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WATBUG: A FORTRAN IV Algorithm for Calculating the Climatic Water Budget

by

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The Use of the Climatic Water Budget
in Water Resources Management and Control

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TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
	Capabilities and Restrictions	2
	Evaluation of the Program	3
II.	PREPARATION OF INPUT	4
III.	INTERPRETING THE OUTPUT	8
IV.	DESCRIPTION OF THE ALGORITHM	10
	Main Program	10
	Subroutine MAIN	10
	Subroutine DATE	11
	Subroutine MATHER	12
	Subroutine DAY	14
	Subroutine DIFF	15
	Subroutine BAL	15
	Subroutine EVAPO	17
	Subroutine INIT	17
	Subroutine OUTPUT	17
	Subroutines TOTM and TOTY	17
	Subroutine CONV	18
SELECTED REFERENCES		18
APPENDIX 1 - PROGRAM WATBUG		19
APPENDIX 2 - SAMPLE INPUT		47
APPENDIX 3 - SAMPLE OUTPUT		51

I. INTRODUCTION

A FORTRAN IV computer program (WATBUG) is presented in order that it may aid in the calculation of climatic water budgets. The program is designed to be used for a variety of problems while requiring a minimum amount of input information. At the same time, every attempt has been made to make the code transparent and, as a result, it should be easy to modify when additional or alternative computations are desired. Many of the restrictions of past programs (e.g., Stone, et al., 1971) have been removed and the algorithm can calculate, for example, daily and/or monthly water budgets. Although the main purpose of this report is to describe the program, the significance and background of water budget analysis should, at least, be mentioned.

The far-reaching importance and history of water balance climatology is underscored by an extensive literature as well as by the dedication of researchers who have repeatedly performed arduous hand calculations in order to obtain those all-important estimates of evapotranspiration, soil moisture storage, runoff and deficit. A recent survey of the applications of the water budget in physical geography, for instance, indicates that, in addition to a rich history, its use is ongoing, if not expanding, in a variety of fields ranging from geomorphology to agriculture (Carter, et al., 1973). Even more recently, a detailed discussion of the nature and variety of techniques, as well as their uses in modern environmental analysis, has been compiled by Mather (1978). After reading through these, or any number of other papers, it seems clear that (1) the water budget has been and will continue to be a particularly important theme in climatology and (2) its betterment is a highly rewarding research endeavor.

Thornthwaite's (1948) approach to the water budget has often been singled out for criticism because (1) it is empirically based and, (2) it has been highly successful (Lee, 1978; Terjung, 1976). Although I strongly support arguments for more rigorous and/or systematic research in climatology, it can be said that many of the critics of empirical water budgets have misinterpreted the purpose and utility of regression--broadly defined. Researchers may correctly use morphological links and/or regression when (1) the data necessary for more rigorous analyses are lacking or not "realistically" obtainable and/or (2) the physical-biotic mechanisms that produce the desired answer are either well-known, unknown or unimportant. This is acceptable science, as most beginning texts in the sciences indicate. Lee (1978:135), however, believes "There is no adequate method of predicting evapotranspiration rates in the biosphere based on simple weather-element data." We may quibble about what constitutes "adequate" or problems of scale, but it is undeniable that empirically-based water budgets have been very successful at satisfying the only criterion on which they should be judged--accuracy (McGuinness and Bordne, 1972). The only real problem with such procedures is that they can "fool" an unsuspecting student or researcher into believing that they "explain" environmental processes or that they work equally well in all environments. These methods were never intended to be used for explanatory purposes and, as Thornthwaite (1961) would argue, they are merely temporary and useful only where they provide an answer where none better is available.

Until "better" methods and data are available, it is hoped that this program will contribute to the already extensive literature by lessening the laborious computations which have been traditionally associated with the climatic water budget.

Capabilities and Restrictions

Program WATBUG currently relies on the Thornthwaite (1948) method of calculating potential evapotranspiration (APE) although the subroutine where those estimates are made can be easily replaced by another, if desired. If the reader would like to see a comparison of techniques, it is suggested that McGuinness and Bordne (1972) or Mather (1978) be consulted. WATBUG has the following advantages over most previously published water budget programs (e.g., see Stone, et al., 1971):

1. Budgets can be computed on a monthly or daily basis.

2. The program can iterate over periods of record up to 40 years for monthly budgets or up to one year for daily budgets in order to "balance the budget". These limits can also be easily raised. This procedure is similar to that normally done by hand to obtain the initial soil moisture value.

3. Initial values of actual soil moisture and a station's heat index (see Thornthwaite and Mather, 1957) are not required as long as "balancing" (item 2 above) is performed on at least a year's data.

4. Following the balancing of the soil moisture budget, budgets may be calculated on a day-by-day or month-by-month basis.

5. No "look-up" tables (arrays from which values are interpolated) are needed as all relationships are explicitly specified. This tends to make computations more accurate and, as a result, WATBUG's computations may not always agree with those by performed by hand using tables which make discrete jumps at regular intervals.

6. The program can be easily modified as logical groups of computations have been segregated and appear as subroutines. Also, for ease of modification, WATBUG is extensively commented and the program logic has been kept simple--even, in a few places, at the expense of a more computationally-efficient code.

7. The required input is minimal, i.e., air temperature, precipitation and a few initial parameters.

8. The raw air temperature and precipitation information can be in a variety of units as WATBUG will make the translations. At the same time, the format by which the climatic data appears is flexible because it is specified by the user.

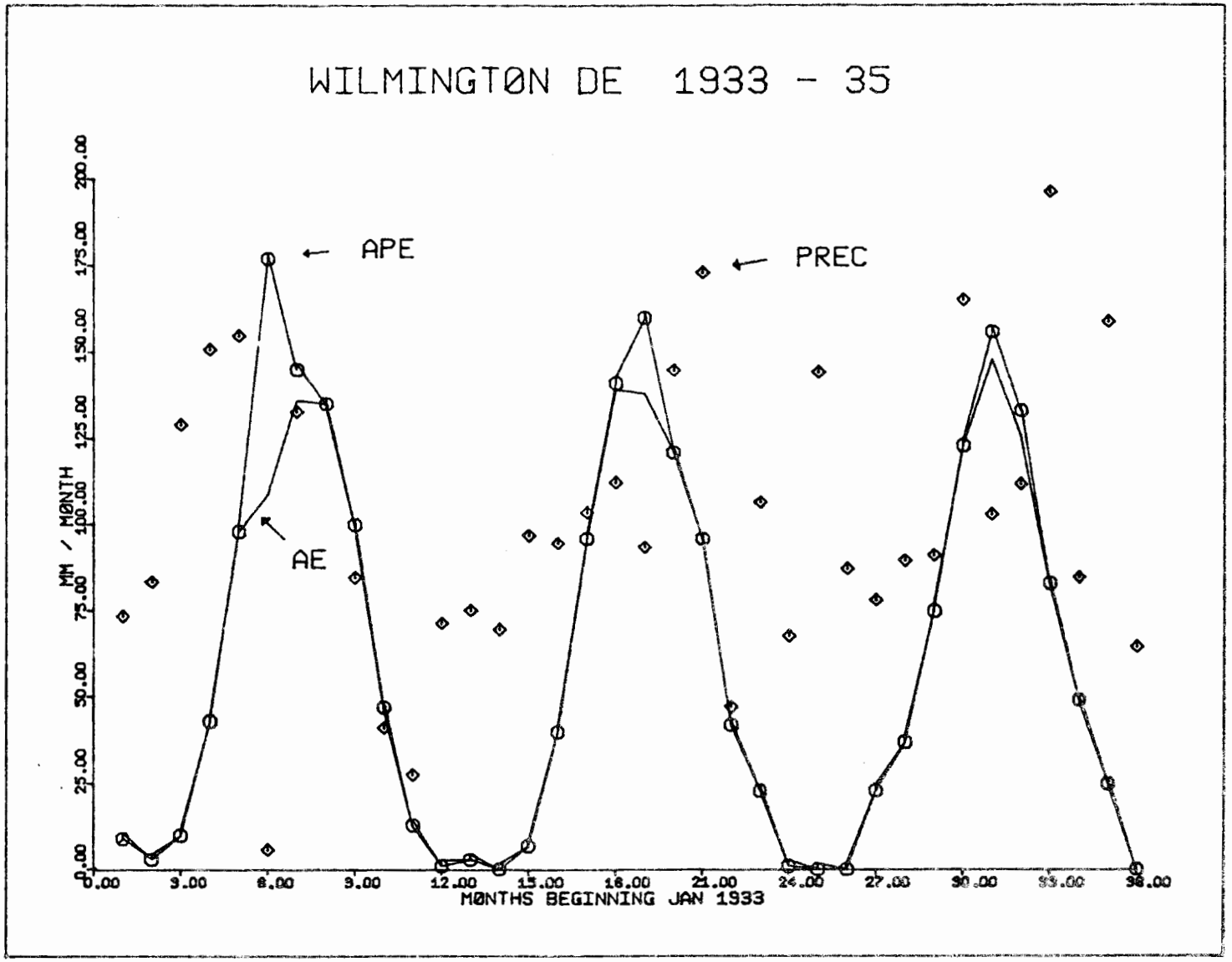


Figure 1. Exemplary monthly water budget at Wilmington, DE 1933 - 1935. The diamonds are precipitation magnitudes (PREC) while the curves represent potential evapotranspiration (APE) and actual evapotranspiration (AE). [Note: (1) The APE curve is distinguished from the AE curve by circles which are plotted at the data points; (2) PREC for August 1933 was not plotted because its value is 309 mm.]

9. Multiple budgets, i.e., on different stations and/or non-consecutive time series may be done in a single run.

The only requirement is that periods of time to be evaluated as a single budget should be consecutive. Because of its general nature, however, WATBUG does not perform a number of problem-specific computations.

The algorithm, for example, does not derive estimates of runoff as such functions are numerous and site specific. Moreover, only two soil moisture resistance functions (i.e., to evapotranspiration) are contained by WATBUG and both are single soil layer models. A multiple soil layer model was considered but without detailed knowledge of the vegetation cover and soil characteristics such precision would be unwarranted. Such procedures may be added to WATBUG with little difficulty by anyone familiar with simple programming and the water budget. These omissions notwithstanding, the program should aid both researchers and students in the computation of climatic water budgets.

Evaluation of the Program

WATBUG was tested on a variety of multi-annual monthly and daily data sets and all of the program's options were tried. One such monthly budget was plotted and is presented in figure 1. The results of each run were compared to hand computations made by J. R. Mather and WATBUG's answers were, in all cases, within a mm or two of the hand-computed values. The reasons for these slight differences are discussed elsewhere in this report. Because of the chance that possible problems were overlooked, users are encouraged to contact the author if errors are discovered.

II. PREPARATION OF INPUT

Program WATBUG only requires three control cards (records of at least 72 characters) for each station and/or new time period to be evaluated. Card one merely contains a 72-character problem label (anything you want, i.e., valid FORTRAN characters) in columns 1 through 72. These columns may be left blank or filled at the user's discretion but this card must appear as the first card in a new problem. On the second card, all the required initial parameters must be specified.

All information required on control card (record) two is summarized in table 1. Although many of the initial parameters on control card two need not be specified, others must. For this reason, reading table 1 carefully and in its entirety is prerequisite to a successful run. Computing jargon has been kept to a minimum so that most users who are familiar with the water budget can easily read table 1. Users should be somewhat careful in selecting the balancing period (N), because it can significantly affect the results if incorrect.

Balancing can be accomplished for any portion of the entire climatic record beginning with the first day or month, although periods of time which are not multiples of complete years should not be "balanced." If data remain beyond the "period of balancing," they can be budgeted on a day-by-day or month-by-month basis at the user's request, i.e., if NT is greater than N. Given a couple of further initial parameters (see ST(1) and HEAT in table 1) balancing can also be skipped if desired (N = 1), and all computations will be undertaken on a day-by-day or month-by-month basis. Once control card two has been successfully punched, the last control card (number three) can be set up.

Control card three specifies the format by which the raw air temperature and precipitation data are to be read. Any standard FORTRAN format is acceptable although no more than two observations (one on each variable) may be encoded on a single data card (record). The format statement may appear anywhere in columns 1-72 of control card three. WATBUG first reads an air temperature value and then a precipitation magnitude. This sequence is repeated over and over again until the entire data set is read. If on each data card, for example, you had encoded air temperature in columns 6-10 and precipitation in columns 16-20, with the decimals punched, and each card represented one time period (i.e., day or month), then the following formats could be used:

```
(5X,F5.0,5X,F5.0)

(2(5X,F5.0))

(2F10.0).
```

If the user is unfamiliar with FORTRAN format statements, nearly any beginning FORTRAN manual can be consulted. Control card three is followed by the raw

Table 1

Preparation of Control Card Number Two

Variable Name	Columns	Just.[1]	Description of the Parameter and Defaults[2]
N	1-5	R	Number of months or days over which soil moisture balancing is to occur. If N is left blank or equals 1 or 0, balancing does not take place and ST(1) and HEAT must be specified.
NT	6-10	R	Total number of months or days over which the water budget is to be calculated. NT should be greater than or equal to N. If it equals 0 or is left blank, it is set equal to N.
KD	11-15	R	Day of the month where the first calculations are to begin. KD should be less than or equal to the number of days in month KM. If left blank or zero in daily or day-by-day computations, it is set equal to the first day of the month, i.e., 1. When KD is left blank or set at zero and monthly or month-by-month computations are being made, KD will be set equal to a representative day for the middle of month KM, i.e., 15.
KM	16-20	R	First month of calculations. KM must be between zero and 12. When KM is left blank or set at zero, it is assumed to be 1, i.e., the first month of the year--January.
KY	21-25	R	First year of calculations. Include the last two digits of the year only. If KY is left blank, it is assumed to equal zero and the first year of computation will be 1900.
FC	26-30	N	Soil water holding capacity, or field capacity, of the top (only) soil layer in mm. FC must be specified. If not, it will be assumed to be zero.
SM	31-35	N	Determines which one of two resistance functions of soil moisture to evapotranspiration will be used. When SM is left blank or set at zero, the availability of soil moisture to evapotranspiration will decline linearly with the ratio of actual soil moisture to field capacity. Any other numeric designation will result in soil moisture being withdrawn at the maximum possible rate until the ratio of actual soil moisture to field capacity drops below 0.7 after which time a linear decline in availability is assumed (see Mather, 1974: 106, curves C and G).

Table 1 (Continued)

Variable Name	Columns	Just.[1]	Description of the Parameter and Defaults[2]
LAT	36-40	N	The station latitude in degrees.
DT	41-45	N	Determines whether the calculations are to be daily or monthly. If DT is left blank or set at zero, monthly or month-by-month computations are assumed. Any other numeric designation will result in daily or day-by-day budgeting.
TUNIT	46-50	N	Indicates the units of the raw air temperature data in order that they may be properly translated into degrees Celsius. 1.0 indicates that the raw data are in degrees Fahrenheit. 2.0 means Kelvin while any other numeric designation, or leaving TUNIT blank, indicates degrees Celsius.
PUNIT	51-55	N	Indicates the units of the raw precipitation data in order that they may be properly translated into mm. 1.0 indicates that the raw data are in cm, 2.0 means inches and 3.0 means hundreths of an inch. Leaving PUNIT blank, or giving it any other numeric designation, indicates mm.
ST(1)	56-60	N	Estimated soil moisture content (mm) of the top (only) soil layer just prior to the beginning of computations. ST(1) only needs to be specified when balancing is not done. Otherwise, it is computed during balancing.
HEAT	61-65	N	Estimated (Thornthwaite, 1948) heat index for the station. HEAT only needs to be specified when balancing is not done.
INDEX	66-70	N	Should be set greater than zero when calcuations for a subsequent station and/or time period are to follow the computations to which this control card refers. INDEX may be left blank or set at zero if only a single water budget is desired.

[1]"Just." refers to column justification. "R" indicates that the designated numerical value should be "right justified," i.e., placed as far to the right in the five-column field as possible. A decimal point should not be punched. "N" means that no justification is required, i.e., the number may appear anywhere in the proper five-column field; but, the decimal point should be punched.

[2]Each parameter must either be left blank or specified by a number. No letters or other non-numeric characters are acceptable.

air temperature and precipitation information; that is, your entire card data set for each station and/or new time period must contain control cards one, two and three (in that order) followed by the raw data (see Appendix 2 for examples).

When computations are daily or day-by-day and they include a leap year, a corrective action may be desired. If so, see the discussion at subroutine DATE.

III. INTERPRETING THE OUTPUT

Unlike Thornthwaite and Mather (1957), WATBUG's water budget results are formatted with the variables across the paper (columns) and time periods on the vertical dimension (rows). This minor alteration was made because (1) most of science uses this form of a data matrix and (2) it is more efficient--programmatically.

The program first writes the information contained on control card number one which can be useful in later identifying a particular problem or run (see Appendix 3 for sample results). Following this, WATBUG writes (1) the number of months (or days) over which balancing is to occur, (2) the total number of months (or days) to be evaluated, (3) the soil moisture (or field) capacity (mm) and (4) the latitude (degs). Each of these numbers is labelled for easy identification. WATBUG then proceeds to write and label the monthly or daily computations.

Monthly and daily budgets are formatted alike except that each case represents a month in the former and a day in the latter. The first variable is either the monthly designations (under the heading "MO") or the daily designations (labelled "DY"). In addition to the numeric time period labels--DY or MO--the year is specified at the very beginning of a new year's calculations. When daily budgets are being written, monthly labels are similarly printed at the beginning of each new month. Reading left to right across the output table, the following variables (with their associated labels in parens) appear:

1. air temperature (TEMP) in °C
2. unadjusted potential evapotranspiration (UPE) in mm
3. adjusted potential evapotranspiration (APE) in mm
4. precipitation (PREC) in mm
5. precipitation minus adjusted potential evapotranspiration (DIFF) in mm
6. soil moisture storage (ST) in mm
7. change in storage from the preceding day or month (DST) in mm
8. actual evapotranspiration (AE) in mm
9. soil moisture deficit (DEF) in mm
10. soil moisture surplus (SURP) in mm.

Users should note that regardless of the units of the raw input data, the results are given in whole mm's. At the end of each year (and month in daily budgets) totals of APE, PREC, AE, DEF and SURP are given.

Yearly totals are calculated from each January 1 (or the first case read for the first year) to either the end of that year (December 31) or the end of processing--whichever comes first. In either case, the totals are printed at the end of the calendar year at the bottom of the appropriate column. When daily or day-by-day budgets are being calculated, monthly totals are also calculated and written at the end of each month--in the appropriate columns. Again, the summing begins with the first day of the month (or first case read) and ends with the last day of the month or the end of processing--whichever comes first. At the end of computations, the total number of cases evaluated is printed and labelled in order that the user may check to see if the proper number of computations have been made.

When water budget computations are done by hand, or by programs which rely heavily on look-up tables, intermediate values are often rounded to whole numbers at each step in the computational sequence. As a result, rounding errors may accumulate. WATBUG, on the other hand, does not round during the computation of any of the budget terms thereby minimizing these errors. After the budget terms have been calculated, however, they are rounded to the nearest whole mm just prior to their being written onto paper. This was done (1) because accuracy beyond a whole mm is superfluous and (2) to be consistent with previous presentations of water budget results (Thornthwaite and Mather, 1957). As a result, a hand check of WATBUG's results will appear to show minor accounting errors. If, for example, WATBUG calculated an APE of 131.6 mm, with an associated PREC of 58.2 mm, then the difference (DIFF) would be

$$DIFF = PREC - APE = -73.4. \quad \text{mm} \qquad (1)$$

The program would then print the rounded versions of these numbers. Judging from the output, therefore, the equation would be

$$58 - 132 = -73 \quad \text{mm} \qquad (2)$$

which, according to most mathematics texts, is incorrect. Actually, however, the "correct" difference is closer to -73 than -74 (the answer derived by hand from the output values of PREC and APE). Rounding inconsistencies become even more apparent in monthly and yearly totals as they can accumulate. WATBUG's yearly totals, for example, could easily be dissimilar to totals calculated by hand from the output tables by 5, 10 or more mm. The reader is again cautioned, however, that WATBUG's values are probably more correct than their hand-produced counterparts.

Another apparent problem in interpreting the results occurs when daily budgets are calculated over a leap year and no corrective action is taken prior to running the program. Because WATBUG does not contain a leap year correction, users may either (1) delete February 29 from the input data or (2) be a bit careful in interpreting the results as the day labels will be one day ahead of their associated values following February 28 of a leap year. The former is probably the easiest corrective action, and it should have a minimal impact if budgets are calculated for time periods longer than a month or two. See the discussion of subroutine DATE if more details about leap year problems and corrections are desired.

IV. DESCRIPTION OF THE ALGORITHM

Methods of computation contained in program WATBUG are described in this section. The discussion is organized by subroutine, i.e., each subroutine is described in a separate subsection. Subroutines are presented in the general order that they are called by subroutine MAIN with the exception of the main program (figure 2). That is, the main program is described first followed by subroutines MAIN, DATE, MATHER, DAY, DIFF and so on.

Relationships appear in "quasi-FORTRAN" in order that the discussion and the appended source program (Appendix 1) are more easily comparable. At the same time, the exact form of an "equation" may differ slightly from its appended counterpart in order that this narrative may be more easily understood by readers without a strong background in computing. For users not at all familiar with FORTRAN equations, explanations of operators and/or procedures peculiar to FORTRAN are provided. This section is not recommended for the casual user but it should be helpful to those using the algorithm for research.

Main Program

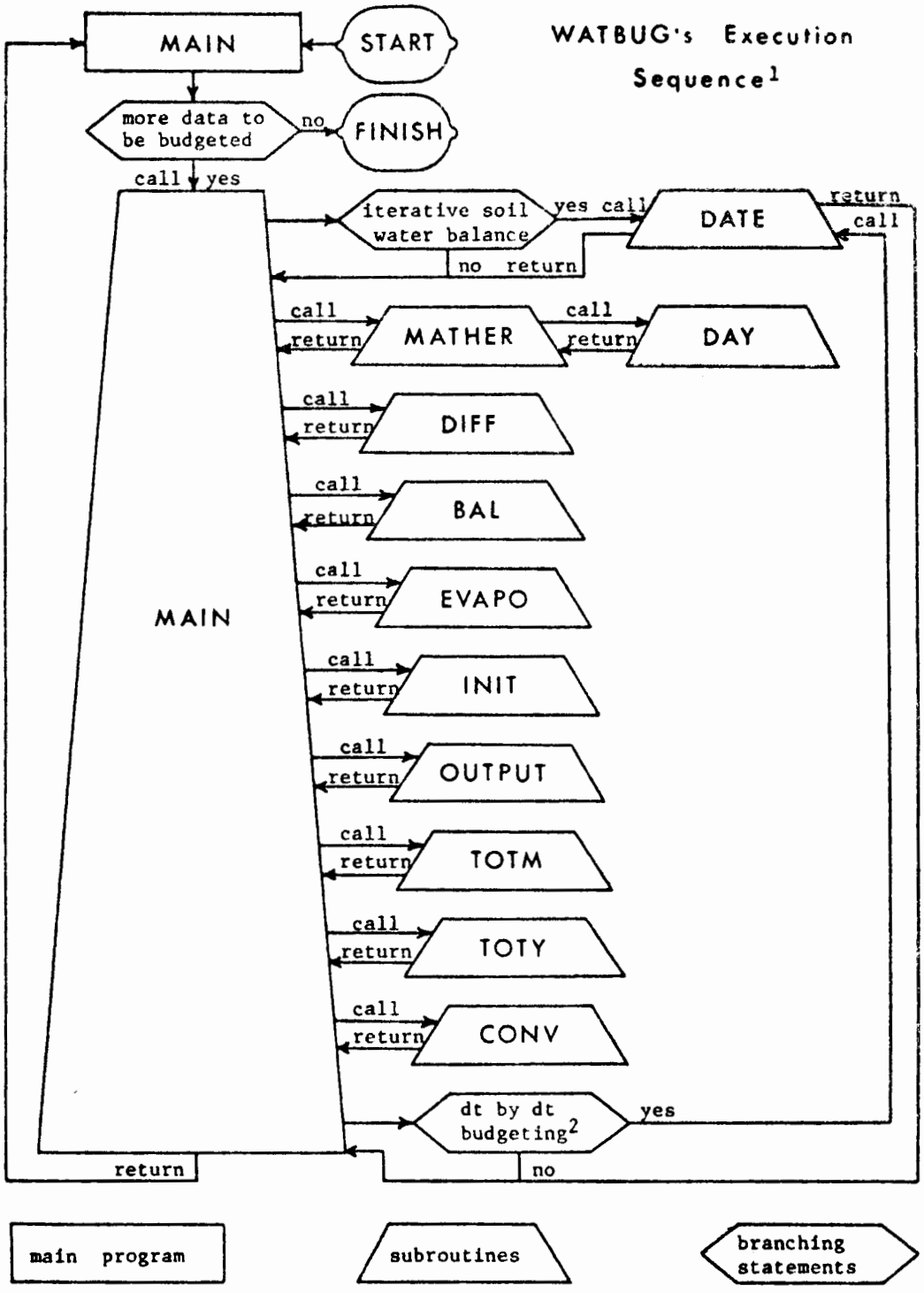
The main program performs no calculations but rather serves to (1) give initial dimensions to all arrays, (2) read the initial constants and semi-constants, (3) set the default options, (4) specify execution time array sizes, and (5) test whether or not calculations for more than a single station are to occur. Normally, the main program would control the sequence in which subroutines and functions are called; however, in this case, that task is relegated to subroutine MAIN.

The reason for this structure is that the size of the arrays used by the subroutines can be reduced from their initialized size by setting their dimensions equal to an argument which is specified in the main program and then transferred into the appropriate subroutines. This tends to lessen computational time and expense. All significant arrays are dimensioned in this fashion as M (which equals N + 1) where N is the number of months or days over which soil moisture balancing is to occur. These matrices have been given a maximum dimension of 481 which allows for a balancing of one year for daily budgets or 40 years for monthly budgets. If balancing over longer periods of time is required the initial dimensions of 481 will have to be increased.

Subroutine MAIN

Once all the initial constants and semi-constants have been initialized or read by the main program, they are transferred into subroutine MAIN which controls the sequence of calculations. In addition, subroutine MAIN (1) reads the necessary climatic information (air temperature and precipitation) and their format, (2) makes the appropriate unit translations to degrees Celsius and mm, (3) performs summations of daily and monthly values, (4) formats and writes the results onto file 6 (the line printer) and (5) keeps track of how many days or months have been processed. Subprogram MAIN is divided into four major sections. Each section controls a specific type of

Figure 2.



1. see text for descriptions of the subroutines and main program.
2. dt refers to month or day.

calculation sequence, i.e., monthly balancing, daily balancing, month-by-month calculations, or day-by-day calculations.

When the argument DT (time period index) is equal to zero and N (number of time periods over which balancing is to occur) is greater than one, monthly balancing of the soil water regime, N time periods long, is performed by iteration. (Note: N should be a multiple of 12 for monthly balancing to be legitimate.) These calculations begin at sequence number 167. When the balancing is complete and the results have been written, N is compared to NT (the total number of time periods over which the water budget is to be calculated). If NT is greater than N, subroutine MAIN transfers control to statement number 130 (sequence number 264) which represents the beginning of month-by-month calculations which are then performed on the remaining NT - N months. If N is not specified or is equal to one, balancing by iteration is skipped and month-by-month calculations are made exclusively. Following this, control is returned to the main program which either begins calculations for a new station or terminates processing.

When DT is not equal to zero, daily calculations are assumed. If N is greater than one, at the same time, subroutine MAIN undertakes daily balancing of the soil moisture budget for a period of N days beginning at statement number 60 (sequence number 207). (Note: N should be a multiple of 365 if daily balancing by iteration is specified.) Once N days have been balanced, N is compared with NT. When N is equal to NT control is returned to the main program. Otherwise, the subroutine goes to statement 190 (sequence number 340) in order to do day-by-day calculations for the residual NT - N days. If N equals one, all iteration is bypassed and calculations for NT days are done on a day-by-day basis beginning at statement 190. In either case, when a total of NT calculations have been made, control is transferred back to the main program.

Regardless of which of the four types of calculations are made, the sequence in which other subroutines are called by subroutine MAIN is essentially the same--with one minor exception--subroutine DATE. The sequence is subroutine DATE, MATHER, DAY (which is called by MATHER not MAIN), DIFF, BAL, EVAPO, INIT, OUTPUT, TOTM, TOTY, and CONV (figure 2). When monthly or daily balancing is being performed, DATE is called first, i.e., before MATHER, whereas when month-by-month or day-by-day calculations are made DATE is the last subroutine called. Each of these subroutines are described in the ensuing pages and, again, they are discussed in the order that they are called by subroutine MAIN.

Subroutine DATE

Subroutine DATE generates the day and month designations that will appear on the output. The subroutine requires the number of days over which balancing is to occur (N), the maximum array size for climatic variables (M), the initial or previous day designation (KD), the initial or previous month designation (KM), the time period index (DT) and the array DAYS which gives the number of days in each month.

It should be noted that no correction for leap year is made; therefore, users ought to be careful in interpreting daily or day-by-day output where a calculation for February 29 has been made. In such cases, the day designations on the output will be a day ahead of the day to which the day's water budget corresponds, i.e., for days following February 28. At the same time, daylength calculations made by subroutine DAY will be slightly incorrect although the error is insignificant. When daily balancing is performed on a leap year, N should be incremented by one in order to account for the 366-day year. The alternative to suffering the above is, of course, to remove February 29 and accept the small error introduced by that action. Regardless of which way the problem is handled the water budget values will be little influenced.

Depending on the type of calculations being made, DATE returns either the designations for the next day (DY(N) and KD) or month (MON(N) and KM) or, if balancing is occurring, an array of daily (DY) or monthly (MON) designations N values long. A couple of examples should illustrate the subprogram's function. If, for example, DATE were called just prior to the balancing of a daily water budget over a year, it would most likely receive the necessary arguments: N = 365, M = 366, KD = 1, KM = 1 and DT = 1. It would then return the arrays DY and MON each containing 365 day and month labels, respectively. On the other hand, if DATE were called just after a day-by-day calculation had been made for December 18, for instance, it would return values of KD = 19, KM = 12, DY(N) = 19 and MON(N) = 12 which would be used to label the next day's budget values.

When monthly calculations are made the day is held constant at 15--a representative day for the month. This value is important in that it is used in obtaining a daylength correction for the month via subroutines DAY and MATHER. When balancing is desired subroutine MATHER is called next in order to obtain potential evapotranspiration.

Subroutine MATHER

Subprogram MATHER is the hub of the algorithm as it calculates daily or monthly potential evapotranspiration according to the well-known Thornthwaite (1948) methodology. Since this discussion is presented to describe the procedures and use of the program, the author's choice and the accuracy of the Thornthwaite approach will not be examined as that has been done many times before (e.g., see McGuinness and Bordne, 1972). Suffice it to say, the approach has proven to be highly accurate in deriving monthly water budgets while requiring only a minimum amount of input information, i.e., air temperature and precipitation. The Thornthwaite method is less accurate in deriving daily potential evapotranspiration although such calculations can be useful in examining general within-month trends. Individual daily values should not be considered accurate, however. The subroutine requires a number of input parameters.

In particular, subroutine MATHER requires N, M, an array containing the air temperature data (T) in °C, the array DAYS, latitude (LAT), daylength (DL), as well as the day and month designations KD, KM, DT, MON and DY. When

soil moisture balancing does not occur (i.e., N = 1), MATHER also requires an estimate of the station's heat index (HEAT). Using these variables, the subroutine calculates and returns to subroutine MAIN: an array of monthly heat indices (H), HEAT (Note: H and HEAT are only calculated during balancing), an empirical coefficient (A), an array of unadjusted potential evapotranspiration values (PE), and finally an array of adjusted potential evapotranspiration values (APE). When soil moisture balancing occurs, these arrays contain N climatic values. Otherwise, they are single climatic-valued arrays although it should be remembered that their actual size is N + 1. Calculations begin with the heat index when balancing is to be done.

Consistent with the Thornthwaite approach, a station's heat index is obtained from

$$HEAT = (12.0 / XN) \sum_{I=1}^{N} (T(I) / 5.0) ** 1.514 \qquad (3)$$

where T(I) is the mean daily or monthly temperature and XN (XN = N) is the number of days or months over which balancing (if specified) is to occur. The double star "**" is a FORTRAN operator indicating that the quantity to the left of the stars is to be raised to the power at the right of the stars. A single star "*", on the other hand, is the FORTRAN operator which specifies multiplication. Once again, when N refers to days, it should be a multiple of 365 or, if the time unit is months, N should be a multiple of 12 as HEAT is not defined for periods other than whole years. When computations are to be made on a day-by-day or month-by-month basis, HEAT cannot be correctly calculated and, therefore, must be supplied by the user. In such cases, the above-described calculation or HEAT will be circumvented. An empirically-derived exponent is next defined as

$$A = 6.75 / 10.0 ** 7.0 * HEAT ** 3.0 - 7.71 / 10.0 ** 5.0 * HEAT ** 2.0 + 1.79 / 10.0 ** 2.0 * HEAT + 0.49 . \qquad (4)$$

Unadjusted potential evapotranspiration is subsequently calculated as a function of T(I), HEAT, and A. Its form is

$$PE(I) = 16.0 * (10.0 * T(I) / HEAT) ** A . \quad mm \qquad (5)$$

The reader should be aware that units specified as "mm" can be either mm/day or mm/month depending upon the mode of analysis, i.e., daily or monthly. When $T(I) \geq 26.5$, PE(I) is not estimated from the above but rather it becomes

$$PE(I) = - 415.85 + 32.24 * T(I) - 0.43 * T(I) ** 2.0 \quad mm \qquad (6)$$

where the above relationship was developed from, and explains virtually all the variance in, Thornthwaite's (1948: 94) correction table. When daily computations are made, PE(I) is divided by 30.

Following this, PE(I) is adjusted for variable day and month lengths. That is, adjusted potential evapotranspiration (APE(I)) is calculated as

$$APE(I) = PE(I) * (DAYS(KM + 1) / 30.0) * (DL / 12.0) \quad mm \quad (7)$$

where DAYS(KM + 1) is the number of days in month KM and DL is the daylength (hours). Daylength calculations are made by subroutine DAY (discussed next) while DAYS(KM + 1) is selected from the array DAYS. Again, when soil moisture balancing is being done the output arrays PE and APE are filled with N values. Otherwise, single climatic values are returned to subroutine MAIN.

Subroutine DAY

This subprogram estimates both the solar declination (DECD) and daylength (DL) although the former is not used again. Required input includes: the array DAYS, LAT, KD, KM and DT.

Although the approach taken is quite simple, as the anomalies of time are not considered, the maximum error possible in length of day estimates for mid-latitude locations is on the order of 10 to 15 minutes. Most estimates, however, are only off by a few minutes. Users are again reminded that no correction is made for leap year.

The first step is to calculate the number of days since January 1 and this value is stored as "SUM." SUM is then used to get the number of days since the last vernal equinox (DAYL). Declination (DECD) is then calculated from

$$DECD = 23.45 * SIN(DAYL / 365.0 * 6.2832) \quad deg \quad (8)$$

which was found to be a very good approximation to more detailed calculations based upon Kepler's law (Vowinckel and Orvig, 1972). In FORTRAN, trigonometric functions of a quantity or function X are expressed, for example, as SIN(X) which is equivalent to sin X. Some common ones are SIN(X), COS(X), ARCOS(X) and ATAN(X) for the tangent of X. Once DECD has been calculated and converted to radians (DECR), daylength can be calculated (Sellers, 1965).

When the sun is on the horizon the cosine of the zenith angle (CZ) should approach zero. Here, however, it is set slightly greater than zero in order to adjust the solar geometric equations which refer to the center of the solar disc. If this modification were not made, the cosine law would predict sunset when one-half the disc is still above the horizon. In general,

$$CZ = SIN(DECR) * SIN(ALAT) + COS(DECR) * COS(ALAT) * COS(H) \quad (9)$$

where ALAT is the latitude in radians, and H is the hour angle in radians. Since CZ is known at sunset and sunrise, H can be solved for by

$$H = ARCOS((CZ - SIN(DECR) * SIN(ALAT))/ (COS(DECR) * COS(ALAT))) . \quad rad \quad (10)$$

After H is calculated, it is translated into hours, i.e., daylength (DL) becomes

$$DL = 24.0 * H / 3.1416 . \quad \text{hr} \quad (11)$$

Subroutine DAY then returns to subroutine MAIN with a value for DECD and DL.

Subroutine DIFF

Subroutine DIFF calculates the difference (D(I)) between adjusted evapotranspiration (APE(I)) and precipitation (P(I)) as well as the deficit (DEF(I)). The required input includes the precipitation and adjusted evapotranspiration arrays (P and APE) as well as their dimensions (M) and looping limit (N). The calculation is

$$D(I) = P(I) - APE(I). \quad \text{mm} \quad (12)$$

When D(I) is less than zero, DEF(I) is set equal to D(I). Otherwise, DEF(I) equals zero. Subprogram DIFF then returns N new values of D(I) and DEF(I) to subroutine MAIN.

Subroutine BAL

Subroutine BAL is extremely important since it (1) iteratively balances the soil moisture budget for N months or days and/or (2) calculates month-by-month or day-by-day removal or addition of soil moisture. Required input includes: N, M, the array of differences between precipitation and adjusted potential evapotranspiration (D), the soil moisture field capacity (FC), an index which specifies which one of two soil moisture resistance (to evapotranspiration) functions is to be used (SM), DT, the array DAYS and KM. When month-by-month or day-by-day calculations are to be made without any previous balancing, an initial soil moisture storage value (ST(1)) must be included among the input values. The subroutine then calculates, and returns to subprogram MAIN, an array of soil moisture storage values (ST) as well as arrays of soil moisture surplus (SUR) and the difference in soil moisture storage between present and previous months/days (DST). Calculations are made for N time periods and all terms are in mm per time period. BAL begins with a test in order to determine whether balancing is to be performed or not.

When monthly or daily balancing is to take place, N will be greater than one, i.e., a multiple of 12 or 365, and BAL will begin its balancing computations by setting initial values. Conversely, if N equals one, month-by-month or day-by-day calculations are assumed and BAL will only make calculations for one time period each time it is called by subroutine MAIN. Although all the mathematical relationships are exactly the same whether balancing occurs or not, the balancing operations are fundamentally different; that is, balancing requires that soil moisture at the beginning of a balancing period must be equivalent to soil moisture at the end of the balancing period. In other words, the algorithm assumes that there will be no significant (net) increase or decrease in soil water over N time periods of computation. In order to accomplish this, a hypothetical time period (N + 1) is used.

On the first pass through the iteration procedures, soil moisture storage terms are continually adjusted until

$$ABS(ST(N + 1) + DST(1) - ST(1)) < 1.0. \quad \text{mm} \quad (13)$$

ABS(X) is a FORTRAN function of X equivalent to $|X|$. During the first set of iterations, however, DST(1) is equal to zero and so it has no impact. After the above relationship has been satisfied once, ST(1) is re-computed, beginning at statement 90 (sequence number 747), and DST(1) then becomes

$$DST(1) = ST(1) - ST(N + 1) \quad \text{mm} \quad (14)$$

which may no longer be zero. The soil moisture budget is then re-calculated over the N time periods until relationship (13) is again satisfied with $DST(1) \neq 0.0$. After the second set of iterations, i.e., when the soil moisture budget has been "balanced," subroutine BAL returns to subroutine MAIN. Whether or not balancing is done, the ensuing computations are made.

Monthly calculations for the removal of soil moisture are made on an approximate day-by-day basis, i.e., assuming 30 days in a month. Soil moisture storage for each day (I) in the 30-day month is derived as

$$ST(I) = ST(I - 1) + D(I) * RATIO / 30.0 \quad \text{mm/day} \quad (15)$$

where RATIO = ST(I - 1) / FC. RATIO is the "normal" resistance of soil moisture to evapotranspiration used by Thornthwaite and Mather (Mather, 1974: 106. See curve C). Alternatively, when RATIO is greater than or equal to 0.7 and SM (set by the user) is greater than zero, ST(I) will be obtained from

$$ST(I) = ST(I - 1) + D(I) / 30.0. \quad \text{mm/day} \quad (16)$$

For a monthly or month-by-month budget the above computations for ST(I) are repeated 30 times. The last value of ST(I) is taken to be the new soil moisture for the month which is also subscripted "I". Daily or day-by-day computations are dissimilar in that only one computation is made for each day. The equations used, however, are identical to the above with the exception that the division by 30.0 is not made. In the event that D(I) is greater than zero (equation (12)), the removal steps are skipped and, beginning at statement 50 (sequence number 722), soil moisture is incremented by

$$ST(I) = ST(I - 1) + D(I). \quad \text{mm} \quad (17)$$

If, as a result, ST(I) is greater than or equal to FC, surplus is first calculated as

$$SUR(I) = ST(I) - FC \quad \text{mm} \quad (18)$$

and then ST(I) is set equal to FC. On the other hand, SUR(I) is set at zero when ST(I) is less than FC. Following these, a final calculation is made for DST(I) such that

$$DST(I) = ST(I) - ST(I - 1). \quad \text{mm} \quad (19)$$

It should be noted that unreasonable values of ST(I), i.e., less than 1.0, are set at 1.0, while SUR(I) is set at zero when D(I) is less than or equal to zero. Once the above computations are made, subroutine BAL either (1) returns to subprogram MAIN or (2) begins a new pass through the above relationships in order to balance the soil moisture budget.

Subroutine EVAPO

Subroutine EVAPO calculates the actual evapotranspiration and associated water deficit. The input used by EVAPO includes: N, M and the arrays D, APE, P, and DST. From these EVAPO generates the actual evapotranspiration array (AE) and a deficit array (DEF).

When D(I) is greater than or equal to zero, AE(I) is set equal to APE(I). Otherwise, AE(I) becomes

$$AE(I) = P(I) + ABS(DST(I)). \quad \text{mm} \quad (20)$$

And last, the deficit is calculated as

$$DEF(I) = APE(I) - AE(I) \quad \text{mm} \quad (21)$$

Subroutine INIT

Subroutine INIT merely re-sets (initializes) all the N values of any array (SUM) equal to zero. Its function, in this context, is to clear those arrays which are being used to keep track of monthly or yearly totals of APE, P, AE, DEF and SUR. Once an array has been initialized, INIT returns to subroutine MAIN.

Subroutine OUTPUT

Subprogram OUTPUT is used to fill specified elements of a single output array (OUT) with the values of each water budget variable. The values of OUT (after a minor modification to be described in the section on subroutine CONV) are then written onto paper. In this case, elements 2 through 10 of OUT are replaced with PE(L), APE(L), P(L), D(L), ST(L), DST(L), AE(L), DEF(L) and SUR(L) where L can refer to either of the subscripts I or N used by subprogram MAIN. Subroutine OUTPUT then returns to subroutine MAIN.

Subroutines TOTM and TOTY

Subroutines TOTM and TOTY are identical in form. The former is used to keep a running total of APE, P, AE, DEF and SUR over the month (for daily or day-by-day computations only). As these values are contained in elements 3, 4, 8, 9 and 10 of the array OUT (specified by the array IND), only OUT, IND and the array dimensions N and NN are required as input. The totals are stored in the array SUM. Subroutine TOTY performs an identical function on a yearly basis (for daily or monthly balancing and/or day-by-day or month-by-month computations). Once the appropriate elements of the array SUM have been incremented, these subprograms return to subroutine MAIN. At the end of a month or year, the array SUM is initialized with zeros by subroutine INIT.

Subroutine CONV

Subroutine CONV rounds off (converts) values of the output array (OUT), all except air temperature, to the nearest whole number before writing them. CONV requires an array (X) of dimension NUM and it rounds those elements of X from element MIN through element MAX. It should be understood that the array X is actually the array OUT. The rounded values are not used in computations but they are consistent and comparable with calculations done from tables by hand. After the specified values of X have been rounded to the nearest whole number, subroutine CONV returns to subroutine MAIN.

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APPENDIX 1

PROGRAM WATBUG

```
      DIMENSION T(481),P(481),PE(481),APE(481),D(481),MON(481),LABEL(18)
     1          ,DAYS(13),H(481),AE(481),ST(481),DST(481),DEF(481),
     2          SUR(481),DY(481)
      DATA DAYS/0.0,31.0,28.0,31.0,30.0,31.0,30.0,31.0,31.0,30.0,31.0,
     1     30.0,31.0/
      REAL LAT,INDEX
C
C     ************************************************************
C     *                                                          *
C     *  THIS ALGORITHM WAS DEVELOPED BY C. WILLMOTT AT THE DEPARTMENT *
C     *  OF GEOGRAPHY, UNIVERSITY OF DELAWARE IN 1978 IN ORDER TO  *
C     *  FACILITATE THE CALCULATION OF CLIMATIC WATER BUDGETS.  A  *
C     *  MINIMUM AMOUNT OF DATA (I.E., AIR TEMPERATURE, PRECIPITATION *
C     *  AND A FEW INITIAL PARAMETERS) AND NO "LOOK-UP" TABLES ARE *
C     *  REQUIRED AS ALL RELATIONSHIPS ARE EXPLICITLY SPECIFIED.  THE *
C     *  PROGRAM WAS REFINED ON A BURROUGHS' B7700 ALTHOUGH STANDARD *
C     *  (ANSI COMPATIBLE) FORTRAN WAS USED.  IT SHOULD, THEREFORE, RUN *
C     *  WITH FEW OR NO MODIFICATIONS ON MOST MODERATE TO LARGE SIZED *
C     *  MACHINES.  IF PROBLEMS ARE ENCOUNTERED, HOWEVER, USERS ARE *
C     *  URGED TO CONTACT THE AUTHOR.                            *
C     *                                                          *
C     ************************************************************
C
C     INITIAL PARAMETERS:
C
C     "LABEL" - 72 CHARACTER ALPHANUMERIC PROBLEM TITLE.
C
C     "N"   NUMBER OF MONTHS OR DAYS OVER WHICH SOIL MOISTURE
C           BALANCING IS TO OCCUR.  IF N EQUALS ONE BALANCING
C           DOES NOT OCCUR AND ST(1) MUST BE SPECIFIED.
C
C     "NT" - TOTAL NUMBER OF MONTHS OR DAYS OVER WHICH THE WATER BUDGET
C            IS TO BE CALCULATED.
C
C     "ND"  THE DAY OF THE MONTH WHERE THE FIRST CALCULATIONS
C           ARE TO BEGIN.  ND MUST BE LESS THAN OR EQUAL
```

```
C              TO THE NUMBER OF DAYS IN MONTH KM.
C
C      "KM" - THE FIRST MONTH OF CALCULATIONS.
C             KM MUST BE BETWEEN ZERO AND 12.
C
C      "KY" - THE FIRST YEAR OF CALCULATIONS. LAST TWO DIGITS ONLY.
C
C      "FC" - SOIL WATER HOLDING OR FIELD CAPACITY OF THE TOP (ONLY)
C             SOIL LAYER IN MM.
C
C      "SM" - DETERMINES A RESISTANCE FUNCTION OF SOIL WATER TO REMOVAL
C             BY EVAPOTRANSPIRATION. BLANK OR ZERO INDICATES THAT THE
C             AVAILABILITY OF SOIL MOISTURE TO EVAPOTRANSPIRATION WILL
C             DECLINE LINEARLY WITH THE RATIO OF ACTUAL TO POTENTIAL
C             MAXIMUM SOIL MOISTURE. ANY OTHER NUMERIC DESIGNATION
C             WILL RESULT IN AN ALTERNATIVE PROCEDURE WHERE MOISTURE IS
C             WITHDRAWN AT THE MAXIMUM RATE UNTIL THE ACTUAL/POTENTIAL
C             RATIO DROPS BELOW 0.7 AT WHICH TIME A LINEAR DECLINE IN
C             AVAILABILITY IS ASSUMED (SEE MATHER, 1974: 106 - CURVES
C             C AND G).
C
C      "LAT" - THE LATITUDE IN DEGREES.
C
C      "DT" - TIME DIFFERENTIAL. BLANK OR ZERO INDICATES MONTHLY
C             CALCULATIONS. ANY OTHER NUMBER CAUSES DAILY CALCULATIONS.
C
C      "TUNIT" - DESIGNATES THE UNITS OF AIR TEMPERATURE. 1.0 MEANS
C                THE RAW TEMPERATURE DATA ARE IN DEGREES FAHRENHEIT.
C                2.0 MEANS DEGREES KELVIN. ANY OTHER NUMERIC
C                DESIGNATION OR A BLANK MEANS DEGREES CELSIUS.
C
C      "PUNIT" - UNITS OF PRECIPITATION. 1.0 MEANS THE RAW DATA
C                ARE IN CM. 2.0 MEANS INCHES. 3.0 MEANS HUNDRETHS
C                OF AN INCH. OTHER DESIGNATIONS OR BLANKS MEANS MM.
C
C      "ST(1)"   ESTIMATED SOIL MOISTURE CONTENT OF THE TOP SOIL
```

```
C                LAYER JUST PRIOR TO THE BEGINNING OF CALCULATIONS.
C                ST(1) ONLY NEEDS TO BE SPECIFIED WHEN BALANCING
C                IS NOT TO BE DONE (SEE NOTE BELOW). ST(1) IS IN MM.
C
C     "HEAT" - ESTIMATED HEAT INDEX. IT NEEDS TO BE SPECIFIED
C              ONLY WHEN SOIL MOISTURE BALANCING DOES NOT
C              OCCUR (NOTE: BALANCING SHOULD ONLY BE SPECIFIED FOR
C              PERIODS CONTAINING ONE OR MORE COMPLETE YEARS OF DATA).
C
C     "INDEX" - SHOULD BE SET GREATER THAN ZERO WHEN CALCULATIONS
C               FOR A SUBSEQUENT STATION ARE TO FOLLOW THESE.(NOTE:
C               CONTROL PARAMETERS AND DATA MUST BE INCLUDED
C               SEQUENTIALLY IN THE INPUT DATA SET FOR EACH STATION
C               THAT IS TO BE EVALUATED).
C
C     READ INITIAL PARAMETERS:
C
   10 READ(5,1000,END=20,ERR=20) LABEL,N,NT,KD,KM,KY,FC,SM,LAT,DT,
     1                           TUNIT,PUNIT,ST(1),HEAT,INDEX
      NNN= NNN + 1
C
C     ASSUMED PARAMETER VALUES, I.E., WHEN THEY ARE NOT SPECIFIED.
C
      IF (N.EQ.0) N= 1
      IF (NT.EQ.0) NT= N
      IF (KD.EQ.0.AND.DT.NE.0.0) KD= 1
      IF (KD.EQ.0.AND.DT.EQ.0.0) KD= 15
      IF (KM.EQ.0) KM= 1
C
C     SET THE ARRAY SIZES FOR CALCULATING A SOIL WATER BALANCE.
C
      M= N + 1
C
C     CALL THE MAIN SUBPROGRAM WHICH CONTROLS ALL CALCULATIONS.
C
      CALL MAIN(N,NT,M,FC,LAT,KD,KM,KY,DT,UT,HEAT,SM,I,P,EE,APE,D,DA,
```

```
     1           H,AE,ST,DST,DEF,SUR,MON,LABEL,TUNIT,PUNIT)                    109
                                                                               110
C                                                                              111
C      TEST TO SEE IF SUBSEQUENT STATIONS ARE TO BE EVALUATED.                 112
C                                                                              113
       IF (INDEX.GT.0.0) GO TO 10                                              114
C                                                                              115
   20  CONTINUE                                                                116
       STOP                                                                    117
 1000  FORMAT (18A4,/,5I5,9F5.0)                                               118
       END                                                                     119
C*****************************************************************************120
       SUBROUTINE MAIN(N,NT,M,FC,LAT,KD,KM,KY,DT,DY,HEAT,SM,T,P,PE,APE,D       121
      1        ,DAYS,H,AE,ST,DST,DEF,SUR,MON,LABEL,TUNIT,PUNIT)                122
       REAL LAT,T(M),P(M),PE(M),APE(M),D(M),DAYS(13),H(M),DY(M),AE(M),         123
      1     ST(M),DST(M),DEF(M),SUR(M),MON(M),FMT(18),LABEL(18)               124
       DIMENSION OUT(10),SUMM(5),SUMY(5)                                       125
       INTEGER IND(5)/3,4,8,9,10/                                              126
C                                                                              127
C      READ THE DATA FORMAT (FMT).                                             128
C                                                                              129
       READ(5,1000) FMT                                                        130
       NNN= 0                                                                  131
C                                                                              132
C      UNIT CORRECTION FACTORS.                                                133
C                                                                              134
       C1= 1.0                                                                 135
       C2= 1.0                                                                 136
       FK= 0.0                                                                 137
       IF (TUNIT.EQ.1.0) FK= 32.0                                              138
       IF (TUNIT.EQ.1.0) C1= 5.0 / 9.0                                         139
       IF (TUNIT.EQ.2.0) FK= 273.16                                            140
       IF (PUNIT.EQ.1.0) C2= 10.0                                              141
       IF (PUNIT.EQ.2.0) C2= 25.4                                              142
       IF (PUNIT.EQ.3.0) C2= 0.254                                             143
C                                                                              144
C      READ AIR TEMPERATURE AND PRECIPITATION DATA.
```

```
C                                                                       145
      DO 10 I= 1,N                                                      146
        READ(5,FMT,END=290,ERR=280) T(I),P(I)                           147
        NNN= NNN + 1                                                    148
C                                                                       149
C     UNIT TRANSLATIONS.                                                150
C                                                                       151
        T(I)= C1 * (T(I) - FK)                                          152
        P(I)= C2 * P(I)                                                 153
C                                                                       154
   10 CONTINUE                                                          155
C                                                                       156
      KY= KY + 1900                                                     157
C                                                                       158
C     TEST FOR DAILY, MONTHLY, DAY BY DAY OR MONTH BY MONTH BUDGETING.  159
C                                                                       160
      IF (DT.NE.0.0.AND.N.EQ.1) GO TO 70                                161
      IF (DT.EQ.0.0.AND.N.EQ.1) GO TO 20                                162
      IF (DT.NE.0.0) GO TO 60                                           163
C***                                                                    164
C***  HERE FOR MONTHLY BALANCING.                                       165
C***                                                                    166
      CALL DATE(N,M,KD,KM,DY,MON,DT,DAYS)                               167
      CALL MATHER(N,M,H,T,HEAT,A,PE,APE,DAYS,LAT,DL,KD,KM,DT,MON,DY)    168
      CALL DIFF(N,M,P,APE,D,DEF)                                        169
      CALL BAL(N,M,ST,D,FC,SM,SUR,DST,DT,DAYS,KM)                       170
      CALL EVAPO(N,M,D,AE,APE,P,DST,DEF)                                171
C                                                                       172
C     WRITE MONTHLY INPUT DATA AND RESULTS.                             173
C                                                                       174
   20 CONTINUE                                                          175
C                                                                       176
      WRITE(6,1010) LABEL                                               177
      WRITE(6,1020) N,NT,FC,LAT                                         178
C                                                                       179
      IF (N.EQ.1) GO TO 130                                             180
```

```
C                                                                       181
      I= 0                                                              182
      GO TO 40                                                          183
   30 CONTINUE                                                          184
      CALL CONV(SUMY,5,1,5)                                             185
      WRITE(6,1030) SUMY                                                186
   40 CALL INIT(SUMY,5)                                                 187
      WRITE(6,1040) KY                                                  188
C                                                                       189
      KY= KY + 1                                                        190
      WRITE(6,1050)                                                     191
   50 I= I + 1                                                          192
C                                                                       193
C     ROUND OFF TO NEAREST WHOLE NUMBER AND GET TOTALS BEFORE WRITING.  194
C                                                                       195
      CALL OUTPUT(PE,APE,P,D,ST,DST,AE,DEF,SUR,M,OUT,I)                 196
      CALL TOTY(OUT,10,IND,SUMY,5)                                      197
      CALL CONV(OUT,10,2,10)                                            198
      OUT(1)= T(I)                                                      199
C                                                                       200
      WRITE(6,1060) MON(I),OUT                                          201
      IF (I.LT.N.AND.MON(I).EQ.12) GO TO 30                             202
      IF (I.EQ.N.AND.NT.GT.N) GO TO 130                                 203
      IF (I.EQ.N) GO TO 290                                             204
      GO TO 50                                                          205
C                                                                       206
   60 CONTINUE                                                          207
C***                                                                    208
C***  HERE FOR DAILY BALANCING.                                         209
C***                                                                    210
      CALL DATE(N,M,KD,KM,DY,MON,DT,DAYS)                               211
      CALL MATHER(N,M,H,T,HEAT,A,PE,APE,DAYS,LAT,DL,KD,KM,DT,MON,DY)    212
      CALL DIFF(N,M,P,APE,D,DEF)                                        213
      CALL BAL(N,N,ST,D,FC,SM,SUR,DST,DT,DAYS,KM)                       214
      CALL EVAPO(N,M,D,AE,APE,P,DST,DEF)                                215
C                                                                       216
```

```
C
C     WRITE DAILY INPUT DATA AND RESULTS.                                    217
C                                                                            218
   70 CONTINUE                                                               219
C                                                                            220
      WRITE(6,1010) LABEL                                                    221
      WRITE(6,1070) N,NT,FC,LAT                                              222
C                                                                            223
      IF (N.EQ.1) GO TO 190                                                  224
C                                                                            225
      I= 0                                                                   226
      GO TO 90                                                               227
   80 CONTINUE                                                               228
      CALL CONV(SUMM,5,1,5)                                                  229
      CALL CONV(SUMY,5,1,5)                                                  230
      WRITE(6,1080) SUMM                                                     231
      WRITE(6,1030) SUMY                                                     232
   90 CALL INIT(SUMY,5)                                                      233
      WRITE(6,1040) KY                                                       234
      KY= KY + 1                                                             235
      GO TO 110                                                              236
  100 CONTINUE                                                               237
      CALL CONV(SUMM,5,1,5)                                                  238
      WRITE(6,1080) SUMM                                                     239
  110 CALL INIT(SUMM,5)                                                      240
      WRITE(6,1090) MON(I+1)                                                 241
      WRITE(6,1100)                                                          242
  120 I= I + 1                                                               243
      KD= DY(I)                                                              244
      KM= MON(I)                                                             245
C                                                                            246
C     ROUND OFF TO NEAREST WHOLE NUMBERS AND GET TOTALS BEFORE WRITING.      247
C                                                                            248
      CALL OUTPUT(PE,APE,P,D,ST,DST,AE,DEF,SUR,M,OUT,I)                      249
      CALL TOTM(OUT,10,IND,SUMM,5)                                           250
      CALL TOTY(OUT,10,IND,SUMY,5)                                           251
      CALL CONV(OUT,10,2,10)                                                 252
```

```
      OUT(1)= T(I)                                                              253
C                                                                               254
      WRITE(6,1060) KD,OUT                                                      255
      IF (I.LT.N.AND.MON(I).EQ.12.AND.DY(I).EQ.DAYS(KM+1)) GO TO 80             256
      IF (I.LT.N.AND.DY(I).EQ.DAYS(KM+1)) GO TO 100                             257
      IF (I.EQ.N.AND.NT.LE.N) GO TO 290                                         258
      IF (I.EQ.N) GO TO 190                                                     259
      GO TO 120                                                                 260
C***                                                                            261
C***  HERE FOR MONTH BY MONTH CALCULATIONS.                                     262
C***                                                                            263
  130 CONTINUE                                                                  264
      N1= 0                                                                     265
      IF (N.GT.1) N1= 1                                                         266
C                                                                               267
C     GET THE INITIAL SOIL MOISTURE, MONTH AND DAY.                             268
C                                                                               269
      IF (N.GT.1) ST(1)= ST(N)                                                  270
      KD= 15                                                                    271
      IF (N.GT.1) KM= MON(N) + 1                                                272
      IF (KM.GE.13) KM= 1                                                       273
      DY(1)= KD                                                                 274
      MON(1)= KM                                                                275
C                                                                               276
C     SET INITIAL PARAMETERS.                                                   277
C                                                                               278
      NN= NT - N                                                                279
      IF (N.EQ.1) NN= NT                                                        280
      IF (NNN.EQ.1) NNN= 0                                                      281
      N= 1                                                                      282
      LL= 0                                                                     283
      N= N + 1                                                                  284
C                                                                               285
C     TEST FOR APPROPRIATE LABELS.                                              286
C                                                                               287
      IF (NNN.EQ.0) GO TO 150                                                   288
```

```
      IF (KM.GT.1.AND.N1.EQ.1) GO TO 170                                289
      IF (KM.GT.1) GO TO 160                                            290
C                                                                       291
  140 CONTINUE                                                          292
C                                                                       293
C     WRITE LABELS, YEAR AND LAST YEAR'S TOTALS.                        294
C                                                                       295
      CALL CONV(SUMY,5,1,5)                                             296
      WRITE(6,1030) SUMY                                                297
  150 CALL INIT(SUMY,5)                                                 298
      WRITE(6,1040) KY                                                  299
      KY= KY + 1                                                        300
  160 CONTINUE                                                          301
      WRITE(6,1050)                                                     302
C                                                                       303
C     READ INPUT DATA AND CALL BUDGET SUBROUTINES.                      304
C                                                                       305
  170 LL= LL + 1                                                        306
      IF (NNN.EQ.0) GO TO 180                                           307
      READ(5,FMT,END=290,ERR=280) T(N),P(N)                             308
      T(N)= C1 * (T(N) - FK)                                            309
      P(N)= C2 * P(N)                                                   310
  180 NNN= NNN + 1                                                      311
C                                                                       312
      CALL MATHER(N,M,H,T,HEAT,A,PE,APE,DAYS,LAT,DL,KD,KM,DT,MON,DY)    313
      CALL DIFF(N,M,P,APE,D,DEF)                                        314
      D(N+1)= D(N)                                                      315
      CALL BAL(N,M,ST,D,FC,SM,SUR,DST,DT,DAYS,KM)                       316
      ST(N)= ST(N+1)                                                    317
      SUR(N)= SUR(N+1)                                                  318
      DST(N)= DST(N+1)                                                  319
      CALL EVAPO(N,M,D,AE,APE,P,DST,DEF)                                320
C                                                                       321
C     ROUND OFF TO NEAREST WHOLE NUMBER AND GET TOTALS BEFORE WRITING.  322
C                                                                       323
      CALL OUTPUT(PE,APE,P,D,ST,DST,AE,DEF,SUR,M,OUT,N)                 324
```

```
      CALL TOTY(OUT,10,IND,SUMY,5)                                      325
      CALL CONV(OUT,10,2,10)                                            326
      OUT(1)= T(N)                                                      327
C                                                                       328
C     WRITE RESULTS AND GET THE NEXT MONTH.                             329
C                                                                       330
      WRITE(6,1060) KM,OUT                                              331
      CALL DATE(N,M,KD,KM,DY,MON,DT,DAYS)                               332
C                                                                       333
      IF (NN.EQ.LL) GO TO 290                                           334
      IF (KM.EQ.1) GO TO 140                                            335
      GO TO 170                                                         336
C***                                                                    337
C***  HERE FOR DAY BY DAY CALCULATIONS.                                 338
C***                                                                    339
  190 CONTINUE                                                          340
      N1= 0                                                             341
      IF (N.GT.1) N1= 1                                                 342
C                                                                       343
C     GET THE INITIAL SOIL MOISTURE, MONTH AND DAY.                     344
C                                                                       345
      IF (N.GT.1) ST(1)= ST(N)                                          346
      IF (N.GT.1) KD= DY(N) + 1                                         347
      IF (N.GT.1) KM= MON(N)                                            348
      IF (KD.GT.DAYS(KM+1)) GO TO 200                                   349
      DY(1)= KD                                                         350
      MON(1)= KM                                                        351
      GO TO 210                                                         352
  200 CONTINUE                                                          353
      KM= KM + 1                                                        354
      KD= 1                                                             355
      IF (KM.GE.13) KM= 1                                               356
      DY(1)= KD                                                         357
      MON(1)= KM                                                        358
  210 CONTINUE                                                          359
C                                                                       360
```

```
C     INITIALIZE PARAMETERS.                                                    361
C                                                                               362
      NN= NT - N                                                                363
      IF (N.EQ.1) NN= NT                                                        364
      IF (NNN.EQ.1) NNN= 0                                                      365
      N= 1                                                                      366
      L= 0                                                                      367
      M= N + 1                                                                  368
C                                                                               369
C     TEST FOR APPROPRIATE LABELS.                                              370
C                                                                               371
      IF (NNN.EQ.0) GO TO 230                                                   372
      IF (KD.NE.1.AND.KM.NE.1.AND.N1.EQ.1) GO TO 260                            373
      IF (KD.NE.1.OR.KM.NE.1) GO TO 240                                         374
C                                                                               375
  220 CONTINUE                                                                  376
C                                                                               377
C     WRITE LABELS,THE YEAR AND MONTH AND LAST YEAR'S OR MONTH'S TOTALS.        378
C                                                                               379
      CALL CONV(SUMM,5,1,5)                                                     380
      CALL CONV(SUMY,5,1,5)                                                     381
      WRITE(6,1080) SUMM                                                        382
      WRITE(6,1030) SUMY                                                        383
  230 CALL INIT(SUMY,5)                                                         384
      WRITE(6,1040) KY                                                          385
      KY= KY + 1                                                                386
      GO TO 250                                                                 387
  240 CONTINUE                                                                  388
      CALL CONV(SUMM,5,1,5)                                                     389
      WRITE(6,1080) SUMM                                                        390
  250 CALL INIT(SUMM,5)                                                         391
      WRITE(6,1090) KM                                                          392
      WRITE(6,1100)                                                             393
C                                                                               394
C     READ INPUT DATA AND CALL BUDGET SUBROUTINES.                              395
C                                                                               396
```

```
  260 L= L + 1                                                                  397
      IF (NNN.EQ.0) GO TO 270                                                   398
      READ(5,FMT,END=290,ERR=280) T(N),P(N)                                     399
      T(N)= C1 * (T(N) - FK)                                                    400
      P(N)= C2 * P(N)                                                           401
  270 NNN= NNN + 1                                                              402
C                                                                               403
      CALL MATHER(N,M,H,T,HEAT,A,PE,APE,DAYS,LAT,DL,KD,KM,DT,MON,DY)            404
      CALL DIFF(N,M,P,APE,D,DEF)                                                405
      D(N+1)= D(N)                                                              406
      CALL BAL(N,M,ST,D,FC,SM,SUR,DST,DT,DAYS,KM)                               407
      ST(N)= ST(N+1)                                                            408
      SUR(N)= SUR(N+1)                                                          409
      DST(N)= DST(N+1)                                                          410
      CALL EVAPO(N,M,D,AE,APE,P,DST,DEF)                                        411
C                                                                               412
C     ROUND OFF TO NEAREST WHOLE NUMBER AND GET TOTALS BEFORE WRITING.          413
C                                                                               414
      CALL OUTPUT(PE,APE,P,D,ST,DST,AE,DEF,SUR,M,OUT,N)                         415
      CALL TOTM(OUT,10,IND,SUMM,5)                                              416
      CALL TOTY(OUT,10,IND,SUMY,5)                                              417
      CALL CONV(OUT,10,2,10)                                                    418
      OUT(1)= T(N)                                                              419
C                                                                               420
C     WRITE RESULTS AND GET A NEW DATE.                                         421
C                                                                               422
      WRITE(6,1060) KD,OUT                                                      423
      CALL DATE(N,M,KD,KM,DY,MON,DT,DAYS)                                       424
C                                                                               425
      IF (NN.EQ.L) GO TO 290                                                    426
      IF (KM.EQ.1.AND.KD.EQ.1) GO TO 220                                        427
      IF (KD.EQ.1) GO TO 240                                                    428
      GO TO 260                                                                 429
C                                                                               430
C     WRITE FINAL MESSAGES AND TOTALS.                                          431
C                                                                               432
```

```
  280 CONTINUE                                                          433
      WRITE(6,1110) NNN + 1                                             434
      GO TO 300                                                         435
  290 CONTINUE                                                          436
      IF (DT.NE.0.0) WRITE(6,1080) SUMM                                 437
      WRITE(6,1030) SUMY                                                438
      WRITE(6,1120) NNN                                                 439
  300 CONTINUE                                                          440
      WRITE(6,1130)                                                     441
      RETURN                                                            442
 1000 FORMAT (18A4)                                                     443
 1010 FORMAT ('0',18A4)                                                 444
 1020 FORMAT (//,'  NO. OF MONTHS OVER WHICH BALANCING OCCURS IS ',I5,//  445
     *,'  TOTAL NO. OF MONTHS EVALUATED IS',I5,//,                      446
     *'  SOIL MOISTURE CAPACITY IS ',F5.1,' MM ',//,                   447
     *'  LATITUDE IS ',F4.1)                                           448
                                                                        449
 1030 FORMAT (/,'  YEARLY TOTALS',3X,2I6,18X,3I6)                       450
 1040 FORMAT (///,'  YEAR IS ',I4)                                      451
 1050 FORMAT (//,'  MO    TEMP   UPE   APE  PREC  DIFF    ST   DST    AE  452
     *   DEF  SURP',/)                                                  453
 1060 FORMAT (I4,2X,F6.1,9I6)                                           454
 1070 FORMAT (//,'  NO. OF DAYS OVER WHICH BALANCING OCCURS IS ',I5,//,  455
     *'  TOTAL NO. OF DAYS EVALUATED IS ',I5,//,                       456
     *'  SOIL MOISTURE CAPACITY IS ',F5.1,' MM ',//,                   457
     *'  LATITUDE IS ',F4.1)                                           458
 1080 FORMAT (/,'  MONTHLY TOTALS',2X,2I6,18X,3I6)                      459
 1090 FORMAT (//,'  MONTH IS ',I2)                                      460
 1100 FORMAT (//,'  DY    TEMP   UPE   APE  PREC  DIFF    ST   DST    AE  461
     *   DEF  SURP',/)                                                  462
 1110 FORMAT (///,'  ERROR ENCOUNTERED IN THE DATA AT RECORD ',I5)      463
 1120 FORMAT (///,'  PROCESSING TERMINATED AFTER RECORD ',I5)           464
 1130 FORMAT ('1')                                                      465
      END                                                               466
C*************************************************************************  467
      SUBROUTINE DATE(N,M,KD,KM,DY,MON,DT,DAYS)                         468
```

```
      REAL DY(M),MON(M),DAYS(13)                                        469
                                                                        470
C                                                                       471
C     GENERATE DAY AND MONTH DESIGNATIONS.                              472
C                                                                       473
C     TEST FOR MONTHLY, DAILY, MONTH BY MONTH OR DAY BY DAY             474
C     CALCULATIONS.                                                     475
C                                                                       476
      IF (DT.NE.0.0.AND.N.EQ.1) GO TO 60                                477
      IF (DT.EQ.0.0.AND.N.EQ.1) GO TO 50                                478
      IF (DT.NE.0.0) GO TO 20                                           479
C                                                                       480
C     MONTHLY CALCULATIONS.                                             481
C                                                                       482
      KD= 15                                                            483
      KM= KM - 1                                                        484
      IF (KM.LE.0) KM= 0                                                485
      DO 10 I= 1,N                                                      486
        KM= KM + 1                                                      487
        IF (KM.GE.13) KM= 1                                             488
        MON(I)= KM                                                      489
        DY(I)= KD                                                       490
   10 CONTINUE                                                          491
      GO TO 80                                                          492
C                                                                       493
C     DAILY CALCULATIONS.                                               494
C                                                                       495
   20 CONTINUE                                                          496
      K= 1                                                              497
      KD= KD - 1                                                        498
      IF (KD.LE.0) KD= 0                                                499
      IF (KD.GT.0) K= KD                                                500
      KM= KM - 1                                                        501
      IF (KM.LE.0) KM= 0                                                502
      J= 0                                                              503
   30 KM= KM + 1                                                        504
      IF (KD.GT.DAYS(KM+1)) KD= 1                                       505
```

```
      IF (KM.GE.13) KM= 1                                              505
      DO 40 I= K,DAYS(KM+1)                                            506
        J= J + 1                                                       507
        MON(J)= KM                                                     508
        DY(J)= I                                                       509
   40 CONTINUE                                                         510
      IF (J.GE.N) GO TO 80                                             511
      K= 1                                                             512
      GO TO 30                                                         513
C                                                                      514
C     MONTH BY MONTH CALCULATIONS.                                     515
C                                                                      516
   50 CONTINUE                                                         517
      KD= 15                                                           518
      KM= KM + 1                                                       519
      IF (KM.GE.13) KM= 1                                              520
      DY(N)= KD                                                        521
      MON(N)= KM                                                       522
      GO TO 80                                                         523
C                                                                      524
C     DAY BY DAY CALCULATIONS.                                         525
C                                                                      526
   60 CONTINUE                                                         527
      KD= KD + 1                                                       528
      DY(N)= KD                                                        529
      MON(N)= KM                                                       530
      IF (KD.GT.DAYS(KM+1)) GO TO 70                                   531
      GO TO 80                                                         532
   70 CONTINUE                                                         533
      KM= KM + 1                                                       534
      KD= 1                                                            535
      IF (KM.GE.13) KM= 1                                              536
      DY(N)= KD                                                        537
      MON(N)= KM                                                       538
   80 CONTINUE                                                         539
      RETURN                                                           540
```

```
      END                                                                    541
C*****************************************************************************542
      SUBROUTINE MATHER(N,M,H,T,HEAT,A,PE,APE,DAYS,LAT,DL,KD,KM,DT,MON,      543
     1        DY)                                                            544
      REAL LAT,H(M),T(M),PE(M),APE(M),DAYS(13),MON(M),DY(M)                  545
C                                                                            546
C     CALCULATE POTENTIAL EVAPOTRANSPIRATION.                                547
C                                                                            548
C     WHEN LAT IS GREATER THAN 50 DEGS, THE DAYLENGTH CORRECTION             549
C     REMAINS EQUAL TO THAT FOR 50 DEGS. ALAT IS, THEREFORE,                 550
C     USED AS THE ARGUMENT FOR SUBROUTINE DAY.                               551
C                                                                            552
      ALAT= LAT                                                              553
      IF (ALAT.GE.50.0) ALAT= 50.0                                           554
C                                                                            555
C     CALCULATE THE HEAT INDEX DURING BALANCING ON THE FIRST CALL            556
C     OF MATHER. ON THE SECOND CALL, GO DIRECTLY TO "PE" CALCULATIONS.       557
C                                                                            558
      IF (N.LT.12) GO TO 40                                                  559
      IF (N.LT.365.AND.DT.NE.0.0) GO TO 40                                   560
C                                                                            561
      XN= N                                                                  562
      HEAT= 0.0                                                              563
      DO 30 I= 1,N                                                           564
        IF (T(I).LE.0.0) GO TO 10                                            565
        H(I)= (T(I) / 5.0) ** 1.514                                          566
        GO TO 20                                                             567
   10   H(I)= 0.0                                                           568
   20   CONTINUE                                                            569
        HEAT= HEAT + H(I)                                                    570
   30 CONTINUE                                                             571
C                                                                            572
C     ADJUST "HEAT" FOR BUDGETS GREATER THAN                                 573
C     A YEAR.                                                                574
C                                                                            575
      HEAT= HEAT * 12.0 / XN                                                 576
```

```
C                                                                       577
C     NOTE: "A" IS AN EMPIRICALLY                                       578
C     DERIVED EXPONENT BASED UPON "HEAT".                               579
C                                                                       580
   40 CONTINUE                                                          581
      A= 6.75 / 10.0 ** 7.0 * HEAT ** 3.0-7.71 / 10.0 ** 5.0 * HEAT **  582
     1   2.0+1.79 / 10.0 ** 2.0 * HEAT+0.49                            583
C                                                                       584
C     GET INITIAL MONTHLY PE, I.E. BASED UPON 30 DAYS IN                585
C     A MONTH AND 12HOURS IN A DAY.                                     586
C     NOTE: PE(I) AND APE(I) ARE CALCULATED IN MM / MONTH               587
C     OR DAY.                                                           588
C                                                                       589
      DO 70 I= 1,N                                                      590
        IF (T(I).LE.0.0) GO TO 50                                       591
        PE(I)= 16.0 * (10.0 * T(I) / HEAT) ** A                         592
C                                                                       593
C     CORRECT FOR TEMPERATURES GREATER THAN 26.5 DEG C.                 594
C     SEE THORNTHWAITE (1948) FOR EXPLANATION.                          595
C                                                                       596
        IF (T(I).GE.26.5) PE(I)= (-41.58547 + 3.22441 * T(I)-0.04325 *  597
     1                            T(I) ** 2.0) * 10.0                   598
C                                                                       599
C     CORRECT PE(I) FOR DAILY CALCULATIONS.                             600
C                                                                       601
        IF (DT.NE.0.0) PE(I)= PE(I) / 30.0                              602
        GO TO 60                                                        603
   50   PE(I)= 0.0                                                      604
   60   CONTINUE                                                        605
        KD= DY(I)                                                       606
        KM= MON(I)                                                      607
C                                                                       608
C     ADJUST PE FOR DAYLENGTH AND THE NUMBER OF DAYS IN A MONTH.        609
C                                                                       610
        CALL DAY(DAYS,ALAT,KD,KM,DT,DECD,DL)                            611
        APE(I)= PE(I) * (DAYS(KM + 1) / 30.0) * (DL / 12.0)             612
```

```
   70 CONTINUE                                                              613
      RETURN                                                                614
      END                                                                   615
C*************************************************************************** 616
      SUBROUTINE DAY(DAYS,LAT,KD,KM,DT,DECD,DL)                             617
      REAL DAYS(13)                                                         618
      REAL LAT                                                              619
C                                                                           620
C     CALCULATE THE NUMBER OF HOURS IN A                                    621
C     DAY AND THE SOLAR DECLINATION ASSOCIATED WITH THAT                    622
C     DAY. THE INPUT REQUIRED INCLUDES: THE MONTH (KM),                     623
C     THE DAY (KD) AND THE LATITUDE (LAT).                                  624
C                                                                           625
      X= 0.0                                                                626
      DO 10 I= 1,KM                                                         627
        X= X + DAYS(I)                                                      628
   10 CONTINUE                                                              629
      SUM= X + KD                                                           630
C                                                                           631
C     GET THE NUMBER OF DAYS SINCE THE VERNAL EQUINOX (MARCH 21).           632
C                                                                           633
      DAYL= SUM - 80.0                                                      634
      IF (DAYL.LE.0.0) DAYL= 285.0 + SUM                                    635
C                                                                           636
C     CALCULATE THE DECLINATION.                                            637
C                                                                           638
      DECD= 23.45 * SIN(DAYL / 365.0 * 6.2832)                              639
      DECR= DECD * 0.017453                                                 640
C                                                                           641
C     CALCULATE THE NUMBER OF HOURS OF DAYLIGHT CORRESPONDING               642
C     TO DAY KD AND MONTH KM (SEE SELLERS, 1965).                           643
C                                                                           644
      CZ= COS(1.5708 + 0.01745 * (100.0 / 60.0))                            645
      ALAT= LAT * 0.017453                                                  646
      XX= COS(DECR) * COS(ALAT)                                             647
      IF (XX.LE.0.0) GO TO 20                                               648
```

```
      CSH= (CZ - SIN(DECR) * SIN(ALAT)) / XX                                649
      H= ARCOS(CSH)                                                         650
      DL= 24.0 * H / 3.1416                                                 651
      GO TO 30                                                              652
C                                                                           653
C     ERROR MESSAGE - DIVIDE BY ZERO OR LESS.                               654
C                                                                           655
   20 WRITE(6,1000)                                                         656
C                                                                           657
   30 CONTINUE                                                              658
      RETURN                                                                659
 1000 FORMAT ('0',' ERROR - DIVIDE BY ZERO OR LESS - LAT. ',//,             660
     *'  OR THE DECLINATION IS PROBABLY INCORRECT ')                       661
      END                                                                   662
C*************************************************************************663
      SUBROUTINE DIFF(N,M,P,APE,D,DEF)                                      664
      REAL P(M),APE(M),D(M),DEF(M)                                          665
C                                                                           666
C     COMPARE APE(I) WITH PRECIPITATION (P(I)).                             667
C                                                                           668
      DO 10 I= 1,N                                                          669
        D(I)= P(I) - APE(I)                                                 670
        DEF(I)= 0.0                                                         671
        IF (D(I).LT.0.0) DEF(I)= D(I)                                       672
   10 CONTINUE                                                              673
      RETURN                                                                674
      END                                                                   675
C*************************************************************************676
      SUBROUTINE BAL(N,M,ST,D,FC,SM,SUR,DST,DT,DAYS,KM)                     677
      REAL ST(M),D(M),SUR(M),DST(M),DAYS(13)                                678
C                                                                           679
C     ITERATE FOR SOIL MOISTURE TERMS THAT BALANCE                          680
C     THE WATER BUDGET ON THE FIRST CALL OF BAL. ON A SECOND CALL           681
C     AND/OR WHEN N IS ONE, BAL DOES MONTH BY MONTH OR DAY BY               682
C     DAY SOIL MOISTURE CALCULATIONS.                                       683
C                                                                           684
```

```
      IF (N.EQ.1) GO TO 10                                                    685
C                                                                             686
      ST(N + 1)= 0.0                                                          687
      ST(1)= 300.0                                                            688
      DST(1)= 0.0                                                             689
      K= 0                                                                    690
      Z= 0.0                                                                  691
   10 CONTINUE                                                                692
      DO 80 I= 2,N + 1                                                        693
        IF (D(I).GE.0.0) GO TO 50                                             694
C                                                                             695
C     TEST FOR MONTHLY OR DAILY WITHDRAWAL.                                   696
C                                                                             697
        IF (DT.NE.0.0) GO TO 30                                               698
C                                                                             699
C     WITHDRAWAL FOR MONTHLY BUDGETS (NOTE: THIS IS DONE ON                   700
C     AN APPROXIMATE DAY BY DAY BASIS).                                       701
C                                                                             702
        X1= ST(I - 1)                                                         703
        DO 20 J= 1,30                                                         704
          RATIO= ST(I - 1) / FC                                               705
          ST(I)= ST(I - 1) + D(I) * RATIO / 30.0                              706
          IF (RATIO.GE.0.7.AND.SM.GT.0.0) ST(I)= ST(I - 1) + D(I) / 30.0      707
          ST(I - 1)= ST(I)                                                    708
   20   CONTINUE                                                             709
        ST(I - 1)= X1                                                         710
        GO TO 40                                                              711
   30   CONTINUE                                                             712
C                                                                             713
C     WITHDRAWAL FOR DAILY BUDGETS.                                           714
C                                                                             715
        ST(I)= ST(I-1) + ST(I-1) / FC * D(I)                                  716
        IF ((ST(I-1) / FC).GE.0.7.AND.SM.GT.0.0) ST(I)= ST(I-1) + D(I)        717
C                                                                             718
   40   CONTINUE                                                             719
        IF (ST(I).LE.1.0) ST(I)= 1.0                                          720
```

```
      GO TO 70                                                          721
50    CONTINUE                                                          722
      ST(I)= ST(I-1) + D(I)                                             723
      IF (ST(I).GE.FC) GO TO 60                                         724
      SUR(I)= 0.0                                                       725
      GO TO 70                                                          726
60    SUR(I)= ST(I) - FC                                                727
      ST(I)= FC                                                         728
70    CONTINUE                                                          729
      DST(I)= ST(I) - ST(I-1)                                           730
      IF (D(I).LE.0.0) SUR(I)= 0.0                                      731
80 CONTINUE                                                             732
C                                                                       733
      IF (N.EQ.1) GO TO 160                                             734
C                                                                       735
      K= K + 1                                                          736
C                                                                       737
C     TESTS FOR BALANCES                                                738
C                                                                       739
      IF (K.GT.50) GO TO 160                                            740
      XX= ABS(ST(N + 1) + DST(1) - ST(1))                               741
      IF (XX.LT.1.0.AND.Z.EQ.1.0) GO TO 160                             742
      IF (XX.LT.1.0) GO TO 90                                           743
      ST(1)= ST(N + 1) + DST(1)                                         744
      GO TO 10                                                          745
C                                                                       746
90 CONTINUE                                                             747
      IF (D(1).GE.0.0) GO TO 130                                        748
      IF (DT.NE.0.0) GO TO 110                                          749
C                                                                       750
C     BALANCE FOR THE FIRST MONTH                                       751
C                                                                       752
      X2= ST(N + 1)                                                     753
      DO 100 L= 1,30                                                    754
        RATIO= ST(N + 1) / FC                                           755
        ST(1)= ST(N + 1) + D(1) * RATIO / 30.0                          756
```

```
        IF (RATIO.GE.0.7.AND.SM.GT.0.0) ST(1)= ST(N + 1) + D(1) / 30.0
        ST(N + 1)= ST(1)
  100 CONTINUE
      ST(N + 1)= X2
      GO TO 120
  110 CONTINUE
C
C     BALANCE FOR THE FIRST DAY
C
      ST(1)= ST(N + 1) + ST(N + 1) / FC * D(1)
      IF ((ST(N + 1) / FC).GE.0.7.AND.SM.GT.0.0) ST(1)= ST(N + 1) + D(1)
C
  120 CONTINUE
      IF (ST(1).LE.1.0) ST(1)= 1.0
      GO TO 150
  130 CONTINUE
      ST(1)= ST(N + 1) + D(1)
      IF (ST(1).GE.FC) GO TO 140
      SUR(1)= 0.0
      GO TO 150
  140 SUR(1)= ST(1) - FC
      ST(1)= FC
  150 CONTINUE
      DST(1)= ST(1) - ST(N + 1)
      IF (D(1).LE.0.0) SUR(1)= 0.0
      Z= 1.0
      GO TO 10
C
  160 CONTINUE
C
      RETURN
      END
C*************************************************************************
      SUBROUTINE EVAPO(N,M,D,AE,APE,P,DST,DEF)
      REAL D(M),AE(M),APE(M),P(M),DST(M),DEF(M)
C
```

```
C       CALCULATE ACTUAL EVAPOTRANSPIRATION AND DEFICIT.                        793
C                                                                               794
        DO 10 I= 1,N                                                            795
          AE(I)= APE(I)                                                         796
          IF (D(I).LT.0.0) AE(I)= P(I) + ABS(DST(I))                            797
          DEF(I)= APE(I) - AE(I)                                                798
     10 CONTINUE                                                                799
        RETURN                                                                  800
        END                                                                     801
C*******************************************************************************802
        SUBROUTINE INIT(SUM,N)                                                  803
        DIMENSION SUM(N)                                                        804
C                                                                               805
C       INITIALIZE ARRAY "SUM" WITH ZEROS.                                      806
C                                                                               807
        I= 0                                                                    808
     10 I= I + 1                                                                809
        SUM(I)= 0.0                                                             810
        IF (I.LT.N) GO TO 10                                                    811
        RETURN                                                                  812
        END                                                                     813
C*******************************************************************************814
        SUBROUTINE OUTPUT(PE,APE,P,D,ST,DST,AE,DEF,SUR,M,OUT,L)                 815
        DIMENSION PE(M),APE(M),P(M),D(M),ST(M),DST(M),AE(M),DEF(M),SUR(M),      816
       1          OUT(10)                                                     817
C                                                                               818
C       FILL THE OUTPUT ARRAY "OUT".                                            819
C                                                                               820
        OUT(2)= PE(L)                                                           821
        OUT(3)= APE(L)                                                          822
        OUT(4)= P(L)                                                            823
        OUT(5)= D(L)                                                            824
        OUT(6)= ST(L)                                                           825
        OUT(7)= DST(L)                                                          826
        OUT(8)= AE(L)                                                           827
        OUT(9)= DEF(L)                                                          828
```

```
      OUT(10)= SUR(L)                                                          829
      RETURN                                                                   830
      END                                                                      831
C*****************************************************************************832
      SUBROUTINE TOTM(X,N,IND,SUM,NN)                                          833
      DIMENSION SUM(NN),IND(NN),X(N)                                           834
C                                                                              835
C     SUM VALUES OF "X" SPECIFIED BY "IND" OVER THE MONTH.                     836
C                                                                              837
      I= 0                                                                     838
   10 I= I + 1                                                                 839
      J= IND(I)                                                                840
      SUM(I)= SUM(I) + X(J)                                                    841
      IF (I.LT.NN) GO TO 10                                                    842
      RETURN                                                                   843
      END                                                                      844
C*****************************************************************************845
      SUBROUTINE TOTY(X,N,IND,SUM,NN)                                          846
      DIMENSION SUM(NN),IND(NN),X(N)                                           847
C                                                                              848
C     SUM VALUES OF "X" SPECIFIED BY "IND" OVER THE YEAR.                      849
C                                                                              850
      I= 0                                                                     851
   10 I= I + 1                                                                 852
      J= IND(I)                                                                853
      SUM(I)= SUM(I) + X(J)                                                    854
      IF (I.LT.NN) GO TO 10                                                    855
      RETURN                                                                   856
      END                                                                      857
C*****************************************************************************858
      SUBROUTINE CONV(X,NUM,MIN,MAX)                                           859
      DIMENSION X(NUM)                                                         860
C                                                                              861
C     ROUND X(I) OFF TO NEAREST WHOLE NUMBER                                   862
C                                                                              863
      I= MIN - 1                                                               864
```

```
10 I= I + 1                                                    865
   IF (X(I).EQ.0.0) GO TO 20                                   866
   Y= ABS(X(I))                                                867
   J= X(I) / Y                                                 868
   K= Y + 0.5                                                  869
   X(I)= K * J                                                 870
20 IF (I.LT.MAX) GO TO 10                                      871
   RETURN                                                      872
   END                                                         873
```

APPENDIX 2

SAMPLE INPUT

```
SAMPLE MONTHLY WATER BUDGET ONE YEAR LONG. DATA FROM SEABROOK, N.J..          1
  12   12     1     1    77 300.0      40.0                                   2
(2F10.5)                                                                     3
       0.9       87.0                                                        4
       1.2       93.0                                                        5
       5.9      102.0                                                        6
      11.3       88.0                                                        7
      17.5       92.0                                                        8
      22.3       91.0                                                        9
      24.7      112.0                                                       10
      23.7      113.0                                                       11
      20.2       82.0                                                       12
      14.0       85.0                                                       13
       7.6       70.0                                                       14
       2.3       93.0                                                       15
```

```
SAMPLE DAILY WATER BUDGET ONE MONTH LONG. DATA FROM SEABROOK, N. J.          1
   1   30     1     6   53300.0       40.0  1.0           300.0 58.2        2
(2F10.0)                                                                    3
     11.7       11.0                                                        4
     12.8        1.0                                                        5
     17.8        0.0                                                        6
     18.9        0.0                                                        7
     23.3        0.0                                                        8
     25.0       15.0                                                        9
     25.6        1.0                                                       10
     22.8        0.0                                                       11
     22.2        0.0                                                       12
     23.9        0.0                                                       13
     20.0        0.0                                                       14
     17.2        0.0                                                       15
     18.9        1.0                                                       16
     16.7       14.0                                                       17
     13.9        0.0                                                       18
     17.8        0.0                                                       19
     20.0        0.0                                                       20
     18.9        0.0                                                       21
     21.1        0.0                                                       22
     24.4        0.0                                                       23
     26.1        0.0                                                       24
     26.7        0.0                                                       25
     25.0        0.0                                                       26
     22.2        0.0                                                       27
     20.0        0.0                                                       28
     22.8        0.0                                                       29
     27.2        0.0                                                       30
     26.7        0.0                                                       31
     26.1        2.0                                                       32
     25.6        1.0                                                       33
```

APPENDIX 3

SAMPLE OUTPUT

SAMPLE MONTHLY WATER BUDGET ONE YEAR LONG. DATA FROM SEABROOK, N.J..

NO. OF MONTHS OVER WHICH BALANCING OCCURS IS 12

TOTAL NO. OF MONTHS EVALUATED IS 12

SOIL MOISTURE CAPACITY IS 300.0 MM

LATITUDE IS 40.0

YEAR IS 1977

MO	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURP
1	0.9	1	1	87	86	300	0	1	0	86
2	1.2	2	1	93	92	300	0	1	0	92
3	5.9	16	17	102	85	300	0	17	0	85
4	11.3	41	45	88	43	300	0	45	0	43
5	17.5	75	94	92	-2	298	-2	94	0	0
6	22.3	105	133	91	-42	259	-39	130	3	0
7	24.7	122	156	112	-44	223	-35	147	9	0
8	23.7	115	137	113	-24	206	-17	130	7	0
9	20.2	92	96	82	-14	197	-9	91	4	0
10	14.0	55	53	85	32	229	32	53	0	0
11	7.6	23	19	70	51	280	51	19	0	0
12	2.3	4	4	93	89	300	20	4	0	69
YEARLY TOTALS			756	1108				734	23	374

PROCESSING TERMINATED AFTER RECORD 12

SAMPLE DAILY WATER BUDGET ONE MONTH LONG. DATA FROM SEABROOK, N.J..

NO. OF DAYS OVER WHICH BALANCING OCCURS IS 1

TOTAL NO. OF DAYS EVALUATED IS 30

SOIL MOISTURE CAPACITY IS 300.0 MM

LATITUDE IS 40.0

YEAR IS 1953

MONTH IS 6

DY	TEMP	UPE	APE	PREC	DIFF	ST	DST	AE	DEF	SURF
1	11.7	1	2	11	9	300	0	2	0	9
2	12.8	2	2	1	-1	299	-1	2	0	0
3	17.8	3	3	0	-3	296	-3	3	0	0
4	18.9	3	3	0	-3	292	-3	3	0	0
5	23.3	4	5	0	-5	288	-5	5	0	0
6	25.0	4	5	15	10	298	10	5	0	0
7	25.6	4	5	1	-4	293	-4	5	0	0
8	22.8	4	5	0	-5	289	-4	4	0	0
9	22.2	3	4	0	-4	285	-4	4	0	0
10	23.9	4	5	0	-5	280	-5	5	0	0
11	20.0	3	4	0	-4	276	-4	4	0	0
12	17.2	2	3	0	-3	274	-3	3	0	0
13	18.9	3	4	1	-3	271	-2	3	0	0
14	16.7	2	3	14	11	282	11	3	0	0
15	13.9	2	2	0	-2	280	-2	2	0	0

16	17.8	3	3	0	-3	277	-3	3	0	0
17	20.0	3	4	0	-4	274	-4	4	0	0
18	18.9	3	4	0	-4	270	-3	3	0	0
19	21.1	3	4	0	-4	267	-4	4	0	0
20	24.4	4	5	0	-5	262	-4	4	1	0
21	26.1	4	6	0	-6	257	-5	5	1	0
22	26.7	5	6	0	-6	252	-5	5	1	0
23	25.0	4	5	0	-5	248	-4	4	1	0
24	22.2	3	4	0	-4	244	-4	4	1	0
25	20.0	3	4	0	-4	241	-3	3	1	0
26	22.8	4	5	0	-5	238	-4	4	1	0
27	27.2	5	6	0	-6	233	-5	5	1	0
28	26.7	5	6	0	-6	228	-4	4	1	0
29	26.1	4	6	2	-4	226	-3	5	1	0
30	25.6	4	5	1	-4	222	-3	4	1	0
MONTHLY TOTALS			127	46				114	13	9
YEARLY TOTALS			127	46				114	13	9

PROCESSING TERMINATED AFTER RECORD 30