Estimating Evapotranspiration from Solar Radiation

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With discussion by **Jerald E. Christiansen, F. ASCE, Professor, Civil and Irrigation Engineering, Utah State University, Logan, Utah**

Studies conducted throughout the world have shown that evaportranspiration (consumptive use) by crops like grass in humid and semihumid areas can be predicted adequately for short time periods by using an energy balance approach. Methods for estimating seasonal evapotranspiration in irrigated areas of the western United States developed during the 1920 to 1950 period, used mean air temperature as the primary climatic variable even though studies by L. J. Briggs and H. L. Shantz[1] showed solar radiation to be the primary causative factor in transpiration. Numerous attempts have been made during the past 15 yr to adapt these seasonal estimating methods to short periods of time, such as a week or 10 days. The results of these studies have generally indicated that other meteorological variables must be used if reliable short period estimates are to be obtained.

Thousands of short period measurements of evapotranspiration, E_t, were made in the western United States from 1925 to 1960, many of which have not been published in detail. These data were collected, re-evaluated, and converted to ratios of evapotranspiration to solar radiation, R_s, at various stages of growth. The major factors affecting this ratio derived from the energy balance equation are given in

$$\frac{E_t}{R_s} \cong 1 - r - \frac{R_{et}}{R_s} - \frac{A}{R_s} - \frac{G}{R_s} \qquad (1)$$

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[1] Briggs, L. J., and Shantz, H. L., "Hourly Transpiration Rate on Clear Days as Determined by Cyclic Environmental Factors," Journal of Agricultural Research, Vol. 5 No. 14, January, 1916.

The ratio E_t/R_s represents the combined effects of reflectance, r, relative effects of effective or net thermal radiation R_{et}, heat flux to or from air by vertical turbulent transfer ($\pm A$), and heat flux to or from the soil ($\pm G$), plus other minor components. The ratio E_t/R_s will be about 0.55, or E_t will be equal to net radiation, R_n, when a green crop is adequately watered and transpiring, and A and G are approximately equal to zero. However, many irrigated crops do not have dense, actively transpiring vegetation all season. For example, shortly after planting a row crop, a large part of net radiation may be used in heating the air and soil (A and G increase). This causes the E_t/R_s ratio to be small. As the crop develops greater transpiration surface in moderate climates, E_t/R_s increases to about 0.55. In arid regions, where additional heat may be received from the air heated in adjacent dry areas, A will become negative, and the E_t/R_s ratio will be greater than 0.55. Air temperature also has direct effects on the ratio because of the non-linear saturated vapor pressure-temperature relationship and its effect on effective thermal radiation.

A tabular summary of mean measured ratios for various irrigated crops and stages of growth was presented in the paper with procedures for using these ratios to estimate evapotranspiration.

A tabular summary of weekly mean daily and total monthly solar radiation was also presented for twenty western United States locations. Methods were given for estimating solar radiation for other areas where only limited climatic data were available.

Empirical techniques were presented for estimating potential evapotranspiration, E_{tp}, based on E_t/R_s ratios from selected crops in which evaporating and transpiring surfaces were not limiting the vaporization of water. The crops used were alfalfa from Arizona, near the coast of California, Nebraska, and Washington (no cutting periods used); cotton, in August, in Arizona and California; oats in Nebraska; and winter wheat in Kansas and Texas. The results showed that the E_t/R_s ratio increased linearly with mean air temperature. Because these data were based on crops with adequate soil moisture, the correlation equation can be used to estimate potential evapotranspiration as follows

$$E_{tp} = (0.014\,T - 0.37)\,R_s \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which E_{tp} represents potential evapotranspiration in in. per day; T is the mean air temperature, in °F; and R_s represents solar radiation, in in. per day. Reasonable reliable estimates using Eq. 2 can be expected for periods as short as 5 days to 10 days because two variables are used.

Christiansen, in his discussion, briefly summarized the results Carlos J. Grassi[2] obtained using a multiple correlation approach to predicting evapotranspiration. Grassi related evapotranspiration rates to all meteorological

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[2] Grassi, Carlos J., "Estimation of Evapotranspiration From Climatic Formulas," thesis presented to Utah State University, at Logan, Utah, in 1964, in partial fulfillment of the requirements for the degree of Master of Science.

and crop data provided by the authors in addition to theoretical solar radiation reaching the outer atmosphere.

The U. S. Bureau of Reclamation also analyzed the original data provided by the authors and modified the proposed procedure. The modification resulted in a single curve for each crop in place of a curve for each crop in each climatic region. This was accomplished by computing the estimated potential evapotranspiration, E_{tp}, for each sampling period using Eq. 2. Then the ratios E_t/E_{tp} were plotted as the ordinate instead of E_t/R_s, but using the same seasonal scales to obtain a mean curve for each crop. This technique requires a basic assumption, i.e., the ratio E_t/E_{tp} must be unique at a given stage of growth. The ratio of E_t/E_{tp} may depend on the magnitude of E_{tp} in addition to stage of growth. However, the convenience of using a single curve for each crop outweighs minor differences if the E_t/E_{tp} ratio versus stage of growth approaches a unique relationship. It eliminates the need for a crop curve in each region. It should improve the estimate of E_t in a given year because both solar radiation and air temperature are used. This ratio also would reflect minor differences in E_t between crops resulting from differences in sensible heat transfer properties of the foliage when cover is essentially complete.

REFERENCE: Paper 3737, Journal of the Irrigation and Drainage Division, Proceedings of ASCE, Vol. 89, No. IR4, pages 15-41, December, 1963. Discussion: Jerald E. Christiansen, IR2:Jun 64:63:3941. Closure: IR1:Mar 65:203:4242.