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## PEAK WATER REQUIREMENTS OF CROPS IN SOUTHERN IDAHO[a]

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### INTRODUCTION

Peak water requirements for crops in southern Idaho were determined from frequency distributions of evapotranspiration rates for 1-day, 3-day, 7-day, 15-day, and 30-day averaging periods. Daily evapotranspiration for a well watered reference crop (alfalfa), measured with a precision weighing lysimeter, and meteorological data were used to verify the calculations of daily evapotranspiration. Previously, peak water requirements for crops in southern Idaho were determined from soil sampling data which represented averages of 10-day to 20-day periods. The frequency analysis of daily evapotranspiration (ET) presented in this paper provides the probable or expected peak water requirements for irrigation intervals of 1 day to 30 days.

This study was prompted by the needs of engineers who must now design more carefully the capacity of irrigation systems and projects. Capacities must be designed to closer tolerances because of increasing water costs and the inflexible capacities inherent in self-propelled and solid set sprinkler systems which are now finding much greater use. Also, extensive acreages of high-value crops that are extremely sensitive to plant water stress are grown in the area. Since the irrigation intervals for these crops may range from 3 days to 5 days, the design of irrigation systems for these crops requires data on expected, short-period ET rates.

Two years of lysimeter measurements of ET and the associated energy balance components were used to develop and verify procedures for estimating ET from meteorological data. These procedures were then used to calculate

ET from meteorological data for a 5-yr period, and the frequency distributions were computed from these estimates. Daily rates during the peak 30-day period were as high as 0.43 in./day (11.0 mm), while 10-day peak requirements were 0.35 in./day (8.8 mm).

## PROCEDURES

Daily ET measurements on alfalfa were obtained with a precision lysimeter during the 1968 and 1969 growing seasons. Alfalfa was selected as a reference crop because: (1) It is widely grown in the area; (2) it has an extensive root system that minimizes the effects of decreasing soil water on ET; (3) it provides dense crop cover; (4) it has a low leaf resistance to the diffusion of water vapor; and (5) it is aerodynamically a rough crop. When all of these factors are combined, high rates of water use result under arid conditions. Evapotranspiration from well watered, actively growing alfalfa with 8 in. (20 cm) or more of growth approaches the maximum possible ET for farm crops in arid regions where there is advective sensible heat input from the air.

Since only 2 yr of lysimeter measurements of ET and accompanying energy balance data were available for such a crop, procedures were developed for the calculation of peak water requirements from meteorological data. A combination equation which combines energy balance and aerodynamic transfer terms was used to accomplish this. The values of the coefficients in the combination equation were determined from the available data, as were procedures for estimating the values of parameters for which meteorological measurements were not available. After testing and verification, the procedures were used to compute the peak water requirements for frequency distribution analysis. The frequency distributions constructed from these estimates covered a longer period than would have been available with the lysimeter data alone. This procedure also permitted including the days immediately following normal cuttings of alfalfa.

*Lysimeter Measurement of Daily ET.*—The precision weighing lysimeter capable of hourly measurements of ET is similar to that described by Ritchie and Burnett (6). It was installed in a 7-acre (2.8 ha) field early in 1968 for research on water requirements of irrigated crops. The lysimeter tank is 6-ft square and 4 ft deep (1.83 m × 1.83 m × 1.22 m). Weight changes are determined with an electronic load cell and are recorded with a data acquisition system, along with measurements of soil temperature, air temperature and humidity, solar and net radiation, and windspeeds at different elevations.

Nearly a year's time was required for data reduction. Consequently only data for 1968 and 1969 were available for this analysis.

The field and lysimeter tank were planted to alfalfa in the spring of 1968 and managed according to local farming practices. The water content of the soil within and without the tank was kept as similar as possible. To insure that water would not be limiting, the field was irrigated to keep the water content at the 18-in. depth within the tensiometer range (0.2 atm to 0.6 atm). According to the results of van Bavel (7), ET from alfalfa is not influenced significantly under high evaporative conditions until the soil-water tension approaches 4 atm.

*Estimation of 5 yr of ET Data.*—Procedures developed for estimating ET in a computerized irrigation scheduling program (4) were modified for estima-

ting ET from meteorological data for previous years. A modified Penman equation (4) was used to compute estimates of daily evaporative flux, $E^*$, from a well watered reference crop like alfalfa with 20 cm or more of top growth, i.e.,

$$E^* = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma}(15.36)(1.0 + 0.01W)(e_s - e_d) \qquad (1)$$

in which $\Delta$ = the slope of the saturation vapor pressure-temperature curve, $de/dT$, in mb $C^{-1}$ at 20° C and 1 atm pressure); $\gamma$ is the psychrometric constant (0.66 mb $C^{-1}$ at 1 atm pressure); $e_s$ is the mean saturation vapor pressure, in mb (mean at maximum and minimum daily air temperatures); and $e_d$ is the saturation vapor pressure at mean dew point temperature in mb. Parameters $\Delta/(\Delta + \gamma)$ and $\gamma/(\Delta + \gamma)$ are mean air temperature weighting factors whose sum is 1.0; $W$ is total daily wind run in miles at a height of 2 m; $R_n$ is daily net radiation in cal cm$^{-2}$ day$^{-1}$; and $G$ is soil heat flux in cal cm$^{-2}$ day$^{-1}$. For convenience, the term $1.0 + 0.01 W$ in Eq. 1 will be referred to as the wind function, $W_f$. Units are mixed to eliminate the need to convert standard U.S. Weather Service observations.

It was necessary to evaluate and modify the wind function because ET estimated by Eq. 1 for the irrigated area of southern Idaho was usually substantially lower than that measured for alfalfa. The low estimates occurred primarily when a high proportion of the energy used for evapotranspiration came from the advection of sensible heat to the irrigated area from the surrounding desert lands. The amount of crop cover greatly affected the response of the crop to such advective conditions.

To calibrate the wind function, Eq. 1 was solved for $W_f$. ET as measured with the precision weighing lysimeter, $R_n$ and $G$ as measured at the lysimeter site, and $W$ as measured at the nearby Weather Service station were used to compute the relationship of the required wind function to $W$.

Since measurements of $R_n$ required in Eq. 1 were not available from the meteorological data, procedures similar to those developed for an irrigation scheduling program (4) were used to estimate $R_n$ after further evaluation and calibration of coefficients. The equations as used in the scheduling program were

$$R_n = 0.77 R_s - R_b \quad \cdots\cdots\cdots\cdots\cdots \qquad (2)$$

$$R_b = \left(a \frac{R_s}{R_{so}} + b\right) R_{bo} \quad \cdots\cdots\cdots\cdots\cdots \qquad (3)$$

$$R_{bo} = (0.32 - 0.044 \sqrt{e_d})(11.71 \times 10^{-9}) \frac{T_2^4 + T_1^4}{2} \quad \cdots\cdots \qquad (4)$$

in which $R_s$ is observed solar radiation for a day; $R_{so}$ is solar radiation that would be expected on that day if there were no clouds; 0.77 $R_s$ represents the net shortwave radiation in cal cm$^{-2}$ day$^{-1}$ absorbed by a green crop with full cover with albedo taken to be 0.23; $R_b$ is the net outgoing longwave radiation in cal cm$^{-2}$ day$^{-1}$; $R_{bo}$ is the net outgoing longwave radiation on a clear day in cal cm$^{-2}$ day$^{-1}$; $e_d$ is the saturation vapor pressure at mean dew point temperature in mb; $11.71 \times 10^{-9}$ is the Stefan-Boltzmann constant in cal cm$^{-2}$ day$^{-1}$ K$^{-4}$; and $T_2$ and $T_1$ are the maximum and minimum daily air temperatures, respectively, in °K.

evaluated for November through February because this period was not important to our immediate needs. The sine function goes to zero on January 15 and July 15, causing this relationship to equal 0.325 on these dates (compared to 0.32 in Eq. 4).
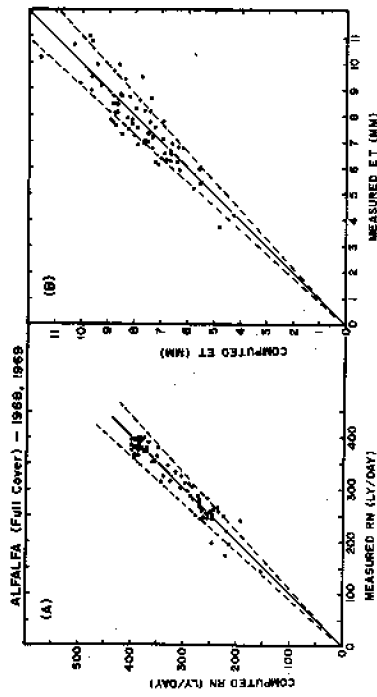


FIG. 1.—(a) COMPUTED COMPARED WITH MEASURED NET RADIATION AND (b) COMPUTED ET COMPARED WITH THAT MEASURED WITH SENSITIVE WEIGHING LYSIMETER FOR WELL WATERED CROP OF ALFALFA WITH FULL COVER AT KIMBERLY, IDAHO. (Dashed lines indicate ± 10 % limits about 1:1 line.)
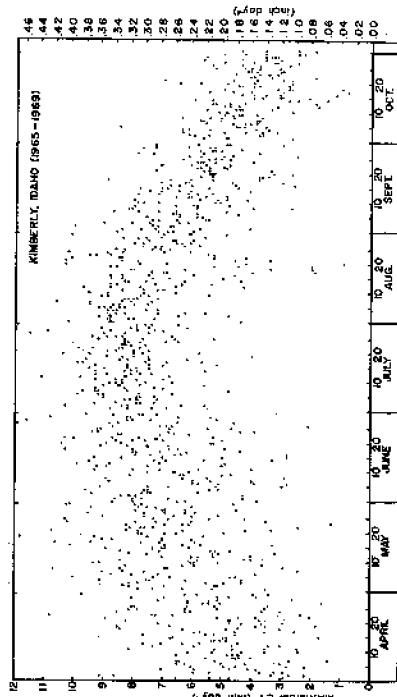


FIG. 2.—ESTIMATED DAILY ET FOR WELL WATERED CROP OF ALFALFA WITH FULL COVER AT KIMBERLY, IDAHO, COMPUTED FROM 5 YR OF METEOROLOGICAL DATA WITH CALIBRATED AND VERIFIED COMBINATION EQUATION.

The value of $R_n$ estimated after making the subject adjustments was compared with the measured $R_n$. As shown in Fig. 1(a), most of the estimated values were within ± 10 % of the measured values which was considered satisfactory for this study. These data are for partly cloudy and clear days.

ET was estimated using Eq. 1 with the adjusted wind function and procedures for estimating $R_n$, and then compared with available lysimeter ET data [see

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Measured values of $R_n$, $R_s$, and the distribution of $R_{so}$ determined for Kimberly, Idaho, were used to adjust the constants in equations 2, 3, and 4.

*Computation of Frequency Distributions.*—With the calibrated wind function and revised procedures for estimating $R_n$, daily ET was computed for the months of April through September for 5 yr, 1965 through 1969, along with 3-day, 7-day, 15-day, and 30-day running averages for each year. The necessary meteorological data were obtained at the Kimberly, Idaho, U.S. Agricultural Weather Service Station. The frequency distributions for the estimated daily ET were calculated from these data by ranking the data for 10-day periods (3 periods for each month) for all 5 yr and then calculating the respective cumulative frequency percentages. The peak 30-day period was selected from these results and the data for this period were composited. Frequency distributions were then computed for this peak period.

## RESULTS AND ANALYSIS

*Modification of Combination Equation.*—For the evaluation of the wind function, $W_f$, 82 days of data for the period May through August, 1968 and 1969, were selected. Days were used when crop cover was complete, the crop was at least 8 in. (20 cm) in height, and other conditions were favorable. The following linear regression equation was obtained from the data:

$$W_f = (0.75 + 0.017W) \text{ for } W \text{ at } 12 \text{ ft } (3.65 \text{ m}) \quad \ldots \ldots \ldots \ldots (5)$$

or approximately:

$$W_f = (0.75 + 0.0185W) \text{ for } W \text{ at } 2 \text{ m} \quad \ldots \ldots \ldots \ldots (6)$$

This relation yields values considerably greater than the wind function contained in Eq. 1 for cases when $W > 50$ miles per day. Use of this relation makes a considerable difference in the estimated net radiation by Eq. 1 for Kimberly, Idaho, because $W$ at 12 ft is generally greater than 100 miles per day.

Verification and calibration of the constants in the procedures for estimating net radiation for Idaho conditions gave $a = 1.22$ and $b = -0.18$ for Eqs. 2 and 3. These values compare favorably with those derived from Pruitt's (4) data for Davis, Calif., as used previously ($a = 1.35$ and $b = -0.35$). Comparison of estimated versus measured net radiation showed that the difference between surface emittance (0.98) and the constant in the Brunt equation for effective emittance of the atmosphere (0.32 in Eq. 4) must be varied seasonally to improve the net radiation estimates. Use of Eq. 4 as stated gave estimates of net radiation that were on the average 10 % too high in the spring and 10 % too low in the fall. The writers were not able to account for this seasonal change by an expression using available meteorological data. So a seasonally dependent empirical term was substituted for the constant 0.32 in the effective emittance term of Eq. 4:

$$0.325 + 0.045 \sin \left\{ 30 \left[ \left( \frac{M+D}{30} \right) - 1.5 \right] \right\} \quad \ldots \ldots \ldots \ldots (7)$$

in which $M$ is the number of the month, 1-12; $D$ is the day of the month; and the argument of the sine function is, in degrees. This adjustment improved the estimates and did not require any additional meteorological data. It was not

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Fig. 1(b)]. Most of the daily estimated values were within ± 10 % of the measured values, which was considered satisfactory for computing peak water requirements.

*Frequency Distribution Analysis of Daily ET.*—The computed daily ET values for the months of April through September for the 5 yr 1965-1969 are presented in Fig. 2. These give the distribution of ET for a well watered reference crop. (Alfalfa does reach this state on some years by May 1.) The wide range of the daily values vividly demonstrates the need for frequency distribution analyses to guide engineering planning. Single-day peak values for May through August were approximately equal, about 0.47 in./day (12 mm). Variation is greater during May than during July because periods of cool, cloudy weather occur in May compared with generally clear, warm days in July. The very low values for the period August 10-25 occurred during an unprecedented period of heavy cloud cover and rain in 1968.

The frequency distributions of daily ET calculated by 10-day periods are presented in Fig. 3. The 10-day running average of the data in Fig. 2 coincided quite closely with the 50 % level shown in Fig. 3. The dip in the frequency distributions in early June results from the rainy and cloudy weather typical of that time. The decrease during mid-August was accentuated by the exceptionally wet period in 1968, but it existed even when the data for that period were excluded. Minor variations in curves were smoothed because data were limited. To illustrate the use of these curves, on August 1 the peak daily ET for the reference crop for southern Idaho would be expected to be less than 0.43 in./day (11 mm) 98 % of the time. It would be less than 0.32 in./day (8 mm) 50 % of the time, etc.

The peak 30-day period was from July 11 to August 10. Results of the detailed frequency distribution analysis for this period for 1-day, 3-day, 7-day, 15-day, and 30-day averaging periods are summarized in Fig. 4. The 98 % level was the highest level calculated because data were insufficient to establish a reliable 100 % level. The peak value at the 50 % level was almost constant for the 3-day to 30-day averaging periods at about 0.32 in./day (8.15 mm), and agreed quite closely with a calculated 10-day running average of the 5 yr of daily values.

The individual frequency distributions for the respective averaging periods were not completely symmetrical, which accounts for the shape of the curves in Fig. 4. According to these results, a 10-day averaging period accounts for most of the cyclic variation. The downward trend in the curves for frequency levels less than 50 % as opposed to the expected upward trend was due to the lower rates of daily ET which occurred before and after the peak period (Fig. 3). These lower rates effected the values of the running average for the longer averaging periods. Theoretically, for a sufficiently long averaging period, all levels would be expected to converge at the 50 % level if a normal distribution existed.

Because of clear skies, warm dry climate, and low rainfall probability during the 30-day peak period, the range in daily values is much less than during the remainder of the growing season (see Fig. 2). The respective probability levels in Fig. 4 are, therefore, much closer together than they would be for other 30-day periods.

As an example of the use of ET frequency data, if one were designing a system for an irrigation interval of 5 days and depleted soil water were to be replaced, the capacity of the system required to meet all conditions 98 % of
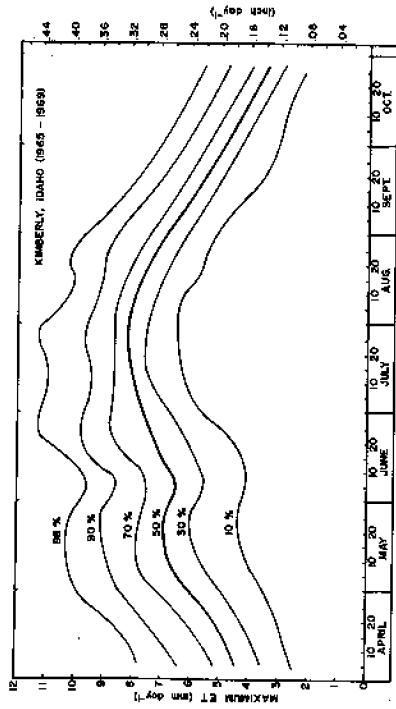


FIG. 3.—FREQUENCY DISTRIBUTIONS FOR ESTIMATED DAILY MAXIMUM ET FOR WELL WATERED CROP OF ALFALFA WITH FULL COVER CALCULATED FROM 5 YR OF DATA FOR KIMBERLY, IDAHO.
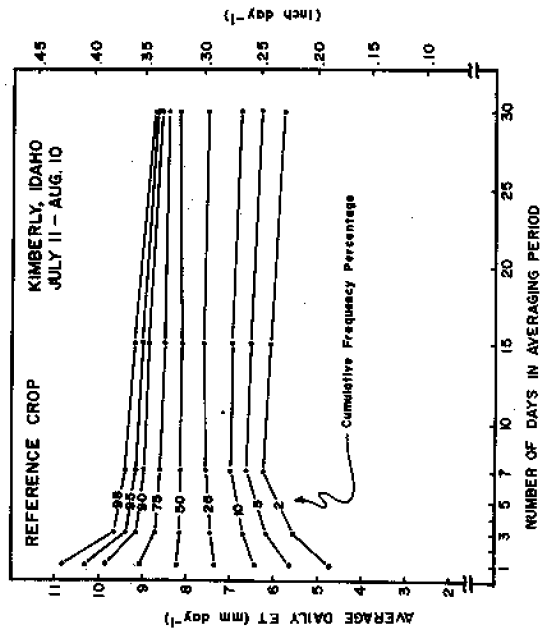


FIG. 4.—CUMULATIVE FREQUENCY PERCENTAGES OF AVERAGE DAILY ET ESTIMATED FROM METEOROLOGICAL DATA WITH COMBINATION EQUATION FOR 1-DAY, 3-DAY, 7-DAY, 15-DAY, AND 30-DAY AVERAGING PERIODS FOR PEAK 30-DAY PERIOD AT KIMBERLY, IDAHO.

the time (Fig. 4) would be 0.38 in./day (9.6 mm). The capacity at the 70 % level would be 0.33 in./day (8.5 mm). In other words, if one could economically accept the capacity to meet the peak 5-day demand all but 30 % of the time, the design requirement would be reduced by 13 %. The designer must consider the effects of not fully replenishing the soil water every 5 days in selecting the desired probability ET level that the system will meet. The differences would be greater for 1-and 3-day averaging periods, and less for longer periods.

The information in Figs. 3 and 4 can be related to crops not meeting all of the requirements of the reference crop by crop coefficients or other means that have been previously described (1,2,3,4,5,8).

## SUMMARY AND CONCLUSIONS

To provide information for designing and planning irrigation systems, peak water use requirements for well watered alfalfa were determined for southern Idaho from frequency distributions of evapotranspiration rates determined from lysimeter measurements and micrometeorological data. A combination equation was modified by adjusting the wind function to give better estimates of daily ET rates for arid climates for an actively growing, aerodynamically rough, well watered crop with full cover. Meteorological data were then used to compute expected ET with acceptable accuracy.

The daily ET computed for a reference crop for southern Idaho showed large daily variations and demonstrated the need for frequency analysis for precise engineering planning. For the period May through August, the peak single-day rate exceeded 0.4 in./day (10 mm). The peak 30-day period for southern Idaho is from July 11 through August 10.

The results of this study provide reliable estimates of expected peak ET rates for the reference crop. As such information becomes available, it increases the need for information on the expected yield and economic-return relationships of crops when managed at the various probability levels of peak ET rate.

## ACKNOWLEDGMENT

## APPENDIX.—REFERENCES

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