Elevation — A Bias Error in SCS Blaney Criddle ET Estimates

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ABSTRACT

ELEVATION adjustments for evapotranspiration estimates are investigated. Bluegrass and alfalfa data from throughout the Western states are used to determine an elevation adjustment for the SCS Blaney Criddle formula. Six to ten percent upward adjustment per 1000 m altitude increase above sea level is required for calculated evapotranspiration.

INTRODUCTION

The influence of elevation on consumptive use has been recognized for years. For example, Jensen et al. (1970) gave elevation adjustments for the Modified Jensen Haise method. Adjustments were based on data collected from elevations ranging from 255 m in Washington, 1160 m in Idaho, and 2805 m in Colorado. Doorenbos and Pruitt (1977) in referring to the Blaney Criddle method state that "it should be used with skepticism at high altitudes due to the fairly low mean daily temperatures (cold nights) even though daytime radiation levels are high." They further state that, with the possible exception of the Penman and Pan methods with data collected on site, the use of methods for calculating reference crop ET will remain problematic for high altitude areas. They recommend adjusting calculated reference crop evapotranspiration values upwards some 10 percent for each 1000 m altitude change above sea level when using the FAO Blaney Criddle method. Documentation to support this adjustment is not given. Recently, however, Allen and Brockway (1983) have documented and applied a 10% increase for the FAO Blaney Criddle for Idaho. Cuenca et al. (1981) precent data showing that the SCS Blaney Criddle (1967) under-predicts crop water use for a high altitude arid climate. They explain this "partially due to the fact that the SCS Blaney Criddle evenly weighs day and night temperatures in computing an average temperature. At high elevation arid sites, night temperatures can be very low during the growing season, while plants respond to the higher daytime temperatures." The estimates by Cuenca et al. were apparently done without any local calibration of the formula.

The purpose of this paper is to investigate elevation adjustments for SCS Blaney Criddle evapotranspiration estimates. The recommended adjustments are based primarily on recently acquired measurements of the consumptive use of Kentucky bluegrass at locations ranging in elevation from 35 m to 2195 m. Bluegrass satisfies the usual definition of a crop providing reference crop evapotranspiration, i.e. "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos and Pruitt, 1977). The bluegrass data were selected because they comprise a data base that has been collected from a rather broad region using similar methods of measuring ET. The elevation adjustments have been confirmed using consumptive use measurements on alfalfa. The alfalfa data used have been extracted from several references. Although we have some concerns about the uniformity of methods of measurement between sites, the results are similar to those found for Kentucky bluegrass.

The Blaney Criddle method has been and remains very popular for estimating ET from climatic data because percent sunshine data varies only with latitude and season and temperature data are easily acquired. Adjustments for elevation would be equally easy to apply, since elevation for any spot on the earth is readily obtained.

The authors are working on consumptive use studies in a state, Wyoming, where elevations vary from 953 m to approximately 3000 m for its cropland. Much of the production is on mountain valleys with elevations greater than 1800 m. An average of about 15.8 million acre-feet of surface water are produced each year by precipitation in Wyoming (Wyoming State Engineer's Office, 1973). Both in-state and out-of-state demands for this water are increasing at a rapid rate. For example, Wyoming's current industrial-urban water demand amounts to over 150,000 acre-feet and is projected to reach 500,000 acre-feet by the year 2000 (Wyoming Conservation Commission, 1981) while in the ten Great Plains states it has been estimated that electric power plants alone may consumptively use an additional one million acre-feet of water by the year 2000 (Borrelli, 1981). The need to define agriculture's present use is naturally increasing also. It is becoming increasingly important to estimate consumptive use on a state-wide basis using readily available data. Historically, and currently, in Wyoming as in many states available climatic data consists of daily maximum and minimum temperatures and precipitation. As more use is made of automatic weather stations, this situation will gradually change. Other data such as that required for the FAO Blaney Criddle can be estimated, but in many cases these requirements cause additional steps that are not well understood or are so time consuming that they may be avoided by policy makers. The SCS Blaney Criddle remains one method of estimating evapotranspiration that is straightforward and relatively accurate if locally calibrated. With the large elevation variations that occur throughout Wyoming and other states, elevation adjustments to

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Location	Latitude	Longitude	Elevation, m	Mean annual precipi- tation, cm	Mean annual tempera- ture, °C	Average frost free period, days	Years of data
Laramie, WY	41°19'N	105°41'W	2,195	25.4	4.9	113	1976-1978
Wheatland, WY	42°05'N	104°57'W	1,433	20.5	9.5	133	1976-1978
Fort Collins, CO	40°35'N	105°05'W	1,525	36.3	8.9	140	1977-1978
Northglemn, CO	39°54'N	104°59'W	1,665	31.2	10.1	155	1977-1978
Santa Ana, CA	33° 45'N	117°42'W	35	32.8	17.2	316	1970-1974

estimate ET using the SCS Blaney Criddle are of special interest.

APPROACH AND RESULTS

Kentucky Bluegrass

Borrelli, et al. (1981) recently reported measured consumptive use values for Kentucky bluegrass at five sites in the western United States. The sites range in elevation from 35 m to 2195 m above sea level (Table 1). Measurements in Wyoming and Colorado were taken using small weighable lysimeters in which available moisture depletion was never allowed to exceed 35%. Measurements in California were taken at the University of California South Coast Field Station in Santa Ana (Youngner, 1979). Measurements were from plots having automatic irrigation when a tensiometer at either the 15 or 30 cm depths reached 40 cb. These were defined as medium tensiometer treatments and probably do not totally meet the criteria of unlimited water availability.

The consumptive use measurements for Kentucky bluegrass (Borrelli et al., 1981) were used to calibrate the SCS (1967) version of the Blaney Criddle formula for monthly estimates of E_{tp}, where

$$u = 25.4\, k_t k_c f \quad [1]$$

in which u = the consumptive use (which may be assumed to be E_{tp} in this study) for the month in millimeters; k_t = a coefficient related to temperature; k_c = a crop growth stage coefficient for the month; and f = a consumptive use factor. The SCS coefficient k_t was related to temperature by

$$k_t = 0.0311t + 0.240 \quad [2]$$

in which t = the mean temperature for the month, in degrees centigrade. The consumptive use factor f is defined as

$$f = \frac{(1.8t + 32)}{100} p \quad [3]$$

in which p = the monthly percentage of daytime hours of the year. Calibration of the formula by Borrelli et al. (1981) consisted of calculating k_c values for each month using the averages of the measured consumptive use and temperature data over two or more seasons. Two factors indicate that the general k_t relationship of equation [2], as given by the SCS, does not appropriately account for the temperature effect of an individual crop, such as Kentucky bluegrass. First, the seasonal variations of the calibrated crop coefficients formed U-shaped curves. This is not consistent with the shape of the curves for the SCS coefficients, which are bell-shaped. Secondly, following the release of the publication by Borrelli et al. (1981) which presented the calibrated k_c values, numerous inquiries were received requesting information on coefficients at sites not included in the original data set. In response to these inquiries, linear regressions were performed for the monthly crop coefficients versus temperatures. As a first approximation, regressions were performed for each month. The results indicated a strong relation between temperature and the k_c values. Linear regressions were then performed by grouping the data for the four cooler months — April, May, Sept. and Oct. — and for the three warmer months — June, July and Aug. Again, a good relation between temperature and the k_c values was found. Part of this is probably unexplained temperature effect and part an elevation effect.

Jensen (1966) has suggested that the use of monthly crop growth stage coefficients in the Blaney Criddle formula is an indirect adjustment for variation in average solar radiation during the season. This suggestion apparently was based on the assumption that lawn grass does not have a dormant period during the growing season and thus should not exhibit stage of growth characteristics for individual months. Borrelli et al. (1981) have clearly shown that, at high temperatures, cool season grasses such as Kentucky bluegrass will exhibit heat stress that reduces their evapotranspiration rates below what would be expected with the warm temperatures. Thus the k_c values derived herein, although called crop growth stage coefficients, probably reflect the combined effects of crop growth characteristics and seasonal radiation variation.

The SCS temperature coefficient k_t was recomputed based on the original Kentucky bluegrass consumptive use data set (Borrelli et al. 1981), giving

$$k_t = 0.0059t + 0.755 \quad [4]$$

TABLE 2. CALIBRATED CROP GROWTH STAGE COEFFICIENTS FOR KENTUCKY BLUEGRASS AVERAGED FOR THE 5 SITES OF TABLE 1.

Month	Coefficient
April	0.97
May	1.00
June	1.10
July	1.06
August	0.98
September	0.97
October	0.89

TABLE 3. COMPARISONS OF ESTIMATED (U) VS MEASURED (ET) CONSUMPTIVE USE, MM, FOR KENTUCKY BLUEGRASS.

Month	Laramie, WY		Wheatland, WY		Fort Collins, CO		Northglenn, CO		Santa Ana, CA	
	u	ET	u	ET	u	ET	u	ET	u	ET
Apr	69	58	86	100	—	—	—	—	106	104
May	101	114	125	124	—	—	—	—	135	103
Jun	137	165	161	146	134	172	160	156	154	131
July	157	183	181	168	178	152	184	190	168	169
Aug	128	134	146	124	146	146	151	153	154	145
Sep	91	93	106	113	111	109	117	136	123	108
Oct	56	59	68	70	—	—	66	80	97	77
Season	739	806	873	855	569	579	678	715	937	837
	8% Underestimate		2% Overestimate		2% Underestimate		5% Underestimate		12% Overestimate	

* Estimated values calculated using k_t of equation [4].

TABLE 4. STATISTICS COMPARING DIFFERENCES, MM, BETWEEN MONTHLY MEASURED ET AND CALCULATED ET FOR KENTUCKY BLUEGRASS USING (1) THE ORIGINAL SCS-BC USING k_c VALUES FOR PASTURE GRASS; (2) THE SCS-BC METHOD WITH CALIBRATED k_c AND k_t VALUES AND (3) AS IN 2 ABOVE BUT WITH AN ELEVATION ADJUSTMENT OF 9.1% PER 1000 M ELEVATION INCLUDED (FOR THE FIVE LOCATIONS LARAMIE, WHEATLAND, FORT COLLINS, NORTHGLENN, AND SANTA ANA).

Month	Measured vs original SCS-BC		Measured vs SCS-BC with calibrated k_t and k_c		Measured vs SCS-BC with calibrated k_t and k_c and elev adj	
	Mean diff	St. dv. of diff	Mean diff	St. dv. of diff	Mean diff	St. dv. of diff
Apr	36.3	13.6	9.0	6.2	13.3	2.5
May	33.3	29.9	15.3	15.6	7.3	6.8
Jun	30.2	28.0	19.6	14.8	14.4	13.1
Jul	19.8	20.3	14.4	11.4	16.4	9.8
Aug	14.2	12.2	7.8	8.7	7.8	9.3
Sep	22.0	11.2	9.0	7.7	6.4	6.3
Oct	27.3	15.2	9.8	8.7	5.8	5.8

Crop growth stage coefficients (k_c) were then recalculated to account for the loop effect between monthly temperatures and monthly consumptive use coefficients as discussed by the SCS (1967). Crop growth stage coefficients — averaged for the five sites — are given in Table 2. The seasonal variation of these coefficients form the typical bell-shaped curves depicted by the SCS.

The calibrated crop growth stage coefficients of Table 2 were used to estimate consumptive use of Kentucky bluegrass at the five sites for which the original measurements were obtained. The estimated consumptive use values (u) are compared with the actual measured values (ET) in Table 3. Assuming a perfect fit of the calibrated data, the estimated consumptive use values should perfectly match the measured values. However, at the higher elevation site (Laramie) an underestimation occurs while at the lowest elevation site (Santa Ana) an overestimation occurs. At the intermediate elevation sites (Wheatland, Fort Collins and Northglenn) the estimated and measured consumptive use values compare rather closely. Basically the results support the premise that SCS Blaney Criddle estimates of reference crop ET values should be adjusted upward with increasing elevation above sea level. However, in this case the adjustment is not with respect to sea level. An upward or downward adjustment should be made depending on whether the location at which estimates are being calculated has an elevation which is greater or lower, respectively, than the location at which the formula is calibrated. For example, the average coefficients of Table 2 apply without elevation adjustment at an elevation of 1350 m. For Kentucky bluegrass, for the season (April through October) our estimates give a 9.4% adjustment per 1000 m elevation and for the summer months (June through August) this adjustment is 7.6%. Thus if seasonal ET estimates are being made at an location having an elevation of 2350 m and using the coefficients of Table 2, then an upward adjustment of 9.4% should be applied. Likewise, estimates at 350 m elevation should be adjusted downward 9.4%, etc.

The authors strongly urge local calibration when using the SCS Blaney Criddle. As shown in Table 4, calibration of the SCS-Blaney Criddle for Kentucky bluegrass improved the ET estimates for the five locations considered herein. Application of the elevation adjustments for estimating consumptive use of lawn grass in Wyoming will use the SCS Blaney Criddle method calibrated at Laramie and Wheatland. Estimates at other locations will use the calibrated values for either Laramie or Wheatland and elevation adjustments based on the differences between the elevation of Laramie or Wheatland and the elevation of the site in question.

Alfalfa

Alfalfa consumptive use data were obtained from the literature for the nine sites listed in Table 5. These sites were selected based on availability of data to give a comparision and/or confirmation of the elevation adjustments which were determined for bluegrass. The main criteria was to have sites with a wide elevation range. Unlike the bluegrass data, the alfalfa data for the different sites were not collected during the same years or even using the same procedures.

The procedure used for bluegrass was applied to the alfalfa data. The computed temperature coefficient was