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A Study of Local Evapotranspiration (III)
- Evaluation of Evapotranspiration Models -

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1. Introduction

Arid and semiarid regions of the southwestern United States are characterized by sporadic precipitation, a limited water supply, and high rates of incident solar energy. In arid regions, which occupy one-third of the world's land surface, available water is very limited. Therefore, actual evapotranspiration (AET) is low in these regions. However, as a consequence of the warm and dry climates, potential evapotranspiration (PET) that would occur if moisture supply is not limited, is extremely high, and available water will evaporate rapidly. If there is abundant moisture in the soil, the two rates are assumed to be equal (AET/PET $\simeq$ 1). If the soil water content decrease to a certain level for that soil, AET declines, and the ratio of AET/PET declines with decreasing soil water content (AET/PET $<$ 1).

This study examined the applicability of various AET/PET relationships to the problem of estimating actual evapotranspiration. Several well-known evapotranspiration (ET) models were examined with daily data during the summer rainy period to find the practical basis of the models, and to assess possibilities for application of the concepts in the study area. The following approaches were examined: (1) the Morton's complementary relationship; (2) Thornthwaite and Mather's AET/PET vs. soil moisture relationship; and (3) the Priestley-Taylor model.

2. Data

The tests utilized the daily meteorological, flux and soil water content data measured from the Monsoon 90 experiment at Walnut Gulch watershed located in southwestern Arizona about

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120 km southeast of Tucson, U.S.A.. Data used in this study were measured during the summer rainy period from DOY (Day of Year) 90198 through DOY 90227 at Lucky Hills watershed, and from DOY 90202 through DOY 90223 at Kendall watershed (Fig. 1).

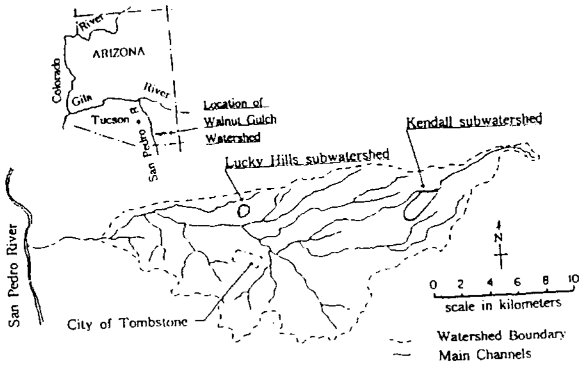

Fig. 1. USDA-ARS Walnut Gulch Experimental Watershed Location Map.

3. Analyses and Results

3.1 Morton's Complementary Relationship

Morton[7] defined the complementary relationship as AET + PET = 2PET" where AET is the actual evapotranspiration, 2PET" is the value of PET for a dry region, and PET" denotes the initial value of PET for a saturated region (Fig. 2). Morton's complementary approach for the estimation of AET requires well-defined linear relationships between PET and soil moisture content (SM), and AET and SM. The dependence was tested at Walnut Gulch Experimental Watershed, using PET estimates, and AET and SM measurements.

The relationships for PET or AET vs. SM are shown in Figs. 3 and 4 during the summer rainy period at Lucky Hills and Kendall watersheds. Results of statistical analyses are summarized in Tables 1 and 2. The plotted data in Figs. 3 and 4 suggest linear relationships, but the regression results indicate that the relationship between SM and PET or AET was not well defined. Especially, there was a very weak correlation explaining only a few percent of the variance between PET and SM.

The scatter plots and the regression analyses reveal that Morton's complementary relationships do not hold at this site on a daily basis. His model requires that PET (or AET) be related to soil moisture. The test results show that other meteorological factors such as incoming solar radiation, available energy, or perhaps wind, affect PET or AET regardless of the level of soil moisture. This conclusion is based on the fact that PET or AET are affected

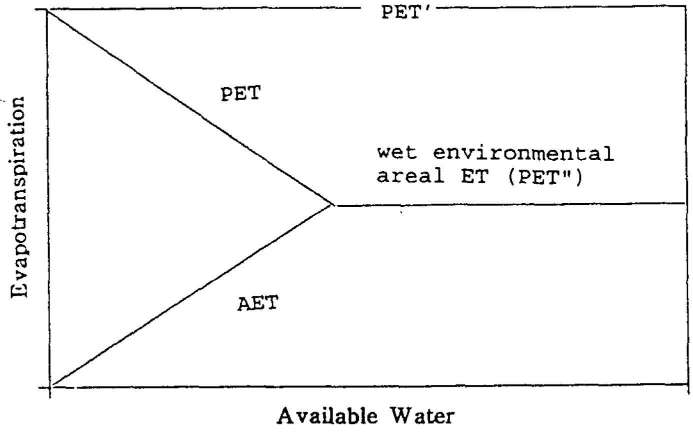

Fig. 2. Complementary Relationship between Actual and Potential Evapotranspiration (after Morton, 1983).

Table 1. The Relationship of PET Vs. SM and AET Vs. SM at Lucky Hills Watershed during the Summer Rainy Period.

No	Regression Equations	r^2	SEE
1	PET = -0.015(SM) + 6.577	2	1.36
2	AET = 0.032(SM) + 0.980	25	0.72

1) The relationship between PET and SM with all data
2) The relationship between AET and SM with all data
r^2: coefficient of simple determination (%)
SEE : standard error of estimate of the regression (mm/day)

Table 2. The Relationship of PET Vs. SM and AET Vs. SM at Kendall Watershed during the Summer Rainy Period.

No	Regression Equations	r^2	SEE
1	PET = -0.049(SM) + 10.185	10	1.28
2	AET = 0.031(SM) + 0.552	18	0.57

1) The relationship between PET and SM with all data
2) The relationship between AET and SM with all data
r^2: coefficient of simple determination (%)
SEE : standard error of estimate of the regression (mm/day)

by the energy availability as well as by soil water condition. The failure of Morton's model at Walnut Gulch confirms its shortcomings, at least for application on a daily or short-period basis.

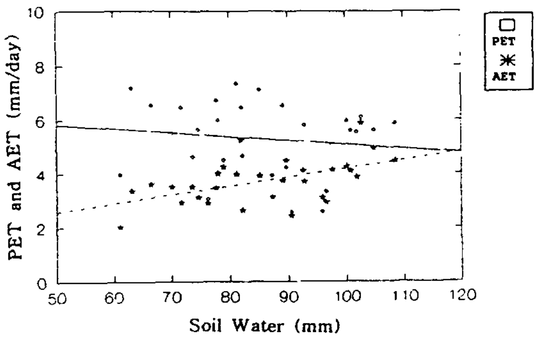

Fig. 3. The Relationship between Daily PET and AET as a Function of SM during the Summer Rainy Period (1990) at Lucky Hills Watershed.

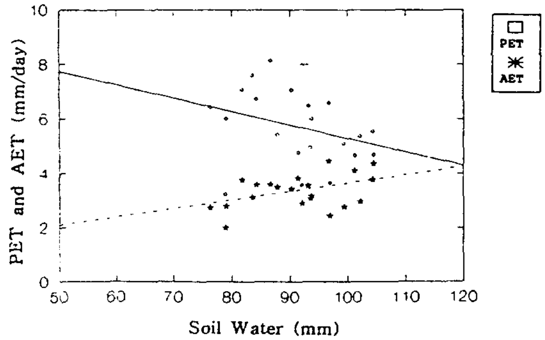

Fig. 4. The Relationship between Daily PET and AET as a Function of SM during the Summer Rainy Period (1990) at Kendall Watershed.

3.2 Thornthwaite and Mather's AET/PET Vs. Soil Moisture Relationship

Thornthwaite and Mather[11] base their model upon a linear relationship between k (=AET/PET) and SM, and reported that the ratio of k declined linearly with decreasing SM. Holmes[5] reported that soil texture affects the relationship between k and SM. The surface of sand samples dried quickly and AET fell below PET early in the drying cycle. However, for heavier, finer textured soils, the soil surface remained moist for a longer period and AET $\simeq$ PET over a larger part of the available moisture range. Others have reported similar effects associated with the rate of evaporation.[3, 4, 6] The k vs. SM relationship for estimation of AET was tested at Walnut Gulch Experimental Watershed, using Penman PET-and measured AET and SM (Figs. 5 and 6). The linear regression model has only limited predictive value, however, as it explains only about one-third of the variance (Table 3) and the SEE is

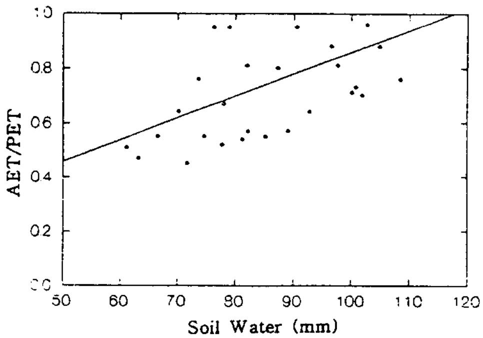

Fig. 5. Plot of Relationship between Daily AET/PET as a Function of SM during the Summer Rainy Period (1990) at Lucky Hills Watershed.

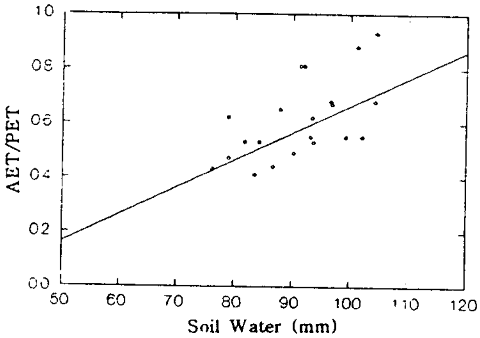

Fig. 6. Plot of Relationship between Daily AET/PET as a Function of SM during the Summer Rainy Period (1990) at Kendall Watershed.

Table 3. The Relationship between k Vs. SM at Lucky Hills and Kendall Watersheds during the Summer Rainy Period.

No	Regression Equations	r^2	SEE
1	k = 0.008(SM) + 0.058	28	0.17
2	k = 0.010(SM) - 0.337	36	0.12

1) with all data at Lucky Hills watershed
2) with all data at Kendall watershed
r^2: coefficient of simple determination (%)
SEE : standard error of estimate of the regression (mm/day)

relatively large. The poorly defined relationships displayed in Figs. 5 and 6 invalidate the AET/PET vs. SM method at Walnut Gulch. Therefore, the Thornthwaite approach [k = f(SM)] is not applicable to Walnut Gulch.

3.3 The Priestley and Taylor Approach

The Priestley-Taylor model[10] is defined as AET = $\alpha \cdot W(R_n + G)$ where AET is the actual ET (mm/day); W is the dimensionless weighting factor; R_n is net radiation (mm/day); G is ground heat flux (mm/day); and α= [daily AET/W(R_n + G)] is a model coefficient. Priestley and Taylor determined that α = 1.26 for saturated areas, and $\alpha < 1.26$ for drying conditions. Empirical modifications have been proposed for the α term so that the Priestley-Taylor equation can predict AET. Often, α has been defined as a function of soil water content [α = f(SM)].[1, 2, 9]

The relationship is examined at Walnut Gulch in Figs. 7 and 8, and Table 4. The coefficient α is plotted as a function of SM for all days in the summer rainy period at Lucky Hills and Kendall. The regression analysis reveals that the linear model explains only about

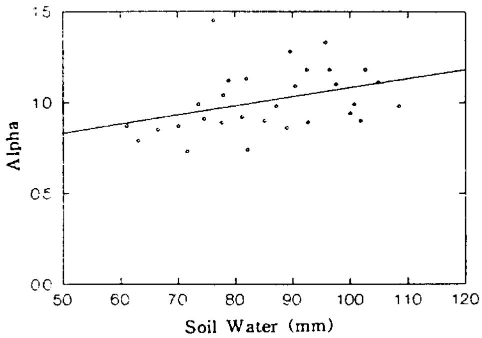

Fig. 7. Plot of Relationship between Daily α as Function of SM during the Summer Rainy Period (1990) at Lucky Hills Watershed.

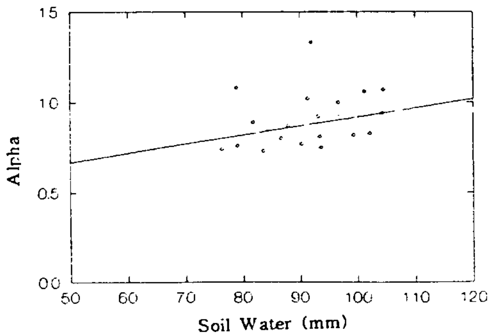

Fig. 8. Plot of Relationship between Daily α as Function of SM during the Summer Rainy Period (1990) at Kendall Watershed.

Table 4. The Relationship between α Vs. SM at Lucky Hills and Kendall Watershed during the Summer Rainy Period.

No	Regression Equations	r^2	SEE
1	α = 0.005(SM) + 0.582	14	0.16
2	α = 0.005(SM) + 0.419	9	0.15

1) with all data at Lucky Hills watershed
2) with all data at Kendall watershed
r^2: coefficient of simple determination (%)
SEE : standard error of estimate of the regression (mm/day)

one-tenth of the variance (Table 4) and the SEE is relatively large. Furthermore, the offset term is assumed 0.5, implying that the ratio α = AET/W(R_n + G) is large even when SM = 0. Table 4 does show similar slopes for Lucky Hills and Kendall, suggesting similar trends between α and SM at both watersheds. It is quite clear that the Priestley-Taylor approach [α = f(SM)] is not successful at Walnut Gulch.

4. Conclusions

The relationship between AET and PET as a function of soil water content as suggested by Thornthwaite-Mather, Morton and Priestley-Taylor was studied to determine the realistic meaning of the concepts and to evaluate possibilities of application of the concept in the study area. However, the test results indicated some inadequacy. The low correlation between PET, AET and soil moisture condition raised some doubt concerning the validity of methods, and indicated the effects of energy availability on the relationship between PET, AET and soil water content regardless of soil water condition. The test results lead me to conclude that other meteorological factors such as incoming solar radiation, available energy, or perhaps wind, affect PET or AET regardless of the level of soil moisture. This conclusion is based on the fact that PET or AET are affected by the energy availability as well as by soil water condition.

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