PAPER NO. MCR 87-106

SPREADSHEET TEMPLATES FOR THE CALCULATION OF PENMAN REFERENCE EVAPOTRANSPIRATION

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For presentation at the 1987 Mid-Central Regional Meeting of
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Sheraton Inn, St. Joseph, MO
March 6-7, 1987

SUMMARY:

Algorithms were optimized for use in a spreadsheet template for the calculation of Penman reference evapotranspiration (ETr). The user friendly template should work well in much of the central U.S. The ETr template performed acceptably in 3 popular spreadsheet products, given its magnitude and complexity.

KEYWORDS:
Evapotranspiration, Irrigation management, climate data, microcomputers, computers, water conservation

American Society of Agricultural Engineers

St. Joseph, MI 49085-9659

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ABSTRACT

Algorithms, well documented in the literature, were optimized for use in a spreadsheet template for the calculation of Penman reference evapotranspiration (ETr) for alfalfa. The ETr template should have applicability in much of the central United States as well as give a user friendly approach to climatic data management and irrigation scheduling. The ETr template was implemented in three popular spreadsheet products, Multiplan (Version 3.0), Lotus 123 (Release 2.0), and SuperCalc3 (Release 2.1). Given the magnitude and complexity of the problem, all three products gave acceptable performance. In typical use, regardless of hardware configuration, Multiplan was by far the fastest because of two unique recalculation features. Session time from load through save in SuperCalc3 was a significant factor at the slower processor speed (4.77 Mhz) and without the Intel 8087 math coprocessor. Lotus 123 and SuperCalc3 had significantly better implementations of the math coprocessor as compared to Multiplan.

INTRODUCTION

Diminishing water supplies and increasing pumping costs have increased the need for efficient use and conservation of water and energy. Production costs have risen sharply and many farmers are facing a steadily decreasing profit margin. It is well documented that irrigation scheduling saves water and energy. Irrigation scheduling is a tool irrigators can use to manage dates and amounts of irrigation. The premise is to apply water when needed in the necessary amount, but not more water than needed and not sooner than needed. How much is needed can be estimated from evapotranspiration (ET) prediction equations. A simple definition of evapotranspiration (ET) is water use by crops. It is the combined evaporation from soil surrounding the plant and the transpiration from the plant itself.

Sometimes, when speaking in general terms, we say the peak water use for corn is 7.5 to 9 mm/day (0.30 - 0.35 in/day). However, this generalization represents the results of a given set of conditions. In this example, the conditions are adequate soil water, corn at full canopy, and a highly evaporative set of climatic conditions. Although the peak water use of a crop is useful to know in designing an irrigation system, the peak water use value isn't very informative in managing irrigation dates and amounts. ET and precipitation vary from season to season. Irrigation scheduling using daily ET and precipitation values can make significant water savings possible in cool wet years and alert the farmer to higher irrigation requirements in hot dry years.

The algorithms to calculate ET are usually multistage. Generally, a reference ET value is calculated from climatic variables based on well-watered conditions. The reference value is then modified by a crop coefficient which takes into account crop type and growth stage. Sometimes, it is further modified by a coefficient relating actual soil water to well-watered conditions. Computer spreadsheet software which is widely available today offers individual irrigators an easy to learn and use data management system. The visual interface with the data allows for easy data entry and correction. The presence of data and results located in close proximity help the user develope a better feel for how climatic conditions affect crop water use.

This report deals with the development of efficient algorithms to be used in a spreadsheet template to calculate the reference ET value for alfalfa (ETr) using a modified Penman approach. Additional simple templates could then be developed to modify for crop type and stage of growth and to manage irrigation dates and amounts. This report also discusses implementation of these ETr algorithms on three of the most popular personal computer spreadsheet products; Multiplan, Lotus 123, and SuperCalc3.

THEORY OF ALGORITHMS

The Penman combination equation can be visualized as the combination of two parts, an energy balance term and a mass transport term. In simplified form, Penman reference ET (ETr), which may be alternately referred to as potential ET, is;

$$ETr = G1*(Rn-G) + G2*C*(WF*VPD) \quad (1)$$

where G1 and G2 are weighting factors whose sum is 1, Rn is net radiation, G is the soil heat flux, C is a conversion factor to express results in units of energy, WF is the wind function and VPD is the vapor pressure deficit.

This particular method calculates ETr for alfalfa using methods similar to procedures outlined by Burman et al. (1980), Burman et al. (1983), and also Kincaid and Heerman (1974) with some exceptions as will be noted. It should also be noted that many of the equations will be left in English units as much of the weather data is most readily available in this form. In addition the primary use of the template is for irrigators not often accustomed to SI units. The conversion of this template to SI units would be relatively easy. This conversion was not attempted as the requirement of conversion of weather data to SI units would adversely affect template size and performance. On a daily basis, the climatic data required are maximum and minimum temperatures (degrees Fahrenheit) for the previous 24 hour period, the drybulb and wetbulb temperature (degrees Fahrenheit) at the 8:00 A.M. observation time, the daily solar radiation (langleys), the wind run (miles/day) and the precipitation (inches) for the previous 24 hours. Actually precipitation is not required to calculate ETr, but is often required for irrigation scheduling procedures.

The soil heat flux (G in Equation 1) is often neglected in calculating ETr as pointed out by Burman et al. (1980), Burman et al. (1983). It is periodic in nature, some days positive and other days negative. Kincaid and Heerman (1974) used an empirical formula for soil heat flux apparently first suggested by Jensen et al. (1971). Results from the KSU Colby Branch Experiment Station have shown that the inclusion of this formula has no significant effect on cumulative ET over the course of the season and only a small effect on day to day predictions. The soil heat flux term has been excluded from the model in further discussions.

The conversion factor (C in Equation 1) has a value of 15.36, expressed in cal/cm^2-day-mbar.

The wind function (WF in Equation 1) is calibrated to the reference crop alfalfa (Wright and Jensen, 1972) and can be expressed as;

$$WF = AW + (CW*W) \quad (2)$$

where W is the wind run in miles/day, AW and CW are constants in the wind function with AW having a value of 0.75 for alfalfa and CW the wind constant being evaluated by the expression;

$$CW = 0.02426/(ANH^{0.143}) \quad (3)$$

where the wind constant (CW) is used to correct wind run to an appropriate anemometer height and to convert to appropriate units and crop type. The anemometer height (ANH) is given in feet.

The vapor pressure deficit (VPD in Equation 1) is the difference between saturation vapor pressure (VPS) and actual vapor pressure (VPA).

Saturation vapor pressure (VPS) can be calculated by an equation developed by Brooker (1967);

$$VPS = EXP(54.63-(12301.7/(T+460))-5.17*LN(T+460)) \quad (4)$$

where VPS is expressed in psia, and the air temperature (T) is expressed in degrees Fahrenheit. In calculating ETr, the saturation vapor pressure is evaluated at both the minimum and maximum temperature that occurred during the preceding 24 hours. The average of the two values is used in further calculations of ETr. The equation as used to calculate the mean value of VPS (mbars) is;

$$VPS = 68.95 * ((EXP(54.63-(12301.7/(TMX+460))-5.17*LN(TMX+460)) + EXP(54.63-(12301.7/(TMN+460))-5.17*LN(TMN+460))) / 2 \quad (5)$$

where TMX is the maximum daily temperature (degrees Fahrenheit) and TMN is the minimum daily temperature (degrees Fahrenheit).

Actual vapor pressure (VPA) can be calculated from drybulb and wetbulb temperatures by combining the work of Brunt (1941) and Brooker (1967). Brunt observed that;

$$VPA = B*(TO-TW) + VPSwb \quad (6)$$

where TO and TW are the drybulb and wetbulb temperatures (degrees Fahrenheit) respectively, VPSwb is the saturation vapor pressure, psia, evaluated at TW [Using Equation 4, Brooker (1967)] and B is the slope of the wet bulb line. A major simplification can be made in calculation of VPA by observing that an average value of the slope, B, can be used over the range of typical values of wetbulb and drybulb temperatures that occur in crop production in the midwest. For VPA in psia and temperatures in degrees Fahrenheit, an average value for B is -0.00534. Using 8:00 A.M. observations for wetbulb and drybulb temperatures, the combined equations for VPA is;

$$\mathrm{VPA} = 68.95 * ((-0.00534*(\mathrm{TO}-\mathrm{TW})) + \mathrm{EXP}(54.63-(12301.7/(\mathrm{TW}+460))-5.17*\mathrm{LN}(\mathrm{TW}+460))) \quad (7)$$

where VPA is now expressed in mbars. Equations 5 and 7 will not work accurately at temperatures below 32 degrees Fahrenheit. In this model, actual vapor pressure (VPA) is calculated from the 8:00 a.m. observation temperatures. The saturation vapor pressure (VPS) required in the ETr equation is the average of the calculated saturation vapor pressures at the maximum and minimum temperatures during the preceding 24 hours. On isolated occasions, rapidly changing conditions during this time lag will result in calculation of actual vapor pressures greater than the saturation vapor pressure. As a result, a negative vapor pressure deficit is predicted. This problem is alleviated by putting a conditional statement in the model to check for a VPA greater than VPS. If true, the value of (VPS-VPA) is set to zero. This procedure to calculate vapor pressures is widely used in ETr equations in the arid and semi-arid regions where actual vapor pressures may not change very rapidly. However, caution may be warranted in semi-humid and humid areas. Actual vapor pressures during the period between maximum and minimum temperature may be required for accurate ETr prediction in these areas.

The first weighting term (G1 in Equation 1) represents the slope of the saturation vapor pressure temperature curve divided by the quantity, slope of the vapor pressure temperature curve plus the psychrometric constant. Burman et al. (1980) indicated that the psychrometric constant is not truly a constant and that altitude has an effect on it. However, the psychrometric constant is often assumed to be constant, and for the sake of performance efficiency in the templates, the weighting term (G1) was assumed to vary only with air temperatures and is given by;

$$\mathrm{G1} = 0.041+(0.0125*(\mathrm{TMX}+\mathrm{TMN})/2)-(0.00004534*(((\mathrm{TMX}+\mathrm{TMN})/2)^{2})) \quad (8)$$

where temperatures are in degrees Fahrenheit. The other weighting term, G2, is obtained by subtracting G1 from one.

Net Radiation (Rn) in langleys, is equal to the net shortwave radiation minus the net outgoing longwave radiation;

Rn = ((1-REF) * SR) - Rb (9)

where REF is the reflectance or albedo of the reference crop (Alfalfa = 0.23), SR is the daily solar radiation in langleys, and Rb is the net outgoing longwave radiation given by;

Rb = (ALW*(SR/CDR) + BLW) * RLO (10)

where typical values of ALW and BLW are given by Burman et al. (1980) with values of 1.22 and -0.18 for ALW and BLW reported for southern Idaho, the quantity SR/CDR is a cloudiness factor, the ratio of actual solar radiation to calculated clear day solar radiation and RLO is the net clear day outgoing longwave radiation. If the solar radiation (SR) is greater than the calculated clear day solar radiation (CDR), the ratio SR/CDR is set equal to 1. CDR in langleys, is calculated by algorithms presented by Cengiz et al. (1981). The equation is as follows;

CDR = ACD+(BCD*SIN((2*PI*((JDAY+10.5)/365-(PI/2))) (11)

where PI is equal to 3.14159, and JDAY is the the day of the year, the two constants ACD and BCD, which change only with latitude, are 491 and 246 for Colby Kansas, latitude 39 degrees 23 minutes. Accuracy for weather station location is not critical for these constants. Table 1 lists values of ACD and BCD for latitudes in the central region of the United States as well as formulae for developing other values. Though the values of CDR calculated by Equation 9 are less than tabular values reported by Jensen (1974), they do compare favorably with graphical values for the central United States reported by Fritz (1949). Equation 9 allows for the easy calculation of CDR without the inclusion of extensive lookup tables in the ETr computer program.

RLO in langleys, the net clear day outgoing longwave radiation can be calculated by;

$$RLO = (BRA+(BRB*SQRT(VPA))) * 11.71 * ((((TMX+TMN- 64)/360)+2.73)^4) \quad (12)$$

where the first expression represents the Brunt (1934) atmospheric emissivity equation. Typical values of the Brunt coefficients BRA and BRB are given by Burman et al. (1980), with

BRA and BRB having values 0.325 and -0.044 for southern Idaho. The value 11.71 and the final expression when combined as shown represent the Stefan-Boltzmann constant and the average daily temperature (degrees Fahrenheit) converted to degrees Kelvin raised to the fourth power. There is some discrepancy in the literature as to how the equation for RLO should be expressed and calculated. Burman et al. (1980) used the mean daily temperature raised to the fourth power (similar to Equation 12) while Kincaid and Heerman (1974) used the average of the maximum and minimum temperatures raised to the fourth power. Though the methods are indeed different, either method will give similar results due to the magnitude of the temperatures in degrees Kelvin raised to the fourth power.

The combined reference evapotranspiration (Etr) equation as used in the model is;

$$ETr = ETF * ((G1*Rn) + (15.36 * (1-G1) * (AW+CW*W) *(VPS-VPA))) \quad (13)$$

where ETF is a conversion factor to express ETr in characteristic units, (ETF = 0.01709 or 0.000673 for results in mm/day and in/day, respectively) and all other terms have been previously defined.

The algorithms as implemented in the spreadsheet templates are identical with a few minor exceptions. The conditional statement of comparing VPA and VPS is included in the calculation of ETr. The conditional statement on the SR/CDR ratio is included in the calculation of Rn. An approximation of day of year using month of year and day of month is made in calculation of CDR. A complete listing of headings, algorithms, and constants as used in the templates for the three products is included in Appendix A.

COMPARISON OF SPREADSHEETS

The original ETr template was written for Microsoft Multiplan (Version 3.0). It was then converted for use in Lotus 123 (Release 2.0) and Computer Associates' SuperCalc3 (Release 2.1). Multiplan besides being the spreadsheet of choice for the major author has some unique features that aid in the development of complex spreadsheet templates. Multiplan allows columns, rows, blocks (ranges) and/or individual cells to be named as variables (Lotus 123 also has a naming feature, however it isn't implemented in the same fashion). The naming feature is extremely useful in writing, understanding, and debugging complex cell formulas.

All three products have had recent updates and can be considered excellent vehicles for ETr algorithms. All three products have more than enough rows and columns for any reasonable ETr template. Each product supports the Intel 8087 or 80287 math coprocessors for faster operation and can use a mouse input device. Multiplan and Lotus 123 support macros, and Lotus 123 and SuperCalc3 support graphics.

A number of performance benchmarks were performed on the completed ETr templates for each of the spreadsheet products (Table 2). The benchmarks were performed at two processor speeds and with and without the prescence of the Intel 8087 math coprocessor.

One of the most striking differences between templates was in template size as stored to disk (Figure 1). The template in Lotus 123 and SuperCalc3 consumed over 2.5 times the disk space required by Multiplan. This difference in file sizes was also reflected in increased times for loading and saving for the Lotus 123 and SuperCalc3 templates (Figures 2 and 3). Though the processor at higher speed did decrease the loading and saving time, the math coprocessor had no effect with the exception of SuperCalc3. Evidently SuperCalc3 must do rather extensive manipulation of the data in both the load and save process. In SuperCalc3, the math coprocessor saved approximately 15 and 30% of the time required for the normal loading and saving process, respectively. In addition, SuperCalc3 load and save times were over twice that of Lotus 123, even though file sizes were similar.

In a spreadsheet template of this magnitude (May 1 - Sept 30) and complexity, recalculation time is a significant factor. The template contains a total of 2839 cells (167 rows, 17 columns) of which 1072 cells contain formulas. The performance of the software products depended on whether the math coprocessor was present. Without it, Multiplan was faster than the other two products, with the math coprocessor, in recalculation of the entire template from initial data entry, Lotus 123 has the shortest recalculation times (Table 2 and Figure 4) followed by SuperCalc3 and then Multiplan. However, Multiplan (versions 2.0 and 3.0 only) has two unique features in recalculation that can make it much faster than indicated by the figures. Multiplan can be allowed to recalculate during the data entry process and does not lock the keyboard between calculations. In addition and more importantly, Multiplan does not have to recalculate any cells that have previously been calculated at any time in the current or even past sessions. SuperCalc3 has this feature to a very limited extent, as it does save some time when cells have been previously calculated in the current session. However the savings are not nearly as dramatic and the entire template has to be recalculated at least once in the current session to experience these savings. In a typical ETr template session where one would enter just one or a few days of data, Multiplan would be many times faster than the other two products. The effect of Multiplan only having to recalculate altered cells can be seen in Figure 5. In a template where nearly half of the data cells are empty, Multiplan saves approximately 40% in recalculation time as compared to a full template while Lotus 123 and Supercalc are unaffected. Once again it should be pointed out that typically one would not enter half the data in one session.

The average effect of hardware configuration across software products is shown in Figure 6. The effect of increasing processor speed from the standard slow 4.77 MHz to the faster 8 Mhz results in approximately 33% shorter recalculation times across all products. There are considerable differences in the effect of the math coprocessor between Multiplan (recalculation time reduction, 1/3) and the other two products (recalculation time reduction, 2/3). Lotus 123 and SuperCalc3 appear to have achieved much better implementation of the math coprocessor.

Sample sessions in the ETr templates for the three products is included in Appendix B.

CONCLUSIONS

Widely used algorithms have been optimized for use in spreadsheet templates for the calculation of Penman reference evapotranspiration (ETr) for alfalfa. Using a spreadsheet to calculate ETr gives a user friendly approach to climatic data management and irrigation scheduling. In addition, the highly visible database and resultant ETr help the user over time develop a better feel for how climatic conditions can affect crop water use.

Given the magnitude and complexity of the problem, all three products give acceptable performance. In typical use Multiplan will probably be by far the fastest. Session time from load through save in SuperCalc3 is significant at the slow speed and without the coprocessor. However performance speed is not always the most important criteria. The speed criteria should be balanced against availability of and familiarity with a particular product within a person's working environment.

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Table 1. Coefficients ACD and BCD for the clear day solar radiation equation associated with latitudes in the cental United States.*

Latitude, Degrees	Minutes	ACD, langleys	BCD, langleys	Longest day, hours
36	0	515	230	14.6
36	20	513	231	14.7
36	40	511	233	14.7
37	0	508	235	14.7
37	20	506	236	14.8
37	40	503	238	14.8
38	0	501	240	14.8
38	20	499	241	14.9
38	40	496	243	14.9
39	0	494	245	14.9
39	20	491	246	15.0
39	40	489	248	15.0
40	0	486	249	15.0
40	20	484	251	15.1
40	40	482	252	15.1
41	0	479	254	15.1
41	20	477	255	15.2
41	40	474	257	15.2
42	0	472	258	15.3
42	20	469	260	15.3
42	40	467	261	15.3
43	0	464	262	15.4
43	20	462	264	15.4
43	40	459	265	15.5
44	0	457	266	15.5
44	20	454	268	15.5
44	40	452	269	15.6

* Formulae from Cengiz (et al. 1981)

ACD = [sin(LAT)*(46.355*LD - 574.3885) +
816.41*cos(LAT)*sin(pi*LD/24)] * (0.29*cos(LAT) + 0.52)

BCD = [sin(LAT)*(574.3885 - 1.509*LD) -
26.59*cos(LAT)*sin(pi*LD/24)] * (0.29*cos(LAT) + 0.52)

$LD = 0.267 * \sin^{-1} [0.5 + (0.007895/\cos(LAT)) + 0.2168875*\tan(LAT)]^{0.5}$

LD = Longest day, hours. LAT = Latitude, degrees. pi = 3.1416

Table 2. Comparison of template characteristics as affected by software product and computer hardware specifications.

Characteristic	Multiplan* Speed and Coprocessor				Lotus 123 Speed and Coprocessor				SuperCalc3 Speed and Coprocessor			
	5M	8M	5M/8087	8M/8087	5M	8M	5M/8087	8M/8087	5M	8M	5M/8087	8M/8087
Template size (K)	49	49	49	49	135	135	135	135	128	128	128	128
Load template, sec.	12	6	12	6	36	27	37	27	93	68	81	57
Save template, sec.	12	10	12	10	21	17	24	17	83	61	58	42
Recalculation												
Half template, sec.	27	19	22	15	60	40	20	11	75	53	27	19
Full template, sec.	48	34	33	21	60	40	20	11	75	53	27	19
Recalculation ratios												
Half/Full	0.56	0.56	0.67	0.71	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Compared to 5M	1.00	0.71	0.69	0.44	1.00	0.67	0.33	0.18	1.00	0.71	0.36	0.25
Compared to 8M	1.41	1.00	0.97	0.62	1.50	1.00	0.50	0.28	1.42	1.00	0.51	0.36
Compared to 5M/8087	1.45	1.03	1.00	0.64	3.00	2.00	1.00	0.55	2.78	1.96	1.00	0.70
Compared to 8M/8087	2.29	1.62	1.57	1.00	5.45	3.64	1.82	1.00	3.95	2.79	1.42	1.00

* Multiplan recalculation times can be much smaller than values shown. Multiplan allows for calculation during data entry and also does not have to recalculate any formulas previously calculated.

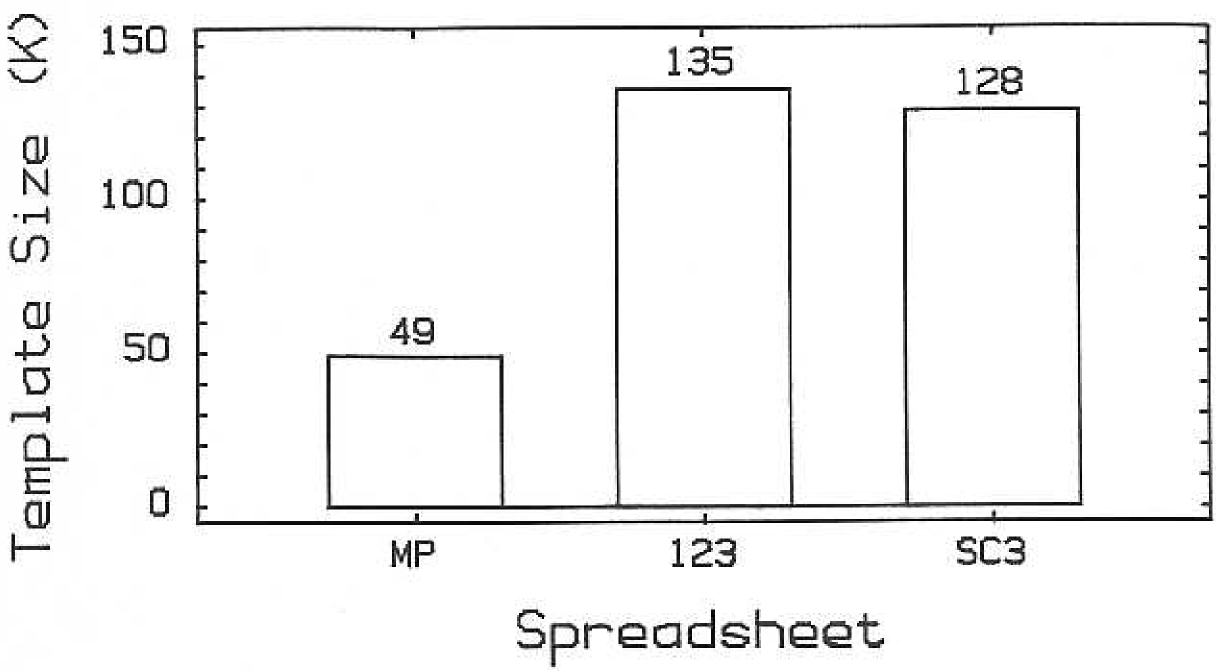

Figure 1. Size in Kilobytes of the ETr template as implemented in Multiplan, Lotus 123, and SuperCalc3.

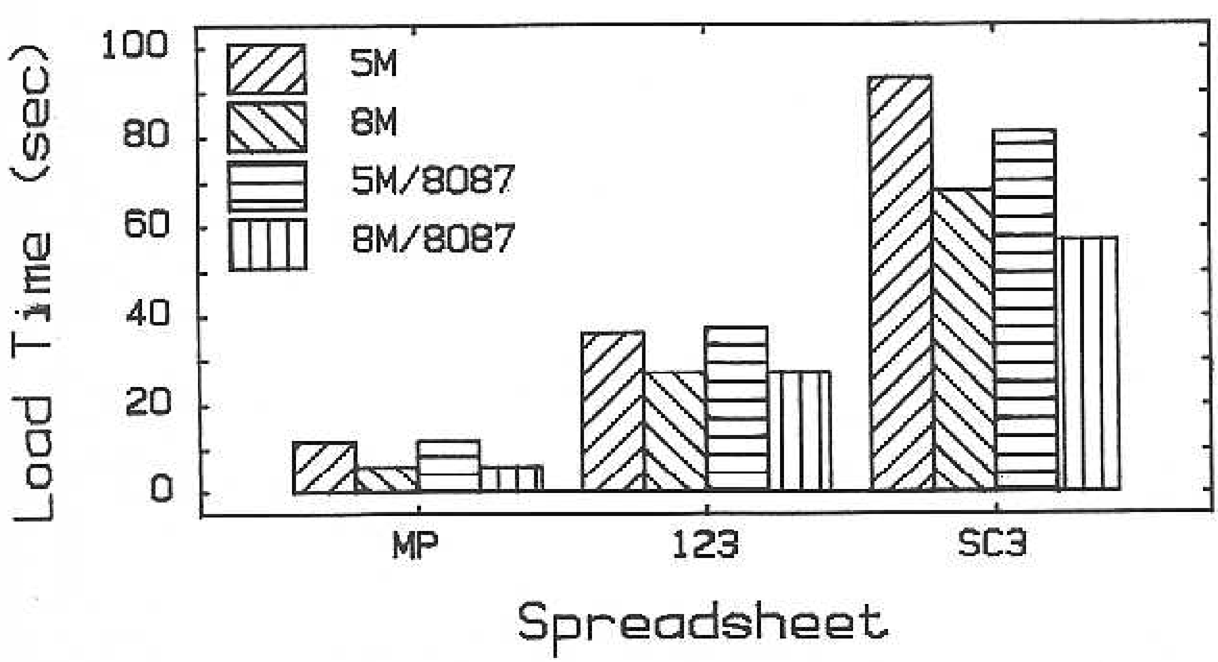

Figure 2. Time in seconds required for loading of the ETr template as implemented in Multiplan, Lotus 123, and SuperCalc3.

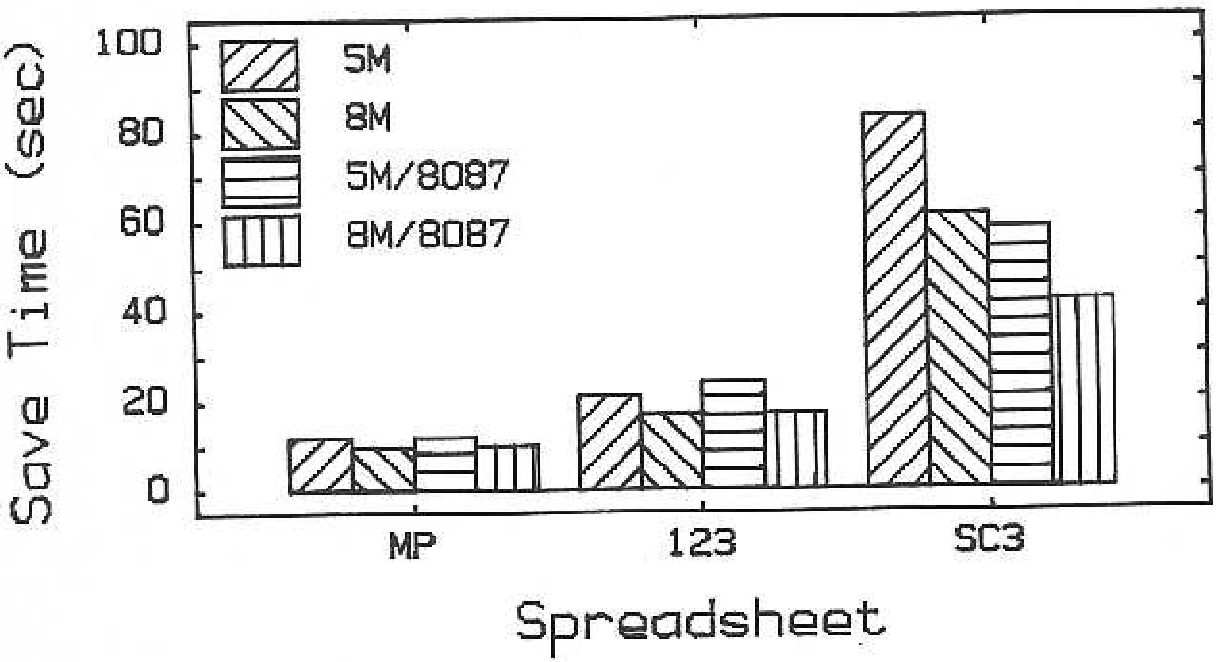

Figure 3. Time in seconds required for saving of the ETr template as implemented in Multiplan, Lotus 123, and SuperCalc3.

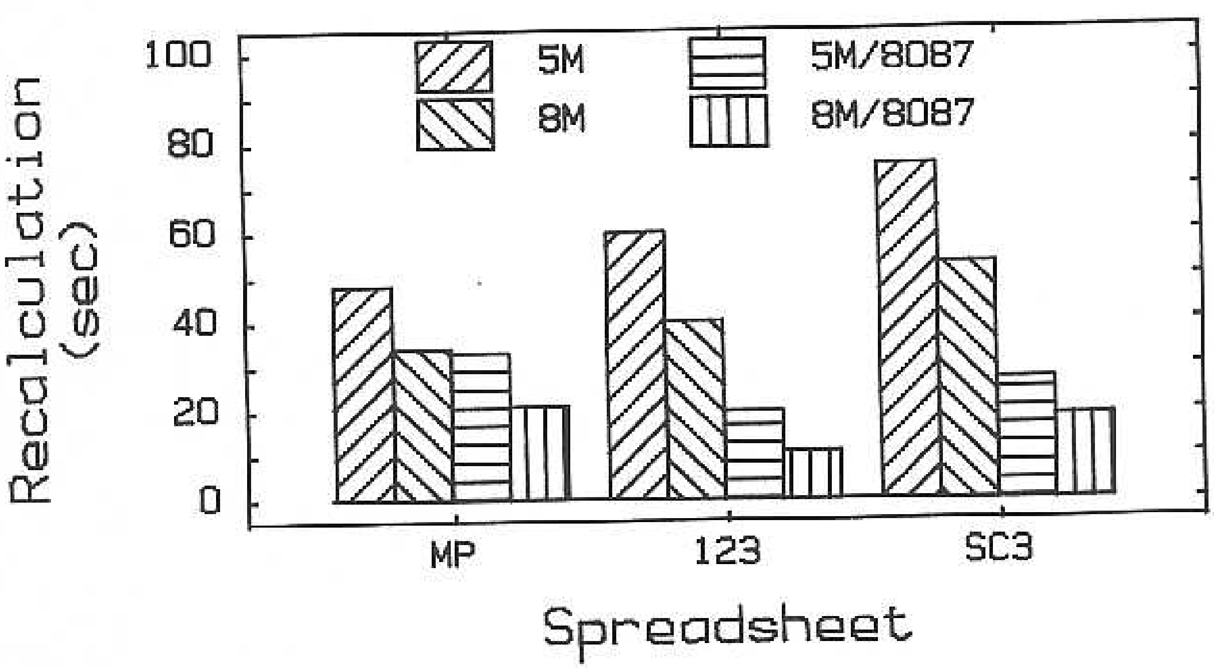

Figure 4. Time in seconds required to recalculate the full ETr template as implemented in Multiplan, Lotus 123, and SuperCalc3. Note: Multiplan 3.0 has recalculation methods that result in times much shorter than shown when some cells have been previously calculated.

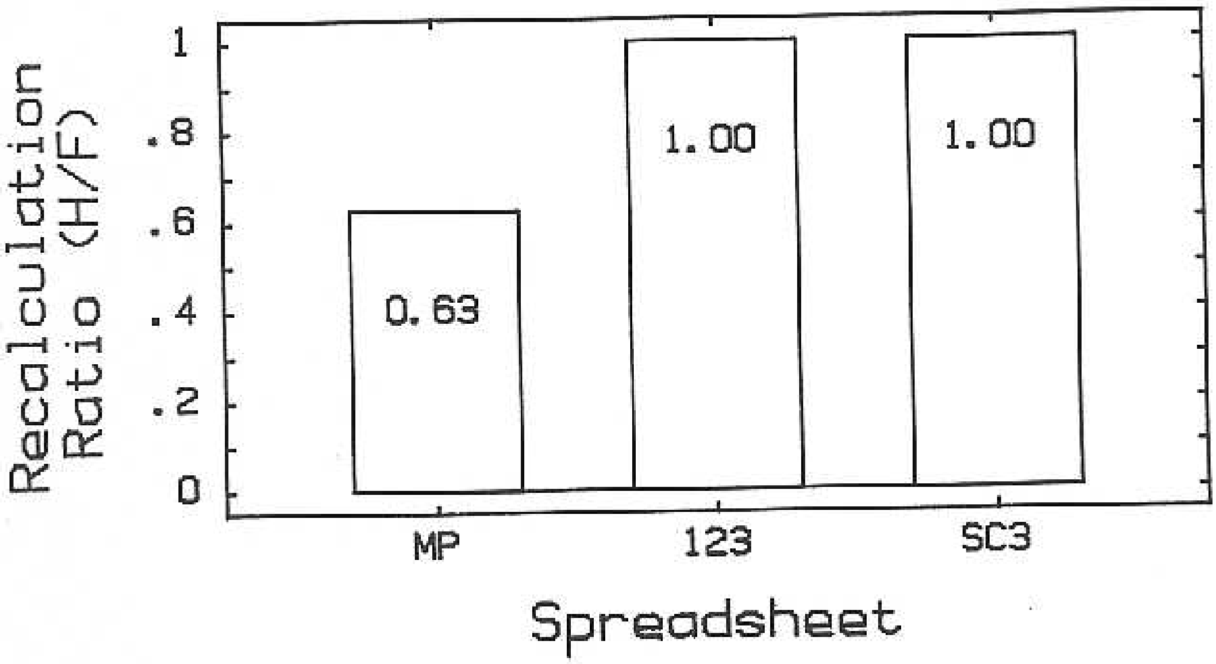

Figure 5. The ratio of recalculation times of a half full ETr template as compared to a full template for Multiplan, Lotus 123, and SuperCalc3, assuming that half the template data is entered in the current session.

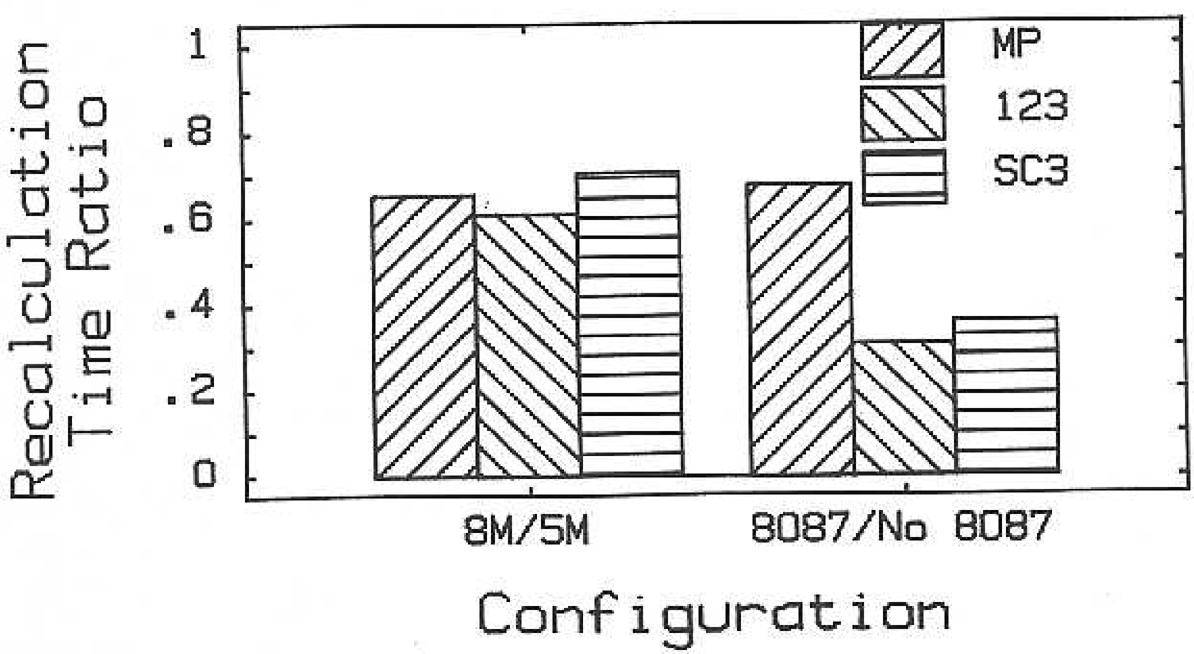

Figure 6. Comparison of ETr recalculation time ratios as affected by hardware configuration for Multiplan, Lotus 123, and SuperCalc3.

APPENDIX A ALGORITHMS AND CONSTANTS

The following list of equations, headings and constants can be used to reconstruct the ETr template in Multiplan 3.00, Lotus 123, or SuperCalc3. A set of sample data and results is included to check validity of reconstructed formulas.

Table A1. Column formats in the ETr template.

Column MP	Column 123 & SC3	Width	Decimal Places
1	A	3	0
2	B	4	-
3	C	4	0
4	D	4	0
5	E	4	0
6	F	4	0
7	G	4	0
8	H	5	0
9	I	5	0
10	J	5	2
11	K	5	2
12	L	4	0
13	M	4	0
14	N	4	0
15	O	5	2
16	P	5	1
17	Q	5	1

Table A2. List of constants in the ETr template for Colby, Ks.

Constants*	Current Location MP	Current Location 123 & SC3	Current Value	Description
ANH	R157C2	B157	2	Anemometer height, ft
ALW	R158C2	B158	1.22	LW Radiation A Coefficient
BLW	R159C2	B159	-0.18	LW Radiation B Coefficient
REF	R160C2	B160	0.23	Reflectance or Albedo
ACD	R161C2	B161	491	Clear day A Coefficient
BCD	R162C2	B162	246	Clear day B Coefficient
BRA	R163C2	B163	0.325	Brunt A Coefficient
BRB	R164C2	B164	-0.044	Brunt B Coefficient
ETF	R165C2	B165	0.000673	Conversion Factor for ETr
AW	R166C2	B166	0.75	Wind A Coefficient

In Multiplan 3.00, these constants are also named variables appearing in formulas. Typical modification for other locations will involve changing the values of ANH, ACD, and BCD. ETr is currently expressed in in/day, change ETF to 0.01709 for results in mm/day. The remaining constants should not be changed unless the user knows exactly what corresponding constants and formulas may also be changing.

Table A3. List of date and climatic input variables in the ETr template.

Table Heading	Variable Name*	Current Location MP	123 & SC3	Description
Month	MONTH	R2:154C1	A2:A154	Month (Numeric) 5 - 9
Month	-	R2:154C2	B2:B154	Month (Alpha) May 1-Sep 30
Day	DAY	R2:154C3	C2:C154	Day of Month 1 - 31
Tmx	TMX	R2:154C4	D2:D154	Maximum Daily Temp., F
Tmn	TMN	R2:154C5	E2:E154	Minimum Daily Temp., F
Tob	TO	R2:154C6	F2:F154	Observation Temp., 8 am F
Twt	TW	R2:154C7	G2:G154	Wetbulb Temperature, 8 am F
SRad	SR	R2:154C8	H2:H154	Solar Radiation, langleys
Wind	W	R2:154C9	I2:I154	Wind Run, miles/day
Rain	RAIN	R2:154C10	J2:J154	Precipitation, inches

* Variable names as used in formulas in Multiplan 3.00 template. No variable names are used in the template for Lotus 123 and SuperCalc3.

Table A4. Sample data and results for ETr template.

Examples of valid ETr results for given climatic data.

Month		Day	Tmx	Tmn	Tob	Twt	SRad	Wind	Rain	ETr	RN	Rlo	CDR	G1	VPA	VPS
5	MAY	1	100	75	75	65	600	50	0.00	0.30	328	141	648	0.79	17.4	47.5
5	MAY	2	75	50	55	52	475	25	0.00	0.16	265	142	651	0.65	12.2	21.0

Examples of valid CW results for a given anemometer height.

ANH 3
CW 0.02073

ANH 2
CW 0.02197

Table A5. List of computed variables and formulas in Multiplan 3.00.

Table Heading	Variable Name	Current Location	Description and Formula
ETr	ETr	R2:154C11	Reference Evapotranspiration, in/day IF(VPS<VPA,RN*G1*ETF,(RN*G1+15.36*(1-G1)*(AW+CW*W)*(VPS-VPA))*ETF)
RN	RN	R2:154C12	Net Radiation, langleys IF(SR>CDR,(((1-REF)*SR)-((ALW+BLW)*RLO)), ((((1-REF)*SR)-((ALW*(SR/CDR))+BLW)*RLO)))
Rlo	RLO	R2:154C14	Clear day Net Outgoing Longwave Radiation, langleys (BRA+(BRB*SQRT(VPA)))*11.71*((((TMX+TMN-64)/360)+2.73^4)
CDR	CDR	R2:154C15	Clear day Solar Radiation, langleys ACD+(BCD*SIN((2*PI()*((((MONTH-1)*30)+DAY+10.5)/365)-(PI()/2)))
G1	G1	R2:154C16	Weighting factor 0.041+(0.0125*((TMX+TMN)/2))-(4.534E-05*(((TMX+TMN)/2)^2))
VPA	VPA	R2:154C17	Actual Vapor Pressure, mbars 68.95*((-0.00534*(TO-TW))+EXP(54.63-(12301.7/(TW+460))-5.17*LN(TW+460)))
VPS	VPS	R2:154C18	Saturation Vapor Pressure, mbars 68.95*((EXP(54.63-(12301.7/(TMX+460))-5.17*LN(TMX+460)) +EXP(54.63-(12301.7/(TMN+460))-5.17*LN(TMN+460)))/2)
CW	-	R167C2	Wind Constant (Calculated from Anemometer Height ANH) 0.02426/(ANH^0.143)

Table A6. List of computed variables and formulas in Lotus 123.

Table Heading	Current Location	Description and Formula
ETr	K2:K154	Reference Evapotranspiration, in/day @IF(Q2<P2,L2*O2*$B$165,(L2*O2+15.36*(1-O2)*($B$166+$B$167*I2)*(Q2-P2))*$B$165)
RN	L2:L154	Net Radiation, langleys @IF(H2>N2,(((1-$B$160)*H2)-(($B$158+$B$159)*M2)), (((1-$B$160)*H2-(($B$158*(H2/N2))+$B$159)*M2*)))
Rlo	M2:M154	Clear day Net Outgoing Longwave Radiation, langleys ($B$163+($B$164*@SQRT(P2)))*11.71*((((D2+E2-64)/360)+2.73)^4
CDR	N2:N154	Clear day Solar Radiation, langleys +$B$161+($B$162*@SIN(2*@PI*(((A2-1)*30)+C2+10.5)/365-(@PI/2)))
G1	O2:O154	Weighting factor 0.041+(0.0125*(D2+E2)/2)-(0.00004534*(((D2+E2)/2)^2))
VPA	P2:P154	Actual Vapor Pressure, mbars 68.95*((-0.00534*(F2-G2))+@EXP(54.63-(12301.7/(G2+460))-5.17*@LN(G2+460)))
VPS	Q2:Q154	Saturation Vapor Pressure, mbars 68.95*((@EXP(54.63-(12301.7/(D2+460))-5.17*@LN(D2+460)) +@EXP(54.63-(12301.7/(E2+460))-5.17*@LN(E2+460)))/2
CW	B167	Wind Constant (Calculated from Anemometer Height ANH) 0.02426/($B$157^0.143)

Table A7. List of computed variables and formulas in SuperCalc3.

Table Heading	Current Location	Description and Formula *
ETr	K2:K154	Reference Evapotranspiration, in/day IF(Q2<P2,L2*O2*B165,(L2*O2+15.36*(1-O2)*(B166+B167*I2)*(Q2-P2))*B165)
RN	L2:L154	Net Radiation, langleys IF(H2>N2,(((1-B160)*H2)-((B158+B159)*M2)), (((1-B160)*H2-((B158*(H2/N2))+B159)*M2*)))
Rlo	M2:M154	Clear day Net Outgoing Longwave Radiation, langleys (B163+(B164*SQRT(P2)))*11.71*((((D2+E2-64)/360)+2.73)^4
CDR	N2:N154	Clear day Solar Radiation, langleys B161+(B162*SIN(2*PI*(((A2-1)*30)+C2+10.5)/365-(PI/2)))
G1	O2:O154	Weighting factor 0.041+(0.0125*(D2+E2)/2)-(0.00004534*(((D2+E2)/2)^2))
VPA	P2:P154	Actual Vapor Pressure, mbars 68.95*((-0.00534*(F2-G2))+EXP(54.63-(12301.7/(G2+460))-5.17*LN(G2+460)))
VPS	Q2:Q154	Saturation Vapor Pressure, mbars 68.95*((EXP(54.63-(12301.7/(D2+460))-5.17*LN(D2+460)) +EXP(54.63-(12301.7/(E2+460))-5.17*LN(E2+460)))/2
CW	B167	Wind Constant (Calculated from Anemometer Height ANH) 0.02426/(B157^0.143)

* SuperCalc3 users can use the replicate command to copy formulas and to adjust cell references as required. Cells B157 through B167 are used in an absolute sense and should not be adjusted.

APPENDIX B. SAMPLE SESSIONS

Multiplan (Version 3.0) Template ETIRR.MP

Begin at the system prompt A>. The following table of actions would result in example calculations of ETr for May 1.
NOTE: <CR> is carriage return, -> is the right arrow.

Current Display	Press these Keys	Comments
A>	MP <CR>	At prompt, MP will load if it exists on current A drive.
Blank Template	TLB:ETIRR.MP	Load (TL) file ETIRR.MP from the B drive.
ETIRR.MP Template	Arrow keys as required.	Move to desired date and column 4 for maximum temp.
Cursor at column 4, current date	85->	Enter maximum temp. 85. Move to cell 5, current date.
Cursor at column 5, current date	65->	Enter minimum temperature of 65. Move to next column.
Cursor at column 6, current date	67->	Enter drybulb temperature of 67. Move to next column.
Cursor at column 7, current date	66->	Enter wetbulb temperature of 66. Move to next column.
Cursor at column 8, current date	420->	Enter solar radiation value of 420. Move to next column.
Cursor at column 9, current date	100->	Enter wind run of 100. Move to next column.
Cursor at column 10, current date	1.00->	Enter precipitation of 1. Move to next column.
Cursor at ETr column	Shift !	This will insure all calculations are made.
0.21	POR1:2C1:11 and <CR>	This is ETr value for day. Setup for printing rows 1-2 columns 1-11. To setup for 5 rows, type POR1:5C1:11.
0.21	P	Print table.
0.21	TSB:ETIRR.MP and <CR>	Save all changes to disk B.
0.21	Q	Exit to system prompt.

APPENDIX B. SAMPLE SESSIONS

Lotus 123 (Release 2.0) Template ETIRR.WK1

Begin at the system prompt B>. The following table of actions would result in example calculations of ETr for May 1.
NOTE: <CR> is carriage return, -> is the right arrow.

Current Display	Press these Keys	Comments
B>	A:123	At prompt, 123 will load if it exists on the A drive.
Blank Template	/FR and use arrow keys to to highlight ETIRR.WK1 <CR>	File retrieve (FR) ETIRR.WK1 from the B drive.
ETIRR.WK1 Template	Arrow keys as required.	Move to desired date and column D for maximum temp.
Cursor at column D, current date	85->	Enter maximum temp. 85. Move to next column, current date.
Cursor at column E, current date	65->	Enter minimum temperature of 65. Move to next column.
Cursor at column F, current date	67->	Enter drybulb temperature of 67. Move to next column.
Cursor at column G, current date	66->	Enter wetbulb temperature of 66. Move to next column.
Cursor at column H, current date	420->	Enter solar radiation value of 420. Move to next column.
Cursor at column I, current date	100->	Enter wind run of 100. Move to next column.
Cursor at column J, current date	1.00->	Enter precipitation of 1. Move to next column.
Cursor at ETr column	[F9] Function key	This will insure all calculations are made.
0.21	/PPRA1.K2 and <CR>	ETr value for day. Setup for printing for range A1 to K2. Setup for 5 rows is /PPRA1.K5.
0.21	G	Print table.
0.21	Q	Quit print menu.
0.21	/FS and <CR>	Save all changes to disk B.
0.21	/Q and Y	Exit to system prompt.

APPENDIX B. SAMPLE SESSIONS

SuperCalc3 (Release 2.1) Template ETIRR.CAL

Begin at the system prompt A>. The following table of actions would result in example calculations of ETr for May 1.
NOTE: <CR> is carriage return, <ESC> is escape.

Current Display	Press these Keys	Comments
A>	SC3	At prompt, SC3 will load if it exists on the A drive. Hit any key to begin.
Blank Template	/LB:ETIRR and <CR>	Load the file ETIRR.CAL from the B drive.
ETIRR.CAL Template	Arrow keys as required.	Move to desired date and column D for maximum temp.
Cursor at column D, current date	85<CR>	Enter maximum temp. 85. Move to next column, current date.
*******Note:Cell cursor advances in same direction it was last moved by arrow keys********		
Cursor at column E, current date	65<CR>	Enter minimum temperature of 65. Move to next column.
Cursor at column F, current date	67<CR>	Enter drybulb temperature of 67. Move to next column.
Cursor at column G, current date	66<CR>	Enter wetbulb temperature of 66. Move to next column.
Cursor at column H, current date	420<CR>	Enter solar radiation value of 420. Move to next column.
Cursor at column I, current date	100<CR>	Enter wind run of 100. Move to next column.
Cursor at column J, current date	1.00<CR>	Enter precipitation of 1. Move to next column.
Cursor at ETr column	Shift !	This will insure all calculations are made.
0.21	/ODA1:K2 and <CR>	ETr value for day. Setup for printing for range A1 to K2. Setup for 5 rows is /ODA1:K5.
0.21	P Hit any key	Print table. Return to spreadsheet after printing.
0.21	/S <ESC> <CR> and OA	Save all changes to disk B.
0.21	/Q and Y	Exit to system prompt.