Approaches to ET Measurement

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Evapotranspiration (ET) is the most difficult parameter of the water budget to measure, as it involves transfers of both energy and mass that often change rapidly in space and time, and can require measurement of a number of related parameters. Methods for measuring ET range from relatively direct but resource-intensive methods, to more easily obtained empirical estimates.

The most precise and direct method for measuring ET is generally considered to be a weighing lysimeter in which vegetation is grown on a scale (sometimes quite large). Weight changes due to precipitation and drainage are monitored and ET is measured in terms of the weight of water lost. Other methods measure changes in soil moisture, water vapor, or latent heat energy, or water budget parameters from which ET can be readily determined. Shuttleworth (page 22) presents significant aspects of lysimeters and other methods commonly used for relatively direct measurements of ET. Baker (page 24) describes a few of these in more detail, highlighting the care that is warranted in instrumentation set-up and data interpretation. Direct-measurement methods are generally expensive, time-consuming, and data-intensive, and are most often employed by the research community. However, these methods provide high-quality data important for evaluating or calibrating estimates obtained by the empirical, but perhaps more routine, approach, which is the focus of this article.

ET Without a Research Grant

What do those who need ET values but lack large research grants do? Commonly, ET is estimated using empirical or analytical equations. A number of these equations calculate ET using relatively inexpensive and readily available weather data such as temperature, relative humidity, solar radiation, and wind speed. The equations were originally developed to estimate ET over crops, which are flat and homogeneous. Do these calculations translate to natural settings, at scales of watersheds? Not likely without some error, but in many situations this is the best that can be done. Precipitation and other water budget data (such as runoff) can provide boundary values for such ET estimates.

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Estimating ET: the Natural World

While the simplest approximation of ET is the difference between precipitation and runoff, most estimators recognize the significant control that climate exerts on ET and incorporate local weather parameters into the calculation.

Weather data have usually been included in an ET estimate using a two-step approach. First, potential ET is calculated using equations such as Penman, Priestley-Taylor, Thornthwaite, or Blaney-Criddle. While various and sometimes contrasting definitions of potential ET have been used by different researchers, in general, potential ET is the amount of ET that would occur in a given setting under conditions of unlimited water availability to meet the evaporative demand of the local climate. In the semi-arid Southwest, potential ET is usually far greater than actual ET from the water-limited soils and plants, such that the sum of potential ET and runoff far exceeds precipitation. Therefore, the second step is to adjust ET estimates to account for the water budget discrepancy by assuming actual ET is a fraction of potential ET. Measured runoff or other water budget parameters are used to tweak the potential ET down to a value that is reasonable.

Increasingly, an estimation of "reference crop evaporation" (ET_o) is being used instead of potential ET. ET_o is an estimate of what ET would be over a highly studied

Vegetation type	Location	ET rate (inches/year)
Saltcedar	Gila River, AZ	56
Saltcedar	Middle Rio Grande, NM	42-57
Saltcedar	Middle Rio Grande, NM	34-49
Saltcedar	Colorado River near Blythe, AZ	28-30
Cottonwood	Middle Rio Grande, NM	65-85
Cottonwood	Middle Rio Grande, NM	44-53
Cottonwood	San Pedro River, AZ	19-28
Mesquite	San Pedro River, AZ	27
Mesquite	San Pedro River, AZ	25-26
Honey mesquite	Colorado River near Blythe, AZ	19
Russian olive	Middle Rio Grande, NM	42-50
Ponderosa pine	Northern AZ, high elevation	20
Ponderosa pine	Nevada and northern NM	11-19
Pinyon-juniper	Northern AZ, mid-elevation	16
Pinyon-juniper	Nevada	12
Grass	Middle Rio Grande, NM	2.8-23
Shrub	Middle Rio Grande, NM	0-14
Mixed; low elevation	Middle Rio Grande, NM	0-16
Xerophytes	Nevada	9-12
Sagebrush	Nevada	12
Sage and bitterbrush	Nevada	10-18

ET rates for various natural vegetation types across the Southwest. Data are from federal and state agencies and universities; ET rates were obtained by various direct and empirical methods.

"reference" vegetation, that is, well-watered and actively transpiring grass of a certain height. ET_o is calculated using the Penman-Monteith equation, and expresses the energy available to evaporate water and the wind available to transport water vapor from the ground into the air, for the reference vegetation type. The second step again is to relate this value to the actual vegetation in the area of interest by multiplying ET_o by a crop-specific factor to obtain "crop evapotranspiration." Such factors are now being developed for natural vegetation types and landscapes.

The table below left illustrates the ranges of ET estimates that have been measured and calculated for various types of natural vegetation in the Southwest.

Crop Factors: the Farmer's Advantage

Farmers, who need to predict their irrigation needs as precisely as possible, have an advantage over those estimating ET from natural areas, as crop factors for many types of well-watered crops already have been determined. To do this, ET is measured directly for a specific crop, usually using a lysimeter in a research environment, and the specific crop factor is assigned to account for the difference between the measured and ET_o values. Farmers can calculate the ET_o for their location from local weather measurements and multiply it by the established crop factor to estimate actual ET demand.

This approach assumes that the value of the crop factor derived at one site under one set of climate conditions applies to the same crop elsewhere, independent of the climate conditions, which may not be the case. Nonetheless, it is currently the standard approach recommended by the United Nations Food and Agriculture Organization (see Allen and others, 1998). Recently, Shuttleworth (2006) proposed the one-step Matt-Shuttleworth equation, which uses crop factors but also calculates the effect of the aerodynamic characteristics of the crop based on its height.

A Further Step: Predicting Changes

Can estimates of ET rates be used to model the effects of vegetation change? While the earliest meteorological models ignored vegetation, meteorologists now commonly use the Penman-Monteith equation. The vegetation parameters required in the equation are either defined as constants or obtained through submodels for each ecosystem. Thus meteorological models now make predictions of the impact of land use changes, such as Amazonian deforestation, or of climate change itself, given changes in land cover. Recently, the more advanced hydrological models are using this approach as well.

References

Allen, R.G., L.S. Pireira, D. Raes, and M. Smith, 1998. Crop evapotranspiration—Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, www.fao.org/docrep/X0490E/x0490e00.htm.

Shuttleworth, W.J., 2006. Towards one-step estimation of crop water requirements, Trans.of Amer. Soc. of Agr. and Biol. Engineers, 49(4): 925-935.