EVAP MEMO NUMBER 3

COMPUTER PROGRAMS TO CALCULATE EVAPORATION BY THE PENMAN METHOD

by P.B. Wright

1. Introduction

Program E2 calculates daily values of Potential Evaporation by the Penman formula, and monthly and yearly means of these daily values.

In different versions of the program, different data are used. In every case the formula is evaluated daily.

As at present written, the program deals with one station for one year. It could be easily modified, by someone familiar with the Metocode language, to cater for several station-years in one run.

2. The Penman Formula

The formula on which the calculation is based can be expressed as follows:

$$E = \frac{\frac{\Delta}{\gamma} H + E_a}{\frac{\Delta}{\gamma} + 1}$$

where

$$E_a = 0.35 (e_a - e_d) \left(1 + \frac{U_2}{100}\right)$$

and

$$H = H_{IN} + H_{OUT}$$

where

$$H_{IN} = A R_A \left(0.18 + 0.55 \frac{n}{N}\right)$$

and

$$H_{OUT} = B \sigma T^4 (0.56 - 0.09 \sqrt{e_d}) \left(0.1 + 0.9 \frac{n}{N}\right)$$

A = Albedo factor; can be taken as 0.95 for open water or 0.75 for grass.

B = Black body correction; can be taken as 1 for open water or 0.95 for grass.

T = Screen air temperature in degrees K.

e_a, e_d are in mm of mercury

n, N are in hours per day

U_2 = wind speed in miles per day at 2 metres.

E = evaporation in mm per day.

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For the meaning of these and other symbols please refer to the literature.

3. The Modified Penman Formula

In order to cater for the following matters:

(1) Calculation of R_A and N from the solar declination D;

(2) Calculation of e_a and Δ by the computer;

(3) Input of meteorological data in suitable units;

the formula was modified as follows. The formula below is, apart from rounding errors, exactly equivalent to that above. In everything that follows, the following units will be used:

e_a, e_d in mb

U in kts at 15 metres above ground

T in ^oC

n in hours per day

E, H, E_b in mm per day.

Other notation:

L is the latitude of the station

D is the declination of the sun.

$$E = \frac{\Delta H + E_b}{\Delta + 0.65} \qquad (1)$$

where

$$\Delta = \frac{4098\, e_a}{(T + 237)^2} \quad , \quad e_a = \exp\left(19.1 - \frac{4098}{T + 237}\right) \qquad (2)$$

$$E_b = 0.0341\ (u + 5)\ (e_a - e_d) \qquad (3)$$

$$H = H_{IN} + H_{OUT} \qquad (4)$$

$$H_{IN} = AP \left(\frac{n}{h} + 2.5 \right) \quad (5)$$

$$H_{OUT} = BQ \left(\frac{T + 273}{100} \right)^4 \left(\frac{n}{h} + 0.847 \right) 0.0236 \quad (6)$$

$$P = 1.08 \left[h \sin D \sin L + \sin \frac{180h}{7\pi} \cos D \cos L \right] \quad (7)$$

$$Q = \left(\sqrt{e_d} - 7.18 \right) 0.078 \quad (8)$$

$$h = -0.0175 \left[\sin^{-1} \left(- \tan L \tan D \right)^{\circ} - 90^{\circ} \right] \quad (9)$$

4. Data Required

The following sets of data may be required, different sets for different versions of the program.

(1) A block of magtape containing 365 items of net radiation data commencing March 1, units mm, layout in the form:

B2; -; 2000; 386; -

G3; 2000;

X1; 2020; 0; 366; 1; 4; 2;

(2) A similar block containing incoming radiation data.

(3) A block of magtape containing 365 daily temperatures commencing March 1, units degrees C, layout in the form:

B2; -; 4200; 386; -

G3; 4200;

G3; 4203;

X1; 4221; 0; 365; 1; 4; 2;

(4) A similar block of daily wind speeds, units kts at 15 metres.

(5) A similar block of daily vapour pressures, units mb.

(6) A similar block of daily sunshine, units hours per day.

(7) Block 11 of magtape number METW0001 (on TSN 114D), which contains daily declinations.

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5. How to get data in suitable form

If you are using:

(a) the mean of max temp and min temp (as an estimate of mean daily temp)

(b) the 09h vapour pressure (as an estimate of the mean daily VP);

and if your data are punched on paper tape in the form shown in Appendix 6; then you can use Program E8. This will read in these data and convert them to the form required for items (3), (4), (5) and (6).

If your data are in a different form (e.g., on magtape mixed in with other data) or if you want to use different approximations (e.g., the mean of 24 hourly temperatures as an estimate of mean daily temp) then you will need to write a program to convert them to the form required. You will also need to do this to obtain the radiation data, and for this purpose Program E4 can be used as a guide.

6. Versions of the Program

Version E21 - Use of Radiation Data

This version uses formulae (1), (2) and (3) (see para. 3). It requires data items (1), (3), (4), (5) (see para. 4) and the optional extra requires (2) in addition. The sequence of operations performed is listed in Appendix 8, and the contents of the working stores at various times are shown in Appendix 9.

It first prints out daily values of E, H and E_b for the period March 1 to February 28, using the net radiation directly as H in (1). It then finds and prints out means and standard deviations of these quantities:

(a) for successive 30-day periods commencing March 2

(b) for 365-day period commencing March 1.

As an optional extra, it then repeats the process using incoming radiation, which it converts to net radiation by means of an empirical linear relationship which can be chosen by the user.

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Version E22 Use of Radiation Data. Puts Results on Magtape

This version does the same as E21. It then puts the set (or two sets) of values of E on magtape in layout of the form:

B2; -; 4200; 406; -

G3; 4200;

G3; 4220;

X1; 4241; 0; 365; 1; 5; 2;

Version E23 - Use of Sunshine Data

This version uses all the formulae in para. 3. It requires data items (3), (4), (5), (6) and (7) (see para. 4). The sequence of operations performed is listed in Appendix 8, and the contents of the working stores at various times is shown in Appendix 9.

The table of solar declinations for each day of the year is printed as the first part of the output. This table was calculated as a sine wave; the resulting values were then compared with the declination table in Whitaker's Almanac and a few simple corrections made. The values are probably all correct to the nearest day. Variations in the time of the equinox are allowed for by using Appendix 10 and inserting the "Equinox Number" in the program.

The program then prints out daily values of E, H, H_{IN}, H_{OUT} and E_b for the period March 1 to February 28. It then finds and prints out means and standard deviations of these quantities:

(a) for successive 30-day periods commencing March 2

(b) for 365-day period commencing March 1.

Version E 24 - Use of Sunshine Data, Puts Results on Magtape

This version does the same as E23. It then puts the set of values of E on magtape in layout as given in Version E22.