REVISITING THE THORNTHWAITE AND MATHER WATER BALANCE

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ABSTRACT: This technical note elucidates confusion currently present in research using and/or citing the 1955 and 1957 editions of the Thornthwaite and Mather Water Balance (or Budget) owing to corrections to errant tables in the 1955 edition made *by the authors* for the 1957 edition. Confusion over the two editions and the formulas used have clouded the results of research, management, and educational publications ever since, resulting in frequent misunderstanding of the method's utility as well as how its results compare with other frequently used methods for estimating evapotranspiration.

KEY TERMS: Water Budget, Water Balance, Evapotranspiration, Thornthwaite Method

While conducting a review of recent literature on evapotranspiration (**E_t**) methods for the third edition of *Watershed Hydrology*, I reviewed "A Comparison of Six Potential Evapotranspiration Methods for Regional Use in the Southeastern United States," by Lu, *et al* (2005). I had earlier noted and wanted to also include reference to similar papers by Federer, *et al* (1996), and Vörösmarty, *et al* (1998). These publications – and several others over the years – thoroughly compare **E_t** estimates by available methods, discuss their merits, and rank their suitability for several sites and situations.

My concern arises because some of these – and other – authors (including hydrology texts and instructors' water balance websites) cite a version of the Thornthwaite and Mather Water Balance (**T&MWB)** that they do not in fact use, or they criticize the results but use the older version, etc. The method used in one of the studies above is cited as the "1948 Thornthwaite equation for **PET**" (Potential Evapotranspiration) implying that the formula shown was used for the calculation. If that is the case, then it is not up to date since Thornthwaite (and Mather) published the **PET** calculation tables *seven years* later, in 1955 and a revised edition in 1957. I try here to straighten it out.

> "The climatic water balance was introduced into the literature by C. W. Thornthwaite in 1944 (*Transactions of the AGU*, Vol. 26, Part V, pp. 683-693) and used by him as the basis for a new and improved classification of climates in 1948 (*Geographical Review*, 38(1)55-94). Since that time, further studies of the water balance by the staff of the Laboratory of Climatology have led to revisions and extensions of the balance itself and its applications. These have been summed up in a publication by Thornthwaite and Mather in 1955 ("The Water Balance," *Publications in Climatology* VIII (1):1-104, Laboratory of Climatology, Centerton NJ." [Text citations in the original]

That quote appeared in the 1957 Foreword by D. B. Carter (who published site-specific water balances while at the Laboratory of Climatology, and while I am not absolutely certain of the authorship, he appears to have been attempting to call attention to the difference between the 1955 and 1957 publications, cited herein as C. W. Thornthwaite and J. R. Mather's "Instructions and Tables for the Computing Potential Evapotranspiration and the Water Balance," *Publications in Climatology* X(3):311 pp. published in 1957). However, in 1955, C. W. Thornthwaite and J. R. Mather had published the first version entitled simply "The Water Balance." It subsequently received legitimate criticism for having the potential evapotranspiration (**PET**) too low in winter and too high in summer.

Russ Mather personally told me when I met him – as I recall in the early 1990s – that Thornthwaite had, accordingly, adjusted the tables used to calculate the unadjusted **PET** values *by hand* so that they were no longer a family of straight lines on log-log paper, but slightly curved. I had already discovered that fact when I converted the 80+ pages of tables into equations for use in the original Fortran II-D version for calculating the annual water balance. (That version – using my equations derived from the 1957 tables – has been super-

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seded by an APL version and, subsequently, by a commercially-available and easy-too-use interactive version in PC:SOLVE, which was derived from APL). Now I understood why as well as how there were differences between the 1955 and 1957 versions.

One may readily identify the two versions by the fact that the 1955 unadjusted monthly **PET** varies from 20 to 40 inches, and the day length (latitude- and monthly-determined) correction factors are in the 0 to 4 range. The 1957 version reverses the respective magnitudes, with unadjusted **PET** values in the 0-4 inch range, and the correction factors ranging from about 20 to 40.

In fact, some of the several published comparative analyses that *did* use the 1957 version found the Thornthwaite-Mather values for monthly **PET** in the middle of the range of estimates by several different methods, but occasionally some authors mistakenly proclaimed them wrong based on the legitimate flaws in the 1955 publication. One publication (van Hylckama, 1956) – between the two versions – doesn't shed much light on which estimation method for monthly **PET** was used. It is not clear whether he used the 1955 or 1957 tabulated values for the water balance calculations, and either, I suppose, is possible since the publication doesn't include the specific identifying **PET** or correction factor values.

The bottom line is that 1957 version of the Thornthwaite and Mather of the water balance – and its accompanying estimation of **PET** – is OK. Since it does not account for vegetative effects at all, it is most useful and, perhaps, the most accurate estimate of **PET** since the vegetation is the component in the water balance that is most variable and introduces the most potential for error. The **T&MWB** merely requires inputs of mean monthly temperature, precipitation, latitude, and an estimate of soil storage capacity. Thus, the **PET** values are calculated based on observed temperature (and day-length) data and, when applied to typical, calibrated paired experimental watersheds where one is treated and the other is a control, may be correlated with and evaluated for any change in runoff quantity and timing. Thus the method permits partitioning Actual Evapotranspiration (**AET**) into its evaporation and transpiration components based on field knowledge of the experimental watersheds.

Ultimately, I find that the **T&MWB** is useful for *description, classification, management*, and *research*. The method's biggest shortcoming is the minimum time division, the month. That may produce a situation where end-of-the-month precipitation should not in fact appear as runoff until the following month, a delay that may be confusing in the computed water balance. However, the mean annual computations do wrap around: for example, mean annual January runoff, is based on mean annual December runoff.

For reference, the most recent version of all the formulae for the calculation of **PET** based on the 1957 calculations is reported in the Second Edition of *Watershed Hydrology* (Black, 1996). I am planning to explain the difference between the 1955 and 1957 publications in the Third Edition, in preparation.

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