 39 sec. Shoots out 4.5' for 12" drop	720 x .18 = 128	
Garfield 0.5 (East)	8" steel pipe, fairly constant flow rate. About 3" deep water. Drops about 12" in 12" horiz.	210	District outlet location not known.??
Arthur St. (East)	8" steel pipe. Varies from full (12" drop in 12" horiz) to zero.	640/2 = 320	The District drain isn't apparent. Maybe the pump also lifts the water from the district drains. Joe estimates "a lot of the flow, but less than 50%" is from the Sea.
Arthur 0.5 (East)	8" steel pipe. 60-70% full, constant.	450	

These flow rates are only rough estimates. It did not appear that the existing propeller meters were particularly accurate, based upon the fluctuation in the needles and high flow rate numbers given when the flow rates were quite small. For example, some of them registered flows in the 4 CFS range when the flows were obviously much smaller.

However, an estimate of these sump flows might be:
West side: 420 GPM (equivalent continuous)
East side: 1250 GPM on the 5 examined (out of 12 total),
with perhaps 12/5 x 1250 = 3000 GPM total on East side

Possible total pumped: 3400 GPM, a large portion of which may or may not actually be flow from the district collector lines on the East side of the Sea.

Joe estimated that 1 - 1.5% of the total pump flow rate on the West side is due to inflow from the Salton Sea. His estimate at the Arthur Street sump is noted, also. In short, the conclusion is that although this number should be included in the water balance, it is insignificant.

At none of the locations was a good or even reasonable site seen for measurement of surface drain water flows into the Salton Sea. The methodology of measuring the reported "direct to the Sea" flows needs to be examined.

A quick check of the monthly drain flows into the sea shows that they are not considerably different from month-to-month.

Item 3. District drain flows directly into the Whitewater River storm channel.

We visited 6 sites which provide flows directly into the Whitewater River storm channel. The visits are listed from North to South.

Location	Notes	Flow rate
Valley Sanitary District 45-500 Van Buren Indio, CA 92201 (619) 347-2356 Rex Sharp, Dir. of Operations	There is almost no flow in the Whitewater Channel (WW) north of this point. VSD handles the wastewater from Indio and a few outlying areas. They receive an average of 4.5 - 4.7 MGD during the year, and directly discharge 3.2 MGD to the storm channel (WW). The rest is applied to pastures. Rex is sending the details. Evidently, north of Fred Waring street the WW has no flow at all.	2222 GPM ave. continuous.
Ave. 50 (west side)	Pipe outlet is perhaps 20' below the fields.	70 GPM (CMB & JML consensus)
Ave. 51 (east side)	Can't see the drain outlet alone, because operational discharge from the ends of one of the laterals mixes with it underground in a pipe before discharging to the surface.	
Ave 52 (east side)	18" ID pipe	10-30 GPM
Ave 56 (east)	Overgrown outlet. Can't see the pipe	
Lincoln drain (east side)	Almost stagnant water in a large channel	300 GPM??

These drain discharges are not monitored or metered by CVWD. There are no flow measurement locations.

In addition, the Lincoln gauge site on the WW was visited. There were piles of sand on the banks near it, indicating recent cleaning. Also, the velocities were very different at different points across the water surface, and the water depth varied by at least 100% due to sand deposition. The water was quite shallow.

Conclusions:

- The drain discharges are probably not measured accurately
- The inflows to the WW are not measured
- Contributions from the City of Indio and operation discharge must be included in an examination of drain flows.

Item 4. Pumping water depths.

Four visits/calls were made to learn a bit more about this. Joe only participated in the first one with me.

Visit #1: Talk with Karl Bockler, Sales Engineer
McCalla Division of Layne-Western Co.
53-381 Hwy 111
Coachella, CA 92236
619-398-8887

Karl has worked in the area for a few years and does "a lot" of well pump evaluations. McCalla drills wells and also replaces old pumps. Here are the key points he made:

- One can drill 2 wells 50 feet apart and one will produce 500 GPM and the next 5 GPM. The differences in stratification are tremendous.
- If the water table is within 50' of the surface, they must install a 200' liner (sanitary seal). They do this by pumping 200' of concrete slurry around the casing.
- The average depth of domestic wells is 400-500'
- A typical pumping plant efficiency for wells is 60% - 70%. This includes both motor and impeller.
- Most agricultural irrigation wells have 500-600 GPM.
- Pumping water levels vary greatly in the valley, from about 10' or so to about 170'. The drawdown (part of the pumping water level) depends upon the casing, flow rate, and location. Karl didn't seem to have any general rules about where there was a particular pumping level, and we didn't press the topic with him.
- Karl gave us the following information about some recent wells they have dug:

Location	Static (ft)	Pumping	GPM
Ave 41, Wash .5 (North of Indio)	125	135	50
Ave. 55, Filmore (E. of Thermal)	11'		
Ave. 71, Hayes (V. near S. Sea, E side)	2'	100'	50
Ave 82, Buchanon SW side, above CVWD distrib. pipelines	120'	131'	400
Ave 83, Johnson (fish farm area on W side of SS)	83	95	350

- Karl also showed us drilling logs from a variety of recent wells. **The drawdowns shown are for development purposes. The estimated pumping depth (estimated by me) for 600 GPM is shown on the far RH column for the agricultural wells. Unfortunately, I did not copy down the casing size.

T	R	Sec	Static, ft	GPM	Dwdn. ft	Test hrs	P.L.@ 600 GPM
5S	7E	7 (NW of Indio)	125	50	10	4	
8S	8E	10 SW, near SS, above dis. syst.	189	1000	19	22	200'
7S	8E	24 SW, near SS, W of Hwy 86	68	4000	101	8	83
7S	8E	24	68	4000	99	8	83
7S	8E	25	30	3400	139	24	54
7S	8E	25	15	3000	140	24	43
7S	8E	22 South center, near Hwy 86 & ave 70.	71	2000	137	6	112
6S	8E	24 3 mi E of Thermal	71	2000	66	12	91
7S	7E	3 Far W & Center Above dist. syst.	125	250	85	4	
6S	7E	29 near L. Cahuilla	130	3000	12.5	5	133
7S	7E	2 N. of L. Cahuilla by 2 mi; W of canal	23				
6S	8E	14 1 mi. NE of Thermal	8	250	50	8	

The pumps with 50 and 250 GPM were not adjusted for 600 GPM because it would be unreasonable to assume that those would be used for such a high flow rate.

What Joe and I did not see were the results of pump tests which Karl has run. He did, however, provide us with a copy of the form which he uses. He also provided us with some well logs.

Visit #2 City of Indio. The City of Indio maintains its own wells.
The following are the pumped volumes by month and year, in AF

	J	F	M	A	M	J	J	A	S	O	N	D
1990	619	729	968	1101	1344	871	1606	1457	1281	1077	983	810
1991	725	762	712	972	1196	1344	1403	1412	1157	1173	972	743
1992	766	648	732	1019	1269	1346	1555	1478	1277	1169	990	753

Annual totals: 1990: 12,846 AF
1991: 13,002
1992: 12,570

Note: A typical annual discharge into the Whitewater Storm Channel is about 4300 AF.

The City of Indio also keeps reasonable records on pumping water levels in its wells. The following is a summary which I have pulled off of their data.

Well #	Date	Static	Dwdn	GPM
1A	July 56	32	15.3	1500
	Sept. 76	19	22	2000
	April 85	25	5	1965
	May 89	31	19	1900
	Feb 92	32	16	1800
	May 93	38	10	1800
1B	Dec 76	20	16	1000
	June 80	27	14	1000
	Feb 86	27	14	1150
	Dec 92	37	10	1250
	May 93	37	4	1000
1C	Feb 70	19	53	2000
	Feb 86	41	24	1750
	Dec 89	56	30	1800
	Feb 92	57	28	2000
	May 93	52	32	1850
2A	Dec. 76	39	31	1000
	May 82	50	24.5	1000
	July 86	68	9	975
	May 87	64	11	925
	May 90	66	7	7
2B	Dec 76	39	13	1000
	April 85	60	11	1275
	May 89	83	23	1800
	April 92	73	30	1800
	May 93	90	21	1775
2C	May 75	45	23	1700
	May 85	63	17	1600
	April 92	73	29	2475
	May 93	93	26	2275
3A	Dec. 76	44	12	1500
	Aug 86	86	14	1300
	June 90	83	12	1500
	May 93	93	17	1650
3B	June 80	62	21	1950
	June 86	90	18	1750
	May 89	88	29	2025
3C	April 75	41	35	2000
	April 86	78	17	2000
	June 89	79	32	1600
	Jan 90	79	18	1800
	July 91	96	41	2100
4A	June 86	74	24	1650
	Aug 92	118	17	1600
4B	April 92	94	6	800
	Aug 92	98	30	1600

Visit #3 - Under observation, I was permitted to visually scan through about 10 volumes of well logs which CVWD has in a library. Evidently there are many more volumes, but I did not see the actual library. The well logs contain information about the strata encountered, but I was looking for information on drawdown and static water levels. Unfortunately, I did not see a single recent test which could indicate present water levels.

Phone Call - The same well logs that are stored in CVWD's library can be inspected at the Riverside County Environmental Health Dept., address 79733 Country Club. I believe it is in Palm Desert or Palm Springs. The primary contact person is Tim Taylor. (619-863-7000). I talked to a Don Park who indicated he is quite knowledgeable about the local groundwater conditions.

I will follow up my short conversation with Don, as he has made some observations of rising fluorides in the lower aquifer (below the aquitard) which indicate movement between the perched water table and the lower aquifer. I have no sense at all right now about the magnitude of the movement, nor of the quantity and quality of his measurements.

ESTIMATING LEACHING REQUIREMENTS

by
Marvin E. Jensen
22 Sep 93

INTRODUCTION

Numerous publications summarize salinity research conducted during the past half-century. Much of the research involved estimating the soil leaching requirements based on the salt tolerance of the crop and the salinity of the applied water (rainfall + irrigation water). Major recent publications are ASCE Manual 71 "Agricultural Salinity Assessment and Management" edited by Tanji (1990); "Salinity Management" by Hoffman et al. (1990); "Soil Properties and Efficient Water Use: Water Management for Salinity Control" by Hoffman and van Genuchten (1983); FAO Paper 29 "Water Quality for Agriculture" by Ayers and Wescot (1976); and the classic salinity reference, USDA Handbook 60 "Diagnosis and Improvement of Saline and Alkali Soils; (U.S. Salinity Laboratory Staff, 1954). Prendergast (1992) reviewed recent publications, refined several equations, and presented a model of crop yield response to irrigation water salinity. More important, he evaluated the model using experimental field data. Prendergast presented an excellent summary of key leaching equations which are summarized in the next section using Prendergast's notations.

THEORY

Applied water salinity, C_i, is calculated as:

$$C_i = \frac{[(R - Ro)\, C_r + W C_w]}{(R - Ro + W)} \tag{1}$$

where R is rainfall during the growing season, Ro is rainfall runoff, C_r is the salinity of rainfall, and W and C_w are the depth and salinity of infiltrated irrigation water, respectively. Evapotranspiration (ET) required for maximum yield, ET_m, can be estimated using either pan evaporation, E_p, or grass reference ET, ET_o, and appropriate crop coefficients, K_c.

$$ET_m = K_c ET_o = 0.85\, K_c E_p \tag{2}$$

Soil salinity will reduce yields and ET. The reduction in ET can be estimated using the following linear relationships that have been established during the past 4 decades:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{ET_a}{ET_m}\right) \tag{3}$$

where Y_a and Y_m are the actual and maximum yield, respectively, ET_a and ET_m are the actual and maximum ET, respectively, and K_y is the crop response factor (Stewart, 1972; and Doorenbos and Kassam, 1979).

Prendergast substituted Y for relative yield, Y_a/Y_m, to obtain the following equation for estimating ET when yield is reduced because of salinity.

$$ET = ET_m\left[\frac{Y}{K_y} + 1 - \frac{1}{K_y}\right] \tag{4}$$

The depth of water required (irrigation plus net rainfall), I, is:

$$I = \frac{ET}{(1 - LF)} \tag{5}$$

Combining Eq. 2 with Eq. 4 gives the depth of water as a function the crop and major climate-related variables:

$$I = \frac{K_c ET_o}{K_y(1 - LF)}(Y + K_y - 1) \tag{6}$$

Eq. 6 assumes that there is no water flow through cracks that bypasses the root zone, or that such flow is very small.

The depth of irrigation water required, W, is:

$$W = I - (R - Ro) \tag{7}$$

Prendergast (1992) used the leaching equation of Rhoades (1974) to characterize the average rootzone salinity because of its simplicity:

$$C_s = 0.5\,K C_i(1 + 1/LF) \tag{8}$$

where C_s is the average rootzone salinity of the soil solution, C_i is the applied water salinity, LF is the leaching fraction, and K is an empirical coefficient. He also reported that the more complex equation of Hoffman and van Genuchten (1983) could be used. The two equations with coefficients recommended by the authors and coefficients that best fit experimental data are compared in Fig.1.

Prendergast used the relative crop yield function by Maas and Hoffman (1977) to relate rootzone salinity to crop yield:

$$Y(\%) = 100 - B(C_{se} - A), \qquad C_{se} > A \tag{9}$$

where Y is relative yield, A is the threshold rootzone saturation extract salinity defined as the maximum salinity at which no yield reduction occurs, B is the percentage yield reduction per unit salinity increase, and C_{se} is the average rootzone salinity measured as the soil saturation extract. Hoffman et al. (1990) assumed that $C_{se} = C_s/2$. Prendergast used 2.5 as the ratio of the saturation extract to the water content at field capacity.

The resulting equation for relative crop yield is:

$$Y = 1 + 0.01AB - 0.002BK\left(1 + \frac{1}{LF}\right)\left\{C_w - \frac{(R - Ro)\,K_y(1 - LF)\,(C_w - C_r)}{K_c\,ETo\,(Y + K_y - 1)}\right\},$$

$$for\ 1 > Y > \left\{1 - K_y + \frac{K_y(R - Ro)\,(1 - LF)}{K_c\,ETo}\right\} \tag{10}$$

In evaluating Eq. 10 using field experimental data, Prendergast found that a Rhoades coefficient of K = 1.03 instead of 0.8 suggested by Rhoades, and the Hoffman-van Genuchten coefficient δ/z = 0.11 instead 0.2 best fit the experimental data in Australia. The model developed by Prendergast represents an integrated approach to estimating relative crop yield and ET as affected by soil salinity and leaching fraction. It can be used as a production function to evaluate the use of irrigation water of different salinities and different leaching fractions on crop yields.

ESTIMATING LEACHING REQUIREMENTS

Ayers and Wescot (1976), using the relationship by Rhoades (1974), proposed the following equation for estimating the leaching requirement:

$$LR = \frac{EC_i}{5\,EC_{se} - EC_i} \tag{11}$$

where EC_i is the electrical conductivity of the applied water and EC_{se} is the electrical conductivity of the saturation extract for a given crop for a yield reduction of 10 % or less. Hoffman and van Genuchten (1983) analyzed the data from leaching experiments and developed the following equation for the linearly averaged mean rootzone salinity.

$$C_s = C_i\left(\frac{1}{L} + \frac{\delta}{z\,LF}\ln\left[LF + (1 - LF)\,e^{-z/\delta}\right)\right) \tag{12}$$

where LF is the leaching fraction, z is the depth of the root zone, and δ = 0.2 z. When dividing C_s by 2.0 to approximate the electrical conductivity of the saturation extract, the mean rootzone salinity expressed as electrical conductivity relative to the salinity of the applied water and LF is shown in Fig. 2. The crop tolerance threshold value, C_t, as a function of the salinity of applied water and LF was obtained by subtracting the value of rootzone salinity at a LF of 50 % which was the LF used in the experiments (Fig. 3). Crop salinity tolerance values were summarized by Maas and Hoffman (1977) and can be found in numerous other publications.

REFERENCES

Ayers, R.S., and D.W. Wescot. 1976. Water Quality for Agriculture. FAO Irrig. and Drain. Paper No. 29, Rome, 111 pp.

Doorenbos, J., and A.H. Kassam. 1979. Yield Response to Water. FAO Irrig. and Drain. Paper 33, FAO Rome, 202 pp.

Hoffman, G.J. 1990. Leaching fraction and root zone salinity control. Pp. 237-261. In K.K. Tanji (ed), Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engr. Practice No. 71. ASCE, New York, 631 pp.
Hoffman, G.J., T.A. Howell, and K.H. Solomon (eds). 1990. Management of Farm Irrigation Systems. ASAE Monograph, ASAE St. Joseph, 1056 pp.

Hoffman, G.J., J.D. Rhoades, and J. Letey. 1990. Salinity management. Pp. 667-715. In: G.J. Hoffman, T.A. Howell, and K.H. Solomon (eds). Management of Farm Irrigation Systems. ASAE Monograph, ASAE St. Joseph, 1056 pp.

Hoffman, G.J., and M.Th. van Genuchten. 1983. Soil properties and efficient water use: management for salinity control. Pp 73-85. In: H.M. Taylor, W.R. Jordan, and T.R. Sinclair (eds), Limitations to Efficient Water Use in Crop Production. Am. Soc. Agron., Crop Sci. Soc. Am. and Soil Sci. Soc. Am., Madison, 568 pp.

Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance - current assessment. J. Irrig. and Drain. Div., ASCE 103(IR2):115-134.

Prendergast, J.B. 1992. A model of crop yield response to irrigation water salinity: theory, testing and application. Irrig. Sci. 13:157-164.

Rhoades, J.D. 1974. Drainage for salinity control. Pp 433-461. In: J. van Schilfgaarde (ed), Drainage for Agriculture, Agronomy Mono. 17, Am. Soc. Agron.

Stewart, J. 1972. Prediction of water production functions and associated irrigation programs to minimize crop yield and profit losses due to limited water. PhD Thesis, University of California-Davis, Univ. Microfilms 73-16, 934.

Tanji, K.K. (ed). 1990. Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice No. 71. ASCE, New York, 631 pp.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook 60.

FIGURE LEGENDS

1. Comparison of relative soil solution salinity as a function of leaching Fraction.

2. Mean rootzone salinity expressed as electrical conductivity as a function of the salinity of applied water based on Eq. 12 (Comparable to Fig. 12.3, Hoffman, 1990).

3. Leaching requirement, LR, as a function of the salinity of applied water and crop salt-tolerance threshold (Comparable to Fig. 12.4, Hoffman, 1990).

ROOTZONE SALINITY v. LEACHING FRACTION

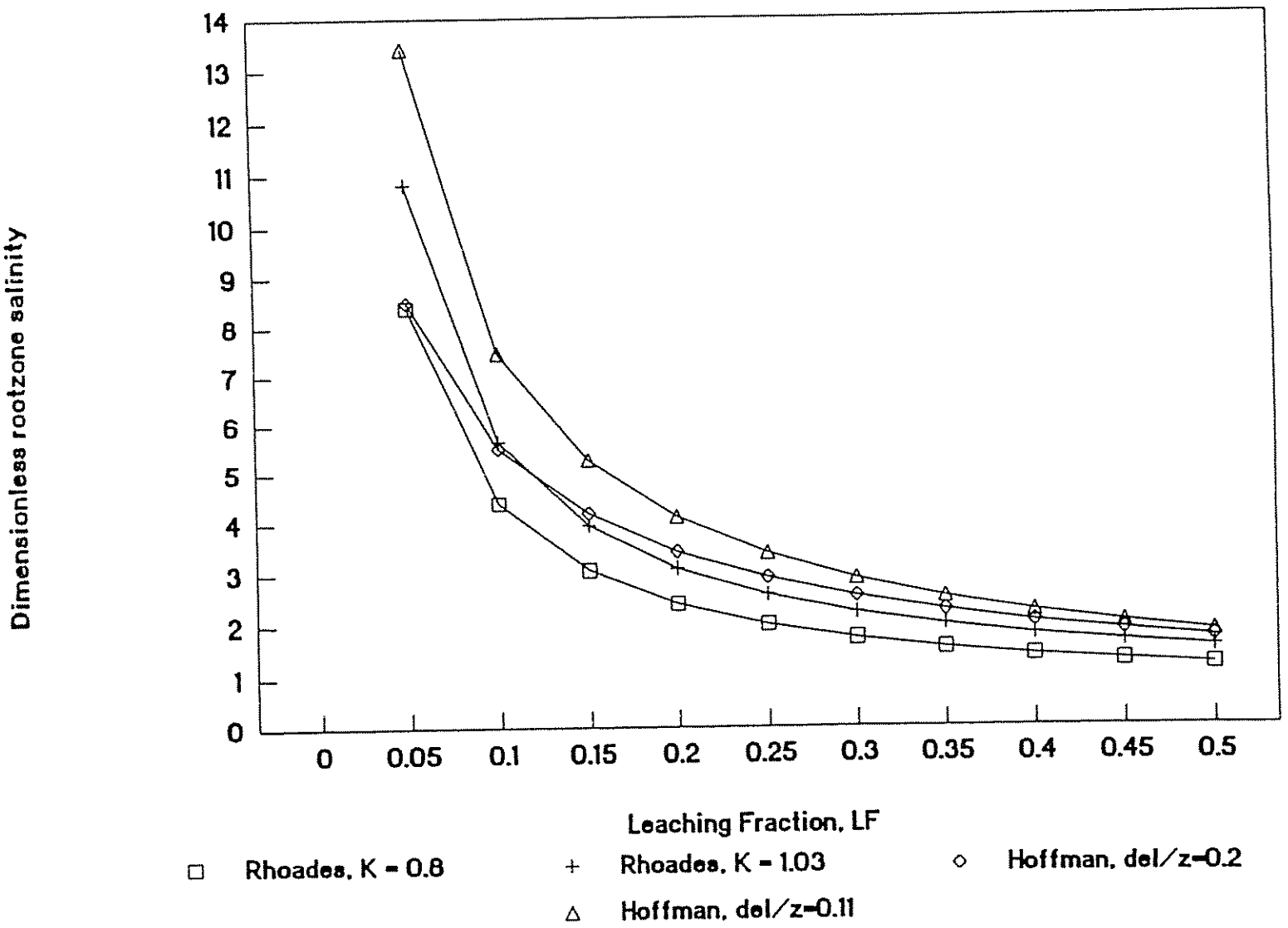


Fig. 1

ROOTZONE SALINITY

HOFFMAN (1990), Fig. 12.3

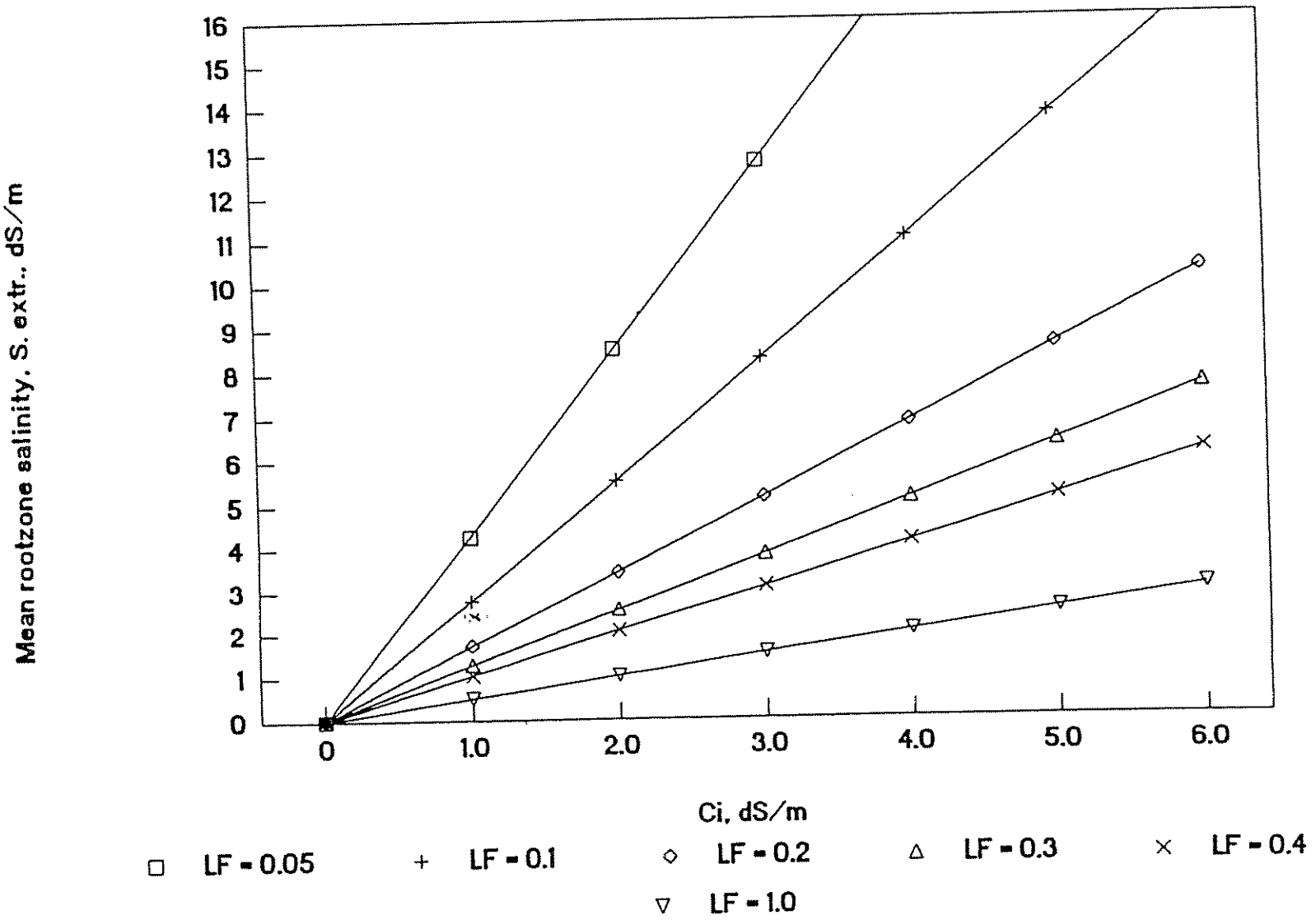


Fig. 2

LEACHING REQUIREMENT

HOFFMAN (1990), Fig. 12.4

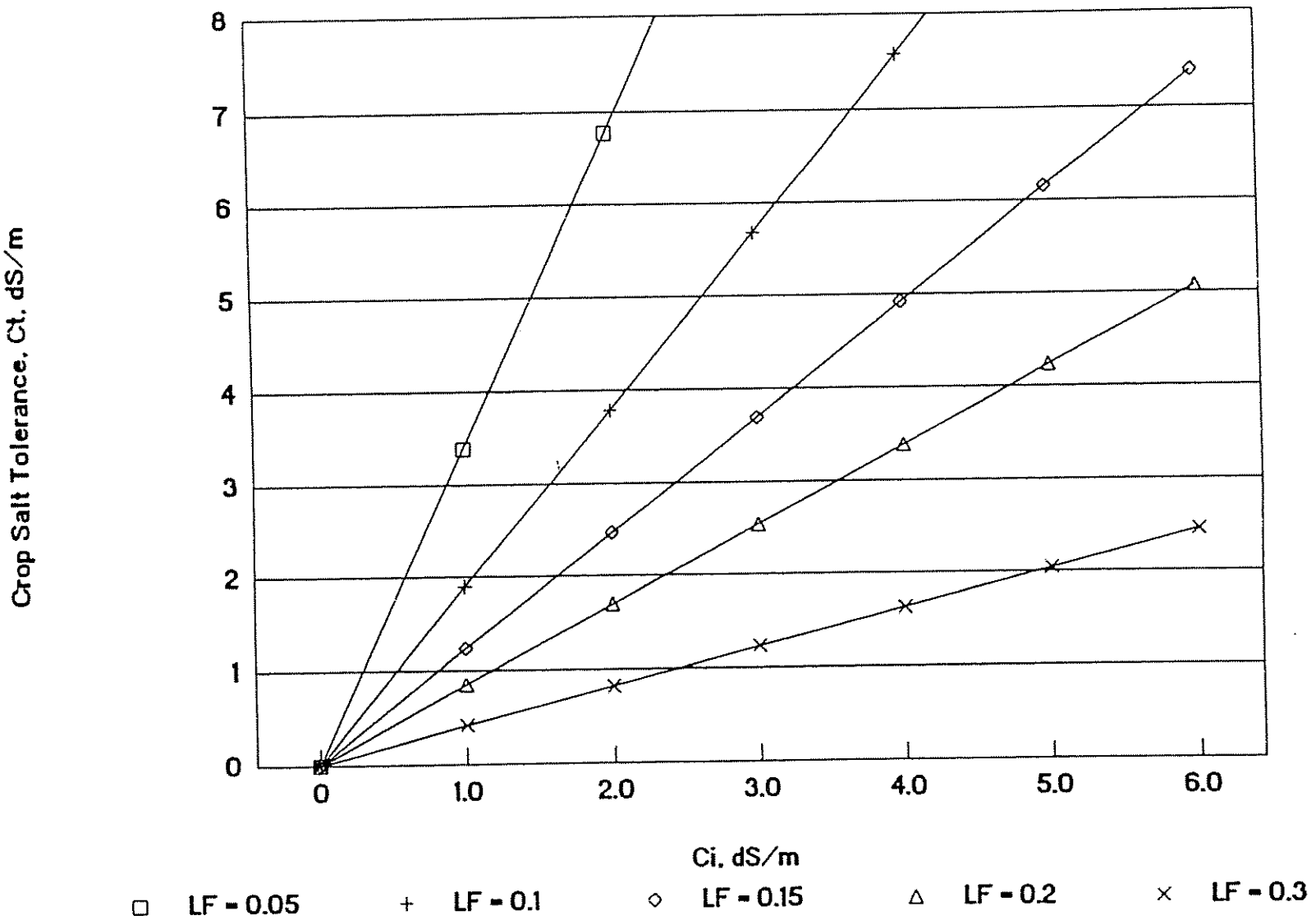


Fig. 3

EVALUATING EFFECTIVE RAINFALL IN CVWD

by
Marvin E. Jensen
01 Oct 93

INTRODUCTION

In my previous report (Effective Precipitation, 20-Sep-93), I summarized several procedures developed for estimating effective precipitation (the SCS-USDA method, SCS, 1970; and Hershfield, 1964) and reviewed several other papers on effective precipitation (Kopec et al., 1984; Nieber and Patwardhan, 1988; and Patwardhan et al., 1990). In this report, I summarize an evaluation of effective rainfall in the Coachella Valley Water District (CVWD) using a combination of methods.

ESTIMATING RAINFALL RUNOFF

Methods for estimating runoff from small watersheds for use in hydrological models have been summarized in monographs edited by Haan et al. (1982) and Hanks and Ritchie (1991). Specific aspects surface runoff, storage and routing, including the SCS-USDA method of estimating the abstraction of precipitation were described by Huggins (1982). Williams (1991) summarized adaptations of the SCS-USDA method for use in modeling.

PROCEDURES

Rainfall Interception

No specific data or equations for rainfall interception by agricultural crops was found in a brief search of agronomic literature. Therefore, the method used by Nieber and Patwardhan (1988) was used in this analysis. Their equation converted to inches of rainfall is:

$$I = 0.03\,TP\left(\frac{R}{0.5\,R + 0.06}\right) \tag{1}$$

where I = the interception of rainfall by crops, R is rainfall and TP is days since planting. I is limited to 0.2 S. For this analysis, the date of planting of annual crops was assumed to be 15 October.

Rainfall Runoff

The SCS rainfall-runoff relation was used to estimate runoff:

$$Q = \frac{(R - I_a)^2}{R - I_a + S} = \frac{(R - 0.2S)^2}{R + 0.8S} \tag{2}$$

where Q is the cumulative direct runoff, R is the cumulative rainfall and S is the maximum potential retention. The initial abstraction (I_a) in a typical storm is $I_a = 0.2$ S. The value of the maximum surface retention after runoff begins, S, in inches is obtained from the SCS Curve Number (CN):

$$S = \frac{1000}{CN} - 10 \tag{3}$$

For this analysis, soil type "D" was used. Type D soil is classified as having a very slow infiltration, i.e., less than 0.05 in/h when wet. Rainfall events for the period 1986-92 at Thermal, California were used. When rains occurred on consecutive days, they were called Day 1, Day 2 and Day 3 rains. For Day 1 rains, Condition II for average conditions was used. For Day 2 and Day 3 rains, Condition III (wet) was assumed.

The antecedent moisture Condition I is for dry soils, as prior to or after plowing or cultivating. Condition II is for average conditions. Condition III is for saturated soil due to heavy rainfall (or light rainfall with low temperature 5 days prior to a storm).

The curve number selected was CN = 89 for row crops, Condition II, and CN = 96 for row crops, Condition III. The maximum retention (S) for these two conditions was 1.24 in. for Condition II and 0.42 in. for Condition III.

Non-Beneficial Evaporation after Rains

After a rain, or several days of rains, the soil surface is wet and evapotranspiration is greater than that occurring just before the rain. The method developed at Kimberly Idaho of estimating the increase in evaporation due to rains or irrigations was used as summarized on page 118 of ASCE Manual 70 (Jensen et al., 1990):

$$E+ = 0.35\,[t_d + 1.5)]\,[K_1 - K_a K_{cb}]\,ET_o \tag{4}$$

where E+ is the increase in ET, t_d is the number of days after a rain usually required for soil surface to appear visually dry, which for clay loam soils may be 7 days or more. For sandy soils, t_d may be 3 days or less. For this analysis, a value of 7 was used. The maximum rate of ET after a rain is determined by the value of K_1, which was set at 1.2 for use with ET_o. K_{cb} is the basal crop coefficient and K_a is the relative effect of reduced soil water. The resulting crop coefficient is $K_c = K_a K_{cb}$. For this analysis, a weighted average crop coefficient was used. The weighted average monthly K_c values were calculated using the distribution of major crops in CVWD.

JMLord's crop coefficients for alfalfa-based reference ET were adapted for use with ET_o by multiplying his coefficients by 1.2 based on the relationship $ET(alf)/ET_o = 1.2$. Therefore, $K_{co} = 1.2\ K_{ca}$ where K_{co} is the crop coefficient to be used with ET_o and K_{ca} is the corresponding coefficient to be used with alfalfa-based reference ET. For rainfall less than that obtained from Eq. 4, the increase in evaporation was limited to the amount of rainfall.

The distribution of rains during the period 1986-92 were obtained from climatological data provided by CVWD for Thermal, California. CIMIS reference ET values (ET_o) for Thermal were obtained from the report by Boyle (Styles, 1993) for the years 1987-90. Average monthly ET_o values were used for 1986, 1991 and 1992. Since there was little rainfall from May through August, the analysis was carried out for the period September-April.

RESULTS

Rainfall Events

The number of single day storms for the September-April period was 109. The number of 2-day storms was 25. Only 5 storms produced rainfall for three consecutive days. The average rainfall for Day 1, Day 2 and Day 3 is summarized in Fig. 1.

Fig. 1. Average precipitation for Day 1, Day 2 and Day 3 storms at Thermal, California for the period 1986-92.

Most of the rainfall occurred on Day 1 and Day 2 except in December. The distribution of rainfall events by depth increments and days is summarized by months in Figures 2-9. Most of the rains provided only 0 to 0.2-inch of rainfall. Only a few rains exceeded 0.8-inch in February.

Fig. 2-9. Distribution of precipitation for Days 1, 2 and 3 for September through April at Thermal, California for the period 1986-92.

Adjusted Crop Coefficients

The mean monthly JMLord's crop coefficients for major crops grown in CVWD adjusted for use with ET_o reference ET are summarized in Figures 10-12.

Fig. 10-12. Mean monthly crop coefficients adjusted from JMLord's alfalfa-based reference ET coefficients for use with ET_o in the CVWD.

The dates of planting, full cover and harvest used in the analysis are summarized in Table 1. Several minor adjustments of the "interval" were needed so that the harvest date minus "4 x interval" did not precede the effective cover date.

The average monthly coefficients for the individual major crops are summarized in Table 2. The weighted average crop coefficient for each month is summarized in the last row of Table 2.

Estimated Runoff and Increased Evaporation

A summary of the results obtained from estimating interception of rainfall, runoff and increased evaporation following rainfall is presented in Table 3. The estimated total runoff was 2.8 inches for the 6-year period or 14 percent of the total rainfall. The estimated evaporation of rainfall from that intercepted by crops plus that which wetted the soil was 52 percent. Except for November, the effective rainfall ranged from 40 to 50 percent for the period October through February. It decreased to 20 percent in March.

The average annual effective rainfall was 34 percent of the total. Styles (1990) estimated 30 percent. The details of the computations is presented in Appendix A.

The percentage distribution of effective rainfall is presented in Fig. 13. Rainfall during the summer months is essentially non-effective because of small amounts and high evaporation rates.

AVERAGE PRECIPITATION - 1986-92

THERMAL, CALIF

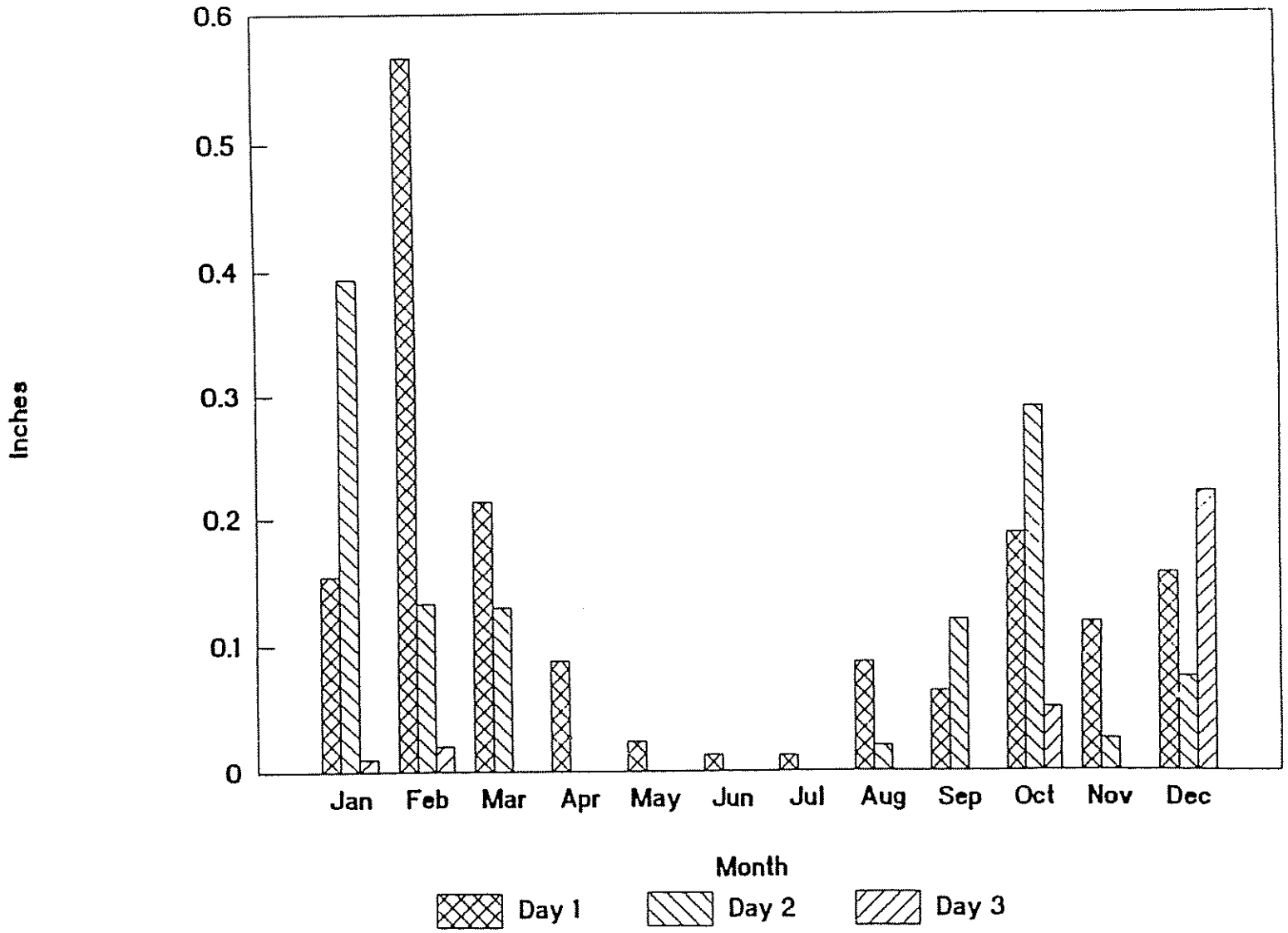


Fig 1

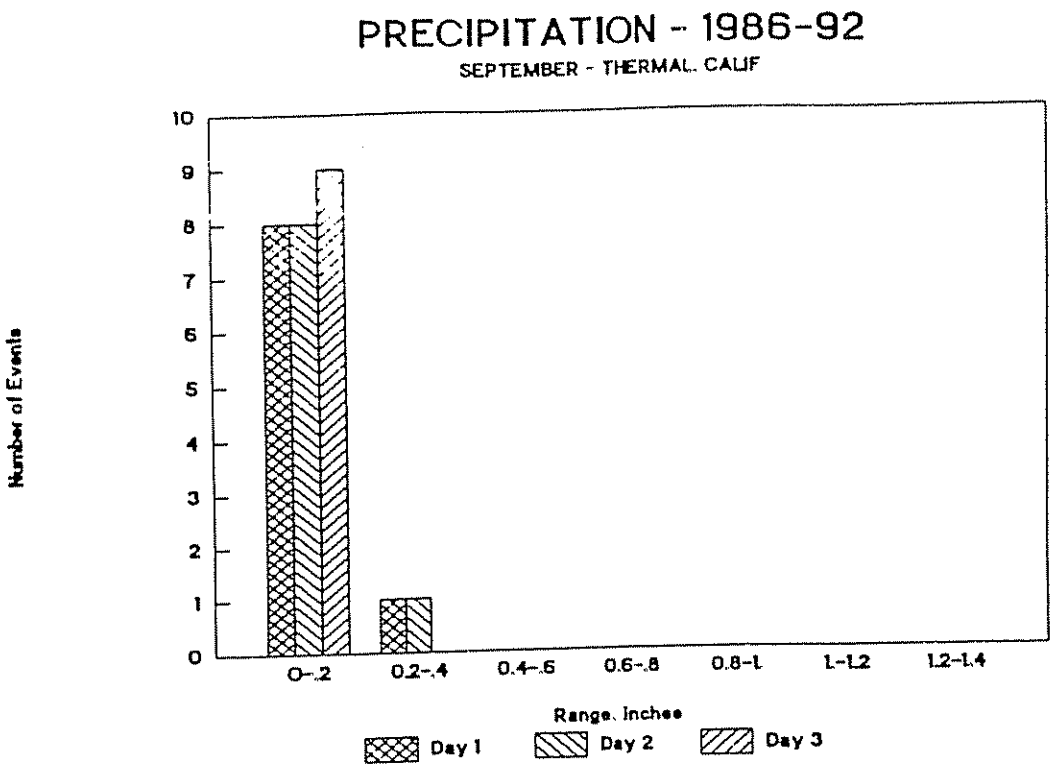

PRECIPITATION - 1986-92
SEPTEMBER - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, Inches
Day 1
Day 2
Day 3

Fig. 2

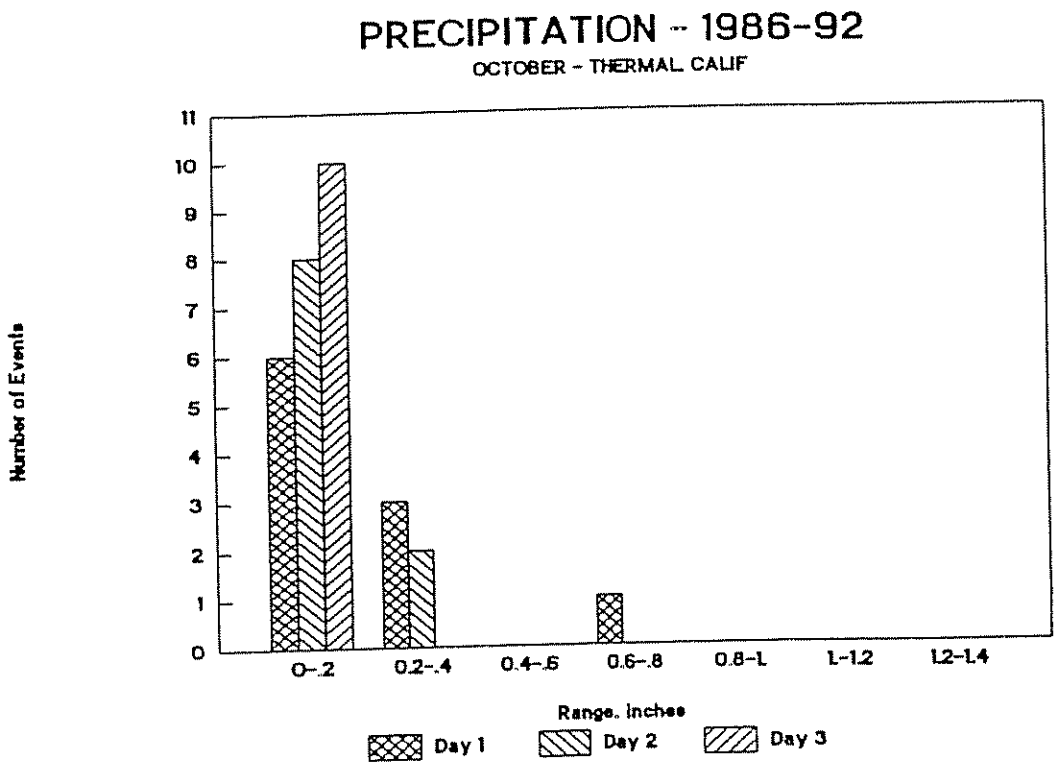

PRECIPITATION - 1986-92
OCTOBER - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
11
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, Inches
Day 1
Day 2
Day 3

Fig. 3

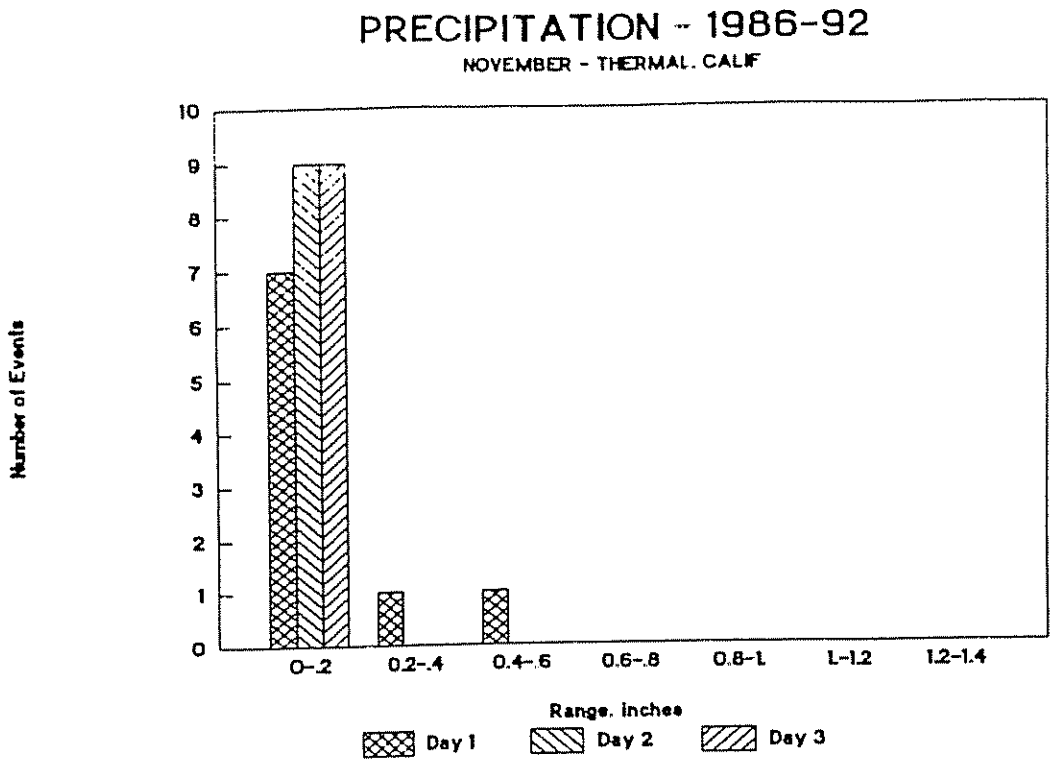

PRECIPITATION - 1986-92
NOVEMBER - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, inches
Day 1
Day 2
Day 3

Fig. 4

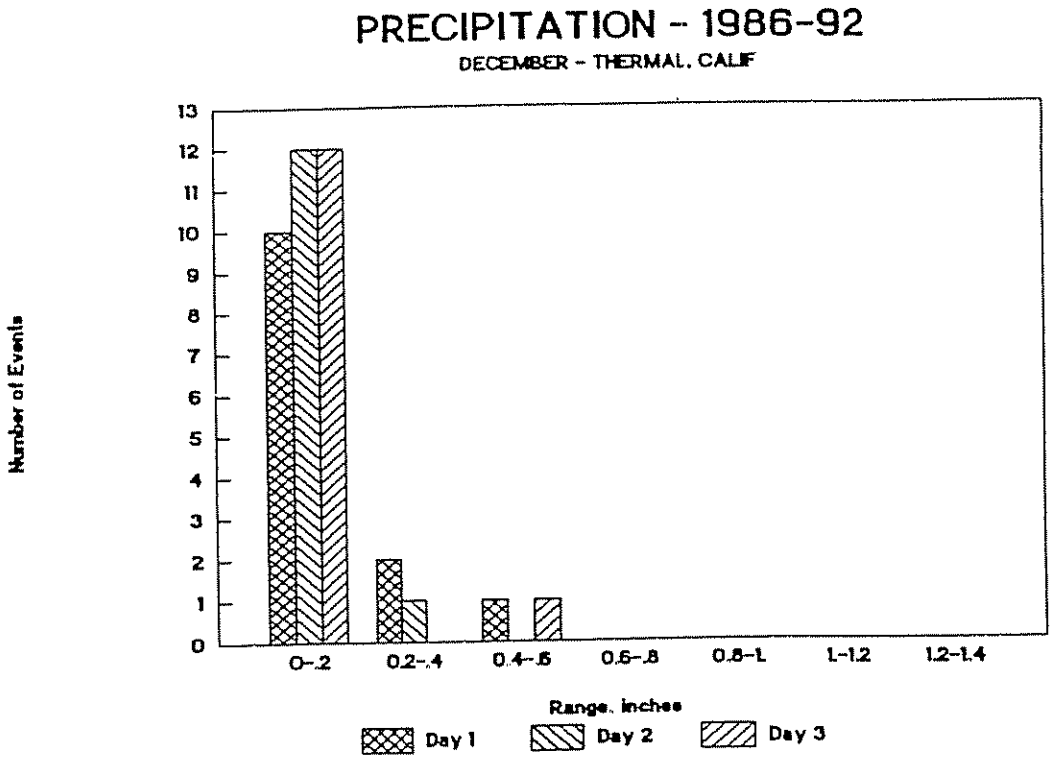

PRECIPITATION - 1986-92
DECEMBER - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
11
12
13
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, inches
Day 1
Day 2
Day 3

Fig. 5

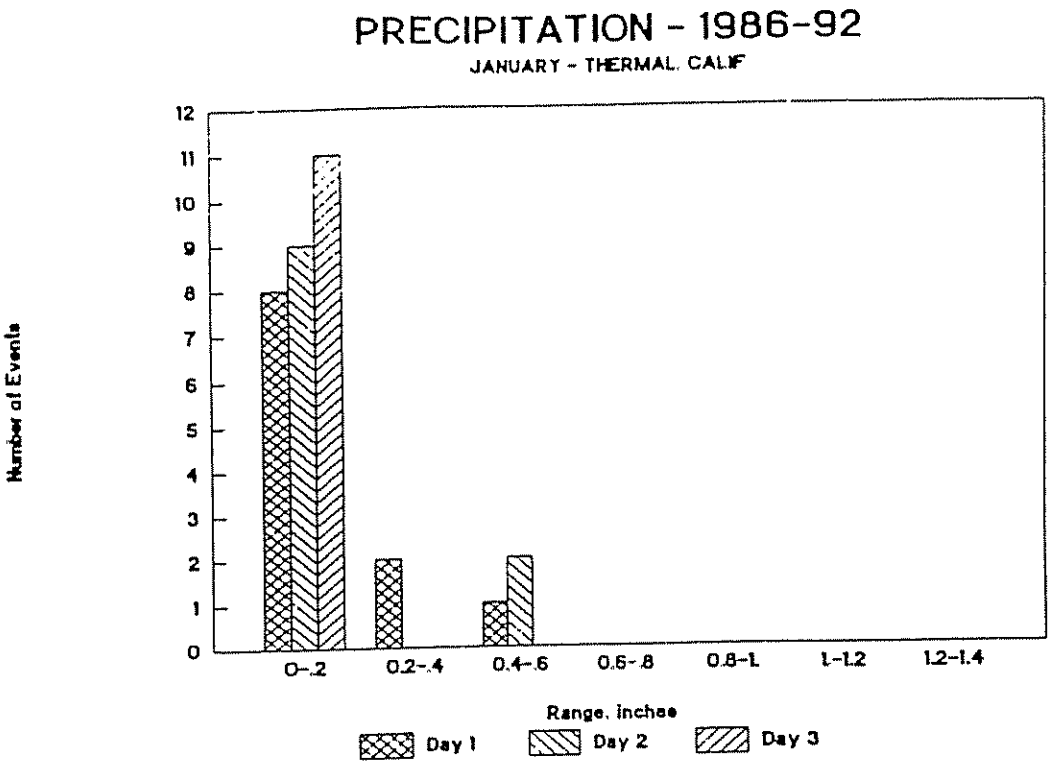

PRECIPITATION - 1986-92
JANUARY - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
11
12
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1.
1-1.2
1.2-1.4
Range, inches
Day 1
Day 2
Day 3

Fig. 6

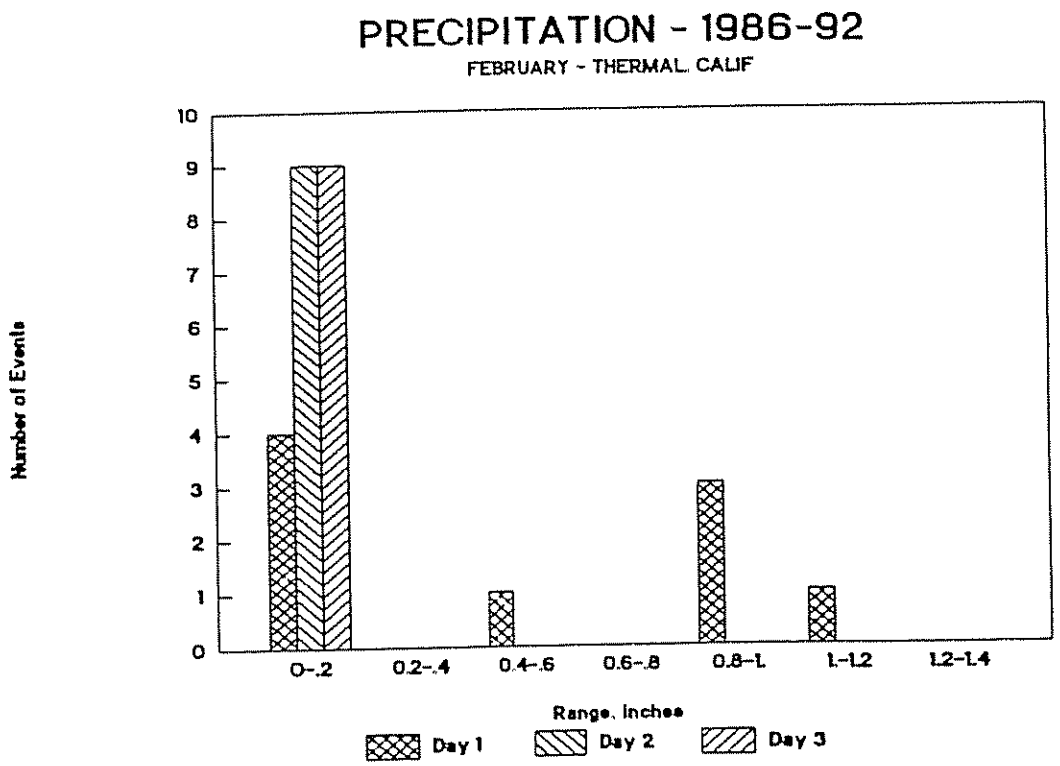

PRECIPITATION - 1986-92
FEBRUARY - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1.
1-1.2
1.2-1.4
Range, inches
Day 1
Day 2
Day 3

Fig. 7

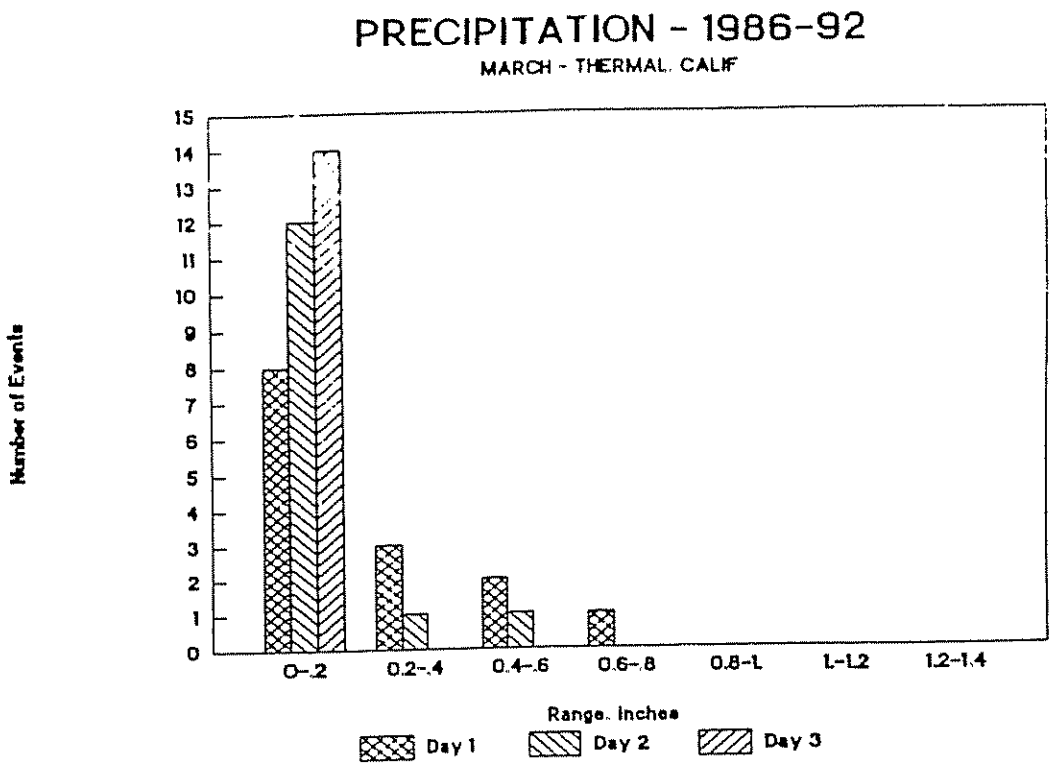

PRECIPITATION - 1986-92
MARCH - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, Inches
Day 1
Day 2
Day 3

Fig. 8

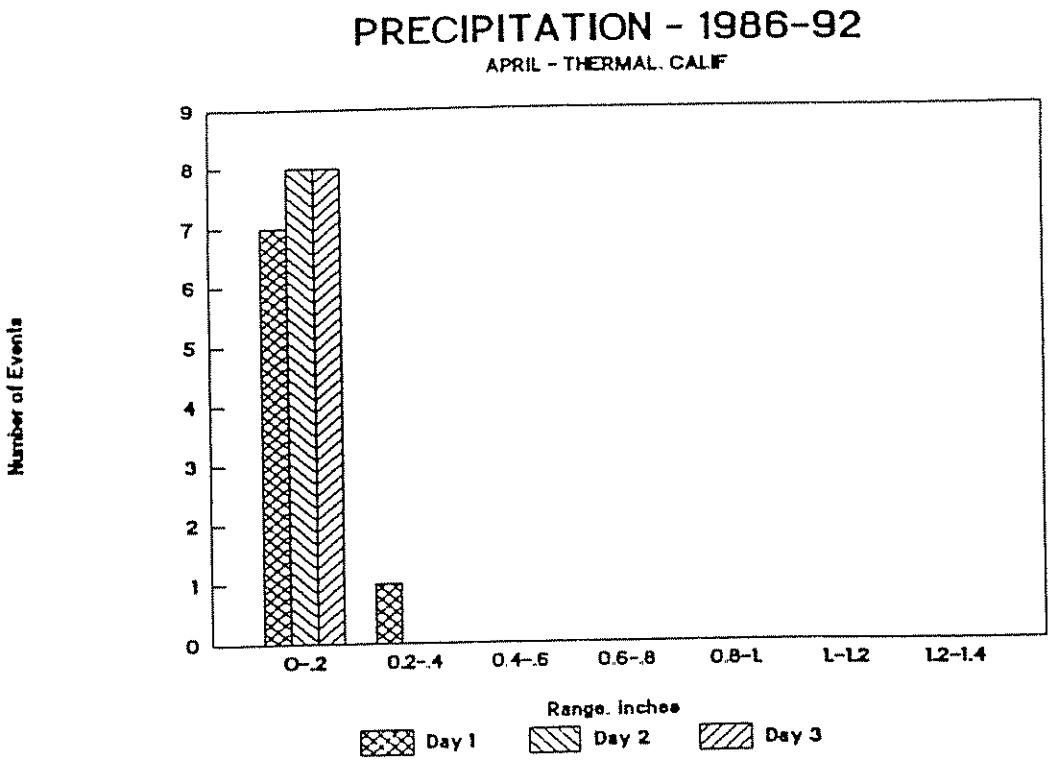

PRECIPITATION - 1986-92
APRIL - THERMAL, CALIF
Number of Events
0
1
2
3
4
5
6
7
8
9
0-.2
0.2-.4
0.4-.6
0.6-.8
0.8-1
1-1.2
1.2-1.4
Range, Inches
Day 1
Day 2
Day 3

Fig. 9

CVWD CROP COEFFICENTS

Adjusted JMLord Kc's for ETo

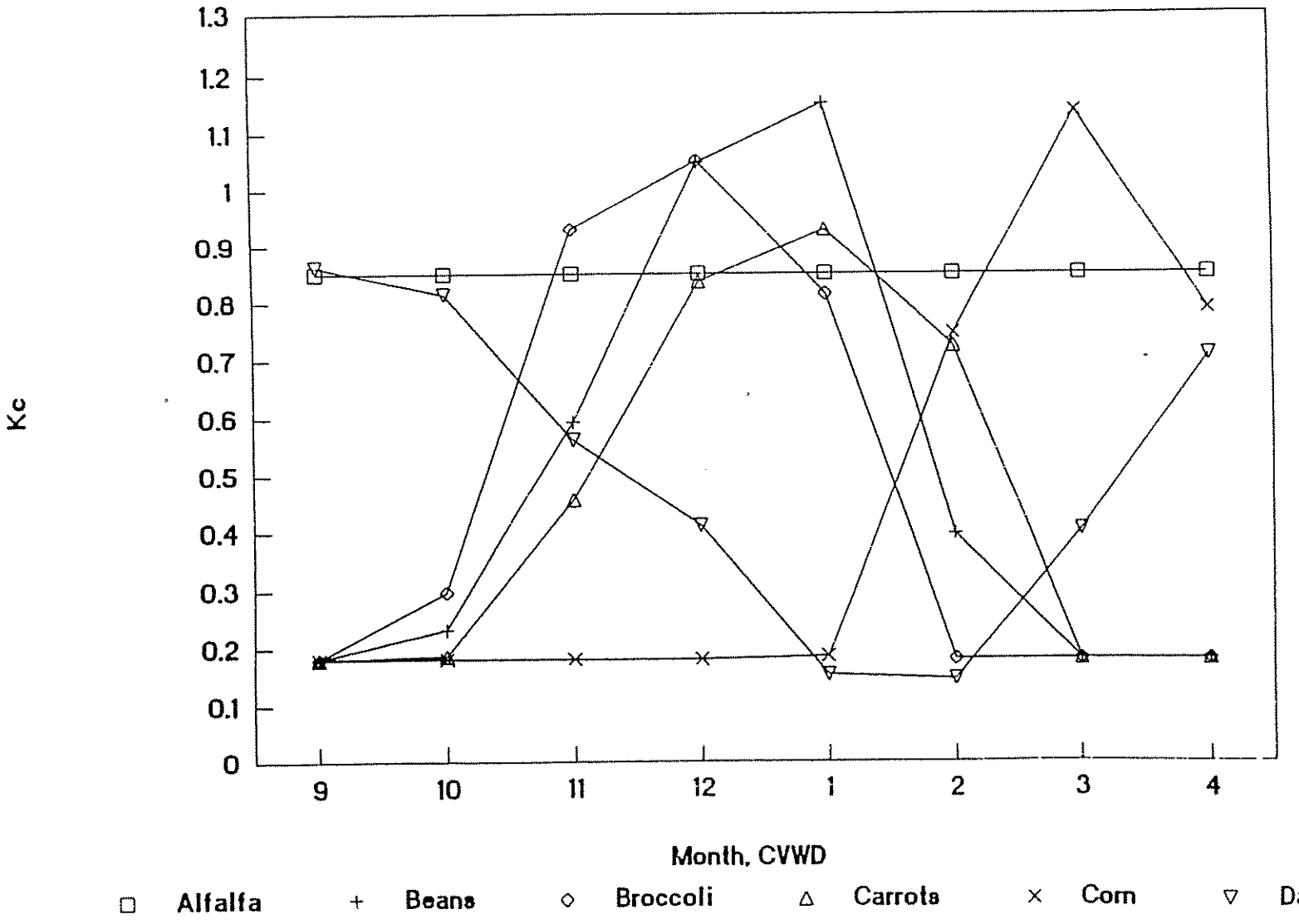


Fig. 10

CVWD CROP COEFFICENTS

Adjusted JMLord Kc's for ETo

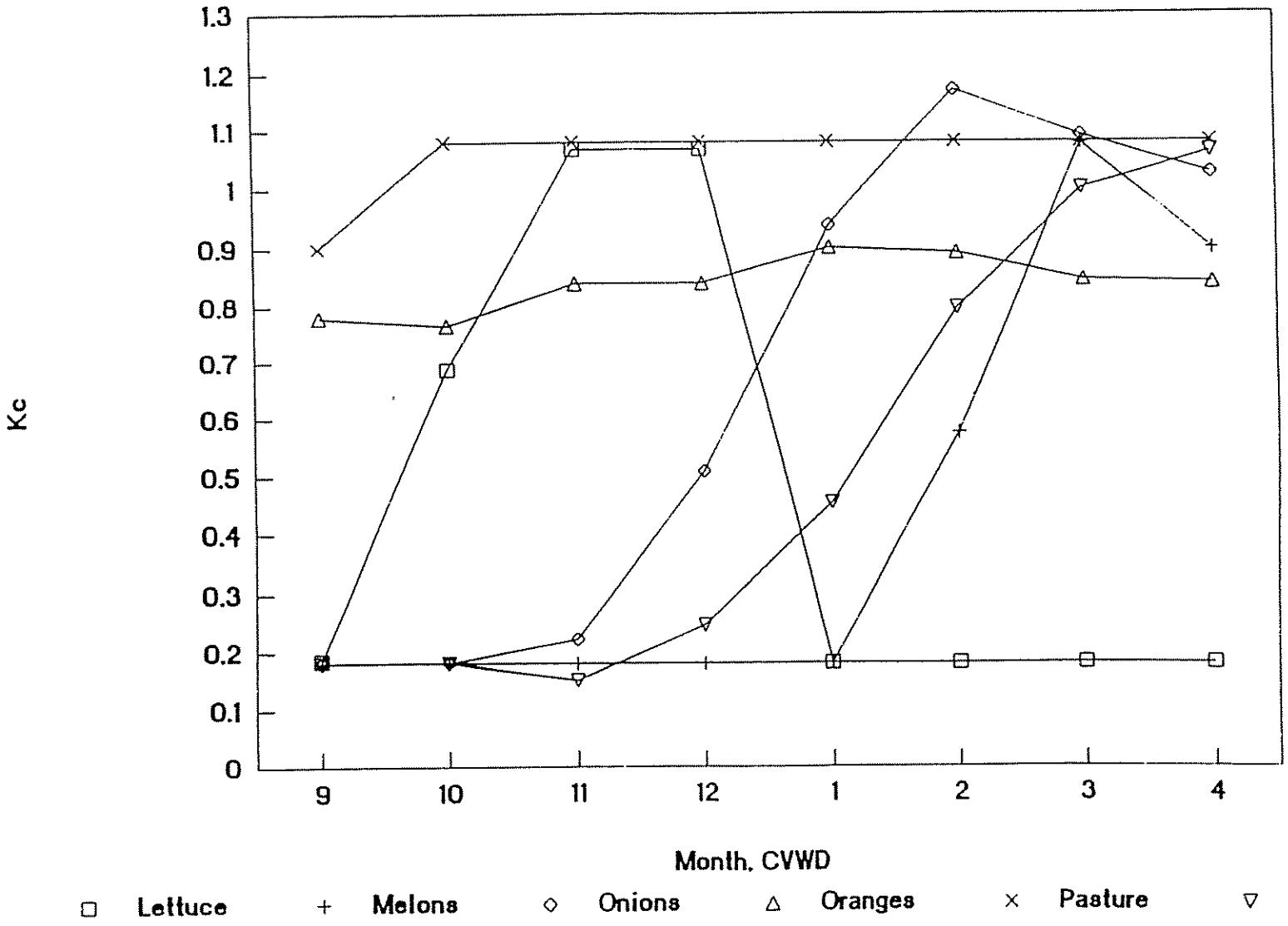


Fig 11

CVWD CROP COEFFICENTS

Adjusted JMLord Kc's for ETo

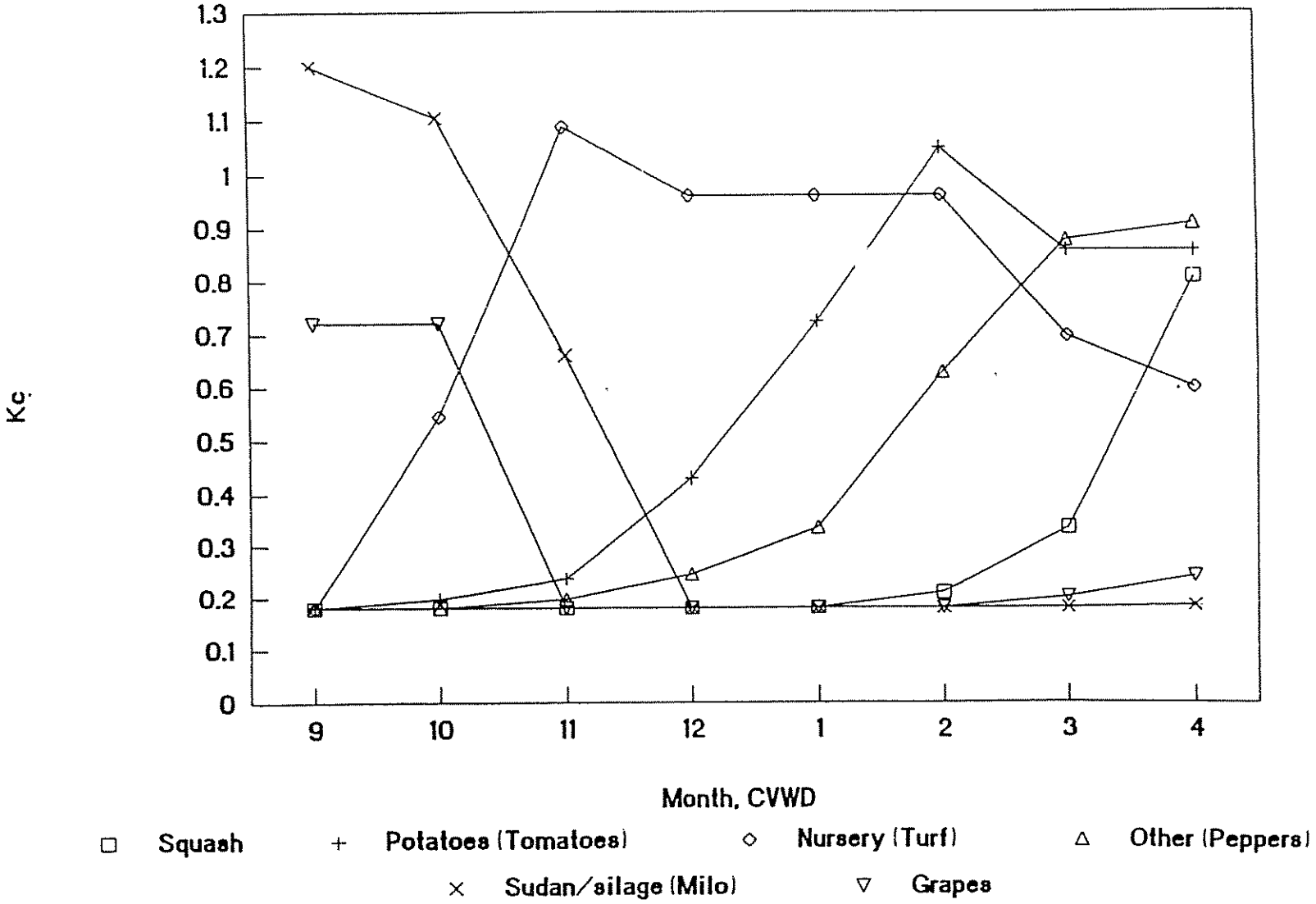


Fig. 12

Table 1. Distribution of major crops and estimated planting, full cover and harvest dates in the CVWD.

Crop	acres	Interval 1)	Planting Date	Planting CD	Full cover Date	Full cover CD	Harvest Date	Harvest CD	Comment
FIELD CROPS:									
Alf. hay	2,130	20	01-Sep	244	06-Jun	528	31-Aug	608	Season
I. pasture	1,555	84	01-Sep	244	29-Sep	272	31-Aug	608	Season
Sudan/sil.	2,940	25	14 Apr	104	07-Aug	219	15-Nov	319	Milo Kc
Other	1,267	79	14 Apr	104	03-Jan	3	15-Nov	319	Pasture Kc
FRUIT CROPS:									
Dates	5,689	40	01-Jan	1	24-Jul	205	31-Dec	365	
Citrus	13,094	52	01-Jan	1	06-Jun	157	31-Dec	365	Oranges Kc
Grapes	12,008	30	01-Mar	60	03-Jul	184	31-Oct	304	
Other	454	40	01-Mar	60	24-May	144	31-Oct	304	Peaches Kc
TRUCK CROPS:									
Beans	892	15	01-Oct	274	31-Dec	365	01-Mar	425	
Broccoli	810	15	01-Oct	274	03-Dec	337	01-Feb	397	
Carrots	1,140	20	14-Oct	287	25-Dec	359	15-Mar	439	
Corn, sw	4,582	15	14-Jan	379	17-Mar	441	16-May	501	
Lettuce	2,596	25	14-Sep	257	12-Sep	255	21-Dec	355	
Okra	414	20	01-Nov	305	10-Jan	375	31-Mar	455	Soybean Kc
Onion, dry	588	25	01-Nov	305	04-Feb	400	15-May	500	
Peppers	1,245	15	01-Nov	305	01-Apr	456	15-May	516	
Potatoes	870	15	01-Nov	305	16-Mar	440	15-May	500	
Squash	647	15	01-Feb	397	01-May	486	30-Jun	546	
Watermelon	724	20	01-Jan	1	12-Mar	436	31-Dec	516	Melon Kc
Misc. veg.	786	15	01-Nov	305	01-Apr	456	15-May	516	Pepper Kc
Nursery	790	5	01-Oct	274	10-Apr	465	01-Feb	485	Turf Kc
Other	2,077	15	01-Nov	305	01-Apr	456	15-May	516	Pepper Kc

1) Interval refers to the days in periods 1-4 after full cover (JMLord's Crop Coefficients).

Table 2. Average crop coefficients for major crops in the CVWD for use with CIMIS values of Eto in estimating effective rainfall.

Crop	Area, acres	Monthly Kc for ETo Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Cmt.
FIELD CROPS:										
Alf. hay	2,130	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	1)
I. pasture	1,555	1.08	0.90	1.08	1.08	1.08	1.08	1.08	1.08	1)
Sudan/sil.	2,940	1.10	0.66	0.18	0.18	0.18	0.18	0.18	0.18	2)
Other	1,267	0.90	1.08	1.08	1.08	1.08	1.08	1.08	1.08	3)
FRUIT CROPS:										
Dates	5,689	0.86	0.81	0.56	0.41	0.15	0.15	0.40	0.71	
Citrus	13,094	0.78	0.83	0.84	0.84	0.90	0.89	0.84	0.84	4)
Grapes	12,008	0.72	0.72	0.18	0.18	0.18	0.18	0.20	0.24	
Other	454	0.90	0.89	0.18	0.18	0.18	0.18	0.11	0.61	5)
TRUCK CROPS:										
Bean	892	0.18	0.23	0.59	1.05	1.15	0.40	0.18	0.18	
Broccoli	810	0.18	0.30	0.93	1.05	0.81	0.18	0.18	0.18	
Carrots	1,140	0.18	0.19	0.46	0.84	0.93	0.72	0.18	0.18	
Corn, sw	4,582	0.18	0.18	0.18	0.18	0.18	0.75	1.14	0.79	
Lettuce	2,596	0.19	0.69	1.07	1.07	0.18	0.18	0.18	0.18	
Okra	414	0.18	0.18	0.23	0.73	1.14	1.14	0.70	0.18	6)
Onion, dry	588	0.18	0.18	0.22	0.51	0.94	1.17	1.09	1.03	
Peppers	1,245	0.18	0.18	0.15	0.25	0.45	0.80	1.00	1.06	
Potatoes	870	0.18	0.20	0.24	0.43	0.72	1.05	0.86	0.86	
Squash	647	0.18	0.18	0.18	0.18	0.18	0.33	0.81	0.21	
Watermelon	724	0.18	0.18	0.18	0.18	0.18	0.57	1.08	0.90	7)
Misc. veg.	786	0.18	0.18	0.15	0.25	0.45	0.80	1.00	1.06	8)
Nursery	790	0.18	0.49	0.92	0.96	0.96	0.96	0.96	0.96	9)
Other	2,077	0.18	0.18	0.15	0.25	0.45	0.80	1.09	1.06	10)
Total	57,298									
Total Ac x Kc		35,319	36,053	29,245	30,318	28,808	32,109	35,354	35,512	
Average Kc		0.62	0.63	0.51	0.53	0.50	0.56	0.62	0.62	

1) Season
2) Milo Kc
3) Pasture Kc
4) Oranges Kc
5) Peaches Kc
6) Soybean Kc
7) Melon Kc
8) Pepper Kc
9) Turf Kc
10) Pepper Kc

Table 3. Summary of Day 1, Day 2, and Day 3 rains, and estimated runoff and increased evaporation following rains for Thermal, California, 1986-92.

	Rain Storms				
	Day 1	Day 2	Day 3	Day 4	Total
Total rainfall, inches	16.3	3.9	0.5	0	20.7
Rainfall events	125	25	5		155
Runoff (RO), inches	1.65	1.0	0.15	0	2.8
Runoff (RO), percent	10	26	30	--	14
Increased evaporation (E+), inches					10.8
Increased evaporation (E+), percent					52
Total losses (RO + E+), inches					13.6
Total losses (RO + E+), percent					66
Effective rainfall (ER), inches					7.1
Effective rainfall (ER), percent					34

Summary by Months

Month	Rain	Runoff	E+	RO + E+	ER, in.	ER, %
January	2.74	0.53	1.11	1.63	1.11	40
February	5.39	1.15	1.83	2.97	2.42	45
March	3.76	0.45	2.55	3.00	0.76	20
April	0.70	0.00	0.70	0.70	0.00	0
May	0.19	0.00	0.19	0.19	0.00	0
June	0.09	0.00	0.09	0.09	0.00	0
July	0.10	0.00	0.10	0.10	0.00	0
August	0.54	0.00	0.54	0.54	0.00	0
September	0.81	0.00	0.81	0.81	0.00	0
October	2.61	0.37	1.13	1.50	1.11	43
November	1.11	0.04	0.69	0.73	0.38	34
December	2.69	0.28	1.10	1.38	1.31	49
Annual	20.73	2.81	10.83	13.64	7.09	
Percent	100	14	52	66	34	

EFFECTIVE PRECIPITATION - 1986-92

THERMAL, CALIF

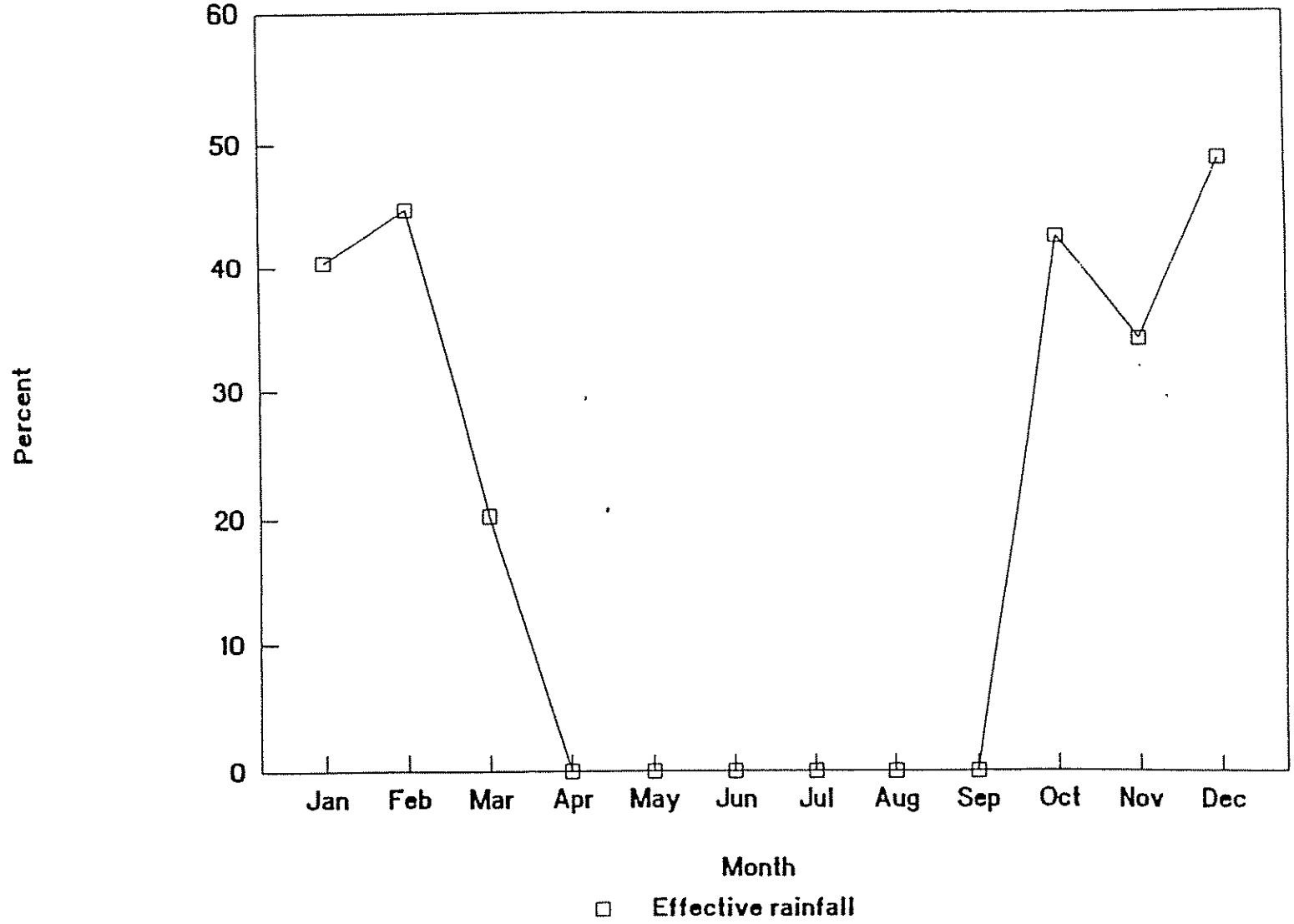


Fig. 13

Rainfall-Irrigation Interaction

In an analysis of factors affecting the ordering of water in the IID, Gutwein and Lang (1993) showed that rainfall amounts, though small, greatly affected the demand for water. They reported a sharp drop in water orders following rainfall events. On an annual basis, water diversions expressed on a depth basis decreased by a factor of 2.3 times the annual rainfall amount. Therefore, reduced water orders appear to over-compensate for rainfall. However, this relationship does not reflect the decrease in evaporative demand associated with a rainy period.

SUMMARY AND CONCLUSIONS

Most of the rainfall occurred on Day 1 and Day 2 of storm periods except in December. Most of the rains provided only 0 to 0.2-inch of rainfall. Only a few rains exceeded 0.8-inch in February.

The estimated total runoff was 2.8 inches for the 6-year period or 14 percent of the total rainfall. The estimated evaporation of rainfall from that intercepted by crops plus that which wetted the soil was 52 percent. Except for November, the effective rainfall ranged from 40 to 50 percent for the period October through February. It decreased to 20 percent in March. The average annual effective rainfall was 34 percent of the total. Rainfall during the summer months is essentially non-effective because of small amounts and high evaporation rates.

REFERENCES

Gutwein, B.J., and R.J. Lang. 1993. Regional irrigation water demand. J. Irrig. and Drain. Engr. 119(5):829-847.

Haan, C.T., H.P. Johnson, and D.L. Brakensiek(eds). 1982. Hydrologic Modeling of Small Watersheds. ASAE Mono. 5, ASAE, St. Joseph, 543 pp.

Hanks, R.J., and J.T. Ritchie (eds). 1991. Modeling Plant and Soil Systems. Agron. Mono. 31, Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am., Madison, 561 pp.

Hershfield, D.M. 1964. Effective rainfall and irrigation water requirements. J. Irrig. and Drain. Div., ASCE 90(2):33-47.

Huggins, L.F. 1982. Surface runoff, storage and routing. Pp. 169-225. In: C.T. Haan, H.P. Johnson, and D.L. Brakensiek(eds). 1982. Hydrologic Modeling of Small Watersheds. ASAE Mono. 5, ASAE, St. Joseph, 543 pp.

Jensen, M.E., R.D. Burman, and R.G. Allen (eds). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, New York, 360 pp.

Kopec, A.R., M.N. Langley, and M.G. Bos. 1984. Major variables which influence effective precipitation. ICID Bull. 33(2):65-70, & 84.

Nieber, J.L., and A.S. Patwardhan. 1988. Estimation of effective rainfall. Research project completion report, Contract No. USDI-5-CR-81-07420, USDI, Bureau of Reclamation, Feb. Denver, Colo., 73 pp.

Patwardhan, A.S., J.L. Nieber, and E.L. Johns. 1990. Effective rainfall estimation methods. J. Irrig. and Drain. Engr. 116(2):182-193.

Soil Conservation Service. 1970. Technical Release 21. SCS, USDA, 92 pp.

Styles, S. 1993. On-Farm Irrigation Efficiency: Special Technical Report, Coachella Water District. April.

Williams, J.R. 1991. Runoff and water erosion. Pp. 439-455. In: R.J. Hanks, and J.T. Ritchie (eds). 1991. Modeling Plant and Soil Systems. Agron. Mono. 31, Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am., Madison, 561 pp.

APPENDIX A

Effective Rainfall Calculations

Row 01-Oct-93 EFFECTIVE RAINFALL - THERMAL, CALIF \CVWD-ER

	B	C	D	E	F	G	H	I	J	K	L	M	N
2	==========												
3													
4	INPUT DATA:		For Day 1, assume Condition II (average condition)										
5			For Day 2, assume Condition III (wet condition)										
6			For Day 3, assume Condition III (wet condition)										
7			Soil Type = "D", very slow infiltration, less than 0.05 in/h when wet.										
8			Curve Number (CN):Condition II, row crops, average, =						89	Smx =	1.24 in		
9			Condition I, row crops, soils dry =						78	Smx =	2.82 in		
10			Condition III, row crops, soils wet=						96	Smx =	0.42 in		
11			(Maximum retention, Smx = 1000/CN - 10)										
12											Inter	Calculation	
13	Period: 1986-92		Storms, inches				Days from	Day 1	Day 2	Day 3	Day1	Day2	Day2
14	Year	Mo	Day 1	Day 2	Day 3	Day 4	planting	Int, in	Int, in	Int, in	Inter	Inter	Inter
15	----------												
16	1986	1	0.01				90	0.002	0.00	0.00	0.02	0.00	0.00
17	1986	1	0.08				90	0.02	0.00	0.00	0.09	0.00	0.00
18	1987	1	0.03				90	0.01	0.00	0.00	0.04	0.00	0.00
19	1988	1	0.44	0.52			90	0.09	0.10	0.00	0.17	0.17	0.00
20	1988	1	0.30				90	0.06	0.00	0.00	0.15	0.00	0.00
21	1989	1	0.09	0.59			90	0.02	0.12	0.00	0.09	0.18	0.00
22	1990	1					90	0.00	0.00	0.00	0.00	0.00	0.00
23	1991	1	0.26	0.07	0.01		90	0.05	0.01	0.00	0.15	0.08	0.02
24	1991	1	0.12				90	0.02	0.00	0.00	0.11	0.00	0.00
25	1992	1	0.18				90	0.04	0.00	0.00	0.13	0.00	0.00
26	1992	1	0.04				90	0.01	0.00	0.00	0.05	0.00	0.00
27	1986	2	0.52				120	0.10	0.00	0.00	0.23	0.00	0.00
28	1986	2	1.15				120	0.23	0.00	0.00	0.26	0.00	0.00
29	1987	2	0.16	0.09	0.02		120	0.03	0.02	0.00	0.16	0.12	0.04
30	1988	2	0.94				120	0.19	0.00	0.00	0.25	0.00	0.00
31	1989	2	0.01				120	0.00	0.00	0.00	0.02	0.00	0.00
32	1990	2	0.01				120	0.00	0.00	0.00	0.02	0.00	0.00
33	1991	2					120	0.00	0.00	0.00	0.00	0.00	0.00
34	1992	2	0.92	0.17			120	0.18	0.03	0.00	0.25	0.17	0.00
35	1992	2	0.82	0.14			120	0.16	0.03	0.00	0.25	0.15	0.00
36	1992	2	0.44				120	0.09	0.00	0.00	0.22	0.00	0.00
37	1986	3	0.19				150	0.04	0.00	0.00	0.22	0.00	0.00
38	1986	3	0.21				150	0.04	0.00	0.00	0.23	0.00	0.00
39	1987	3	0.18				150	0.04	0.00	0.00	0.21	0.00	0.00
40	1988	3	0.00				150	0.00	0.00	0.00	0.30	0.00	0.00
41	1989	3	0.03				150	0.01	0.00	0.00	0.07	0.00	0.00
42	1990	3	0.00				150	0.00	0.00	0.00	0.00	0.00	0.00
43	1991	3	0.57				150	0.11	0.00	0.00	0.29	0.00	0.00
44	1991	3	0.02	0.21			150	0.00	0.04	0.00	0.05	0.23	0.00
45	1991	3	0.21	0.46			150	0.04	0.09	0.00	0.23	0.28	0.00
46	1992	3	0.72				150	0.14	0.00	0.00	0.30	0.00	0.00
47	1992	3	0.08	0.04			150	0.02	0.01	0.00	0.14	0.09	0.00
48	1992	3	0.27	0.03			150	0.05	0.01	0.00	0.25	0.07	0.00
49	1992	3	0.49	0.03			150	0.10	0.01	0.00	0.29	0.07	0.00
50	1992	3	0.01	0.01			150	0.00	0.00	0.00	0.03	0.03	0.00
51	1986	4	0.01				180	0.00	0.00	0.00	0.03	0.00	0.00
52	1987	4	0.00				180	0.00	0.00	0.00	0.00	0.00	0.00
53	1988	4	0.17				180	0.03	0.00	0.00	0.25	0.00	0.00
54	1988	4	0.19				180	0.04	0.00	0.00	0.26	0.00	0.00

55	1989	4	0.00			180	0.00	0.00	0.00	0.00	0.00	0.00
6	1990	4	0.01			180	0.00	0.00	0.00	0.03	0.00	0.00
57	1991	4	0.00			180	0.00	0.00	0.00	0.00	0.00	0.00
58	1992	4	0.32			180	0.06	0.00	0.00	0.31	0.00	0.00
59	1986	5	0.00			210	0.00	0.00	0.00	0.00	0.00	0.00
60	1987	5	0.00			210	0.00	0.00	0.00	0.00	0.00	0.00
61	1988	5	0.00			210	0.00	0.00	0.00	0.00	0.00	0.00
62	1989	5	0.00			210	0.00	0.00	0.00	0.00	0.00	0.00
63	1990	5	0.02			210	0.00	0.00	0.00	0.07	0.00	0.00
64	1991	5	0.00			210	0.00	0.00	0.00	0.00	0.00	0.00
65	1992	5	0.12			210	0.02	0.00	0.00	0.25	0.00	0.00
66	1992	5	0.05			210	0.01	0.00	0.00	0.15	0.00	0.00
67	1986	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
68	1987	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
69	1988	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
70	1989	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
71	1990	6	0.09			240	0.02	0.00	0.00	0.25	0.00	0.00
72	1991	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
73	1992	6	0.00			240	0.00	0.00	0.00	0.00	0.00	0.00
74	1986	7	0.01									
75	1986	7	0.02									
76	1987	7	0.03									
77	1988	7	0.00									
78	1989	7	0.01									
79	1990	7	0.00									
80	1991	7	0.02									
1	1992	7	0.01									
82	1986	8	0.00									
83	1987	8	0.11									
84	1988	8	0.39									
85	1989	8										
86	1990	8	0.01	0.02								
87	1991	8	0.00									
88	1992	8	0.01									
89	1986	9	0.03									
90	1987	9	0.08									
91	1988	9	0.00									
92	1989	9	0.02									
93	1990	9	0.20									
94	1990	9	0.05									
95	1991	9	0.12	0.23								
96	1991	9	0.07	0.01								
97	1992	9	0.00									
98	1986	10	0.22	0.34		0	0.000	0.000	0.00	0.00	0.00	0.00
99	1987	10	0.38	0.34	0.05	0	0.000	0.000	0.00	0.00	0.00	0.00
100	1987	10	0.01			0	0.000	0.000	0.00	0.00	0.00	0.00
101	1987	10	0.01			0	0.000	0.000	0.00	0.00	0.00	0.00
102	1987	10	0.74			0	0.000	0.000	0.00	0.00	0.00	0.00
103	1988	10	0.00			0	0.000	0.000	0.00	0.00	0.00	0.00
104	1989	10				0	0.000	0.000	0.00	0.00	0.00	0.00
105	1990	10	0.02			0	0.000	0.000	0.00	0.00	0.00	0.00
6	1991	10	0.00			0	0.000	0.000	0.00	0.00	0.00	0.00
7	1992	10	0.31	0.19		0	0.000	0.000	0.00	0.00	0.00	0.00
108	1986	11	0.13			30	0.026	0.000	0.00	0.04	0.00	0.00

109	1987	11	0.34			30	0.053	0.000	0.00	0.05	0.00	0.00
10	1987	11	0.46	0.03		30	0.056	0.006	0.00	0.06	0.01	0.00
111	1987	11	0.09	0.02		30	0.018	0.004	0.00	0.03	0.01	0.00
112	1988	11	0.00			30	0.000	0.000	0.00	0.00	0.00	0.00
113	1989	11	0.00			30	0.000	0.000	0.00	0.00	0.00	0.00
114	1990	11	0.01			30	0.002	0.000	0.00	0.01	0.00	0.00
115	1991	11	0.03			30	0.006	0.000	0.00	0.01	0.00	0.00
116	1992	11	0.00			30	0.000	0.000	0.00	0.00	0.00	0.00
117	1986	12	0.05	0.02		60	0.010	0.004	0.00	0.04	0.02	0.00
118	1987	12	0.08			60	0.016	0.000	0.00	0.06	0.00	0.00
119	1987	12	0.54	0.01	0.02	60	0.108	0.002	0.00	0.12	0.01	0.02
120	1988	12	0.01			60	0.002	0.000	0.00	0.01	0.00	0.00
121	1988	12	0.01			60	0.002	0.000	0.00	0.01	0.00	0.00
122	1989	12				60	0.000	0.000	0.00	0.00	0.00	0.00
123	1990	12	0.00			60	0.000	0.000	0.00	0.00	0.00	0.00
124	1991	12	0.27	0.01	0.42	60	0.054	0.002	0.08	0.10	0.01	0.11
125	1991	12	0.19			60	0.038	0.000	0.00	0.09	0.00	0.00
126	1991	12	0.07			60	0.014	0.000	0.00	0.05	0.00	0.00
127	1992	12	0.15	0.29		60	0.030	0.058	0.00	0.08	0.10	0.00
128	1992	12	0.19			60	0.038	0.000	0.00	0.09	0.00	0.00
129	1992	12	0.32	0.04		60	0.064	0.008	0.00	0.10	0.04	0.00

130 ----------

131		16.30	3.91	0.52	0.00	20.73	
132			Storms, inches				
133		Day 1	Day 2	Day 3	Day 4	Total	
134	Runoff =	1.65	1.02	0.15	0.00	2.81	13.6%
35	Incr Evap =					10.83	52.2%
36							
137							
138	Total losses					13.64	65.8%
139	Effective rainfall					7.09	34.2%
140							

141 MONTHLY SUMMARY: D,E,F,G P,R,T AA

142			Rain	Runoff	E+	RO + E+	ER, in.	ER, %	
143	R16-26	Jan	2.74	0.53	1.11	1.63	1.11	40%	40.4
144	R27-36	Feb	5.39	1.15	1.83	2.97	2.42	45%	44.8
145	R37-50	Mar	3.76	0.45	2.55	3.00	0.76	20%	20.2
146	R51-58	Apr	0.70	0.00	0.70	0.70	0.00	0%	0.0
147	R59-66	May	0.19	0.00	0.19	0.19	0.00	0%	0.0
148	R67-73	Jun	0.09	0.00	0.09	0.09	0.00	0%	0.0
149	R74-81	Jul	0.10	0.00	0.10	0.10	0.00	0%	0.0
150	R82-88	Aug	0.54	0.00	0.54	0.54	0.00	0%	0.0
151	R89-97	Sep	0.81	0.00	0.81	0.81	0.00	0%	0.0
152	R98-107	Oct	2.61	0.37	1.13	1.50	1.11	43%	42.6
153	R108-116	Nov	1.11	0.04	0.69	0.73	0.38	34%	34.1
154	R117-129	Dec	2.69	0.28	1.10	1.38	1.31	49%	48.9
155			----------						
156	Annual		20.73	2.81	10.83	13.64	7.09	34%	

01-Oct-93 EFFECTIVE RAINFALL - THERMAL, CALIF \CVWD-ER

Page 118, ASCE Man. 70: Incr E = 0.35[1.5 + Td][(K1 - Kc) ETo]
Td = 7 days for clay loams soils
Pot E+ = 0.35[8.5][(K1 - Kc)ETo]
Limit = E+ (P - RO)/(0.35(8.5)(K1 - Kc)ETo)
K1 = 1.2

O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
Runoff calculations								Non-beneficial evaporation calculations				
Day 1		Day 2		Day 3					Increased evaporation after rains			
Run off, inches Threshold	Amount	Run off, inches Threshold	Amount	Run off, inches Threshold	Amount	ETo In/d	Avg Kc	ET in.	P - RO In.	Pot E+ In.	Limit In.	Actual E+	Mo
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.010	0.165	0.010	0.010	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.080	0.165	0.080	0.080	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.030	0.165	0.030	0.030	1
0.247	0.026	0.083	0.223	0.083	0	0.079	0.50	0.040	0.711	0.165	0.711	0.165	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.300	0.165	0.300	0.165	1
0.247	0	0.083	0.278	0.083	0	0.079	0.50	0.040	0.402	0.165	0.402	0.165	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.000	0.165	0.000	0.000	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.340	0.165	0.340	0.165	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.120	0.165	0.120	0.120	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.180	0.165	0.180	0.165	1
0.247	0	0.083	0	0.083	0	0.079	0.50	0.040	0.040	0.165	0.040	0.040	1
0.247	0.049	0.083	0	0.083	0	0.136	0.56	0.076	0.471	0.258	0.471	0.258	2
0.247	0.381	0.083	0	0.083	0	0.136	0.56	0.076	0.769	0.258	0.769	0.258	2
0.247	0	0.083	0	0.083	0	0.136	0.56	0.076	0.270	0.258	0.270	0.258	2
0.247	0.249	0.083	0	0.083	0	0.136	0.56	0.076	0.691	0.258	0.691	0.258	2
0.247	0	0.083	0	0.083	0	0.136	0.56	0.076	0.010	0.258	0.010	0.010	2
0.247	0	0.083	0	0.083	0	0.136	0.56	0.076	0.010	0.258	0.010	0.010	2
0.247	0	0.083	0	0.083	0	0.136	0.56	0.076	0.000	0.258	0.000	0.000	2
0.247	0.237	0.083	0.015	0.083	0	0.136	0.56	0.076	0.838	0.258	0.838	0.258	2
0.247	0.181	0.083	0.007	0.083	0	0.136	0.56	0.076	0.772	0.258	0.772	0.258	2
0.247	0.026	0.083	0.000	0.083	0	0.136	0.56	0.076	0.414	0.258	0.414	0.258	2
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.190	0.326	0.190	0.190	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.210	0.326	0.210	0.210	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.180	0.326	0.180	0.180	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.000	0.326	0.000	0.000	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.030	0.326	0.030	0.030	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.000	0.326	0.000	0.000	3
0.247	0.067	0.083	0	0.083	0	0.189	0.62	0.117	0.503	0.326	0.503	0.326	3
0.247	0	0.083	0.030	0.083	0	0.189	0.62	0.117	0.200	0.326	0.200	0.200	3
0.247	0	0.083	0.179	0.083	0	0.189	0.62	0.117	0.491	0.326	0.491	0.326	3
0.247	0.131	0.083	0	0.083	0	0.189	0.62	0.117	0.589	0.326	0.589	0.326	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.120	0.326	0.120	0.120	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.300	0.326	0.300	0.300	3
0.247	0.040	0.083	0	0.083	0	0.189	0.62	0.117	0.480	0.326	0.480	0.326	3
0.247	0	0.083	0	0.083	0	0.189	0.62	0.117	0.020	0.326	0.020	0.020	3
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.010	0.425	0.010	0.010	4
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.000	0.425	0.000	0.000	4
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.170	0.425	0.170	0.170	4
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.190	0.425	0.190	0.190	4

0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.000	0.425	0.000	0.000	4
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.010	0.425	0.010	0.010	4
0.247	0	0.083	0	0.083	0	0.246	0.62	0.153	0.000	0.425	0.000	0.000	4
0.247	0.004	0.083	0	0.083	0	0.246	0.62	0.153	0.316	0.425	0.316	0.316	4
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.000	0.532	0.000	0.000	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.000	0.532	0.000	0.000	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.000	0.532	0.000	0.000	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.000	0.532	0.000	0.000	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.020	0.532	0.020	0.020	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.000	0.532	0.000	0.000	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.120	0.532	0.120	0.120	5
0.247	0	0.083	0	0.083	0	0.298	0.6	0.179	0.050	0.532	0.050	0.050	5
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.090	0.671	0.090	0.090	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
0.247	0	0.083	0	0.083	0	0.322	0.5	0.161	0.000	0.671	0.000	0.000	6
						0.295	0.5	0.148	0.010	0.615	0.010	0.010	7
						0.295	0.5	0.148	0.020	0.615	0.020	0.020	7
						0.295	0.5	0.148	0.030	0.615	0.030	0.030	7
						0.295	0.5	0.148	0.000	0.615	0.000	0.000	7
						0.295	0.5	0.148	0.010	0.615	0.010	0.010	7
						0.295	0.5	0.148	0.000	0.615	0.000	0.000	7
						0.295	0.5	0.148	0.020	0.615	0.020	0.020	7
						0.295	0.5	0.148	0.010	0.615	0.010	0.010	7
						0.265	0.3	0.079	0.000	0.708	0.000	0.000	8
						0.265	0.3	0.079	0.110	0.708	0.110	0.110	8
						0.265	0.3	0.079	0.390	0.708	0.390	0.390	8
						0.265	0.3	0.079	0.000	0.708	0.000	0.000	8
						0.265	0.3	0.079	0.030	0.708	0.030	0.030	8
						0.265	0.3	0.079	0.000	0.708	0.000	0.000	8
						0.265	0.3	0.079	0.010	0.708	0.010	0.010	8
						0.238	0.62	0.148	0.030	0.411	0.030	0.030	9
						0.238	0.62	0.148	0.080	0.411	0.080	0.080	9
						0.238	0.62	0.148	0.000	0.411	0.000	0.000	9
						0.238	0.62	0.148	0.020	0.411	0.020	0.020	9
						0.238	0.62	0.148	0.200	0.411	0.200	0.200	9
						0.238	0.62	0.148	0.050	0.411	0.050	0.050	9
						0.238	0.62	0.148	0.350	0.411	0.350	0.350	9
						0.238	0.62	0.148	0.080	0.411	0.080	0.080	9
						0.238	0.62	0.148	0.000	0.411	0.000	0.000	9
0.247	0	0.083	0.098	0.083	0	0.160	0.63	0.101	0.462	0.271	0.462	0.271	10
0.247	0.013	0.083	0.098	0.083	0	0.160	0.63	0.101	0.659	0.271	0.659	0.271	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.010	0.271	0.010	0.010	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.010	0.271	0.010	0.010	10
0.247	0.140	0.083	0	0.083	0	0.160	0.63	0.101	0.600	0.271	0.600	0.271	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.000	0.271	0.000	0.000	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.000	0.271	0.000	0.000	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.020	0.271	0.020	0.020	10
0.247	0	0.083	0	0.083	0	0.160	0.63	0.101	0.000	0.271	0.000	0.000	10
0.247	0.003	0.083	0.022	0.083	0	0.160	0.63	0.101	0.475	0.271	0.475	0.271	10
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.130	0.207	0.130	0.130	11

0.247	0.006	0.083	0	0.083	0	0.101	0.51	0.051	0.334	0.207	0.334	0.207	11
0.247	0.031	0.083	0	0.083	0	0.101	0.51	0.051	0.459	0.207	0.459	0.207	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.110	0.207	0.110	0.110	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.000	0.207	0.000	0.000	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.000	0.207	0.000	0.000	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.010	0.207	0.010	0.010	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.030	0.207	0.030	0.030	11
0.247	0	0.083	0	0.083	0	0.101	0.51	0.051	0.000	0.207	0.000	0.000	11
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.070	0.143	0.070	0.070	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.080	0.143	0.080	0.080	12
0.247	0.056	0.083	0	0.083	0	0.072	0.53	0.038	0.514	0.143	0.514	0.143	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.010	0.143	0.010	0.010	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.010	0.143	0.010	0.010	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.000	0.143	0.000	0.000	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.000	0.143	0.000	0.000	12
0.247	0	0.083	0	0.083	0.150	0.072	0.53	0.038	0.550	0.143	0.550	0.143	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.190	0.143	0.190	0.143	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.070	0.143	0.070	0.070	12
0.247	0	0.083	0.069	0.083	0	0.072	0.53	0.038	0.371	0.143	0.371	0.143	12
0.247	0	0.083	0	0.083	0	0.072	0.53	0.038	0.190	0.143	0.190	0.143	12
0.247	0.004	0.083	0	0.083	0	0.072	0.53	0.038	0.356	0.143	0.356	0.143	12

	1.65		1.02		0.15							10.83
Day 1		Day 2		Day 3					Increased evaporation after rains			
Run off, inches		Run off, inches		Run off, inches		ETo	Avg	ET	P - RO	Pot E+	Limit	Actual
hreshold	Amount	Threshold	Amount	Threshold	Amount	In/d	Kc	in.	In.	In.	In.	E+

EVALUATING REFERENCE EVAPOTRANSPIRATION ESTIMATES FOR IID

by
Marvin E. Jensen
12 Oct 93

INTRODUCTION

During the Technical Work Group (TWG) discussions on 15 September 1993, we discussed the 20 percent decrease in estimated grass reference evapotranspiration (ET_o) from 1987 to 1992 (from 82.8 inches to 65.8 inches). Such a large magnitude of change is very unusual for an arid environment where the main diving force (solar radiation) is expected to remain relatively constant during the 6-year period. Although CIMIS ET_o values can be used directly for estimating evaporative demand and crop ET, accurate climatological data are needed for confirming ET values and estimating crop ET where crop coefficients are related to climate, or crop growth models require weather input. Likewise, estimates of evaporation from water surfaces require either a modified Penman-Monteith equation or a calibration of evaporation v. ET_o. These estimates are needed to provide alternative estimates of on-farm irrigation efficiencies.

Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle/Styles (1993) report were provided by Charles Burt. UPDATE1.DBF contains data for only the three CIMIS sites 41 (Mulberry), 68 (Seeley) and 87 (Meloland). The purpose of reviewing CIMIS evaporation (ET_o) and weather data was to evaluate possible changes in the sensors, particularly the solar radiation sensor, during the 6-year period that may have caused part of the large decrease in evaporative demand.

PROBABLE CAUSES OF ERRORS IN THE DATA

Mean monthly CIMIS solar radiation values from the CIMIS Station 41 (Mulberry) file were first compared with values shown on pages A-52 and A-53 from the Boyle/Styles report (Styles, 1993). Significant differences were found beginning in September 1987. Differences became more frequent from 1990 through 1992. Therefore, in order to evaluate ET_o estimates using mean monthly data, it was first necessary to evaluate the accuracy of all of the mean monthly values shown in the tables for the three sites for which an analysis was desired (CIMIS Station 41, Mulberry; CIMIS Station 68, Seeley; and CIMIS Station 87, Meloland).

The CIMIS data file contains values with various flags noted on some data. I contacted and obtained a listing of the flags used in CIMIS from Rick Snyder, University of California/Davis. However, some of the flags in the data file were not the same as those in the original CIMIS files.

For CIMIS Station 41, it soon became apparent that the solar radiation values shown on pages A-52 to A-53 were averages for each month using **all of the data**. However, whenever there apparently was an instrument problem, a **"zero"** appeared in the daily data with a "C" flag. Other flags in the solar radiation data were H and Y. The H-flag was used when one or more hourly values was severe. The Y-flag was not explained for solar radiation, but for other variables it is used when the value is outside of a specific range. Thus, it became apparent that an independent evaluation of mean monthly ET_o estimates could not be made without first evaluating all of the mean monthly input data. Since the mean monthly values contained averaging errors, the values obtained with Pruitt's spreadsheet program cannot be compared directly either CIMIS ET_o values or my estimates of ET_o.

PROCEDURES

Evaluating Mean Monthly Weather Data

Daily data for each of the three CIMIS stations (CIMIS-41, CIMIS-68, and CIMIS 87) corresponding to the sites used in the Boyle/Styles report were used. Data for each of the main weather variables, solar radiation, maximum and minimum air temperatures, dewpoint temperature and wind run in the UPDATE1.DBF file were first exported to a WK1 file for each of the three stations. Mean monthly values of the variables of interest were then obtained by "excluding" all daily values that were zero. In the case of dewpoint, there were also some large negative values with an "L" flag were excluded. Values with other flags were included if they appeared reasonable.

Estimating Reference ET

After cleaning up the data from the UPDATE1.DBF file, a spreadsheet program was set up to estimate mean monthly reference evapotranspiration values using the Penman (1963) and Penman-Monteith (P-M) method (Smith, 1991). The same estimate of net radiation was used with both methods. Therefore, the main differences between these two methods were the procedures used to estimate vapor pressure deficit, the aerodynamic component and the weighting of the radiation and aerodynamic terms of the combination equation. The equations used are summarized in Appendix A. The two methods are explained in ASCE Manual 70 Jensen et al., 1990) with recent modifications of the P-M method summarized by Smith (1991).

Vapor Pressure Deficit. The calculated vapor pressure deficit used in the Penman (1963) method was based on the difference between the saturation vapor pressure at **mean air temperature** and saturation vapor pressure at **dewpoint temperature**. The P-M method uses the difference between mean of the saturation vapor pressure at **maximum and minimum air temperatures** and saturation vapor pressure at **dewpoint temperature**.

Wind Function. The Penman (1963) method uses a linear wind function $W_f = 1.0 + 0.536\ u2$ where u2 the mean wind speed at a height of 2 meters in m/s, or $W_f = 1.0 + 0.01\ u2$ where u2 is the daily wind run at a height of 2 meters in miles per day. The P-M method uses an aerodynamic wind function that is related to the heights of temperature, humidity and wind speed measurements, the height of the reference crop and its leaf-area-index, canopy resistance and surface roughness. Therefore, P-M estimates can be adjusted for specific weather instruments and site conditions.

Relative Cloud Cover or Percent of Possible Sunshine

Cloud cover or percent of possible sunshine is not a CIMIS variable, but is needed in estimating net radiation. Daily **extraterrestrial solar radiation** (R_a) was first calculated for latitude 33 degrees N using equations from the Insolation Data Manual (Solar Energy Research Institute, 1980). A solar constant of 0.082 megajoules per square meter per minute (MJ/(m^2 min) or 1.96 langleys per minute was used.

The ratio of **clear day solar radiation** (R_{so}) to extraterrestrial solar radiation, R_{so}/R_a, varies during the year because of changes in the declination of the sun. A functional relationship between R_{so} and R_a was developed by selecting high daily values of solar radiation near the middle of each month from the CIMIS data sets and relating these to R_a. The resulting equation for IID is given in Appendix A.

Mean Daily Albedo

Mean daily albedo also changes with solar declination or zenith angle. Hourly albedo values have been developed as a function of latitude (Dong et al., 1992). However, a mean daily functional relationship between albedo and latitude remains to be developed. Therefore, I modified the albedo function developed by Wright (ASCE Manual p. 137) to obtain a functional relationship applicable throughout the year. The resulting equation is in Appendix A.

CONDITIONS THAT COULD CAUSE LARGE DECREASES IN ANNUAL REFERENCE ET

Major Variables

Solar radiation is the main energy input affecting the evaporative demand during the year. If sensor calibrations drifted over the six-year period, then a calculated decrease in reference ET might be caused partly by instrument error. The other two main variables affecting estimated reference ET are humidity, as indicated by **dewpoint**, and **wind speed** as indicated by total daily wind run.

Indirect Rainfall Effects

A significant increase in annual rainfall occurred during the last two years of the six-year period as shown in Table 1. Very low rainfall in 1989 could be expected to slightly increase mean annual solar radiation with a corresponding decrease in mean annual humidity (dewpoint). Similarly, the unusually high rainfall in 1991, and especially in 1992, would have opposite effects lowering the evaporative demand in 1991 and 1992.

Table 1. Summary of rainfall recorded at CIMIS Stations 41, 68 and 87.

Year	Station 41		Station 68		Station 87		Average
	Inches	Percent	Inches	Percent	Inches	Percent	Inches
1987	3.51	82	- -	- -	- -	- -	3.51
1988	3.30	77	3.10	75	- -	- -	3.20
1989	2.11	49	2.86	69	- -	- -	2.49
1990	2.36	55	1.52	37	2.95	66	2.28
1991	6.34	147	5.94	144	3.31	74	5.20
1992	8.19	190	7.27	176	7.24	161	7.57
Average	4.30	100	4.14	100	4.50	100	4.04
Avg., 90-92	5.63	131	4.91	119	4.50	100	5.01
Percent of 1987-1992 average							124%

Most of the rainfall occurs during the October-March period. The annual rainfall during the six-year period for the three CIMIS sites is shown in Figure 1. The relative effects of increased rainfall and associated cloudiness on solar radiation, dewpoint temperature and wind speed for the CIMIS 41 station is shown in Figure 2. Mean annual solar radiation remained fairly constant from 1987 through 1990, but decreased significantly in 1991 and 1992. Likewise, mean wind speed decreased greatly in 1991 and 1992. Mean annual dewpoint temperature increased in 1991 and 1992. The climatic conditions in 1991 and 1992 would decrease estimated reference ET from the long-term average. Clearly, rainfall, though very limited, has significant effects on the variables affecting the evaporative demand in the Imperial Irrigation District.

Fig. 1. Annual rainfall for CIMIS Station 41 (Mulberry), Station 68 (Seeley), and Station 87 (Meloland) from 1987 to 1992.

Fig. 2. Relative Effects of rainfall on climatic variables that determine estimated reference ET.

RESULTS OF ANALYSES

Corrected Mean Climate Data

The mean monthly data for CIMIS Station 41 shown on pages A-52 and A-53 of the Boyle/Styles report are generally low starting in 1988 when instrument problems apparently resulted in "zeros" in the CIMIS data file. The relative magnitudes of these effects for Station 41 are illustrated in Fig. 3. Most of the mean monthly climatic variables were 4 to 6 percent low. Smaller effects existed for CIMIS Stations 68 and especially Station 87 with only three years of data. Apparently, these stations were newer and had fewer instrument problems.

Fig. 3. Relative effects of including "zeros" when computing 1987-1992 mean monthly values for CIMIS Station 41 reported on pages A-52 and A-53 of the Boyle/Styles report (Styles, 1993).

A summary of the data from the data file UPDATE1.DBF relative to that reported on pages A-52 to A-53 for Station 41 and on page A-49 for Station 87 is presented in Appendix B. Values for Station 68 were not available in the Styles report for comparison although they could have been generated by including all values in calculated monthly means.

Decreasing Annual Reference ET

After correcting mean monthly climate data, the estimates of annual ET for CIMIS Stations 41, 68 and 87 using the Penman-Monteith and Penman (1963) equations showed a general downward trend similar to that obtained from the CIMIS ET_o data are illustrated in Figures 4-6.

Fig. 4-6. Comparison of annual reference ET for CIMIS Stations 41, 68 and 87 computed with the Penman-Monteith and Penman (1963) equations with CIMIS values.

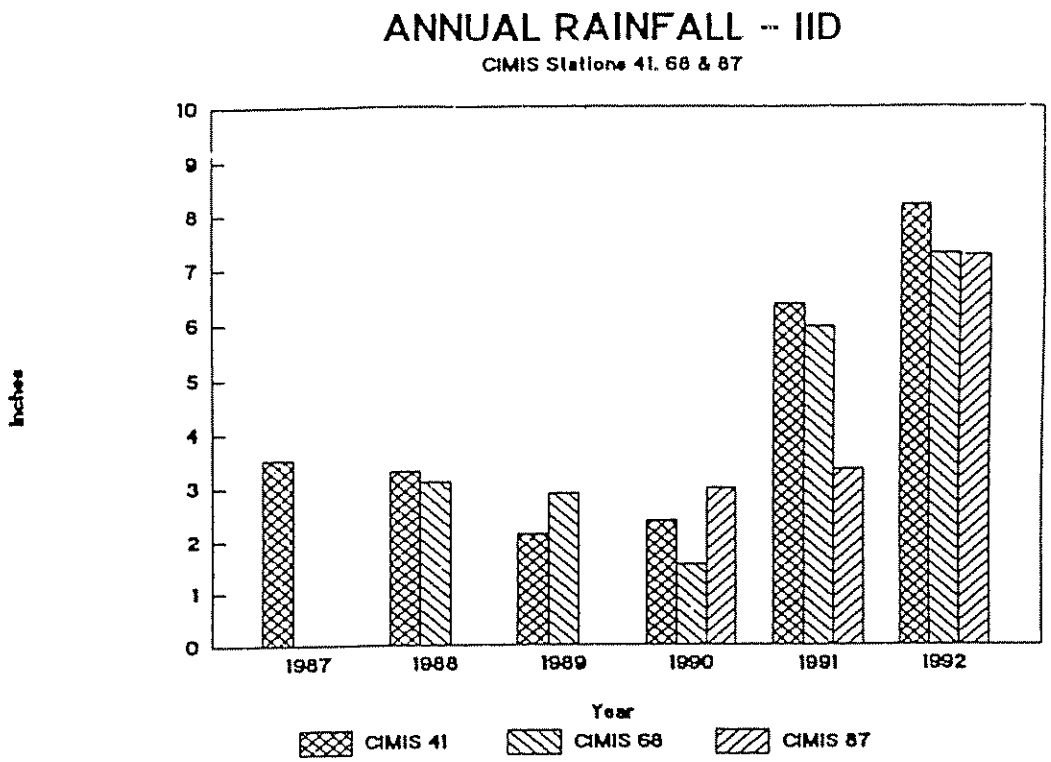

ANNUAL RAINFALL -- IID
CIMIS Stations 41, 68 & 87
Inches
10
9
8
7
6
5
4
3
2
1
0
1987
1988
1989
1990
1991
1992
Year
CIMIS 41
CIMIS 68
CIMIS 87

Fig. 1

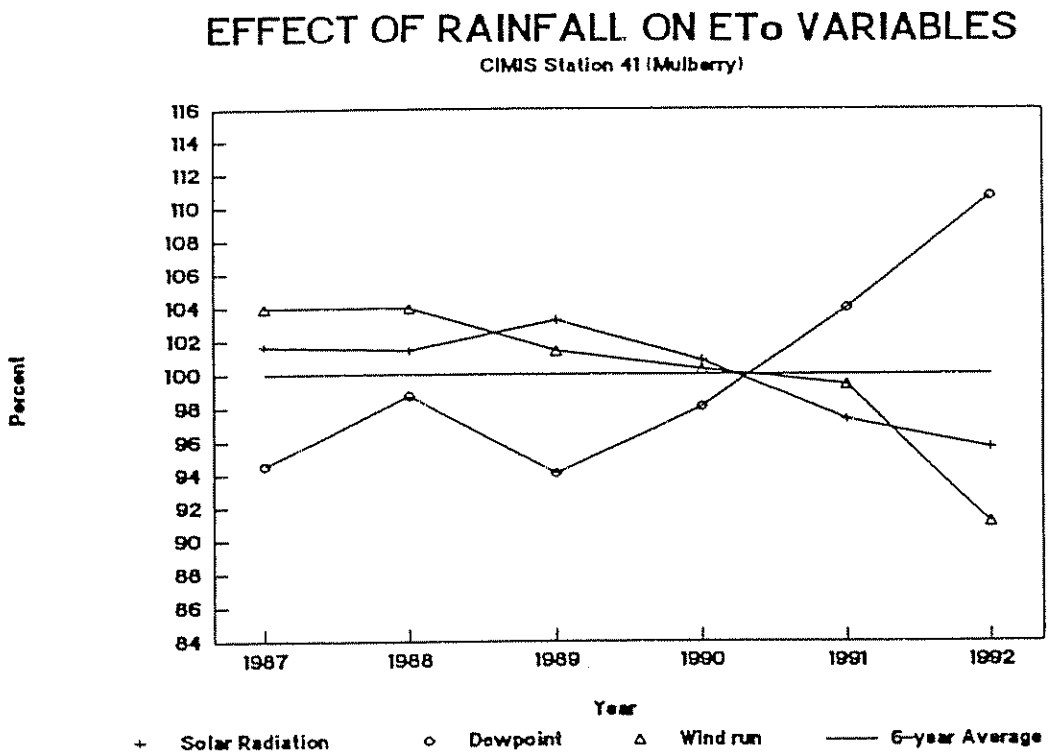

EFFECT OF RAINFALL ON ETo VARIABLES
CIMIS Station 41 (Mulberry)
Percent
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
86
84
1987
1988
1989
1990
1991
1992
Year
Solar Radiation
Dewpoint
Wind run
6-year Average

Fig. 2

DATA FROM PAGES A-52 & A-53

Styles (1993) CIMIS Station 41

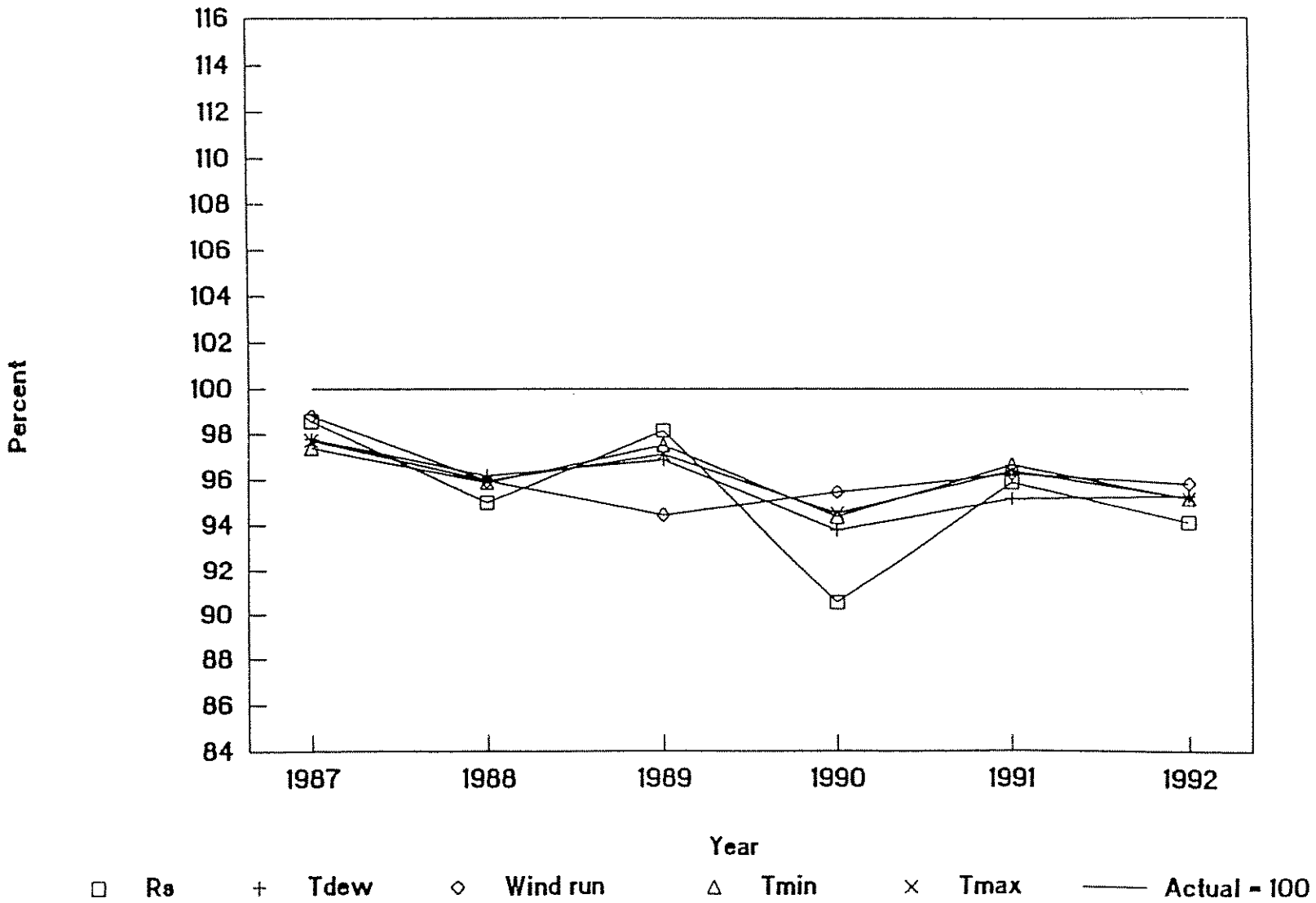


Fig. 3

REFERENCE ET EVALUATIONS - CIMIS 41

Mulberry Site

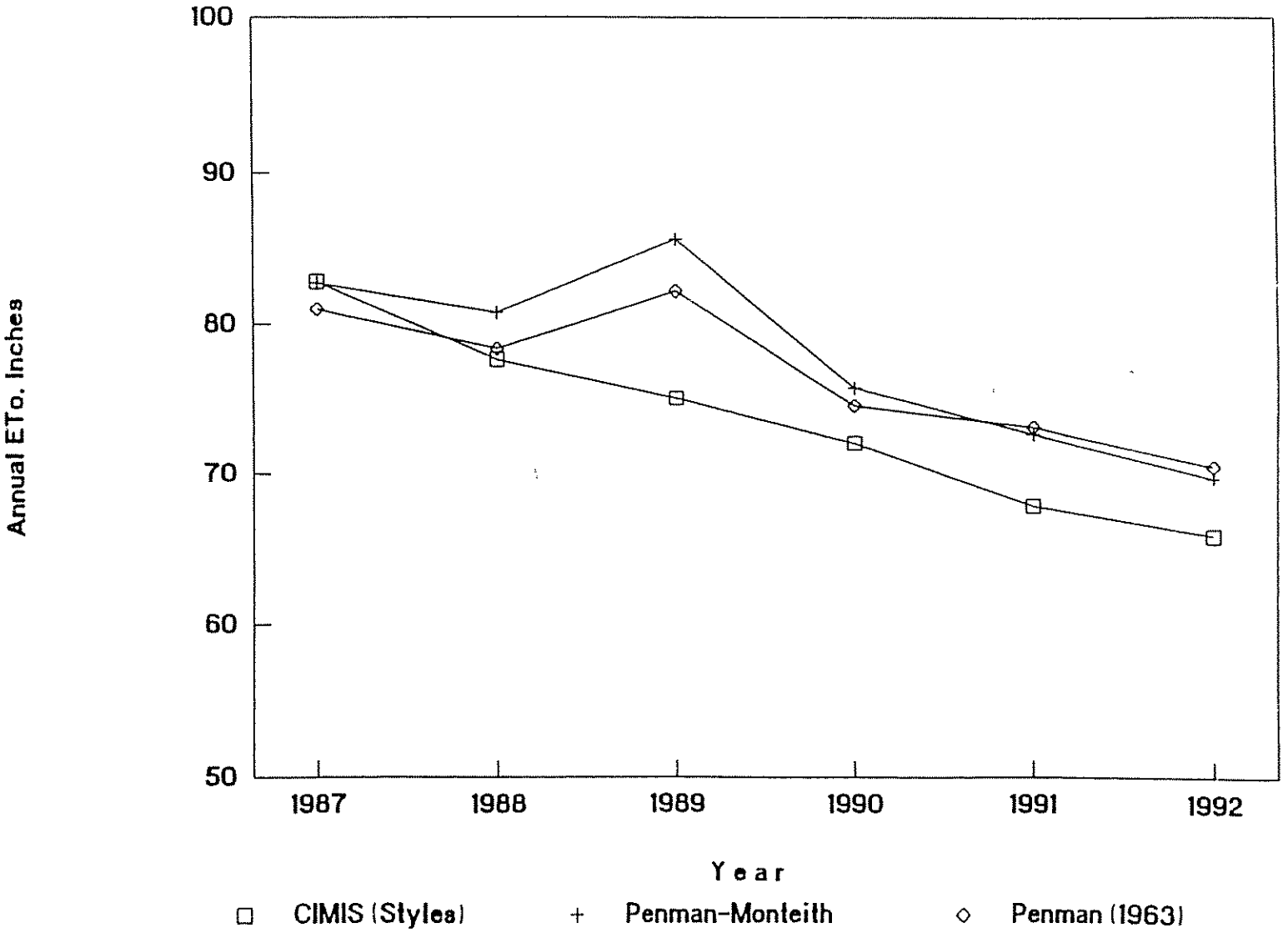


Fig 4

REFERENCE ET EVALUATIONS - CIMIS 68

Seeley Site

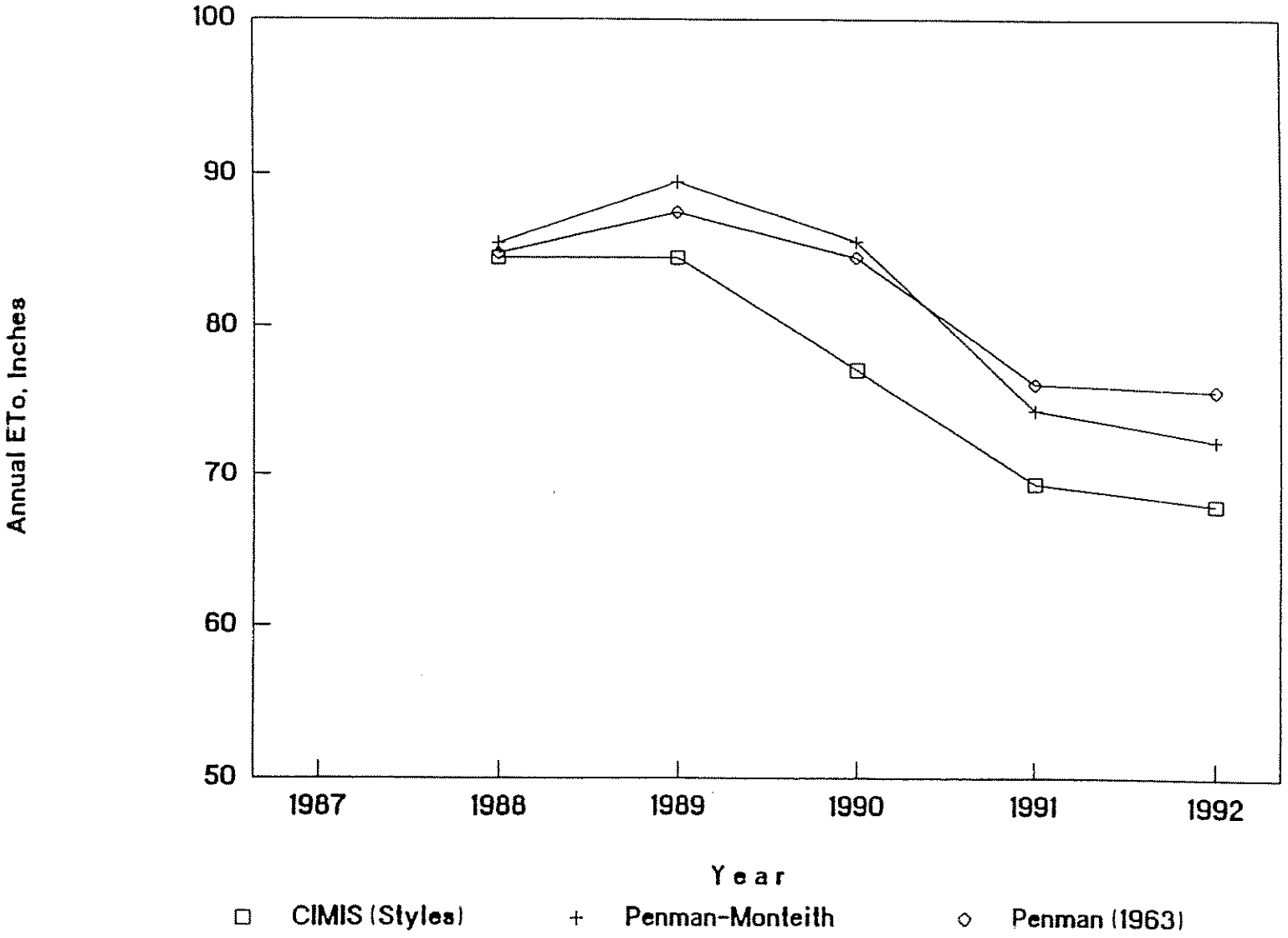


Fig. 5

REFERENCE ET EVALUATIONS - CIMIS 87

Meloland Site

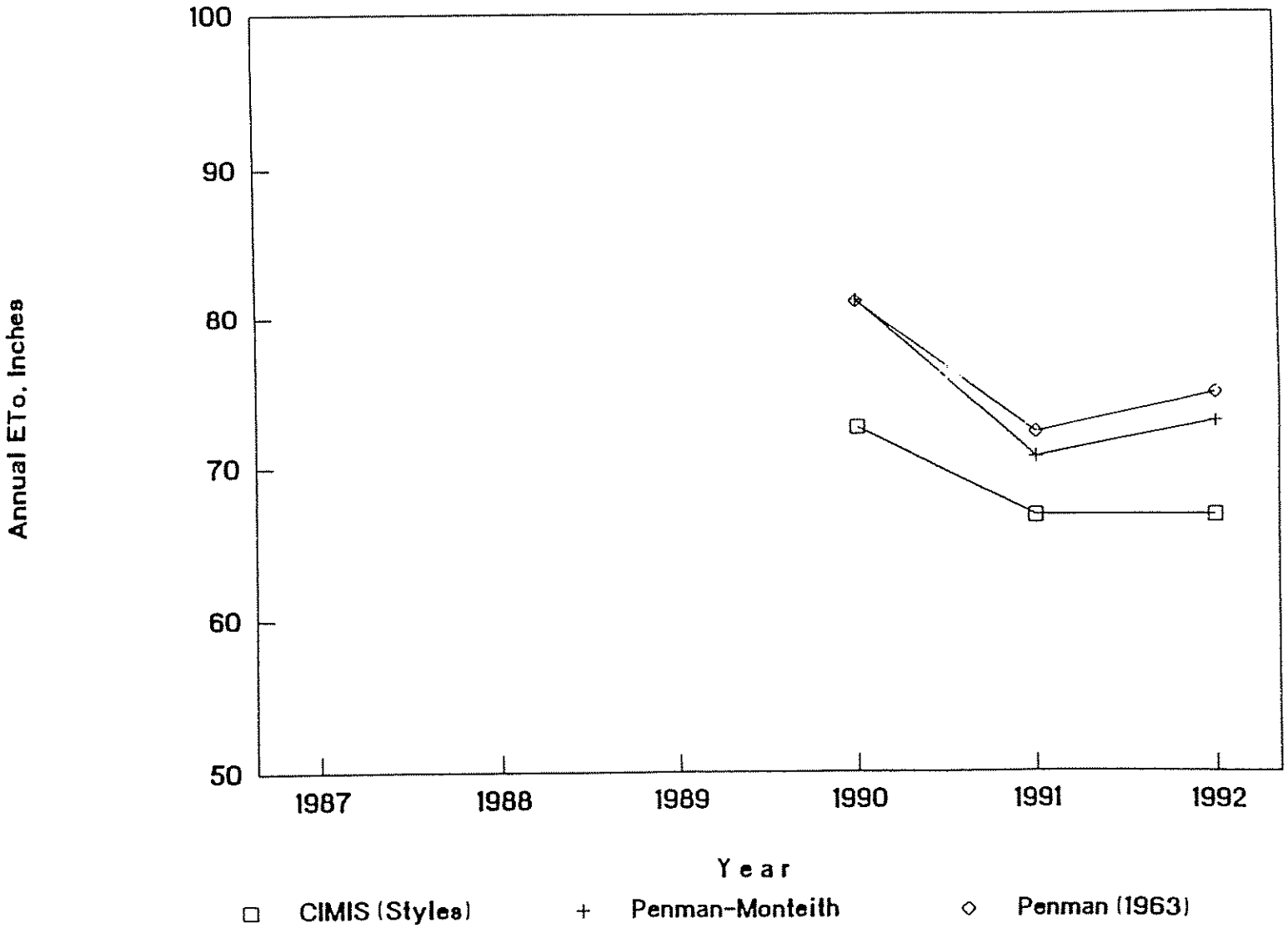


Fig 6

Monthly Reference ET

Comparisons of estimated mean monthly reference ET values using the P-M and Penman (1963) equations with CIMIS values are shown in Figures 7-9 for the period 1990-1992. The three-year period, 1990-1992, is used because data from all three sites were available for this period. Clearly, the estimates using the combination equations and my procedures exceed CIMIS values from May through October. The estimates were made using average monthly data while the CIMIS values are averages of daily values which in turn are based on hourly totals.

The main effect of the differences in mean monthly estimates appear to reflect the lag in temperature from solar radiation. The largest differences occurred at CIMIS Station 68 (Meloland) as shown in Fig. 9. This site currently is in alfalfa which would have higher humidity and lower wind speeds at instrument height than at grass sites. A first adjustment in the P-M method would be to change the crop height and aerodynamic roughness over which the measurements are made relative to the other two sites.

Fig. 7-9. Comparison of mean monthly reference ET for CIMIS Stations 41, 68 and 87 computed with the Penman-Monteith and Penman (1963) equations with CIMIS values for the period 1990-1992.

Differences Between CIMIS and P-M Values

A comparison of mean monthly reference ET estimates using the P-M equation and mean monthly climatic data averaged for the three stations with CIMIS values is shown in Fig. 10. The Penman-Monteith and Penman (1963) equations used with mean monthly climatic data were consistently about 8 to 9 percent higher than the CIMIS values. It would be fairly simple to modify the P-M equation to more closely match the CIMIS values at each site. The first general adjustments might be to use the vapor pressure deficit based on mean air temperature, or to increase the canopy resistance for the reference crop. A summary of annual values is shown in Appendix A.

Fig. 10. Comparison of mean reference ET estimates for the three stations computed with the Penman-Monteith equation with average CIMIS values for the period 1990-1992.

Differences Between CIMIS Sites

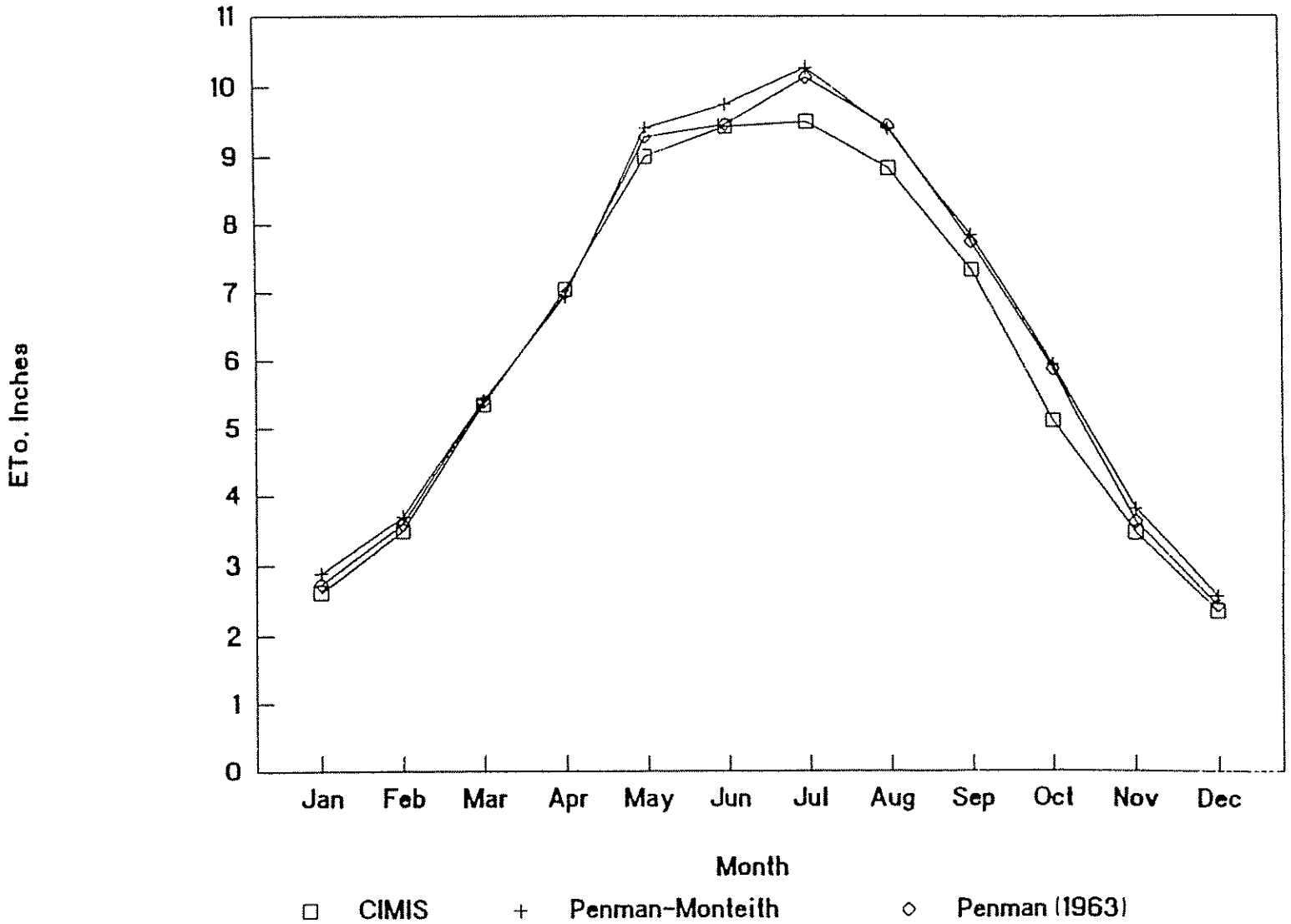
A comparison of differences between CIMIS sites is shown in Fig. 11 using the CIMIS data and in Fig. 12 using the P-M equation. Clearly, the reference ET values at CIMIS site 68 is higher from March through June than at the other two sites. Site 68, Seeley, is on the west side of the valley and the higher early season values probably reflect the drier air flow from the west.

Fig. 11. Comparison of mean monthly reference ET at the three sites as indicated by CIMIS values.

Fig. 12. Comparison of mean monthly reference ET at the three sites as indicated by P-M values.

REFERENCE ET EVALUATIONS - CIMIS 41

Mulberry Site



REFERENCE ET EVALUATIONS - CIMIS 68

Seeley Site

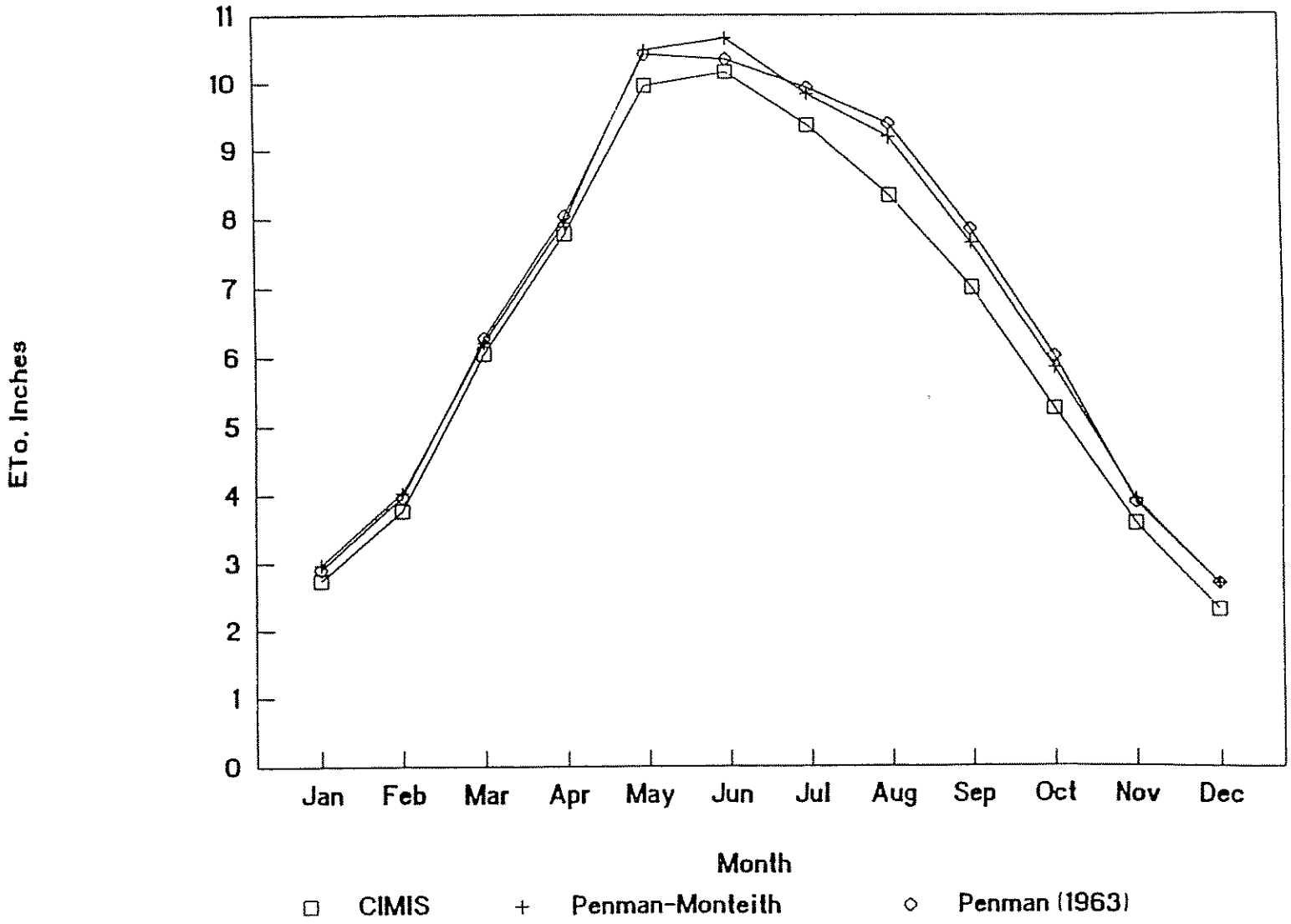


Fig. 8

REFERENCE ET EVALUATIONS - CIMIS 87

Meloland Site

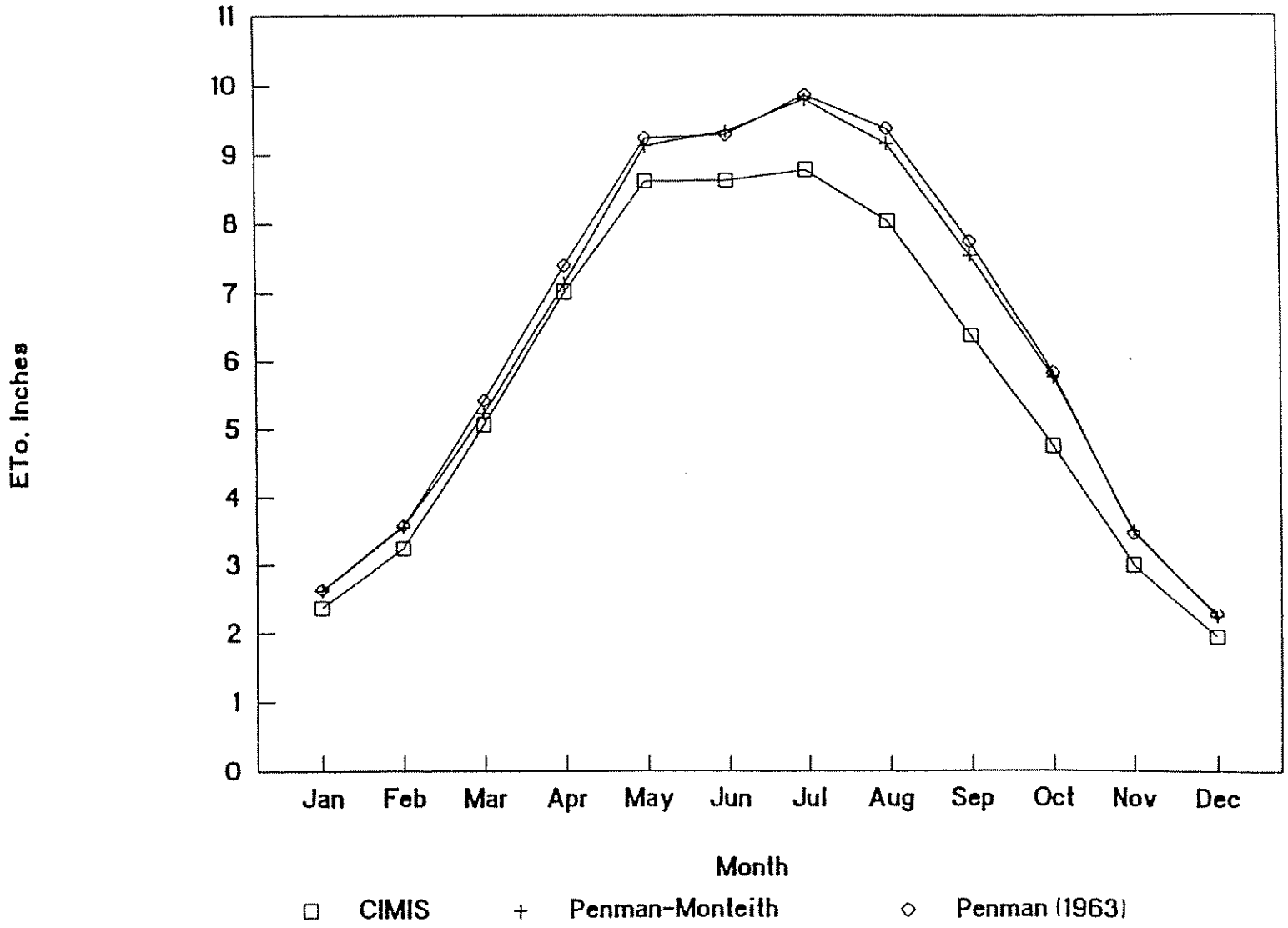


Fig 9

COMPARISON OF CIMIS SITES - ETo IID

Sites 41, 68 and 87

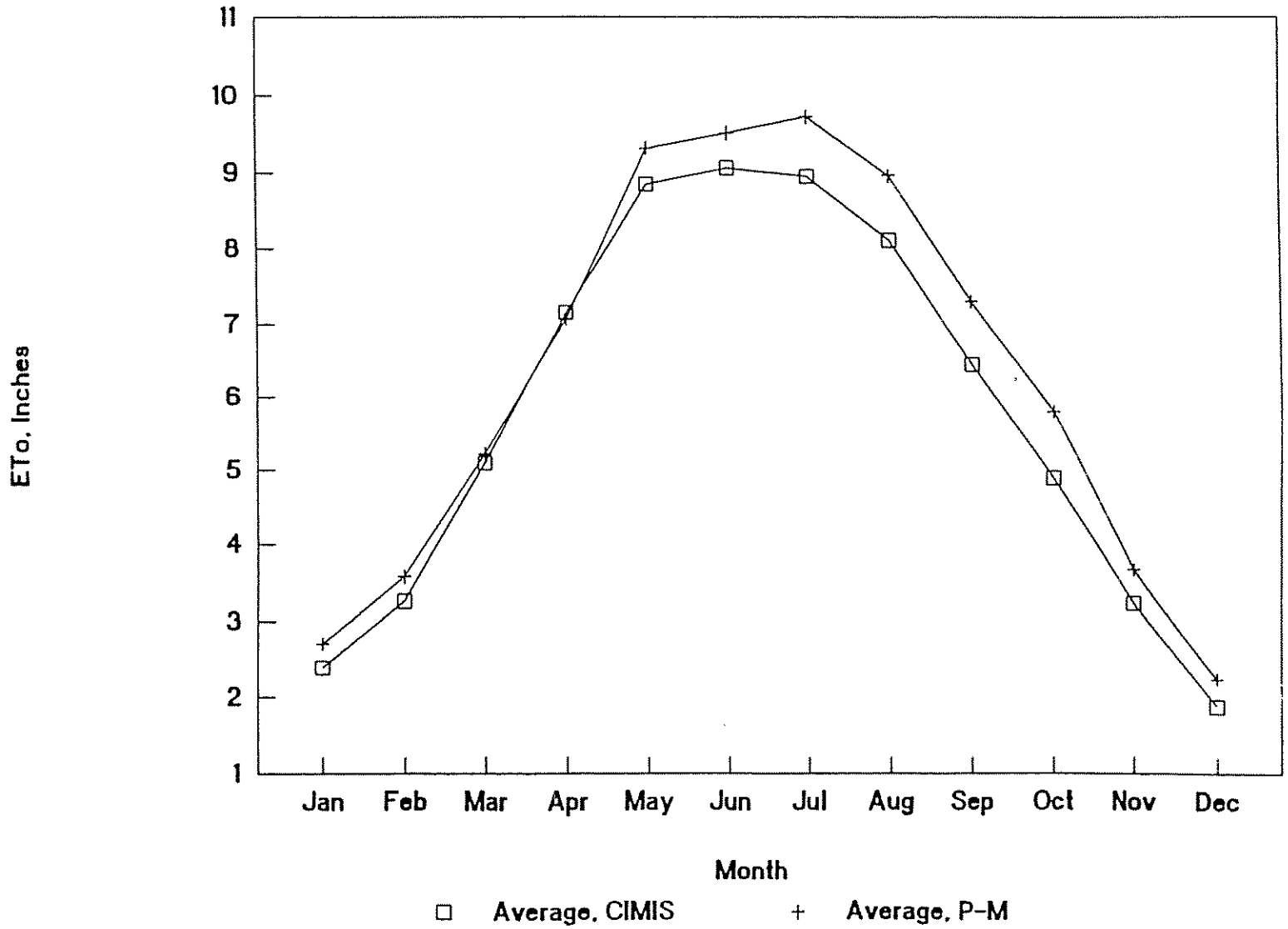


Fig 10

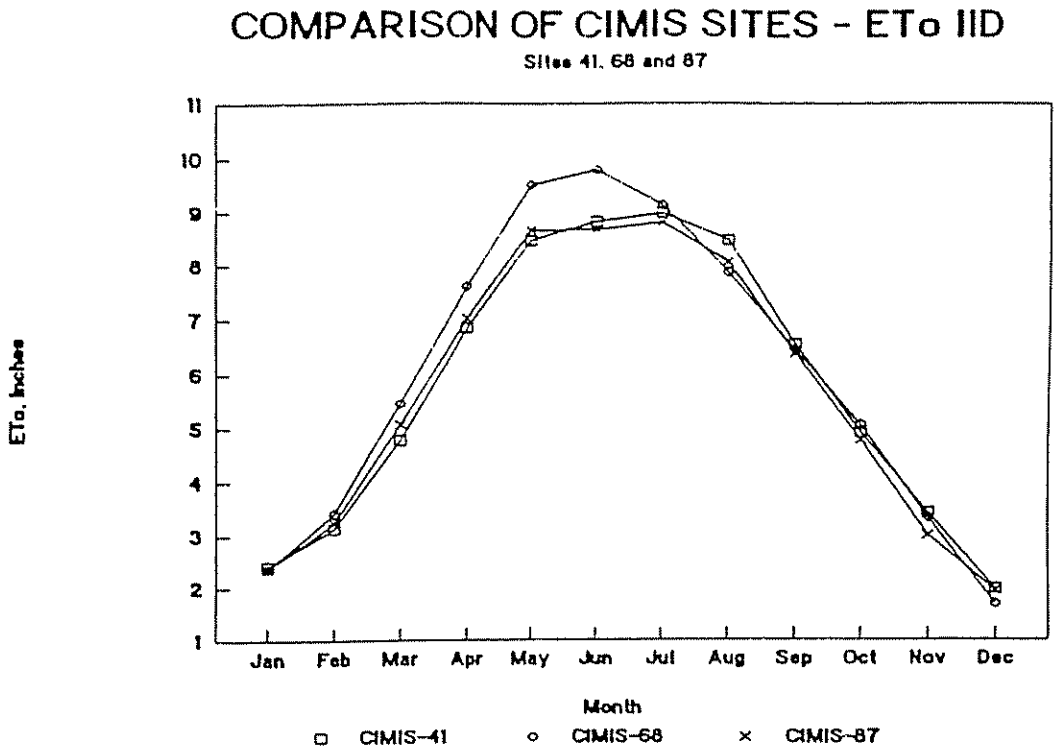

COMPARISON OF CIMIS SITES - ETo IID
Sites 41, 68 and 87
ETo, inches
11
10
9
8
7
6
5
4
3
2
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
CIMIS-41
CIMIS-68
CIMIS-87

Fig 11

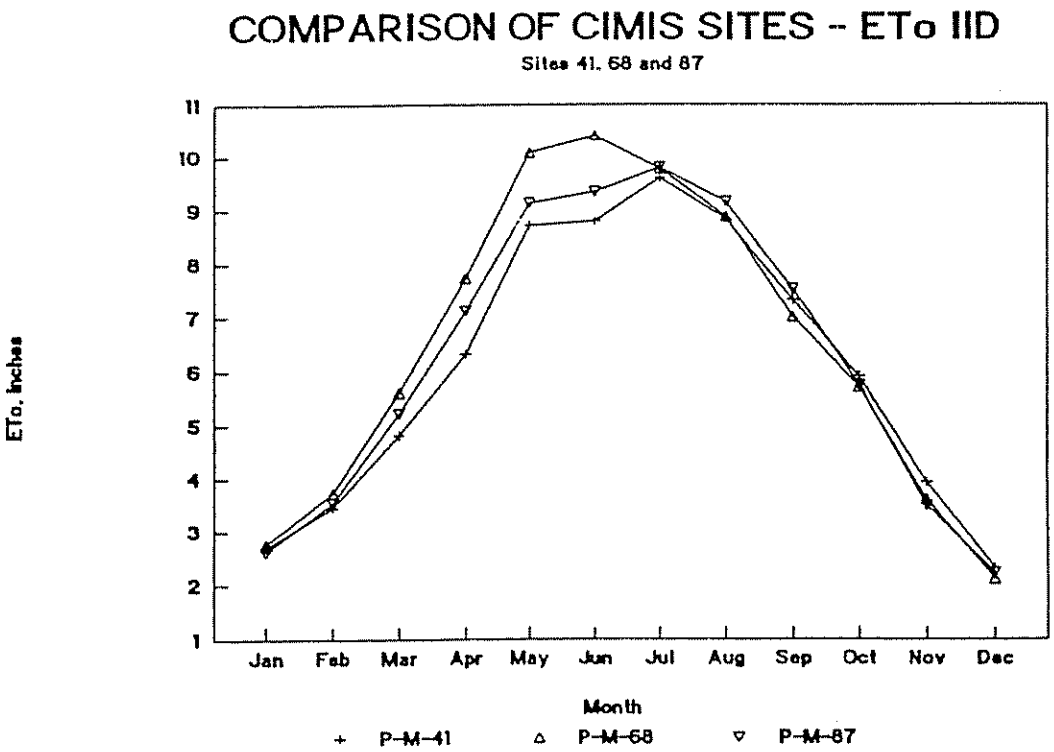

COMPARISON OF CIMIS SITES - ETo IID
Sites 41, 68 and 87
ETo, inches
11
10
9
8
7
6
5
4
3
2
1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
P-M-41
P-M-68
P-M-87

Fig 12

SUMMARY AND CONCLUSIONS

Mean monthly climatic variables from CIMIS files that are computed without deleting zeros and negative values may have significant errors. The resulting mean values may be significantly lower than means that exclude the zero or negative data. CIMIS evaporation (ET_o) values include estimates for days when climatic data are zero, or flagged for various reasons.

Above normal rainfall in 1991 and 1992 in the IID significantly lowered mean annual solar radiation, increased mean annual dewpoint temperature and decreased mean annual wind speed. Changes in these climatic variables significantly affected estimates of annual reference ET based on the Penman-Monteith and Penman (1963) equations.

A spreadsheet program was developed to estimate reference ET for three IID CIMIS sites using the Penman-Monteith and Penman (1963) combination equations. When comparing estimates for 1990-1992, when data were available for all three sites, the resulting annual estimates of reference ET with the Penman-Monteith and Penman (1963) equations using mean monthly climatic data were consistently about 8-9 percent higher than the CIMIS values.

REFERENCES

Allen, R.G., M.E. Jensen, J.L. Wright, and R.D. Burman. 1989. Operational estimates of reference evapotranspiration. Agron. J. 81:650-662.

Dong, A., S.R. Grattan, J.J. Carroll, and C.R.K. Prashar. 1992. Estimation of daytime net radiation over well-watered grass. J. Irrig. and Drain. Div., ASCE, 118(3):466-479.

Jensen, M.E., R.D. Burman, and R.G. Allen (eds). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, New York, 360 pp.

Penman, H.L. 1963. Vegetation and Hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England, 125 pp.

Solar Energy Research Institute. 1980. Insolation Data Manual. Golden, Colorado.

Smith, M. 1991. Report on the expert consultation on procedures for revision of FAO Guidelines for prediction of crop water requirements. 28-31 May 1990, Rome, 56 pp.

Styles, S. 1993. On-Farm Irrigation Efficiency: Special Technical Report, Coachella Water District. April.

APPENDIX A

EQUATIONS USED TO ESTIMATE REFERENCE ET

Net Radiation

$$R_n = (1 - \alpha) R_s - R_b \tag{A-1}$$

where R_n is net radiation, MJ/(m^2 day), α = albedo, and R_b = net long-wave radiation, MJ/(m^2 day).

Net Long-Wave Radiation

$$R_b = \left(a \frac{R_s}{R_{so}} + b\right) R_{bo} \tag{A-2}$$

where R_b is net long-wave radiation, MJ/(m^2 day), R_s = measured solar radiation, R_{so} = clear-day solar radiation, and for these estimates, a = 1.126 and b = -0.07. Net long-wave radiation on a clear day, R_{bo}, was calculated as follows:

$$R_{bo} = (a_1 + b_1 \sqrt{e_d}) \frac{4.90}{10^9} \frac{(T_x^4 + T_n^4)}{2} \tag{A-3}$$

where $a_1 = 0.26 + 0.1 \exp\{-[0.0154(CD - 177)]^2\}$, CD = calendar day (1-365), and $b_1 = -0.139$ for e_d in kPa.

Albedo

$$\alpha = 0.23 + 0.06 [1 - \cos (\frac{2 \pi CD}{365} - 2.96] \tag{A-4}$$

where α is albedo and CD = calendar day. Eq. A-4 is essentially the same as that of Wright, page 137, ASCE Manual 70.

Clear-Day Solar Radiation

$$R_{so} = R_a [0.725 + 0.025 \cos (\frac{2 \pi CD}{365} - 2.6] \tag{A-5}$$

where R_{so} is clear-day solar radiation, R_a = extraterrestrial solar radiation and CD = the calendar day. Eq. A-5 was based on observed high values of solar radiation from CIMIS data and calculated daily R_a values. The range in atmospheric transmissibility ranges from 0.69 in December-January to 0.75 in June-July. FAO uses a constant of 0.75 for R_{so}/R_a (Smith, 1991).

Penman (1963) Equation

$$\lambda ET_o = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma} 6.43 W_f (e_o - e_d) \tag{A-6}$$

where λET_o is the latent heat energy in MJ/(m^2 day), λ = the latent heat of vaporization at mean air temperature, Δ = the slope of the saturation vapor pressure-temperature curve at mean air temperature, γ = the psychrometric constant that is a function of the specific heat of moist air, atmospheric pressure and latent heat of vaporization, R_n = net radiation, G = soil heat flux, $W_f = 1 + 0.536\ u_2$, u_2 = mean daily wind speed in m/s, e_o = saturation vapor pressure at mean air temperature, and e_d = saturation vapor pressure at dewpoint temperature. G, which would be very small for monthly estimates, was assumed to be zero. Equation 7.13 in Manual 70 was used for Δ, 7.15 for γ, and a slight modification of Eq. 7.11 was used for e_o and e_d (Smith, 1991). ET_o in depth units is obtained by dividing by the latent heat of vaporization per unit depth.

Penman-Monteith Equation

$$\lambda ET_o = \frac{\Delta}{\Delta + \gamma^*}(R_n - G) + \frac{\lambda}{\Delta + \gamma^*} \rho \frac{0.622\lambda}{P} 86{,}400 \frac{(e_o - e_d)}{r_a} \tag{A-7}$$

where ρ = the density of moist air, kg/m^3, P = atmospheric pressure, kPa, $\gamma^* = \gamma(1 + r_c/r_a)$, r_c = canopy resistance, and r_a = aerodynamic resistance in s/m. The other variables are the same as in Penman's equation except e_o is the mean of the saturation vapor pressure at maximum and minimum air temperatures. The aerodynamic resistance is based on the heights of air temperature, humidity and wind speed measurements as follows (Allen et al., 1989):

$$r_a = \frac{\left[\ln\left(\frac{z_m - d}{z_{om}}\right)\right]\left[\left(\frac{z_h - d}{z_{oh}}\right)\right]}{k^2 u_z} \tag{A-8}$$

where r_a has units of s/m, z_m is the height of wind measurement, z_h is the height of air temperature and humidity measurements, d is the zero displacement height above the surface, z_{om} is the roughness length parameter for momentum transfer (m), and z_{oh} is roughness length of the vegetation for vapor and heat transfer, k = the von Karman constant (0.41), and u_z is the mean wind speed in m/s at height z. A simplified version of Eq. A-7 for either grass or alfalfa reference crop is presented as Eq. 19 and 20 by Allen et al. (1989).

A printout of the equations as used in the spreadsheet is shown on page A-3.

ETo, CIMIS-41

```
A19: [W4] +A18+1
B19: [W10] 1987
C19: [W4] 1
D19: [W5] 15
E19: (F2) [W7] 19.55878057
F19: (F0) [W7] +E19/0.041868
G19: (F2) [W7] +E19*(0.725+0.025*@COS(2*@PI*D19/365-2.6))
H19: (F0) [W7] +G19/0.041868
I19: (F0) [W7] 296.6
J19: (F2) [W7] 0.041868*I19
K19: (F2) [W7] +I19/H19
L19: (F1) [W7] 69.322580645
M19: (F1) [W7] (+L19-32)/1.8
N19: (F1) [W7] 34.935483871
O19: (F1) [W7] (+N19-32)/1.8
P19: (F1) [W7] 32.387096774
Q19: (F1) [W7] (+P19-32)/1.8
R19: (F0) [W6] 107.935483871
S19: (F2) [W6] 0.447*(+R19/24)
E98: (F1) [W7] 0.5*(M19+O19)
F98: (F3) [W7] (0.611*@EXP(17.27*M19/(M19+237.3))+0.611*@EXP(17.27*O19/(O19+237.3)))/2
G98: (F3) [W7] 0.611*@EXP(17.27*Q19/(Q19+237.3))
H98: (F3) [W7] 4098*(0.611*@EXP(17.27*E98/(E98+237.3)))/(E98+237.3)^2
I98: (F2) [W7] 2.501-(2.361*10^-3)*E98
J98: (F3) [W7] (1.013*$K$5/(0.622*I98))*10^-3
K98: (F3) [W7] +H98/(H98+J98)
L98: (F3) [W7] 0.23+0.06*(1-@COS(2*@PI*D19/365-2.96))
M98: (F2) [W7] (1-L98)*J19
N98: (F3) [W7] 0.26+0.1*@EXP(-(0.0154*(D19+30-207))^2)
O98: (F2) [W7] (N98-0.139*G98^0.5)*4.9*((M19+273.2)^4+(O19+273.2)^4)/(2*10^9)
P98: (F2) [W7] (1.126*K19-0.07)*O98
Q98: (F2) [W7] +M98-P98
E179: [W7] 31
F179: (F3) [W7] 0.611*@EXP(17.27*E98/(E98+237.3))
G179: (F2) [W7] +K98*Q98
H179: (F2) [W7] (1-K98)*6.43*(1+0.536*S19)*(F179-G98)
I179: (F2) [W7] +G179+H179
J179: (F2) [W7] +I179/I98
K179: (F2) [W7] +E179*J179/25.4
L179: (F3) [W7] (1+($G$11/$N$9)*S19)*J98
M179: (F3) [W7] +H98/(H98+L179)
N179: (F2) [W7] +M179*Q98
O179: [W7] +J98/(H98+L179)
P179: (F2) [W7] +O179*((185370/$N$9)*I98/(E98+273.2))*S19*(F98-G98)
Q179: (F2) [W7] +N179+P179
R179: (F2) [W6] +Q179/I98
S179: (F2) [W6] +E179*R179/25.4
```

APPENDIX B

1. Summary of CIMIS data for three sites in the Imperial Irrigation District showing the differences in mean monthly climatic data between the CIMIS files after deleting zeros with the mean values reported by Styles (4 pages).

2. Relationship between clear-day solar radiation and extraterrestrial solar radiation as indicated by mean observed values and as represented by Eq. A-5.

3. Estimated albedo used in estimating daily net radiation based on the data of Wright, ASCE Manual 70, page 137.

4. Tabular summary of annual reference ET values as indicated by CIMIS and by the Penman-Monteith and Penman (1963) estimating methods (1 page).

5. Tabular summary of mean monthly reference ET values as indicated by CIMIS and by the Penman-Monteith and Penman (1963) estimating methods.

7. Copies of the spreadsheet results for the three sites, CIMIS 41, 68 and 87 (6 pages each).

07-Oct-93 SUMMARY OF IID CIMIS DATA \IID-SUM

EVAPORATION (ETo) DATA FROM CIMIS/STYLES FILES, STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, Evap, in/day

(Values from Styles Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	0.226	0.212	0.205	0.197	0.185	0.180	0.201
Apr-Sep values	0.323	0.277	0.289	0.274	0.257	0.255	0.279
Annual total, in.	82.5	77.4	74.8	72.0	67.6	65.6	73.3

(Styles, 1993; p. A-52 - A53)

Month	1987	1988	1989	1990	1991	1992	Avg
Average	6.90	6.48	6.26	6.01	5.65	5.48	6.13
Apr-Sep values	0.323	0.276	0.290	0.274	0.258	0.254	0.279
Annual total, in.	82.8	77.7	75.1	72.1	67.8	65.8	73.6

SOLAR RADIATION FROM CIMIS/STYLES FILES, STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, ly/day

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	501.4	500.4	509.3	497.5	480.1	471.9	493.4
Average, Apr-Sep	645.0	629.2	643.6	632.3	627.8	607.4	630.9

(Styles, 1993; p. A-52 - A53)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	494.2	475.3	499.9	450.5	460.3	444.1	470.7
Average, Apr-Sep	638.7	589.0	643.6	560.5	605.3	560.2	599.5
Ratios (Styles/Actual)							
Average	0.986	0.950	0.982	0.905	0.959	0.941	0.954
Average, Apr-Sep	0.990	0.936	1.000	0.886	0.964	0.922	0.950

MAXIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, Maximum Temp, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	88.1	88.9	90.4	87.5	85.9	86.9	87.9

(Styles, 1993; p. A-52 - A53)

Average	86.1	85.3	87.8	82.7	82.8	82.7	84.6
Ratios (Styles/Actual)							
	0.977	0.959	0.971	0.946	0.964	0.951	0.961

MINIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, Minimum Temp, F

(Values from Styles' Disk) Year

Year	1987	1988	1989	1990	1991	1992	Avg
Average	53.7	53.2	52.7	53.1	54.1	55.8	53.8

(Styles, 1993; p. A-52 - A53)

Average	52.3	51.0	51.4	50.1	52.3	53.1	51.7
Ratios (Styles/Actual)							
Average	0.975	0.959	0.975	0.943	0.966	0.951	0.961

IID CIMIS DATA

DEWPOINT TEMPERATURE FROM CIMIS/STYLES, STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, Dewpoint, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	45.0	47.0	44.8	46.7	49.5	52.7	47.6

(Styles, 1993; p. A-52 - A53)

Average	44.0	45.2	43.4	43.8	47.1	50.2	45.6
Ratios (Styles/Actual)							
Average	0.980	0.962	0.971	0.937	0.952	0.952	0.959

WIND RUN FROM CIMIS/STYLES STATION 41, Mulberry:

SUMMARY BY YEARS - CIMIS #41, Wind run, mi/day

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average	125.5	125.5	122.4	121.1	120.0	110.0	120.7

(Styles, 1993; p. A-52 - A53)

Average	124.0	120.4	120.4	115.6	115.5	105.4	116.9
Ratios (Styles/Actual)							
Average	0.988	0.959	0.983	0.955	0.963	0.958	0.968

EVAPORATION (ETo) DATA FROM CIMIS/STYLES FILES, STATION 68, Seeley:

(Tabular values not available in Styles, 1993)

SUMMARY BY YEARS - CIMIS #68, Evap, in/day

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average		0.225	0.231	0.211	0.190	0.186	0.209
Avg, Apr-Sep		0.297	0.317	0.291	0.267	0.265	0.287

SOLAR RADIATION FROM CIMIS/STYLES FILES, STATION 68, Seeley:

SUMMARY BY YEARS - CIMIS #68, Rs, ly/day

(Values from Styles' Disk) Year

Year	1987	1988	1989	1990	1991	1992	Avg
Average		517.9	511.6	500.1	493.8	492.0	503.1
Avg, Apr-Sep		646.8	643.2	627.5	633.2	631.2	636.4

MAXIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 68, Seeley:

SUMMARY BY YEARS - CIMIS #68, Maximum Temp, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average		88.7	89.9	88.0	86.0	86.6	87.8
Avg, Apr-Sep		98.4	100.2	98.5	95.7	98.5	98.2

MINIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 68, Seeley:

SUMMARY BY YEARS - CIMIS #68, Minimum Temp, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average		54.4	54.2	54.5	55.0	56.3	54.9
Avg, Apr-Sep		63.9	64.9	65.9	63.9	66.9	65.1

IID CIMIS DATA

DEWPOINT TEMPERATURE FROM CIMIS/STYLES, STATION 68, Seeley:

SUMMARY BY YEARS - CIMIS #68, Dewpoint Temp, F

(Values from Styles' Disk) Year

Year	1987	1988	1989	1990	1991	1992	Avg
Average		41.2	39.3	43.3	50.2	48.8	44.5
Avg, Apr-Sep		47.9	46.0	51.2	55.9	57.3	51.7

WIND RUN FROM CIMIS/STYLES STATION 68, Seeley:

SUMMARY BY YEARS - CIMIS #68, Wind run, mi/day

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average		123.4	130.9	133.4	120.6	100.3	121.7
Avg, Apr-Sep		132.6	148.6	152.7	137.1	121.6	138.5

EVAPORATION (ETo) DATA FROM CIMIS/STYLES FILES, STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Evap, in/day

(Values from Styles' Disk) Year

Year	1987	1988	1989	1990	1991	1992	Avg
Average				0.198	0.175	0.183	0.185
Avg Apr-Sep				0.274	0.242	0.261	0.259
(Styles, 1993; p. A-49)							
Average				6.06	5.33	5.58	5.66
Ratios (Styles/Actual)				0.996	0.999	0.996	0.997

SOLAR RADIATION FROM CIMIS/STYLES FILES, STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Solar rad, ly/d

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average				496.1	480.5	479.3	485.3
Apr-Sep				624.4	615.8	611.1	617.1
(Styles, 1993; p. A-49)							
Average				491.7	480.0	479.3	483.6
Apr-Sep				617.8	615.8	611.2	614.9
Ratios (Styles/Actual)							
Average				0.991	0.999	1.000	0.997
Apr-Sep				0.990	1.000	1.000	0.996

MAXIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Max Temp, F

(Values from Styles' Disk) Year

Year	1987	1988	1989	1990	1991	1992	Avg
Average				87.6	86.2	87.4	87.0
(Styles, 1993; p. A-49)							
Average				87.3	85.7	87.4	86.8
Ratios (Styles/Actual)				0.997	0.995	1.000	0.997

IID CIMIS DATA

MINIMUM TEMPERATURES FROM CIMIS/STYLES FILES, STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Min Temperature, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average				54.9	55.1	57.0	55.7

(Styles, 1993; p. A-49)

Average				54.4	54.5	56.7	55.2
Ratios (Styles/Actual)				0.990	0.988	0.995	0.991

DEWPOINT TEMPERATURE FROM CIMIS/STYLES, STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Dewpoint, F

(Values from Styles' Disk)

Year	1987	1988	1989	1990	1991	1992	Avg
Average			45.4	53.2	51.4	50.0	

(Styles, 1993; p. A-49)

Average			45.3	52.7	49.5	49.2	
Ratios (Styles/Actual)				0.998	0.992	0.963	0.984

WIND RUN FROM CIMIS/STYLES STATION 87, Meloland:

SUMMARY BY YEARS - CIMIS #87, Wind run, mi/d

(Values from Styles' Disk)

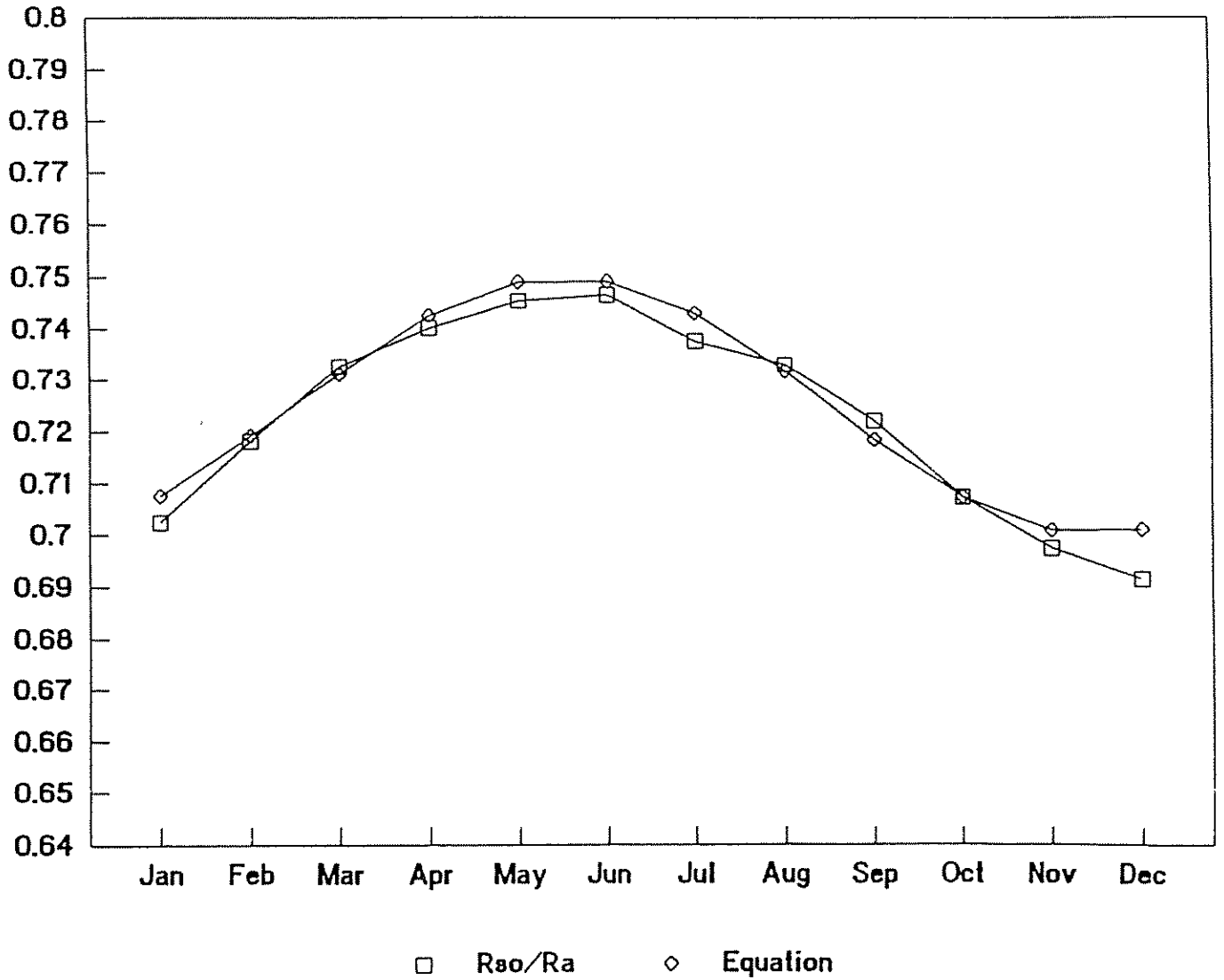
Year	1987	1988	1989	1990	1991	1992	Avg
Average				122.3	116.1	104.6	114.3

(Styles, 1993; p. A-49)

Average				122.3	115.9	104.6	114.3
Ratios (Styles/Actual)				1.000	0.998	1.000	0.999

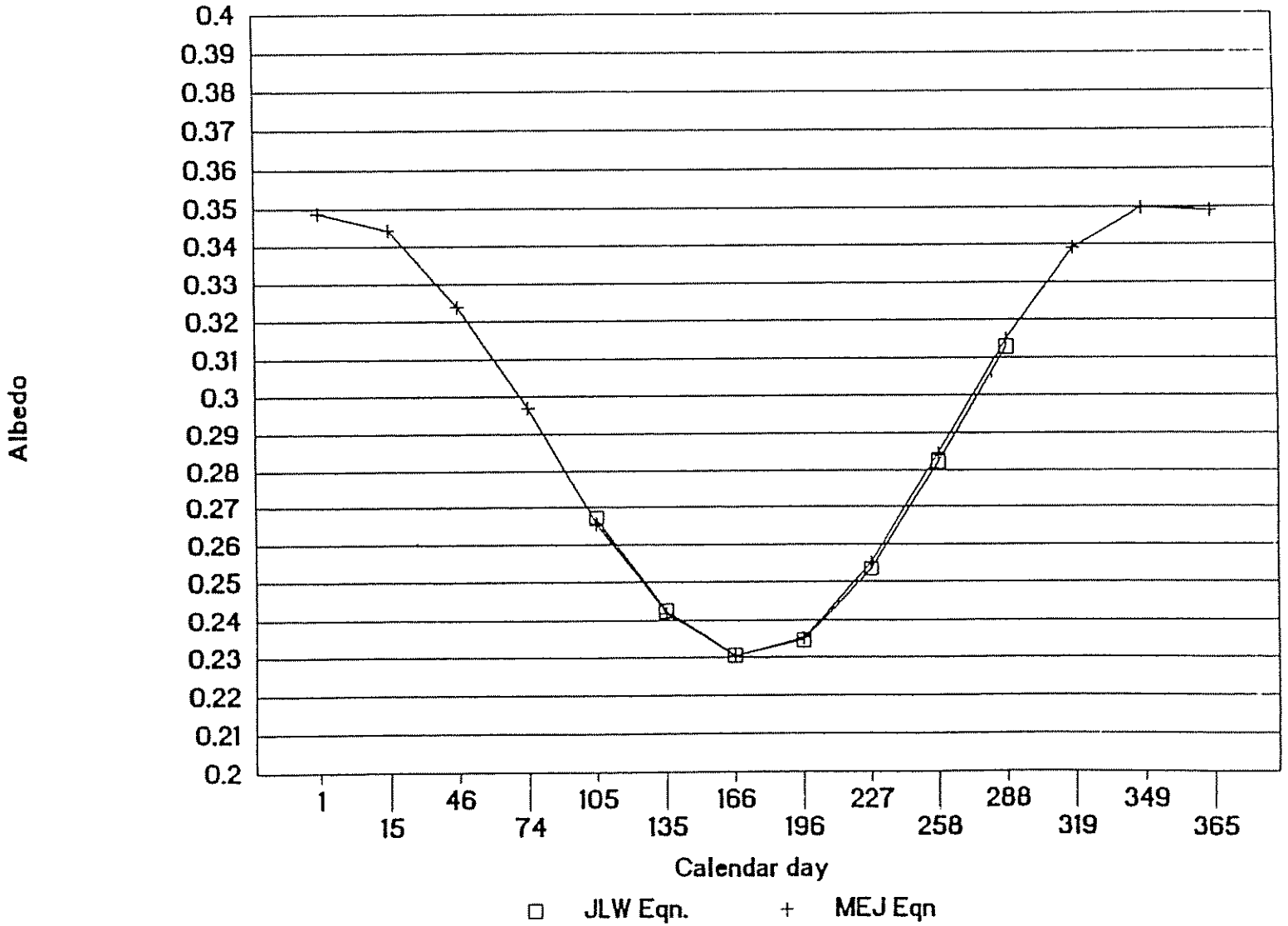
SOLAR RADIATION - IID

Ratio, Clear Day/Potential



B-6

ESTIMATED ALBEDO



14-Oct-93 ESTIMATES OF IMPERIAL VALLEY ETo - 1987-1992 \ETO-IVAL

Year	Station	Penman-Monteith		Styles CIMIS		Penman (1963)		Average	
1987	C41 Mulberry	82.7		82.8		81.0		82.2	
	C68 Seeley								
	C87 Meloland								
	Average	82.7		82.8		81.0		82.2	
1988	C41 Mulberry	80.8		77.7		78.4		79.0	
	C68 Seeley	85.5		84.5		84.8		84.9	
	C87 Meloland								
	Average	83.2		81.1		81.6		82.0	
1989	C41 Mulberry	85.6		75.1		82.2		81.0	
	C68 Seeley	89.5		84.5		87.5		87.2	
	C87 Meloland								
	Average	87.6		79.8		84.9		84.1	
1990	C41 Mulberry	75.8		72.1		74.6		74.2	
	C68 Seeley	85.6		77.1		84.5		82.4	
	C87 Meloland	81.2		72.6		81.1		78.3	
	Average	80.9		73.9		80.1		78.3	
1991	C41 Mulberry	72.7		67.8		73.2		71.2	
	C68 Seeley	74.4		69.4		76.2		73.3	
	C87 Meloland	70.7		66.9		72.3		70.0	
	Average	72.6		68.0		73.9		71.5	
1992	C41 Mulberry	69.7		65.8		70.5		68.7	
	C68 Seeley	72.3		67.9		75.7		72.0	
	C87 Meloland	73.0		66.9		74.9		71.6	
	Average	71.7		66.9		73.7		70.7	
All years	C41 Mulberry	77.9		73.6		76.7		76.0	
	C68 Seeley	81.5		76.7		81.7		80.0	
	C87 Meloland	75.0		68.8		76.1		73.3	
	Average	78.1	100.0%	73.0	100.0%	78.2	100.0%	76.4	100.0%
For years 1990-1992:									
1990		80.9	107.8%	73.9	106.2%	80.1	105.5%	78.3	106.5%
1991		72.6	96.7%	68.0	97.7%	73.9	97.4%	71.5	97.3%
1992		71.7	95.5%	66.9	96.1%	73.7	97.1%	70.7	96.2%
	Average	75.0	100.0%	69.6	100.0%	75.9	100.0%	73.5	100.0%
Percent of 1990-1992 average:			102.1		94.7		103.2	100.0	
Percent of CIMIS average:			107.8		100.0		109.0		

Variability between estimates:	Std dev	CV, %
1990	3.10	3.8
1991	2.52	3.5
1992	2.86	4.0

13-Oct-93 COMPARISON OF CIMIS SITES 41, 68 AND 87 \ETo-SUM1

Month	CIMIS SITE 41, Eto			CIMIS SITE 68, Eto			CIMIS SITE 87, Eto			Overall
	CIMIS In/mo	P-M In/mo	Penman In/mo	CIMIS In/mo	P-M In/mo	Penman In/mo	CIMIS In/mo	P-M In/mo	Penman In/mo	average In/mo
Jan	2.62	2.89	2.74	2.73	2.97	2.90	2.37	2.62	2.64	2.72
Feb	3.49	3.69	3.58	3.77	4.03	3.97	3.24	3.55	3.57	3.65
Mar	5.35	5.42	5.40	6.06	6.21	6.28	5.06	5.22	5.42	5.60
Apr	7.04	6.93	6.98	7.79	7.94	8.04	7.02	7.13	7.40	7.36
May	9.00	9.41	9.28	9.97	10.49	10.43	8.63	9.13	9.24	9.51
Jun	9.43	9.75	9.46	10.17	10.66	10.35	8.63	9.34	9.29	9.68
Jul	9.50	10.27	10.14	9.36	9.83	9.93	8.78	9.80	9.86	9.72
Aug	8.84	9.40	9.44	8.34	9.19	9.39	8.04	9.16	9.38	9.02
Sep	7.32	7.84	7.74	7.00	7.65	7.85	6.37	7.54	7.74	7.45
Oct	5.11	5.94	5.87	5.26	5.85	6.02	4.75	5.76	5.82	5.60
Nov	3.46	3.80	3.61	3.58	3.93	3.88	2.99	3.49	3.44	3.57
Dec	2.34	2.55	2.42	2.30	2.69	2.70	1.94	2.23	2.28	2.38
Average	73.5	77.9	76.7	76.3	81.5	81.7	67.8	75.0	76.1	76.3
Pct, CIMIS	100.0	106.0	104.3	100.0	106.7	107.1	100.0	110.6	112.2	
Grouped average							72.5	78.1	78.2	
Pct, CIMIS							100.0	107.7	107.8	

11-Oct-93 ESTIMATED REFERENCE ET - IID \ETO-CM41

Column = C D E F G H I J K L M N O P Q R S

SITE INPUT DATA: Lat, degrees = 33.00 or 0.5759 Radians

Elevation, m = -50 m Atm. pressure 101.90 kPa Energy units = MJ/(m^2 day) = MJ*

Measurement height: Temp & dewpoin 2.00 m Wind 2.00 m

Reference crop: Grass

hc = 0.12 m

zom = 0.0147 m zov = 0.1zom= 1E-03 m

d = 0.0800 m LAI = 2.88 rm = 207.7 / u2

rc = 69.44 s/m

Clear day solar radiation = Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)] Based on maximum Rs values

INPUT DATA: SITE:CIMIS Station 41, Mulberry

Year	Mo	CD	Ra MJ*	Ra ly/day	Rso MJ*	Rso ly/day	Rs ly/day	Rs MJ*	n/N	Maximum temp deg F	Maximum temp deg C	Minimum temp deg F	Minimum temp deg C	Dewpoint temp deg F	Dewpoint temp deg C	Wind run mi/day	Wind run m/s
1987	1	15	19.56	467	13.84	331	297	12.42	0.90	69.3	20.7	34.9	1.6	32.4	0.2	108	2.01
1987	2	46	24.41	583	17.55	419	378	15.83	0.90	73.5	23.0	41.4	5.2	36.6	2.5	138	2.56
1987	3	74	30.65	732	22.41	535	508	21.28	0.95	77.5	25.3	43.0	6.1	38.1	3.4	145	2.71
1987	4	105	36.31	867	26.97	644	627	26.25	0.97	91.4	33.0	52.3	11.3	41.7	5.4	124	2.31
1987	5	135	39.96	954	29.93	715	671	28.09	0.94	93.6	34.2	58.6	14.8	42.8	6.0	154	2.86
1987	6	166	41.36	988	30.98	740	713	29.86	0.96	105.3	40.7	66.2	19.0	40.1	4.5	136	2.54
1987	7	196	40.60	970	30.16	720	701	29.35	0.97	105.4	40.8	69.8	21.0	51.3	10.7	140	2.60
1987	8	227	37.69	900	27.57	658	603	25.26	0.92	104.9	40.5	74.2	23.4	61.3	16.3	154	2.87
1987	9	258	32.84	784	23.59	563	517	21.63	0.92	100.6	38.1	62.7	17.0	50.2	10.1	124	2.31
1987	10	288	26.70	638	18.89	451	360	15.09	0.80	94.0	34.5	60.6	15.9	59.2	15.1	99	1.84
1987	11	319	21.02	502	14.73	352	313	13.09	0.89	77.2	25.1	44.9	7.1	47.9	8.8	82	1.54
1987	12	349	18.14	433	12.72	304	243	10.16	0.80	65.0	18.4	35.6	2.0	37.9	3.3	103	1.91
1988	1	15	19.56	467	13.84	331	293	12.27	0.89	69.3	20.7	35.5	1.9	37.1	2.8	106	1.98
1988	2	46	24.41	583	17.55	419	393	16.47	0.94	76.7	24.8	40.2	4.6	41.3	5.2	108	2.02
1988	3	74	30.65	732	22.41	535	461	19.30	0.86	82.3	28.0	43.3	6.3	38.7	3.7	125	2.33
1988	4	105	36.31	867	26.97	644	544	22.78	0.84	84.7	29.3	48.2	9.0	47.2	8.5	126	2.35
1988	5	135	39.96	954	29.93	715	573	24.01	0.80	93.1	34.0	54.5	12.5	42.6	5.9	186	3.46
1988	6	166	41.36	988	30.98	740	701	29.35	0.95	101.5	38.6	62.7	17.1	49.8	9.9	136	2.54
1988	7	196	40.60	970	30.16	720	661	27.65	0.92	106.5	41.4	73.9	23.3	64.2	17.9	149	2.77
1988	8	227	37.69	900	27.57	658	624	26.14	0.95	105.1	40.6	73.2	22.9	62.9	17.2	124	2.31
1988	9	258	32.84	784	23.59	563	431	18.03	0.76	102.5	39.2	66.2	19.0	52.0	11.1	119	2.21
1988	10	288	26.70	638	18.89	451	421	17.61	0.93	96.0	35.6	61.2	16.2	55.7	13.2	102	1.90
1988	11	319	21.02	502	14.73	352	310	12.98	0.88	78.5	25.8	44.3	6.8	40.5	4.7	114	2.12
1988	12	349	18.14	433	12.72	304	291	12.18	0.96	70.3	21.3	34.9	1.6	31.8	-0.1	111	2.06
1989	1	15	19.56	467	13.84	331	285	11.93	0.86	69.1	20.6	34.8	1.5	32.7	0.4	101	1.89
1989	2	46	24.41	583	17.55	419	395	16.52	0.94	75.0	23.9	39.2	4.0	40.2	4.6	123	2.28
1989	3	74	30.65	732	22.41	535	429	17.98	0.80	88.3	31.3	47.6	8.7	47.7	8.7	113	2.10
1989	4	105	36.31	867	26.97	644	633	26.50	0.98	92.4	33.6	53.1	11.7	48.6	9.2	120	2.24
1989	5	135	39.96	954	29.93	715	693	29.00	0.97	95.3	35.2	57.0	13.9	41.4	5.2	161	3.00
1989	6	166	41.36	988	30.98	740	713	29.84	0.96	104.8	40.5	62.8	17.1	41.8	5.4	146	2.72
1989	7	196	40.60	970	30.16	720	656	27.48	0.91	108.5	42.5	71.5	21.9	53.2	11.8	141	2.63
1989	8	227	37.69	900	27.57	658	624	26.14	0.95	104.4	40.2	70.4	21.3	61.5	16.4	129	2.40
1989	9	258	32.84	784	23.59	563	543	22.72	0.96	102.7	39.3	65.3	18.5	50.3	10.1	128	2.37
1989	10	288	26.70	638	18.89	451	420	17.60	0.93	91.3	32.9	54.8	12.7	44.5	6.9	113	2.11
1989	11	319	21.02	502	14.73	352	334	13.96	0.95	81.1	27.3	43.0	6.1	40.4	4.6	103	1.93
1989	12	349	18.14	433	12.72	304	274	11.47	0.90	71.9	22.2	32.8	0.5	34.9	1.6	90	1.69

55	1990	1	15	19.56	467	13.84	331	244	10.20	0.74	72.3	22.4	34.8	1.5	37.1	2.8	103	1.91
56	1990	2	46	24.41	583	17.55	419	362	15.16	0.86	73.0	22.8	36.1	2.3	36.6	2.6	123	2.29
57	1990	3	74	30.65	732	22.41	535	490	20.52	0.92	81.3	27.4	44.8	7.1	43.8	6.5	132	2.46
58	1990	4	105	36.31	867	26.97	644	490	20.50	0.76	86.6	30.3	52.5	11.4	50.6	10.3	125	2.32
59	1990	5	135	39.96	954	29.93	715	660	27.63	0.92	92.2	33.4	55.4	13.0	41.9	5.5	162	3.03
60	1990	6	166	41.36	988	30.98	740	672	28.14	0.91	103.5	39.7	64.3	17.9	48.9	9.4	121	2.26
61	1990	7	196	40.60	970	30.16	720	579	24.24	0.80	105.5	40.8	74.1	23.4	61.3	16.3	144	2.68
62	1990	8	227	37.69	900	27.57	658	425	17.77	0.64	101.1	38.4	72.2	22.3	63.2	17.3	117	2.17
63	1990	9	258	32.84	784	23.59	563	538	22.52	0.95	99.7	37.6	68.7	20.4	62.5	17.0	112	2.09
64	1990	10	288	26.70	638	18.89	451	439	18.39	0.97	91.1	32.8	55.5	13.0	49.7	9.8	94	1.74
65	1990	11	319	21.02	502	14.73	352	246	10.29	0.70	77.0	25.0	44.8	7.1	36.9	2.7	114	2.12
66	1990	12	349	18.14	433	12.72	304	262	10.97	0.86	66.6	19.2	34.2	1.2	28.2	-2.1	107	2.00
67	1991	1	15	19.56	467	13.84	331	209	8.77	0.63	67.6	19.8	38.4	3.5	35.2	1.8	90	1.68
68	1991	2	46	24.41	583	17.55	419	356	14.91	0.85	78.4	25.8	42.9	6.0	46.2	7.9	101	1.88
69	1991	3	74	30.65	732	22.41	535	450	18.83	0.84	71.7	22.0	43.4	6.3	43.1	6.2	145	2.70
70	1991	4	105	36.31	867	26.97	644	599	25.07	0.93	83.3	28.5	48.0	8.9	46.9	8.3	140	2.61
71	1991	5	135	39.96	954	29.93	715	699	29.24	0.98	89.2	31.8	53.3	11.8	50.7	10.4	145	2.71
72	1991	6	166	41.36	988	30.98	740	574	24.02	0.78	96.3	35.7	62.2	16.8	55.4	13.0	132	2.46
73	1991	7	196	40.60	970	30.16	720	655	27.41	0.91	102.3	39.1	69.7	20.9	62.9	17.2	122	2.27
74	1991	8	227	37.69	900	27.57	658	611	25.59	0.93	104.2	40.1	73.4	23.0	62.3	16.8	122	2.27
75	1991	9	258	32.84	784	23.59	563	495	20.70	0.88	99.7	37.6	70.4	21.4	63.8	17.7	113	2.11
76	1991	10	288	26.70	638	18.89	451	400	16.73	0.89	93.5	34.2	60.3	15.7	53.9	12.2	121	2.25
77	1991	11	319	21.02	502	14.73	352	255	10.66	0.72	77.6	25.3	46.0	7.8	31.8	-0.1	121	2.25
78	1991	12	349	18.14	433	12.72	304	222	9.31	0.73	66.5	19.2	41.6	5.3	41.6	5.3	87	1.61
79	1992	1	15	19.56	467	13.84	331	272	11.38	0.82	68.6	20.3	37.5	3.1	37.8	3.2	91	1.70
80	1992	2	46	24.41	583	17.55	419	339	14.20	0.81	74.0	23.4	45.7	7.6	47.0	8.4	106	1.97
81	1992	3	74	30.65	732	22.41	535	426	17.83	0.80	75.1	23.9	46.8	8.2	51.1	10.6	98	1.82
82	1992	4	105	36.31	867	26.97	644	493	20.64	0.77	89.2	31.8	53.6	12.0	52.7	11.5	92	1.71
83	1992	5	135	39.96	954	29.93	715	636	26.61	0.89	93.6	34.2	61.2	16.2	58.0	14.5	110	2.04
84	1992	6	166	41.36	988	30.98	740	627	26.24	0.85	99.9	37.7	64.0	17.8	58.6	14.8	127	2.37
85	1992	7	196	40.60	970	30.16	720	633	26.49	0.88	103.8	39.9	73.8	23.2	65.0	18.4	135	2.51
86	1992	8	227	37.69	900	27.57	658	584	24.46	0.89	105.1	40.6	78.1	25.6	69.7	20.9	145	2.70
87	1992	9	258	32.84	784	23.59	563	389	16.30	0.69	104.0	40.0	71.0	21.7	61.4	16.3	108	2.01
88	1992	10	288	26.70	638	18.89	451	389	16.27	0.86	92.0	33.3	60.5	15.8	54.8	12.7	106	1.98
89	1992	11	319	21.02	502	14.73	352	308	12.87	0.87	75.2	24.0	41.7	5.4	36.7	2.6	106	1.97
90	1992	12	349	18.14	433	12.72	304	235	9.83	0.77	62.9	17.2	36.0	2.2	39.5	4.1	97	1.80

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93 BASIC CALCULATIONS:			E	F	G	H	I	J	K	L	M	N	O	P	Q
94						delta(D)		gamma(g)							
95			Tavg	eo	ed		Lamda(L)		f(Tavg)		Rns		Rbo	Rb	Rn
96	Year	Mo	CD	C	kPa	kPa	kPa/C	MJ/kg	kPa/C	D/(D+g)	Albedo	MJ*	a1	MJ*	MJ*	MJ*
97															
98	1987	1	15	11.2	1.568	0.621	0.088	2.47	0.067	0.568	0.344	8.14	0.260	4.86	4.57	3.57
99	1987	2	46	14.1	1.852	0.734	0.105	2.47	0.067	0.609	0.324	10.70	0.262	4.79	4.53	6.17
100	1987	3	74	15.7	2.083	0.778	0.114	2.46	0.067	0.629	0.297	14.96	0.268	5.00	4.99	9.97
101	1987	4	105	22.1	3.182	0.895	0.162	2.45	0.068	0.705	0.266	19.28	0.289	5.93	6.08	13.19
102	1987	5	135	24.5	3.535	0.937	0.184	2.44	0.068	0.730	0.242	21.30	0.326	7.41	7.31	13.99
103	1987	6	166	29.9	4.935	0.843	0.242	2.43	0.068	0.780	0.230	22.98	0.357	9.56	9.71	13.28
104	1987	7	196	30.9	5.082	1.290	0.254	2.43	0.068	0.788	0.235	22.45	0.352	8.17	8.38	14.06
105	1987	8	227	32.0	5.227	1.849	0.268	2.43	0.068	0.797	0.255	18.82	0.315	5.39	5.18	13.64
106	1987	9	258	27.6	4.306	1.239	0.216	2.44	0.068	0.760	0.285	15.47	0.281	5.11	4.91	10.56
107	1987	10	288	25.2	3.632	1.716	0.190	2.44	0.068	0.737	0.315	10.34	0.265	3.25	2.70	7.64
108	1987	11	319	16.1	2.101	1.135	0.117	2.46	0.067	0.635	0.339	8.65	0.261	3.89	3.62	5.03
109	1987	12	349	10.2	1.408	0.773	0.083	2.48	0.067	0.554	0.350	6.61	0.260	4.38	3.63	2.97
110	1988	1	15	11.3	1.572	0.749	0.089	2.47	0.067	0.570	0.344	8.05	0.260	4.52	4.20	3.85
111	1988	2	46	14.7	1.989	0.883	0.108	2.47	0.067	0.616	0.324	11.14	0.262	4.44	4.38	6.75
112	1988	3	74	17.1	2.362	0.797	0.124	2.46	0.067	0.647	0.297	13.57	0.268	5.05	4.55	9.02
113	1988	4	105	19.1	2.612	1.107	0.138	2.46	0.068	0.672	0.266	16.73	0.289	5.15	4.54	12.19
114	1988	5	135	23.2	3.381	0.930	0.172	2.45	0.068	0.717	0.242	18.20	0.326	7.31	6.09	12.11
115	1988	6	166	27.8	4.394	1.218	0.218	2.44	0.068	0.762	0.230	22.59	0.357	8.26	8.23	14.36
116	1988	7	196	32.3	5.406	2.052	0.273	2.42	0.068	0.800	0.235	21.15	0.352	6.55	6.31	14.85
117	1988	8	227	31.8	5.210	1.957	0.266	2.43	0.068	0.795	0.255	19.48	0.315	5.15	5.13	14.34
118	1988	9	258	29.1	4.626	1.321	0.233	2.43	0.068	0.773	0.285	12.90	0.281	5.00	3.95	8.95
119	1988	10	288	25.9	3.824	1.515	0.198	2.44	0.068	0.744	0.315	12.07	0.265	3.72	3.65	8.42
120	1988	11	319	16.3	2.161	0.855	0.118	2.46	0.067	0.637	0.339	8.58	0.261	4.59	4.23	4.35
121	1988	12	349	11.5	1.610	0.605	0.090	2.47	0.067	0.572	0.350	7.92	0.260	4.92	4.97	2.96
122	1989	1	15	11.1	1.555	0.629	0.088	2.47	0.067	0.566	0.344	7.82	0.260	4.83	4.35	3.47
123	1989	2	46	13.9	1.891	0.846	0.103	2.47	0.067	0.606	0.324	11.17	0.262	4.49	4.45	6.73
124	1989	3	74	20.0	2.844	1.126	0.145	2.45	0.068	0.681	0.297	12.64	0.268	4.40	3.67	8.97
125	1989	4	105	22.6	3.285	1.167	0.167	2.45	0.068	0.711	0.266	19.46	0.289	5.26	5.46	14.00
126	1989	5	135	24.5	3.632	0.886	0.184	2.44	0.068	0.731	0.242	21.99	0.326	7.57	7.73	14.27
127	1989	6	166	28.8	4.758	0.899	0.229	2.43	0.068	0.771	0.230	22.97	0.357	9.27	9.40	13.57
128	1989	7	196	32.2	5.521	1.381	0.271	2.42	0.068	0.799	0.235	21.02	0.352	8.09	7.73	13.29
129	1989	8	227	30.8	5.004	1.861	0.253	2.43	0.068	0.787	0.255	19.48	0.315	5.29	5.27	14.20
130	1989	9	258	28.9	4.617	1.241	0.230	2.43	0.068	0.771	0.285	16.25	0.281	5.19	5.27	10.99
131	1989	10	288	22.8	3.240	0.997	0.168	2.45	0.068	0.713	0.315	12.06	0.265	4.80	4.70	7.36
132	1989	11	319	16.7	2.282	0.851	0.121	2.46	0.067	0.642	0.339	9.23	0.261	4.62	4.61	4.61
133	1989	12	349	11.3	1.652	0.687	0.089	2.47	0.067	0.570	0.350	7.46	0.260	4.69	4.44	3.02
134	1990	1	15	12.0	1.696	0.750	0.092	2.47	0.067	0.579	0.344	6.69	0.260	4.57	3.47	3.22
135	1990	2	46	12.5	1.747	0.736	0.095	2.47	0.067	0.587	0.324	10.25	0.262	4.69	4.23	6.02
136	1990	3	74	17.2	2.328	0.971	0.125	2.46	0.067	0.649	0.297	14.43	0.268	4.61	4.43	10.00
137	1990	4	105	20.9	2.836	1.254	0.152	2.45	0.068	0.691	0.266	15.05	0.289	4.92	3.87	11.18
138	1990	5	135	23.2	3.327	0.904	0.172	2.45	0.068	0.717	0.242	20.95	0.326	7.38	7.15	13.80
139	1990	6	166	28.8	4.661	1.180	0.229	2.43	0.068	0.771	0.230	21.66	0.357	8.47	8.07	13.59
140	1990	7	196	32.1	5.287	1.853	0.270	2.43	0.068	0.798	0.235	18.54	0.352	6.95	5.81	12.73
141	1990	8	227	30.4	4.739	1.981	0.248	2.43	0.068	0.784	0.255	13.24	0.315	5.00	3.28	9.96
142	1990	9	258	29.0	4.438	1.934	0.231	2.43	0.068	0.772	0.285	16.11	0.281	3.60	3.62	12.49
143	1990	10	288	22.9	3.245	1.214	0.169	2.45	0.068	0.714	0.315	12.60	0.265	4.26	4.37	8.23
144	1990	11	319	16.1	2.089	0.742	0.117	2.46	0.067	0.634	0.339	6.80	0.261	4.87	3.49	3.31
[illegible]	1990	12	349	10.2	1.447	0.523	0.083	2.48	0.067	0.554	0.350	7.13	0.260	5.07	4.57	2.56
146	1991	1	15	11.7	1.547	0.696	0.091	2.47	0.067	0.575	0.344	5.75	0.260	4.68	3.01	2.74

147	1991	2	46	15.9	2.128	1.064	0.116	2.46	0.067	0.632	0.324	10.08	0.262	4.08	3.61	6.47
148	1991	3	74	14.2	1.804	0.947	0.105	2.47	0.067	0.609	0.297	13.24	0.268	4.46	3.91	9.33
149	1991	4	105	18.7	2.514	1.093	0.135	2.46	0.068	0.666	0.266	18.41	0.289	5.15	5.03	13.38
150	1991	5	135	21.8	3.042	1.260	0.159	2.45	0.068	0.702	0.242	22.18	0.326	6.34	6.54	15.64
151	1991	6	166	26.2	3.881	1.500	0.201	2.44	0.068	0.747	0.230	18.49	0.357	7.41	5.95	12.54
152	1991	7	196	30.0	4.748	1.957	0.243	2.43	0.068	0.781	0.235	20.97	0.352	6.55	6.24	14.72
153	1991	8	227	31.5	5.111	1.917	0.263	2.43	0.068	0.793	0.255	19.06	0.315	5.21	5.08	13.98
154	1991	9	258	29.5	4.512	2.022	0.237	2.43	0.068	0.776	0.285	14.81	0.281	3.45	3.17	11.65
155	1991	10	288	24.9	3.581	1.420	0.188	2.44	0.068	0.735	0.315	11.47	0.265	3.88	3.60	7.86
156	1991	11	319	16.6	2.146	0.606	0.120	2.46	0.067	0.640	0.339	7.04	0.261	5.30	3.95	3.09
157	1991	12	349	12.2	1.556	0.894	0.094	2.47	0.067	0.583	0.350	6.05	0.260	4.20	3.17	2.89
158	1992	1	15	11.7	1.575	0.770	0.091	2.47	0.067	0.575	0.344	7.46	0.260	4.49	3.84	3.62
159	1992	2	46	15.5	1.958	1.099	0.113	2.46	0.067	0.626	0.324	9.60	0.262	3.96	3.33	6.27
160	1992	3	74	16.1	2.031	1.280	0.117	2.46	0.067	0.634	0.297	12.53	0.268	3.82	3.15	9.38
161	1992	4	105	21.9	3.046	1.358	0.160	2.45	0.068	0.703	0.266	15.16	0.289	4.76	3.77	11.39
162	1992	5	135	25.2	3.618	1.648	0.191	2.44	0.068	0.738	0.242	20.18	0.326	5.76	5.36	14.81
163	1992	6	166	27.7	4.279	1.680	0.217	2.44	0.068	0.761	0.230	20.20	0.357	7.16	6.33	13.87
164	1992	7	196	31.6	5.090	2.111	0.263	2.43	0.068	0.794	0.235	20.26	0.352	6.36	5.85	14.41
165	1992	8	227	33.1	5.459	2.480	0.284	2.42	0.068	0.806	0.255	18.22	0.315	4.17	3.88	14.35
166	1992	9	258	30.8	4.980	1.857	0.254	2.43	0.068	0.788	0.285	11.66	0.281	3.86	2.73	8.93
167	1992	10	288	24.6	3.460	1.466	0.185	2.44	0.068	0.731	0.315	11.15	0.265	3.76	3.38	7.76
168	1992	11	319	14.7	1.941	0.736	0.108	2.47	0.067	0.616	0.339	8.51	0.261	4.80	4.38	4.12
169	1992	12	349	9.7	1.337	0.822	0.081	2.48	0.067	0.547	0.350	6.39	0.260	4.23	3.38	3.01

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172 REFERENCE ET ESTIMATES:				F	G	H	I	J	K	L	M	N	O	P	Q	R	S
173					Penman (1963), (eo-ed) = f(Tavg)							Penman-Monteith (Smith, 1991):					
174																	
175				f(Tavg)	Aero term							Rad	Aero term				
176				eo	Rad term		ETo	ETo	ETo	g*	D/	term	g/		ETo	ETo	ETo
177	Year	Mo	CD	Days/mo	kPa	MJ*	MJ*	MJ*	mm/d	In/mo	kPa/C	(D+g*)	MJ*	(D+g*)	MJ*	MJ*	mm/d	In/mo
178																		
179	1987	1	15	31	1.329	2.03	4.09	6.12	2.47	3.02	0.112	0.440	1.57	0.3347	4.95	6.52	2.64	3.22
180	1987	2	46	28	1.613	3.76	5.25	9.01	3.65	4.03	0.125	0.456	2.81	0.2931	6.44	9.25	3.75	4.13
181	1987	3	74	31	1.784	6.27	5.88	12.15	4.93	6.02	0.128	0.471	4.69	0.2777	7.46	12.16	4.93	6.02
182	1987	4	105	30	2.666	9.31	7.51	16.82	6.87	8.11	0.120	0.574	7.58	0.2398	9.40	16.98	6.93	8.19
183	1987	5	135	31	3.075	10.21	9.40	19.62	8.03	9.80	0.133	0.580	8.12	0.2144	11.68	19.80	8.10	9.89
184	1987	6	166	30	4.211	10.35	11.25	21.61	8.89	10.50	0.126	0.657	8.72	0.1855	13.79	22.51	9.26	10.94
185	1987	7	196	31	4.461	11.08	10.35	21.43	8.83	10.77	0.128	0.665	9.36	0.1789	12.59	21.95	9.04	11.03
186	1987	8	227	31	4.745	10.87	9.60	20.47	8.44	10.30	0.134	0.667	9.09	0.1700	11.69	20.79	8.57	10.46
187	1987	9	258	30	3.690	8.02	8.47	16.49	6.77	7.99	0.121	0.641	6.77	0.2026	10.36	17.13	7.03	8.31
188	1987	10	288	31	3.201	5.63	4.99	10.62	4.35	5.31	0.110	0.634	4.84	0.2263	5.84	10.68	4.38	5.34
189	1987	11	319	30	1.834	3.19	2.99	6.18	2.51	2.96	0.102	0.534	2.69	0.3076	3.47	6.15	2.50	2.95
190	1987	12	349	31	1.242	1.65	2.73	4.37	1.77	2.15	0.110	0.431	1.28	0.3472	3.29	4.57	1.84	2.25
191	1988	1	15	31	1.341	2.19	3.37	5.57	2.25	2.75	0.111	0.444	1.71	0.3347	4.23	5.94	2.40	2.93
192	1988	2	46	28	1.671	4.16	4.05	8.21	3.33	3.67	0.113	0.489	3.30	0.3050	5.21	8.51	3.45	3.80
193	1988	3	74	31	1.951	5.84	5.89	11.73	4.77	5.82	0.120	0.507	4.58	0.2770	7.63	12.21	4.96	6.06
194	1988	4	105	30	2.217	8.18	5.29	13.48	5.49	6.48	0.121	0.534	6.51	0.2611	6.91	13.42	5.46	6.45
195	1988	5	135	31	2.850	8.69	9.97	18.65	7.62	9.31	0.146	0.540	6.55	0.2130	13.30	19.85	8.11	9.90
196	1988	6	166	30	3.743	10.94	9.12	20.06	8.24	9.73	0.126	0.634	9.10	0.1980	11.52	20.62	8.47	10.00
197	1988	7	196	31	4.851	11.87	8.95	20.83	8.59	10.48	0.132	0.675	10.01	0.1688	11.12	21.13	8.72	10.64
198	1988	8	227	31	4.691	11.40	8.07	19.47	8.03	9.80	0.121	0.686	9.84	0.1768	9.45	19.29	7.95	9.71
199	1988	9	258	30	4.026	6.92	8.62	15.54	6.39	7.55	0.119	0.662	5.92	0.1942	10.19	16.12	6.63	7.83
200	1988	10	288	31	3.340	6.27	6.06	12.33	5.05	6.17	0.111	0.640	5.39	0.2202	7.03	12.42	5.09	6.21
201	1988	11	319	30	1.859	2.77	5.01	7.78	3.16	3.73	0.115	0.507	2.20	0.2884	6.08	8.28	3.36	3.97
202	1988	12	349	31	1.354	1.69	4.34	6.03	2.44	2.97	0.113	0.442	1.31	0.3304	5.31	6.62	2.67	3.26
203	1989	1	15	31	1.319	1.97	3.87	5.84	2.36	2.88	0.109	0.445	1.54	0.3403	4.62	6.17	2.49	3.04
204	1989	2	46	28	1.594	4.08	4.21	8.29	3.36	3.70	0.119	0.466	3.14	0.3028	5.54	8.67	3.51	3.87
205	1989	3	74	31	2.336	6.11	5.27	11.38	4.64	5.66	0.115	0.557	4.99	0.2603	7.02	12.01	4.90	5.97
206	1989	4	105	30	2.751	9.96	6.48	16.44	6.72	7.93	0.119	0.584	8.18	0.2375	8.33	16.51	6.75	7.97
207	1989	5	135	31	3.082	10.42	9.92	20.35	8.33	10.16	0.136	0.575	8.20	0.2120	12.80	21.01	8.60	10.49
208	1989	6	166	30	3.960	10.45	11.11	21.56	8.86	10.47	0.130	0.637	8.65	0.1897	14.34	22.99	9.45	11.16
209	1989	7	196	31	4.810	10.61	10.69	21.31	8.79	10.72	0.129	0.679	9.02	0.1711	13.19	22.21	9.16	11.18
210	1989	8	227	31	4.438	11.18	8.05	19.24	7.92	9.67	0.123	0.673	9.55	0.1816	9.77	19.32	7.96	9.71
211	1989	9	258	30	3.981	8.48	9.15	17.63	7.25	8.56	0.122	0.653	7.17	0.1934	11.15	18.32	7.53	8.90
212	1989	10	288	31	2.777	5.25	7.02	12.26	5.01	6.12	0.116	0.592	4.36	0.2388	8.36	12.72	5.20	6.34
213	1989	11	319	30	1.901	2.96	4.91	7.87	3.20	3.78	0.111	0.521	2.41	0.2911	6.08	8.49	3.45	4.07
214	1989	12	349	31	1.341	1.72	3.44	5.16	2.09	2.55	0.105	0.459	1.39	0.3461	4.37	5.75	2.33	2.84
215	1990	1	15	31	1.400	1.86	3.56	5.43	2.19	2.68	0.110	0.456	1.47	0.3317	4.64	6.11	2.47	3.02
216	1990	2	46	28	1.454	3.53	4.24	7.78	3.15	3.47	0.119	0.446	2.69	0.3138	5.60	8.29	3.35	3.70
217	1990	3	74	31	1.969	6.49	5.23	11.72	4.76	5.81	0.123	0.503	5.03	0.2725	6.88	11.91	4.84	5.91
218	1990	4	105	30	2.466	7.73	5.39	13.13	5.35	6.32	0.120	0.558	6.24	0.2490	6.80	13.04	5.32	6.28
219	1990	5	135	31	2.846	9.89	9.27	19.16	7.83	9.56	0.136	0.557	7.69	0.2200	11.88	19.57	8.00	9.77
220	1990	6	166	30	3.966	10.47	9.07	19.54	8.03	9.49	0.120	0.657	8.93	0.1953	11.03	19.96	8.20	9.69
221	1990	7	196	31	4.780	10.16	9.28	19.44	8.02	9.78	0.130	0.675	8.60	0.1711	11.19	19.79	8.16	9.96
222	1990	8	227	31	4.338	7.81	7.08	14.89	6.13	7.48	0.118	0.678	6.75	0.1866	7.99	14.74	6.07	7.40
223	1990	9	258	30	4.003	9.64	6.42	16.07	6.61	7.80	0.116	0.666	8.32	0.1964	7.39	15.71	6.46	7.63
224	1990	10	288	31	2.800	5.88	5.64	11.51	4.71	5.74	0.107	0.612	5.04	0.2450	6.40	11.43	4.67	5.70
225	1990	11	319	30	1.825	2.10	5.45	7.55	3.06	3.62	0.115	0.503	1.67	0.2908	6.31	7.98	3.24	3.83

226	1990	12	349	31	1.246	1.42	4.29	5.71	2.30	2.81	0.112	0.427	1.09	0.3434	4.94	6.03	2.44	2.97
7	1991	1	15	31	1.372	1.57	3.51	5.09	2.06	2.51	0.105	0.464	1.27	0.3432	3.80	5.07	2.05	2.50
228	1991	2	46	28	1.808	4.08	3.54	7.62	3.09	3.41	0.110	0.513	3.31	0.2989	4.56	7.87	3.19	3.52
229	1991	3	74	31	1.618	5.69	4.13	9.82	3.98	4.85	0.128	0.450	4.20	0.2887	5.13	9.33	3.78	4.61
230	1991	4	105	30	2.154	8.91	5.47	14.38	5.85	6.91	0.127	0.516	6.90	0.2585	7.21	14.11	5.74	6.78
231	1991	5	135	31	2.613	10.98	6.36	17.34	7.08	8.64	0.129	0.553	8.64	0.2347	8.40	17.04	6.96	8.49
232	1991	6	166	30	3.410	9.37	7.20	16.57	6.80	8.03	0.124	0.619	7.76	0.2091	8.92	16.68	6.84	8.08
233	1991	7	196	31	4.244	11.50	7.14	18.63	7.67	9.36	0.120	0.670	9.86	0.1878	8.50	18.36	7.56	9.22
234	1991	8	227	31	4.634	11.09	7.99	19.09	7.87	9.60	0.120	0.686	9.59	0.1785	9.19	18.78	7.74	9.45
235	1991	9	258	30	4.118	9.04	6.42	15.46	6.36	7.51	0.116	0.671	7.81	0.1930	7.28	15.09	6.21	7.33
236	1991	10	288	31	3.159	5.78	6.54	12.31	5.04	6.15	0.119	0.613	4.82	0.2211	7.85	12.67	5.19	6.33
237	1991	11	319	30	1.886	1.98	6.54	8.52	3.46	4.09	0.118	0.504	1.56	0.2830	7.46	9.01	3.66	4.32
238	1991	12	349	31	1.425	1.68	2.66	4.34	1.76	2.14	0.103	0.476	1.37	0.3405	2.81	4.18	1.69	2.07
239	1992	1	15	31	1.376	2.08	3.16	5.25	2.12	2.59	0.105	0.463	1.68	0.3419	3.63	5.31	2.15	2.62
240	1992	2	46	28	1.759	3.93	3.26	7.19	2.92	3.21	0.112	0.503	3.15	0.2999	3.86	7.01	2.85	3.14
241	1992	3	74	31	1.827	5.95	2.55	8.49	3.45	4.21	0.108	0.518	4.86	0.2993	3.11	7.97	3.24	3.95
242	1992	4	105	30	2.623	8.00	4.64	12.64	5.16	6.09	0.106	0.601	6.84	0.2542	5.43	12.27	5.01	5.92
243	1992	5	135	31	3.213	10.93	5.53	16.46	6.74	8.23	0.114	0.625	9.27	0.2225	6.54	15.80	6.47	7.90
244	1992	6	166	30	3.726	10.56	7.13	17.68	7.26	8.58	0.122	0.640	8.88	0.2007	8.93	17.80	7.31	8.63
245	1992	7	196	31	4.639	11.44	7.87	19.31	7.96	9.71	0.126	0.676	9.75	0.1759	9.35	19.10	7.87	9.61
246	1992	8	227	31	5.068	11.56	7.91	19.47	8.04	9.81	0.130	0.685	9.83	0.1653	9.38	19.22	7.93	9.68
247	1992	9	258	30	4.449	7.03	7.35	14.39	5.92	7.00	0.114	0.689	6.15	0.1857	8.33	14.48	5.96	7.04
248	1992	10	288	31	3.089	5.68	5.78	11.46	4.69	5.72	0.113	0.621	4.82	0.2284	6.59	11.41	4.67	5.70
249	1992	11	319	30	1.674	2.54	4.75	7.29	2.96	3.49	0.112	0.492	2.03	0.3065	5.55	7.58	3.07	3.63
250	1992	12	349	31	1.202	1.65	2.18	3.83	1.54	1.88	0.107	0.429	1.29	0.3560	2.58	3.88	1.56	1.91

251 ----------

2 SUMMARY OF REF ET ESTIMATES:

3

	Year	Styles CIMIS		Penman: Aero term Rad term Inches	Aero term Inches	ETo In/d	ETo Inches	Pct	Penman-Monteith (Smith, 1991) Rad term Inches	Aero term Inches	ETo In/d	ETo Inches	Pct
254													
255													
256	1987	82.8	112.6%	39.7	39.8	0.185	81.0	105.6%	32.6	48.7	0.189	82.7	106.2%
257	1988	77.7	105.6%	39.0	38.0	0.179	78.4	102.3%	32.0	47.2	0.184	80.8	103.7%
258	1989	75.1	102.1%	40.1	40.6	0.188	82.2	107.2%	33.1	50.9	0.195	85.6	109.8%
259	1990	72.1	98.0%	37.1	36.1	0.170	74.6	97.3%	30.6	43.9	0.173	75.8	97.4%
260	1991	67.8	92.2%	39.4	32.5	0.167	73.2	95.5%	32.3	39.1	0.166	72.7	93.4%
261	1992	65.8	89.5%	39.2	29.9	0.161	70.5	92.0%	33.0	35.3	0.159	69.7	89.5%
262													
263	Average	73.6	100.0%	39.1	36.1		76.7	100.0%	32.3	44.2		77.9	100.0%
264				52.0%	48.0%				42.2%	57.8%			

265 Month	Penman: In/mo	Penman-Monteith: In/mo
266 Jan	2.74	2.89
267 Feb	3.58	3.69
268 Mar	5.40	5.42
269 Apr	6.98	6.93
270 May	9.28	9.41
271 Jun	9.46	9.75
272 Jul	10.14	10.27
273 Aug	9.44	9.40
274 Sep	7.74	7.84
275 Oct	5.87	5.94
276 Nov	3.61	3.80
277 Dec	2.42	2.55

11-Oct-93 ESTIMATED REFERENCE ET - IID \ETO-CM68

Row ==========

3 Column = C D E F G H I J K L M N O P Q R S

4 SITE INPUT DATA: Lat, degrees = 33.00 or 0.5759 Radians

5 Elevation, m = -50 m Atm. pressure 101.90 kPa Energy units = MJ/(m^2 day) = MJ*

6 Measurement height: Temp & dewpoint 2.00 m Wind 2.00 m

7 Reference crop: Grass

8 hc = 0.12 m

9 zom = 0.0147 m zov = 0.1zom= 1E-03 m 207.7

10 d = 0.0800 m LAI = 2.88 ra = -----

11 rc = 69.44 s/m u2

12 Clear day solar radiation = Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)] Based on maximum Rs values

13 ----------

14 INPUT DATA: SITE:CIMIS Station 68, Seeley

15

16				Ra	Ra	Rso	Rso	Rs	Rs		Maximum temp		Minimum temp		Dewpoint temp		Wind	run
17	Year	Mo	CD	MJ*	ly/day	MJ*	ly/day	ly/day	MJ*	n/N	deg F	deg C	deg F	deg C	deg F	deg C	mi/day	m/s
18																		
19	1987	1	15	19.56														
20	1987	2	46	24.41														
21	1987	3	74	30.65														
22	1987	4	105	36.31														
23	1987	5	135	39.96														
24	1987	6	166	41.36														
25	1987	7	196	40.60														
26	1987	8	227	37.69														
27	1987	9	258	32.84														
28	1987	10	288	26.70														
29	1987	11	319	21.02														
30	1987	12	349	18.14														
31	1988	1	15	19.56	467	13.84	331	296	12.38	0.89	69.5	20.8	37.2	2.9	32.4	0.2	103.7	1.93
32	1988	2	46	24.41	583	17.55	419	412	17.23	0.98	77.0	25.0	42.2	5.7	36.6	2.6	108.1	2.01
33	1988	3	74	30.65	732	22.41	535	545	22.82	1.02	82.5	28.1	45.9	7.7	31.9	0.0	125.5	2.34
34	1988	4	105	36.31	867	26.97	644	588	24.61	0.91	84.8	29.3	51.1	10.6	40.0	4.4	151.3	2.82
35	1988	5	135	39.96	954	29.93	715	725	30.34	1.01	93.8	34.4	57.1	13.9	34.6	1.5	166.3	3.10
36	1988	6	166	41.36	988	30.98	740	720	30.13	0.97	101.0	38.3	65.0	18.4	45.9	7.7	145.8	2.71
37	1988	7	196	40.60	970	30.16	720	654	27.40	0.91	105.2	40.7	73.0	22.8	64.6	18.1	120.9	2.25
38	1988	8	227	37.69	900	27.57	658	623	26.08	0.95	103.9	39.9	72.3	22.4	58.6	14.8	112.0	2.09
39	1988	9	258	32.84	784	23.59	563	572	23.93	1.01	101.4	38.6	64.7	18.1	43.8	6.6	99.4	1.85
40	1988	10	288	26.70	638	18.89	451	432	18.07	0.96	95.5	35.3	60.4	15.8	48.1	9.0	87.5	1.63
41	1988	11	319	21.02	502	14.73	352	344	14.42	0.98	79.0	26.1	46.1	7.9	32.7	0.4	138.5	2.58
42	1988	12	349	18.14	433	12.72	304	305	12.78	1.00	70.5	21.4	37.5	3.1	25.3	-3.7	121.7	2.27
43	1989	1	15	19.56	467	13.84	331	313	13.11	0.95	68.3	20.2	36.1	2.3	28.6	-1.9	106.7	1.99
44	1989	2	46	24.41	583	17.55	419	403	16.88	0.96	75.1	23.9	41.7	5.4	35.6	2.0	150.7	2.81
45	1989	3	74	30.65	732	22.41	535	523	21.91	0.98	83.8	28.8	49.4	9.7	40.0	4.5	162.3	3.02
46	1989	4	105	36.31	867	26.97	644	628	26.27	0.97	91.4	33.0	55.2	12.9	44.6	7.0	152.5	2.84
47	1989	5	135	39.96	954	29.93	715	695	29.12	0.97	94.3	34.6	60.1	15.6	38.8	3.8	191.5	3.57
48	1989	6	166	41.36	988	30.98	740	713	29.85	0.96	103.6	39.8	64.5	18.0	40.2	4.6	162.1	3.02
49	1989	7	196	40.60	970	30.16	720	658	27.53	0.91	107.7	42.1	72.0	22.2	50.7	10.4	115.8	2.16
50	1989	8	227	37.69	900	27.57	658	618	25.89	0.94	103.5	39.7	71.5	21.9	52.7	11.5	128.9	2.40
51	1989	9	258	32.84	784	23.59	563	547	22.91	0.97	100.5	38.1	66.1	18.9	49.0	9.5	140.8	2.62
52	1989	10	288	26.70	638	18.89	451	429	17.95	0.95	89.0	31.6	56.2	13.4	44.8	7.1	110.9	2.07
53	1989	11	319	21.02	502	14.73	352	337	14.13	0.96	81.9	27.7	41.9	5.5	35.2	1.8	81.0	1.51
54	1989	12	349	18.14	433	12.72	304	274	11.47	0.90	80.3	26.9	35.8	2.1	10.6	-11.9	67.2	1.25

55	1990	1	15	19.56	467	13.84	331	304	12.73	0.92	74.7	23.7	36.3	2.4	29.6	-1.3	102.9	1.92
56	1990	2	46	24.41	583	17.55	419	378	15.82	0.90	74.5	23.6	37.6	3.1	33.3	0.7	125.5	2.34
57	1990	3	74	30.65	732	22.41	535	508	21.28	0.95	81.5	27.5	46.2	7.9	40.0	4.5	147.5	2.75
58	1990	4	105	36.31	867	26.97	644	606	25.35	0.94	87.4	30.8	54.7	12.6	45.5	7.5	168.3	3.14
59	1990	5	135	39.96	954	29.93	715	691	28.93	0.97	91.8	33.2	58.3	14.6	35.8	2.1	229.5	4.27
60	1990	6	166	41.36	988	30.98	740	700	29.33	0.95	104.8	40.5	65.9	18.8	42.5	5.8	143.2	2.67
61	1990	7	196	40.60	970	30.16	720	653	27.32	0.91	105.1	40.6	74.2	23.4	59.8	15.4	136.3	2.54
62	1990	8	227	37.69	900	27.57	658	618	25.86	0.94	102.1	38.9	72.0	22.2	63.0	17.2	120.3	2.24
63	1990	9	258	32.84	784	23.59	563	498	20.84	0.88	99.4	37.5	70.1	21.1	60.5	15.9	118.2	2.20
64	1990	10	288	26.70	638	18.89	451	439	18.37	0.97	90.7	32.6	57.1	13.9	43.7	6.5	96.2	1.79
65	1990	11	319	21.02	502	14.73	352	328	13.75	0.93	77.8	25.4	45.4	7.5	35.0	1.7	112.7	2.10
66	1990	12	349	18.14	433	12.72	304	278	11.65	0.92	65.8	18.8	36.0	2.2	30.9	-0.6	99.7	1.86
67	1991	1	15	19.56	467	13.84	331	291	12.17	0.88	68.2	20.1	38.5	3.6	40.9	4.9	67.2	1.25
68	1991	2	46	24.41	583	17.55	419	373	15.62	0.89	78.6	25.9	44.3	6.8	45.4	7.5	90.6	1.69
69	1991	3	74	30.65	732	22.41	535	491	20.57	0.92	71.9	22.2	44.5	7.0	42.5	5.8	174.9	3.26
70	1991	4	105	36.31	867	26.97	644	640	26.80	0.99	84.0	28.9	50.5	10.3	45.2	7.3	164.2	3.06
71	1991	5	135	39.96	954	29.93	715	698	29.23	0.98	89.6	32.0	57.4	14.1	49.1	9.5	208.4	3.88
72	1991	6	166	41.36	988	30.98	740	699	29.26	0.94	95.9	35.5	63.4	17.5	52.2	11.2	156.0	2.91
73	1991	7	196	40.60	970	30.16	720	657	27.49	0.91	102.2	39.0	70.4	21.3	60.8	16.0	101.7	1.89
74	1991	8	227	37.69	900	27.57	658	596	24.93	0.90	103.1	39.5	72.2	22.3	64.4	18.0	110.0	2.05
75	1991	9	258	32.84	784	23.59	563	510	21.34	0.90	99.3	37.4	69.2	20.7	63.7	17.6	82.1	1.53
76	1991	10	288	26.70	638	18.89	451	433	18.13	0.96	93.6	34.2	60.8	16.0	52.8	11.6	110.7	2.06
77	1991	11	319	21.02	502	14.73	352	321	13.44	0.91	78.3	25.7	46.0	7.8	40.4	4.7	104.4	1.94
78	1991	12	349	18.14	433	12.72	304	218	9.11	0.72	67.2	19.6	42.3	5.7	44.9	7.2	77.4	1.44
79	1992	1	15	19.56	467	13.84	331	280	11.70	0.85	68.8	20.4	38.9	3.8	42.2	5.7	82.0	1.53
80	1992	2	46	24.41	583	17.55	419	370	15.49	0.88	73.7	23.2	46.2	7.9	43.2	6.2	99.1	1.85
81	1992	3	74	30.65	732	22.41	535	466	19.52	0.87	75.5	24.2	48.7	9.3	44.6	7.0	121.2	2.26
82	1992	4	105	36.31	867	26.97	644	618	25.87	0.96	88.3	31.3	55.7	13.1	48.3	9.0	109.1	2.03
83	1992	5	135	39.96	954	29.93	715	670	28.04	0.94	93.7	34.3	62.2	16.8	54.9	12.7	113.9	2.12
84	1992	6	166	41.36	988	30.98	740	717	30.03	0.97	98.7	37.1	66.1	18.9	54.5	12.5	182.8	3.40
85	1992	7	196	40.60	970	30.16	720	664	27.82	0.92	103.7	39.8	73.3	22.9	63.0	17.2	144.0	2.68
86	1992	8	227	37.69	900	27.57	658	581	24.30	0.88	104.3	40.2	75.7	24.3	67.7	19.8	113.9	2.12
87	1992	9	258	32.84	784	23.59	563	538	22.50	0.95	102.4	39.1	68.8	20.4	55.3	13.0	66.1	1.23
88	1992	10	288	26.70	638	18.89	451	420	17.60	0.93	91.2	32.9	59.4	15.2	45.5	7.5	60.5	1.13
89	1992	11	319	21.02	502	14.73	352	334	14.00	0.95	75.2	24.0	43.1	6.2	31.0	-0.6	54.1	1.01
90	1992	12	349	18.14	433	12.72	304	247	10.32	0.81	63.5	17.5	37.4	3.0	34.9	1.6	56.8	1.06

91 ----------

93 BASIC CALCULATIONS:			E	F	G	H	I	J	K	L	M	N	O	P	Q
94						delta(D)		gamma(g)							
95			Tavg	eo	ed		Lamda(L)		f(Tavg)		Rns		Rbo	Rb	Rn
96	Year	Mo	CD	C	kPa	kPa	kPa/C	MJ/kg	kPa/C	D/(D+g)	Albedo	MJ*	al	MJ*	MJ*	MJ*
97															
98	1987	1	15	0.0	0.611	0.611	0.044	2.50	0.066	0.401	0.344	0.00	0.260	4.14	-0.29	0.29
99	1987	2	46													
100	1987	3	74													
101	1987	4	105													
102	1987	5	135													
103	1987	6	166													
104	1987	7	196													
105	1987	8	227													
106	1987	9	258													
107	1987	10	288													
108	1987	11	319													
109	1987	12	349													
110	1988	1	15	11.9	1.607	0.621	0.092	2.47	0.067	0.578	0.344	8.12	0.260	4.90	4.60	3.52
111	1988	2	46	15.3	2.040	0.735	0.112	2.46	0.067	0.624	0.324	11.65	0.262	4.87	5.05	6.61
112	1988	3	74	17.9	2.427	0.609	0.129	2.46	0.067	0.657	0.297	16.05	0.268	5.66	6.09	9.95
113	1988	4	105	20.0	2.681	0.839	0.144	2.45	0.068	0.681	0.266	18.07	0.289	5.90	5.65	12.43
114	1988	5	135	24.1	3.510	0.679	0.181	2.44	0.068	0.727	0.242	23.00	0.326	8.15	8.73	14.27
115	1988	6	166	28.3	4.429	1.054	0.224	2.43	0.068	0.767	0.230	23.19	0.357	8.75	8.96	14.23
116	1988	7	196	31.7	5.208	2.080	0.265	2.43	0.068	0.795	0.235	20.96	0.352	6.44	6.14	14.82
117	1988	8	227	31.1	5.027	1.684	0.258	2.43	0.068	0.790	0.255	19.43	0.315	5.70	5.67	13.76
118	1988	9	258	28.4	4.461	0.972	0.224	2.43	0.068	0.767	0.285	17.12	0.281	5.88	6.31	10.82
119	1988	10	288	25.5	3.753	1.145	0.194	2.44	0.068	0.740	0.315	12.38	0.265	4.58	4.61	7.77
120	1988	11	319	17.0	2.224	0.628	0.123	2.46	0.067	0.645	0.339	9.53	0.261	5.27	5.44	4.09
121	1988	12	349	12.2	1.653	0.464	0.094	2.47	0.067	0.582	0.350	8.31	0.260	5.41	5.74	2.56
122	1989	1	15	11.2	1.541	0.531	0.088	2.47	0.067	0.569	0.344	8.60	0.260	5.12	5.11	3.49
123	1989	2	46	14.7	1.935	0.707	0.108	2.47	0.067	0.616	0.324	11.42	0.262	4.90	4.97	6.45
124	1989	3	74	19.2	2.576	0.840	0.139	2.46	0.068	0.672	0.297	15.40	0.268	5.07	5.23	10.18
125	1989	4	105	22.9	3.256	1.003	0.169	2.45	0.068	0.714	0.266	19.30	0.289	5.69	5.85	13.45
126	1989	5	135	25.1	3.641	0.802	0.190	2.44	0.068	0.736	0.242	22.08	0.326	7.86	8.06	14.02
127	1989	6	166	28.9	4.677	0.847	0.230	2.43	0.068	0.772	0.230	22.97	0.357	9.43	9.57	13.41
128	1989	7	196	32.1	5.452	1.259	0.270	2.43	0.068	0.798	0.235	21.06	0.352	8.39	8.04	13.02
129	1989	8	227	30.8	4.945	1.360	0.253	2.43	0.068	0.788	0.255	19.29	0.315	6.44	6.36	12.92
130	1989	9	258	28.5	4.419	1.185	0.226	2.43	0.068	0.768	0.285	16.39	0.281	5.30	5.43	10.96
131	1989	10	288	22.5	3.101	1.010	0.166	2.45	0.068	0.710	0.315	12.30	0.265	4.74	4.74	7.56
132	1989	11	319	16.6	2.312	0.695	0.120	2.46	0.067	0.641	0.339	9.34	0.261	5.06	5.11	4.23
133	1989	12	349	14.5	2.125	0.246	0.107	2.47	0.067	0.613	0.350	7.46	0.260	6.49	6.13	1.32
134	1990	1	15	13.1	1.833	0.554	0.098	2.47	0.067	0.594	0.344	8.35	0.260	5.20	5.03	3.32
135	1990	2	46	13.4	1.839	0.644	0.100	2.47	0.067	0.598	0.324	10.70	0.262	5.00	4.73	5.97
136	1990	3	74	17.7	2.366	0.840	0.128	2.46	0.067	0.654	0.297	14.96	0.268	4.97	4.97	10.00
137	1990	4	105	21.7	2.948	1.036	0.159	2.45	0.068	0.701	0.266	18.62	0.289	5.51	5.44	13.17
138	1990	5	135	23.9	3.383	0.711	0.179	2.44	0.068	0.724	0.242	21.93	0.326	8.02	8.16	13.77
139	1990	6	166	29.7	4.871	0.923	0.239	2.43	0.068	0.778	0.230	22.57	0.357	9.29	9.25	13.32
140	1990	7	196	32.0	5.259	1.753	0.269	2.43	0.068	0.797	0.235	20.90	0.352	7.17	6.81	14.09
141	1990	8	227	30.6	4.822	1.964	0.250	2.43	0.068	0.786	0.255	19.27	0.315	5.05	4.98	14.29
142	1990	9	258	29.3	4.474	1.802	0.235	2.43	0.068	0.775	0.285	14.91	0.281	3.90	3.60	11.31
143	1990	10	288	23.3	3.259	0.969	0.172	2.45	0.068	0.718	0.315	12.58	0.265	4.90	5.02	7.56
144	1990	11	319	16.5	2.144	0.690	0.119	2.46	0.067	0.639	0.339	9.09	0.261	5.04	4.95	4.14
5	1990	12	349	10.5	1.442	0.585	0.085	2.48	0.067	0.558	0.350	7.58	0.260	4.90	4.72	2.86
146	1991	1	15	11.9	1.574	0.869	0.092	2.47	0.067	0.578	0.344	7.98	0.260	4.25	3.91	4.07

147	1991	2	46	16.4	2.168	1.034	0.119	2.46	0.067	0.638	0.324	10.56	0.262	4.17	3.89	6.67
8	1991	3	74	14.6	1.837	0.923	0.107	2.47	0.067	0.614	0.297	14.46	0.268	4.54	4.37	10.09
49	1991	4	105	19.6	2.615	1.024	0.142	2.45	0.068	0.677	0.266	19.68	0.289	5.38	5.65	14.03
150	1991	5	135	23.1	3.187	1.188	0.171	2.45	0.068	0.716	0.242	22.16	0.326	6.62	6.81	15.35
151	1991	6	166	26.5	3.886	1.333	0.204	2.44	0.068	0.750	0.230	22.52	0.357	7.81	7.76	14.76
152	1991	7	196	30.2	4.764	1.817	0.245	2.43	0.068	0.782	0.235	21.03	0.352	6.86	6.56	14.47
153	1991	8	227	30.9	4.936	2.062	0.255	2.43	0.068	0.788	0.255	18.58	0.315	4.87	4.62	13.96
154	1991	9	258	29.0	4.424	2.012	0.232	2.43	0.068	0.773	0.285	15.27	0.281	3.45	3.27	12.00
155	1991	10	288	25.1	3.607	1.364	0.190	2.44	0.068	0.736	0.315	12.42	0.265	4.02	4.06	8.36
156	1991	11	319	16.7	2.182	0.853	0.121	2.46	0.067	0.642	0.339	8.88	0.261	4.61	4.42	4.47
157	1991	12	349	12.7	1.598	1.014	0.096	2.47	0.067	0.589	0.350	5.92	0.260	3.94	2.90	3.02
158	1992	1	15	12.1	1.603	0.914	0.093	2.47	0.067	0.581	0.344	7.67	0.260	4.16	3.67	4.01
159	1992	2	46	15.5	1.952	0.951	0.113	2.46	0.067	0.627	0.324	10.47	0.262	4.31	3.98	6.49
160	1992	3	74	16.7	2.093	1.004	0.121	2.46	0.067	0.642	0.297	13.72	0.268	4.48	4.08	9.65
161	1992	4	105	22.2	3.042	1.151	0.163	2.45	0.068	0.706	0.266	19.00	0.289	5.26	5.31	13.69
162	1992	5	135	25.5	3.654	1.472	0.194	2.44	0.068	0.740	0.242	21.26	0.326	6.16	6.07	15.19
163	1992	6	166	28.0	4.242	1.448	0.220	2.43	0.068	0.764	0.230	23.11	0.357	7.70	7.86	15.25
164	1992	7	196	31.4	5.053	1.966	0.261	2.43	0.068	0.792	0.235	21.28	0.352	6.65	6.44	14.84
165	1992	8	227	32.2	5.236	2.317	0.272	2.42	0.068	0.799	0.255	18.11	0.315	4.44	4.10	14.01
166	1992	9	258	29.8	4.722	1.495	0.241	2.43	0.068	0.779	0.285	16.10	0.281	4.62	4.64	11.46
167	1992	10	288	24.0	3.364	1.038	0.180	2.44	0.068	0.726	0.315	12.06	0.265	4.76	4.66	7.40
168	1992	11	319	15.1	1.968	0.586	0.110	2.47	0.067	0.621	0.339	9.25	0.261	5.26	5.26	3.99
169	1992	12	349	10.2	1.379	0.686	0.083	2.48	0.067	0.555	0.350	6.71	0.260	4.60	3.89	2.83

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72 REFERENCE ET ESTIMATES:

				F	G	H	I	J	K	L	M	N	O	P	Q	R	S
3					Perman (1963), (eo-ed) = f(Tavg)					Penman-Monteith (Smith, 1991):							
174																	
175				f(Tavg)	Aero term							Rad		Aero term			
176				eo	Rad term		ETo	ETo	ETo	g*	D/	term	g/		ETo	ETo	ETo
177	Year	Mo	CD Days/mo	kPa	MJ*	MJ*	MJ*	mm/d	in/mo	kPa/C	(D+g*)	MJ*	(D+g*)	MJ*	MJ*	mm/d	in/mo
178																	
179	1987	1	15	31	0.611	0.12	0.00	0.12	0.05	0.06	0.066	0.401	0.12	0.5987	0.00	0.12	0.05	0.06
180	1987	2	46	28													
181	1987	3	74	31													
182	1987	4	105	30													
183	1987	5	135	31													
184	1987	6	166	30													
185	1987	7	196	31													
186	1987	8	227	31													
187	1987	9	258	30													
188	1987	10	288	31													
189	1987	11	319	30													
190	1987	12	349	31													
191	1988	1	15	31	1.390	2.03	4.25	6.29	2.54	3.10	0.110	0.454	1.60	0.3318	4.89	6.49	2.62	3.20
192	1988	2	46	29	1.743	4.12	5.06	9.19	3.73	4.26	0.113	0.498	3.29	0.2997	6.01	9.30	3.77	4.31
193	1988	3	74	31	2.053	6.54	7.18	13.72	5.58	6.81	0.120	0.518	5.16	0.2706	8.67	13.82	5.62	6.86
194	1988	4	105	30	2.334	8.46	7.69	16.16	6.58	7.78	0.131	0.524	6.51	0.2451	9.51	16.02	6.53	7.71
195	1988	5	135	31	3.012	10.37	10.91	21.28	8.71	10.63	0.138	0.566	8.08	0.2129	13.71	21.79	8.92	10.88
196	1988	6	166	30	3.857	10.91	10.33	21.23	8.72	10.30	0.130	0.633	9.00	0.1925	12.71	21.71	8.92	10.54
197	1988	7	196	31	4.682	11.78	7.57	19.35	7.98	9.73	0.120	0.689	10.20	0.1776	8.89	19.09	7.87	9.60
198	1988	8	227	31	4.532	10.87	8.13	19.00	7.83	9.55	0.116	0.690	9.49	0.1829	9.08	18.57	7.65	9.33
199	1988	9	258	30	3.862	8.29	8.63	16.93	6.95	8.21	0.110	0.670	7.25	0.2037	9.48	16.73	6.87	8.12
200	1988	10	288	31	3.270	5.75	6.64	12.40	5.08	6.20	0.105	0.649	5.04	0.2273	7.05	12.09	4.95	6.04
201	1988	11	319	30	1.936	2.64	7.11	9.75	3.96	4.68	0.126	0.494	2.02	0.2715	8.46	10.48	4.26	5.03
202	1988	12	349	31	1.423	1.49	5.70	7.20	2.91	3.55	0.118	0.442	1.13	0.3171	6.61	7.74	3.13	3.82
203	1989	1	15	31	1.332	1.98	4.59	6.57	2.66	3.24	0.112	0.442	1.54	0.3353	5.23	6.77	2.74	3.34
204	1989	2	46	28	1.669	3.97	5.96	9.93	4.02	4.44	0.130	0.452	2.92	0.2825	7.44	10.36	4.20	4.63
205	1989	3	74	31	2.227	6.84	7.65	14.50	5.90	7.21	0.136	0.505	5.14	0.2461	9.68	14.82	6.04	7.37
206	1989	4	105	30	2.798	9.60	8.32	17.93	7.33	8.65	0.132	0.561	7.55	0.2249	10.61	18.16	7.42	8.77
207	1989	5	135	31	3.191	10.32	11.79	22.11	9.06	11.05	0.149	0.560	7.85	0.2005	14.84	22.69	9.29	11.34
208	1989	6	166	30	3.983	10.34	12.07	22.41	9.21	10.88	0.137	0.627	8.40	0.1856	15.43	23.84	9.80	11.57
209	1989	7	196	31	4.791	10.39	9.89	20.28	8.36	10.21	0.118	0.697	9.07	0.1762	11.30	20.37	8.40	10.25
210	1989	8	227	31	4.445	10.18	9.64	19.82	8.16	9.96	0.123	0.673	8.70	0.1814	11.14	19.84	8.17	9.97
211	1989	9	258	30	3.892	8.42	9.71	18.13	7.45	8.80	0.128	0.638	7.00	0.1927	11.78	18.77	7.71	9.11
212	1989	10	288	31	2.732	5.37	6.77	12.14	4.96	6.05	0.115	0.591	4.47	0.2417	7.71	12.18	4.98	6.08
213	1989	11	319	30	1.891	2.71	5.00	7.71	3.13	3.70	0.101	0.542	2.29	0.3041	5.63	7.92	3.22	3.80
214	1989	12	349	31	1.651	0.81	5.83	6.65	2.69	3.29	0.095	0.528	0.70	0.3328	5.99	6.69	2.71	3.31
215	1990	1	15	31	1.505	1.98	5.03	7.01	2.84	3.46	0.110	0.472	1.57	0.3220	6.08	7.65	3.10	3.78
216	1990	2	46	28	1.534	3.57	5.18	8.76	3.55	3.91	0.120	0.455	2.72	0.3057	6.57	9.29	3.76	4.15
217	1990	3	74	31	2.025	6.54	6.51	13.05	5.31	6.48	0.129	0.496	4.96	0.2625	8.30	13.27	5.39	6.58
218	1990	4	105	30	2.594	9.23	8.04	17.27	7.05	8.33	0.139	0.533	7.02	0.2278	10.13	17.16	7.00	8.27
219	1990	5	135	31	2.973	9.98	13.19	23.17	9.48	11.57	0.165	0.520	7.16	0.1976	16.58	23.74	9.71	11.85
220	1990	6	166	30	4.162	10.37	11.23	21.59	8.88	10.49	0.129	0.650	8.65	0.1852	13.97	22.63	9.31	10.99
221	1990	7	196	31	4.767	11.23	9.27	20.51	8.45	10.32	0.127	0.680	9.58	0.1728	10.92	20.50	8.45	10.32
222	1990	8	227	31	4.384	11.22	7.34	18.57	7.65	9.33	0.120	0.677	9.67	0.1847	8.44	18.12	7.46	9.10
223	1990	9	258	30	4.078	8.76	7.18	15.94	6.56	7.74	0.119	0.665	7.52	0.1929	8.15	15.67	6.44	7.61
224	1990	10	288	31	2.858	5.43	6.72	12.15	4.97	6.06	0.108	0.614	4.64	0.2414	7.30	11.94	4.88	5.96
225	1990	11	319	30	1.872	2.64	5.84	8.48	3.44	4.07	0.115	0.510	2.11	0.2882	6.67	8.78	3.57	4.21

226	1990	12	349	31	1.269	1.60	3.88	5.47	2.21	2.70	0.109	0.438	1.25	0.3466	4.30	5.55	2.24	2.73
227	1991	1	15	31	1.391	2.35	2.37	4.72	1.91	2.33	0.095	0.491	2.00	0.3588	2.45	4.45	1.80	2.20
228	1991	2	46	28	1.863	4.26	3.68	7.93	3.22	3.55	0.105	0.530	3.53	0.3007	4.37	7.90	3.21	3.54
229	1991	3	74	31	1.659	6.20	5.01	11.21	4.55	5.55	0.141	0.433	4.36	0.2715	6.19	10.55	4.28	5.22
230	1991	4	105	30	2.279	9.50	6.88	16.38	6.67	7.88	0.137	0.509	7.14	0.2429	8.84	15.98	6.51	7.69
231	1991	5	135	31	2.823	10.98	9.21	20.20	8.26	10.08	0.156	0.523	8.02	0.2077	11.89	19.91	8.14	9.93
232	1991	6	166	30	3.458	11.06	8.75	19.81	8.13	9.60	0.134	0.603	8.90	0.2014	10.85	19.75	8.10	9.57
233	1991	7	196	31	4.282	11.32	6.96	18.28	7.52	9.18	0.112	0.687	9.95	0.1913	7.64	17.59	7.24	8.83
234	1991	8	227	31	4.468	11.00	6.87	17.87	7.36	8.98	0.115	0.689	9.61	0.1848	7.76	17.37	7.15	8.73
235	1991	9	258	30	4.013	9.27	5.32	14.59	6.00	7.09	0.103	0.692	8.30	0.2036	5.40	13.70	5.63	6.65
236	1991	10	288	31	3.193	6.15	6.52	12.68	5.19	6.34	0.115	0.623	5.21	0.2229	7.54	12.74	5.22	6.37
237	1991	11	319	30	1.907	2.87	4.95	7.82	3.18	3.75	0.111	0.521	2.33	0.2901	5.68	8.00	3.25	3.84
238	1991	12	349	31	1.465	1.78	2.11	3.89	1.57	1.92	0.100	0.491	1.48	0.3433	2.23	3.71	1.50	1.83
239	1992	1	15	31	1.415	2.33	2.45	4.78	1.94	2.36	0.101	0.479	1.92	0.3449	2.81	4.73	1.91	2.33
240	1992	2	46	29	1.765	4.07	3.88	7.95	3.23	3.68	0.109	0.510	3.31	0.3033	4.26	7.57	3.07	3.51
241	1992	3	74	31	1.905	6.19	4.58	10.78	4.38	5.34	0.118	0.506	4.88	0.2817	5.25	10.12	4.11	5.02
242	1992	4	105	30	2.681	9.67	6.03	15.70	6.41	7.57	0.114	0.589	8.06	0.2447	6.95	15.01	6.13	7.24
243	1992	5	135	31	3.268	11.24	6.41	17.65	7.23	8.83	0.116	0.625	9.49	0.2192	7.41	16.90	6.93	8.45
244	1992	6	166	30	3.779	11.64	10.01	21.66	8.89	10.50	0.146	0.602	9.17	0.1863	12.79	21.96	9.02	10.65
245	1992	7	196	31	4.592	11.76	8.55	20.31	8.37	10.21	0.130	0.668	9.91	0.1751	10.31	20.23	8.33	10.17
246	1992	8	227	31	4.814	11.19	6.90	18.10	7.46	9.11	0.117	0.699	9.79	0.1761	7.73	17.52	7.23	8.82
247	1992	9	258	30	4.190	8.93	6.36	15.29	6.29	7.43	0.096	0.714	8.19	0.2025	5.76	13.95	5.74	6.78
248	1992	10	288	31	2.992	5.37	5.53	10.90	4.46	5.44	0.093	0.658	4.86	0.2486	4.79	9.65	3.95	4.82
249	1992	11	319	30	1.717	2.48	4.24	6.72	2.73	3.22	0.090	0.551	2.20	0.3358	3.57	5.77	2.34	2.76
250	1992	12	349	31	1.248	1.57	2.53	4.09	1.65	2.02	0.091	0.479	1.35	0.3846	2.20	3.56	1.44	1.75

251 ----------

252 SUMMARY OF REF ET ESTIMATES:

				Penman: Aero term					Penman-Monteith (Smith, 1991)				
				Rad term		ETo			Rad term	Aero term	ETo		
253													
254 Year	Styles	CIMIS		Inches	Inches	In/d	Inches	Pct	Inches	Inches	In/d	Inches	Pct
255 -------	-------			-------		----------			-------		----------		
256 1987													0.0%
257 1988		82.6	108.3%	40.1	43.0	0.193	84.8	103.7%	33.2	50.6	0.195	85.5	104.9%
258 1989		84.5	110.7%	39.0	46.9	0.200	87.5	107.0%	31.6	56.3	0.205	89.5	109.9%
259 1990		77.1	101.0%	39.8	43.1	0.193	84.5	103.3%	32.2	51.8	0.195	85.6	105.0%
260 1991		69.4	91.0%	41.8	33.1	0.174	76.2	93.3%	34.1	39.0	0.170	74.4	91.3%
261 1992		67.9	89.0%	41.7	32.5	0.173	75.7	92.6%	35.3	35.6	0.165	72.3	88.8%
262		----------		----------					----------				
263 Average		76.3	100.0%	40.5	39.7		81.7	100.0%	33.3	46.7		81.5	100.0%
264				50.5%	49.5%				41.6%	58.4%			

265 Month	Penman: In/mo	Penman-Monteith: In/mo
266 Jan	2.90	2.97
267 Feb	3.97	4.03
268 Mar	6.28	6.21
269 Apr	8.04	7.94
270 May	10.43	10.49
271 Jun	10.35	10.66
272 Jul	9.93	9.83
273 Aug	9.39	9.19
274 Sep	7.85	7.65
275 Oct	6.02	5.85
276 Nov	3.88	3.93
277 Dec	2.70	2.69

87

11-Oct-93 ESTIMATED REFERENCE ET - IID \ETO-CM4

Column = C D E F G H I J K L M N O P Q R S

SITE INPUT DATA: Lat, degrees = 33.00 or 0.5759 Radians

Elevation, m = -50 m Atm. pressure 101.90 kPa Energy units = MJ/(m^2 day) = MJ*

Measurement height: Temp & dewpoin 2.00 m Wind 2.00 m

Reference crop: Grass

hc = 0.12 m

zom = 0.0147 m zov = 0.1zom= 1E-03 m 207.7

d = 0.0800 m LAI = 2.88 ra = -----

rc = 69.44 s/m u2

Clear day solar radiation = Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)] Based on maximum Rs values

INPUT DATA: SITE:CIMIS Station 87, Meloland

Year	Mo	CD	Ra MJ*	Ra ly/day	Rso MJ*	Rso ly/day	Rs ly/day	Rs MJ*	n/N	Maximum temp deg F	Maximum temp deg C	Minimum temp deg F	Minimum temp deg C	Dewpoint temp deg F	Dewpoint temp deg C	Wind mi/day	run m/s
1987	1	15	19.56														
1987	2	46	24.41														
1987	3	74	30.65														
1987	4	105	36.31														
1987	5	135	39.96														
1987	6	166	41.36														
1987	7	196	40.60														
1987	8	227	37.69														
1987	9	258	32.84														
1987	10	288	26.70														
1987	11	319	21.02														
1987	12	349	18.14														
1988	1	15	19.56														
1988	2	46	24.41														
1988	3	74	30.65														
1988	4	105	36.31														
1988	5	135	39.96														
1988	6	166	41.36														
1988	7	196	40.60														
1988	8	227	37.69														
1988	9	258	32.84														
1988	10	288	26.70														
1988	11	319	21.02														
1988	12	349	18.14														
1989	1	15	19.56														
1989	2	46	24.41														
1989	3	74	30.65														
1989	4	105	36.31														
1989	5	135	39.96														
1989	6	166	41.36														
1989	7	196	40.60														
1989	8	227	37.69														
1989	9	258	32.84														
1989	10	288	26.70														
1989	11	319	21.02														
1989	12	349	18.14														

55	1990	1	15	19.56	467	13.84	331	306.9	12.85	0.93	70.7	21.5	37.5	3.0	35.8	2.1	94.1	1.75
56	1990	2	46	24.41	583	17.55	419	377.9	15.82	0.90	73.3	23.0	38.6	3.7	34.8	1.6	114.2	2.13
57	1990	3	74	30.65	732	22.41	535	494.1	20.69	0.92	81.5	27.5	46.9	8.3	40.2	4.6	137.6	2.56
58	1990	4	105	36.31	867	26.97	644	595.9	24.95	0.93	87.7	31.0	55.7	13.2	45.9	7.7	143.8	2.68
59	1990	5	135	39.96	954	29.93	715	681.4	28.53	0.95	92.2	33.5	57.3	14.1	37.2	2.9	183.4	3.42
60	1990	6	166	41.36	988	30.98	740	693.9	29.05	0.94	103.1	39.5	67.0	19.4	44.3	6.8	124.7	2.32
61	1990	7	196	40.60	970	30.16	720	632.4	26.48	0.88	106.4	41.3	75.9	24.4	60.6	15.9	139.0	2.59
62	1990	8	227	37.69	900	27.57	658	622.3	26.05	0.95	103.0	39.5	72.3	22.4	62.6	17.0	117.2	2.18
63	1990	9	258	32.84	784	23.59	563	520.3	21.78	0.92	99.9	37.7	69.7	21.0	60.0	15.6	112.4	2.09
64	1990	10	288	26.70	638	18.89	451	437.2	18.30	0.97	91.3	32.9	57.5	14.2	49.6	9.8	91.3	1.70
65	1990	11	319	21.02	502	14.73	352	325.7	13.64	0.93	76.9	24.9	45.9	7.7	41.1	5.1	112.4	2.09
66	1990	12	349	18.14	433	12.72	304	264.8	11.09	0.87	64.9	18.3	34.5	1.4	32.1	0.0	97.1	1.81
67	1991	1	15	19.56	467	13.84	331	279.9	11.72	0.85	67.7	19.9	39.0	3.9	41.0	5.0	81.0	1.51
68	1991	2	46	24.41	583	17.55	419	370.2	15.50	0.88	79.0	26.1	44.8	7.1	47.0	8.3	94.1	1.75
69	1991	3	74	30.65	732	22.41	535	461.5	19.32	0.86	71.6	22.0	44.1	6.7	44.5	7.0	156.3	2.91
70	1991	4	105	36.31	867	26.97	644	624.9	26.16	0.97	83.8	28.8	50.2	10.1	50.6	10.3	128.2	2.39
71	1991	5	135	39.96	954	29.93	715	687.9	28.80	0.96	89.4	31.9	56.2	13.4	56.3	13.5	171.2	3.19
72	1991	6	166	41.36	988	30.98	740	632.3	26.47	0.85	96.8	36.0	62.5	16.9	62.4	16.9	136.7	2.55
73	1991	7	196	40.60	970	30.16	720	647.1	27.09	0.90	103.2	39.6	71.2	21.8	66.8	19.3	117.4	2.19
74	1991	8	227	37.69	900	27.57	658	598.0	25.04	0.91	104.5	40.3	73.1	22.8	63.5	17.5	117.2	2.18
75	1991	9	258	32.84	784	23.59	563	504.4	21.12	0.90	100.5	38.1	70.2	21.2	63.8	17.7	97.7	1.82
76	1991	10	288	26.70	638	18.89	451	419.6	17.57	0.93	93.1	33.9	61.5	16.4	55.3	12.9	112.0	2.09
77	1991	11	319	21.02	502	14.73	352	321.4	13.46	0.91	77.6	25.4	46.2	7.9	44.6	7.0	99.8	1.86
78	1991	12	349	18.14	433	12.72	304	219.4	9.18	0.72	66.8	19.4	42.7	5.9	42.2	5.7	82.1	1.53
79	1992	1	15	19.56	467	13.84	331	290.4	12.16	0.88	67.9	19.9	39.2	4.0	39.4	4.1	88.2	1.64
80	1992	2	46	24.41	583	17.55	419	363.7	15.23	0.87	73.5	23.1	47.2	8.4	46.9	8.3	98.2	1.83
81	1992	3	74	30.65	732	22.41	535	469.1	19.64	0.88	75.1	23.9	48.7	9.3	47.2	8.4	107.6	2.00
82	1992	4	105	36.31	867	26.97	644	590.7	24.73	0.92	89.1	31.7	55.0	12.8	45.1	7.3	92.4	1.72
83	1992	5	135	39.96	954	29.93	715	637.0	26.67	0.89	94.4	34.6	61.8	16.5	53.8	12.1	108.6	2.02
84	1992	6	166	41.36	988	30.98	740	699.9	29.30	0.95	101.1	38.4	65.7	18.7	51.5	10.8	134.0	2.50
85	1992	7	196	40.60	970	30.16	720	646.6	27.07	0.90	105.4	40.8	73.5	23.1	60.2	15.7	126.2	2.35
86	1992	8	227	37.69	900	27.57	658	578.6	24.23	0.88	106.0	41.1	77.6	25.3	67.7	19.8	113.5	2.11
87	1992	9	258	32.84	784	23.59	563	514.1	21.52	0.91	104.7	40.4	71.7	22.1	64.3	18.0	102.3	1.90
88	1992	10	288	26.70	638	18.89	451	398.9	16.70	0.88	92.5	33.6	60.6	15.9	59.3	15.2	99.5	1.85
89	1992	11	319	21.02	502	14.73	352	329.6	13.80	0.94	75.4	24.1	44.3	6.8	45.7	7.6	94.1	1.75
90	1992	12	349	18.14	433	12.72	304	232.6	9.74	0.77	63.6	17.5	38.3	3.5	36.2	2.3	91.1	1.70

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93 BASIC CALCULATIONS:			E	F	G	H	I	J	K	L	M	N	O	P	Q
94						delta(D)		gamma(g)							
95			Tavg	eo	ed		Lamda(L)		f(Tavg)		Rns		Rbo	Rb	Rn
96	Year	Mo	CD C	kPa	kPa	kPa/C	MJ/kg	kPa/C	D/(D+g)	Albedo	MJ*	a1	MJ*	MJ*	MJ*
97															
98	1987	1	15												
99	1987	2	46												
100	1987	3	74												
101	1987	4	105												
102	1987	5	135												
103	1987	6	166												
104	1987	7	196												
105	1987	8	227												
106	1987	9	258												
107	1987	10	288												
108	1987	11	319												
109	1987	12	349												
110	1988	1	15												
111	1988	2	46												
112	1988	3	74												
113	1988	4	105												
114	1988	5	135												
115	1988	6	166												
116	1988	7	196												
117	1988	8	227												
118	1988	9	258												
19	1988	10	288												
120	1988	11	319												
121	1988	12	349												
122	1989	1	15												
123	1989	2	46												
124	1989	3	74												
125	1989	4	105												
126	1989	5	135												
127	1989	6	166												
128	1989	7	196												
129	1989	8	227												
130	1989	9	258												
131	1989	10	288												
132	1989	11	319												
133	1989	12	349												
134	1990	1	15	12.3	1.663	0.712	0.094	2.47	0.067	0.583	0.344	8.43	0.260	4.68	4.57	3.86
135	1990	2	46	13.3	1.799	0.684	0.100	2.47	0.067	0.598	0.324	10.70	0.262	4.88	4.61	6.09
136	1990	3	74	17.9	2.381	0.847	0.129	2.46	0.067	0.656	0.297	14.54	0.268	4.96	4.81	9.73
137	1990	4	105	22.1	3.000	1.054	0.162	2.45	0.068	0.705	0.266	18.32	0.289	5.49	5.33	12.99
138	1990	5	135	23.8	3.385	0.753	0.177	2.44	0.068	0.723	0.242	21.63	0.326	7.87	7.90	13.74
139	1990	6	166	29.5	4.725	0.990	0.237	2.43	0.068	0.777	0.230	22.36	0.357	9.06	8.93	13.43
140	1990	7	196	32.8	5.480	1.805	0.280	2.42	0.068	0.804	0.235	20.25	0.352	7.13	6.55	13.71
141	1990	8	227	30.9	4.940	1.941	0.255	2.43	0.068	0.789	0.255	19.41	0.315	5.12	5.09	14.32
142	1990	9	258	29.3	4.508	1.770	0.236	2.43	0.068	0.775	0.285	15.58	0.281	3.97	3.85	11.74
143	1990	10	288	23.5	3.313	1.211	0.175	2.45	0.068	0.720	0.315	12.54	0.265	4.30	4.39	8.15
144	1990	11	319	16.3	2.104	0.876	0.118	2.46	0.067	0.637	0.339	9.01	0.261	4.53	4.40	4.61
145	1990	12	349	9.8	1.387	0.613	0.081	2.48	0.067	0.549	0.350	7.21	0.260	4.78	4.36	2.85
146	1991	1	15	11.9	1.563	0.872	0.092	2.47	0.067	0.578	0.344	7.68	0.260	4.24	3.75	3.94

47	1991	2	46	16.6	2.200	1.098	0.120	2.46	0.067	0.641	0.324	10.48	0.262	4.04	3.73	6.75
48	1991	3	74	14.4	1.815	0.999	0.106	2.47	0.067	0.612	0.297	13.59	0.268	4.35	3.92	9.67
149	1991	4	105	19.4	2.595	1.255	0.140	2.46	0.068	0.675	0.266	19.21	0.289	4.83	4.94	14.28
150	1991	5	135	22.7	3.133	1.546	0.167	2.45	0.068	0.711	0.242	21.84	0.326	5.78	5.85	15.98
151	1991	6	166	26.5	3.939	1.927	0.204	2.44	0.068	0.750	0.230	20.38	0.357	6.53	5.82	14.55
152	1991	7	196	30.7	4.905	2.242	0.252	2.43	0.068	0.786	0.235	20.72	0.352	6.03	5.68	15.05
153	1991	8	227	31.5	5.130	2.004	0.263	2.43	0.068	0.793	0.255	18.65	0.315	5.03	4.79	13.86
154	1991	9	258	29.6	4.585	2.021	0.239	2.43	0.068	0.778	0.285	15.11	0.281	3.46	3.24	11.87
155	1991	10	288	25.2	3.581	1.492	0.190	2.44	0.068	0.737	0.315	12.04	0.265	3.73	3.65	8.39
156	1991	11	319	16.6	2.151	1.002	0.120	2.46	0.067	0.641	0.339	8.89	0.261	4.23	4.06	4.84
157	1991	12	349	12.6	1.589	0.914	0.096	2.47	0.067	0.588	0.350	5.97	0.260	4.17	3.10	2.87
158	1992	1	15	12.0	1.572	0.820	0.092	2.47	0.067	0.579	0.344	7.97	0.260	4.37	4.02	3.95
159	1992	2	46	15.7	1.963	1.095	0.115	2.46	0.067	0.630	0.324	10.30	0.262	3.99	3.62	6.68
160	1992	3	74	16.6	2.072	1.105	0.120	2.46	0.067	0.641	0.297	13.81	0.268	4.23	3.88	9.93
161	1992	4	105	22.3	3.081	1.023	0.163	2.45	0.068	0.707	0.266	18.16	0.289	5.58	5.38	12.78
162	1992	5	135	25.6	3.698	1.412	0.195	2.44	0.068	0.741	0.242	20.22	0.326	6.31	5.89	14.33
163	1992	6	166	28.5	4.461	1.299	0.226	2.43	0.068	0.768	0.230	22.55	0.357	8.13	8.08	14.47
164	1992	7	196	31.9	5.255	1.781	0.268	2.43	0.068	0.796	0.235	20.71	0.352	7.10	6.68	14.03
165	1992	8	227	33.2	5.532	2.316	0.285	2.42	0.069	0.806	0.255	18.05	0.315	4.50	4.14	13.91
166	1992	9	258	31.2	5.091	2.060	0.259	2.43	0.068	0.791	0.285	15.40	0.281	3.45	3.31	12.09
167	1992	10	288	24.8	3.508	1.724	0.186	2.44	0.068	0.733	0.315	11.44	0.265	3.22	2.98	8.46
168	1992	11	319	15.5	1.997	1.044	0.113	2.46	0.067	0.626	0.339	9.12	0.261	4.06	4.00	5.12
169	1992	12	349	10.5	1.396	0.722	0.085	2.48	0.067	0.559	0.350	6.33	0.260	4.53	3.59	2.75

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172 REFERENCE ET ESTIMATES:

					F	G	H	I	J	K	L	M	N	O	P	Q	R	S
						Penman (1963), (eo-ed) = f(Tavg)							Penman-Monteith (Smith, 1991):					
					f(Tavg)	Aero term							Rad	Aero term				
					eo	Rad term		ETo	ETo	ETo	g*	D/	term	g/		ETo	ETo	ETo
Year	Mo	CD	Days/mo		kPa	MJ*	MJ*	MJ*	mm/d	In/mo	kPa/C	(D+g*)	MJ*	(D+g*)	MJ*	MJ*	mm/d	In/mo
1987	1	15	31															
1987	2	46	28															
1987	3	74	31															
1987	4	105	30															
1987	5	135	31															
1987	6	166	30															
1987	7	196	31															
1987	8	227	31															
1987	9	258	30															
1987	10	288	31															
1987	11	319	30															
1987	12	349	31															
1988	1	15	31															
1988	2	46	29															
1988	3	74	31															
1988	4	105	30															
1988	5	135	31															
1988	6	166	30															
1988	7	196	31															
1988	8	227	31															
1988	9	258	30															
1988	10	288	31															
1988	11	319	30															
1988	12	349	31															
1989	1	15	31															
1989	2	46	28															
1989	3	74	31															
1989	4	105	30															
1989	5	135	31															
1989	6	166	30															
1989	7	196	31															
1989	8	227	31															
1989	9	258	30															
1989	10	288	31															
1989	11	319	30															
1989	12	349	31															
1990	1	15	31		1.429	2.25	3.73	5.98	2.42	2.95	0.106	0.469	1.81	0.3348	4.32	6.13	2.48	3.02
1990	2	46	28		1.530	3.64	4.68	8.32	3.37	3.71	0.115	0.465	2.83	0.3128	5.71	8.54	3.46	3.81
1990	3	74	31		2.050	6.39	6.31	12.70	5.16	6.30	0.125	0.507	4.94	0.2653	7.87	12.80	5.21	6.36
1990	4	105	30		2.655	9.15	7.40	16.56	6.76	7.99	0.128	0.557	7.24	0.2335	9.01	16.25	6.63	7.84
1990	5	135	31		2.944	9.93	11.05	20.98	8.58	10.47	0.145	0.549	7.54	0.2105	13.91	21.45	8.77	10.71
1990	6	166	30		4.120	10.43	10.10	20.52	8.44	9.97	0.121	0.662	8.89	0.1904	11.84	20.73	8.53	10.07
1990	7	196	31		4.987	11.01	9.60	20.61	8.50	10.38	0.128	0.687	9.41	0.1679	11.29	20.70	8.54	10.43
1990	8	227	31		4.477	11.29	7.48	18.77	7.73	9.44	0.118	0.683	9.78	0.1831	8.54	18.33	7.55	9.21
1990	9	258	30		4.089	9.10	7.11	16.21	6.66	7.87	0.116	0.670	7.86	0.1940	7.98	15.84	6.52	7.70
1990	10	288	31		2.903	5.87	5.82	11.69	4.78	5.83	0.106	0.622	5.07	0.2412	6.34	11.41	4.67	5.69
1990	11	319	30		1.857	2.94	4.86	7.79	3.16	3.74	0.115	0.508	2.34	0.2894	5.65	7.99	3.24	3.83

226	1990	12	349	31	1.214	1.56	3.44	5.00	2.02	2.46	0.107	0.431	1.23	0.3544	3.88	5.11	2.06	2.52
227	1991	1	15	31	1.391	2.27	2.55	4.83	1.95	2.38	0.101	0.476	1.88	0.3480	2.81	4.69	1.90	2.31
228	1991	2	46	28	1.893	4.33	3.56	7.89	3.20	3.53	0.107	0.529	3.57	0.2966	4.34	7.92	3.22	3.55
229	1991	3	74	31	1.637	5.92	4.08	10.00	4.05	4.95	0.133	0.444	4.29	0.2818	5.12	9.42	3.82	4.66
230	1991	4	105	30	2.260	9.64	4.79	14.43	5.88	6.94	0.122	0.536	7.65	0.2579	6.18	13.84	5.64	6.66
231	1991	5	135	31	2.752	11.37	6.07	17.44	7.12	8.69	0.140	0.544	8.69	0.2208	8.25	16.94	6.92	8.45
232	1991	6	166	30	3.458	10.91	5.83	16.74	6.86	8.11	0.126	0.618	8.99	0.2064	7.68	16.67	6.84	8.07
233	1991	7	196	31	4.407	11.83	6.46	18.29	7.53	9.19	0.118	0.680	10.23	0.1847	7.68	17.91	7.37	9.00
234	1991	8	227	31	4.634	11.00	7.58	18.58	7.66	9.34	0.118	0.690	9.56	0.1794	8.70	18.26	7.52	9.18
235	1991	9	258	30	4.158	9.23	6.03	15.26	6.28	7.41	0.110	0.685	8.13	0.1956	6.54	14.67	6.03	7.13
236	1991	10	288	31	3.198	6.18	6.11	12.30	5.04	6.15	0.115	0.622	5.22	0.2223	7.08	12.30	5.04	6.15
237	1991	11	319	30	1.893	3.10	4.11	7.21	2.93	3.46	0.109	0.524	2.53	0.2935	4.75	7.29	2.96	3.50
238	1991	12	349	31	1.464	1.69	2.65	4.34	1.76	2.14	0.102	0.486	1.40	0.3399	2.71	4.10	1.66	2.03
239	1992	1	15	31	1.400	2.29	2.95	5.24	2.12	2.59	0.104	0.470	1.86	0.3419	3.27	5.13	2.07	2.53
240	1992	2	46	29	1.790	4.21	3.28	7.48	3.04	3.47	0.109	0.513	3.43	0.3019	3.65	7.08	2.87	3.28
241	1992	3	74	31	1.890	6.36	3.76	10.12	4.11	5.02	0.113	0.516	5.13	0.2896	4.26	9.38	3.81	4.65
242	1992	4	105	30	2.685	9.04	6.03	15.06	6.15	7.27	0.107	0.605	7.73	0.2509	6.57	14.30	5.84	6.90
243	1992	5	135	31	3.282	10.62	6.49	17.11	7.01	8.56	0.114	0.631	9.04	0.2203	7.43	16.47	6.75	8.24
244	1992	6	166	30	3.903	11.12	9.06	20.18	8.29	9.80	0.125	0.644	9.32	0.1940	11.02	20.34	8.36	9.87
245	1992	7	196	31	4.735	11.17	8.74	19.91	8.21	10.02	0.122	0.687	9.63	0.1754	10.16	19.80	8.16	9.96
246	1992	8	227	31	5.096	11.22	7.38	18.60	7.68	9.37	0.117	0.709	9.87	0.1702	8.17	18.04	7.45	9.09
247	1992	9	258	30	4.551	9.56	6.77	16.33	6.73	7.95	0.112	0.698	8.44	0.1844	7.58	16.02	6.60	7.80
248	1992	10	288	31	3.123	6.20	4.79	10.99	4.50	5.49	0.110	0.629	5.32	0.2292	5.54	10.87	4.45	5.43
249	1992	11	319	30	1.757	3.20	3.33	6.53	2.65	3.13	0.107	0.513	2.63	0.3067	3.91	6.53	2.65	3.13
250	1992	12	349	31	1.272	1.54	2.98	4.51	1.82	2.23	0.105	0.447	1.23	0.3529	3.14	4.37	1.77	2.15

251 ----------

252 SUMMARY OF REF ET ESTIMATES:

253				Penman: Aero term					Penman-Monteith (Smith, 1991)				
				Rad term		ETo			Rad term	Aero term	ETo		
254	Year	Styles	CIMIS	Inches	Inches	In/d	Inches	Pct	Inches	Inches	In/d	Inches	Pct
255	-------	-------		-------		----------			-------		----------		
256	1987												
257	1988												
258	1989												
259	1990	72.6	107.1%	40.3	39.3	0.185	81.1	106.6%	33.2	46.4	0.185	81.2	108.3%
260	1991	63.9	94.2%	42.2	28.8	0.165	72.3	95.0%	34.8	34.6	0.161	70.7	94.3%
261	1992	66.9	98.7%	41.7	31.6	0.171	74.9	98.4%	35.5	36.0	0.167	73.0	97.4%
262		----------		----------					----------				
263	Average	67.8	100.0%	41.4	33.3		76.1	100.0%	34.5	39.0		75.0	100.0%
264				55.4%	44.6%				46.9%	53.1%			

265	Month	Penman: In/mo	Penman-Monteith: In/mo
266	Jan	2.64	2.62
267	Feb	3.57	3.55
268	Mar	5.42	5.22
269	Apr	7.40	7.13
270	May	9.24	9.13
271	Jun	9.29	9.34
272	Jul	9.86	9.80
273	Aug	9.38	9.16
274	Sep	7.74	7.54
275	Oct	5.82	5.76
276	Nov	3.44	3.49
277	Dec	2.28	2.23

EVALUATING EVAPORATION ESTIMATES FOR IID

by
Marvin E. Jensen
18 Oct 93

INTRODUCTION

Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle/Styles (1993) report were used in this study as was done for reference ET estimates. The purpose of evaporation estimates is to evaluate various equations for estimating evaporation for use in water balance estimates for the Imperial Irrigation District and the Coachella Valley Water District.

PROCEDURES

The main changes in net radiation estimates for water surfaces involves the difference in albedo between water surface and the reference crop and the temperature of the evaporating surface.

Mean Daily Albedo

Mean daily albedo changes with solar declination or zenith angle. Hourly albedo values have been developed as a function of latitude (Dong et al., 1992). However, a mean daily functional relationship between albedo and latitude remains to be developed. Therefore, I modified the albedo function developed by Wright (ASCE Manual p. 137) to obtain a functional relationship applicable throughout the year. The resulting equation is in Appendix A.

Measurements and Estimates of Salton Sea Evaporation

Mean monthly and mean annual evaporation values presented by Hely et al. (1966) were used as a check in evaluating various equations for estimating evaporation.

Equations and Methods Used

The equations and procedures used are summarized in Appendix A.

RESULTS OF ANALYSES

Evaporation From Salton Sea and Fresh Water

Monthly evaporation estimates made by the USGS using three methods, water budget, energy budget and mass transfer, and measurements of variables in 1961-1962 are summarized in Fig. 1. The average annual evaporation was 71.8 inches for the period. When adjusted for salinity (E x 1.02), the average evaporation from fresh water for 1961-62 was 73.2 inches. A table of the USGS values adjusted for fresh water is in Appendix B.

Fig. 1. Estimated monthly evaporation from fresh water based on evaporation from the Salton Sea in 1961 and 1962 (From Hely et al., 1966).

MONTHLY EVAPORATION - USGS

Salton Sea, California

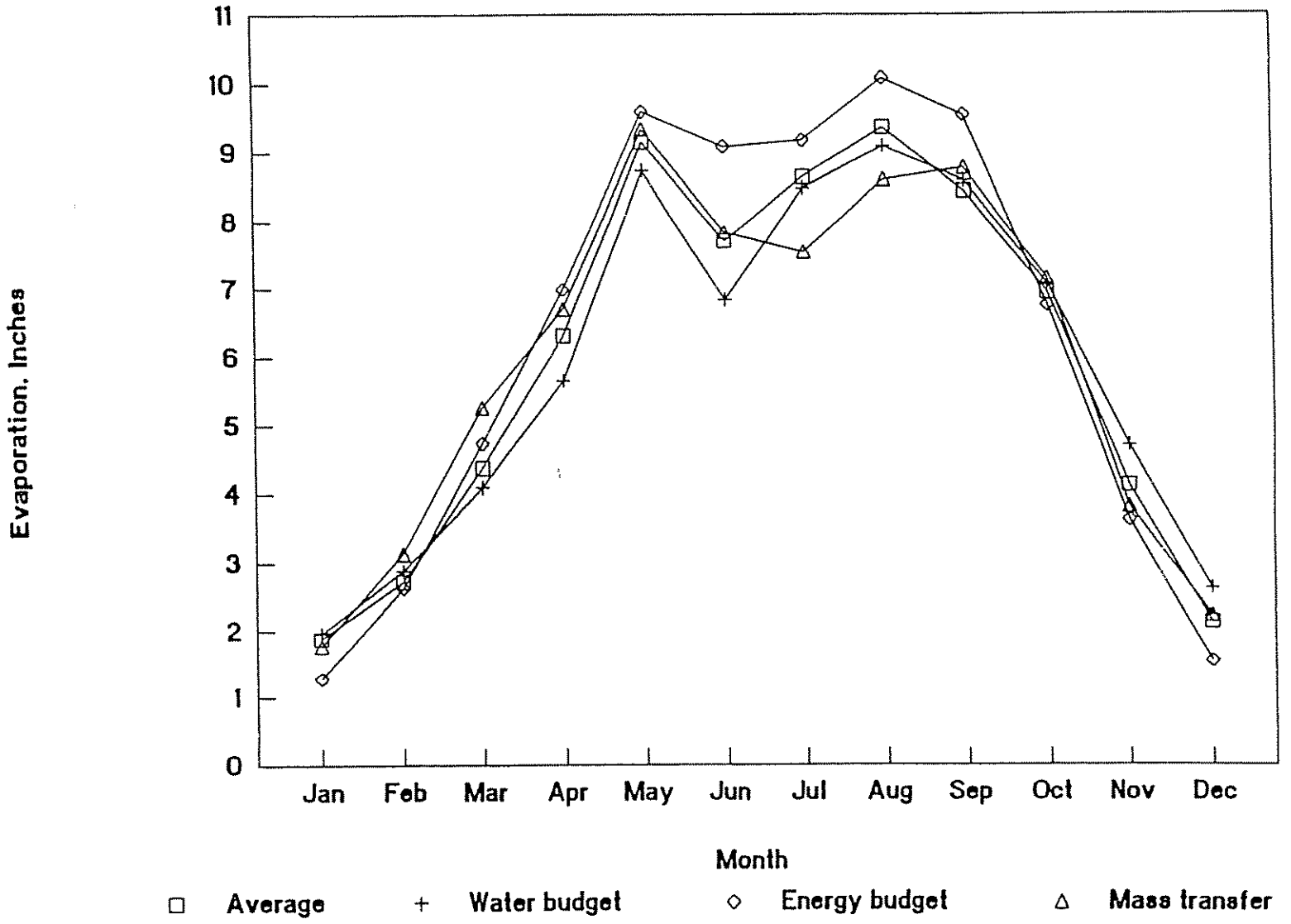

Fig. 1

2

The average evaporation for the 1948-1962 period was 69 inches which was considered to be the normal rate. When adjusted for salinity, the normal average is 70.4 inches.

Estimates of Annual Fresh Water Evaporation Using CIMIS Data

Estimates of annual evaporation from fresh water reservoirs for three CIMIS sites in the IID are shown in Figures 2-4. The methods compared are: 1) USGS 1961-62 average x 1.02; CIMIS ET_o; 2) Penman-Monteith (P-M) evaporation with z_o = 0.0002 m, r_c = 0, and using mean air temperature to compute the vapor pressure deficit; 3) Penman E_o arbitrarily reduced by 0.9 (Penman E_o x 0.9); and 4) Priestley-Taylor (P-T) potential evaporation.

Fig. 2-4. Mean annual evaporation for CIMIS Stations 41, 68 and 87 computed with the Penman-Monteith, Penman (1963) E_o and Priestley-Taylor equations compared with CIMIS ET_o values.

Estimates of Mean Monthly Fresh Water Reservoir Evaporation

Average monthly evaporation estimates for CIMIS Stations 41, 68 and 87 are compared with USGS monthly values in Figure 5. The lag in the USGS values in the spring and the higher monthly values in the fall are typical of lakes where heat storage is involved. A tabular summary of these values is presented in Appendix B.

Fig. 5. Comparison of mean monthly reference ET for CIMIS Stations 41, 68 and 87 computed with the Penman-Monteith and Penman (1963) equations with CIMIS values and USGS 1961-62 values.

Estimates of Mean Monthly Flowing Fresh Water Evaporation

Because the surface of flowing water is not as smooth as reservoir surfaces, the roughness parameter in the P-M equation was increased from 0.0002 m to 0.001 m. The P-M equation is sensitive to changes in the roughness parameter when it is very small. Wieringa (1992) suggested a value of z_o = 0.005 a smooth surface (Featureless land surface without any noticeable obstacles and with negligible vegetation, i.e., ... or fallow open country.) A value of 0.015 m was used for reference ET estimates. Penman E_o values were used without adjustment. A tabular summary of these values is presented in Appendix B.

Summary of Annual Fresh Water Evaporation Estimates

A summary of fresh water reservoir and flowing water annual evaporation estimates is presented in Table 1. Average CIMIS ET_o values were about equal to average estimated evaporation from reservoirs, but were about 87 percent of estimated evaporation from flowing fresh water.

Table 1. - Summary of estimated annual evaporation from reservoirs and canals/rivers in the IID.

Period	Station 41 Inches	Station 41 Percent	Station 68 Inches	Station 68 Percent	Station 87 Inches	Station 87 Percent	Average Inches
Annual fresh water reservoir evaporation, inches							
All years:							
CIMIS ET_o	73.6		76.3		67.8		72.6
P-M	75.9		74.5		72.5		74.3
P E_o x 0.9	73.7		77.6		74.3		75.2
P-T	67.1		69.0		71.1		69.1
Average	72.5	99.6	74.3	102.1	71.4	98.1	72.8
Annual fresh water evaporation from canals and rivers, inches							
All years:							
P-M	86.4		83.7		80.0		83.4
Pen E_o	81.2		86.2		82.6		83.6
Average	83.8	100.5	85.5	102.5	81.3	97.5	83.4

Simplified Estimates of Fresh Water Reservoir Evaporation Estimates

A regression analysis of P-M estimates of daily monthly fresh water evaporation v. R_s x T_{avg} is shown in Fig. 6. Simplified estimates of mean daily monthly fresh water evaporation can be made using the following equation derived for CIMIS Site 41.

$$E = 0.76 + 0.0097\,(R_s\,Tavg), \quad mm/day \tag{1a}$$

where E is evaporation, mm/day, R_s = solar radiation in MJ/(m^2 day), and T_{avg} = average daily temperature in degrees C. The R-squared value for this regression was 0.969. The same equation for E in in/day, solar radiation in ly/day and temperature in degrees F is:

$$E = 0.03 + \frac{0.89}{10^5}\,[R_s\,(T_{avg} - 32)], \quad inch/d \tag{1b}$$

If this procedure is acceptable, regressions for both reservoir and flowing water evaporation involving all three locations can be included in this report.

Fig. 6. Estimated mean daily monthly evaporation v. the product of solar radiation and mean monthly air temperature.

EVAPORATION ESTIMATES - CIMIS 41

Mulberry Site

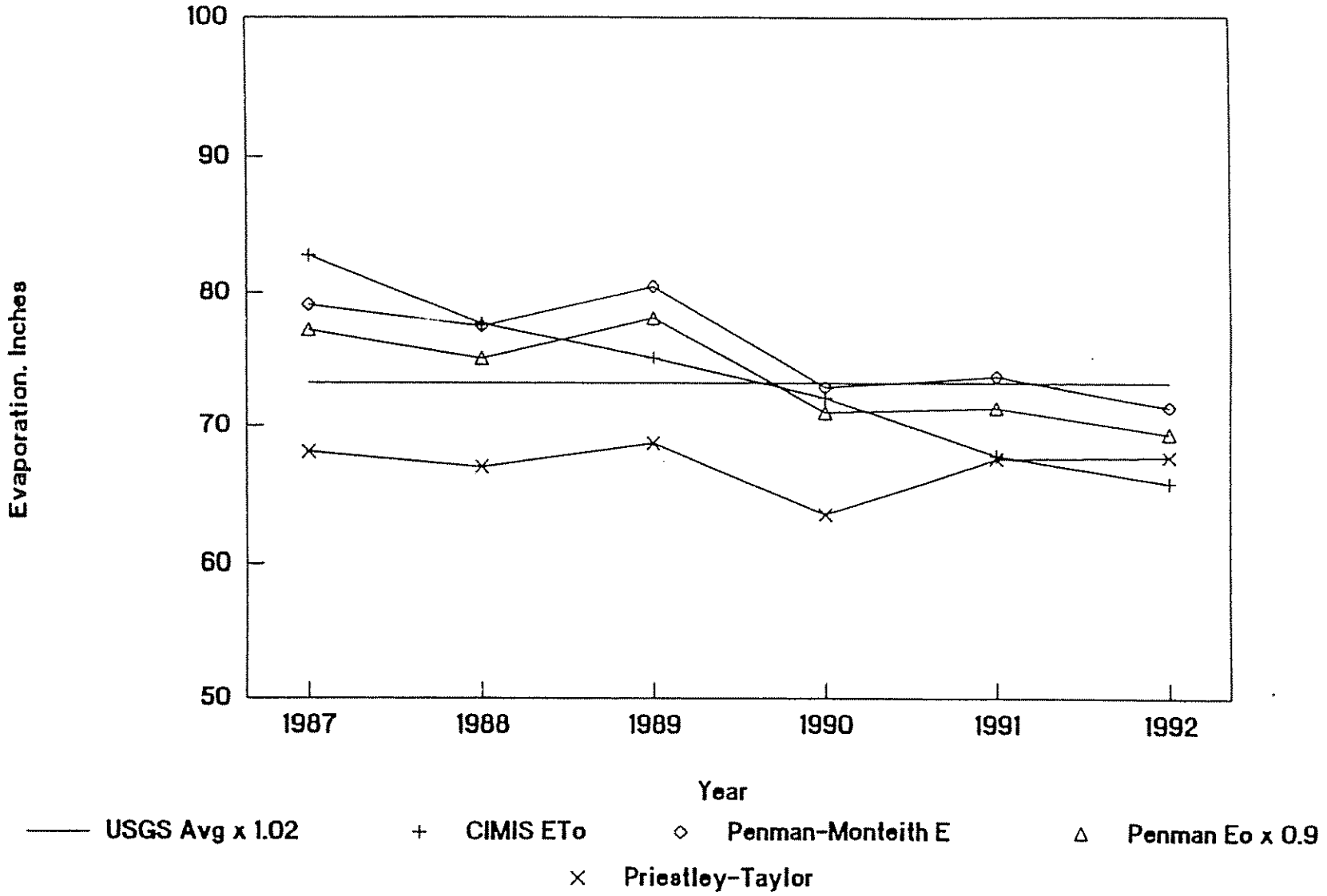

Fig 2.

EVAPORATION ESTIMATES - CIMIS 68

Seeley Site

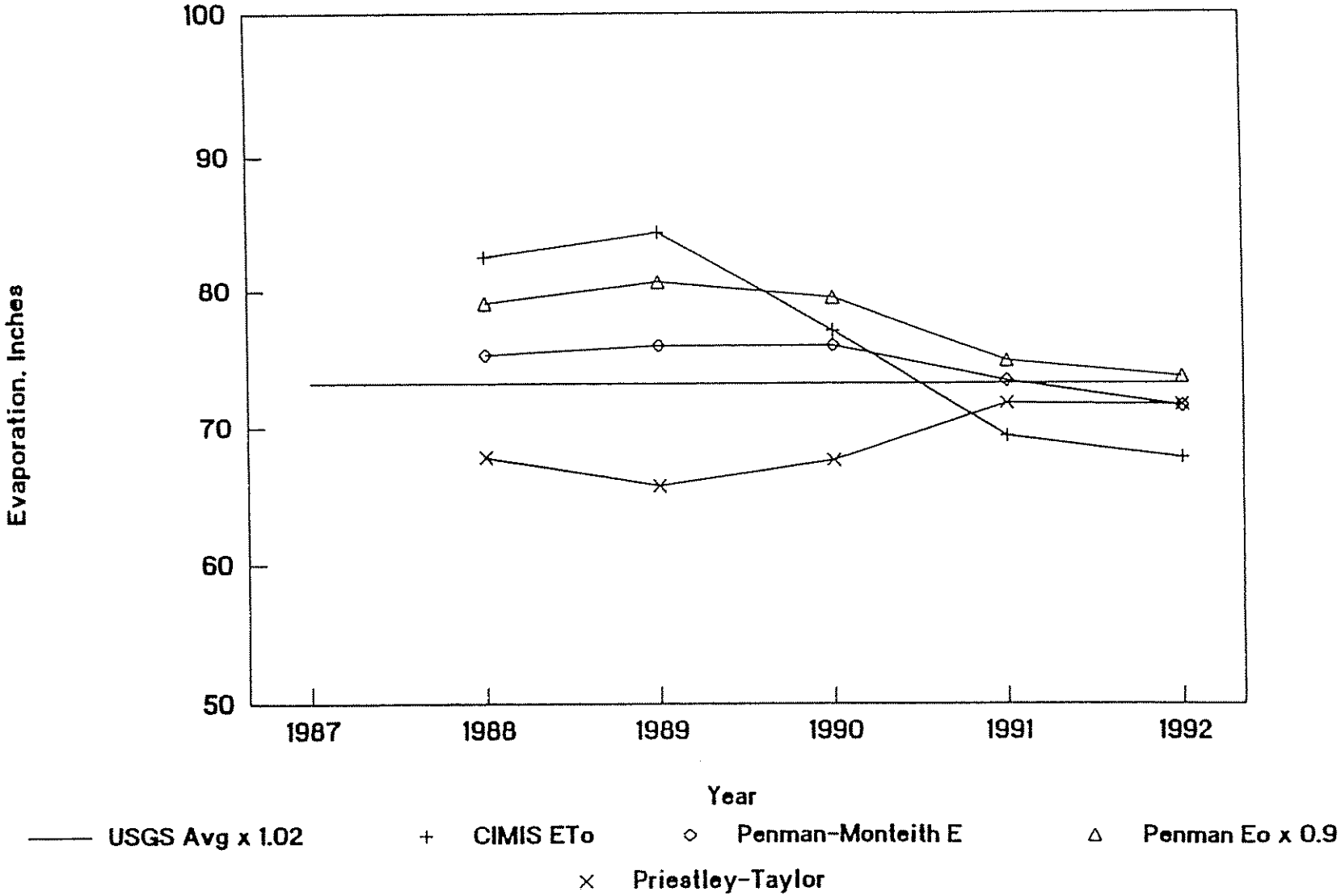

Fig. 3

EVAPORATION ESTIMATES - CIMIS 87

Meloland Site

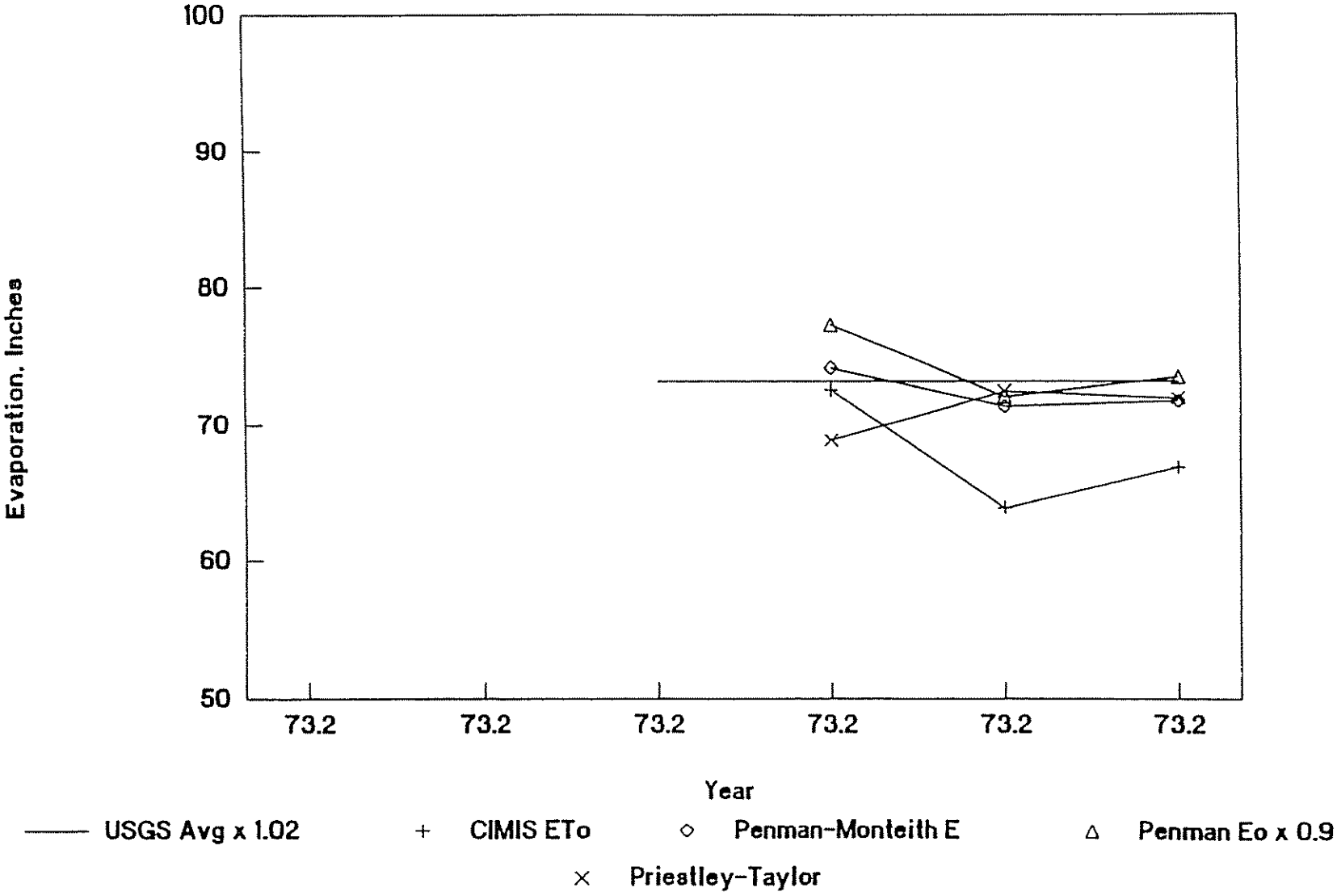

Fig. 4

EVAPORATION ESTIMATES - IMPERIAL VALLEY

CIMIS Sites 41, 68 & 87

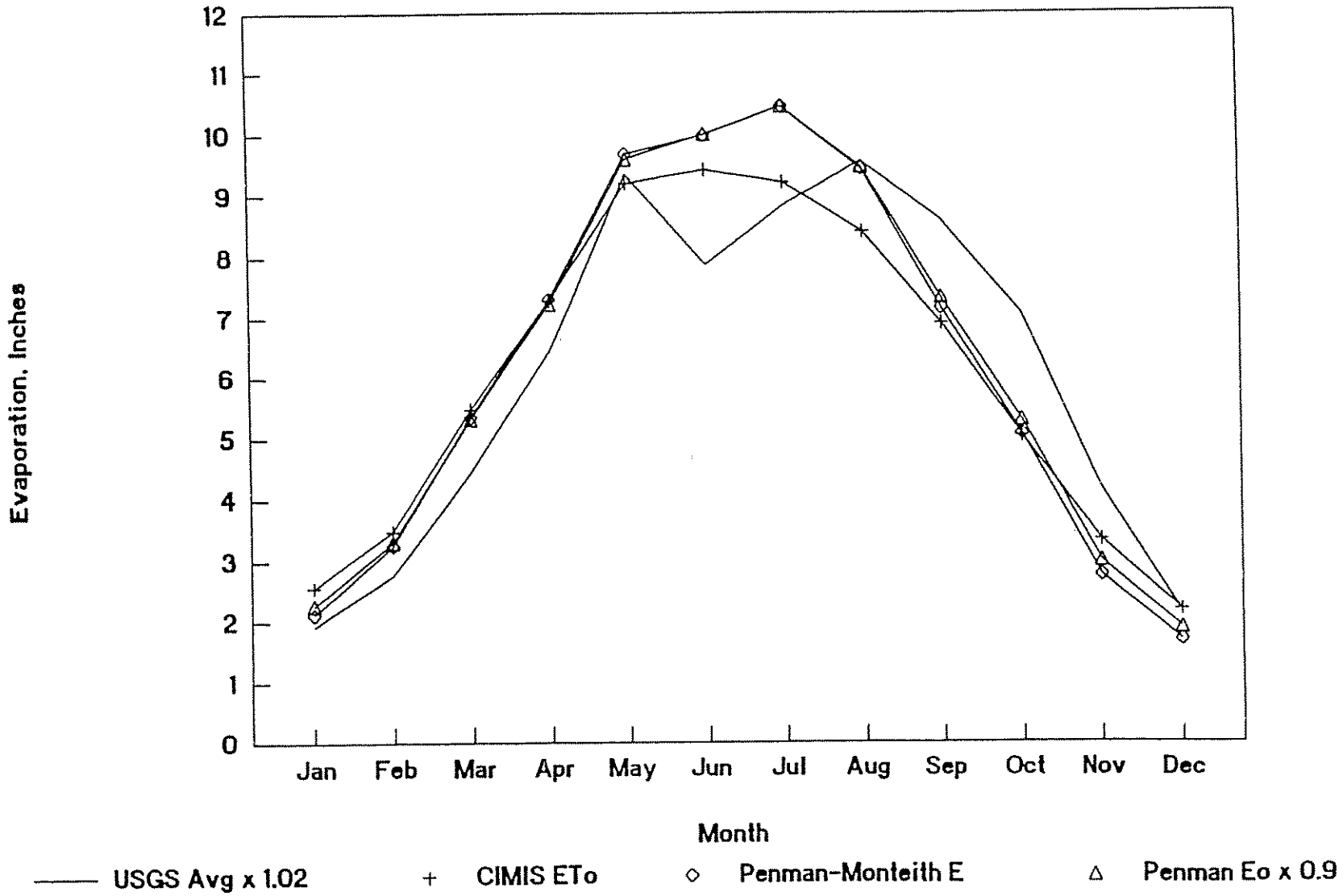

Fig 5

8

EVAPORATION ESTIMATES - CIMIS 41

Mulberry Site

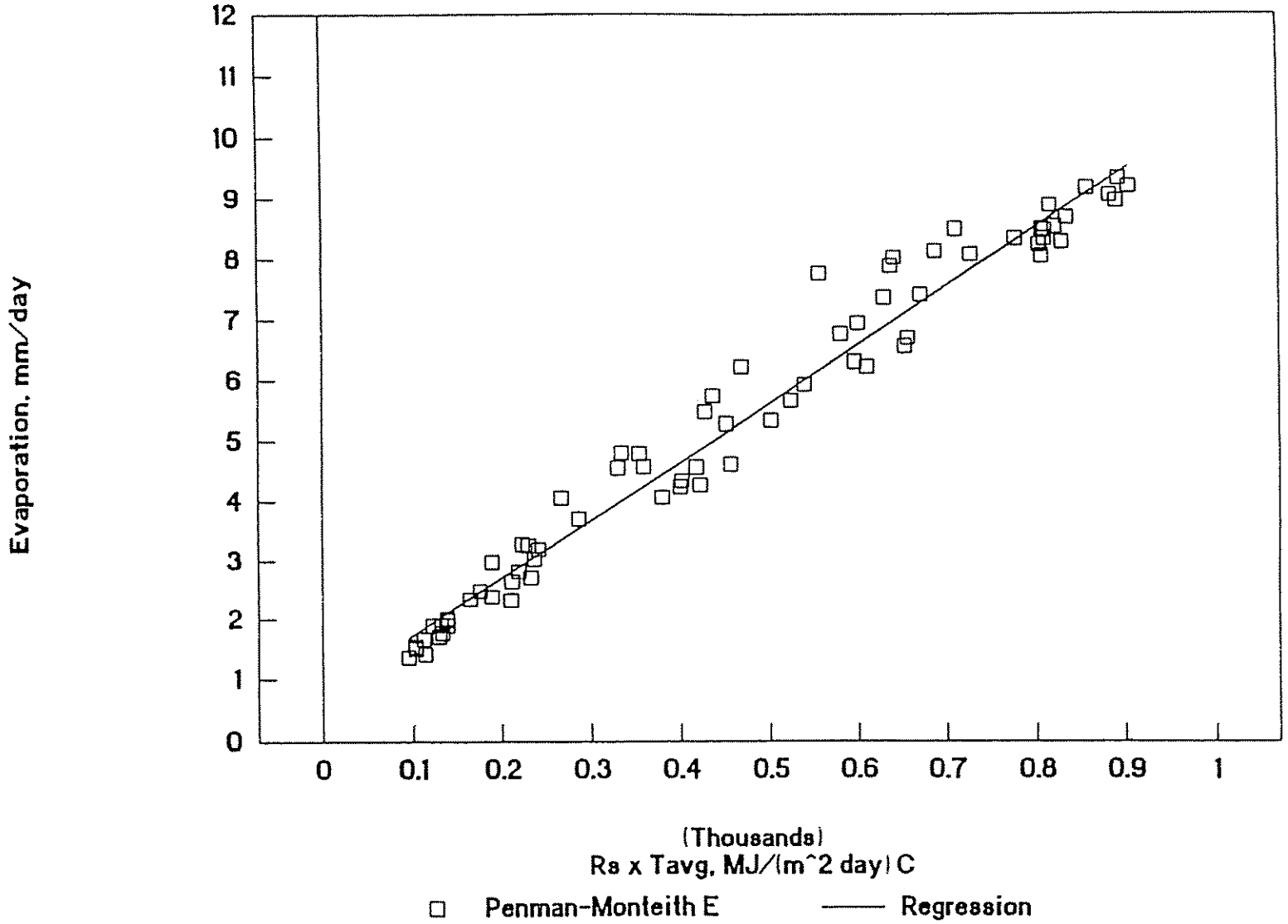

Fig. 6

SUMMARY AND CONCLUSIONS

A spreadsheet program was developed to estimate mean monthly evaporation from IID fresh water reservoirs and flowing fresh water. The Priestley-Taylor estimates of reservoir evaporation for data from three IID CIMIS sites was essentially equal to the adjusted normal evaporation from the Salton Sea. The estimated mean annual fresh water evaporation from reservoirs in the IID was 73 inches. The estimated mean annual evaporation from flowing fresh water evaporation using the Penman-Monteith and Penman (1963) combination equations was 83 inches.

Mean monthly evaporation from fresh water reservoirs and flowing canals and rivers can be made using a simple linear equation with the main variable being the product solar radiation and mean air temperature.

REFERENCES

Allen, R.G., M.E. Jensen, J.L. Wright,and R.D. Burman. 1989. Operational estimates of reference evapotranspiration. Agron. J. 81:650-662.

Brutsaert, W.H. 1982. Evaporation into the Atmosphere. D. Reidel Publishing Co., Dordrecht, Holland, Boston, and London, 299 pp.

Culf, A.D., and J.H. Gash. 1993. Longwave radiation from clear skies in Niger: A comparison of observations with simple formulas. Am. Meteorol. Soc. 32:539-547.

Dong, A., S.R. Grattan, J.J. Carroll, and C.R.K. Prashar. 1992. Estimation of daytime net radiation over well-watered grass. J. Irrig. and Drain. Div., ASCE, 118(3):466-479.

Hely, A.G., G.H. Hughes, and B. Irelan. 1966. Hydrologic Regimen of Salton Sea, California. Geologic Survey prof. Paper 486-C, 36 pp.

Jensen, M.E., R.D. Burman, and R.G. Allen (eds). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, New York, 360 pp.

Penman, H.L. 1963. Vegetation and Hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England, 125 pp.

Priestley, C.H.B., and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Monthly Weather Review 100:81-92.

Solar Energy Research Institute. 1980. Insolation Data Manual. Golden, Colorado.

Smith, M. 1991. Report on the expert consultation on procedures for revision of FAO Guidelines for prediction of crop water requirements. 28-31 May 1990, Rome, 56 pp.

Styles, S. 1993. On-Farm Irrigation Efficiency: Special Technical Report, Coachella Water District. April.

Wieringa, J. 1992. Updating the Davenport roughness classification. J. Wind Engr. and Industrial Aerodynamics 41-44:357-368.

APPENDIX A

EQUATIONS USED TO ESTIMATE EVAPORATION

Net Radiation

A slight modification of the net radiation equation used for reference ET was made for evaporation to enable using a recently calibrated equation for downward long-wave radiation and water surface temperature for upward long-wave radiation.

$$R_n = (1 - \alpha) R_s + R_{ld} - R_{lu} \tag{A-1}$$

where R_n is net radiation, MJ/(m^2 day) , α = albedo, R_{ld} = downward long-wave radiation, and R_{lu} = upward long-wave radiation, MJ/(m^2 day).

Net Long-Wave Radiation

Net long-wave radiation was calculated in a manner similar to that used for reference ET estimates except for separating downward and upward long-wave radiation.

$$R_b = \left(a \frac{R_s}{R_{so}} + b\right)(R_{ld} - R_{lu}) \tag{A-2}$$

where R_b is net long-wave radiation, (R_{ld} - R_{lu}) = R_{bo} = net long-wave radiation on a clear day, MJ/(m^2 day),R_s = measured solar radiation, and R_{so} = clear-day solar radiation. Adjustment for cloud cover was the same as used for reference ET, a = 1.126 and b = -0.07 (Wright, Manual 70, p. 137).

Downward long-wave radiation was calculated using a recent calibration of Brutsaert's atmospheric emissivity equation (Brutsaert, 1982). Culf and Gash (1993) calibrated Brutsaert's original equation for a dry climate replacing the constant 1.24 with 1.31, i.e., $\epsilon_a = 1.31(10\ e_d/T_{kavg})^{1/7}$. The USGS estimated the reflectance of long-wave radiation, r, from water surfaces to be 0.03 based on measurement made during the 1961-1962 Salton Sea study (Hely et al., 1966).

$$R_{ld} = (1 - r)\, 1.31 \frac{4.90\, T_{kavg}^4}{10^9} \left(\frac{10\, e_d}{T_{kavg}}\right)^{1/7} \tag{A-3}$$

where e_d is saturation vapor pressure at dewpoint temperature, r = the reflected long-wave radiation from water, T_{kavg} is the average absolute temperature (K), and the Stefan-Boltzmann constant is $\sigma = 4.903/10^9$ MJ/(m^2 day).

Upward long-wave radiation was calculated using the emissivity for water surface, ϵ_w = 0.97 and the water temperature.

$$R_{lu} = \epsilon_w \frac{4.90}{10^9} (T_{ko}^4) \tag{A-4}$$

Mean air temperature was assumed for water surface temperature since Hely et al. (1966) reported that the temperature of shallow streams in the area differed only slightly from mean air temperature.

Albedo

The major difference in net radiation estimates for water surfaces v. reference crops is the albedo. During the Lake Hefner studies in the 1950s, the USGS developed a table of water albedo values v. cloud cover and height. In the 1961-62 study, the USGS used these values, but reported only a few example values of reflected solar radiation for periods during the year based on the tabular values. Using these limited data, I developed a functional relationship for water surface albedo. A comparison of the following equation with reported values is shown in Fig. A-1.

$$\alpha_w = 0.060 + 0.021[1 - \cos(\frac{2\pi CD}{365} - 2.9] \tag{A-5}$$

where α_w is albedo for the water surface and CD = calendar day (1-365).

Clear-Day Solar Radiation

Clear-day solar radiation was based on the same relationship used for the reference ET estimates.

$$R_{so} = R_a [0.725 + 0.025\cos(\frac{2\pi CD}{365} - 2.6] \tag{A-6}$$

where R_{so} is clear-day solar radiation, R_a = extraterrestrial solar radiation and CD = the calendar day. Eq. A-6 was based on observed high values of solar radiation from CIMIS data and calculated daily R_s values. The range in atmospheric transmissibility ranges from 0.69 in December-January to 0.75 in June-July. FAO uses a constant of 0.75 for R_{so}/R_a (Smith, 1991).

Penman (1963) Equation for Evaporation

The change in albedo is the main difference in Penman evaporation estimates, E_o. Penman suggested a minor change in the wind function for the following equation for evaporation based on Lake Hefner studies:

$$\lambda E_o = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma} 6.43 W_f (e_o - e_d) \tag{A-7}$$

where λET_o is the latent heat energy in MJ/(m^2 day), λ = the latent heat of vaporization at mean air temperature, Δ = the slope of the saturation vapor pressure-temperature curve at mean air temperature, γ = the psychrometric constant that is a function of the specific heat of moist air, atmospheric pressure and latent heat of vaporization, R_n = net radiation, G = soil heat

flux, $W_f = 0.5 + 0.536\ u_2$, where u_2 = mean daily wind speed in m/s, e_o = saturation vapor pressure of the water surface which was assumed to be at mean air temperature, and e_d = saturation vapor pressure at dewpoint temperature. G, which would be very small for monthly estimates, was assumed to be zero. Equation 7.13 in Manual 70 was used for Δ, 7.15 for γ, and a slight modification of Eq. 7.11 was used for e_o and e_d (Smith, 1991). E_o in depth units is obtained by dividing by the latent heat of vaporization per unit depth.

Penman-Monteith Equation

The Penman-Monteith equation is the same for both water surfaces and vegetated surfaces except the atmospheric resistance term, r_a, changes because of the surface roughness and canopy resistance, r_c, which was set at "0" for water. In addition, I based the vapor pressure deficit on the saturation pressure using average and dewpoint temperatures instead of using the mean of the deficit based on maximum and minimum temperatures.

$$\lambda E = \frac{\Delta}{\Delta + \gamma^*}(R_n - G) + \frac{\lambda}{\Delta + \gamma^*}\rho\frac{0.622\lambda}{P}86,400\frac{(e_o - e_d)}{r_a} \qquad \text{(A-8)}$$

where ρ = the density of moist air, kg/m^3, P = atmospheric pressure, kPa, $\gamma^* = \gamma(1 + r_c/r_a)$, r_c = canopy resistance, and r_a = aerodynamic resistance in s/m. The other variables are the same as in Penman's equation. Therefore, since the canopy resistance is "zero" for water, the radiation term is identical to that in the Penman equation (Penman, 1966).

The aerodynamic resistance is based on the heights of air temperature, humidity and wind speed measurements and surface roughness as follows (Allen et al., 1989):

$$r_a = \frac{\left[\ln\left(\frac{z_m - d}{z_{om}}\right)\right]\left[\left(\frac{z_h - d}{z_{oh}}\right)\right]}{k^2 u_z} \qquad \text{(A-9)}$$

where r_a has units of s/m, z_m is the height of wind measurement, z_h is the height of air temperature and humidity measurements, d is the zero displacement height above the surface, z_{om} is the roughness length parameter for momentum transfer (m), and z_{oh} is roughness length of the vegetation for vapor and heat transfer, k = the von Karman constant (0.41), and u_z is the mean wind speed in m/s at height z. Since a water surface does not have form drag effects as does a vegetated surface, the roughness length for heat and vapor transfer was set equal to that for surface roughness.

Wieringa (1992) recently updated roughness length values and reported a value of z_{om} = 0.0002 m (2×10^{-4} m) for sea with a free fetch of several km, but indicated that it was dependent on wind speed. Furthermore, he indicated that where a changes in surface roughness occur, we need to consider surface conditions for several km upwind.

Since our first interest is to estimate evaporation as compared to the USGS estimates, initial calculations were made using z_{om} = 0.0002 m. These estimates would be applicable to reservoir evaporation since prior studies have shown that there is little difference in evaporation with effective

diameter of the water surface greater than 12 feet (Hely et al., 1966, p. C18).
Since our interest is also evaporation from canals and rivers, or flowing water, the roughness length for open sea is not appropriate. The Penman-Monteith equation is very sensitive to changes in surface roughness from values of 0.0002 meter to 0.01 m. I used 0.015 for short grass for reference ET estimates. A value of 0.005 was suggested for fallow open country and 0.03 m for level land with low vegetation Wieringa (1992). As a compromise, I used a value of 0.001 m for estimates of evaporation from flowing water surfaces.

Priestley and Taylor Equation

Priestley and Taylor (1972) proposed a simplified version of the combination equation for large areas with wet surfaces using data from oceans and wet surfaces. The variables are the same as for the previous equations.

$$E = 1.26 \frac{\Delta}{\Delta + \gamma} R_n \qquad \text{(A-10)}$$

Equations Used

A printout of the equations as used in the spreadsheet is shown on page A-5.

ESTIMATED ALBEDO

Water Surfaces - IID

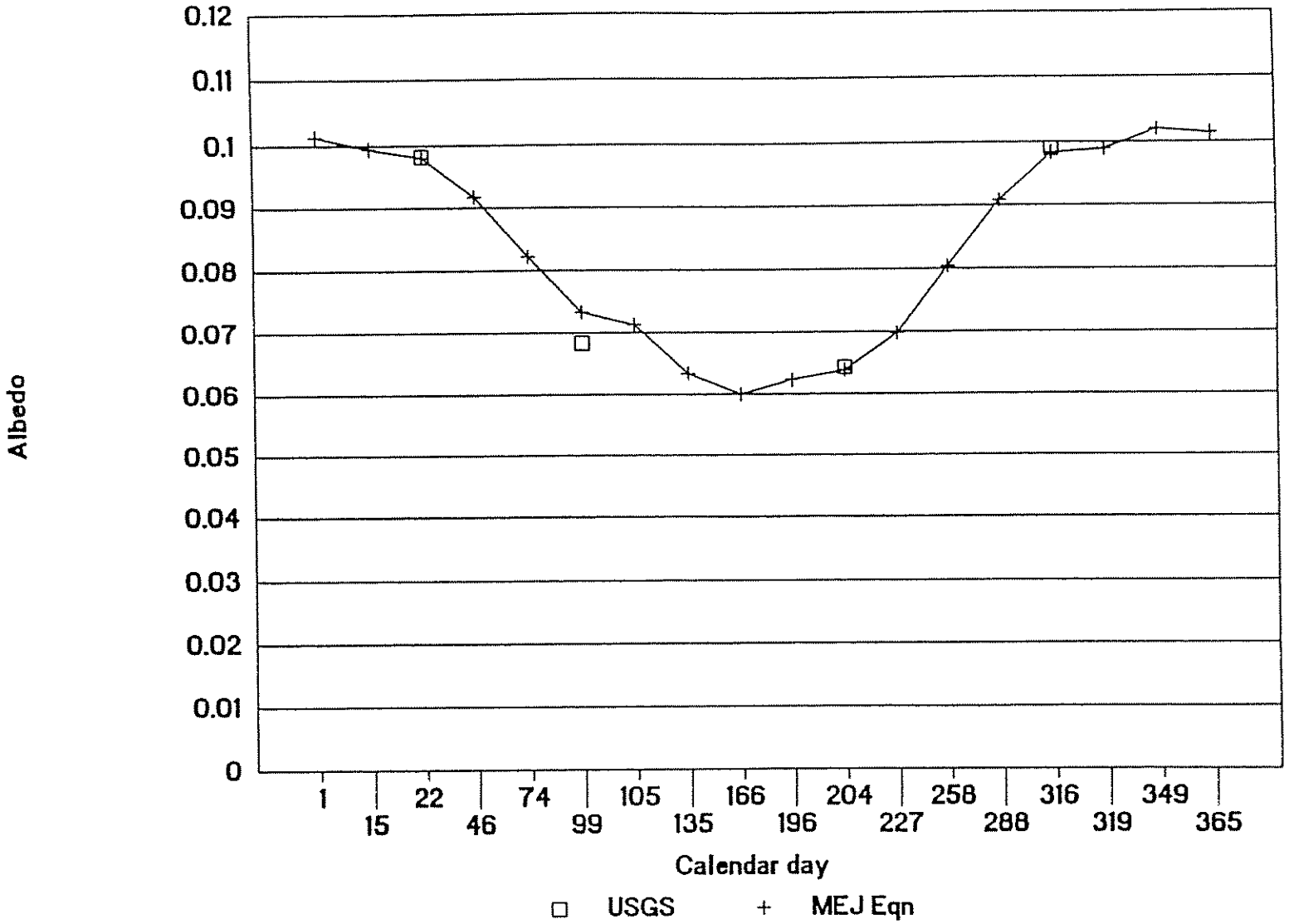

Fig. A-1

A-5

E, CIMIS-41

```
H8: [W7] 'Water:
 J: [W7] '  hc =
I8: [W7] 0
J8: [W7] 'm
H9: [W7] "zom =
I9: (S0) [W7] 0.0002
J9: [W7] 'm
K9: [W7] "zov =
L9: [W7] "zom =
M9: (S0) [W7] +I9
N9: [W7] 'm
P9: (F1) [W7] (@LN(($N$6-$I$10)/$I$9)*@LN(($K$6-$I$10)/$N$9))/(0.41^2)
H10: [W7] "d =
I10: (F4) [W7] 0
J10: [W7] 'm
K10: [W7] "LAI =
L10: [W7] 24*I8
O10: [W7] "ra =
P10: [W7] ' -----
H11: [W7] "rc =
I11: (F2) [W7] 0
J11: (F2) [W7] 's/m
P11: [W7] '   u2
H12: [W7] ' Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)]
O12: [W7] 'Based on maximum Rs values
A19: [W4] +A18+1
 19: [W10] 1987
C19: [W4] 1
D19: [W5] 15
E19: (F2) [W7] 19.55878057
F19: (F0) [W7] +E19/0.041868
G19: (F2) [W7] +E19*(0.725+0.025*@COS(2*@PI*D19/365-2.6))
H19: (F0) [W7] +G19/0.041868
I19: (F0) [W7] 296.6
J19: (F2) [W7] 0.041868*I19
K19: (F2) [W7] +I19/H19
L19: (F1) [W7] 69.322580645
M19: (F1) [W7] (+L19-32)/1.8
N19: (F1) [W7] 34.935483871
O19: (F1) [W7] (+N19-32)/1.8
P19: (F1) [W7] 32.387096774
Q19: (F1) [W7] (+P19-32)/1.8
R19: (F0) [W6] 107.935483871
S19: (F2) [W6] 0.447*(+R19/24)
A98: [W4] +A97+1
B98: [W10] 1987
C98: [W4] 1
D98: [W5] 15
E98: (F1) [W7] 0.5*(M19+O19)
F98: (F3) [W7] (0.611*@EXP(17.27*M19/(M19+237.3))+0.611*@EXP(17.27*O19/(O19+237.3)))/2
G98: (F3) [W7] 0.611*@EXP(17.27*Q19/(Q19+237.3))
H98: (F3) [W7] 4098*(0.611*@EXP(17.27*E98/(E98+237.3)))/(E98+237.3)^2
I98: (F2) [W7] 2.501-(2.361*10^-3)*E98
J98: (F3) [W7] (1.013*$K$5/(0.622*I98))*10^-3
```

```
J98: (F3) [W7] +H98/(H98+J98)
 98: (F3) [W7] 0.06+0.021*(1-@COS(2*@PI*D19/365-2.9))
M98: (F2) [W7] (1-L98)*J19
N98: (F1) [W7] 0.97*1.31*(4.903/10^9)*R98^4*(10*G98/R98)^(1/7)
O98: (F2) [W7] 0.97*4.903*(R98)^4/(10^9)
P98: (F2) [W7] (1.126*K19-0.07)*(O98-N98)
Q98: (F2) [W7] +M98-P98
R98: [W6] +E98+273.2
S98: [W6] +Q98/J19
A179: [W4] +A178+1
B179: [W10] 1987
C179: [W4] 1
D179: [W5] 15
E179: [W7] 31
F179: (F3) [W7] 0.611*@EXP(17.27*E98/(E98+237.3))
G179: (F2) [W7] +K98*Q98
H179: (F2) [W7] (1-K98)*6.43*(0.5+0.536*S19)*(F179-G98)
I179: (F2) [W7] +G179+H179
J179: (F2) [W7] +I179/198
K179: (F2) [W7] +E179*J179/25.4
L179: (F3) [W7] (1+($I$11/$P$9)*S19)*J98
M179: (F3) [W7] +H98/(H98+L179)
N179: (F2) [W7] +M179*Q98
O179: [W7] +J98/(H98+L179)
P179: (F2) [W7] +O179*((185370/$P$9)*I98/(E98+273.2))*S19*(F98-G98)*$P$176
Q179: (F2) [W7] +N179+P179
 179: (F2) [W6] +Q179/I98
 179: (F2) [W6] +E179*R179/25.4
T179: (F3) [W8] +N179
U179: (F2) [W10] +T179/$I98
V179: (F2) [W7] +$E179*U179/25.4
W179: (F3) [W7] 1.26*N179
X179: (F2) [W7] +W179/$I98
Y179: (F2) [W7] +$E179*X179/25.4
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APPENDIX B

1. Summary of Salton Sea evaporation values adjusted for salinity (From Hely et al., 1966).

2. Summary of evaporation from fresh water reservoirs in the IID.

3. Summary of evaporation from flowing fresh water canals and rivers in the IID.

4. Summary of estimated evaporation from fresh reservoir water for CIMIS sites 41, 68 and 87 in IID (3 pages).

5. Summary of estimated evaporation from flowing fresh water canals and rivers for CIMIS sites 41, 68, and 87 in IID (3 pages).

7. Copy of the spreadsheet results for CIMIS site 41 (6 pages).

SOURCE: Hydrologic Regimen of Salton Sea, California. USGS Professional Paper 486-C, 1966.

Table 7. - Monthly evaporation from Salton Sea, in inches, determined by three methods.

	1961				1962			
Month	Water budget	Energy budget	Mass transfer	Average evap.	Water budget	Energy budget	Mass transfer	Average evap.
Jan	1.70	1.28	1.77	1.58	2.23	1.73	2.59	2.18
Feb	3.07	2.63	3.14	2.95	2.70	2.24	2.55	2.50
Mar	4.35	4.73	5.26	4.78	3.84	3.96	4.10	3.97
Apr	6.18	6.98	6.69	6.62	5.14	6.77	6.11	6.01
May	8.47	9.60	9.34	9.14	9.00	9.67	8.86	9.18
Jun	6.93	9.09	7.85	7.96	6.73	8.50	7.22	7.48
Jul	8.17	9.18	7.55	8.30	8.81	10.07	8.12	9.00
Aug	9.36	10.09	8.61	9.35	8.83	10.02	9.29	9.38
Sep	9.08	9.55	8.78	9.14	8.10	7.56	7.56	7.74
Oct	7.36	6.74	7.15	7.08	6.77	6.16	7.42	6.78
Nov	4.45	3.62	3.82	3.96	4.94	3.21	4.67	4.27
Dec	2.32	1.53	2.22	2.02	2.93	1.07	2.64	2.21
Annual	71.4	75.0	72.2	72.9	70.0	71.0	71.1	70.7

AVERAGES:

Month	Water budget	Energy budget	Mass transfer	Average evap.	Average x 1.02	For transfer Average x 1.02
Jan	1.97	1.51	2.18	1.88	1.92	1.92
Feb	2.89	2.44	2.85	2.72	2.78	2.78
Mar	4.10	4.35	4.68	4.37	4.46	4.46
Apr	5.66	6.88	6.40	6.31	6.44	6.44
May	8.74	9.64	9.10	9.16	9.34	9.34
Jun	6.83	8.80	7.54	7.72	7.87	7.87
Jul	8.49	9.63	7.84	8.65	8.82	8.82
Aug	9.10	10.06	8.95	9.37	9.55	9.55
Sep	8.59	8.56	8.17	8.44	8.61	8.61
Oct	7.07	6.45	7.29	6.93	7.07	7.07
Nov	4.70	3.42	4.25	4.12	4.20	4.20
Dec	2.63	1.30	2.43	2.12	2.16	2.16
Annual	70.7	73.0	71.7	71.8	73.2	73.2

18-Oct-93 ESTIMATES OF EVAPORATION FROM FRESH WATER RESERVOIRS, IID - 1987-1992 \E-IVAL

Year	Station	CIMIS ETo	P-M E	Penman Eo x 0.9	Priestley-Taylor	Average
		Inches	Inches	Inches	Inches	Inches
1987	C41 Mulberry	82.8	79.1	77.2	68.1	76.8
	C68 Seeley					
	C87 Meloland					
	Average	82.8	79.1	77.2	68.1	76.8
1988	C41 Mulberry	77.7	77.5	75.1	67.0	74.3
	C68 Seeley	82.6	75.3	79.1	67.9	76.2
	C87 Meloland					
	Average	80.2	76.4	77.1	67.5	75.3
1989	C41 Mulberry	75.1	80.5	78.1	68.7	75.6
	C68 Seeley	84.5	76.0	80.7	65.8	76.8
	C87 Meloland					
	Average	79.8	78.3	79.4	67.3	76.2
1990	C41 Mulberry	72.1	72.9	71.0	63.5	69.9
	C68 Seeley	77.1	76.0	79.6	67.7	75.1
	C87 Meloland	72.6	74.2	77.3	68.9	73.3
	Average	73.9	74.4	76.0	66.7	72.7
1991	C41 Mulberry	67.8	73.7	71.4	67.6	70.1
	C68 Seeley	69.4	73.4	74.9	71.8	72.4
	C87 Meloland	63.9	71.4	72.1	72.5	70.0
	Average	67.0	72.8	72.8	70.6	70.8
1992	C41 Mulberry	65.8	71.4	69.4	67.7	68.6
	C68 Seeley	67.9	71.6	73.7	71.7	71.2
	C87 Meloland	66.9	71.8	73.5	72.0	71.1
	Average	66.9	71.6	72.2	70.5	70.3
All years	C41 Mulberry	73.6	75.9	73.7	67.1	72.5
	C68 Seeley	76.3	74.5	77.6	69.0	74.3
	C87 Meloland	67.8	72.5	74.3	71.1	71.4
	Average	72.6	74.3	75.2	69.1	72.8
Pct of USGSx1.02 avg:		99.1	101.4	102.7	94.4	99.4
For years 1990-1992:						
1990		73.9	74.4	76.0	66.7	74.8
1991		67.0	72.8	72.8	70.6	70.9
1992		66.9	71.6	72.2	70.5	70.2
Average		69.3	72.9	73.7	69.3	72.0
Pct of 1990-1992 avg:		96.3	101.4	102.4	96.3	100.0
Pct of USGSavg x 1.02:		94.6	99.6	100.6	94.6	98.3

USGS average (1961 and 1962) x 1.02 = 73.2

18-Oct-93 ESTIMATES OF EVAPORATION FROM FLOWING FRESH WATER, IID - 1987-1992 \EF-IVAL\E-

Year	Station	CIMIS ETo	P-M E	Penman Eo [redacted]	Priestley-Taylor	Average
		Inches	Inches	Inches	Inches	Inches
1987	C41 Mulberry	82.8	90.8	85.8	68.1	81.9
	C68 Seeley					
	C87 Meloland					
	Average	82.8	90.8	85.8	68.1	81.9
1988	C41 Mulberry	77.7	88.9	83.4	67.0	79.3
	C68 Seeley	82.6	85.3	87.9	67.9	80.9
	C87 Meloland					
	Average	80.2	87.1	85.7	67.5	80.1
1989	C41 Mulberry	75.1	92.7	86.8	68.7	80.8
	C68 Seeley	84.5	87.2	89.7	65.8	81.8
	C87 Meloland					
	Average	79.8	90.0	88.3	67.3	81.3
1990	C41 Mulberry	72.1	83.4	78.9	63.5	74.5
	C68 Seeley	77.1	86.5	88.4	67.7	79.9
	C87 Meloland	72.6	83.4	85.9	68.9	77.7
	Average	73.9	84.4	84.4	66.7	77.4
1991	C41 Mulberry	67.8	83.0	79.3	67.6	74.4
	C68 Seeley	69.4	81.1	83.2	71.8	76.4
	C87 Meloland	63.9	77.9	80.1	72.5	73.6
	Average	67.0	80.7	80.9	70.6	74.8
1992	C41 Mulberry	65.8	79.6	77.1	67.7	72.6
	C68 Seeley	67.9	78.5	81.9	71.7	75.0
	C87 Meloland	66.9	78.6	81.7	72.0	74.8
	Average	66.9	78.9	80.2	70.5	74.1
All years	C41 Mulberry	73.6	86.4	81.9	67.1	77.2
	C68 Seeley	76.3	83.7	86.2	69.0	78.8
	C87 Meloland	67.8	80.0	82.6	71.1	75.4
	Average	72.6	83.4	83.6	69.1	77.1
Pct of USGSx1.02 avg:		99.1	113.9	114.1	94.4	105.4
For years 1990-1992:						
1990		73.9	84.4	84.4	66.7	80.9
1991		67.0	80.7	80.9	70.6	76.2
1992		66.9	78.9	80.2	70.5	75.3
Average		69.3	81.3	81.8	69.3	77.5
Pct of 1990-1992 avg:		89.4	105.0	105.6	89.4	100.0
Pct of USGSavg x 1.02:		94.6	111.1	111.8	94.6	105.8

USGS average (1961 and 1962) x 1.02 = 73.2

SUMMARY OF EVAPORATION ESTIMATES:

Year	CIMIS-41, Mulberry Styles CIMIS, ETo		Penman Eo: Rad term Inches	Aero Inches	Eo Inches	Pct	Priestley-Taylor: Inches	Pct	Penman-Monteith: zo= 2E-04 Rad term Inches	Aero Inches	E Inches	Pct
1987	82.8	112.6%	53.0	31.1	85.8	104.8%	68.1	101.5%	53.0	24.6	79.1	104.3%
1988	77.7	105.6%	52.1	29.7	83.4	101.8%	67.0	99.8%	52.1	23.9	77.5	102.2%
1989	75.1	102.1%	53.5	31.6	86.8	106.0%	68.7	102.4%	53.5	25.5	80.5	106.2%
1990	72.1	98.0%	49.4	28.0	78.9	96.4%	63.5	94.6%	49.4	22.1	72.9	96.1%
1991	67.8	92.2%	52.6	25.2	79.3	96.8%	67.6	100.7%	52.6	19.7	73.7	97.1%
1992	65.8	89.5%	52.6	22.9	77.1	94.2%	67.7	100.9%	52.6	17.3	71.4	94.1%
Average	73.6	100.0%	52.2	28.1	81.9	100.0%	67.1	100.0%	52.2	22.2	75.8	100.0%
			65.0%	35.0%		73.7 Lake E		1.02USGS:	70.2%	29.8%	75.8 Lake E	

Month	CIMIS Eto	CM/USGS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	PxO.9/USGS	In/mo	P-M: In/mo	PM/GS
Jan	2.62	1.36	2.74	1.42	2.48	1.16	1.92	2.26	1.18
Feb	3.49	1.26	3.58	1.29	3.59	1.16	2.78	3.41	1.23
Mar	5.35	1.20	5.40	1.21	5.63	1.13	4.46	5.39	1.21
Apr	7.04	1.09	6.98	1.08	7.53	1.05	6.44	7.17	1.11
May	9.00	0.96	9.28	0.99	10.26	0.99	9.34	9.70	1.04
Jun	9.43	1.20	9.46	1.20	10.79	1.23	7.87	10.03	1.27
Jul	9.50	1.08	10.14	1.15	11.73	1.20	8.82	10.82	1.23
Aug	8.84	0.92	9.44	0.99	10.51	0.99	9.55	9.63	1.01
Sep	7.32	0.85	7.74	0.90	8.01	0.84	8.61	7.24	0.84
Oct	5.11	0.72	5.87	0.83	5.88	0.75	7.07	5.31	0.75
Nov	3.46	0.82	3.61	0.86	3.30	0.71	4.20	2.93	0.70
Dec	2.34	1.08	2.42	1.12	2.15	0.90	2.16	1.94	0.90
Total	73.5	1.00	76.7	1.05	81.9	1.01	73.2	75.8	1.04

SUMMARY OF EVAPORATION ESTIMATES:

Year	CIMIS-68, Seeley Styles CIMIS, ETo		Penman: Aero term Rad term Aero Inches Inches		Eo Inches	Pct	Priestley-Taylor: Inches	Pct	Penman-Monteith:zo= 2E-04 Rad term Aero Inches Inches		E Inches	Pct
1987												
1988	82.6	108.3%	52.7	33.4	87.9	102.0%	67.9	98.5%	52.7	21.0	75.3	101.1%
1989	84.5	110.7%	51.2	36.8	89.7	104.0%	65.8	95.4%	51.2	23.4	76.0	102.1%
1990	77.1	101.0%	52.7	34.0	88.4	102.5%	67.7	98.2%	52.7	21.9	76.0	102.1%
1991	69.4	91.0%	55.9	25.7	83.2	96.5%	71.8	104.1%	55.9	16.2	73.4	98.6%
1992	67.9	89.0%	55.7	24.5	81.9	95.0%	71.7	103.9%	55.7	14.4	71.6	96.2%
Average	76.3	100.0%	53.6	30.9	86.2	100.0%	69.0	100.0%	53.6	19.4	74.5	100.0%
	69.0 Inches		63.5%	36.5%	77.6 Lake E			1.02USG 73.5%	26.5%		74.5 Lake E	

Month	CIMIS Eto	CM/USGS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	PxO.9/USGS	In/mo	P-M: In/mo	PM/GS
Jan	2.73	1.42	2.90	1.51	2.61	1.22	1.92	2.06	1.07
Feb	3.77	1.36	3.97	1.43	3.88	1.26	2.78	3.28	1.18
Mar	6.06	1.36	6.28	1.41	6.40	1.29	4.46	5.59	1.25
Apr	7.79	1.21	8.04	1.25	8.57	1.20	6.44	7.61	1.18
May	9.97	1.07	10.43	1.12	11.36	1.09	9.34	10.04	1.07
Jun	10.17	1.29	10.35	1.31	11.76	1.34	7.87	10.34	1.31
Jul	9.36	1.06	9.93	1.13	11.57	1.18	8.82	10.26	1.16
Aug	8.34	0.87	9.39	0.98	10.48	0.99	9.55	9.27	0.97
Sep	7.00	0.81	7.85	0.91	8.15	0.85	8.61	7.00	0.81
Oct	5.26	0.74	6.02	0.85	5.86	0.75	7.07	4.83	0.68
Nov	3.58	0.85	3.88	0.92	3.42	0.73	4.20	2.64	0.63
Dec	2.30	1.06	2.70	1.25	2.15	0.90	2.16	1.55	0.72
Total	76.3	1.04	81.7	1.12	86.2	1.06	73.2	74.5	1.02

252	SUMMARY OF EVAPORATION ESTIMATES:			Penman:				Priestley-Taylor:		Penman-Monteith: zo= 2E-04			
53		CIMIS-87, Meloland		Rad term	Aero	Eo				Rad term	Aero	E	
254	Year	Styles CIMIS		Inches	Inches	Inches	Pct	Inches	Pct	Inches	Inches	Inches	Pct
255	---	---		---		---		---		---		---	
256	1987												
257	1988												
258	1989												
259	1990	72.6	107.1%	53.6	30.6	85.9	104.0%	68.9	96.9%	53.6	19.2	74.2	102.4%
260	1991	63.9	94.2%	56.4	22.2	80.1	97.1%	72.5	101.9%	56.4	13.7	71.4	98.6%
261	1992	66.9	98.7%	55.9	24.0	81.7	98.9%	72.0	101.2%	55.9	14.3	71.8	99.0%
262		---		---				---		---			
263	Average	67.8	100.0%	55.3	25.6	82.5	100.0%	71.1	100.0%	55.3	15.7	72.5	100.0%
264				68.4%	31.6%	74.3	Lake E		1.02USGS	77.9%	22.1%	72.5	Lake E
265	Month	CIMIS ETo	CM/GS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	Px0.9/USGS		In/mo		P-M: In/mo		PM/GS
266	Jan	2.37	1.23	2.90	1.51	2.48	1.16		1.92			2.02	1.05
267	Feb	3.24	1.17	3.97	1.43	3.60	1.17		2.78			3.09	1.11
268	Mar	5.06	1.13	6.28	1.41	5.70	1.15		4.46			5.08	1.14
269	Apr	7.02	1.09	8.04	1.25	8.00	1.12		6.44			7.15	1.11
270	May	8.63	0.92	10.43	1.12	10.36	1.00		9.34			9.30	1.00
271	Jun	8.63	1.10	10.35	1.31	10.79	1.23		7.87			9.59	1.22
272	Jul	8.78	1.00	9.93	1.13	11.54	1.18		8.82			10.27	1.16
273	Aug	8.04	0.84	9.39	0.98	10.55	0.99		9.55			9.37	0.98
274	Sep	6.37	0.74	7.85	0.91	8.26	0.86		8.61			7.23	0.84
275	Oct	4.75	0.67	6.02	0.85	5.93	0.75		7.07			5.06	0.72
276	Nov	2.99	0.71	3.88	0.92	3.31	0.71		4.20			2.73	0.65
277	Dec	1.94	0.90	2.70	1.25	2.03	0.85		2.16			1.59	0.74
278	Total	67.8	0.93	81.7	1.12	82.5	1.01		73.2			72.5	0.99

SUMMARY OF EVAPORATION ESTIMATES: Penman Eo: FLOWING WATER Priestley-Taylor: Penman-Monteith: zo= 1E-03

Year	CIMIS-41, Mulberry Styles CIMIS, ETo		Penman Eo: Rad term Inches	Aero Inches	FLOWING WATER Eo Inches	Pct	Priestley-Taylor: Inches	Pct	Penman-Monteith: Rad term Inches	Aero Inches	E Inches	Pct
1987	82.8	112.6%	53.0	31.1	85.8	104.8%	68.1	101.5%	53.0	36.1	90.8	105.0%
1988	77.7	105.6%	52.1	29.7	83.4	101.8%	67.0	99.8%	52.1	35.1	88.9	102.9%
1989	75.1	102.1%	53.5	31.6	86.8	106.0%	68.7	102.4%	53.5	37.4	92.7	107.2%
1990	72.1	98.0%	49.4	28.0	78.9	96.4%	63.5	94.6%	49.4	32.5	83.4	96.6%
1991	67.8	92.2%	52.6	25.2	79.3	96.8%	67.6	100.7%	52.6	28.9	83.0	96.1%
1992	65.8	89.5%	52.6	22.9	77.1	94.2%	67.7	100.9%	52.6	25.4	79.6	92.2%
Average	73.6	100.0%	52.2	28.1	81.9	100.0%	67.1	100.0%	52.2	32.6	86.4	100.0%
			65.0%	35.0%	81.9 Canal/river			1.02USGS:	61.6%	38.4%	86.4 Canal	

Month	CIMIS Eto	CM/USGS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	PEo/USGS	In/mo	P-M: In/mo	PM/GS
Jan	2.62	1.36	2.74	1.42	2.48	1.29	1.92	2.78	1.45
Feb	3.49	1.26	3.58	1.29	3.59	1.29	2.78	3.99	1.44
Mar	5.35	1.20	5.40	1.21	5.63	1.26	4.46	6.15	1.38
Apr	7.04	1.09	6.98	1.08	7.53	1.17	6.44	8.02	1.24
May	9.00	0.96	9.28	0.99	10.26	1.10	9.34	11.02	1.18
Jun	9.43	1.20	9.46	1.20	10.79	1.37	7.87	11.31	1.44
Jul	9.50	1.08	10.14	1.15	11.73	1.33	8.82	12.07	1.37
Aug	8.84	0.92	9.44	0.99	10.51	1.10	9.55	10.71	1.12
Sep	7.32	0.85	7.74	0.90	8.01	0.93	8.61	8.24	0.96
Oct	5.11	0.72	5.87	0.83	5.88	0.83	7.07	6.11	0.86
Nov	3.46	0.82	3.61	0.86	3.30	0.79	4.20	3.60	0.86
Dec	2.34	1.08	2.42	1.12	2.15	1.00	2.16	2.41	1.12
Total	73.5	1.00	76.7	1.05	81.9	1.12	73.2	86.4	1.18

252 SUMMARY OF EVAPORATION ESTIMATES:			Penman:		FLOWING WATER		Priestley-Taylor:		Penman-Monteith:zo= 1E-03			
33		CIMIS-68, Seeley	Rad term	Aero	Eo				Rad term	Aero	E	
254 Year	Styles	CIMIS, ETo	Inches	Inches	Inches	Pct	Inches	Pct	Inches	Inches	Inches	Pct
255 -------		-------	-------		----------		----------		-------		----------	
256 1987												
257 1988		82.6	108.3%	52.7	33.4	87.9	102.0%	67.9	98.5%	52.7	30.8	85.3	101.9%
258 1989		84.5	110.7%	51.2	36.8	89.7	104.0%	65.8	95.4%	51.2	34.4	87.2	104.2%
259 1990		77.1	101.0%	52.7	34.0	88.4	102.5%	67.7	98.2%	52.7	32.2	86.5	103.3%
260 1991		69.4	91.0%	55.9	25.7	83.2	96.5%	71.8	104.1%	55.9	23.7	81.1	96.9%
261 1992		67.9	89.0%	55.7	24.5	81.9	95.0%	71.7	103.9%	55.7	21.2	78.5	93.8%
262		----------		----------				----------		----------			
263 Average		76.3	100.0%	53.6	30.9	86.2	100.0%	69.0	100.0%	53.6	28.5	83.7	100.0%
264		69.0 Inches		63.5%	36.5%	86.2 Canal/River			1.02USG	65.3%	34.7%	83.7 Canal	
265 Month		CIMIS Eto	CM/USGS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	PEo/USGS		In/mo		P-M: In/mo	PM/GS
266 Jan		2.73	1.42	2.90	1.51	2.61	1.36		1.92		2.45	1.28
267 Feb		3.77	1.36	3.97	1.43	3.88	1.40		2.78		3.77	1.36
268 Mar		6.06	1.36	6.28	1.41	6.40	1.43		4.46		6.36	1.43
269 Apr		7.79	1.21	8.04	1.25	8.57	1.33		6.44		8.50	1.32
270 May		9.97	1.07	10.43	1.12	11.36	1.22		9.34		11.40	1.22
271 Jun		10.17	1.29	10.35	1.31	11.76	1.49		7.87		11.59	1.47
272 Jul		9.36	1.06	9.93	1.13	11.57	1.31		8.82		11.20	1.27
273 Aug		8.34	0.87	9.39	0.98	10.48	1.10		9.55		10.11	1.06
274 Sep		7.00	0.81	7.85	0.91	8.15	0.95		8.61		7.73	0.90
275 Oct		5.26	0.74	6.02	0.85	5.86	0.83		7.07		5.46	0.77
276 Nov		3.58	0.85	3.88	0.92	3.42	0.81		4.20		3.19	0.76
277 Dec		2.30	1.06	2.70	1.25	2.15	1.00		2.16		1.94	0.90
78 Total		76.3	1.04	81.7	1.12	86.2	1.18		73.2		83.7	1.14

B-9

252 SUMMARY OF EVAPORATION ESTIMATES:			Penman:		FLOWING WATER		Priestley-Taylor:		Penman-Monteith:zo= 1E-03			
3	CIMIS-87, Meloland		Rad term	Aero	Eo				Rad term	Aero	E	
254 Year	Styles CIMIS		Inches	Inches	Inches	Pct	Inches	Pct	Inches	Inches	Inches	Pct
255 -------	-------		-------		-------		-------		-------		-------	
256 1987												
257 1988												
258 1989												
259 1990	72.6	107.1%	53.6	30.6	85.9	104.0%	68.9	96.9%	53.6	28.2	83.4	104.3%
260 1991	63.9	94.2%	56.4	22.2	80.1	97.1%	72.5	101.9%	56.4	20.1	77.9	97.5%
261 1992	66.9	98.7%	55.9	24.0	81.7	98.9%	72.0	101.2%	55.9	21.0	78.6	98.3%
262	-------		-------				-------		-------			
263 Average	67.8	100.0%	55.3	25.6	82.5	100.0%	71.1	100.0%	55.3	23.1	80.0	100.0%
264			68.4%	31.6%	82.5	Canal/River		1.02USGS	70.5%	29.5%	80.0	Canal
265 Month	CIMIS ETo	CM/GS	P-ETo: In/mo	PETo/GS	Pen Eo: In/mo	PEo/USGS		In/mo		P-M:In/mo		PM/GS
266 Jan	2.37	1.23	2.90	1.51	2.48	1.29		1.92			2.33	1.21
267 Feb	3.24	1.17	3.97	1.43	3.60	1.30		2.78			3.47	1.25
268 Mar	5.06	1.13	6.28	1.41	5.70	1.28		4.46			5.64	1.26
269 Apr	7.02	1.09	8.04	1.25	8.00	1.24		6.44			7.82	1.21
270 May	8.63	0.92	10.43	1.12	10.36	1.11		9.34			10.28	1.10
271 Jun	8.63	1.10	10.35	1.31	10.79	1.37		7.87			10.51	1.33
272 Jul	8.78	1.00	9.93	1.13	11.54	1.31		8.82			11.20	1.27
273 Aug	8.04	0.84	9.39	0.98	10.55	1.10		9.55			10.17	1.06
274 Sep	6.37	0.74	7.85	0.91	8.26	0.96		8.61			7.88	0.92
275 Oct	4.75	0.67	6.02	0.85	5.93	0.84		7.07			5.63	0.80
276 Nov	2.99	0.71	3.88	0.92	3.31	0.79		4.20			3.16	0.75
277 Dec	1.94	0.90	2.70	1.25	2.03	0.94		2.16			1.90	0.88
78 Total	67.8	0.93	81.7	1.12	82.5	1.13		73.2			80.0	1.09

18-Oct-93 ESTIMATED EVAPORATION - IID \EV-CM41

Column = C D E F G H I J K L M N O P Q R S

SITE INPUT DATA: Lat, degrees = 33.00 or 0.5759 Radians

Elevation, m = -50 m Atm. pressure 101.90 kPa Energy units = MJ/(m^2 day) = MJ*

Measurement height: Temp & dewpoint 2.00 m Wind 2.00 m

Surface: Water

Instrument site: Water: hc = 0 m

hc, m = 0.12 zom = 2E-04 m zov = zom = 2E-04 m 504.6

zom, m = 0.0148 d = 0.0000 m LAI = 0 ra = -----

d, m = 0.0800 rc = 0.00 s/m u2

Clear day solar radiation = Ra x [0.725 + 0.025 cos(2 Pi CD/365 - 2.6)] Based on maximum Rs values

INPUT DATA: SITE:CIMIS Station 41, Mulberry

Year	Mo	CD	Ra MJ*	Ra ly/day	Rso MJ*	Rso ly/day	Rs ly/day	Rs MJ*	n/N	Maximum temp deg F	Maximum temp deg C	Minimum temp deg F	Minimum temp deg C	Dewpoint temp deg F	Dewpoint temp deg C	Wind run mi/day	Wind run m/s
1987	1	15	19.56	467	13.84	331	297	12.42	0.90	69.3	20.7	34.9	1.6	32.4	0.2	108	2.01
1987	2	46	24.41	583	17.55	419	378	15.83	0.90	73.5	23.0	41.4	5.2	36.6	2.5	138	2.56
1987	3	74	30.65	732	22.41	535	508	21.28	0.95	77.5	25.3	43.0	6.1	38.1	3.4	145	2.71
1987	4	105	36.31	867	26.97	644	627	26.25	0.97	91.4	33.0	52.3	11.3	41.7	5.4	124	2.31
1987	5	135	39.96	954	29.93	715	671	28.09	0.94	93.6	34.2	58.6	14.8	42.8	6.0	154	2.86
1987	6	166	41.36	988	30.98	740	713	29.86	0.96	105.3	40.7	66.2	19.0	40.1	4.5	136	2.54
1987	7	196	40.60	970	30.16	720	701	29.35	0.97	105.4	40.8	69.8	21.0	51.3	10.7	140	2.60
1987	8	227	37.69	900	27.57	658	603	25.26	0.92	104.9	40.5	74.2	23.4	61.3	16.3	154	2.87
1987	9	258	32.84	784	23.59	563	517	21.63	0.92	100.6	38.1	62.7	17.0	50.2	10.1	124	2.31
1987	10	288	26.70	638	18.89	451	360	15.09	0.80	94.0	34.5	60.6	15.9	59.2	15.1	99	1.84
1987	11	319	21.02	502	14.73	352	313	13.09	0.89	77.2	25.1	44.9	7.1	47.9	8.8	82	1.54
1987	12	349	18.14	433	12.72	304	243	10.16	0.80	65.0	18.4	35.6	2.0	37.9	3.3	103	1.91
1988	1	15	19.56	467	13.84	331	293	12.27	0.89	69.3	20.7	35.5	1.9	37.1	2.8	106	1.98
1988	2	46	24.41	583	17.55	419	393	16.47	0.94	76.7	24.8	40.2	4.6	41.3	5.2	108	2.02
1988	3	74	30.65	732	22.41	535	461	19.30	0.86	82.3	28.0	43.3	6.3	38.7	3.7	125	2.33
1988	4	105	36.31	867	26.97	644	544	22.78	0.84	84.7	29.3	48.2	9.0	47.2	8.5	126	2.35
1988	5	135	39.96	954	29.93	715	573	24.01	0.80	93.1	34.0	54.5	12.5	42.6	5.9	186	3.46
1988	6	166	41.36	988	30.98	740	701	29.35	0.95	101.5	38.6	62.7	17.1	49.8	9.9	136	2.54
1988	7	196	40.60	970	30.16	720	661	27.65	0.92	106.5	41.4	73.9	23.3	64.2	17.9	149	2.77
1988	8	227	37.69	900	27.57	658	624	26.14	0.95	105.1	40.6	73.2	22.9	62.9	17.2	124	2.31
1988	9	258	32.84	784	23.59	563	431	18.03	0.76	102.5	39.2	66.2	19.0	52.0	11.1	119	2.21
1988	10	288	26.70	638	18.89	451	421	17.61	0.93	96.0	35.6	61.2	16.2	55.7	13.2	102	1.90
1988	11	319	21.02	502	14.73	352	310	12.98	0.88	78.5	25.8	44.3	6.8	40.5	4.7	114	2.12
1988	12	349	18.14	433	12.72	304	291	12.18	0.96	70.3	21.3	34.9	1.6	31.8	-0.1	111	2.06
1989	1	15	19.56	467	13.84	331	285	11.93	0.86	69.1	20.6	34.8	1.5	32.7	0.4	101	1.89
1989	2	46	24.41	583	17.55	419	395	16.52	0.94	75.0	23.9	39.2	4.0	40.2	4.6	123	2.28
1989	3	74	30.65	732	22.41	535	429	17.98	0.80	88.3	31.3	47.6	8.7	47.7	8.7	113	2.10
1989	4	105	36.31	867	26.97	644	633	26.50	0.98	92.4	33.6	53.1	11.7	48.6	9.2	120	2.24
1989	5	135	39.96	954	29.93	715	693	29.00	0.97	95.3	35.2	57.0	13.9	41.4	5.2	161	3.00
1989	6	166	41.36	988	30.98	740	713	29.84	0.96	104.8	40.5	62.8	17.1	41.8	5.4	146	2.72
1989	7	196	40.60	970	30.16	720	656	27.48	0.91	108.5	42.5	71.5	21.9	53.2	11.8	141	2.63
1989	8	227	37.69	900	27.57	658	624	26.14	0.95	104.4	40.2	70.4	21.3	61.5	16.4	129	2.40
1989	9	258	32.84	784	23.59	563	543	22.72	0.96	102.7	39.3	65.3	18.5	50.3	10.1	128	2.37
1989	10	288	26.70	638	18.89	451	420	17.60	0.93	91.3	32.9	54.8	12.7	44.5	6.9	113	2.11
1989	11	319	21.02	502	14.73	352	334	13.96	0.95	81.1	27.3	43.0	6.1	40.4	4.6	103	1.93
1989	12	349	18.14	433	12.72	304	274	11.47	0.90	71.9	22.2	32.8	0.5	34.9	1.6	90	1.69

55	1990	1	15	19.56	467	13.84	331	244	10.20	0.74	72.3	22.4	34.8	1.5	37.1	2.8	103	1.91
56	1990	2	46	24.41	583	17.55	419	362	15.16	0.86	73.0	22.8	36.1	2.3	36.6	2.6	123	2.29
57	1990	3	74	30.65	732	22.41	535	490	20.52	0.92	81.3	27.4	44.8	7.1	43.8	6.5	132	2.46
58	1990	4	105	36.31	867	26.97	644	490	20.50	0.76	86.6	30.3	52.5	11.4	50.6	10.3	125	2.32
59	1990	5	135	39.96	954	29.93	715	660	27.63	0.92	92.2	33.4	55.4	13.0	41.9	5.5	162	3.03
60	1990	6	166	41.36	988	30.98	740	672	28.14	0.91	103.5	39.7	64.3	17.9	48.9	9.4	121	2.26
61	1990	7	196	40.60	970	30.16	720	579	24.24	0.80	105.5	40.8	74.1	23.4	61.3	16.3	144	2.68
62	1990	8	227	37.69	900	27.57	658	425	17.77	0.64	101.1	38.4	72.2	22.3	63.2	17.3	117	2.17
63	1990	9	258	32.84	784	23.59	563	538	22.52	0.95	99.7	37.6	68.7	20.4	62.5	17.0	112	2.09
64	1990	10	288	26.70	638	18.89	451	439	18.39	0.97	91.1	32.8	55.5	13.0	49.7	9.8	94	1.74
65	1990	11	319	21.02	502	14.73	352	246	10.29	0.70	77.0	25.0	44.8	7.1	36.9	2.7	114	2.12
66	1990	12	349	18.14	433	12.72	304	262	10.97	0.86	66.6	19.2	34.2	1.2	28.2	-2.1	107	2.00
67	1991	1	15	19.56	467	13.84	331	209	8.77	0.63	67.6	19.8	38.4	3.5	35.2	1.8	90	1.68
68	1991	2	46	24.41	583	17.55	419	356	14.91	0.85	78.4	25.8	42.9	6.0	46.2	7.9	101	1.88
69	1991	3	74	30.65	732	22.41	535	450	18.83	0.84	71.7	22.0	43.4	6.3	43.1	6.2	145	2.70
70	1991	4	105	36.31	867	26.97	644	599	25.07	0.93	83.3	28.5	48.0	8.9	46.9	8.3	140	2.61
71	1991	5	135	39.96	954	29.93	715	699	29.24	0.98	89.2	31.8	53.3	11.8	50.7	10.4	145	2.71
72	1991	6	166	41.36	988	30.98	740	574	24.02	0.78	96.3	35.7	62.2	16.8	55.4	13.0	132	2.46
73	1991	7	196	40.60	970	30.16	720	655	27.41	0.91	102.3	39.1	69.7	20.9	62.9	17.2	122	2.27
74	1991	8	227	37.69	900	27.57	658	611	25.59	0.93	104.2	40.1	73.4	23.0	62.3	16.8	122	2.27
75	1991	9	258	32.84	784	23.59	563	495	20.70	0.88	99.7	37.6	70.4	21.4	63.8	17.7	113	2.11
76	1991	10	288	26.70	638	18.89	451	400	16.73	0.89	93.5	34.2	60.3	15.7	53.9	12.2	121	2.25
77	1991	11	319	21.02	502	14.73	352	255	10.66	0.72	77.6	25.3	46.0	7.8	31.8	-0.1	121	2.25
78	1991	12	349	18.14	433	12.72	304	222	9.31	0.73	66.5	19.2	41.6	5.3	41.6	5.3	87	1.61
79	1992	1	15	19.56	467	13.84	331	272	11.38	0.82	68.6	20.3	37.5	3.1	37.8	3.2	91	1.70
80	1992	2	46	24.41	583	17.55	419	339	14.20	0.81	74.0	23.4	45.7	7.6	47.0	8.4	106	1.97
81	1992	3	74	30.65	732	22.41	535	426	17.83	0.80	75.1	23.9	46.8	8.2	51.1	10.6	98	1.82
82	1992	4	105	36.31	867	26.97	644	493	20.64	0.77	89.2	31.8	53.6	12.0	52.7	11.5	92	1.71
83	1992	5	135	39.96	954	29.93	715	636	26.61	0.89	93.6	34.2	61.2	16.2	58.0	14.5	110	2.04
84	1992	6	166	41.36	988	30.98	740	627	26.24	0.85	99.9	37.7	64.0	17.8	58.6	14.8	127	2.37
85	1992	7	196	40.60	970	30.16	720	633	26.49	0.88	103.8	39.9	73.8	23.2	65.0	18.4	135	2.51
86	1992	8	227	37.69	900	27.57	658	584	24.46	0.89	105.1	40.6	78.1	25.6	69.7	20.9	145	2.70
87	1992	9	258	32.84	784	23.59	563	389	16.30	0.69	104.0	40.0	71.0	21.7	61.4	16.3	108	2.01
88	1992	10	288	26.70	638	18.89	451	389	16.27	0.86	92.0	33.3	60.5	15.8	54.8	12.7	106	1.98
89	1992	11	319	21.02	502	14.73	352	308	12.87	0.87	75.2	24.0	41.7	5.4	36.7	2.6	106	1.97
90	1992	12	349	18.14	433	12.72	304	235	9.83	0.77	62.9	17.2	36.0	2.2	39.5	4.1	97	1.80

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147	1991	2	46	15.9	2.128	1.064	0.116	2.46	0.067	0.632	0.092	13.54	27.2	33.22	5.38	8.16	289.1	0.547
48	1991	3	74	14.2	1.804	0.947	0.105	2.47	0.067	0.609	0.082	17.28	26.1	32.44	5.55	11.73	287.3	0.622
149	1991	4	105	18.7	2.514	1.093	0.135	2.46	0.068	0.666	0.071	23.29	28.3	34.52	6.09	17.20	291.8	0.685
150	1991	5	135	21.8	3.042	1.260	0.159	2.45	0.068	0.702	0.063	27.39	30.1	36.02	6.13	21.26	295.0	0.727
151	1991	6	166	26.2	3.881	1.500	0.201	2.44	0.068	0.747	0.060	22.58	32.7	38.24	4.48	18.10	299.4	0.753
152	1991	7	196	30.0	4.748	1.957	0.243	2.43	0.068	0.781	0.062	25.70	35.6	40.19	4.38	21.32	303.2	0.777
153	1991	8	227	31.5	5.111	1.917	0.263	2.43	0.068	0.793	0.070	23.80	36.2	41.02	4.70	19.10	304.7	0.746
154	1991	9	258	29.5	4.512	2.022	0.237	2.43	0.068	0.776	0.080	19.04	35.5	39.91	4.03	15.01	302.6	0.724
155	1991	10	288	24.9	3.581	1.420	0.188	2.44	0.068	0.735	0.091	15.21	31.9	37.58	5.30	9.92	298.1	0.592
156	1991	11	319	16.6	2.146	0.606	0.120	2.46	0.067	0.640	0.099	9.61	25.3	33.53	6.15	3.46	289.7	0.324
157	1991	12	349	12.2	1.556	0.894	0.094	2.47	0.067	0.583	0.102	8.36	25.2	31.57	4.80	3.57	285.4	0.382
158	1992	1	15	11.7	1.575	0.770	0.091	2.47	0.067	0.575	0.099	10.25	24.5	31.33	5.85	4.41	284.9	0.387
159	1992	2	46	15.5	1.958	1.099	0.113	2.46	0.067	0.626	0.092	12.89	27.1	33.03	4.96	7.93	288.6	0.558
160	1992	3	74	16.1	2.031	1.280	0.117	2.46	0.067	0.634	0.082	16.36	27.9	33.30	4.42	11.94	289.2	0.669
161	1992	4	105	21.9	3.046	1.358	0.160	2.45	0.068	0.703	0.071	19.17	30.4	36.05	4.46	14.71	295.0	0.712
162	1992	5	135	25.2	3.618	1.648	0.191	2.44	0.068	0.738	0.063	24.92	32.7	37.72	4.70	20.22	298.4	0.759
163	1992	6	166	27.7	4.279	1.680	0.217	2.44	0.068	0.761	0.060	24.66	33.8	39.01	4.57	20.09	300.9	0.765
164	1992	7	196	31.6	5.090	2.111	0.263	2.43	0.068	0.794	0.062	24.84	36.7	41.03	3.97	20.86	304.7	0.787
165	1992	8	227	33.1	5.459	2.480	0.284	2.42	0.068	0.806	0.070	22.75	38.3	41.88	3.32	19.44	306.3	0.794
166	1992	9	258	30.8	4.980	1.857	0.254	2.43	0.068	0.788	0.080	14.99	35.7	40.63	3.49	11.50	304.0	0.705
167	1992	10	288	24.6	3.460	1.466	0.185	2.44	0.068	0.731	0.091	14.79	31.9	37.39	4.98	9.81	297.7	0.603
168	1992	11	319	14.7	1.941	0.736	0.108	2.47	0.067	0.616	0.099	11.60	25.4	32.68	6.69	4.91	287.9	0.381
169	1992	12	349	9.7	1.337	0.822	0.081	2.48	0.067	0.547	0.102	8.82	24.1	30.45	5.11	3.71	282.8	0.377

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172 EVAPORATION ESTIMATES:

					F	G	H	I	J	K	L	M	N	O	P	Q	R	S
173						Perman (1963), (eo-ed) = f(Tavg)							Perman-Monteith (Smith, 1991):					
174																		
175					f(Tavg)		Aero term						Rad		Aero term			
176					eo	Rad term		Eo	Eo	Eo	g*	D/	term	g/	1	E	E	E
177	Year	Mo	CD	Days/mo	kPa	MJ*	MJ*	MJ*	mm/d	In/mo	kPa/C	(D+g*)	MJ*	(D+g*)	MJ*	MJ*	mm/d	In/mo
179	1987	1	15	31	1.329	2.34	3.10	5.44	2.20	2.69	0.067	0.568	2.34	0.4318	2.63	4.97	2.01	2.45
180	1987	2	46	28	1.613	4.57	4.15	8.71	3.53	3.89	0.067	0.609	4.57	0.3913	3.54	8.10	3.28	3.62
181	1987	3	74	31	1.784	7.74	4.68	12.42	5.04	6.15	0.067	0.629	7.74	0.3709	4.10	11.84	4.81	5.87
182	1987	4	105	30	2.666	11.83	5.84	17.66	7.21	8.52	0.068	0.705	11.83	0.2945	4.75	16.58	6.77	7.99
183	1987	5	135	31	3.075	13.81	7.55	21.35	8.74	10.67	0.068	0.730	13.81	0.2697	6.05	19.86	8.13	9.92
184	1987	6	166	30	4.211	15.07	8.87	23.94	9.85	11.63	0.068	0.780	15.07	0.2202	6.74	21.80	8.97	10.59
185	1987	7	196	31	4.461	16.23	8.19	24.42	10.06	12.28	0.068	0.788	16.23	0.2119	6.14	22.37	9.21	11.24
186	1987	8	227	31	4.745	14.86	7.71	22.57	9.30	11.36	0.068	0.797	14.86	0.2032	5.75	20.61	8.50	10.37
187	1987	9	258	30	3.690	10.29	6.57	16.86	6.92	8.18	0.068	0.760	10.29	0.2402	5.06	15.35	6.30	7.44
188	1987	10	288	31	3.201	7.14	3.74	10.88	4.45	5.44	0.068	0.737	7.14	0.2630	2.79	9.93	4.07	4.97
189	1987	11	319	30	1.834	4.04	2.17	6.21	2.52	2.98	0.067	0.635	4.04	0.3654	1.70	5.73	2.33	2.75
190	1987	12	349	31	1.242	2.00	2.05	4.05	1.63	2.00	0.067	0.554	2.00	0.4462	1.74	3.73	1.51	1.84
191	1988	1	15	31	1.341	2.66	2.55	5.21	2.11	2.57	0.067	0.570	2.66	0.4299	2.24	4.89	1.98	2.41
192	1988	2	46	28	1.671	5.17	3.08	8.25	3.35	3.69	0.067	0.616	5.17	0.3841	2.70	7.87	3.19	3.52
193	1988	3	74	31	1.951	7.21	4.58	11.79	4.79	5.85	0.067	0.647	7.21	0.3531	4.00	11.21	4.56	5.56
194	1988	4	105	30	2.217	10.52	4.12	14.64	5.96	7.04	0.068	0.672	10.52	0.3284	3.58	14.10	5.74	6.78
195	1988	5	135	31	2.850	11.71	8.22	19.93	8.15	9.95	0.068	0.717	11.71	0.2827	7.27	18.98	7.76	9.47
196	1988	6	166	30	3.743	15.93	7.19	23.12	9.49	11.21	0.068	0.762	15.93	0.2379	5.70	21.63	8.88	10.49
197	1988	7	196	31	4.851	17.25	7.15	24.40	10.06	12.28	0.068	0.800	17.25	0.2002	5.42	22.67	9.35	11.41
198	1988	8	227	31	4.691	15.58	6.27	21.85	9.01	10.99	0.068	0.795	15.58	0.2048	4.51	20.09	8.28	10.10
199	1988	9	258	30	4.026	8.88	6.65	15.53	6.38	7.54	0.068	0.773	8.88	0.2268	4.90	13.78	5.66	6.69
200	1988	10	288	31	3.340	7.90	4.56	12.46	5.11	6.23	0.068	0.744	7.90	0.2560	3.36	11.27	4.62	5.64
201	1988	11	319	30	1.859	3.37	3.84	7.20	2.93	3.46	0.067	0.637	3.37	0.3627	3.14	6.51	2.64	3.12
202	1988	12	349	31	1.354	1.86	3.31	5.16	2.09	2.55	0.067	0.572	1.86	0.4279	2.83	4.69	1.89	2.31
203	1989	1	15	31	1.319	2.28	2.91	5.19	2.10	2.56	0.067	0.566	2.28	0.4335	2.42	4.71	1.90	2.32
204	1989	2	46	28	1.594	5.06	3.26	8.32	3.37	3.72	0.067	0.606	5.06	0.3939	2.96	8.02	3.25	3.58
205	1989	3	74	31	2.336	7.70	4.03	11.73	4.78	5.83	0.068	0.681	7.70	0.3186	3.53	11.23	4.58	5.59
206	1989	4	105	30	2.751	12.81	5.01	17.82	7.28	8.60	0.068	0.711	12.81	0.2889	4.17	16.98	6.94	8.19
207	1989	5	135	31	3.082	14.07	8.02	22.09	9.04	11.04	0.068	0.731	14.07	0.2694	6.69	20.76	8.50	10.37
208	1989	6	166	30	3.960	15.21	8.85	24.06	9.89	11.68	0.068	0.771	15.21	0.2293	7.14	22.35	9.19	10.85
209	1989	7	196	31	4.810	15.58	8.47	24.05	9.92	12.11	0.068	0.799	15.58	0.2013	6.39	21.97	9.06	11.06
210	1989	8	227	31	4.438	15.29	6.29	21.58	8.89	10.85	0.068	0.787	15.29	0.2126	4.71	19.99	8.23	10.05
211	1989	9	258	30	3.981	10.86	7.14	18.00	7.40	8.74	0.068	0.771	10.86	0.2285	5.42	16.28	6.69	7.90
212	1989	10	288	31	2.777	6.49	5.37	11.86	4.85	5.91	0.068	0.713	6.49	0.2873	4.14	10.62	4.34	5.30
213	1989	11	319	30	1.901	3.59	3.70	7.29	2.96	3.50	0.067	0.642	3.59	0.3582	3.08	6.67	2.71	3.20
214	1989	12	349	31	1.341	2.00	2.54	4.54	1.83	2.24	0.067	0.570	2.00	0.4300	2.23	4.23	1.71	2.09
215	1990	1	15	31	1.400	2.26	2.68	4.94	2.00	2.44	0.067	0.579	2.26	0.4209	2.42	4.68	1.89	2.31
216	1990	2	46	28	1.454	4.33	3.29	7.62	3.08	3.40	0.067	0.587	4.33	0.4130	3.03	7.37	2.98	3.29
217	1990	3	74	31	1.969	8.13	4.10	12.23	4.97	6.07	0.067	0.649	8.13	0.3513	3.65	11.78	4.79	5.84
218	1990	4	105	30	2.466	9.97	4.19	14.16	5.78	6.82	0.068	0.691	9.97	0.3086	3.47	13.44	5.48	6.47
219	1990	5	135	31	2.846	13.34	7.50	20.84	8.52	10.40	0.068	0.717	13.34	0.2830	6.29	19.63	8.02	9.79
220	1990	6	166	30	3.966	15.28	7.01	22.30	9.16	10.82	0.068	0.771	15.28	0.2291	5.32	20.61	8.47	10.00
221	1990	7	196	31	4.780	14.77	7.38	22.15	9.13	11.15	0.068	0.798	14.77	0.2022	5.44	20.21	8.33	10.17
222	1990	8	227	31	4.338	10.62	5.45	16.06	6.61	8.07	0.068	0.784	10.62	0.2159	3.80	14.42	5.94	7.24
223	1990	9	258	30	4.003	12.44	4.91	17.35	7.13	8.42	0.068	0.772	12.44	0.2277	3.52	15.96	6.56	7.75
4	1990	10	288	31	2.800	7.38	4.18	11.56	4.73	5.77	0.068	0.714	7.38	0.2858	3.07	10.45	4.27	5.21
225	1990	11	319	30	1.825	2.49	4.17	6.67	2.71	3.20	0.067	0.634	2.49	0.3664	3.27	5.76	2.34	2.76

226	1990	12	349	31	1.246	1.48	3.25	4.74	1.91	2.33	0.067	0.554	1.48	0.4456	2.64	4.12	1.66	2.03
227	1991	1	15	31	1.372	1.88	2.59	4.47	1.81	2.21	0.067	0.575	1.88	0.4252	1.94	3.82	1.55	1.89
228	1991	2	46	28	1.808	5.15	2.66	7.81	3.17	3.50	0.067	0.632	5.15	0.3683	2.31	7.46	3.03	3.34
229	1991	3	74	31	1.618	7.14	3.29	10.43	4.23	5.16	0.067	0.609	7.14	0.3907	2.86	10.00	4.05	4.95
230	1991	4	105	30	2.154	11.45	4.33	15.78	6.42	7.59	0.068	0.666	11.45	0.3339	3.83	15.28	6.22	7.35
231	1991	5	135	31	2.613	14.92	5.06	19.99	8.16	9.96	0.068	0.702	14.92	0.2981	4.39	19.31	7.89	9.62
232	1991	6	166	30	3.410	13.53	5.65	19.18	7.86	9.29	0.068	0.747	13.53	0.2526	4.44	17.96	7.36	8.70
233	1991	7	196	31	4.244	16.65	5.53	22.17	9.12	11.14	0.068	0.781	16.65	0.2190	4.08	20.73	8.53	10.41
234	1991	8	227	31	4.634	15.16	6.19	21.34	8.80	10.74	0.068	0.793	15.16	0.2065	4.37	19.53	8.05	9.82
235	1991	9	258	30	4.118	11.65	4.92	16.57	6.81	8.05	0.068	0.776	11.65	0.2235	3.47	15.12	6.22	7.35
236	1991	10	288	31	3.159	7.29	5.05	12.34	5.05	6.17	0.068	0.735	7.29	0.2652	3.88	11.16	4.57	5.58
237	1991	11	319	30	1.886	2.21	5.06	7.27	2.95	3.49	0.067	0.640	2.21	0.3598	3.90	6.11	2.48	2.93
238	1991	12	349	31	1.425	2.08	1.95	4.02	1.63	1.99	0.067	0.583	2.08	0.4171	1.42	3.50	1.41	1.73
239	1992	1	15	31	1.376	2.54	2.34	4.87	1.97	2.40	0.067	0.575	2.54	0.4246	1.86	4.39	1.78	2.17
240	1992	2	46	28	1.759	4.97	2.47	7.44	3.02	3.33	0.067	0.626	4.97	0.3737	1.98	6.95	2.82	3.11
241	1992	3	74	31	1.827	7.57	1.90	9.47	3.85	4.69	0.067	0.634	7.57	0.3661	1.57	9.13	3.71	4.53
242	1992	4	105	30	2.623	10.34	3.43	13.76	5.62	6.64	0.068	0.703	10.34	0.2974	2.62	12.95	5.29	6.25
243	1992	5	135	31	3.213	14.91	4.21	19.12	7.83	9.56	0.068	0.738	14.91	0.2624	3.17	18.08	7.41	9.04
244	1992	6	166	30	3.726	15.30	5.56	20.85	8.56	10.11	0.068	0.761	15.30	0.2386	4.37	19.67	8.07	9.54
245	1992	7	196	31	4.639	16.56	6.19	22.75	9.37	11.44	0.068	0.794	16.56	0.2063	4.51	21.07	8.68	10.60
246	1992	8	227	31	5.068	15.66	6.29	21.95	9.06	11.06	0.068	0.806	15.66	0.1943	4.54	20.20	8.34	10.17
247	1992	9	258	30	4.449	9.06	5.59	14.64	6.03	7.12	0.068	0.788	9.06	0.2122	3.92	12.97	5.34	6.31
248	1992	10	288	31	3.089	7.17	4.38	11.55	4.73	5.77	0.068	0.731	7.17	0.2690	3.20	10.37	4.24	5.18
249	1992	11	319	30	1.674	3.02	3.59	6.62	2.68	3.17	0.067	0.616	3.02	0.3838	2.86	5.88	2.39	2.82
250	1992	12	349	31	1.202	2.03	1.63	3.65	1.47	1.80	0.067	0.547	2.03	0.4533	1.35	3.38	1.37	1.67

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252	SUMMARY OF EVAPORATION ESTIMATES:				Penman Eo:					Priestley-Taylor:			Penman-Monteith:zo= 2E-04					
253			CIMIS-41, Mulberry		Rad term	Aero	Eo						Rad term	Aero	E			
254	Year		Styles CIMIS, ETo		Inches	Inches	Inches	Pct		Inches	Pct		Inches	Inches	Inches	Pct		
255	-------		-------		-------		-------			-------			-------		-------			
256	1987		82.8	112.6%	53.0	31.1	85.8	104.8%		68.1	101.5%		53.0	24.6	79.1	104.3%		
257	1988		77.7	105.6%	52.1	29.7	83.4	101.8%		67.0	99.8%		52.1	23.9	77.5	102.2%		
258	1989		75.1	102.1%	53.5	31.6	86.8	106.0%		68.7	102.4%		53.5	25.5	80.5	106.2%		
259	1990		72.1	98.0%	49.4	28.0	78.9	96.4%		63.5	94.6%		49.4	22.1	72.9	96.1%		
260	1991		67.8	92.2%	52.6	25.2	79.3	96.8%		67.6	100.7%		52.6	19.7	73.7	97.1%		
261	1992		65.8	89.5%	52.6	22.9	77.1	94.2%		67.7	100.9%		52.6	17.3	71.4	94.1%		
262			-------		-------					-------			-------					
263	Average		73.6	100.0%	52.2	28.1	81.9	100.0%		67.1	100.0%		52.2	22.2	75.8	100.0%		
264					65.0%	35.0%		73.7	Lake E		1.02USGS:		70.2%	29.8%	75.8	Lake E		
265	Month	CIMIS Eto	CM/USGS	P-ETo: In/mo	PETo/GSPen Eo: In/mo		Px0.9/USGS			In/mo			P-M: In/mo		PM/GS			
266	Jan	2.62	1.36	2.74	1.42	2.48	1.16			1.92			2.26		1.18			
267	Feb	3.49	1.26	3.58	1.29	3.59	1.16			2.78			3.41		1.23			
268	Mar	5.35	1.20	5.40	1.21	5.63	1.13			4.46			5.39		1.21			
269	Apr	7.04	1.09	6.98	1.08	7.53	1.05			6.44			7.17		1.11			
270	May	9.00	0.96	9.28	0.99	10.26	0.99			9.34			9.70		1.04			
271	Jun	9.43	1.20	9.46	1.20	10.79	1.23			7.87			10.03		1.27			
272	Jul	9.50	1.08	10.14	1.15	11.73	1.20			8.82			10.82		1.23			
273	Aug	8.84	0.92	9.44	0.99	10.51	0.99			9.55			9.63		1.01			
274	Sep	7.32	0.85	7.74	0.90	8.01	0.84			8.61			7.24		0.84			
275	Oct	5.11	0.72	5.87	0.83	5.88	0.75			7.07			5.31		0.75			
276	Nov	3.46	0.82	3.61	0.86	3.30	0.71			4.20			2.93		0.70			
277	Dec	2.34	1.08	2.42	1.12	2.15	0.90			2.16			1.94		0.90			
278	Total	73.5	1.00	76.7	1.05	81.9	1.01			73.2			75.8		1.04			

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EVAPOTRANSPIRATION AND ON-FARM CONSUMPTIVE USE ESTIMATES FOR IID

by
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21 November 1993

INTRODUCTION

The Technical Work Group (TWG) is using several approaches to estimating on-farm irrigation efficiency. One approach is to estimate evapotranspiration (ET) for major crop groups and then apply crop acreages to arrive at total ET. Estimating ET for the numerous crops grown in the Imperial Irrigation District (IID) required summarizing extensive climatic data and selecting and adapting crop coefficient values for convenient use on a daily basis using a spreadsheet approach. In hindsight, writing a separate software program may have been more efficient. For future routine computations, a software program in BASIC or FORTRAN should be considered.

The major input variable used in this analysis was the reference ET (ET_o) values provided by the three CIMIS stations (41, 68 and 87) in the valley. Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle/Styles (1993) report were used in this study as was done for evaluating reference ET estimates.

The procedures developed and used in this analysis will be used in making similar estimates for the Coachella Valley Water District.

PROCEDURES

Alternative Mean Climate Data Sets

Six years of daily ET_o values were available from CIMIS station 41 (Mulberry), five years from Station 68 (Seeley), and three years from Station 87 (Meloland) for the period 1987-1992. If daily estimates for individual years were to be used a matrix of 2192 rows would have been required and numerous repetitive applications of crop coefficients adjusted for individual years would have been required. A spreadsheet approach would have been very cumbersome and the resulting spreadsheet would have been very large.

The alternative approach of establishing a set of mean daily ET_o for 365 days based on the data available from was selected. First, mean daily reference ET values was calculated for each of the three stations. Then, the mean daily values of ET for the three stations were calculated. Even with this reduced matrix, a computer software that enabled using expanded memory was required when estimating ET for individual crops and converting and saving individual crop values. Four sets of spreadsheets were used to enable estimating and saving ET values for all of the crops.

Crop Coefficient Data Sets

Two primary sources of crop coefficients (K_c) were evaluated before selecting coefficients for various crops: 1) University of California Leaflet 21427, and 2) a set coefficients provided by JMLord, Inc. The ASCE Manual 70 and several other references provided alternative values for some crops. Leaflet 21427 (UC, undated) provided starting point information about planting and harvest dates for many crops grown in the IID.

After extensive development of daily coefficients for use in making daily estimates of ET, I was not able to use these values in quantifying ET values for most crops because the values clearly do not represent real crop development characteristics as will be illustrated later. **The UC coefficients appear to be intended for management purposes such as irrigation scheduling and possibly for establishing peak ET values for determining system capacity requirements. They do not appear adequate for estimating quantities of ET.**

The data set provided by JMLord, Inc. uses five values for the growth period from planting to full cover (0, 25, 50, 75, and 100 %), and four values for growth period after full cover (growth intervals 1, 2, 3 and 4). Applying these coefficient on a daily basis would have required interpolation between two data points for seven periods for each crop. This became a very cumbersome procedure using a spreadsheet approach. Therefore, generic equations for daily values were calibrated for the two periods, 1-100 percent of full cover and days after full cover. This required only two equations for each crop instead of seven. The generic equation was based on curves of crop coefficients that were developed from daily lysimeter data for row crops and close planted crops by Wright as summarized in ASCE Manual 70 (Jensen et al., 1990).

Since the JMLord crop coefficients are for use with an alfalfa reference crop, the daily coefficients were multiplied by 1.2 for use with CIMIS reference ET.

Rainfall Values for the Mean Climatic Data Set

Rainfall data from the three CIMIS stations were summarized and grouped into discrete rainfall events for each month of the year. Then, based on the average number of rain storms of different sizes, a set of monthly rain storms was selected to provide approximately the same average total annual rainfall for the 1987-1992 period. With these average rainfall events, an estimate of effective rainfall for each crop could be obtained.

Effective Rainfall

Since almost all of the individual rainfall events were very small, no runoff was assumed and the increase in evaporation following a rain event was based on the following equations (ASCE Manual 70, page 118):

$$E+ = 0.35(1.5 + t_d)(K_1 - K_a K_{cb})\, ET_o \qquad (1)$$

where E+ = the increase in evaporation following wetting of the soil and foliage, t_d is the number of days for the soil surface to visually appear dry (7 days was used for a fine texture soil), K_1 is the maximum value of K_c after a rain or irrigation (1.2 was used), K_{cb} is the basal crop coefficient, and K_a is a dimensionless coefficient that is dependent on available soil water (K_a = 1.0, soil water not limiting, for this analysis). The maximum value of E+ could not exceed the rainfall received.

Major Crop Groupings

A very large number of crops are grown in the IID, but many represent a very small percentage of the irrigated crop land. Therefore, a six-year summary of crops was used to select the major crops for which estimated ET was needed. Then, the average crop acreages were used to estimate the total ET for the average 1987-1992 period.

Cropping Period for ET Estimates

Estimates of ET were made from planting to harvest. Soil water was assumed to be at the drained upper limit, or field capacity, at planting for a fine texture soil (ASCE Manual 70, page 21). Since no information was available on irrigation frequency or rooting depth, available soil water was not assumed to affect ET except as later adjusted for alfalfa.

Evaporation Losses after Preplant-Irrigations

Since ET estimates were desired, no estimates of evaporation losses during and after preplant-irrigations were included in my estimates. Assuming that preplant-irrigations were made prior to planting or for germinating seeds, evaporation estimates can be made. Estimates of evaporation would need to be added when comparing water balance estimates with ET x crop area estimates. This aspect needs to be discussed by the TWG.

Variable or Partial Harvest

Since sugar beets are not harvested and stored for processing as is done in northern states, harvesting of sugar beets was assumed to begin two months before the final harvest date for each of the two planting dates. The total ET was reduced by the average ET for the last two months. This basically assumes that the area of growing beets was reduced linearly for the last 60 days of each growing period.

Adjusting ET Estimates for Alfalfa

It is well established that it is difficult to apply sufficient water to alfalfa to provide leaching, or even to avoid crop water stress and reduced ET rates. The TWG agreed that consideration should be given to average alfalfa hay yields in the IID in estimating alfalfa ET. Therefore, several data sets were selected from the literature to assess crop yield v. ET relationships. Since most of the relationships found in the literature were based on dry matter (DM) production (zero moisture), all values used were converted to DM, if not reported as such, and then a linear regression equation was derived. The equation was then adjusted to represent alfalfa hay at 12 percent moisture and cubed and dehydrated alfalfa (0% moisture). The units were than converted to units of tons per acre and inches of annual ET. Alfalfa yields for the years 1987-1992 were than averaged and the linear equation applied to estimate alfalfa ET.

Evaporation Estimates for Duck Ponds, Fish Farms and Leaching

Average evaporation estimates for ponds and reservoirs in my report "Evaluating Evaporation Estimates for IID" were used for duck ponds, fish farms and for areas being leached. It was assumed that areas being leached remained flooded for at least a month. Therefore, 1/10 of annual pond evaporation was used for estimates of evaporation during leaching.

Total ET and On-Farm Irrigation Efficiency

Total ET was obtained by multiplying ET by the average crop acreage obtained from the Boyle (1993) report. On-farm irrigation efficiency (consumptive use coefficient, C_{∞}) was estimated by two methods: 1) dividing total ET by total water delivered as reported in the Boyle report; and 2) by including an average leaching requirement of 0.12.

INTERMEDIATE RESULTS OF PROCEDURES

Mean Reference ET Data Set

Mean daily reference ET from CIMIS data from the three sites is presented in Fig. 1. Averaging the three stations narrowed the daily variations, but they still existed. A moving five-day mean would have eliminated much of the daily variability. Of interest is the dip in reference ET values during May-June. The USGS Salton Sea study (Hely et al., 1966) showed similar reduced values during this period.

Fig. 1. Mean daily ET from CIMIS Stations 41 (Mulberry), 68 (Seeley) and 87 (Meloland).

Mean Annual Rainfall Distribution Data Set

An analysis of rainfall events for the three stations is summarized in Table 1. For the average 1987-1992 year, the number of rainfall events and amounts are summarized in Table 2. Based on the frequency of rainfall events, 80 percent fall in the range of 0 - 0.25 inch, 16 percent in 0.26-0.50 inch, and 3 percent in 0.51-0.75 inch. Only 1 percent resulted in more than 0.75 inch. The average rainfall for the period was 4.88 inches.

Table 1. Average number of annual rainfall events in each of nine ranges of amounts.

	Range, inches									
Month	0-0.25	0.26-0.50	0.51-0.75	0.76-1.00	1.01-1.25	1.26-1.50	1.51-1.75	1.76-2.00	2.01-2.25	2.26-2.50
Jan	2.6	0.6	0.1	0	0	0	0	0	0	0
Feb	1.7	0.6	0.1	0	0	0	0	0	0	0
Mar	2.9	0.1	0.3	0	0.1	0	0	0	0.1	0.1
Apr	0.8	0	0	0	0	0	0	0	0	0
May	1.1	0.3	0	0	0	0	0	0	0	0
Jun	1.2	0	0	0	0	0	0	0	0	0
Jul	1.1	0	0	0	0	0	0	0	0	0
Aug	2.1	0.1	0.3	0	0	0	0	0	0	0
Sep	1.0	0.3	0.1	0	0	0	0	0	0	0
Oct	1.4	0.3	0.2	0	0	0	0	0	0	0
Nov	1.4	0.1	0.1	0	0	0	0	0	0	0
Dec	6.5	2.7	0.8	0.1	0.1	0	0	0	0	0

AVERAGE REFERENCE ET - IID

CIMIS STATIONS 41, 68 & 87 -- 1987-92

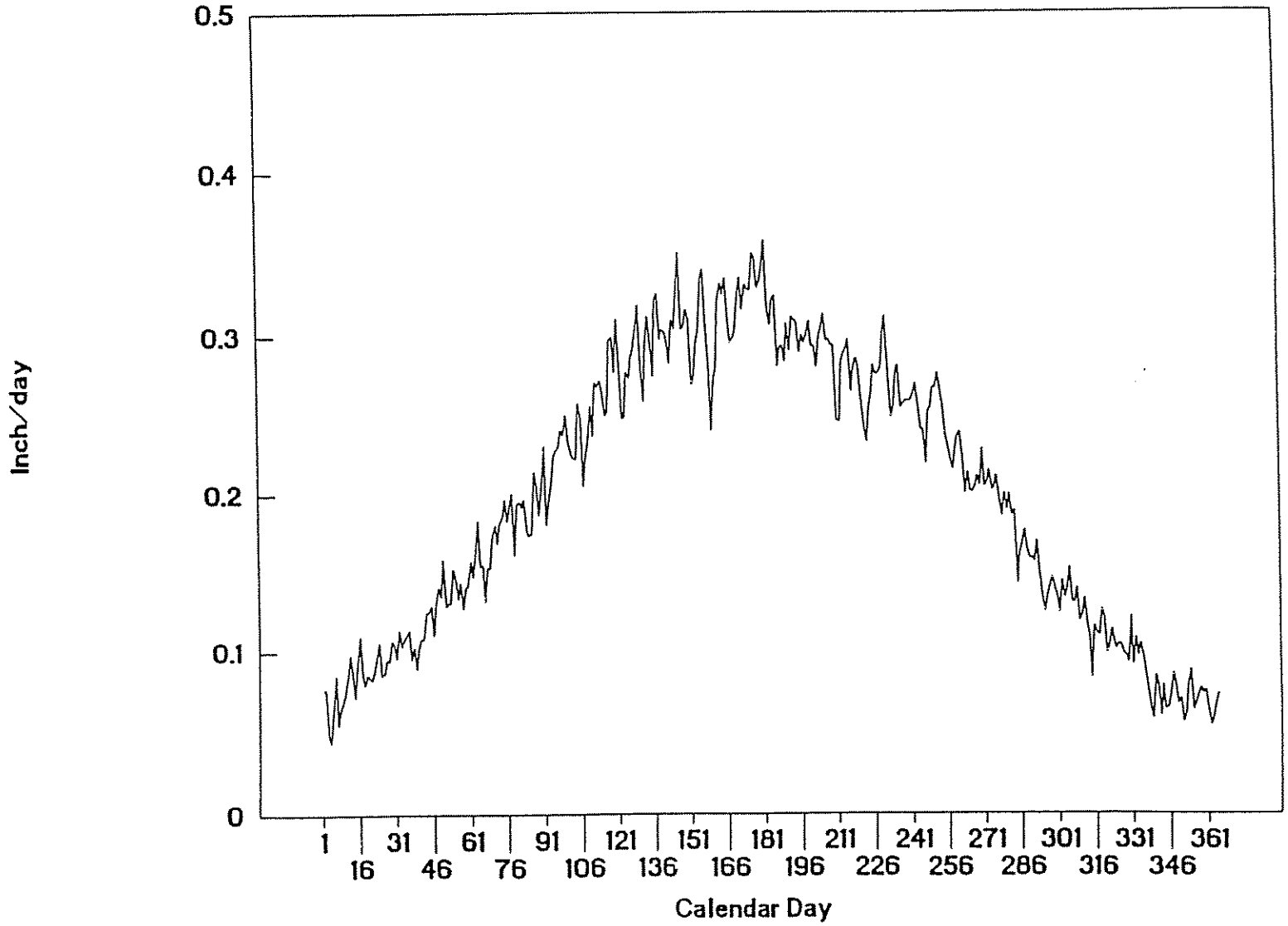

Fig 1

Table 2. Number of rainfall events and amounts used for the average 1987-1992 year in each of nine ranges of amounts.

	Range, inches									
Month	0-0.25	0.26-0.50	0.51-0.75	0.76-1.00	1.01-1.25	1.26-1.50	1.51-1.75	1.76-2.00	2.01-2.25	Total
Jan	2	1								3
Feb	2	0	1							3
Mar	3									3
Apr	1									1
May	1									1
Jun	1									1
Jul	1									1
Aug	2									2
Sep	1									1
Oct	1	1								2
Nov	2									2
Dec	3	1								4
Total	20	3	1	0	0	0	0	0	0	24
Rain	2.50	1.13	0.63	0	0	0	0	0	0	4.25

Crops and Cropping Periods

The major crops and the estimated periods of growth used for these estimates are summarized in Table 3. The acres of each crop are summarized in a later table. Most of the dates were obtained from UC Leaflet 21427.

Crop Coefficients

University of California Crop Coefficients. Daily UC crop coefficient values were first calculated for individual days for the growth periods in Table 3. Sets of UC coefficients are shown in Figures 2 and 3. What is immediately apparent is that changes in the coefficients for crop growth are represented by the straight lines. The impact of these values in estimating the quantity of water consumed in ET was not apparent until they were compared with other coefficients for a crop like barley such as those by JMLord and Wright multiplied by 1.2 (Fig. 4).

Fig. 2. Daily crop coefficients for asparagus, two dates of barley plantings, two dates of cantaloupe plantings and carrots (Calculated from UC Leaflet 21427).

Fig. 3. Daily crop coefficients for cotton, two dates of lettuce plantings, onions, and two dates of sorghum cuttings (Calculated from UC Leaflet 21427).

Fig. 4. Comparison of UC, JMLord, and Wright's daily crop coefficients for barley.

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Table 3. Summary of major crops, growth periods dates, days between planting and full cover, and days between full cover and harvest for IID as used in estimating ET. For Phase II, some refinement is needed in dates which will require assessment of average planting dates, leaf area development rates and harvest dates.

Row 17-Dec-93 SUMMARY OF CROP GROWTH PERIODS AND DAYS TO FULL COVER \CROP-PER

Crop	Start or plant Date	Start or plant CD	Full cover Date	Full cover CD	Harvest Date	Harvest CD	Days Plt-FC	Days FC-Harv	Days Plt-Harv
FIELD:									
Alfalfa, 6/15-7/15 *	15-Jun	166	07-Jul	188		196	22	8	30
Alfalfa Seed	15-Mar	74	- -	- -	01-Aug	213	- -	- -	140
Bermuda Grass	01-Mar	60	- -	- -	01-Oct	274	- -	- -	215
Cotton	31-Mar	90	12-Aug	224	31-Oct	304	134	80	215
Oats	01-Jan	1	05-Mar	64	30-Apr	120	63	56	120
Rye Grass	01-Jan	1	- -	- -	30-Apr	120	- -	120	120
Sudan Grass	01-Apr	91	24-May	144	01-Oct	274	- -	130	184
Sugar Beets-1	30-Jun	181	09-Feb	405	30-Apr	485	224	80	305
Sugar Beets-2	30-Sep	273	10-Feb	406	30-Jun	546	133	140	274
Wheat	01-Jan	1	24-Mar	81	31-May	151	80	70	151
FRUIT:									
Citrus	01-Jan	1	- -	- -	31-Dec	365	- -	- -	365
Peaches/Pecans	01-Apr	91	- -	- -	16-Nov	320	- -	- -	230
TRUCK:									
Artichoke	01-May	121	- -	- -	10-Mar	434	- -	- -	314
Asparagus	01-Jan	1	- -	- -	31-Dec	365	- -	- -	365
Brocolli	15-Sep	258	17-Dec	351	15-Feb	411	93	60	154
Cantaloupe-1	31-Jan	31	12-Mar	71	31-May	151	40	80	121
Cantaloupe-2	31-Jul	212	12-Oct	285	31-Dec	365	73	80	154
Carrots	30-Sep	273	09-Feb	405	30-Apr	485	132	80	213
Cauliflower	01-Oct	274	- -	- -	31-Jan	396	- -	- -	123
Corn, sweet	15-Jan	15	24-Feb	55	15-May	135	40	80	121
Lettuce-1	31-Aug	243	24-Sep	267	02-Jan	367	24	100	125
Lettuce-2	31-Oct	304	21-Dec	355	31-Mar	455	51	100	152
Melons, Honeydew, F	01-Aug	213	12-Oct	285	31-Dec	365	72	80	153
Melons, Water	01-Aug	213	12-Oct	285	31-Dec	365	72	80	153
Onions	31-Dec	365	20-Feb	416	31-May	516	51	100	152
Onion Seed	31-Dec	365	20-Feb	416	31-May	516	51	100	152
Tomatoes, Spring	31-Jan	31	11-Apr	101	30-Jun	181	70	80	151

* Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15.

CROP COEFFICENTS - IID

U of C, L-21427

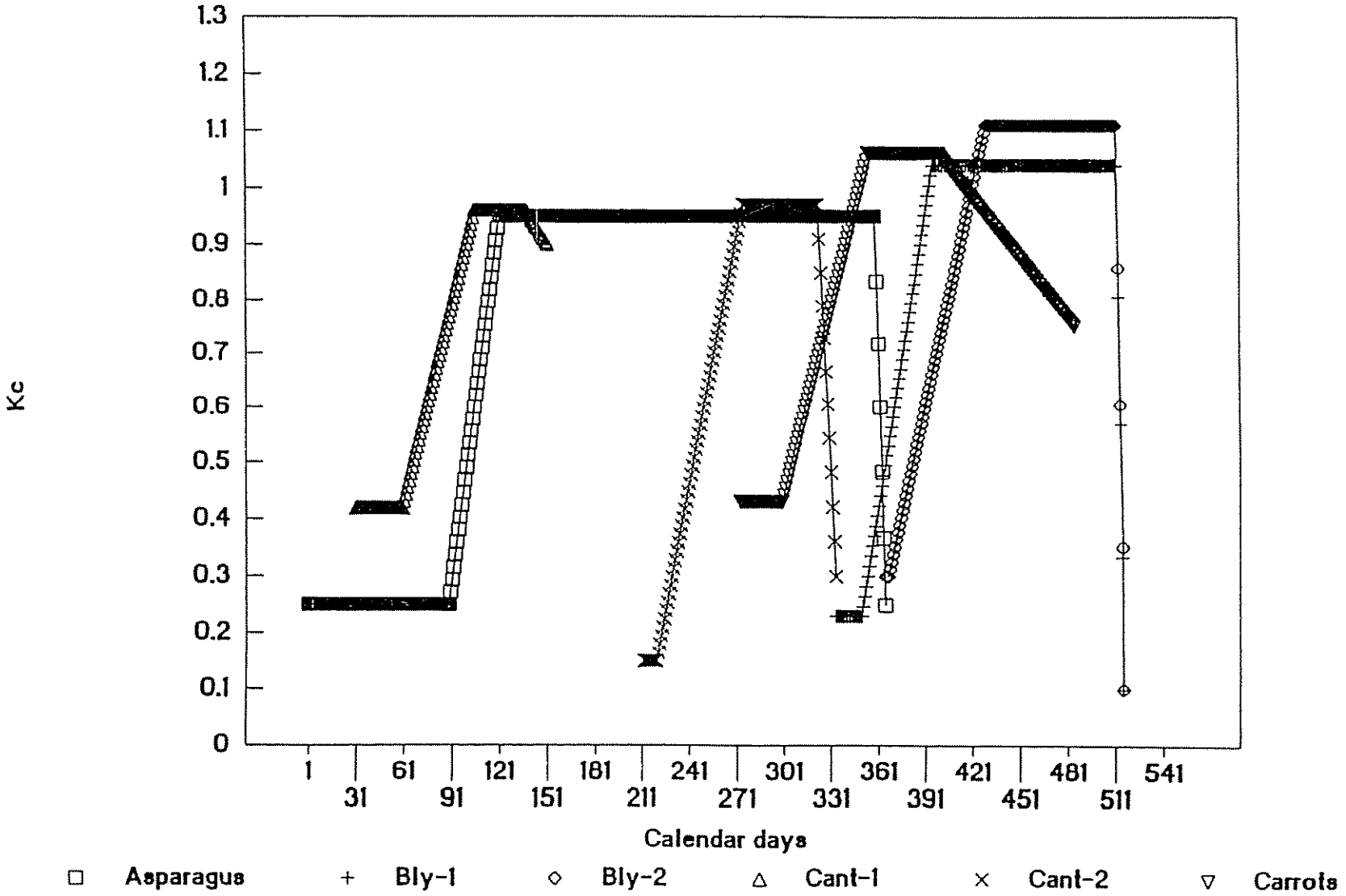


Fig 2

CROP COEFFICENTS - IID

U of C, L-21427

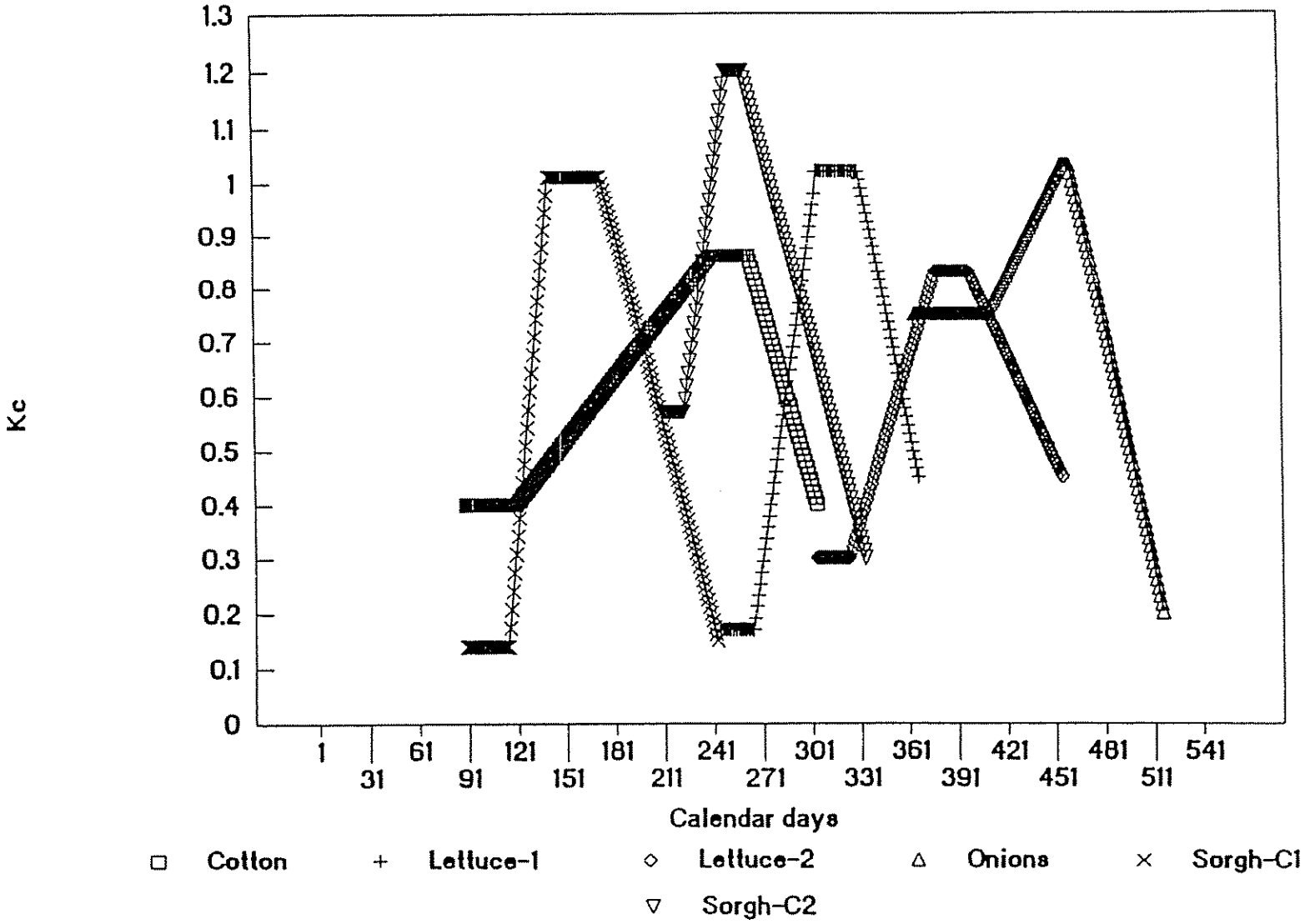


Fig. 3

CROP COEFFICIENTS - IID

JML Kc x 1.2 v. UC Kc

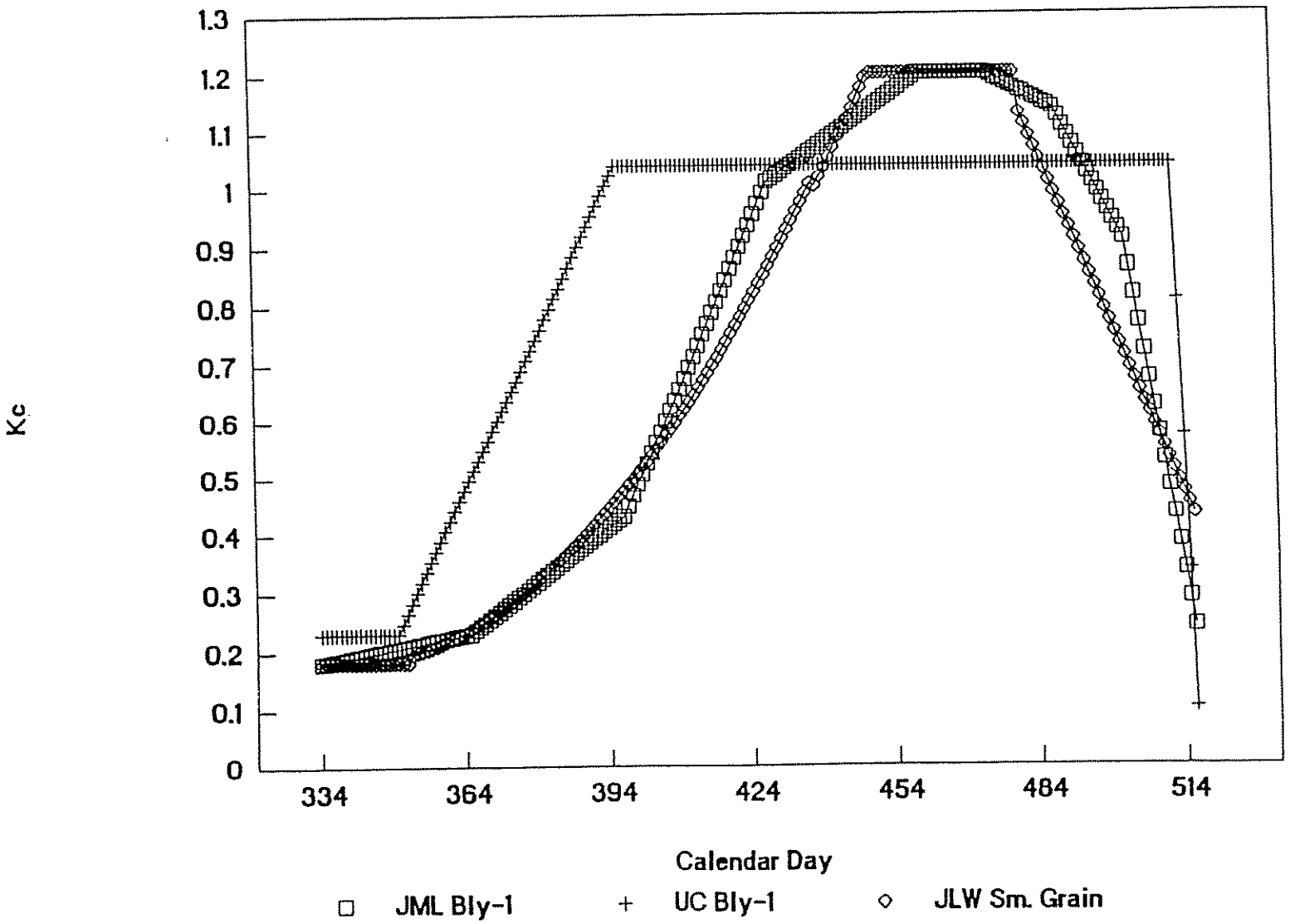


Fig 4

JMLord, Inc. Coefficients. Crop coefficients after plant emergence increase with plant growth or leaf area. The rate of leaf area development typically increases as a function of leaf area as illustrated in Figures 5 for the period before full cover and in ET decrease with maturity as illustrated in Figure 6 for days after full cover. The values in Figures 5 and 6 were based on daily crop coefficient values determined using lysimeter measurements of ET. The curves in the figures are of an exponential or power function type for use with alfalfa as the reference crop. For example, the average equation for row crops (sugar beets, potatoes, corn and beans) illustrated in Figure 5 is:

$$K_{cb} = 0.15 \frac{(P - 30)^{1.8}}{2650}, \; for \; 30 < P < 100 \qquad (2)$$

The equation for small grain illustrated in Fig. 5 is:

$$K_{cb} = 0.15 + \frac{(P - 6)^{1.9}}{5400}, \quad for \; 6 < P < 100 \qquad (3)$$

where P is the percent of the period from planting to full cover. Similar equations approximate the decrease in the coefficient as the crop matures except the value is the maximum minus the power function.

As indicated under Procedures, similar equations were fitted to the coefficients provided by JMLord, Inc. to facilitate calculating daily crop coefficient values which were multiplied by 1.2 for use with the CIMIS reference ET.

Alfalfa Coefficients. The duration of the period between alfalfa cuttings during the summer is about 30 days. A comparison of the UC, JMLord x 1.2 and Wright x 1.2 coefficients for a single period between cutting in mid-summer is shown in Figure 7. Wright's coefficients were based on seven years of daily coefficients determined using a sensitive weighing lysimeter. Clearly, the UC coefficients do not adequately represent the development of leaf area after cutting and use of UC coefficients would clearly over-estimate alfalfa ET. At this point, I decided against using UC-21427 values for quantifying ET values for the IID. Equations adjusted to fit JMLord's data point were developed for the crops involved except for citrus.

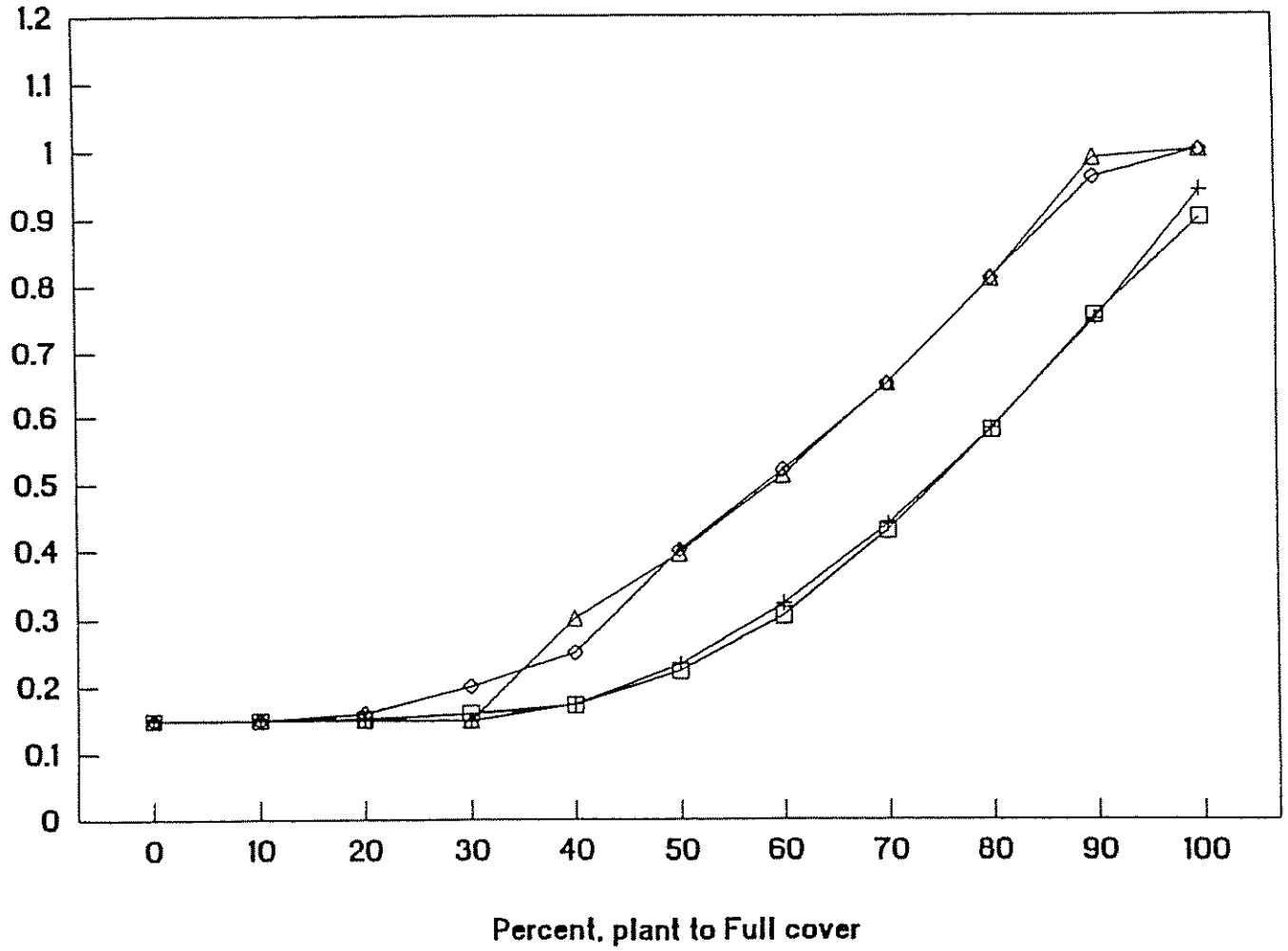
Fig. 5. Wright's daily basal crop coefficients for row crops and small grain from planting to full cover (Wright, Table 6.6, ASCE Manual 70).

Fig. 6. Wright's daily basal crop coefficients for row crops and small grain from full cover to harvest (Wright, Table 6.6, ASCE Manual 70).

Fig. 7. Comparison of UC, JMLord and Wright's daily crop coefficients for alfalfa for a 30-day period from mid-June to mid-July.

J L WRIGHT' BASAL CROP COEFFICENTS

Table 6.6. ASCE Man 70



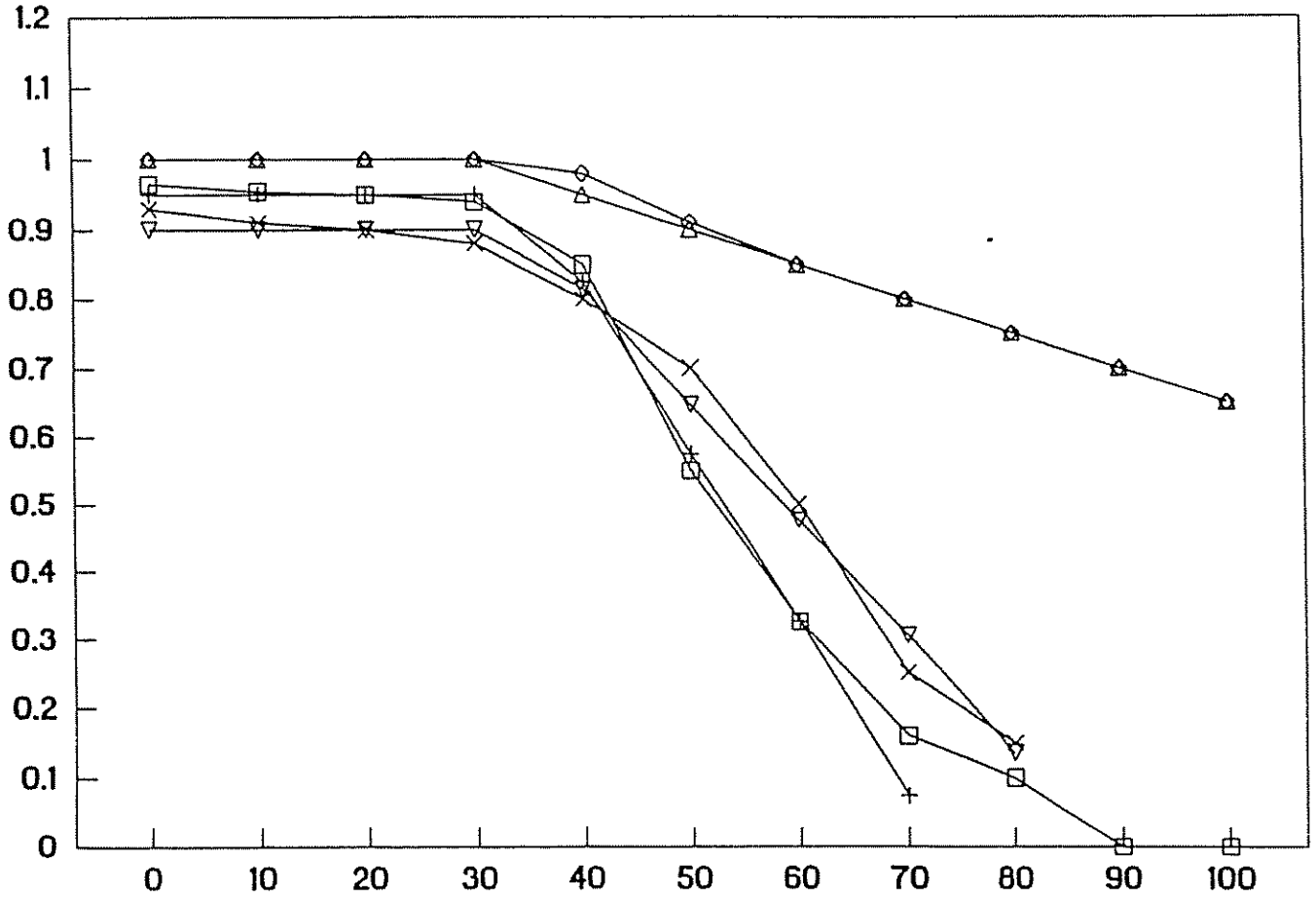
□ JLW Row Crops + Approx Row Crops ◇ JLW Small Grain

△ Approx Small Grain

Fig. 5

J L WRIGHT' BASAL CROP COEFFICENTS

Table 6.6, ASCE Man 70



Days after Full Cover

Fig. 6

□ JLW Small Grain + Approx Small Grain ◇ JLW S. Beets △ Approx S. Beets

× JLW Sw. Corn ▽ Approx Sw. Corn

CROP COEFFICIENTS - IID

JML Kc x 1.2 v. UC Kc

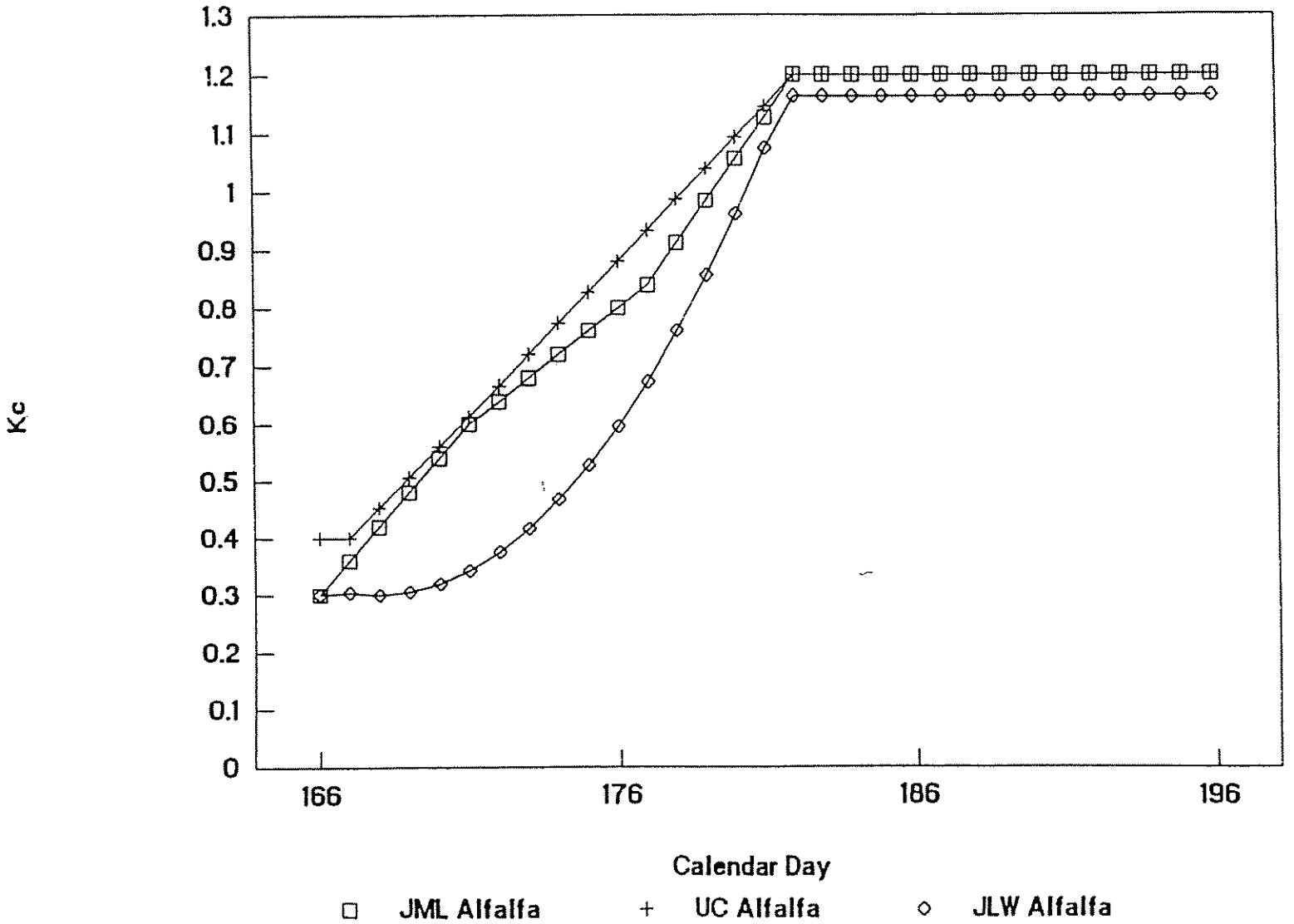


Fig. 7

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Citrus Coefficients. Because JMLord's coefficients for citrus seemed to be much higher than others being recommended, I elected to use the clean cultivated citrus coefficients developed by Pruitt as printed in Table 6.10, ASCE Manual 70.

Grape Coefficients. Although grapes is not a significant crop in the IID, it represents over 20 percent of the crops grown in the Coachella Valley Water District (CVWD). Therefore, an assessment and discussion of alternative crop coefficients for grapes needs to be made at this time. Three sets of coefficients for grapes are available for specific time periods in California: 1) Grimes and Williams (1990), 2) those suggested by C. M. Burt on 17-Sep-93, and 3) those of Pruitt's from Table 6.10, ASCE Manual 70 (Pruitt et al., 1987). Grimes and Williams coefficients are for Thompson Seedless grapes, and those of Pruitt are listed for table grapes. Burt did not specify a grape variety. The three sets of daily grape coefficients are shown in Figure 8 so that TWG suggestions can be obtained before completing ET estimates for the CVWD.

Fig. 8. Comparison of three sets of crop coefficients for grapes grown in California.

Example Application of Procedures

Alfalfa ET. Using the cutting dates suggested in UC Leaflet 21427, ET was estimated for each crop as illustrated in Figure 9 for alfalfa. Since an available soil water factor was not used, the values of the upper drained limit (field capacity), the lower limit, and management allowed depletion are not important. A graph was used for each crop because it served as a check on the procedures and crop curve being used.

Fig. 9. Example crop ET, soil water depletion, and irrigations for a perennial crop of alfalfa with nine cuttings scheduled according to UC Leaflet 21247 dates. A constant root depth is used for perennial crops.

Fig. 10. Example crop ET, soil water depletion, and irrigations for an annual crop like cotton. A variable root depth related to the crop coefficient is used for annual crops.

Example Illustration of Crop and Reference ET

An example of mean reference ET and alfalfa ET showing the effects of cuttings on ET rates for the average 1987-1992 climate is presented in Figure 11. In this case, irrigation dates were snchronized with assumed cuttings. The peaks are the cumulative increases in evaporation following rains. They are shown as occurring on single day because of the way in which they were calculated. The actual increases in evaporation would occur over several days in an exponential decreasing rate and the total for a given day would not exceed $1.2ET_o$. Pruitt's citrus coefficients were reduced to 85 percent (Figure 12).

Fig. 11. Example of mean reference ET, alfalfa ET, and increases in evaporation following rains for 1987-1992 climate.

Fig. 12. Citrus crop coefficents (From Pruitt, 1990).

GRAPE CROP COEFFICIENTS

FOR USE WITH ETo

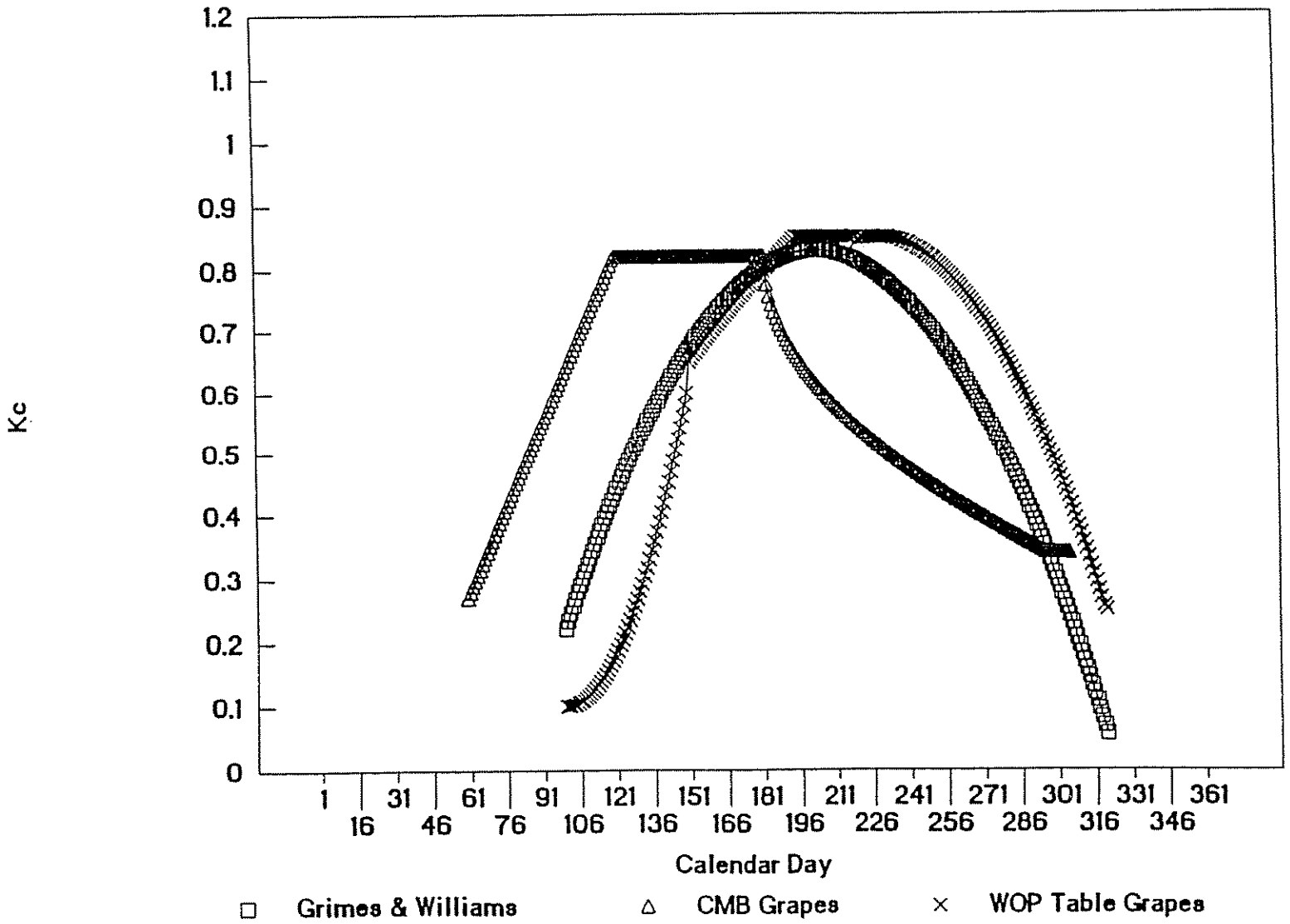

Fig. 8

ESTIMATED ET and SOIL WATER- IID

CROP: ALFALFA, 1987-92

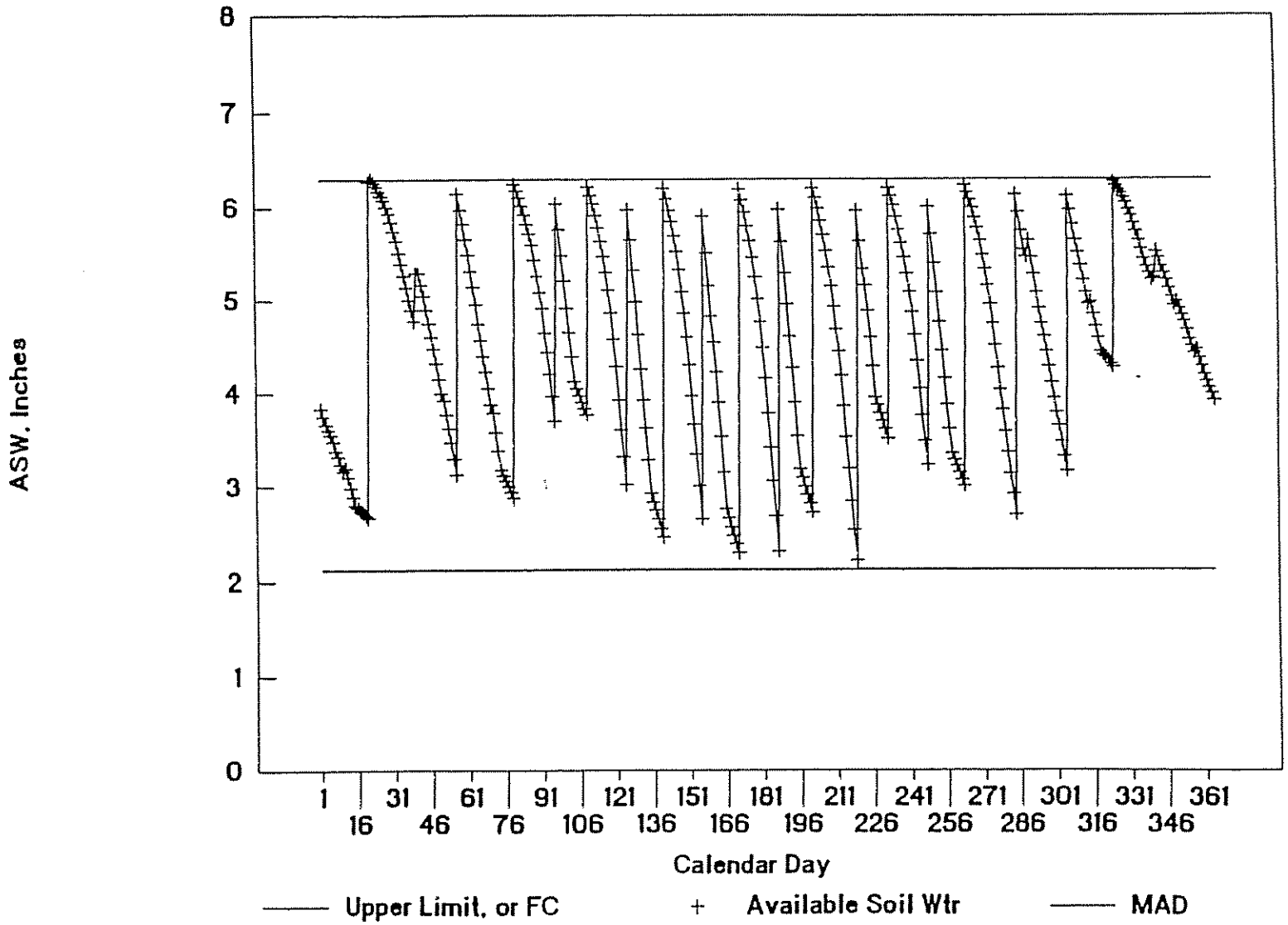

Fig. 9

ESTIMATED ET and SOIL WATER - IID

CROP: COTTON, 1987-92

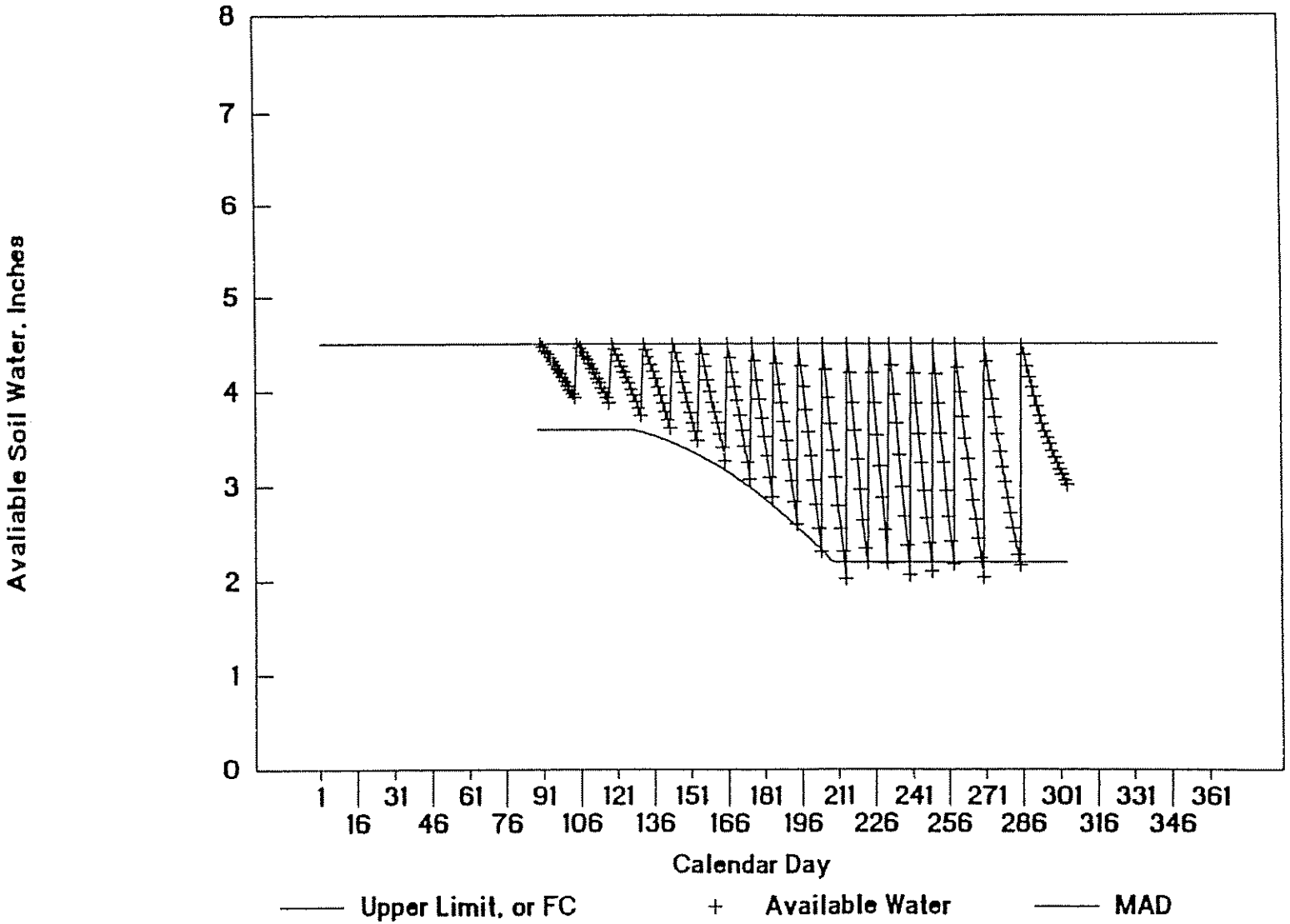

Fig. 10

CIMIS ETo and ESTIMATED ET - IID

CROP: ALFALFA, 1987-92

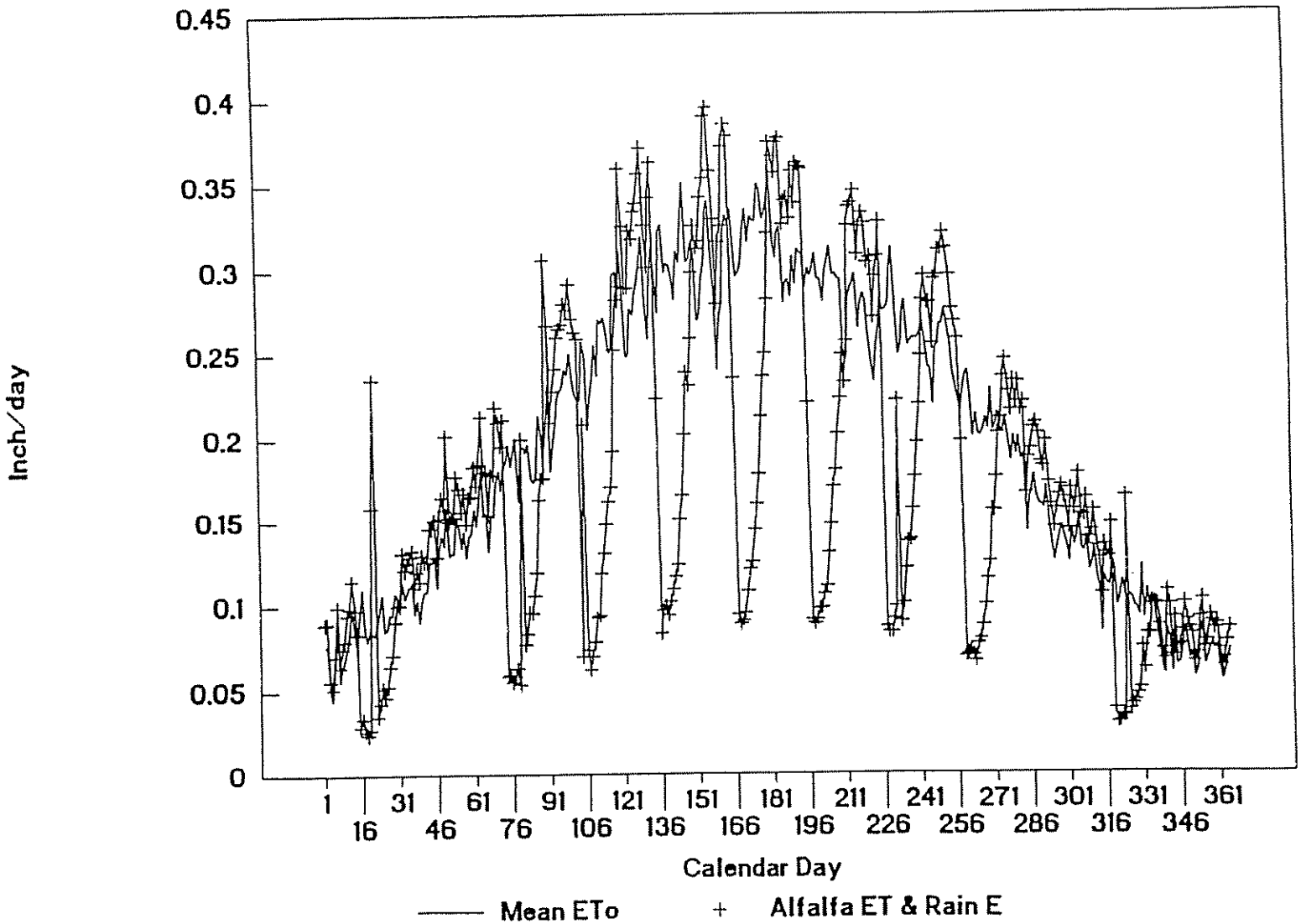

Fig. 11

CITRUS CROP COEFFICIENTS

FOR USE WITH ETo

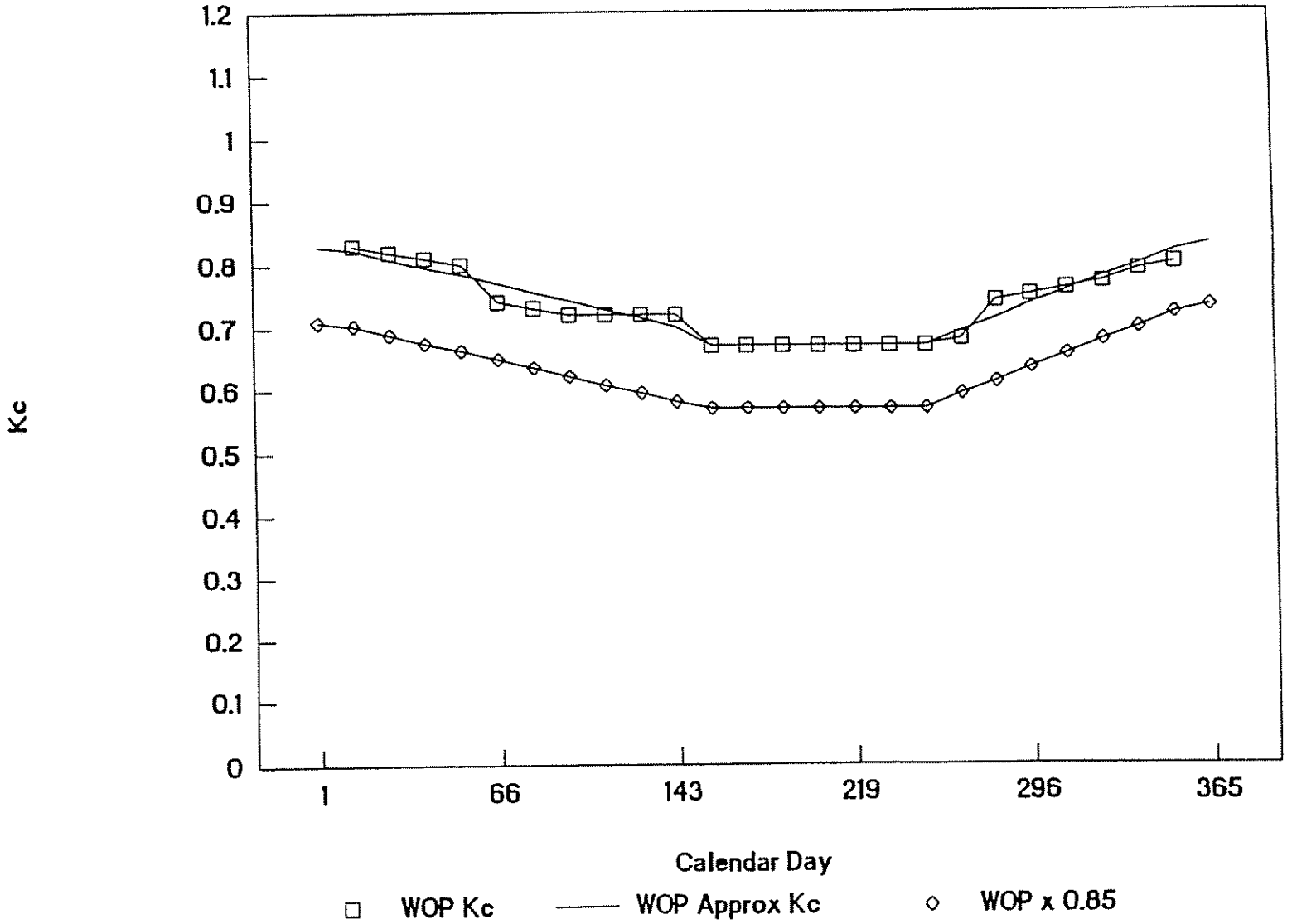

Fig 12

Adjustment of Alfalfa ET Estimates for Reported Yields

Numerous examples of alfalfa ET can be found in the literature. Specific examples of yield-ET relationships are found in more recent literature. These must be reviewed carefully because they do not always present the data in similar units or formats. A selection of data to represent a wide range in ET was used to calibrate a yield-ET relationship. At the low end and covering both dryland and irrigated alfalfa is the set of Bauder et al. (1978) who measured yield and ET over a four-year period in North Dakota. Annual ET ranged from 8 to 28.4 inches (200 to 720 mm) for the four water treatments. Dry matter yields (0% moisture) ranged from 1.2 to 5.7 tons per acre (2.6 to 12.8 t/ha).

Hill et al. (1983) summarized extensive measurements of alfalfa yield-ET data. One data set is from lysimeter measurements made in Nevada over a five-year period with ET ranging from 7 to about 50 inches and yields at 12% moisture ranging from 1 to about 10 tons/acre. Wright (1988) measured alfalfa yields in a sensitive weighing lysimeter over a 7-year period and related the lysimeter yields to the yield in the surrounding 6.4-acre field. Soil water stress was not a variable and field yields were about 5 percent less than lysimeter yields due primarily to windrow effects in the field. Seasonal ET for three cuttings in mid-summer (excluding October) averaged 38.5 inches and lysimeter yields averaged 7.7 tons/acre at 12 percent moisture.

Sammis (1981) summarized alfalfa yield and ET as measure in field experiments and lysimeters. The 1979 line source values at Las Cruses, NM was from a complete year on a plot of alfalfa that was established in 1977. Yield in 1978 was not complete because of mainly mustard plants for the first cutting. Data from 1979 was selected as an example of data obtained using a sprinkler line-source method in an arid environment.

Donnavan and Meek (1983) conducted a water level yield experiment on alfalfa at the Imperial Valley Conservation Research Center from 1975 through 1977. ET was not measured, but was estimated based on the amounts of water applied. Yields were reported on a 10% moisture basis, but the yield-ET regression equation was for dry matter.

Because most of the data reported in the literature are in metric units and most of the values were reported as dry matter (DM, 0% moisture), a calibration of DM with ET was first carried out in metric units and later converted to alfalfa yield at both 12% moisture and 0% moisture and ET in inches. The Kimberly, Idaho lysimeter yields were also adjusted to represent field yields using the regression equation provided by Wright.

The results from the above studies are shown in Figure 13. The results from the ID, ND, NM and NV studies clearly are very close to one another. However, the Donnavan-Meek results do not agree primarily because they are based on water applied and **not measured ET.**

Fig. 13. Summary of alfalfa dry matter yield v. ET data and water applied data (Donnavan-Meek) expressed in metric tons per hectare.

The resulting equation that was used to estimate alfalfa yield at 12 percent moisture and ET in inches for the IID is:

$$Y = -0.70 + 0.218ET \tag{4}$$

where Y = yield in tons/acre and ET is in annual ET in inches. When expressed as ET as a function of yield, Eq. 4 becomes:

ALFALFA YIELD v. ET

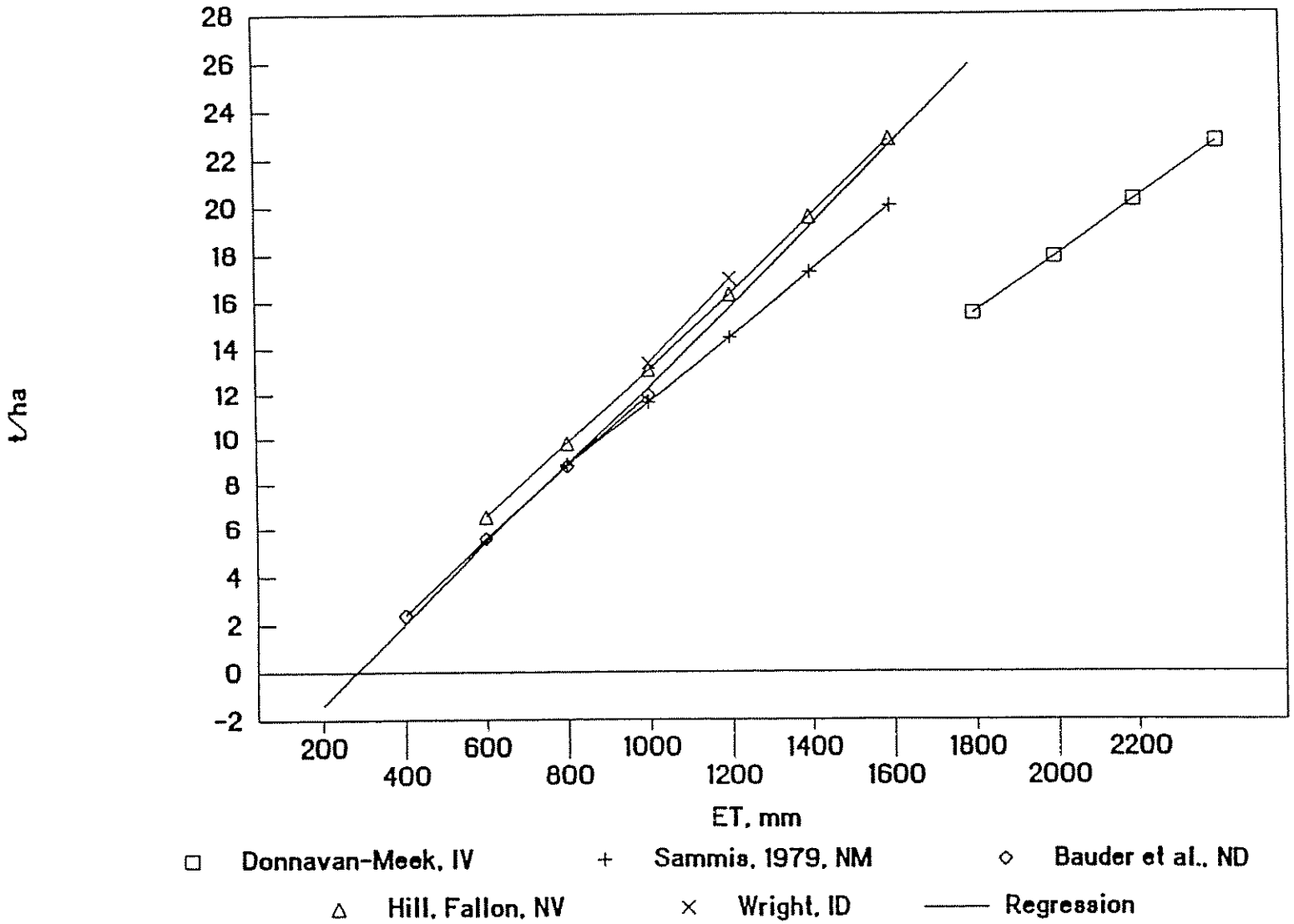

Fig 13

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$$ET = \frac{(Y + 0.70)}{0.218} \quad (5)$$

Assuming that cubed dehydrated has zero moisture, Eq. 4 and 5 are for "0" percent moisture.

$$Y = -0.62 + 0.194\,ET \quad (4a)$$

$$ET = \frac{(Y + 0.62)}{0.194} \quad (5a)$$

The average alfalfa yields for the period 1987-1992 as reported by the Imperial County Agricultural Crop and Livestock report are as follows:

	Year						
	1987	1988	1989	1990	1991	1992	Average
Yield, tons/acre (cubed and dehydrated)	9.60	9.66	9.78	9.70	8.50	7.90	9.19

Using Eq. 5a, the average estimated ET for alfalfa is (9.19 + 0.62)/0.194 = 50.6 inches. This value was used in estimating average total annual ET and on-farm consumptive use coefficient, C_{cu}, and irrigation efficiency.

RESULTS OF ANALYSES

Estimated ET for IID using ET x Area Method

Average Annual ET and On-Farm Irrigation Efficiency. A summary of estimated average ET_o, ET, rainfall, E+ (evaporation after rains), Re (effective rainfall), mean K_c for the season, water delivered (From the Boyle, Styles, 1993, report), and consumptive use coefficents expressed as total ET/(water delivered) for the major crops in IID is shown on page 24. Variations in the values of ET/Wd indicate a need to refine some planting and harvest dates that were used. Effective rainfall was subtracted from total ET to estimate the fraction of irrigation water consumed.

Crop acreages summarized from the Boyle (Styles, 1993) report, percentage distribution of these acreages, and the estimated confidence interval are presented in the spreadsheet on page 25. The Boyle ET values are from the Boyle CVWDR report. The estimated average ET from planting to harvest (excluding preplant-irrigations and evaporation losses) is 1,586,200 ac-ft with an estimated minimum of 1,517,100 and a maximum of 1,655,300 ac-ft.

The average on-farm irrigation consumptive use coefficient was 65 percent. The confidence range of 61 to 70 percent. Estimated effective rainfall, though small, was subtracted from total ET in these calculations.

Variation in Annual On-Farm Consumptive Use Coefficient for 1987-1992. A summary of estimated on-farm consumptive use coefficent and CU_e plus LR by years considering ET from planting to harvest is presented in Figure 14. Individual years were modified to reflect the differences in mean ET_o for individual years and crop acreages in individual years.

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Row 16-Dec-93 SUMMARY OF ET ESTIMATES FOR IID - 1987-1992 \SUMETCIV

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
					SUMMARY									
	Period		Foot-								Sum		Water	7
Crop	Start	End	note	ETo	Rain	ET	E+	Re	Re	Avg Kc	ET+E+	Footnote	del	CUc
				In.	In.	In.	In.	In.	%	- -	In.		In.	%
FIELD:														
Alfalfa	01-Jan	31-Dec	1	72.5	4.4	62.3	1.6	2.7	63%	0.86	50.6	5	67.7	71%
Alf, Seed	15-Mar	01-Aug	2	38.6	0.8	18.3	0.8	0.0	0%	0.47	19.1	3	21.1	90%
Berm Grass	01-Mar	31-Oct		56.1	1.3	53.0	1.3	0.0	0%	0.94	54.6		68.9	79%
Cotton	31-Mar	31-Oct		55.7	1.6	36.5	1.3	0.2	16%	0.66	37.8		52.2	72%
Oats	01-Jan	30-Apr		18.7	2.1	16.3	1.3	0.8	39%	0.87	17.5		22.1	76%
Rye Grass	01-Jan	30-Apr		28.5	2.2	25.9	1.2	1.0	47%	0.91	27.0		46.0	57%
Sudan Gr	01-Apr	01-Oct		46.3	0.8	44.2	0.4	0.3	43%	0.95	44.6		58.7	75%
Sugar Beets1	30-Jun	30-Apr		54.3	4.1	37.8	1.5	2.6	64%	0.70	32.3	4	39.6	75%
Sugar Beets2	30-Sep	30-Jun		48.2	3.9	43.8	1.0	1.8	47%	0.91	35.7	4	39.6	86%
Wheat	01-Jan	31-May		28.2	2.2	23.3	1.3	0.9	42%	0.83	24.6		30.0	79%
FRUIT:														
Citrus	01-Jan	31-Dec		72.5	4.4	51.1	2.9	1.5	34%	0.70	47.0		54.4	84%
Peaches/Peca	01-Apr	15-Nov	No cov	57.3	1.6	43.2	1.5	0.1	5%	0.75	44.7		79.5	56%
TRUCK														
Artichoke	01-May	10-Mar		62.5	3.9	70.2	1.3	3.0	69%	0.97	71.6		79.6	86%
Asparagus	01-Jan	31-Dec		72.5	4.4	57.7	3.2	1.1	26%	0.80	61.0		101.2	59%
Brocolli	01-Oct	01-Feb		13.3	2.2	9.0	0.8	1.4	63%	0.68	12.6		31.0	36%
Cant, Sprg	31-Jan	31-May		25.5	1.5	20.3	1.1	0.5	31%	0.80	21.3		32.4	64%
Cant, Fall	31-Jul	30-Nov		24.0	1.2	18.7	0.9	0.3	26%	0.78	17.1		19.2	87%
Carrots	30-Sep	30-Apr		29.6	3.6	18.0	2.3	1.3	37%	0.61	20.3		39.8	48%
Cauliflower	01-Oct	31-Jan		13.3	2.2	9.0	0.8	1.4	63%	0.68	9.8		37.7	22%
Corn, ear	15-Jan	15-May		22.0	2.1	18.8	1.2	0.8	40%	0.85	20.0		40.0	48%
Lettuce-1	31-Aug	31-Dec		17.8	1.7	16.1	0.4	1.3	76%	0.90	16.5		35.9	42%
Lettuce-2	31-Oct	31-Mar		17.2	3.0	17.1	0.9	2.0	69%	0.99	18.0		35.9	44%
Melons,HDF	01-Aug	31-Dec		31.8	2.1	15.8	1.2	0.9	42%	0.50	16.9		24.2	66%
Melons,Wtr	01-Jan	30-Apr		18.7	2.1	13.6	1.5	0.6	29%	0.73	15.0		40.8	35%
Onions	01-Jan	31-May		37.3	2.3	31.5	1.1	1.2	53%	0.84	32.6		52.8	59%
Onion Seed	01-Jan	31-May		37.3	2.3	31.5	1.1	1.2	53%	0.84	32.6		51.4	61%
Tomatoes,S	31-Jan	31-May		34.8	1.7	25.8	0.9	0.8	45%	0.74	26.7		43.7	59%

1. Same for row and flat alfalfa.
2. Assume production of hay up to 15-March.
3. For only the seed-producing period.
4. Sugar beet harvest begins before the last date of the period. Total ET+E+ was reduced by the average of the last two months (assumes that harvest takes place over two months).
5. (ET + E+) reduced based on regression equation of alfalfa Y-ET using data from locations with many years of Y-ET data (New Mexico, Nevada, Idaho, and North Dakota), and average IID yields for 1987-1992. ET = (Y + 0.62)/0.194, ET in inches and yield in tons/acre at 0 moisture.
6. Several periods, such as for broccoli, cauliflower, etc. need to be verified.
7. The irrigation water consumptive use coefficient, CUc, is CUc = 100(ETc - Re)/Water delivered.

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Row 16-Dec-93 SUMMARY OF ET ESTIMATES FOR IID - 1987-1992 \SUMETCIV

Row	Crop	Crop Distribution 550,178 Average	100.0% Pct	Sum ET+E+-Re Ac-ft/ac	Ac x ET-Re Ac-ft	Distr-ibution %	Confidence interval Crop ET %	Normalized CV	CV^2	Boyle (CVWD) In.	Ft
79	==========										
84	FIELD CROPS:										
85	Alfalfa, row	29,872	5.4%	4.0	119,151	7.5%	10%	0.0038	1.41E-05	70.1	5.8
86	Alfalfa, flat	156,710	28.5%	4.0	625,063	39.4%	10%	0.0197	3.88E-04	70.1	5.8
87	Alfalfa Seed	6,619	1.2%	1.6	10,535	0.7%	10%	0.0003	1.10E-07		
88	Bermuda Grass	6,608	1.2%	4.6	30,064	1.9%	10%	0.0009	8.98E-07		
89	Bermuda Seed	9,845	1.8%	4.6	44,793	2.8%	10%	0.0014	1.99E-06		
90	Cotton	12,960	2.4%	3.1	40,576	2.6%	7%	0.0009	8.02E-07		
91	Oats	2,443	0.4%	1.4	3,400	0.2%	10%	0.0001	1.15E-08		
92	Rye Grass	8,143	1.5%	2.2	17,660	1.1%	10%	0.0006	3.10E-07		
93	Sudan Grass	44,594	8.1%	3.7	164,510	10.4%	10%	0.0052	2.69E-05		
94	Sugar Beets	39,095	7.1%	2.7	103,601	6.5%	10%	0.0033	1.07E-05		
95	Wheat	64,491	11.7%	2.0	127,192	8.0%	10%	0.0040	1.61E-05		
96	Other	2,021	0.4%	1.4	2,812	0.2%	10%	0.0001	7.86E-09		
97	Subtotal	383,400	69.7%			81.3%					
98	FRUIT CROPS:										
99	Citrus	2,221	0.4%	3.8	8,425	0.5%	10%	0.0003	7.05E-08	45.0	3.8
100	Peaches/Pecans	382	0.1%	3.7	1,419	0.1%	10%	0.0000	2.00E-09		
101	Other	6	0.0%	0.0	0	0.0%	10%	0.0000	0.00E+00		
102	Subtotal	2,609	0.5%			0.6%					
103	TRUCK CROPS:										
104	Artichoke	415	0.1%	5.7	2,368	0.1%	15%	0.0001	1.25E-08		
105	Asparagus	5,658	1.0%	5.0	28,215	1.8%	15%	0.0013	1.78E-06		
106	Broccoli	9,731	1.8%	0.9	9,109	0.6%	15%	0.0004	1.85E-07	14.3	1.2
107	Cantaloupes, S	18,974	3.4%	1.7	32,968	2.1%	15%	0.0016	2.43E-06		
108	Cantaloupes, F	7,400	1.3%	1.4	10,357	0.7%	15%	0.0005	2.40E-07		
109	Carrots	13,234	2.4%	1.6	20,918	1.3%	15%	0.0010	9.78E-07	21.0	1.8
110	Cauliflower	6,037	1.1%	0.7	4,267	0.3%	15%	0.0002	4.07E-08		
111	Corn, Ear	2,499	0.5%	1.6	4,002	0.3%	15%	0.0002	3.58E-08		
112	Lettuce	29,070	5.3%	1.3	37,785	2.4%	15%	0.0018	3.19E-06	15.5	1.3
113	Melons, HD, F	1,326	0.2%	1.3	1,772	0.1%	15%	0.0001	7.02E-09		
114	Melons, Wtr	3,462	0.6%	1.2	4,163	0.3%	15%	0.0002	3.87E-08		
115	Onions	10,061	1.8%	2.6	26,314	1.7%	15%	0.0012	1.55E-06		
116	Onion Seed	2,358	0.4%	2.6	6,168	0.4%	15%	0.0003	8.50E-08		
117	Tomatoes, S	6,970	1.3%	2.2	15,093	1.0%	15%	0.0007	5.09E-07		
118	Veg, mixed	1,320	0.2%	2.2	2,858	0.2%	15%	0.0001	1.83E-08		
119	Misc.	7,516	1.4%	2.2	16,276	1.0%	15%	0.0008	5.92E-07		
120	Subtotal	125,617	22.8%			14.0%					
121	MISC:										
122	Duck Pd/Fish F	8,768	1.6%	5.7	49,980	3.2%	10%	0.0016	2.48E-06	87.7	7.3
123	Miscellaneous	2,214	0.4%	5.7	12,622	0.8%	10%	0.0004	1.58E-07		
124	Leaching	3,102	0.6%	0.6	1,768	0.1%	10%	0.0001	3.11E-09		
125	Subtotal	14,085	2.6%			4.1%					

Row				Sum CV^2	CV^0.5	Range of estimates Min	Max
126							
127	Total	1,586,203	Std dev = 34,552	4.74E-04	0.0217	1,517,099	1,655,307
128	Average water delivered to agric. users	2,426,349	Boyle (1993) 5% 0.0250	6.25E-04	0.025	2,305,032	2,547,666
129	Total variance, ET and water delivered			0.001099	0.0331		
130	On-farm consumptive use coefficient	65.4% (Excluding LR)		Std dev=	3.3%	61.0%	69.7%
131							

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Figure 14. Estimated on-farm consumptive use coefficients and percentage of water delivered relative to reference ET/cropped area by year.

Evaluation of Water Delivery v. CIMIS Annual Reference ET

The results clearly show decreasing on-farm consumption of irrigation water from 1987 through 1991. During the same period, the amount of water delivered relative mean annual reference ET times the cropped area increased. These results show that water deliveries were not being reduced as evaporative demand decreased. The trends changed somewhat in 1992.

The above trends are supported by data reported by IID showing farm drainage discharge into the Salton Sea. At this time, I did not have data for 1992. The increase in runoff to the Salton Sea from 1987 through 1991 during years of decreasing evaporative demand supports the above statement that there appears to be a lack of response to changing evaporative demand as measured by the CIMIS. Other factors may have been involved such as the lining of canals during this period which would reduce seepage losses. Adjusting for such chanages may not yet have been taken into account.

Summary of Weather-Based ET Estimates

On-farm ET represents the major consumption of irrigation water delivered to the district. The annual value of $(1 - CU_c)$ should approximate the fraction of irrigation water delivered that drained into the Salton Sea. A comparison of $(1 - CU_c)$ with the ratio of drainage to the Salton Sea relative to the total flow at Drop 1 indicates that these preliminary ET estimates for the IID appear reasonable.

Figure 15. Variation in $(1 - CU_c)$ and ratio of water drained the Salton Sea to total flow at Drop 1.

Proposed Grape Crop Coefficients for IID/CVWD

Since the grape season begins earlier in the IID/CVWD, Pruitt's grape coefficients were shifted forward to reflect earlier growth. The resulting coefficients proposed for use in the CVWD for table grapes is shown in Figure 16. The seasonal total ET using IID reference ET is 47 inches. Boyle used 45 inches in the CVWD report.

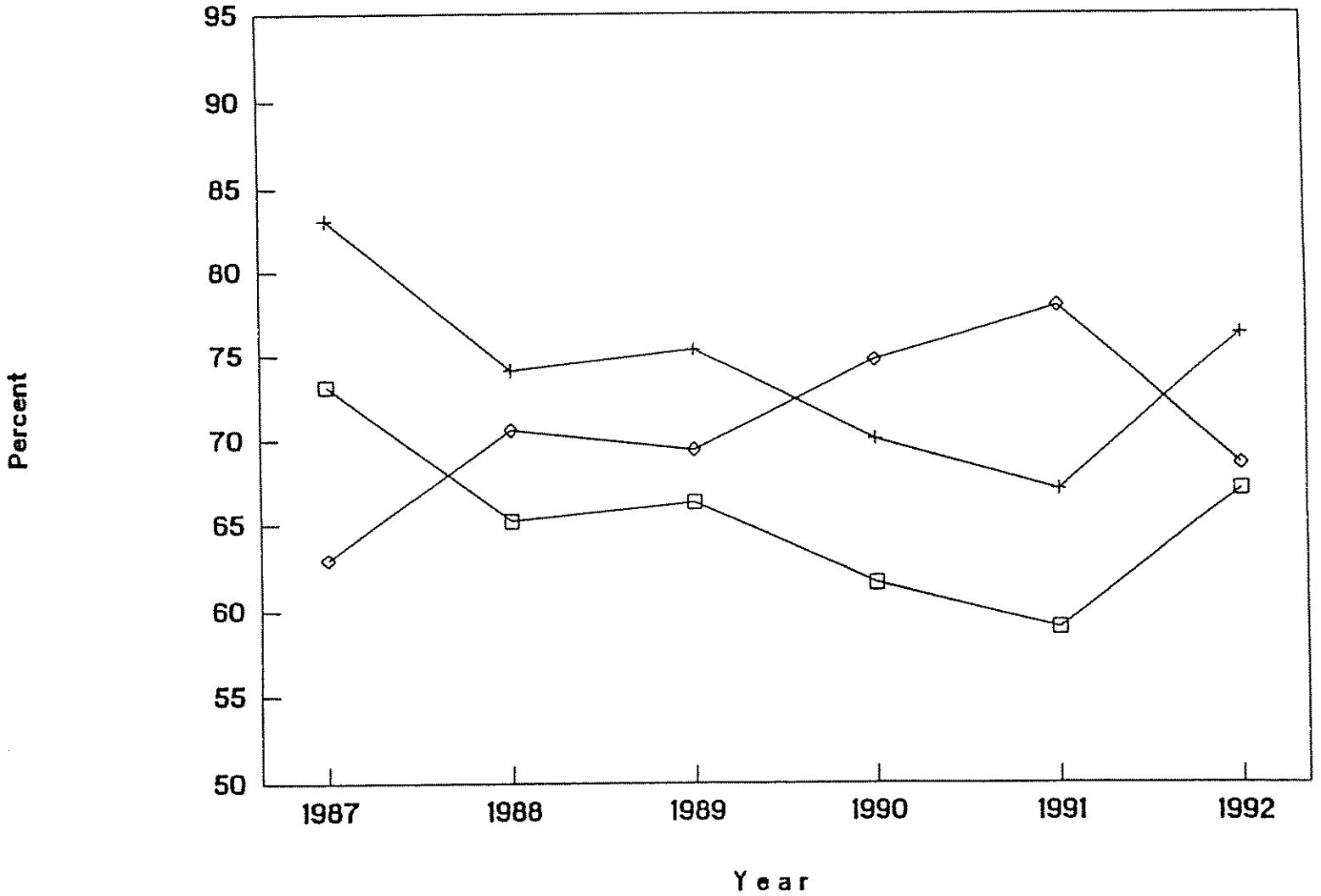
Figure 16. Pruitt's and Burt's grape crop coefficients.

SUMMARY AND CONCLUSIONS

ET can be estimated with reasonable accuracy using existing crop coefficients and reference ET measured by CIMIS. Data on the range of planting, crop development, and harvest dates and leaf-area development rates will be needed in Phase II to enable refining ET estimates. The estimates of mean annual ET relative to water deliveries in the IID from 1987 through show that IID irrigation water orders and deliveries did not respond to decreasing evaporative demand as measured by the CIMIS. Increasing farm drainage to the Salton Sea during the same period shows the same general trend.

CU, LR & WTR DEL/ETo x CROP AREA - IID

CU BY ET x CROP AREA -- 1987-1992



□ CUc, Var A & ETo + (CUc+LR), Var A&ETo ◇ Water Del/ETo x Area

Fig. 14

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ESTIMATED IRRIG CU v. RETURN FLOW - IID

CU BY (ET-Re) x CROP AREA -- 1987-1992

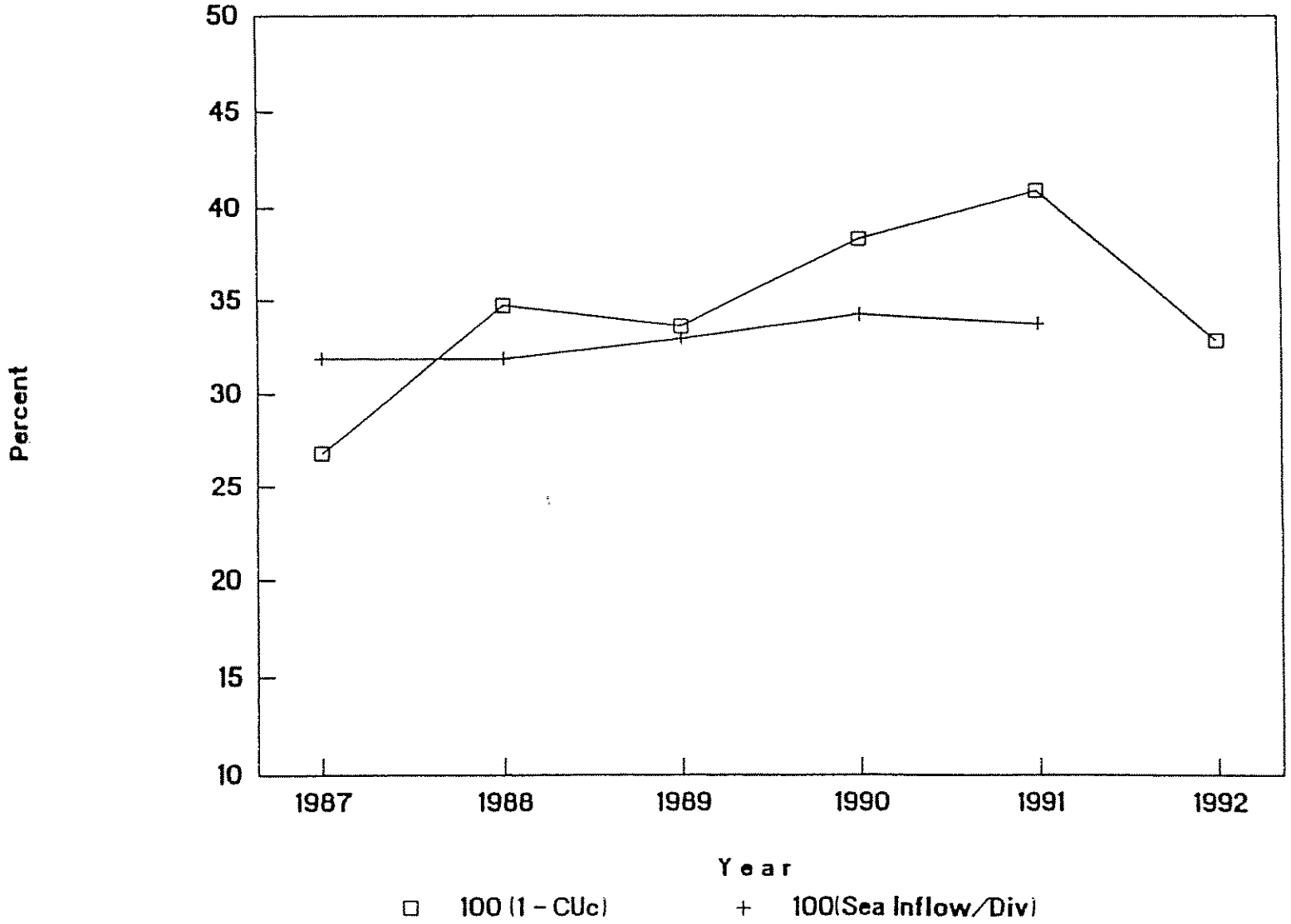

Fig. 15

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TABLE GRAPE CROP COEFFICIENTS

FOR USE WITH ETo

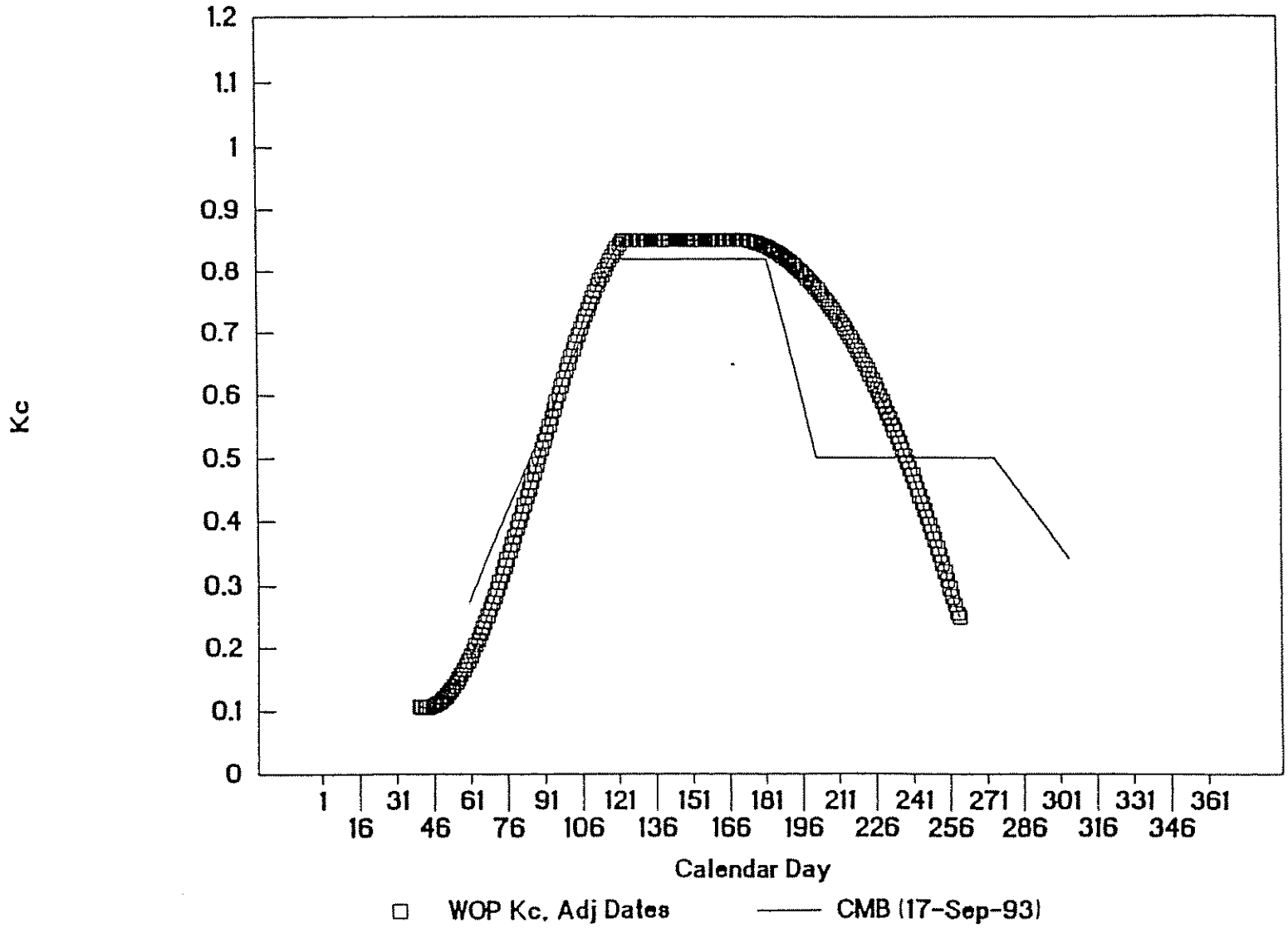

Fig. 16

REFERENCES

Bauder, J.W., A. Bauer, J.M. Ramirez, and D.K. Cassel. 1978. A;lfalfa water use and production on dryland and irrigated sandy loam. Agron. J. 70:95-99.

Grimes, D.W., and L.E. Williams. 1990. Irrigation effects on plant relations and productivity of Thompson seedless grapevines. Crop Sci. 30:255-260.

Hely, A.G., G.H. Hughes, and B. Irelan. 1966. Hydrologic Regimen of Salton Sea, California. Geologic Survey prof. Paper 486-C, 36 pp.

Hill, R.W., E.L. Johns, and D.K. Frevert. 1983. Comparison of Equations Used for Estimating Agricultural Crop Evapotranspiration with Field Research. U.S.Bureau of Reclamation, Denver, 100 pp. plus appendices A-F.

Jensen, M.E., R.D. Burman, and R.G. Allen (eds). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, New York, 360 pp.

Pruitt, W.O., E. Fereres, K. Kaita, and R.L. Snyder. 1987. Reference Evapotranspiration (ET_o) for California. Agr. Exp. Sta. Bull. 1922, Univ. of Calif., 16 pp. and 12 maps.

Styles, S. 1993. On-Farm Irrigation Efficiency: Special Technical Report for the Imperial Irrigation District. August.

University of California. Undated. Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops. Coop. Extension, Div. of Agr. and Natural Resources, Leaflet 21427, 12 pp.

Wright, J.L. 1988. Daily and seasonal evapotranspiration and yield of irrigated alfalfa in southern Idaho. Agron. J. 80:662-669.

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16 Dec-93

APPENDIX A

BASIC ASSUMPTIONS USED IN ESTIMATING EVAPOTRANSPIRATION

Assumptions or conditions assumed in estimating evapotranspiration are summarized on the following page.

Generic equations for the crop coefficients from planting to full cover and days after full cover will be summarized in a separate report after completing the estimates for the CVWD.

Specific spreadsheet files that were used can be made available if needed. However, they are not fully automated and require some manual adjustments in changing crops.

SUMMARY OF JMLORD's CROP COEFFICIENTS AND EQUATIONS - FIELD CROPS "PRELIMINARY" \KC-SUMRY

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
3																			
4	JMLORD:		Test Eqn	Alf(Seed)		Berm-Grass			Cotton		Oats	Rye Grass		Sudan Grass		Sgr Beets-1		Sgr Beets-2	
5	Factor		1	1.2		1.2			1.2		1.2	1.2		1.2		1.2		1.2	
6	Co =		0.15	0.15					0.15										
7	C1 =		10	10					8										
8	C2 =		460	460					224										
9	C3 =		2	2					2										
10	C4 =		6000	6000					10000										
11	C5 =		1	1					1										
12	C6 =		1	1					0.93										
13	C7 =		3E-04	3E-04					2E-03										
14	C8 =		14	14					20										
15	C9 =		2	2					1.5										
16																			
17	Plant, CD		334	334					90										
18	Full C,CD		460	460					224										
19	Harv, CD		516	516					304										

20 BASIC EQUATIONS: Apply Pct or D from CD = 1 to CD(harvest)

21 @IF CDp =< CD =< CDfc, then Pct = 110 * [(CD - CDp)/(CDh - CDfc)]

22 @IF CDfc > CD =< CDh, then D = (CD - CDfc)

23 Planting to full cover: Kc = Factor x [Co + (Pct - C1)^C3/C4], =< C5

24 After full cover: Kc = Factor x [C6 - C7*(D - C8)^C9]

25 CD Pct/D Kc

26 334 0 0.17 For CD(plant) to CD(full cover) Base Equation

335 1 1.00 For CD(full cover) to CD(harvest) Base Equation

After applying base equations, convert to "values" before saving to reduce file size and permit data transfers.

28 Alf(Seed) Cotton

29 CD Pct/D Kc Pct/D Kc Pct/D Kc Pct/D Kc Pct/D Kc

30 ----------

31 1 0 0 0

21-Nov-93 SUMMARY OF ET ESTIMATES FOR IID - 1987-1992 \SUMETCIV

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INPUT DATA:

Climate: Mean CIMIS ETo values from Stations 41, 68 and 87 for 1987-1992.

Rainfall: Mean distribution of rainfall events from CIMIS 41, 68 and 87.

Cropping Dates: Derived mainly from UC Leaflet 21427 and IID Schedule of Major Crops.

Crop Coefficients: Mainly daily values based on generalized curves for JMLord coefficients multiplied by 1.2. Several curves were from W.O. Pruitt (ASCE Manual 70, page 127. Curves were shaped based on daily lysimeter-based data from J.L. Wright (ASCE Manual 70).

Soil: Drained upper limit (FC) = 36 % by volume; Lower Limit = 21 % by volume. Source: ASCE Manual 70, p. 21.

Effective Rain: Total minus the increase in evaporation due to rain, E+, was estimated using the equation on p. 118, ASCE Manual 70. No runoff was assumed for the small events.

ASSUMPTIONS:

1. Soil water was assumed adequate and did not limit ET.

2. No increase in evaporation, E+, was added due to wetting following irrigations because irrigation frequency was not known. Frequency is dependent on depth to the water table and its effects. Data on irrigation frequency would enable estimating this component of ET.

EVAPOTRANSPIRATION AND FARM CONSUMPTIVE USE ESTIMATES FOR CVWD

by
Marvin E. Jensen
21 December 1993

INTRODUCTION

The Technical Work Group (TWG) is using several approaches to estimating farm irrigation efficiency. One approach is to estimate evapotranspiration (ET) for major crop groups and then multiply by crop acreages to arrive at total ET. Estimating ET for the various crops grown in the Coachella Valley Water District (CVWD) required summarizing six years of climatic data and selecting and adapting crop coefficient values for convenient use on a daily basis using a spreadsheet approach. For future routine computations, a software program in BASIC or FORTRAN should be considered as it will simplify recalculations as crop coefficients and/or planting and harvest dates are updated.

The major input variable used in this analysis was reference ET (ET_o) provided by CIMIS station 50 at Thermal, California. Disk file copies (UPDATE.DBF and UPDATE1.DBF) of CIMIS data used in preparing the summary data in the Boyle (Styles, 1993) report were used in this study as was done for evaluating reference ET estimates.

The procedures used in this analysis were essentially the same as used for making ET estimates in the Imperial Irrigation District (IID) except for three crops. Yield-based estimate of alfalfa ET was not used for CVWD, Pruitt's citrus coefficients reduced by 15 percent were used, and a two methods of estimating date ET were used and averaged. Dates are not grown in the IID and the area of citrus is relatively small in IID.

PROCEDURES

Alternative Mean Climate Data Sets

Six years of daily ET_o values were available from CIMIS station 50 (Thermal) for the period 1987-1992. The station was moved between 1989 and 1990 to a site that is more representative of irrigated crops. Five years of data were available from CIMIS Station 55 (Palm Desert), but the ET_o values for that site were about 10 percent less than those at Station 50 during the period 1990-1992. A check of the main variables affecting ET_o at the two sites indicated that the wind speeds at Station 55 were about 2/3 of those at Station 50. This indicates that CIMIS site 55 may not be representative of agricultural crops. Therefore, reference ET values from Station 55 were not used in establishing the set of mean daily reference ET values.

The overlap in data between stations 50 and 55 did provide a means for adjusting the CIMIS 50 reference ET values from 1987 through 1989 to be comparable with 1990-1992 values. The 1987-1989 values were increased 5.2 percent, the net effect of the move. A summary of the annual total reference ET values for Stations 50 and 55 before and after adjustment are shown in Figure 1 along with mean reference ET values for IID.

Fig. 1. Mean annual reference ET from CIMIS Stations 50 and 55, adjusted reference ET values for 1987-1989 for Station 50, and mean reference ET for the IID which is the mean of CIMIS Stations 41 (Mulberry), 68 (Seeley) and 87 (Meloland).

REFERENCE ET - CIMIS 50

THERMAL (50), & PALM DESERT (55), CA

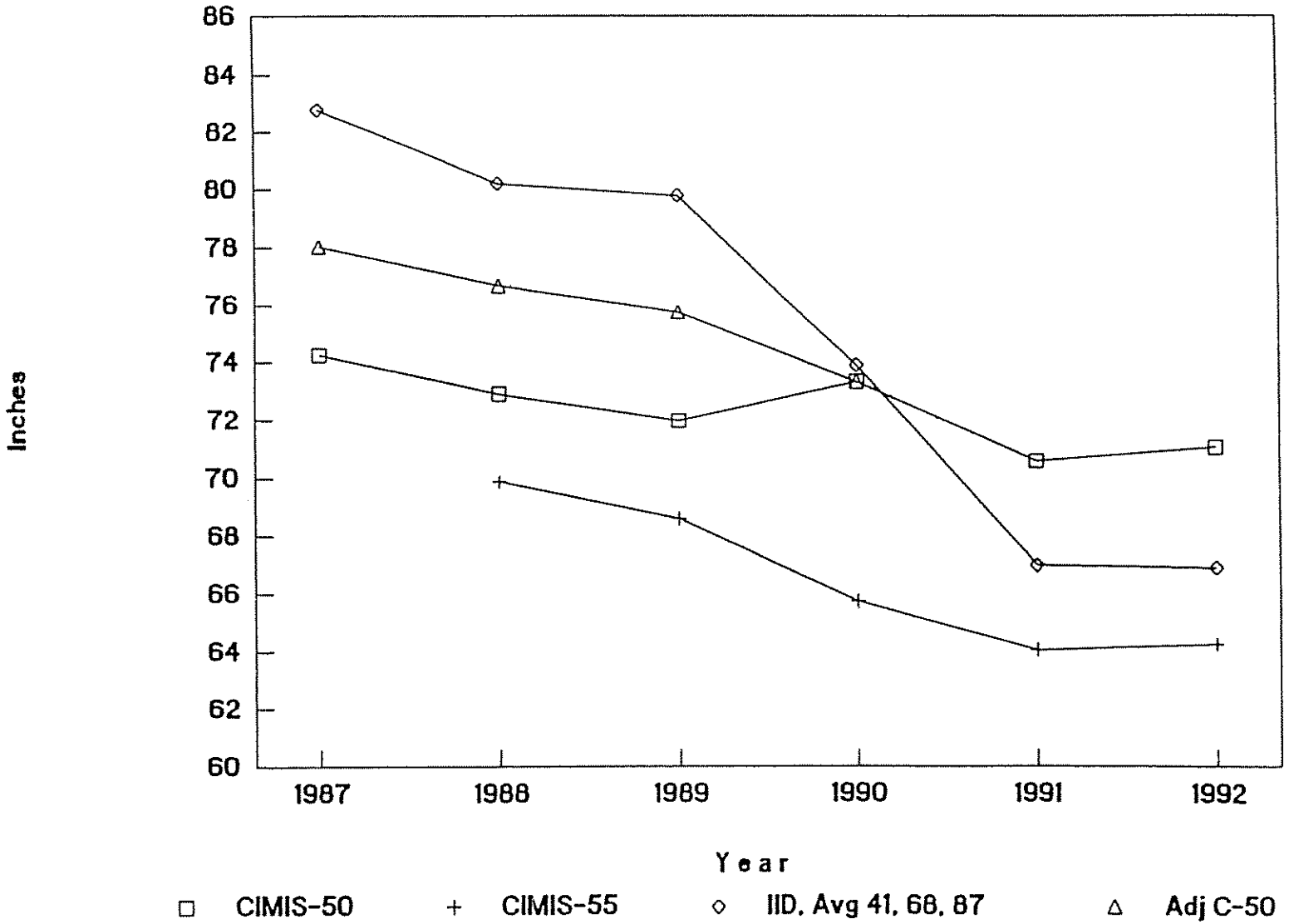


Fig. 1

2

The adjusted six-year values for Station 50 show a general decrease from 1987 to 1992, similar, though not as large as that in IID. The six-year mean annual reference ET values for the two sites were essentially the same, 75.1 inches for IID and 74.2 inches for CVWD.

As noted for IID ET estimates, daily estimates for individual years were not used because a matrix of 2192 rows would have been required. With repetitive applications of crop coefficients, a spreadsheet approach would have been very cumbersome and the resulting spreadsheet would have been very large.

The alternative approach of establishing a set of mean daily ET_o for 365 days based on the data available from CIMIS Station 50 was selected. Even with this reduced matrix, a computer software that enabled using expanded memory was required when estimating ET for individual crops and converting and saving individual crop ET values. Four spreadsheet files were used to enable estimating and saving ET values for all of the crops.

Crop Coefficient Data Sets

Two primary sources of crop coefficients (K_c) were evaluated before selecting coefficients for various crops: 1) University of California Leaflet 21427, and 2) a set coefficients provided by JMLord, Inc. The ASCE Manual 70 and several other references provided alternative values for some crops. Leaflet 21427 (UC, undated) provided starting point information about planting and harvest dates for many crops grown in the IID. For dates, crop ET estimates using coefficients from JMLord, Inc. appeared to be too low when compared with ET estimates using ET/R_s ratios derived from a four-year study by Pillsbury (1941) conducted in the Coachella Valley (1932 and 1936-38). JMLord's coefficents may have been based on Pillsbury's data which were estimates of transpiration and not ET.

Pillsbury's estimates of transpiration were made by taking soil moisture samples below the surface mulch of about 5 inches during periods between irrigations. During the early 1960s, I estimated that the 5-inch soil layer lost as much moisture by evaporation as the next soil layer sampled to arrive at estimates of ET for use the article by Jensen and Haise (1963). Solar radiation was estimated and the resulting mean monthly ET/R_s ratios were included in our 1963 publication. These ratios were used with mean 1987-92 solar radiation data to provide an alternative estimates of ET for dates.

As reported in my ET report for IID, I was not able to use daily crop coefficients derived from UC Leaflet 21427 in quantifying ET values for most crops because the values clearly do not represent real crop development characteristics. **The UC coefficients appear to be intended for management purposes such as irrigation scheduling and possibly for establishing peak ET values for determining system capacity requirements. They do not appear adequate for estimating quantities of ET.**

The data set provided by JMLord, Inc. uses five values for the growth period from planting to full cover (0, 25, 50, 75, and 100 %), and four values for growth periods after full cover (growth intervals 1, 2, 3 and 4). Applying these coefficient on a daily basis would have required interpolation between two data points for seven periods for each crop. This became a very cumbersome procedure using a spreadsheet approach. Therefore, generic equations for daily values were calibrated for the two periods, 1-100 percent of full cover and days after full cover. This required only two equations for each crop instead of seven. The generic equations were based on curves of crop coefficients that were developed from daily lysimeter data for row crops and close planted crops by Wright as summarized in ASCE Manual 70 (Jensen et al., 1990). JMLord crop coefficients were developed for use with an alfalfa reference crop. They were multiplied by 1.2 for use with CIMIS reference ET.

Rainfall Values for the Mean Climatic Data Set

Rainfall data from the Thermal, California provided by the CVWD were summarized and grouped into discrete rainfall events for each month of the year. Then, based on the average number of rain storms of different sizes, a set of monthly rain storms was selected to provide approximately the same average total annual rainfall for the 1987-1992 period. With these average rainfall events, an estimate of effective rainfall for each crop was obtained.

Effective Rainfall

Since most all of the individual rainfall events in the data set were small, no runoff was assumed and the increase in evaporation following a rain event was based on the following equations (ASCE Manual 70, page 118):

$$E+ = 0.35(1.5 + t_d)(K_1 - K_a K_{cb})\, ET_o \qquad (1)$$

where E+ = the increase in evaporation following wetting of the soil and foliage, t_d is the number of days for the soil surface to visually appear dry (7 days was used for a fine texture soil), K_1 is the maximum value of K_c after a rain or irrigation (1.2 was used), K_{cb} is the basal crop coefficient, and K_a is a dimensionless coefficient that is dependent on available soil water (K_a = 1.0, soil water not limiting, for this analysis). The maximum value of E+ could not exceed the rainfall received.

Major Crop Groupings

A large number of crops are grown in the CVWD, but many represent a very small percentage of the irrigated crop land. The most recent crop acreage data provided by JMLord, Inc. grouped most of the truck crops under **miscellaneous vegetables**. Therefore, CVWD reports of individual crops acreages to the USBR and crop acreages from the Boyle (Styles, 1993) report were used to approximate individual crop acreages. A mean six-year summary of major crops were used to estimate the total ET for the average 1987-1992 period.

Cropping Period for ET Estimates

Estimates of ET were made from planting to harvest. Soil water was assumed to be at the drained upper limit, or field capacity, at planting for a fine texture soil (ASCE Manual 70, page 21). Since no information was available on irrigation frequency or rooting depth, available soil water was not assumed to affect ET.

Evaporation Losses after Preplant-Irrigations

Since ET estimates were desired, no estimates of evaporation losses during and after preplant-irrigations were included in my estimates. Assuming that preplant-irrigations were made prior to planting or for germinating seeds, evaporation estimates can be made in Phase II. Estimates of evaporation would need to be added when comparing water balance estimates with ET x crop area estimates.

Adjusting ET Estimates for Alfalfa

Because the soils in the CVWD are more permeable than in the IID, soil water was not assumed to limit alfalfa growth. Therefore, no adjustment of estimated alfalfa ET based on yields was made.

Evaporation Estimates for Duck Ponds, Fish Farms and Leaching

Average evaporation estimates for ponds and reservoirs in my report "Evaluating Evaporation Estimates for IID" were used for duck ponds, fish farms, farm reservoirs, and for areas being leached. It was assumed that areas being leached remained flooded for at least a month. Therefore, 1/10 of annual pond evaporation was used for estimates of evaporation during leaching. Also, based on the percentage of the cropped land in IID that was reported being leached by flooding (less than 1 percent), I assumed that 1 percent of the fallow/leach area in the CVWD was being leached in any one year.

Total ET and Farm Irrigation Efficiency

Total ET was obtained by multiplying crop ET by the estimated crop acreage. The farm irrigation consumptive use coefficient, CU_c, was estimated by dividing the estimated ET of irrigation water by the sum of the estimated Colorado River water delivered to farms and the estimated ground water pumped. An estimate of farm irrigation efficiency was also obtained by including an average leaching requirement of 0.12.

INTERMEDIATE RESULTS OF PROCEDURES

Mean Reference ET Data Set

Mean daily reference ET from CIMIS data from the three sites is presented in Fig. 2. The small dip in reference ET values during May-June is similar to the dip reported during the 1960s USGS Salton Sea study (Hely et al., 1966).

Fig. 2. Mean daily ET from CIMIS Stations 50 (Thermal) for 1987-1992.

Mean Annual Rainfall Distribution Data Set

An analysis of rainfall events for the three stations is summarized in Table 1. For the average 1987-1992 year, the number of rainfall events and amounts are summarized in Table 2. In the IID, 80 percent of the rainfall events produced 0.0 to 0.25 inch of precipitation. CVWD rainfall events were distributed over a wider range than in the IID. Based on the frequency of rainfall events, only 28 percent fall in the range of 0 - 0.25 inch compared to 80 percent in IID, 33 percent in 0.26-0.50 inch v. 16 percent in IID, and 20 percent in 0.51-0.75 inch v. 3 percent in IID. The events that produced more than 0.75-inch was 18 percent v. only 1 percent in the IID. The average rainfall for the period was 3.3 inches. Additional details can be found in my report entitled "Evaluating Effective Rainfall in CVWD" dated 01-Oct-1993.

AVERAGE REFERENCE ET - CVWD

CIMIS STATION 50 -- 1987-92

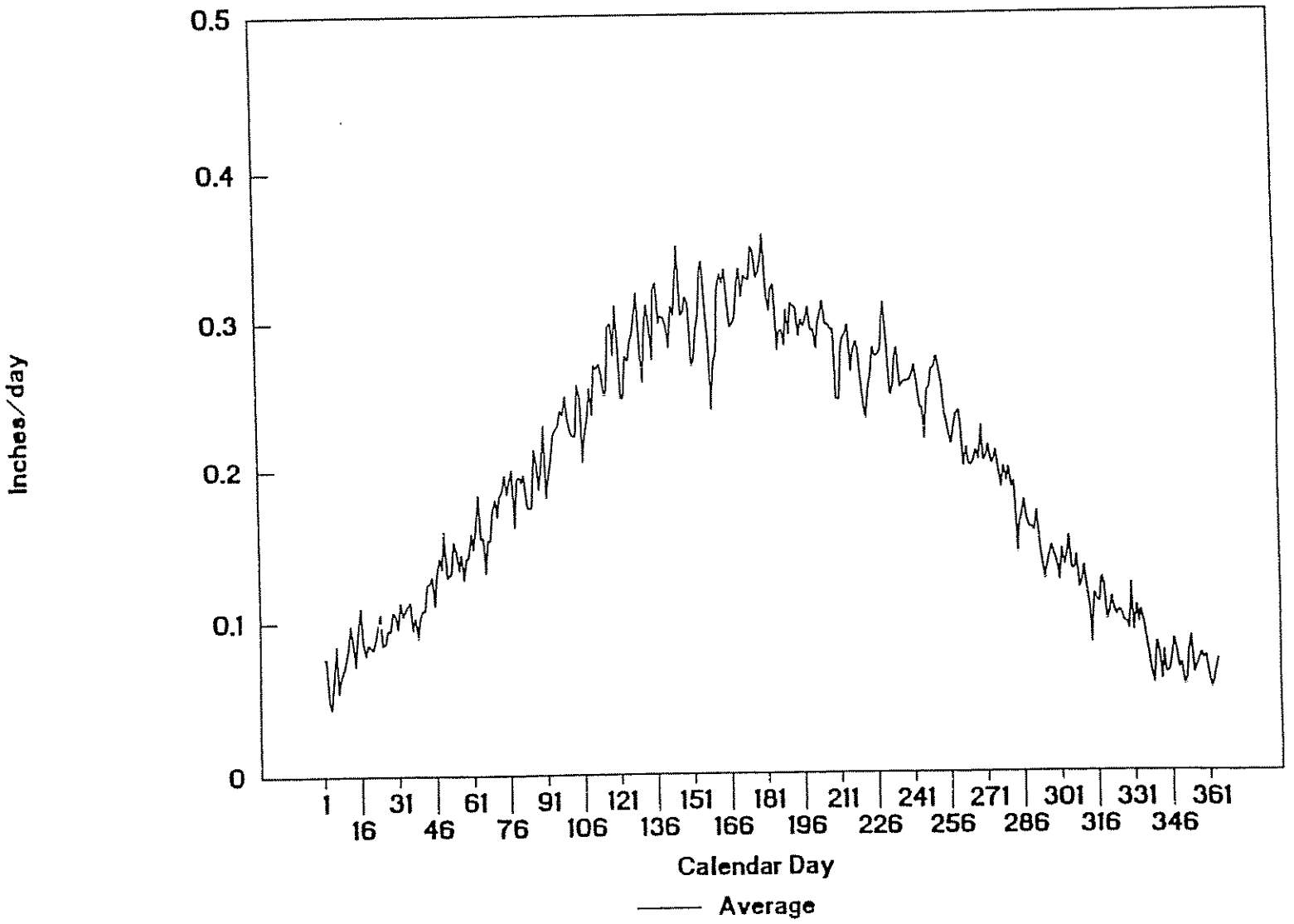


Fig. 2

Table 1. Average number of annual rainfall events in each of seven ranges of amounts from 1986 through 1992.

Month	Range, inches 0-0.20	0.21-0.40	0.41-0.60	0.61-0.80	0.81-1.00	1.01-1.20	1.21-1.40	
Jan	1.29	0.29	0.43	0	0	0	0	
Feb	1.00	0	0.14	0	0.43	0.14	0	
Mar	1.43	0.57	0.43	0.14	0	0	0	
Apr	0.57	0.14	0	0	0	0	0	
May	0.43	0	0	0	0	0	0	
Jun	0.14	0	0	0	0	0	0	
Jul	0.86	0	0	0	0	0	0	
Aug	0.57	0.14	0	0	0	0	0	
Sep	1.00	0.14	0	0	0	0	0	
Oct	0.71	0.71	0	0.14	0	0	0	
Nov	0.86	0.14	0.14	0	0	0	0	
Dec	1.86	0.43	0.29	0	0	0	0	
Avg. rain	1.07	0.77	0.71	0.20	0.39	0.16	0	
Total average annual rainfall								3.3

Table 2. Number of rainfall events and amounts used for the average 1987-1992 year in each of seven ranges of amounts.

Month	Range, inches 0-0.20	0.21-0.40	0.41-0.60	0.61-0.80	0.81-1.00	1.01-1.20	1.21-1.40	Total
Jan	1	1						0.4
Feb	1			1				0.8
Mar	1	1						0.4
Apr	1							0.1
May	1							0.1
Jun	1							0.1
Jul	1							0.1
Aug	1							0.1
Sep	1							0.1
Oct	1	1						0.4
Nov	1							0.1
Dec	2	1						0.5
Events	12	4	0	1	0	0	0	18
Rain	1.2	1.2	0	0.7	0	0	0	3.2

Crops and Cropping Periods

The major crops and the estimated periods of growth used for making ET estimates are summarized in Table 3. Also shown are the estimates of ET and the ET values used in the Boyle report (Styles, 1993). The acres of each crop are summarized in a later spreadsheet table. Some of the dates were obtained from UC Leaflet 21427 and others from the Boyle report.

Table 3. Summary of major crops, growth periods dates, days between planting and full cover, and days between full cover and harvest for IID as used in estimating ET. For Phase II, some refinement is needed in dates which will require assessment of average planting dates, leaf area development rates and harvest dates.

21-Dec-93 SUMMARY OF CROP GROWTH PERIODS AND DAYS TO FULL COVER AND ESTIMATED ET F:\CROP-PER CVWD

		Start or plant		Full cover		Harvest		Days			Est Boyle (1993) ET Table 6-4 (3)	
Crop	Footnote	Date	CD	Date	CD	Date	CD	Plt-FC	FC-Harv	Plt-Harv	Inches	Inches
FIELD:												
Alfalfa, 6/15-7/15	1	15-Jun	166	07-Jul	188		196	23	8	31	63.9	70.1
Cotton		31-Mar	90	12-Aug	224	31-Oct	304	135	80	215	38.4	
Sudan Grass		01-Apr	91	24-May	144	01-Oct	274	- -	130	184	35.6	
Wheat & small grains		01-Jan	1	24-Mar	83	31-May	151	83	68	151	25.9	
					304							
FRUIT:												
Citrus		01-Jan	1	- -	- -	31-Dec	365	- -	- -	365	47.0	45.0
Dates	2	01-Jan	1	- -	- -	31-Dec	365	- -	- -	365	64.3	73.1
Grapes		14-Feb	45	- -	- -	20-Sep	263	- -	- -	219	38.9	39.9
Other tree fruit		01-Apr	91	- -	- -	16-Nov	320	- -	- -	230	45.3	
TRUCK:												
Beans		01-Oct	274	31-Dec	365	01-Mar	425	92	60	151	12.0	
Brocolli		15-Sep	258	17-Dec	351	15-Feb	411	94	60	154	12.3	14.3
Carrots		30-Sep	273	09-Feb	405	30-Apr	485	133	80	213	20.0	21.0
Corn, sweet		15-Jan	15	24-Feb	55	15-May	135	41	80	121	20.6	
Lettuce-1		31-Aug	243	24-Sep	267	02-Jan	367	25	100	125	16.6	15.5
Onions		31-Dec	365	20-Feb	416	31-May	516	52	100	152	29.4	
Peppers		01-Nov	305	01-Apr	456	31-May	516	152	60	212	30.7	
Potatoes		01-Nov	305	24-Feb	420	16-May	500	116	80	196	21.3	
Squash		01-Feb	32	01-Apr	91	31-May	151	60	60	120	19.7	
Watermelon		01-Jan	1	12-Mar	71	31-May	151	71	80	151	23.0	
Misc. vegetables		01-Nov	305	11-Apr	466	30-Jun	546	162	80	242	30.7	
Nurseries		01-Oct	274	12-Oct	285	31-Dec	365	12	80	92	12.7	
Ponds	4	01-Jan	1	- -	- -	31-Dec	365	- -	- -	365	72.8	87.7

1. Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15.
2. Average of estimated ET with JMLord coefficients and estimated ET with Jensen and Haise (1963) ET/Rs coefficients. Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div., Am. Soc. Civ. Engr. 89(IR4):15-41.
3. Styles, S. 1993. On-Farm Irrigation Efficiency - Special Technical Report, Coachella Valley Water District, April.
4. Jensen, M.E. 1993. Report on Evaporation Estimates for IID. 18-Oct, 10 pp + Appendices A & B.

Crop Coefficients

University of California Crop Coefficients. In my IID ET report, daily UC crop coefficient values were first calculated for individual days for the growth periods in Table 3. As I indicated in that IID report, the changes in the coefficients for crop growth are represented by the straight lines. These approximations indicate that these values are not realistic in estimating the quantity of water consumed in ET when compared with other coefficients that change in relation to leaf area development (See Figure 3).

Fig. 3. Comparison of UC, JMLord, and Wright's daily crop coefficients for barley.

JMLord, Inc. Coefficients. Crop coefficients after plant emergence increase with plant growth or leaf area. The rate of leaf area development typically increases as a function of leaf area as illustrated in Figures 4 for the period before full cover and in the ET decrease with maturity as illustrated in Figure 5 for days after full cover. The values in Figures 4 and 5 were based on daily crop coefficient values determined using lysimeter measurements of ET. The curves in the figures are of an exponential or power function type for use with alfalfa as the reference crop. For example, the average equation for row crops (sugar beets, potatoes, corn and beans) illustrated in Figure 4 is:

$$K_{cb} = 0.15 \frac{(P - 30)^{1.8}}{2650}, \; for \; 30 < P < 100 \qquad (2)$$

The equation for small grain illustrated in Fig. 5 is:

$$K_{cb} = 0.15 + \frac{(P - 6)^{1.9}}{5400}, \quad for \; 6 < P < 100 \qquad (3)$$

where P is the percent of the period from planting to full cover. Similar equations approximate the decrease in the coefficient as the crop matures except the value is the maximum minus the power function.

As indicated under Procedures, similar equations were fitted to the coefficients provided by JMLord, Inc. to facilitate calculating daily crop coefficient values which were multiplied by 1.2 for use with the CIMIS reference ET.

Fig. 4. Wright's daily basal crop coefficients for row crops and small grain from planting to full cover (Wright, Table 6.6, ASCE Manual 70).

Fig. 5. Wright's daily basal crop coefficients for row crops and small grain from full cover to harvest (Wright, Table 6.6, ASCE Manual 70).

Alfalfa Coefficients. The duration of the period between alfalfa cuttings during the summer is about 30 days. A comparison of the UC, JMLord x 1.2 and Wright x 1.2 coefficients for a single period between cutting in mid-summer is

CROP COEFFICIENTS - IID

JML Kc x 1.2 v. UC Kc

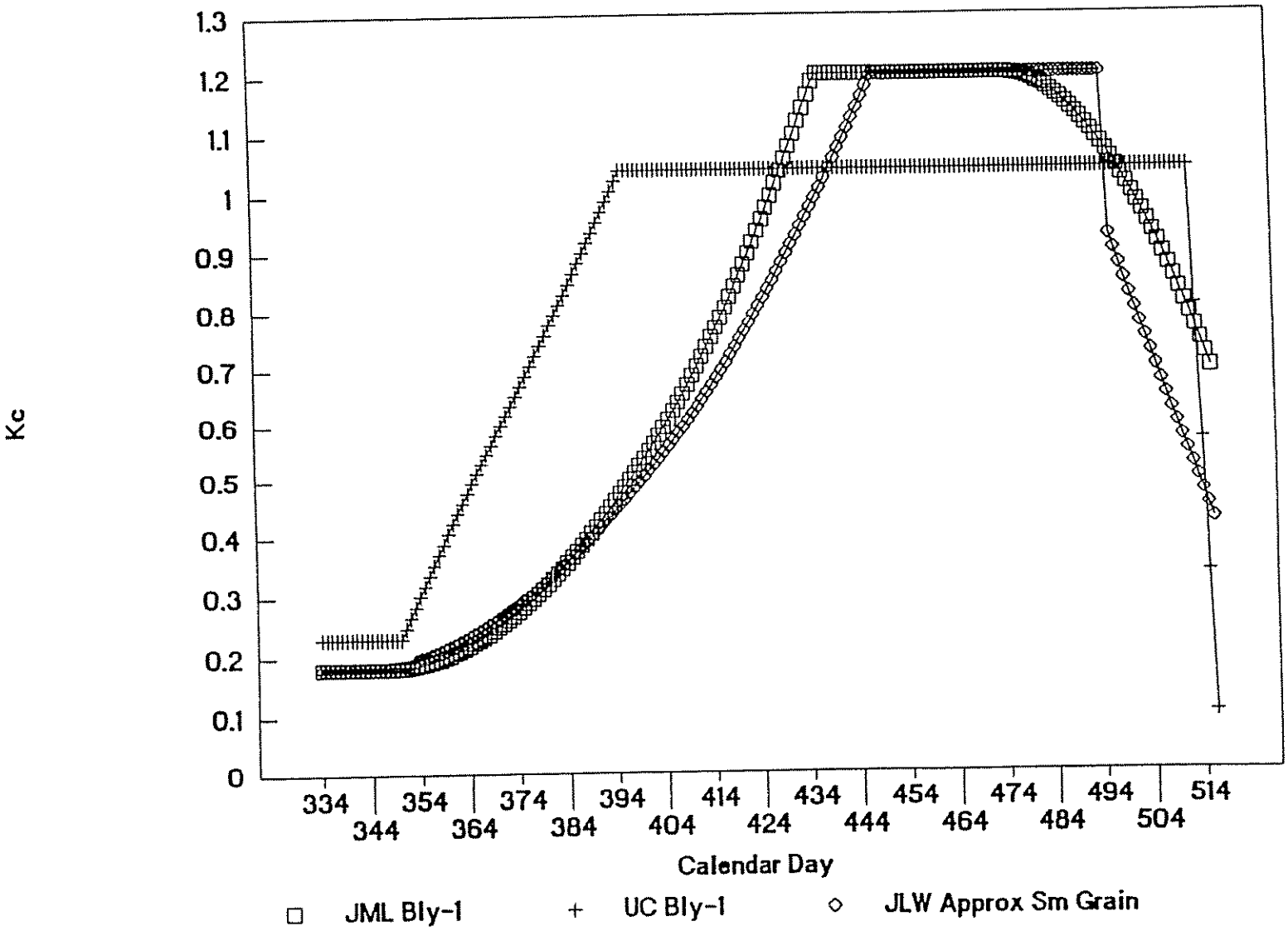


Fig. 3

J L WRIGHT' BASAL CROP COEFFICENTS

Table 6.6, ASCE Man 70

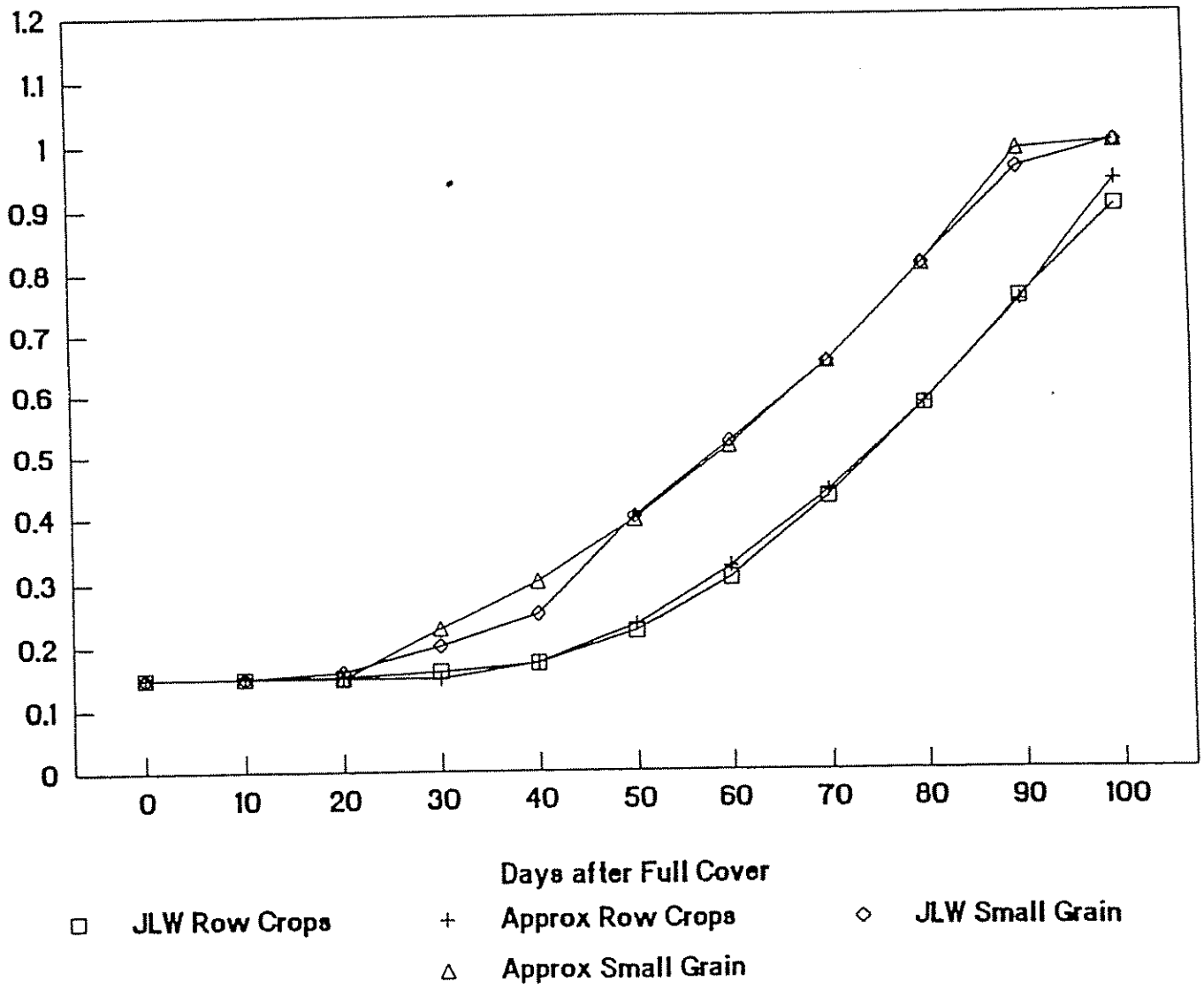
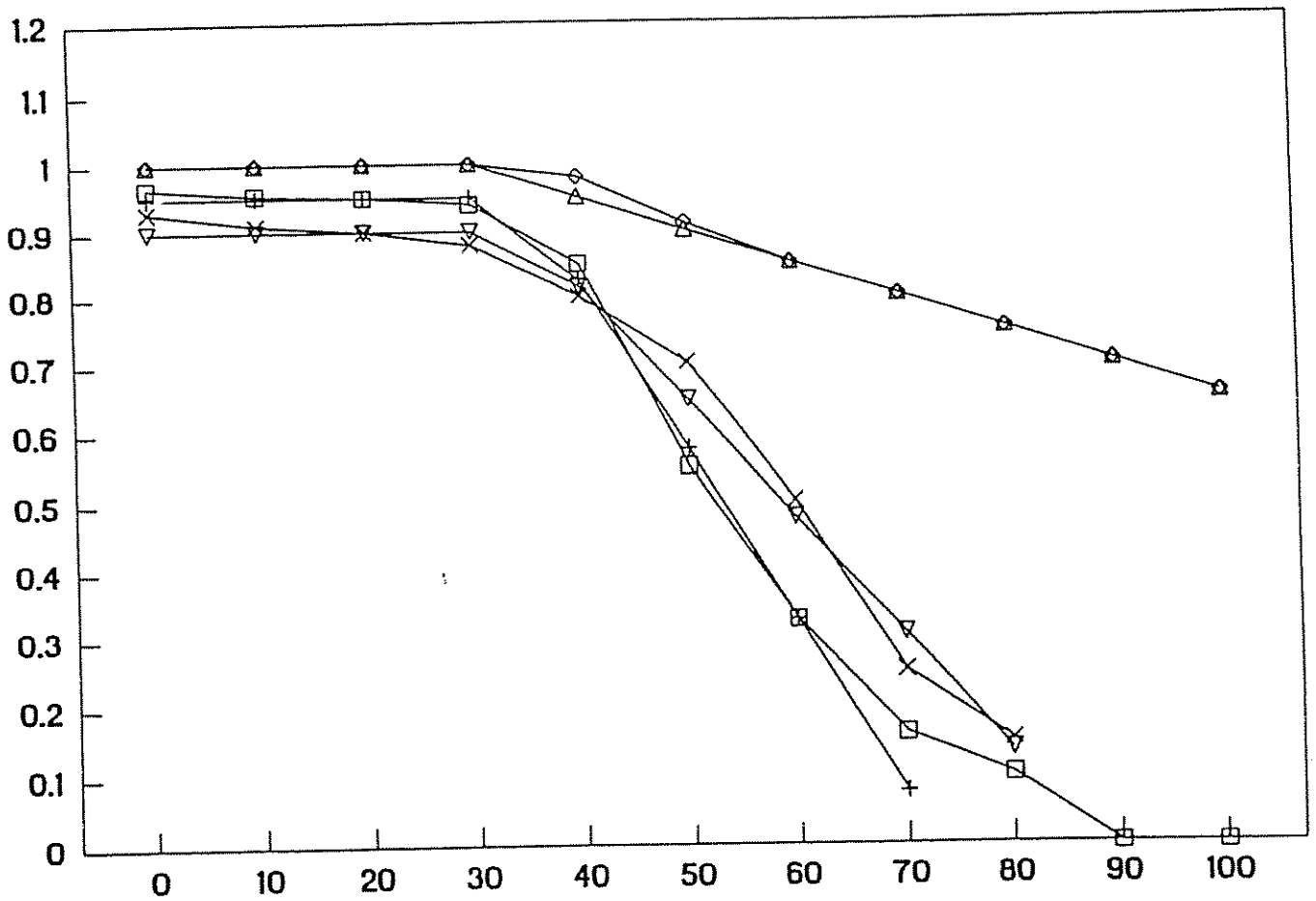


Fig. 4

J L WRIGHT' BASAL CROP COEFFICENTS

Table 6.6, ASCE Man 70



Days after Full Cover

□ JLW Small Grain + Approx Small Grain ◇ JLW S. Beets △ Approx S. Beets

× JLW Sw. Corn ▽ Approx Sw. Corn

Fig. 5

shown in Figure 6. Wright's coefficients were based on seven years of daily coefficients determined using a sensitive weighing lysimeter. Clearly, the UC coefficients do not adequately represent the development of leaf area after cutting and use of UC coefficients would clearly over-estimate alfalfa ET. At this point, I decided against using UC-21427 values for quantifying ET values for the IID. Equations adjusted to fit JMLord's data point were developed for the crops involved except for citrus and grapes.

Fig. 6. Comparison of UC, JMLord and Wright's daily crop coefficients for alfalfa for a 30-day period from mid-June to mid-July.

Citrus Coefficients. Because JMLord's coefficients for citrus seemed to be higher than others being recommended, I elected to use the clean cultivated citrus coefficients developed by Pruitt as printed in Table 6.10, ASCE Manual 70, but I reduced the values by 15 percent (Figure 7).

Fig. 7. Citrus crop coefficients (From Pruitt, 1990).

Grape Coefficients. An assessment of alternative crop coefficients for grapes was made. Three sets of coefficients for grapes are available for specific time periods in California: 1) Grimes and Williams (1990), 2) those suggested by C. M. Burt on 17-Sep-93, and 3) those of Pruitt's from Table 6.10, ASCE Manual 70 (Pruitt et al., 1987). Grimes and Williams coefficients are for Thompson Seedless grapes in the San Joaquin Calley, and those of Pruitt are listed for table grapes. Burt did not specify a grape variety. Pruitt's coefficients, which were for the San Joaquin Valley, were shifted forward to account for the earlier development of grape leaves in the CVWD. Pillsbury (1941) also reported that grapes ripen earlier in this area than in other places. Pruitt's coefficients moved forward and those recommended by C.M Burt are shown in Figure 8.

Fig. 8. Pruitt's adjusted grape coefficients and those recommended by C.M. Burt.

Example Application of Procedures

Alfalfa ET. Using the cutting dates suggested in UC Leaflet 21427, ET was estimated for each crop as illustrated in Figure 9 for alfalfa. Since an available soil water factor was not used, the values of the upper drained limit (field capacity), the lower limit, and management allowed depletion are not important. A graph was used for each crop because it served as a check on the procedures and crop curve being used.

Fig. 9. Example crop ET, soil water depletion, and irrigations for a perennial crop of alfalfa with nine cuttings scheduled according to UC Leaflet 21247 dates. A constant root depth is used for perennial crops.

Fig. 10. Example crop ET, soil water depletion, and irrigations for an annual crop like cotton. A variable root depth related to the crop coefficient is used for annual crops.

CROP COEFFICIENTS - IID

JML Kc x 1.2 v. UC Kc

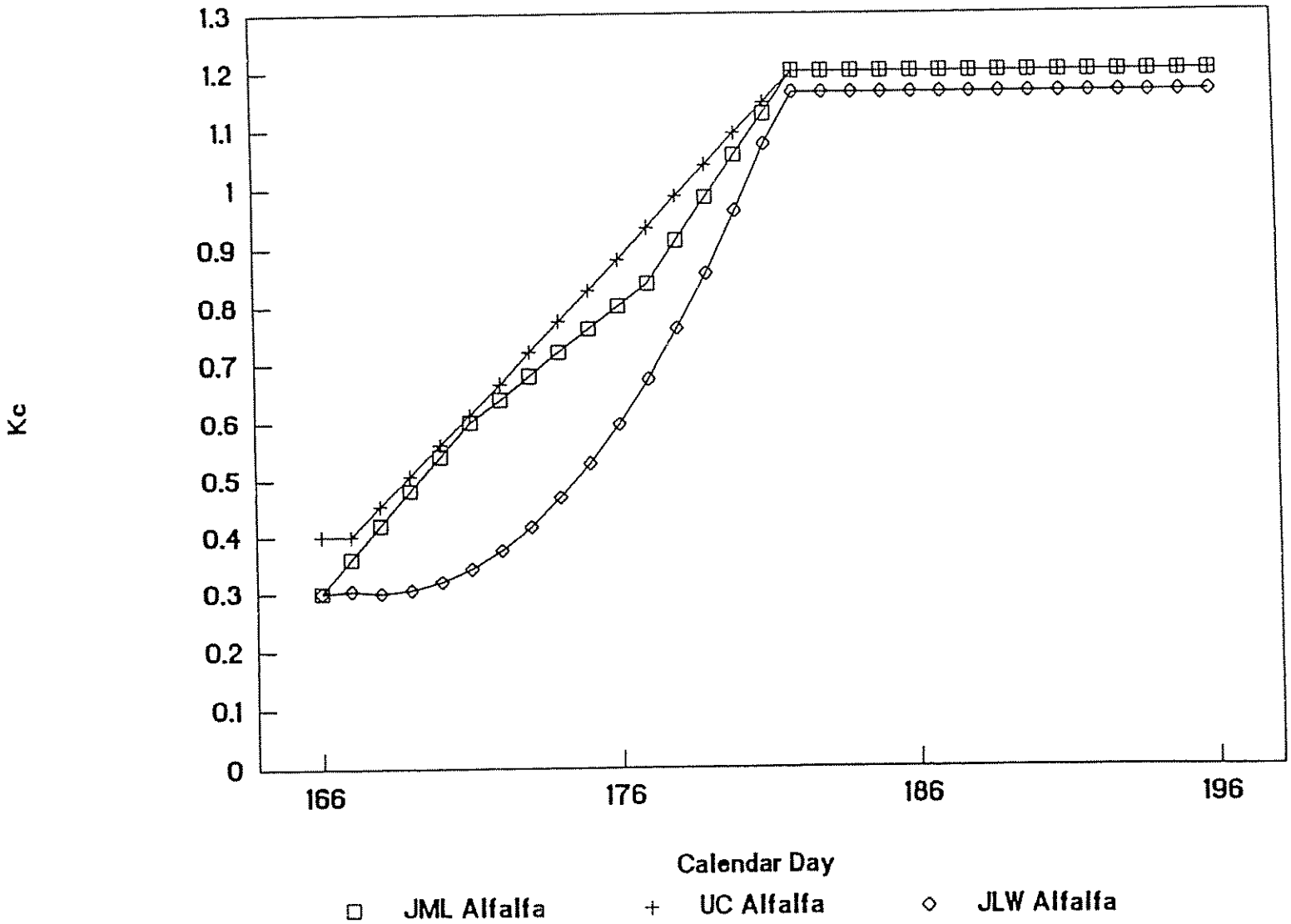


Fig. 6

CITRUS CROP COEFFICIENTS

FOR USE WITH ETo

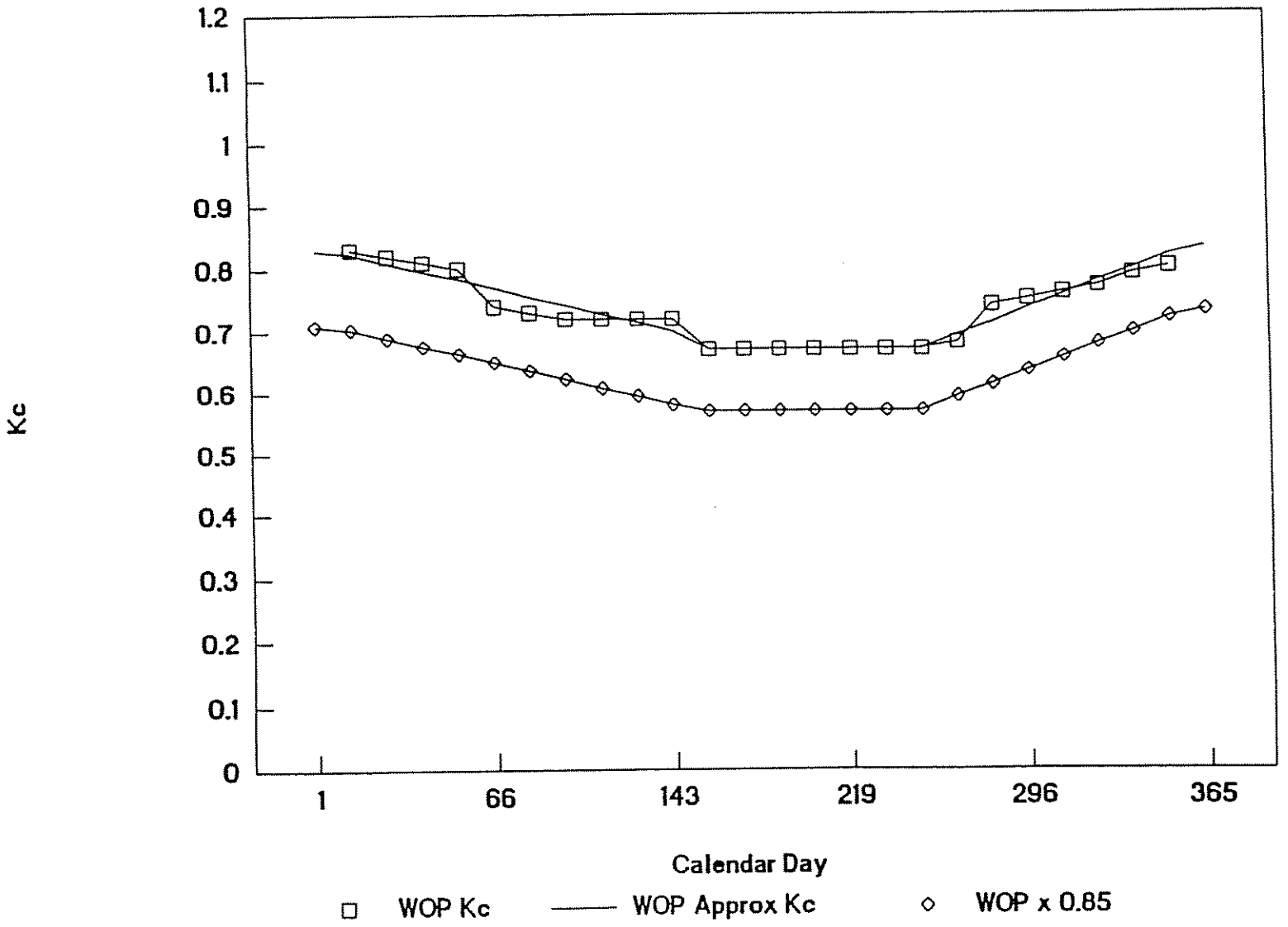


TABLE GRAPE CROP COEFFICIENTS

FOR USE WITH ETo

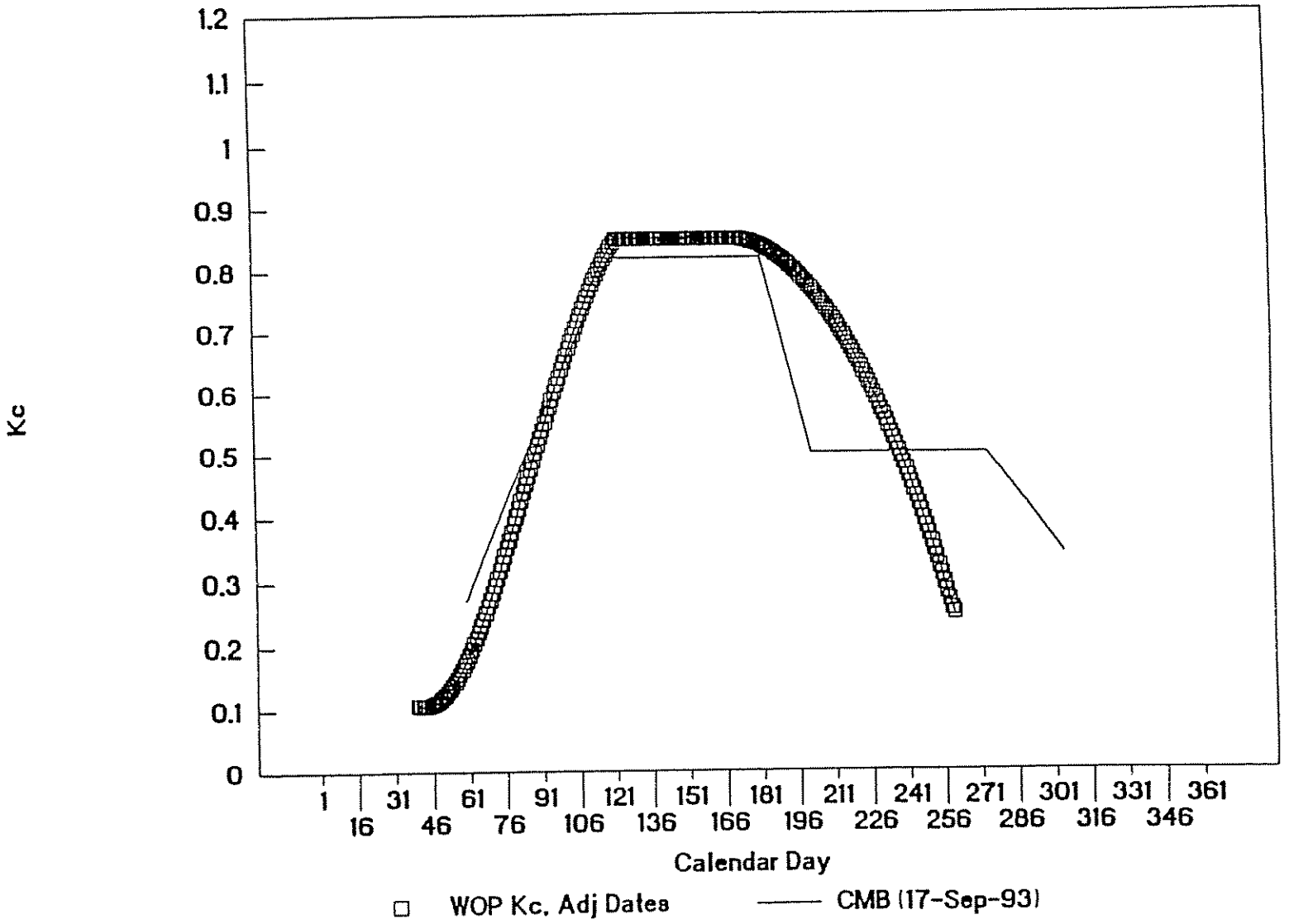


Fig. 8

ESTIMATED ET and SOIL WATER- CVWD

CROP: ALFALFA, 1987-92

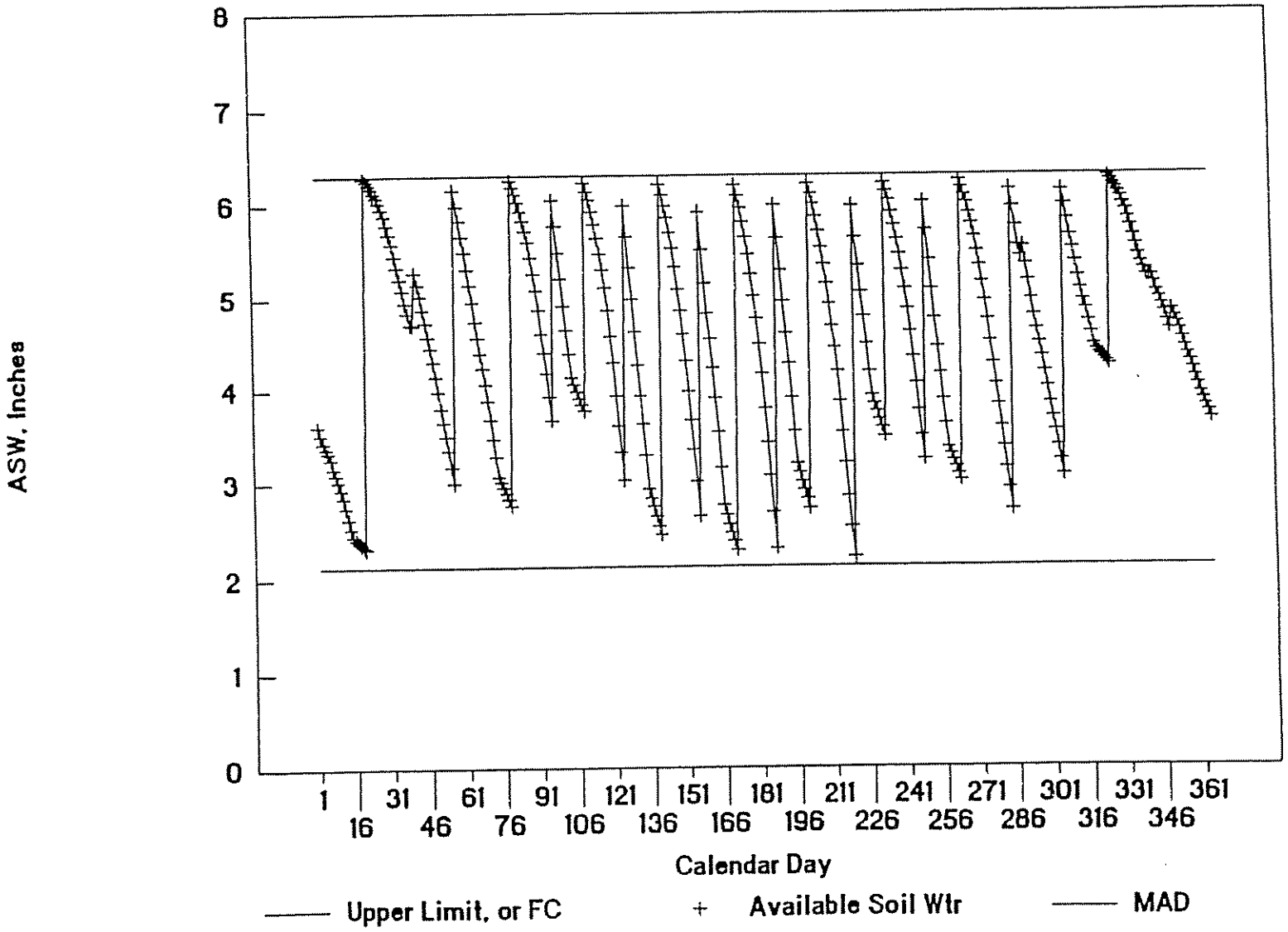


Fig 9

17

ESTIMATED ET and SOIL WATER - CVWD

CROP: COTTON, 1987-92

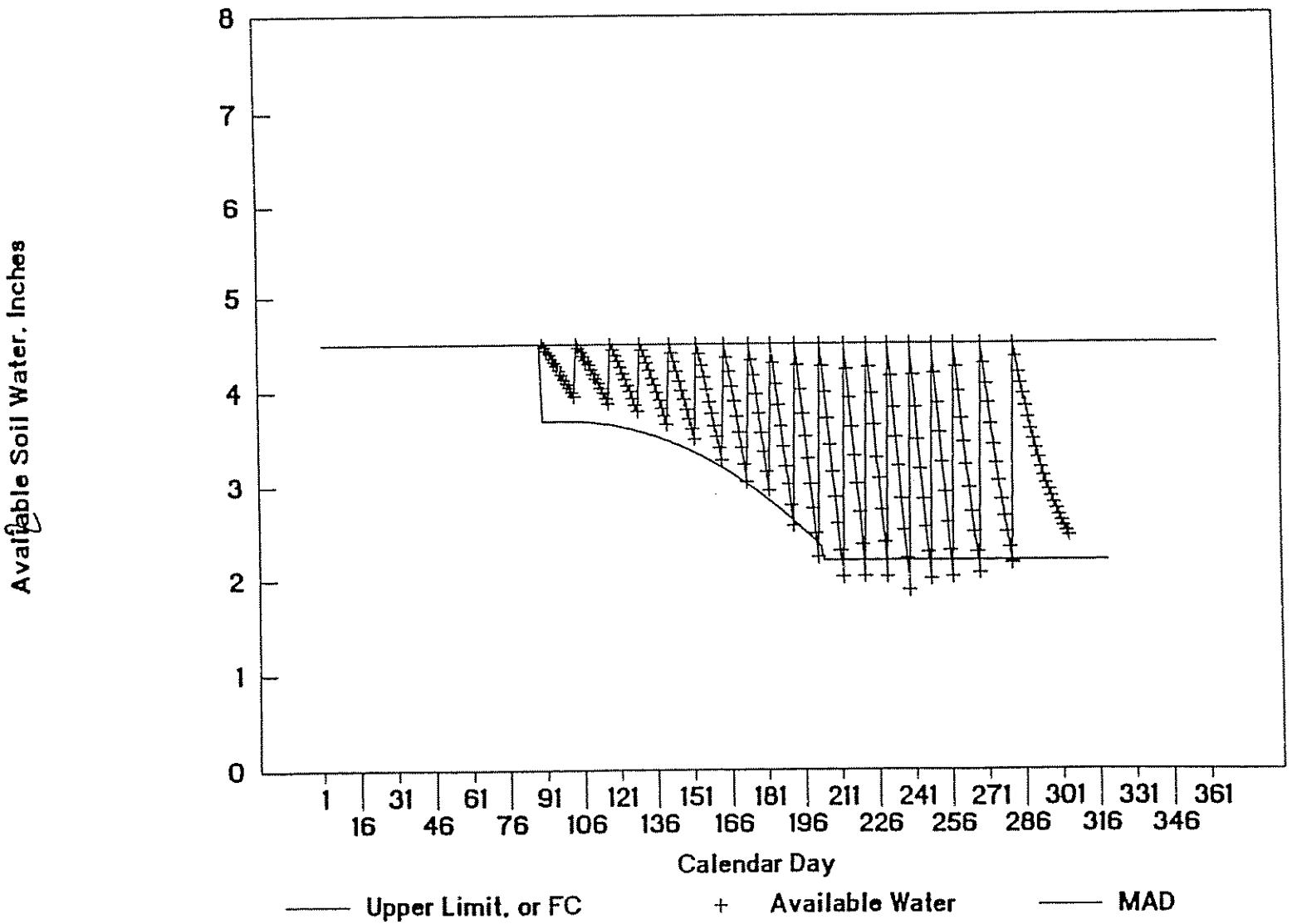


Fig. 10

Dates ET. Estimated monthly ET for dates using JMLord's coefficients and the ET/solar radiation coefficients given by Jensen and Haise (1963) are presented in Figure 11. The average of the two methods, which was used for the ET calculations, is also shown. Pillsbury (1941) noted that if a cover crop, or weeds, were present, transpiration was significantly larger than for cleaned cultivated dates. The use of either cover crops or interplanting of citrus in the date groves can increase ET of date groves as much as 25 percent. Therefore, additional information on the condition of the groves will be needed in Phase II.

Fig. 11. Estimated mean monthly ET for dates using JMLord's coefficients and those of Jensen and Haise (1963).

Example Illustration of Crop and Reference ET

An example of mean reference ET and alfalfa ET showing the effects of cuttings on ET rates for the average 1987-1992 climate is presented in Figure 12. In this case, irrigation dates were synchronized with assumed cuttings. The peaks are the cumulative increases in evaporation following rains. They are shown as occurring on single day because of the way in which they were calculated. The actual increases in evaporation would occur over several days in an exponentially decreasing rate and the total for a given day would not exceed $1.2ET_o$.

Fig. 12. Example of mean reference ET, alfalfa ET, and increases in evaporation following rains for 1987-1992 climate.

Adjustment of Alfalfa ET Estimates for Reported Yields

Estimates of alfalfa ET in the CVWD were not based on yield data. It was assumed that infiltration rates were sufficient to meet replace soil water extracted relative to evaporative demands.

RESULTS OF ANALYSES

Estimated ET for CVWD using ET x Area Method

Average Annual ET and Farm Irrigation Efficiency. A summary of estimated average ET_o, ET, rainfall, E+ (evaporation after rains), Re (effective rainfall), mean K_c for the season, estimated ET and ET values used in the Boyle (Styles, 1993) report is shown on page 22. The estimated overall consumptive use coefficient of irrigation water, CU_c, expressed as total ET/(net water delivered) for the major crops in the CVWD is shown on page 23. Effective rainfall was subtracted from total ET to estimate the fraction of irrigation water consumed. The uncertainty concerning the amount of pumped water and the amount of deep percolation that recharges the aquifer and is pumped is very large. The amount of deep percolation water that is pumped must be subtracted as shown otherwise part of the total water delivered is counted twice.

Crop acreages summarized from the data provide by JMLord and adjusted for individual crops from other sources, percentage distribution of these acreages, and the estimated confidence interval are presented in the spreadsheet on page 23. The Boyle ET values are from the Boyle CVWD report (Styles, 1993). The estimated average ET from planting to harvest (excluding preplant-irrigations and evaporation losses) is 221,600 ac-ft with an estimated minimum of 212,500 and a maximum of 230,600 ac-ft.

ESTIMATED MONTHLY ET - CVWD

DATES: 1987-92

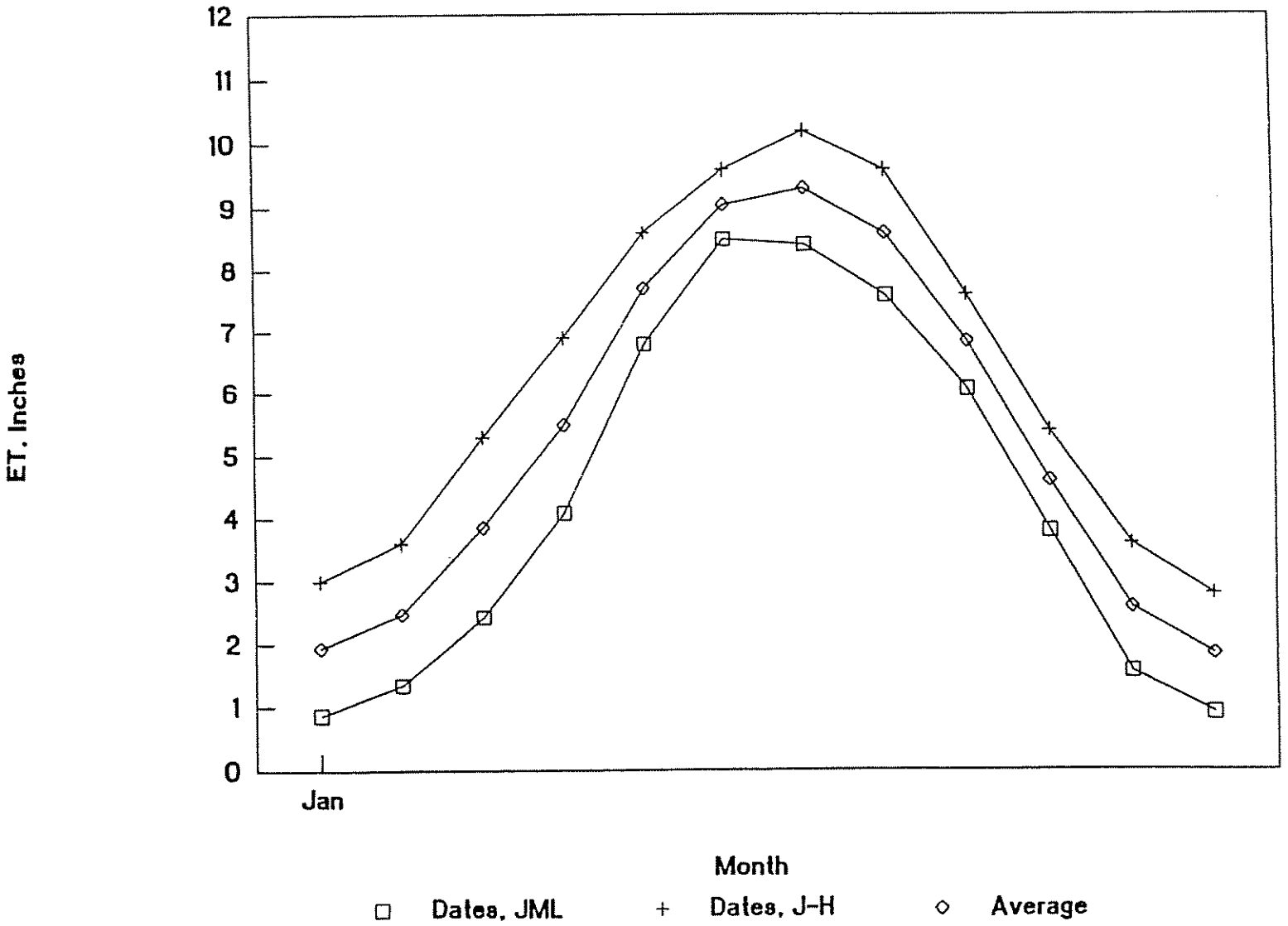


Fig. 11

CIMIS ETo and ESTIMATED ET - CVWD

CROP: ALFALFA, 1987-92

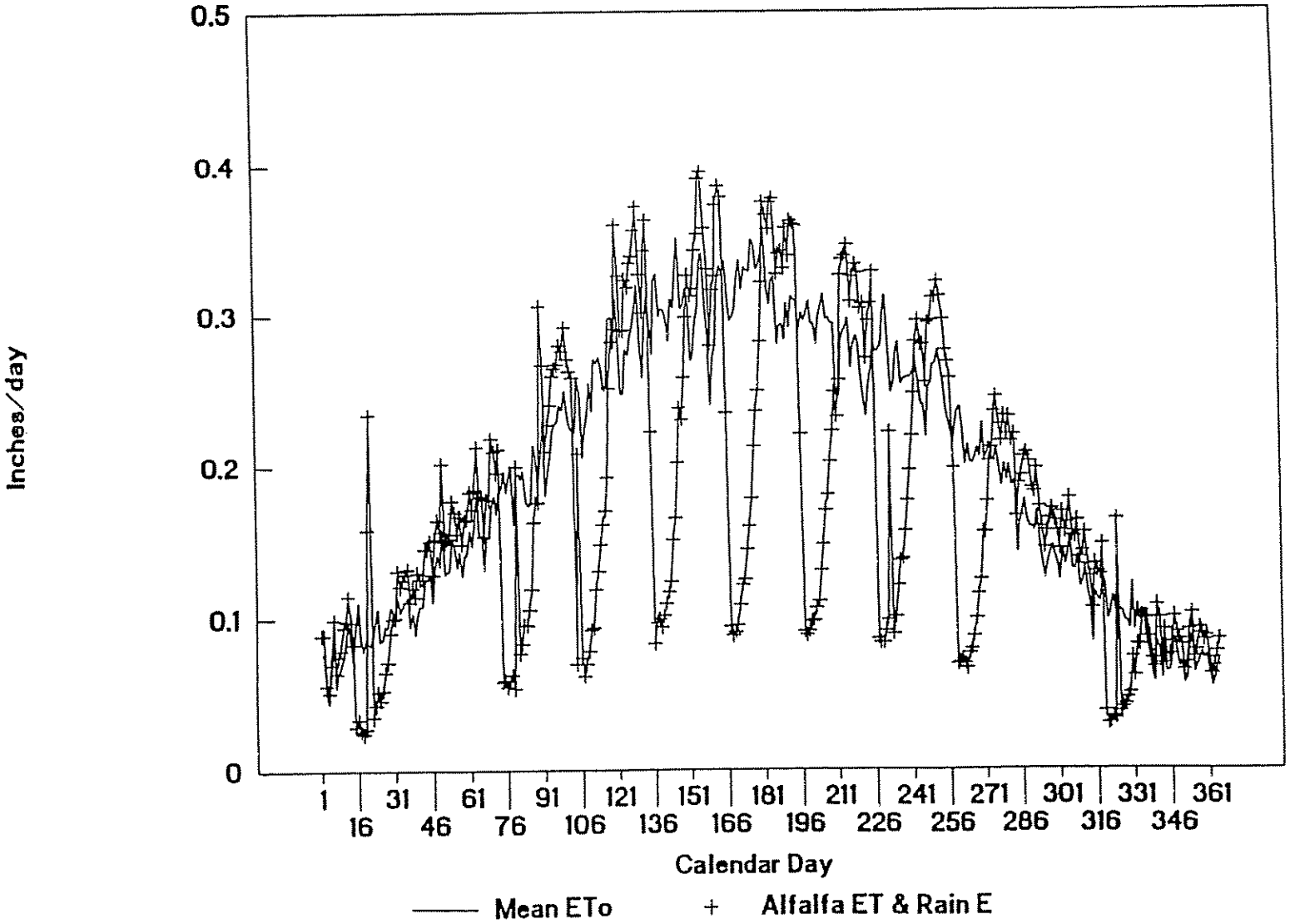


Fig. 12

Row 21-Dec-93 SUMMARY OF ET ESTIMATES FOR CVWD - 1987-1992 \SUMETCIV CVWD

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
28						SUMMARY								Boyle (1993)	
29		Period		Foot-								Sum		Table 6-4	(3)
30	Crop	Start	End	note	ETo	Rain	ET	E+	Re	Re	Avg Kc	ET+E+	Footnote	Inches	
31	FIELD:				In.	In.	In.	In.	In.	%	- -	In.			
32	Alfalfa	01-Jan	31-Dec	1	74.3	3.1	63.9	1.6	2.7	88%	0.86	65.5	1	70.1	
33	Cotton	31-Mar	31-Oct		57.4	0.9	38.4	0.8	0.1	11%	0.67	39.2			
34	Sudan Gr	01-Apr	01-Oct		39.5	0.3	35.6	0.2	0.1	33%	0.90	35.8			
35	Wheat & SmG	01-Jan	31-May		28.7	1.8	25.9	0.9	0.9	51%	0.90	26.8			
36															
37	FRUIT:														
38	Citrus	01-Jan	31-Dec		74.3	3.1	47.0	2.2	0.9	29%	0.63	49.2		45.0	
39	Dates	01-Jan	31-Dec		74.3	3.1	64.3	2.6	0.5	16%	0.87	66.9	2	73.1	
40	Grapes	14-Feb	20-Sep		57.5	0.9	38.9	0.9	0.0	0%	0.68	39.8		39.9	
41	Other T frt	01-Apr	15-Nov	No cov	58.7	1.0	45.3	1.0	0.0	0%	0.77	46.3			
42															
43	TRUCK														
44	Beans	01-Oct	01-Mar		16.9	2.2	12.0	0.7	1.5	68%	0.71	12.7			
45	Brocolli	15-Sep	15-Feb		18.5	2.3	12.3	0.9	1.4	61%	0.66	13.2		14.3	
46	Carrots	30-Sep	30-Apr		30.1	2.7	20.0	1.6	1.1	41%	0.66	21.6		21.0	
47	Corn, sw	15-Jan	15-May		22.9	1.8	20.6	1.0	0.8	44%	0.90	21.6			
48	Lettuce-1	31-Aug	02-Jan		18.1	1.1	16.6	0.4	0.7	64%	0.92	17.0		15.5	
49	Onions	01-Jan	31-May		29.0	1.8	29.4	0.8	1.0	56%	1.01	30.2			
50	Peppers	01-Nov	31-May		34.1	2.4	30.7	1.3	1.1	46%	0.90	32.0			
51	Potatoes	01-Nov	16-May		29.1	2.4	21.3	1.3	1.1	46%	0.73	22.6			
52	Squash	01-Feb	31-May		26.2	1.4	19.7	0.8	0.6	43%	0.75	20.5			
53	Watermelon	01-Jan	31-May		28.7	1.8	23.0	1.1	0.7	39%	0.80	24.1			
54	Misc veget	01-Nov	30-Jun		34.1	2.4	30.7	1.3	1.1	46%	0.90	32.0			
55	Nurseries	01-Nov	31-Dec		13.2	1.4	12.7	0.7	0.7	50%	0.96	13.4			
56	Ponds	01-Jan	31-Dec		74.3	3.1	72.8	0	3.1	100%	0.98	72.8	4	87.7	

57 1. Other cutting dates are: 8/15; 9/15; 11/15; 01/15; 03/15; 04/15; and 05/15.

58 2. Average of estimated ET with JMLord coefficients and estimated ET with Jensen and Haise (1963) ET/Rs coefficients.
Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div., Am. Soc. Civ. Engr. 89(IR4):15-41.

59 3. Styles, S. 1993. On-Farm Irrigation Efficiency - Special Technical Report, Coachella Valley Water District, April.

60 4. Jensen, M.E. 1993. Report on Evaporation Estimates for IID. 18-Oct, 10 pp + Appendices A & B.

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Row 23-Dec-93 SUMMARY OF ET ESTIMATES FOR CVWD - 1987-1992 \SUMET-CV

Row	Crop		Crop Distribution 81,070 100.0% Average	Pct	Sum ET+E+-Re	Ac x ET-Re	Distr-ibution	Confidence interval Crop Normalized ET	CV	CV^2	Boyle (CVWD) In.	Ft
78	FIELD CROPS:		Acres		Ac-ft/ac	Ac-ft	%	%				
79	Alfalfa, forage		5,029	6.2%	5.2	26,318	11.9%	10%	0.0059	3.53E-05	70.1	5.8
80	Cotton		387	0.5%	3.3	1,261	0.6%	10%	0.0003	8.10E-08		
81	Sudan Gr		2,940	3.6%	3.0	8,747	3.9%	10%	0.0020	3.90E-06		
82	Wheat & SmG		380	0.5%	2.2	820	0.4%	10%	0.0002	3.42E-08		
83	Subtotal		8,736	10.8%		37,145	16.8%					
84												
85	FRUIT:											
86	Citrus		14,954	18.4%	4.0	60,190	27.2%	10%	0.0136	1.84E-04	45.0	3.8
87	Dates		5,769	7.1%	5.5	31,922	14.4%	10%	0.0072	5.19E-05	73.1	6.1
88	Grapes		15,376	19.0%	3.3	50,997	23.0%	10%	0.0115	1.32E-04	39.9	3.3
89	Other T frt		454	0.6%	3.9	1,752	0.8%	10%	0.0004	1.56E-07		
90	Subtotal		36,553	45.1%		144,860	65.4%					
91												
92	TRUCK											
93	Beans		900	1.1%	0.9	840	0.4%	10%	0.0002	3.59E-08		
94	Brocolli		900	1.1%	1.0	885	0.4%	10%	0.0002	3.99E-08	14.3	1.2
95	Carrots		1,500	1.9%	1.7	2,563	1.2%	10%	0.0006	3.34E-07	21.0	1.8
96	Corn, sw		4,666	5.8%	1.7	8,088	3.6%	10%	0.0018	3.33E-06		
97	Lettuce-1		3,000	3.7%	1.4	4,075	1.8%	10%	0.0009	8.45E-07	15.5	1.3
98	Onions		1,000	1.2%	2.4	2,433	1.1%	10%	0.0005	3.01E-07		
99	Peppers		1,000	1.2%	2.6	2,575	1.2%	10%	0.0006	3.38E-07		
100	Potatoes		1,000	1.2%	1.8	1,792	0.8%	10%	0.0004	1.63E-07		
101	Squash		1,500	1.9%	1.7	2,488	1.1%	10%	0.0006	3.15E-07		
102	Watermelon		955	1.2%	2.0	1,862	0.8%	10%	0.0004	1.77E-07		
103	Misc veget		900	1.1%	2.6	2,318	1.0%	10%	0.0005	2.73E-07		
104	Nurseries		866	1.1%	1.1	917	0.4%	10%	0.0002	4.28E-08		
105	Subtotal		18,187	22.4%		30,834	13.9%					
106												
107	MISCELLANEOUS											
108	Ponds/Reservoirs	1	1,424	1.8%	5.8	8,271	3.7%	10%	0.0019	3.48E-06	87.7	7.3
109	Fallow/Leach	2	17,264	21.3%	0.6	477	0.2%	10%	0.0001	1.16E-08		
110	Subtotal		18,688	23.1%		8,748	3.9%					
111											Range of estimates Min	Max
112	Total		82,164	101.3%		221,587	100.0%			4.18E-04	0.0204 212,528	230,647
113										Std dev=	4,530 CV =	2.0%
114												
115	Colorado R. water delivered to agr. users					279,000	80%	5%	0.0201	4.03E-04	0.0200 267,805	290,195
116	Pumped water					130,000	37%	40%	0.0748	5.59E-03	0.0747 110,555	149,445
117	Less recycled water (15% of above)				0.15	(61,350)	-18%	60%	-0.0529	2.80E-03	0.0529 (54,854)	(67,846)
118	Net total water delivered					347,650	100%			8.80E-03	0.0938 282,431	412,869
119	Net Confidence interval							19%		Std dev=	32,610 CV =	9.4%
120	Total variance, ET and net water delivered									0.009216	0.0960	
121	Farm irrigation water consumptive use coeff.					63.7% (Excluding LR)				Std dev=	9.6% 44.5%	82.9%
122												

123 1. Boyle (1993) reported 988 ac of ponds and 436 ac of farm reservoirs, total = 1,424 acres.

124 2. Without actual data, it was assumed that 1 percent of the cropped area was being leached and flooded annually.

125 Evaporation was estimated as 10 percent of the annual average evaporation rate.

The estimated average farm irrigation water consumptive use coefficient is 64 percent. The confidence interval ranges was from 45 to 83 percent. Estimated effective rainfall, though small, was subtracted from total ET in these calculations. When adjusted for the leaching requirement, the farm irrigation efficiency was estimated to be 72 percent.

The average farm irrigation water consumptive use coefficient for the CVWD is essentially the same as for the IID. The main difference is the range in the confidence interval between the the two districts. The range in the CU_c estimate for the IID is much smaller than in the CVWD because of greater uncertainty of the amount of water pumped and the amount of deep percolation that is included in the pumped water. Farm irrigation efficiency, like district efficiency, is greater if part of the runoff or deep percolation is recycled.

Evaluation of Water Delivery v. CIMIS Annual Reference ET

At the time of preparing this report, I did not have the estimates of water delivered to farms for each of the years 1987 through 1992. Therefore, I could not assess the response of Colorado River water orders and pumping to changes in evaporative demand (reference ET).

SUMMARY AND CONCLUSIONS

ET can be estimated with reasonable accuracy using existing crop coefficients and reference ET measured by CIMIS provided reliable crop acreages are known. Improved data on the range of planting, crop development, and harvest dates and leaf-area development rates will be needed in Phase II to refine ET estimates. Similarly, data on preplant irrigations and/or irrigations to germinate seeds and establish stands will be needed to assess the evaporation losses during this period of crop development. Improved data on the volume of water pumped and the proportion of deep percolation that is recycled will be needed also to improve the estimate of farm irrigation efficiency.

REFERENCES

Grimes, D.W., and L.E. Williams. 1990. Irrigation effects on plant relations and productivity of Thompson seedless grapevines. Crop Sci. 30:255-260.

Hely, A.G., G.H. Hughes, and B. Irelan. 1966. Hydrologic Regimen of Salton Sea, California. Geologic Survey prof. Paper 486-C, 36 pp.

Jensen, M.E., R.D. Burman, and R.G. Allen (eds). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practice No. 70, New York, 360 pp.

Jensen, M.E., and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. and Drain. Div., ASCE, 89(IR4):15-41.

Pillsbury, A.F. 1941. Observations on the Use of Irrigation Water in the Coachella Valley. Calif. Bull. 649, June.

Styles, S. 1993. On-Farm Irrigation Efficiency: Special Technical Report, Coachella Valley Water District. April.

University of California. Undated. Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops. Coop. Extension, Div. of Agr. and Natural Resources, Leaflet 21427, 12 pp.

APPENDIX A

BASIC ASSUMPTIONS USED IN ESTIMATING EVAPOTRANSPIRATION

Assumptions or conditions assumed in estimating evapotranspiration are summarized on the following page.

Generic equations for the crop coefficients from planting to full cover and days after full cover will be summarized in a separate report.

Specific spreadsheet files that were used can be made available if needed. However, they are not fully automated and require some manual adjustments in changing crops.

22-Dec-93

SUMMARY OF ET ESTIMATES FOR CVWD - 1987-1992

INPUT DATA: Climate: Mean CIMIS ETo values from Station 50 for 1987-1992.

Rainfall: Mean distribution of rainfall events from CIMIS 50.

Cropping Dates: Derived mainly from UC Leaflet 2142CD and IID Schedule of Major Crops.

Crop Coefficients: Mainly daily values based on generalized curves for JMLord coefficients multiplied by 1.2. Several curves were from W.O. Pruitt (ASCE Manual 70, page 127. Curves were shaped based on daily lysimeter-based data from J.L. Wright (ASCE Manual 70).

Soil: Drained upper limit (FC) = 36 % by volume; Lower Limit = 21 % by volume. Source: ASCE Manual 70, p. 21.

Effective Rain: Increase in evaporation due to rain, E+, was estimated using the equation on p. 118, ASCE Manual 70. No runoff was assumed for the small events.

ASSUMPTIONS:

1. Soil water was assumed adequate and did not limit ET.
2. No increase in evaporation, E+, was added due to wetting following irrigations because irrigation frequency was not known. Frequency is dependent on depth to the water table and its effects. Data on irrigation frequency would enable estimating this component of ET.