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6.4 ESTIMATING WATER USE BY SEMIARID RANGELAND VEGETATION DURING THE SUMMER IN SOUTHERN ARIZONA

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1. ABSTRACT

In the Sonoran and Chihuahuan desert regions of the southwestern U.S., the summer "monsoon" is the most dynamic period both from a hydrological and ecological perspective, yet few hydrometeorological measurements exist covering several monsoons to evaluate the water use by shrub and grass dominated communities. Since 1990 hydrometeorological data, including precipitation, runoff, weather data, ~~surface~~ energy fluxes and soil moisture profile measurements, have been collected at the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona. Preliminary results of evapotranspiration estimates using micrometeorological and water balance techniques for several monsoons indicated that energy balance estimates were higher than the water balance estimates. Relative water use is 15% higher in the grass dominated watershed than in the shrub dominated community.

2. INTRODUCTION

Quantification of water use by different vegetation communities is critical for understanding the potential impacts of land use changes on water supplies. This is particularly critical in semiarid regions where anthropogenic disturbances such as cattle grazing on rangelands or climate variations from persistent periods of drought can have a dramatic impact on ecosystem stability which can lead to desertification. Therefore it is imperative that we be able to reliably quantify the water use or the evapotranspiration (ET) of the two main vegetation communities in semiarid regions, namely grass and shrub dominated ecosystems.

Estimates of ET over grass and shrub communities from the energy balance approach, using eddy correlation and variance techniques, for the 1990 and 1992 -1995 monsoon periods were compared to the water balance approach which was considered the most reliable at seasonal time scales. A comparison of relative water use by the shrub versus the grass ecosystem is made using the evaporative fraction concept. These estimations of seasonal water use are very unique and provide a rare chance to evaluate and contrast water use by these two distinct semiarid plant communities during the wet season.

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3. MEASUREMENTS AND THEORY

Estimates of ET were obtained by energy and water balance approaches in a 1.46 ha shrub-dominated subwatershed and a 1.86 ha grass-dominated subwatershed, named Lucky Hills and Kendall, respectively. These sites are located within the Walnut Gulch Experimental Watershed (31.7 North Latitude 110 West Longitude) maintained by the USDA-ARS Southwest Watershed Research Center in Tucson. Complete descriptions of vegetation and soil properties at these sites are given by Kustas and Goodrich (1994). The ET estimates cover the period which is most hydrologically and ecologically active, namely the wet or so-called "monsoon" period during which regions of the southwestern United States receive nearly 2/3 of annual precipitation and practically 100% of the annual runoff [Renard et al., 1993]. This season runs from roughly July through September, or approximately Day of Year (DOY) 180 to 270.

The study sites were similarly instrumented for hydrometeorological measurements of components of the water and energy balances. Precipitation (P) and runoff (Q) were recorded on an event basis, soil moisture (S) was measured prior to and following the monsoon to determine the change in soil moisture storage. Seasonal ET is solved as a residual in the water balance equation which, assuming negligible groundwater recharge, is of the form

$$ET = P - Q - \Delta S \quad (1)$$

The water balance data are provided in Table 1.

The sensible heat flux was estimated by both the eddy correlation method and the variance technique, described in detail by Stannard et al. (1994) and Kustas et al. (1994a), respectively. The latent heat flux, LE, was estimated as a residual using the energy balance equation with hourly measurements of net radiation, Rn, soil heat flux, G, and sensible heat flux, H:

$$LE = Rn - G - H \quad (2)$$

Energy data were not available for either site during 1991 and were not available for Kendall during 1993.

4. ANALYSIS & RESULTS

The ET estimates for the monsoon from the eddy correlation ET_{EC} and variance ET_{VAR} approaches were compared to the values given by the water balance ET_{WB} (Figure 1). Both ET_{EC} and ET_{VAR} are reduced by about 15% because eddy correlation measurements of LE made during the 1990 monsoon by Stannard et al. (1994) indicated that the nighttime LE estimated by residual, namely Eq. (2), was yielding about 0.3 mm higher values on average. Thus for a 90 day period this would accumulate to approximately 30 mm. However, even with this reduction the values of seasonal ET from the energy balance approaches are generally higher than the water balance estimates. In fact, except for the 1992 season, the ET_{EC} values are between 25 and 50 mm higher than ET_{WB}. This results in significant percent differences with ET_{WB}, except for the 1992 season, of 15-40%. Although ET_{VAR} values are generally higher than ET_{WB}, the differences are less than 30 mm with the percentage difference less than 20%, except for the 1993 season.

Another attempt at reducing the differences in ET between the energy and water balance estimates was to compute the ET only for the daytime periods, defined here as when Rn >0, and add to that 10% of the daytime total to account for nighttime ET. The 10% figure is an approximation from Kustas et al. (1994b) who found that nighttime ET calculated from variance and eddy correlation were 13% and 5% of daytime ET respectively. The results, however, do not improve (Figure 2). In fact for ET_{EC}, differences with ET_{WB} actually increase in many cases, with percentage differences typically greater than 20%. This suggests that it is not the nighttime overestimation of ET but more likely an underestimation of H with the eddy correlation system that is causing the significant overestimate of ET. With the variance approach, differences between ET_{VAR} and ET_{WB} are significantly smaller for Lucky Hills, with most years showing ET_{VAR} slightly less than ET_{WB}. The percent differences are in most cases less than 10%, with the 1993 season yielding about a 15% difference. For the Kendall subwatershed, the results using ET_{VAR} are mixed. Differences for the 1990 and 1994 seasons decrease using the daytime data while there are increases for the 1992 and 1995 seasons.

To make a relative water use comparison between the shrub versus grass dominated subwatersheds the evaporative fraction, EF, was computed using the various ET estimates with the available energy (Rn - G) measured for the season,

$$EF = ET/(Rn - G) \qquad (3)$$

With Eq. (3), differences in the amount of energy available for ET between the two sites is normalized by the relative amount of ET and therefore we are able to compare fractions of a conservative quantity, namely the fraction of available energy used for ET. The estimates of EF from the energy balance approaches and from the water balance indicate that EF is generally lower for Lucky Hills than for Kendall (Figure 3). This observation is more apparent in Figure 4 where EF computed from the average of ET_{VAR} and ET_{WB} are shown for Lucky Hills and Kendall. For Kendall, EF ranges from about 0.6 for the 1990 season, which was the wettest of the 5 seasons, to 0.5 for the 1995 season. In comparison, EF for Lucky Hills starts at a maximum of 0.55 for the 1990 season, which is nearly equal to the Kendall site, and reaches a low of 0.4 for the 1993 season. For the '90, '92, '94, and '95 seasons the average difference in EF between Lucky Hills and Kendall is about 0.065 which is nearly a 15% difference in the partitioning of the available energy to ET. In 1992, the only year for which precipitation at Lucky Hills was greater than that at Kendall, the difference in EF remains the same as other years, indicating that relative water use is independent of total precipitation.

5. CONCLUSIONS

Seasonal evapotranspiration estimates over semiarid rangeland watersheds by two techniques have been described. Each technique tends to overestimate ET determined from a simple water balance. Underestimation of sensible heat by the eddy correlation method during the daytime appears to be responsible for the overestimation of LE. Factors contributing to differences in ET estimates are the separation distances between meteorological and soil moisture measurements, especially at Kendall, and the high degree of spatial variability of precipitation and soil moisture at even these small scales. Relative water use, defined by the partitioning of available energy to ET, is nearly 15% higher in the grass dominated region than in the shrub dominated watershed.

6. REFERENCES

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Table 1. Water balance data for Lucky Hills and Kendall.

Lucky Hills						
Year	Start DOY	End DOY	Precipitation (mm)	Runoff (mm)	Change in Soil Moisture (mm)	Evapotranspiration (mm)
1990	200	267	166	32	-17	151
1991	178	268	156	28	1	127
1992	175	274	241	25	2	214
1993	189	272	168	19	6	143
1994	170	271	186	14	-3	175
1995	172	271	178	1	1	176
Kendall						
Year	Start DOY	End DOY	Precipitation (mm)	Runoff (mm)	Change in Soil Moisture (mm)	Evapotranspiration (mm)
1990	200	267	188	12	-7	183
1991	186	268	179	17	17	145
1992	175	260	217	2	10	205
1993	175	272	198	8	11	179
1994	175	271	201	6	8	187
1995	172	271	208	1	8	199

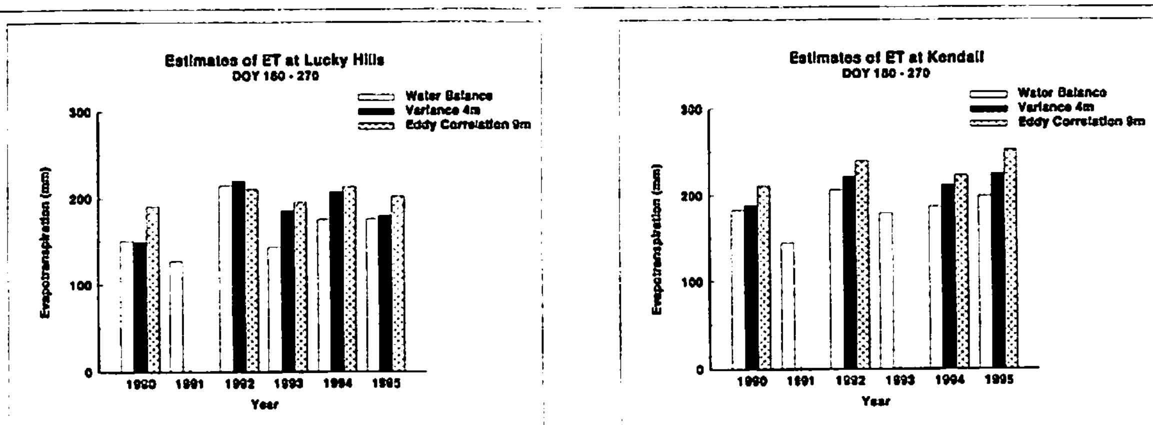

Figure 1. Comparison of water balance, eddy correlation and variance evapotranspiration estimates at Lucky Hills and Kendall, using all-day energy balance data.

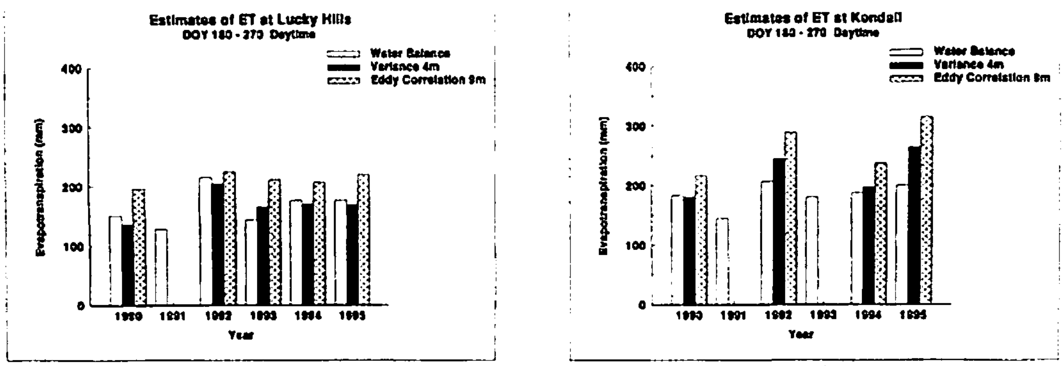

Figure 2. Comparison of water balance, eddy correlation and variance ET estimates at Lucky Hills and Kendall, using daytime (Rn > 0) energy balance data.

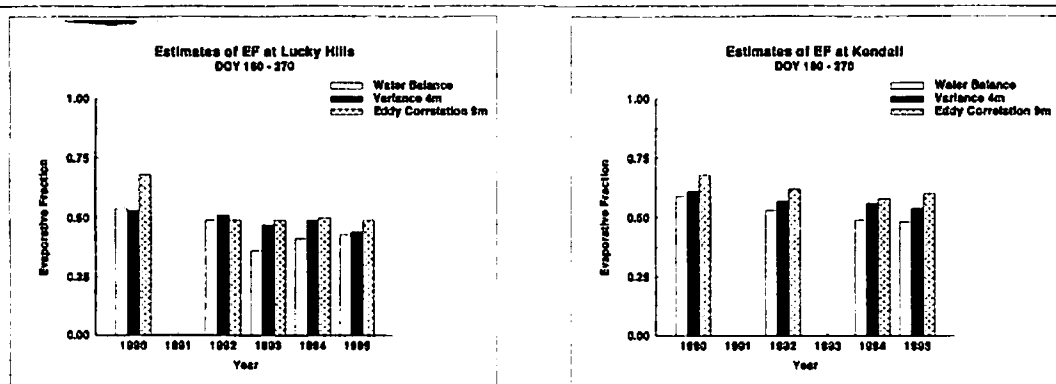

Figure 3. Comparison of evaporative fraction from water balance and energy balance approaches at Lucky Hills and Kendall.

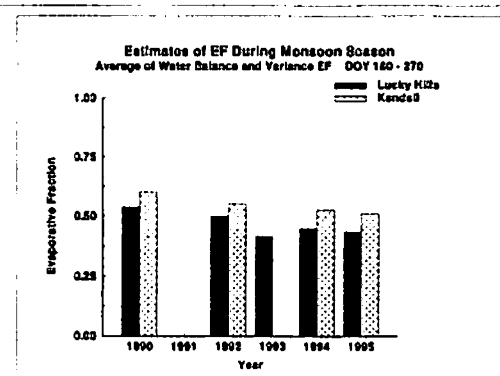

Figure 4. Comparison of evaporative fraction at Lucky Hills and Kendall.