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Operational Estimates of Areal Evapotranspiration and Lake Evaporation — Program WREVAP

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Program WREVAP has evolved from the previously documented Programs REVAP and WEVAP by providing greater flexibility in the input and time period options and by including a technique for taking into account the effects of subsurface heat storage changes on lake evaporation. It includes the CRAE (complementary relationship areal evapotranspiration), CRWE (complementary relationship wet-surface evaporation) and CRLE (complementary relationship lake evaporation) options. The workings of the complementary relationship, the input requirements and the possible options are explained. The program can be run for time periods ranging from one day to a month. Finally, output samples for various options and diverse climatic regions are presented and discussed in some detail.

Résumé

Le programme WREVAP découle des programmes vérifiés REVAP et WEVAP. Ce nouveau programme WREVAP est plus souple pour les paramètres et les options temporelles. Il tient compte des effets, sur l'évaporation lacustre, des variations du stockage de la chaleur sous la surface. Il englobe les options suivantes : évaporation surfacique (CRAE), évaporation à la surface mouillée (CRWE) et évaporation lacustre (CRLE), toutes complémentaires. Les mécanismes de la complémentarité, les paramètres à utiliser et les options possibles sont tous expliqués. Le programme peut être exécuté pour des périodes allant d'une journée à un mois. Enfin, quelques exemples des résultats obtenus pour diverses options et diverses régions climatiques sont présentés et analysés avec suffisamment de détails.

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1. INTRODUCTION

Program WREVAP is the latest in a series of computer models for estimating actual evaporation and transpiration from routinely published records of temperature, humidity and sunshine duration. Like the previous models, Program WREVAP is founded on the concept of a complementary relationship between areal and potential evapotranspiration. The concept takes into account interactions between the evaporating surfaces and the overpassing air, whereby a decrease in the availability of water for areal evapotranspiration causes the overpassing air to become hotter and drier, which in turn causes the potential evapotranspiration to increase. It provides the basis for what is referred to as a CRAE (complementary relationship areal evapotranspiration) model, which permits areal evapotranspiration to be estimated from its effects on the routinely observed temperatures and humidities used in computing potential evapotranspiration, thereby avoiding the complexities of the soil-plant system and the need for locally calibrated coefficients.[1] This means that the results are independent and falsifiable, so that errors in the associated assumptions can be detected and corrected by progressive testing against long-term water-balance estimates of river basin evapotranspiration from an ever-widening range of environments. During the past decade the test range has been expanded from Canada and Ireland to the United States, Australia, New Zealand, Brazil and a number of countries in Africa. The conceptual and empirical foundations of the complementary relationship, its use in providing the basis for operational estimates of areal evapotranspiration, the testing of such estimates against 143 comparable water-budget values and the potential use of such estimates in transforming hydrology from a descriptive and a predictive science are discussed in detail elsewhere (Morton, 1983a).

The complementary relationship can also take into account the modification of the air as it passes from the land environment to the environment of a shallow lake. Thus a few minor changes (Morton, 1983a,b) convert the CRAE model to a CRWE (complementary relationship wet-surface evaporation) model which can provide estimates of lake-size wet surface evaporation from routine climatological observations in the land environment with no locally calibrated coefficients. Although the lake-size wet surface evaporation corresponds to the evaporation from a lake so shallow that seasonal subsurface heat storage changes are negligible, monthly values can be accumulated to provide reliable estimates of annual evaporation from lakes with depths of up to 30 m. This capability has been demonstrated by the good agreement between the annual totals of monthly CRWE model estimates and the comparable water budget estimates for ten lakes in North America and Africa, including two that had average depths exceeding the 30-m limit by more than 100% (Morton, 1983b).

Good monthly estimates of evaporation for lakes of significant depth must take into account seasonal changes in subsurface heat storage by means of vertical temperature profiles. Since this is operationally impracticable, the subsurface heat storage changes have been taken into account in an approximate way (Morton, 1983b) by routing model estimates of lake-size wet surface evaporation through hypothetical heat reservoirs with delay times and storage constants related to the depth and salinity of the lake, using a routing technique similar to those used in routing water through natural reservoirs in hydrology. Although this procedure provided reasonable agreement with water budget estimates for the ten lakes referred to in the preceding paragraph, it proved to be conceptually inadequate when applied to a lake 150 m deep. This is because the routing technique required that the annual lake evaporation be equal to the annual lake-size wet surface evaporation and thus failed to recognize that heat is absorbed into storage during seasons when evaporation consumes a high proportion of the available energy and is released from storage during seasons when evaporation consumes a low proportion of the available energy. The newest version of the CRLE (complementary relationship lake evaporation) models solves this problem by routing the absorbed global radiation (rather than the lake-size wet surface evaporation) through the hypothetical heat reservoir. A paper submitted for publication (Morton, in press) presents the formulation of this most recent CRLE model and a comparison of its

[1] Program VPCOR is needed to process one of the humidity input options for Program WREVAP.

results with the corresponding CRWE model estimates and the corresponding water budget estimates for 17 lakes in North America and Africa.

The main purpose of this report is to provide a complete documentation of the data requirements and operation of Program WREVAP with its CRAE, CRWE and CRLE options. The chief differences between the CRAE and CRWE options of Program WREVAP and the previously documented Programs REVAP and WEVAP (Morton *et al*., 1980) are

(1) The inclusion of the CRLE model has introduced much complexity, because the routing process requires the storage of data and information from previous months.

(2) The provision of greater flexibility has led to the use of values for the declination and radius vector of the sun that are averages of the daily values for each day of the period rather than values for the middle day of each period. Table 1 presents the resultant monthly frequency distributions of the deviations of the Program REVAP (Morton *et al*., 1980) estimates of areal evapotranspiration from the comparable Program WREVAP estimates for 925 station-years in Canada and the southern United States. The monthly deviations are small, and the seasonal pattern ensures that the annual deviations remain small. Because the deviations for the lake-size wet surface evaporation estimates would be even smaller, it can be concluded that CRAE and CRWE model estimates produced by Program WREVAP do not differ significantly from the estimates produced by the models documented in Morton *et al*. (1980) and Morton (1983a,b).

(3) The minimum const.aint on the net long-wave radiation has been changed from 5% to 3% of the surface long-wave radiation. This has little effect and applies only under very hot, humid and cloudy conditions, such as those that prevail at Manaus in the Amazonian rain forest from December to May inclusive (see sample computation in Appendix IV.4).

Program WREVAP is also available for the Hewlett-Packard HP-41CV and HP-41CX hand-held calculators. The documentation is available on request to the senior author.

2. CONCEPTUAL BASIS

The equation describing the complementary relationship is expressed as follows:

$$E_T + E_{TP} = 2E_{TW}$$

Table 1. Frequencies of Monthly Differences between REVAP and WREVAP Estimates of Areal Evapotranspiration Values for Five Years at 185 Stations (925 station-years) in Canada and the Southern United States

mm	January	February	March	April	May	June	July	August	September	October	November	December
1.0	0	0	0	0	0	0	0	0	0	0	0	0
0.9	0	0	0	0	0	0	0	0	0	0	0	0
0.8	0	0	0	0	0	0	0	0	0	0	0	0
0.7	0	0	0	0	0	0	0	0	0	0	0	0
0.6	0	0	0	0	0	0	1	19	0	0	0	0
0.5	0	0	0	0	0	0	4	151	0	0	0	0
0.4	0	0	0	1	0	0	9	213	0	0	0	0
0.3	0	0	0	0	0	0	279	301	0	0	22	0
0.2	0	0	0	0	0	0	341	181	0	136	83	0
0.1	0	0	0	0	0	0	197	48	150	169	31	0
0.0	38	15	0	0	0	0	94	12	773	619	787	924
-0.1	842	735	377	51	4	100	0	0	2	1	2	1
-0.2	18	79	102	52	60	565	0	0	0	0	0	0
-0.3	0	20	80	45	54	256	0	0	0	0	0	0
-0.4	2	32	143	54	110	3	0	0	0	0	0	0
-0.5	11	2	141	69	140	1	0	0	0	0	0	0
-0.6	14	2	65	98	122	0	0	0	0	0	0	0
-0.7	0	3	17	157	135	0	0	0	0	0	0	0
-0.8	0	11	0	176	97	0	0	0	0	0	0	0
-0.9	0	17	0	107	107	0	0	0	0	0	0	0
-1.0	0	9	0	66	80	0	0	0	0	0	0	0
-1.1	0	0	0	41	16	0	0	0	0	0	0	0
-1.2	0	0	0	8	0	0	0	0	0	0	0	0
-1.3	0	0	0	0	0	0	0	0	0	0	0	0

where E_T = areal evapotranspiration, the actual evapotranspiration from an area so large that the effects of the evapotranspiration on the temperature and humidity of the overpassing air are fully developed.

E_{TP} = potential evapotranspiration, as estimated from a solution of the energy balance and vapour transfer equations and representing the evapotranspiration that would occur from a hypothetical moist surface with radiation absorption, heat transfer and vapour transfer characteristics similar to those of the area, and so small that the effects of the evapotranspiration on the overpassing air would be negligible.

E_{TW} = wet environment evapotranspiration, the evapotranspiration that would occur if the soil-plant surfaces of the area were saturated and there were no limitations on the availability of water for evapotranspiration.

Figure 1 provides a schematic representation of the workings of the complementary relationship under conditions of a relatively high radiant-energy supply (solid line) and of a relatively low radiant-energy supply (dashed line). The ordinate represents evapotranspiration and the abscissa represents water supply to the soil-plant surfaces of the area, a quantity that is usually unknown. When there is no water available for areal evapotranspiration (extreme left of Fig. 1), it follows that $E_T = 0$, the air is very hot and dry, and E_{TP} is at its maximum rate of $2E_{TW}$ (the dry environment potential evapotranspiration). As the water supply to

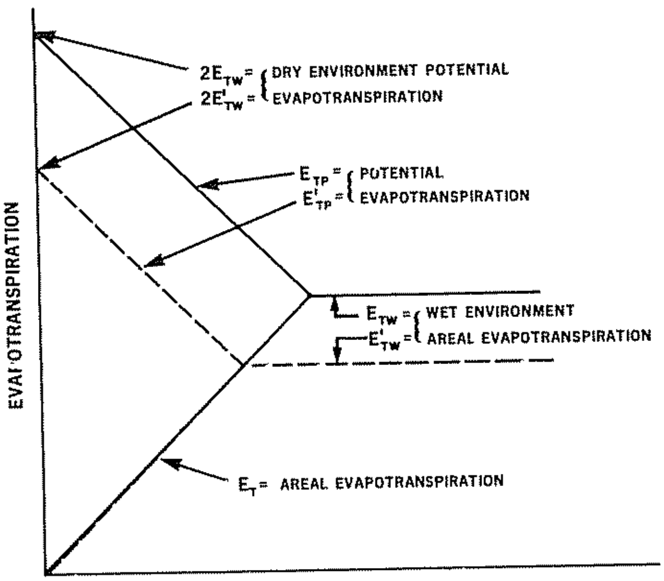

Figure 1. Schematic representation of the complementary relationship.

the soil-plant surfaces of the area increases (moving to the right in Fig. 1) the resultant equivalent increase in E_T causes the overpassing air to become cooler and more humid, and this in turn produces an equivalent decrease in E_{TP}. Finally, when the supply of water to the soil-plant surfaces of the area has increased sufficiently, the values of E_T and E_{TP} converge to that of E_{TW}. Thus, the potential evapotranspiration under completely humid conditions is equal to one-half the potential evapotranspiration under completely arid conditions. Neither E_T nor the availability of water are known, but both E_{TP} and E_{TW} can be estimated from routine climatological observations. Therefore, the CRAE model uses the complementary relationship in the following form:

$$E_T = 2E_{TW} - E_{TP}$$

In the CRAE model, E_{TP} is estimated from a quickly converging solution of the energy balance and vapour transfer equations, and E_{TW} is estimated from the equation for potential evaporation proposed by Priestley and Taylor (1972), as adjusted to take into account the effects of large-scale advection during winter. The two coefficients needed for the adjustment and the vapour transfer coefficient needed in the computation of E_{TP} have been calibrated using data for dry months in arid regions where the sum of E_{TP} and the precipitation approximates $2E_{TW}$ (Morton, 1983a).

The outputs of the CRAE option of Program WREVAP are E_{TP} and E_T in millimetres, and R_T, the net radiation corresponding to soil-plant surfaces at air temperature, in millimetres of evaporation equivalent. The value of E_{TW} is not normally of interest, but if required it can be computed from the following version of the complementary relationship:

$$E_{TW} = (E_T + E_{TP})/2$$

The evaporation from a lake-size wet surface, E_W, differs from the wet-environment areal evapotranspiration, E_{TW}, only because the radiation absorption and vapour transfer characteristics of water differ from those of vegetated land surfaces. The potential evaporation (hereinafter referred to as pan-size wet surface evaporation and denoted by the symbol E_{WP}) differs from the potential evapotranspiration, E_{TP}, for the same reasons. Although the E_W is equal to the value of E_{WP} estimated from observations in the lake environment, it can differ significantly from the value of E_{WP} estimated from observations in the land environment.

Figure 2 provides a schematic representation of the relationship between the lake-size wet surface evaporation and the pan-size wet surface evaporation in the land environment under conditions of constant radiant-energy supply. The ordinate represents evaporation and the abscissa represents the water supply to the soil-plant surfaces of the land environment. Since a lake is defined to be so wide that the effects of upwind shoreline transitions are insignificant (Morton, 1983a,b, in press), the lake-size wet surface evaporation is independent of variations in the water supply to the soil-plant surfaces of the land environment. The complementary relationship, however, predicts that the pan-size wet surface evaporation in a completely dry land environment would be twice the lake-size wet surface evaporation and that it would decrease in response to increases in the water supply to the soil-plant surfaces until it reached a minimum equal to the lake-size wet surface evaporation as shown in Figure 2.

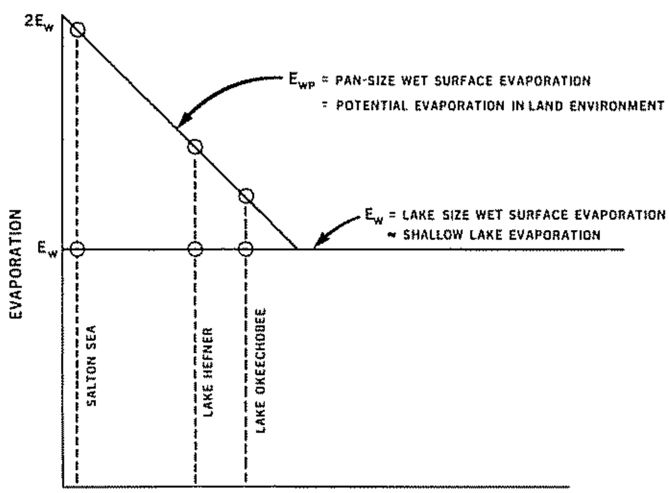

Figure 2. Schematic representation of the relationship between E_W and E_{WP}.

The ratios E_W/E_{WP} have a close correspondence to the well-known pan coefficients that are used to estimate lake evaporation from pan evaporation in the land environment, and the complementary relationship can be used to explain systematic variations in the coefficients. Thus the plotted points in Figure 2 correspond closely to data published by Hounam (1973), which show that the annual Class-A pan coefficient is 0.52 for the Salton Sea in California, where the precipitation less runoff (the water supply to the soil-plant surfaces of the land environment) ~ 60 mm/year; 0.70 for Lake Hefner in Oklahoma, where the precipitation less runoff ~ 700 mm/year; and 0.81 for Lake Okeechobee in Florida, where the precipitation less runoff ~ 1000 mm/year.

The techniques used for estimating E_W and E_{WP} in the CRWE option are almost identical with those used to estimate E_{TW} and E_{TP} in the CRAE option. The only differences are in the use of radiation absorption and vapour transfer characteristics compatible with water surfaces rather than vegetated land surfaces and their effects on the results of the calibration (Morton, 1983a). The outputs of the CRWE option are E_{WP} and E_W in millimetres and R_W, the net radiation corresponding to a wet surface at air temperature, in millimetres of evaporation equivalent.

In the CRLE option, the procedures used to compute the lake evaporation, E_L, and the potential evaporation, E_{LP}, are identical with those used to compute E_W and E_{WP} in the CRWE option. However, the results can be very different because the energy term used in the CRLE option is the net available energy, which depends on the solar and waterborne energy inputs for previous months, rather than the net radiation, which depends on the solar energy input for only the current month. The degree to which the net available energy is affected by the solar and waterborne energy inputs of previous months is controlled by a routing procedure with delay times and storage constants that are functions of the depth and salinity of the lake. With the CRLE option, Figure 2 would make no sense because of the lag between energy inputs and energy availability. Thus for Lake Superior (average depth ~ 148 m) the CRLE estimates of lake evaporation and potential evaporation are both 96 mm during December, when the CRWE estimate of pan-size wet surface evaporation in the land environment is -3 mm.

The main outputs of the CRLE model are E_{LP} and E_L in millimetres and R_L, the net available energy corresponding to a lake surface at air temperature, in millimetres of evaporation equivalent. Subsidiary results are the solar and waterborne energy inputs, G_W^t [GW(W/M**2) in the computer output listing] for the last 12 months of the period and the available solar and waterborne energy at the end of the last month of the period, G_{LE} (GLEND in the computer output listing). These subsidiary outputs, which are in watts per square metre, can be used as inputs if further updating is required.

3. LIMITATIONS

Program WREVAP can provide reliable estimates of areal evapotranspiration, lake-size wet surface evaporation and lake evaporation from routine observations of temperature, humidity and insolation anywhere in the world, with no need for locally optimized coefficients. The latitude and altitude must be known, as must be the long-term average annual precipitation for the areal evapotranspiration option, the water salinity for the lake-size wet surface evaporation option or the water salinity and the average depth for the lake evaporation option. The widespread use of Program WREVAP, however, is subject to several limitations. The most stringent, those related to the CRAE (areal evapotranspiration) option, are as follows:

(1) The CRAE option requires accurate humidity data and these have depended on frequent observations by skilled personnel. This is now one of the more serious limitations to the use of the CRAE models. However, the Humicell, a simple device developed by the Saskatchewan Research Council (Langham, 1969), provides integrated vapour pressure estimates within ±2% for periods exceeding three days. Another more convenient instrument system, which includes a two-channel recorder with temperature sensor, dewcel sensor, solar panel and battery, has been evaluated and is being put into use.

(2) The CRAE option cannot be used for short time intervals because of subsurface heat-storage changes and because of the lag times associated with the change in storage of heat and water vapour in the atmospheric boundary layer after changes in surface conditions or the passage of frontal systems. The time periods could probably be shortened to five days, but for intervals of three days or less the results would always be suspect. This limitation has little significance in hydrological applications because it does not matter much whether the daily evapotranspiration is 3 or 6 mm, as long as the accumulated values for the week or for a longer period are reliable.

(3) It cannot be used near sharp environmental discontinuities, such as a high-latitude coastline or the edge of an oasis, because of advection of heat and water vapour in the lower layers of the atmosphere. Analysis of data from irrigated areas (Morton, 1983a) indicates that the effects of such advections can decrease to near zero with 300 m, but this finding may not be generally applicable.

(4) It requires temperature and humidity inputs from a climatological station whose surroundings are representative of the area of interest.

(5) It cannot be used to predict the effects of natural or man-made changes because it neither uses nor requires knowledge of the soil-vegetation system and because post-change temperatures and humidities are not predictable. However, it can detect and monitor the effects of these changes as temperature, humidity and insolation data become available.

The wet surface and lake evaporation options are relatively insensitive to errors in the humidity and temperature inputs. Furthermore, it does not matter much where in the vicinity of the lake the temperature and humidity inputs are observed, because the complementary relationship automatically takes into account the effects of differing surroundings. Thus the difference between estimates derived from observations in the land environment and estimates derived from observations over the lake would be due primarily to the relatively minor effects of the difference in humidity on the radiation. Moreover, the effects of shoreline advection on the evaporation from lakes or lake-size surfaces can be disregarded and for smaller wet surfaces (i.e., ponds) they can be taken into account by weighting E_L and the E_{LP} using a technique described elsewhere (Morton, in press). However, for the lake evaporation option the length of period is restricted to one month. Finally, the lake evaporation option cannot provide meaningful results unless at least 12 months of continuous input data are available.

4. OPTIONS

This section provides a summary of the output and input options for Program WREVAP. Practical aspects of option selection are discussed in much greater detail in Section 6.2. The output options follow.

4.1 Output Options

The first output option is the choice of outputs from the areal evapotranspiration (CRAE) model, from the wet surface evaporation (CRWE) model, from the lake evaporation (CRLE) model when the required antecedent information is not available or from the lake evaporation (CRLE) model when the required antecedent information is available.

Secondly, there is the choice of outputs for time periods corresponding to months, fractions of months, unequal numbers of days or equal number of days. This choice is available for only the CRAE and CRWE model options, because the CRLE model will provide correct results only for monthly time periods. However, a technique that permits the complementary relationship models to produce hydrologically meaningful daily estimates, with no significant accumulation of error, is described in Section 6.8.

The third choice is a summary tabulation of monthly mean model outputs (entitled MONTHLY TOTALS AVERAGED OVER NYR YEARS). This choice is available only for time period options corresponding to months and fractions of a month.

4.2 Input Options

The input options are used to widen the range of data that can be accepted by Program WREVAP.

The first input option is the choice of average atmospheric pressure (in millibars) or station altitude (in metres above sea level) as the station altitude input.

Secondly, there is the choice of dewpoint temperature (in degrees Celsius or Fahrenheit), vapour pressure (in millibars) or relative humidity (a ratio) as the required humidity inputs. As discussed in Section 6.2, the latter two options must be used with care in estimating areal evapotranspiration.

Thirdly, there is the choice of either the Celsius or the Fahrenheit scale for the required temperature inputs and optional dewpoint inputs.

The fourth choice is the ratio of observed to maximum possible sunshine duration, of observed sunshine duration in hours per day, of observed global radiation in langleys per day or of observed global radiation in megajoules per square metre per day as the required insolation input.

Fifthly, waterborne energy inputs (in watts per square metre) can be accepted when entered in the proper format (see Sections 6.4 and 6.5). If zero, the space can remain blank.

5. PROGRAM LANGUAGE

Program WREVAP has been used successfully on the Control Data Corporation CDC CYBER 74 with the NOS/BE (Network Operating System/Batch Environment) operating system at the Department of Energy, Mines and Resources in Ottawa. It is written in FORTRAN EXTENDED (version 4) language and requires about 52 000 octal words of program storage space. Although execution time varies according to the size of the data base, five years of monthly records would require approximately 0.4 s of the execution time.

It took less than one day for a student to convert Program WREVAP for successful use on both the IBM and the HYPERION microcomputers.

6. DATA PREPARATION

Program WREVAP is designed to accept climatological input data averaged over time periods varying from one day to one month, although as noted in Section 3, the model estimates for periods of three days or less would always be suspect. Calculations can be performed for only a single station or for many stations at a time. The input specifications, data structures and option selections are shown in Appendix I. They are arranged and organized into logical groupings and referred to as Records A to G inclusive. (Appendix V gives the definitions of variable names used in Appendix I, the main program and the subroutines.)

6.1 Record A of File Tape 1

This record specifies the required station characteristics. In the following list, each of these is identified by the appropriate Record A field number.

(1) SITE is the station name.

(2) PHID is the geographical latitude of the station in decimal degrees.

(3) P may be either the average atmospheric pressure in millibars or the altitude of the station above sea level in metres, depending on which option is selected (Record B, field 9).

(4) PPN is the average annual precipitation in millimetres per year. It is used only in the areal evapotranspiration option (Record B, field 4) and may be left blank or have any other value, when the wet surface and lake evaporation options are selected.

(5) DA is the average lake depth in metres. It is used only in the lake evaporation option (Record B, field 4) and may be left blank or have any other real value when the areal evapotranspiration or wet surface evaporation options are selected.

(6) SALT is the salinity or the total dissolved solids in parts per million. Because it is applied in all three options and is applicable only in the wet surface and lake evaporation options (Record B, field 4), it must be left blank or set equal to zero when the areal evapotranspiration option is selected.

6.2 Record B of File Tape 1

This record contains the data control specifications, such as the total number of periods, the number of periods per month and the settings for the output and input options. In the following list, each of these is identified by the appropriate Record B field number.

(1) NN is the total number of time periods for which computations are required. It must be known in advance of the computer run.

(2) M is an integer used to define time periods that correspond to fractions of a month (when INDEX = 2 in field 3 below). With this option the months are divided into M time periods in such a way that the first M-1 periods have the same number of days and the last period has the number of days required to complete the specific months. When INDEX ≠ 2, M must be set equal to 1.

(3) INDEX is the control parameter used in selecting time periods. Choice of monthly periods requires that INDEX = 1; choice of time periods corresponding to fractions of a month (i.e., having M periods per month) requires that INDEX = 2; choice of time periods having unequal numbers of days requires that INDEX = 3; and choice of time periods having an equal number of days (e.g., weeks) requires that INDEX = 4. The use of this control parameter has the advantage that it is only when INDEX = 3 that the starting dates and durations for individual time periods need to be specified. Some suggestions for deriving useful results for daily periods are discussed in Section 6.8.

(4) LK is the control parameter used in model selection. Choice of the CRAE (areal evapotranspiration) option requires that LK = 0, choice of the CRWE (wet surface evaporation) option requires that LK = 1, choice of the CRLE (lake evaporation) option, when there is no antecedent information (see discussion of File Tape 2 and File Tape 3 in Sections 6.6 and 6.7), requires that LK = 2 and choice of the CRLE option when antecedent information is available requires that LK = 3. The setting LK = 3 is used in an updating situation when the solar and waterborne energy inputs for the 12 previous months and the available solar and waterborne energy at the end of the preceding month are known from previous computations and can be used as input. The setting LK = 2 is used when antecedent information is not available, and errors in arbitrarily selected initial values are substantially removed by computing the monthly lake evaporation for the first year three times in succession.

(5) ISUM is a control parameter that can provide a summary tabulation of monthly mean model outputs entitled "MONTHLY TOTALS AVERAGED OVER NYR YEARS." When no tabulation is required the setting must be ISUM = 0, and when the tabulation is required, the setting must be ISUM = 1. This option is available only when INDEX = 1 or 2.

(6) IT is a control parameter in the selection of the Celsius or the Fahrenheit scale for the required air temperature and optional dewpoint temperature inputs. The use of Celsius degrees requires that IT = 0 and the use of Fahrenheit degrees requires that IT = 1.

(7) IS is a control parameter for the selection of optional insolation inputs. The use of the ratio of observed to maximum possible sunshine duration requires that IS = 0, the use of the observed sunshine duration in hours per day requires that IS = 1, the use of the observed global radiation in langleys per day requires that IS = 2, and the use of the observed global radiation in megajoules per square metre per day requires that IS = 3.

(8) IV is a control parameter for the selection of optional humidity inputs. Choice of dewpoint temperatures (in degrees Celsius or Fahrenheit) requires that IV = 0, choice of vapour pressure (in millibars) requires that IV = 1, and choice of relative humidity (as a ratio) requires that IV = 2. Significant errors may result from the use of vapour pressures or relative humidities in the CRAE option (Morton, 1983a), although the vapour pressures can be adjusted satisfactorily by using Program VPCOR (Appendix VI).

(9) IP is a control parameter for the selection of optional station altitude inputs. The choice of average atmospheric pressure (in millibars) requires that IP = 0 and the choice of station altitude (in metres above sea level) requires that IP = 1.

6.3 Record C of File Tape 1

This record contains the date and the period length for the first computation period for each station. It is used only when INDEX = 1, 2 or 4. With these options the information is updated after each computation so that Record C only has to be made once, provided the periods follow a sequence without interruption. This is the chief advantage of the INDEX control parameter. In the following brief comments, each of the time period specifications is identified by the appropriate Record C field number.

(1) STRTDY is the day of the month on which the first computation period starts. For monthly periods (INDEX = 1), and for periods corresponding to

fractions of a month (INDEX = 2), it will always be 1. For time periods having an equal number of days (INDEX = 4), however, it could have any number from 1 to 31.

(2) MONTH is the month number in which STRTDY occurs, beginning with 1 for January and ending with 12 for December.

(3) STRTYR is the calendar year (e.g., 1967) in which STRTDY and MONTH occur.

(4) LENGTH can be any integer value greater than or equal to 1 when INDEX = 1 or 2 and is the number of days in each computation period when INDEX = 4.

6.4 Record D of File Tape 1

This record is used only when INDEX = 1, 2 or 4. It specifies the required climatological data input for each individual time period. If punch cards are being used, one card is required for each period. The data are averages for the specified periods. In the following list, each of the data categories is identified by the appropriate Record D field number.

(1) TD is the optional humidity input as selected with control parameter IV in Table B, field 8.

(2) C1 permits estimated values to be distinguished by the letter "E", when tabulated with the model results. Thus C1 is blank when TD is observed, and C1 = E when TD is estimated.

(3) T is the optional temperature input as selected with control parameter IT in Table B, field 6.

(4) C2 is to T as C1 is to TD.

(5) S is the optional insolation input as selected with control parameter IS in Table B, field 7.

(6) C3 is to S as C1 is to TD.

(7) HADD is the waterborne energy input to the lake in watts per square metre. It can be estimated from the difference between the heat content of the inflows and the heat content of the outflows and is significant only for relatively small, deep reservoirs on large rivers (e.g., Lake Mead or Lake Nasser) and for small lakes that receive cooling water from thermal power plants. When insignificant, HADD can remain blank.

6.5 Record E of File Tape 1

This record is used only when INDEX = 3, i.e., with time periods of unequal length. It specifies the required climatological data input, the date and the period length for individual time periods. As such, it represents a combination of Record C and Record D. Thus field numbers 1 to 7 inclusive are identical with those of Record D, and field numbers 8 to 11 inclusive differ from fields 1 to 4 inclusive of Record C only because STRTDY, MONTH, STRTYR and LENGTH refer to the specific time period rather than to the first computation period. Thus the use of INDEX = 3 and Record E adds considerably to the time needed for data preparation, when compared with the use INDEX ≠ 3 and Records C and D. The INDEX = 3 option, however, permits great flexibility in the definition of LENGTH and this can be helpful in applying Program WREVAP to operational problems. An example of its practicability in deriving useful results for daily periods is presented in Section 6.8.

6.6 Record F of File Tape 2

This record contains the antecedent information required to estimate lake evaporation when LK = 3. It is used in an updating situation, after errors due to arbitrarily selected antecedent information have been substantially removed by computing the monthly lake evaporation for the first year three times in succession, using the option LK = 2. The record can be created by copying Record G of File Tape 3 from the previous run or by copying the information from the output listing of the previous run. GLBGN is the available solar and waterborne energy at the beginning of the month in watts per square metre and is equal to the available solar and waterborne energy at the end of the preceding month (GLEND in Record G of File Tape 3). The quantities denoted by TGW are the antecedent solar and waterborne energy inputs in watts per square metre, with TGW (12) being the value for the preceding month, TGW (11) being the value for the month previous to that, and so on down to TGW (1), which is the value for the current month of the previous year.

6.7 Record G of File Tape 3

This record contains information produced by the lake evaporation model (options LK = 2 or LK = 3), which can provide the antecedent information needed for further updating. Thus the solar and waterborne energy inputs (in watts per square metre) for the first to the twelfth preceding months (TGW (12) to TGW (1), respectively) are identical with those needed in Record F of File Tape 2, and GLEND, the available solar and waterborne energy at the end of the last month of the computation period (in watts per square metre) is identical with GLBGN. The information in Record G of File Tape 3 is automatically listed with the model results, so that it can be preserved in hard copy and used to create a new Record F at some unpredictable time in the future, when updating is required. It should be noted that the record can be created only after at least 12 months of the required data have been observed and used as input to the CRLE model, with LK set equal to 2, followed, optionally, by further updating with LK set equal to 3.

6.8 Useable Daily Estimates

As noted in Section 3, it may be possible to estimate areal evapotranspiration for time periods as short as five days, although for intervals of three days or less the results would always be suspect. The same considerations apply to wet surface evaporation, although such estimates have little physical significance unless accumulated to provide annual totals. It has also been noted in Section 3 that the length of period for the lake evaporation option is restricted to one month. However, there are some applications, such as the real-time water budgets used in forecasting, where daily estimates are required and where Program WREVAP can provide useful results. This is because in hydrological applications it does not matter much whether the daily evapo(transpi)ration is 3 or 6 mm, as long as the accumulated values for five days or more are reliable.

In updating Program WREVAP estimates on a daily basis, it is the lake evaporation option that presents the greatest difficulties. Therefore lake evaporation is discussed in some detail here. The recommended procedure is as follows:

(1) Prepare Record A of File Tape 1 using the characteristics of the lake and leaving PPN blank.

(2) Prepare Record B of File Tape 1 with NN = 1, M = 1, INDEX = 3, LK = 3 and ISUM = 0. The other four fields specify the input data options.

(3) Prepare Record E of File Tape 1 with TD, T, S and HADD being the mean values for the first day of the month, with STRTDY, MONTH and STRTYR describing the first day of the month and with LENGTH = 1.

(4) Prepare Record F of File Tape 2 from the values for the end of the preceding month on Record G of File Tape 3. This defines the required antecedent information for the beginning of the current month. It should be noted that this record can be created only after at least 12 months of the required data have been observed and used as input to CRLE model with LK set equal to 2, followed, optionally, by further updating with LK set equal to 3.

(5) The CRLE model estimate of lake evaporation for the first day is equal to the mean daily evaporation in millimetres per day for a month, with mean climatological inputs and solar declination equal to those of the first day.

(6) In making computations for the second day of the month, it is not necessary to change Records A and B of File Tape 1. Furthermore, Record F of File Tape 2, which provides the required antecedent information at the beginning of the month, remains unchanged throughout the month (the contents of Record G of File Tape 3 are correct only for the last day of the month). Thus the only changes required are in Record E of File Tape 1, where TD, T, S and HADD are set equal to the mean values for the first two days of the month and LENGTH is set equal to 2.

(7) The CRLE model estimate of lake evaporation for the first two days of the month has the same daily mean value as that for a month, with mean climatological inputs and solar declination equal to those of the first two days. The estimated daily evaporation, which is the difference between accumulated evaporation estimate and that for the previous day, has an error that partially compensates for error in the previous estimate. Thus, although percentage errors in the evaporation estimates for individual days are large, the absolute errors due to the use of data for short time periods are not hydrologically significant, and they do not accumulate.

(8) Procedures similar to those set out in steps (6) and (7) should be repeated for each of the remaining days of the month. Near the fifth day the accumulated error associated with the use of short time period data should approach zero, although errors associated with the proration of monthly changes in subsurface heat storage might still be significant. For the last day of the month the input data in Record E of File Tape 1 would be the monthly means, LENGTH would be the number of days in the month, the outputs would be the correctly computed monthly totals with no error associated with the use of short time period data, or with prorating subsurface heat storage changes, and Record G of File Tape 3 would contain the antecedent information needed for Record F of File Tape 2 in continuing with the computation of daily evaporation for the next month.

(9) In continuing the computation into the next month, it is only necessary to read into Record F of File Tape 2 the Record G of File Tape 3 for the previous day (i.e., the last day of the previous month), to repeat step (3), remembering to make the necessary changes in STRTDY, MONTH and STRTYR, and finally to repeat steps (5) to (8) inclusive.

It would not be necessary to start this procedure on the first day of the month. For example, the decision to start daily updating on the twentieth day would require only a single computation of the evaporation for the first 19 days, rather than 19 separate ones.

The procedure described above can be simplified to permit daily updating of areal evapotranspiration or wet surface evaporation estimates. With these options there is no need to use antecedent information so that Record F of File Tape 2, Record G of File Tape 3 and the rigid monthly structure can be dispensed with. Furthermore, the daily estimates would be more reliable because they would not include errors associated with prorating subsurface heat storage changes. This means that the extension of the period length past five days or a week, when errors caused by short period input data become insignificant, is purely a matter of convenience.

There is an alternative procedure for daily updates of areal evapotranspiration or wet surface evaporation estimates. This would involve the use of daily mean input to provide daily estimates, the provisional use of the estimates for a period of five days or a week, and a subsequent proportional correction to make the total for the period agree with the model estimate derived from the mean input for the period. This may provide more realistic daily values than the procedure described in the preceding paragraphs because the error, being prorated, does not include the effects of compensating error. There is no way of proving this possibility, however, and if there were, it is doubtful that the difference would be hydrologically significant. Furthermore, there is the possibility that the accumulated error could become hydrologically significant before being corrected, and there is the obvious nuisance of having to go back and make the corrections. These considerations indicate that it is probably better and certainly more convenient to use the procedure set out in the preceding paragraphs.

7. PROGRAM OPERATION

Program WREVAP is the main program. It reads station specifications, data control specifications, period specifications and input data, and it coordinates the operation of Subroutines INIT, ERRCOD, INIJUL, ORBIT, BDGT 1, TRANLK, BDGT 2, COMPGL, EVANYR and PRTOUT. The main program and the subroutines are listed, with appropriate descriptions and comments, in Appendix II, and their operations and interactions are summarized in Figure 3, the flowchart for the main program.

8. PROGRAM OUTPUT

Subroutine ERRCOD can detect certain obvious errors in the input data or in the station, data control or period specifications and print an appropriate error message. A complete list of the diagnostic error messages is presented in Appendix III. If no such errors are encountered, Subroutine PRTOUT organizes and lists in chronological order, the model outputs and the input data used to calculate them, together with the necessary station and time period identification. Samples of output listings are presented in Appendix IV and are discussed in some detail in Section 8.2. As some of the headings and other information are expressed as symbols that have not been defined in either the text or Appendix V, they are discussed in Section 8.1.

It should be noted that user given input data are normally provided with two decimal accuracy (page 57). However, the input data shown again in the output samples are listed to one decimal accuracy only (page 56). If reproduction of the same results, as shown for example on page 56, is desired, then input data must be in the same decimal accuracy as listed on page 57; otherwise slight differences from the output samples can develop. If evaporation values are required to 1/10 of a millimetre accuracy, then the format statements 321 and 331 of subroutine PRTOUT have to be changed from F5.0 to F5.1 (page 40).

8.1 Output Symbols

Most, but not all, of the output symbols appear on the sample computations shown in Appendix IV. The top line includes the station specifications and provides identification for the model options. Starting from the left of the top line there are

(1) The station name.

(2) PHID, the latitude of the station in decimal degrees.

(3) P, the average atmospheric pressure in millibars; or ALTI, the altitude above sea level in metres, depending on which option has been selected. The former symbol (P) is used generically for both options in the station specifications and the program.

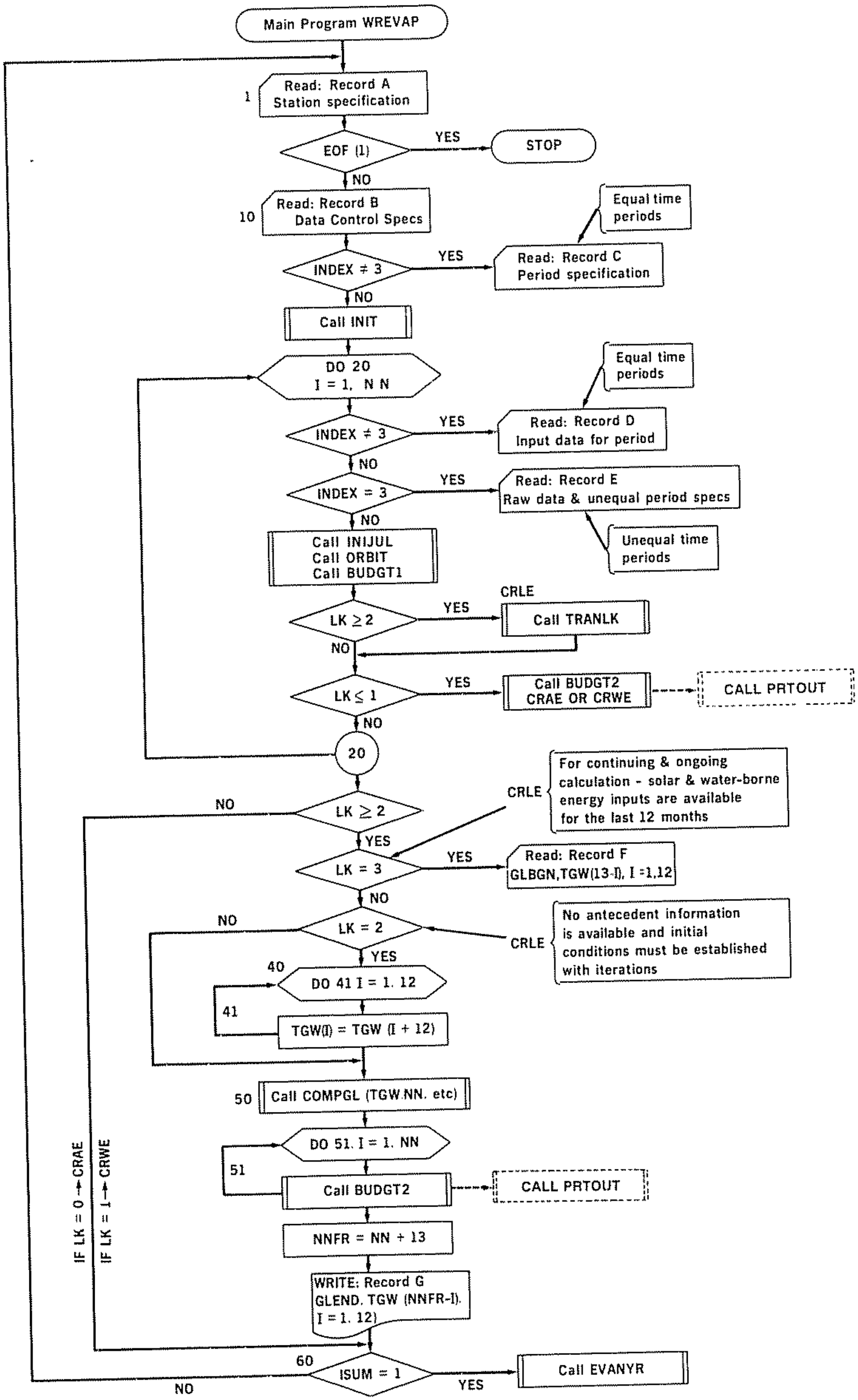

Figure 3. Flowchart of Program WREVAP.

(4) PPN, the average annual precipitation in millimetres per year, when the areal evapotranspiration option has been selected; or DA, the average depth of the lake in metres, when the lake evaporation options have been selected. The space remains blank for the wet surface evaporation option.

(5) SALT, the salinity or total dissolved solids in parts per million. The space remains blank for the areal evapotranspiration option.

(6) NET combines with symbol RAD. directly below to identify the tabulated model estimates, in millimetres of evaporation equivalent, of the net radiation or the net available energy. These estimates correspond to soil-plant surfaces at air temperature, wet surfaces at air temperature or lake surfaces at air temperature, depending on which model option has been selected.

(7) EVAPOTRANSPIRATION identifies the areal evapotranspiration option and combines with the symbols POTENT. and AREAL in the line directly below to provide column headings for the model estimates (in millimetres) of potential evapotranspiration and areal evapotranspiration. WET SURFACE EVAP. identifies the wet surface evaporation option and combines with the symbols PAN-SIZE and LAKE-SIZE in the line directly below to provide column headings for the model estimates (in millimetres) of pan-size wet surface evaporation and lake-size wet surface evaporation. EVAPORATION identifies the lake evaporation options and combines with the symbols POTENT. and LAKE in the line directly below to provide column headings for the model estimates (in millimetres) of potential evaporation and lake evaporation.

(8) The page number.

The second line from the top of the output listing is used to provide column headings for identification of time periods, input data and model estimates. Starting from the left of the second line, these are

(1) YEAR, the year in which the time period begins.

(2) MONTH, the month in which the time period begins.

(3) STARTDAY, the day of the month on which the period begins.

(4) LENGTH, the number of days in the period.

(5) TD, the dewpoint temperature in degrees Celsius; TDF, the dewpoint temperature in degrees Fahrenheit; VD, the vapour pressure in millibars; or RELH, the relative humidity as a ratio, depending on which humidity option is selected. The first of these symbols (TD) is used generically for all four options in the observed data record and the program.

(6) T, the average air temperature in degrees Celsius; or TF, the average air temperature in degrees Fahrenheit, depending on which temperature option is selected. The former symbol (T) is used generically for both options in the observed data record and the program.

(7) S, the ratio of observed to maximum possible sunshine duration; HS, the observed sunshine duration in hours per day; GIL, the incident global radiation in langleys per day; or GIJ, the incident global radiation in megajoules per square metre per day, depending on which insolation option is selected. The first of these symbols (S) is used generically for all four options in the observed data record and in the program.

(8) HADD, the waterborne energy input in watts per square metre. This appears only when data have been entered in field 7 of Record D. Thus the space remains blank for the areal evapotranspiration and wet surface evaporation options and for most lakes with the lake evaporation option.

(9) RAD. combines with the symbol NET in the line immediately above (space 6 of top line) to identify, depending on the model option, the net radiation corresponding to soil-plant surface at air temperature, the net radiation corresponding to wet surface at air temperature or the net available energy corresponding to lake surface at air temperature, all in millimetres of evaporation equivalent.

(10) POTENT. or PAN-SIZE combine with the symbols EVAPOTRANSPIRATION, WET SURFACE EVAP. or EVAPORATION in the line directly above (space 7 of the top line), to identify, depending on the model option, the potential evapotranspiration, pan-size wet surface evaporation or potential evaporation, all in millimetres.

(11) AREAL, LAKE-SIZE or LAKE combine with the symbols EVAPOTRANSPIRATION, WET SURFACE EVAP. or EVAPORATION in the line directly above (space 7 of top line), to identify, depending on the model option, the areal evapotranspiration, the

lake-size wet surface evaporation and the lake evaporation, all in millimetres.

(12) GW(W/M**2) is the solar and waterborne energy input in watts per square metre. This space is blank for the areal evapotranspiration and wet surface evaporation options, and even in the lake evaporation options the data are listed only for the last 12 months of the period. They represent the TGW values in File Tape 3.

The lake evaporation options automatically print two other pieces of information in the line immediately following the input and output listing for the last time period. GLBGN is the available solar and waterborne energy at the beginning of the first time period, and GLEND is the available solar and waterborne energy at the end of the last time period, both in watts per square metre. GLEND is also recorded in File Tape 3.

Subroutine EVANYR is used to produce a table entitled MONTHLY TOTALS AVERAGED OVER NYR YEARS. This requires that ISUM be set equal to 1, that time periods corresponding to months or fractions of months (INDEX = 1 or 2) be selected, and that the total number of time periods be divisible by the number of time periods per year with no remainder. The identifying symbols in the table have been defined previously in this subsection.

8.2 Sample Computations

The use of the CRWE option to compute monthly wet surface evaporation for Pyramid Lake in Nevada, U.S.A., is demonstrated in Appendix IV.1, which includes the output listing for 1935 and 1936, the summary tabulation of MONTHLY TOTALS AVERAGED OVER 2 YEARS and the contents of File Tape 1. In Record B (sixth line, File Tape 1 of Appendix IV.1), NN = 24 time periods, M = 1 time period per month, INDEX = 1 for time periods of a month, LK = 1 for the wet surface evaporation option, ISUM = 1 for production of the summary tabulation, IT = 1 for temperatures and dewpoint temperatures in degrees Fahrenheit, IS = 0 for the use of the ratio of observed to maximum possible sunshine duration as the insolation input, IV = 0 for the use of dewpoint temperature as the humidity input, and IP = 1 for the use of the altitude in metres above sea level as the station altitude input. In Record C (seventh line, File Tape 1 of Appendix IV.1), STRTDY = 1 for the day of the month on which the first period starts, MONTH = 1 for the month (January) during which the first period starts, STRTYR = 1935 for the year during which the first period starts and LENGTH = 1 or any other arbitrarily set integer greater than zero, because when INDEX = 1 or INDEX = 2 the lengths of the time periods are set automatically in the program. In Record D, the dewpoint temperatures, air temperatures and sunshine duration ratios (the first, second and third columns, respectively, File Tape 1, of Appendix IV.1) are monthly means of the observations at Reno, Nevada.

The CRWE model estimates of wet surface evaporation for the two years average 1346 mm/year, which is 71 mm/year, or 5.6% higher than the water budget estimate of evaporation from the lake for the same two years.

The use of the CRLE model to compute monthly lake evaporation for Pyramid Lake without the required antecedent information is demonstrated in Appendix IV.2, which includes the output listing for 1935, the summary tabulation of MONTHLY TOTALS AVERAGED OVER 1 YEARS, the contents of File Tape 1 and the contents of File Tape 3. The contents of Records A, B, C and D of File Tape 1 differ from those for the CRWE sample in Appendix IV.1 only because DA = 61.0 (new entry), NN = 12, LK = 2, and the input data for 1936 are omitted. File Tape 3 contains output data which are presented as GLEND and in the column designated GW(W/M**2) in the output listing.

The very small difference between GLBGN and GLEND for 1935 is of significance because it demonstrates that the effects of antecedent information arbitrarily selected in the program can be substantially removed by computing the monthly evaporation for the first year three times in succession. However, it also points out a potential source of error in the evaporation estimates for the first year when antecedent information is not available, because it is highly unlikely that the amount of subsurface heat storage would be the same at the end as at the beginning of a year. It may also be of interest to note that the CRLE model estimate of the evaporation from Pyramid Lake during 1935 is 1238 mm, which is 38 mm, or 3.0% lower than the 1935 water budget estimates.

The use of the CRLE model to compute monthly lake evaporation for Pyramid Lake when the required antecedent information is available is demonstrated in Appendix IV.3, which includes the output listing for 1936, the summary tabulation of MONTHLY TOTALS AVERAGED OVER 1 YEARS, the contents of File Tapes 1, 2 and 3. The contents of Records A, B, C and D of File Tape 1 differ from those in the sample for 1935 in Appendix IV.2 only because LK = 3, STRTYR = 1936 and the input data for 1936 are used. The contents of File Tape 2 are read from the contents of File Tape 3 for

1935 in Appendix IV.2 with GLBGN set equal to GLEND. File Tape 3 contains output data which are presented as GLEND and in the column designated GW(W/M**2) in the output listing.

The difference between GLBGN and GLEND is of interest because it shows the total evaporation estimated for 1936 with no antecedent information available (LK = 2) would have been 5 mm (4.5885 W-months/m^2) less than the total shown in Appendix IV.3 (LK = 3). It is hoped that this relatively small amount is typical of the error that can be expected during the first year because of the lack of antecedent information. It may also be of interest to note that the CRLE model estimate of the evaporation from Pyramid Lake during 1936 is 1261 mm, which is 12 mm, or 0.9% less than the comparable water budget estimate.

The use of the CRAE option to estimate monthly areal evapotranspiration in the Amazonian rain forest at Manaus, Brazil, is demonstrated in Appendix IV.4, which includes the output listing for a year of long-term monthly mean input data, the summary tabulation of MONTHLY TOTALS AVERAGED OVER 1 YEARS and the contents of File Tape 1. In Record B, NN = 12 time periods, M = 1 time period per month, INDEX = 1 for time periods of a month, LK = 0 for the areal evapotranspiration option, ISUM = 1 for production of the summary tabulation, IT = 0 for temperatures in degrees Celsius, IS = 1 for use of the sunshine duration in hours per day as the insulation input, IV = 1 for use of the vapour pressure in millibars as the humidity input and IP = 1 for use of the altitude in metres above sea level as the station altitude input. In Record C, STRTDY = 1 for the day of the month on which the first period starts, MONTH = 1 for the month (January) during which the first period starts, STRTYR = 9999 (for any value equal to or exceeding 9900 the program prints AVYR) and LENGTH = 31 for the number of days in MONTH (this could be any integer greater than zero, because the period lengths are set internally when INDEX = 1 or INDEX = 2). In Record D, the climatological inputs are the long-term monthly means for Manaus that were published in the *World Survey of Climatology*, Volume 12, page 272.

The CRAE model estimate of areal evapotranspiration at Manaus for an average year is 1564 mm/year, which is 16 mm, or 1% higher than the difference between precipitation and runoff for the nearby 23.5 km^2 Model Basin from February 2, 1980, to February 10, 1981. Furthermore, the use of vapour pressure as the humidity inputs produces model estimates that are somewhat too high, although in the climate of the Amazon, where temperature variations are quite small, the error would not exceed 2 mm/month or 20 mm/year.

The use of the CRAE model to estimate areal evapotranspiration for fractions of a month at Val d'Or, Quebec, is demonstrated in Appendix IV.5, which includes the output listing for 1968, the summary tabulation of MONTHLY TOTALS AVERAGED OVER 1 YEARS and the contents of File Tape 1. In Record B, NN = 60, M = 5 time periods per month, INDEX = 2 for time periods of a fraction of a month, LK = 0 for the areal evapotranspiration option, ISUM = 1 for production of the summary tabulation, IT = 0 for temperatures and dewpoint temperatures in degrees Celsius, IS = 1 for the use of sunshine duration in hours per day as the insolation input, IV = 0 for the use of dewpoint temperature as the humidity input and IP = 0 for the use of average atmospheric pressure in millibars as the station altitude input. In Record C, STRTDY = 1 for the day of the month on which the first period starts, MONTH = 1 for the month (January) during which the first period starts, STRTYR = 1968 for the year during which the first period starts and LENGTH = 31 for the number of days in MONTH (as noted previously this could be any integer greater than zero, because the period lengths are set by the program when INDEX = 1 or INDEX = 2). In Record D, the climatological inputs are period means of the observations at Val d'Or during 1968. It should be noted that the CRAE model estimates are based on the unrounded inputs in Record D and not on the rounded inputs shown on the output listing.

The CRAE model estimate of areal evapotranspiration at Val d'Or during 1968 is 419 mm. Val d'Or is in the basin of the Harricanaw River (drainage area of 3680 km^2), where the difference between the precipitation and runoff during 1968 was 427 mm.

The use of the CRAE model to estimate weekly areal evapotranspiration at Simcoe, Ontario, is demonstrated in Appendix IV.6, which includes the output listing for 52 weeks in 1968 and the contents of File Tape 1. In Record B, NN = 52, M = 1 (for the equal time period or unequal time period options this is not used), INDEX = 4 for equal time periods, LK = 0 for areal evapotranspiration estimates, ISUM = 0 because the summary tabulation cannot be produced, IT = 0 for temperatures and dewpoint temperatures in degrees Celsius, IS = 1 for the use of the sunshine duration in hours per day as the insolation input option, IV = 0 for the use of dewpoint temperature as the humidity input option and IP = 1 for the use of altitude in metres above sea level as the station altitude option. In Record C, STRTDY = 1 for the day of the month on which the first period starts, MONTH = 1 for the month (January) during which the first period starts, STRTYR = 1968 for the year in which the first period starts, and LENGTH = 7 for the number of days in each time period (this is the first example for which this field has had any meaning).

In Record D, the climatological inputs are weekly means of the observations at Simcoe during 1968.

The CRAE model estimate of areal evapotranspiration at Simcoe during 52 weeks in 1968 is 653 mm. Simcoe is near to the 591 km^2 drainage area of Big Creek, where the precipitation less runoff for 1968 was 613 mm.

9. CONCLUSIONS

Program WREVAP is based on the complementary relationship between areal and potential evapotranspiration. It comprises the only available technique that can use routine climatological observations to provide reliable independent estimates of areal evapotranspiration, wet surface evaporation or lake evaporation anywhere in the world with no need for locally calibrated coefficients. The conceptual and empirical foundations for the complementary relationship, its superiority to other hydrometeorological concepts, its use in the formulation of the CRAE, CRWE and CRLE models and evaluations of the reality of the models using comparable water budget estimates from a wide range of environments are documented elsewhere (Morton, 1983a,b, in press). It has also been demonstrated (Morton, 1983a) how independent estimates of evaporation and transpiration, which have been until now the largest and most intractable unknown in the hydrological cycle, can do much to overcome the current stagnation in the science and practice of hydrology by permitting solutions to the water balance equation, by providing a realistic basis for hydrological forecasts, by detecting and monitoring the effects of land-use changes, by detecting the development of errors in hydrometeorological records and by other more obvious applications. Program WREVAP expedites the exploitation of these potentialities by the flexibility of its input, time period and output requirements.

10. ACKNOWLEDGMENTS

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CRAE Model

Station Altitude (meters)
relative humidity (ratio)
temperature (°F or °C)
obs global radiation ($MJ/m^2/day$)
Waterborne Energy Units (W/m^2)

Record A   Station characteristics

1) SITE - station name
2) PhiD - latitude of station in dec. deg
3) P - Altitude of station (m)
4) PPN - Avg Annual precip (mm)
5) DA - Avg Lake depth (m) - blank for Areal Et
6) SALT - Salinity (ppm) - blank for Areal Et

Record B   data control specifications

1) NN - total number of time periods
2) M - time periods or fractions of month
3) INDEX - control parameter for Periods/month (3 ?)
4) LK - Model Selection (CRAE ⇒ LK = 0
5) ISUM - summary tabulation option (CRAE ⇒ Annual 1-2yr ISUM = 0
6) IT - Temperature Units °F ⇒ IT = 1 ; °C ⇒ IT = 0
7) IS - Insolation units IS when radiation units Lang = 2
   " " " $MJ/m^2/day$ = 3
8) IV - humidity inputs vapor pressure units mbars ⇒ IV = 1
   relative humidity units ⇒ IV = 2
   ⇒ significant errors occur in CRAE when using rel. humidity or vapor pressure options -
9) IP - Station Altitude control parameter Units of Alt (m) ⇒ IP =

RECORD C   Date and period length

1) STRTDY - start day of month
2) MONTH - month number which STRTDY starts
3) STRTYR - calender year
4) leuth -

RECORD D   USED when INDEX = 1, 2, 4

1) TD
2) C1
3) T
4) C2
5) S
6) C3
7) HADD

RECORD E   USED when INDEX = 3

RECORD F   USED FOR LAKE Et

RECORD G   USED when RECORD E is being used.

1

LOGICAL INPUT ERROR DIAGNOSTIC

ERROR NUMBER	DIAGNOSTIC
1	STARTING YEAR OF THE PERIOD(STRTYR) SHOULD BE GREATER THAN 0
2	STARTING MONTH OF THE PERIOD(MONTH) SHOULD CORRESPOND TO ONE OF THE MONTHS OF THE CALENDAR YEAR (E.G. 1 FOR JANUARY AND 12 FOR DECEMBER)
3	STARTING DAY OF THE PERIOD(STRTDY) SHOULD BE ONE OF THE DAYS OF THE MONTH(MONTH)
4	LENGTH OF THE PERIOD(LENGTH) SHOULD BE GREATER OR EQUAL TO 1
5	TD VALUE SHOULD BE GREATER THAN 0 WHENEVER THE TD VALUE REPRESENTS THE VAPOUR PRESSURE AT DEW POINT OR RELATIVE HUMIDITY.
6	S VALUE SHOULD BE GREATER THAN OR EQUAL TO 0.
10	INDEX VALUE SHOULD BE EQUAL TO 1, 2, 3 OR 4 (SEE INDEX DESCRIPTION)
11	THE CONTROL PARAMETER IS SHOULD BE EQUAL TO 0, 1, 2 OR 3 (SEE IS DESCRIPTION)
12	THE CONTROL PARAMETER IT SHOULD BE EQUAL TO 0 OR 1 (SEE IT DESCRIPTION)
13	THE CONTROL PARAMETER IV SHOULD BE EQUAL TO 0, 1 OR 2 (SEE IV DESCRTHE CONTROL PARAMETER IPTION)
14	THE CONTROL PARAMETER IP SHOULD BE EQUAL TO 0 OR 1 (SEE IP DESCRIPTION)
15	THE CONTROL PARAMETER LK SHOULD BE EQUAL TO 0, 1 ,2 OR 3
17	THE TOTAL NUMBER OF PERIODS(NN) SHOULD BE GREATER THAN OR EQUAL TO 1, AND WHEN LAKE EVAPORATION ESTIMATES ARE REQUIRED THE TOTAL NUMBER OF PERIODS SHOULD LESS THAN OR EQUAL TO 120. HOWEVER THE LATTER RESTRICTION CAN BE RELAXED IF THE TABLES DIMENSIONED TO 120 ARE CHANGED TO THE TOTAL NUMBER OF PERIODS, THE TABLE DIMENSIONED TO 132 IS CHANGED TO THE TOTAL NUMBER OF PERIOD PLUS 12 AND THE CHARACTER STRING 120 IN THE FORTRAN STATEMENT CALL ERRCOD(18) IS CHANGED TO THE TOTAL NUMBER OF PERIODS
18	THE NUMBER OF PERIODS PER MONTH(M) SHOULD ALWAYS BE GREATER OR EQUAL 1 AND SHOULD ALWAYS BE EQUAL TO 1 WHEN INDEX EQUAL 1, 3 OR 4
19	WHEN ISUM EQUAL 1 (I.E. WHEN MONTHLY TOTALS AVERAGED OVER NYR YEARS ARE REQUIRED) INDEX SHOULD BE EQUAL TO 1 OR 2 (DENOTING MONTHLY STRUCTURE) AND THE TOTAL NUMBER OF PERIODS SHOULD BE DIVISIBLE BY NUMBER OF PERIODS PER YEAR WITH NO REMAINDER
20	VALUE OF DA SHOULD BE GREATER THAN OR EQUAL TO 0.
21	VALUE OF SALT SHOULD BE GREATER THAN OR EQUAL TO 0.
22	VALUE OF PPN SHOULD BE GREATER THAN OR EQUAL TO 0.
23	VALUE OF P SHOULD BE GREATER THAN OR EQUAL TO 0.

OUTPUT SAMPLES

PYRAMID LAKE PHID= 40.00 ALTI= 1160.0 DA= 61.0 SALT= 3500.00

YEAR	MONTH	STARTDAY	LENGTH	TDF	TF	S	NET RAD.	WET SURFACE EVAP. PAN-SIZE	WET SURFACE EVAP. LAKE-SIZE
1935	JAN	1	31	25.0	33.8	.570	15.	30.	24.
1935	FEB	1	28	26.0	39.6	.580	42.	63.	39.
1935	MAR	1	31	23.0	37.9	.760	127.	113.	83.
1935	APR	1	30	29.0	47.7	.710	165.	165.	119.
1935	MAY	1	31	31.0	55.6	.790	224.	243.	172.
1935	JUNE	1	30	34.0	67.1	.960	251.	326.	216.
1935	JULY	1	31	37.0	69.4	.920	235.	331.	211.
1935	AUG	1	31	37.0	72.2	.970	206.	335.	196.
1935	SEPT	1	30	33.0	67.1	.940	148.	269.	143.
1935	OCT	1	31	28.0	49.9	.870	95.	149.	81.
1935	NOV	1	30	23.0	35.3	.680	33.	50.	32.
1935	DEC	1	31	23.0	33.8	.570	5.	25.	20.
1936	JAN	1	31	25.0	38.0	.510	8.	34.	23.
1936	FEB	1	29	26.0	36.0	.570	46.	57.	38.
1936	MAR	1	31	25.0	44.8	.780	126.	144.	92.
1936	APR	1	30	29.0	52.6	.850	189.	207.	142.
1936	MAY	1	31	31.0	57.6	.890	245.	268.	191.
1936	JUNE	1	30	38.0	64.6	.770	218.	275.	186.
1936	JULY	1	31	41.0	74.3	.890	226.	349.	215.
1936	AUG	1	31	38.0	71.4	.880	192.	316.	184.
1936	SEPT	1	30	32.0	61.6	.920	156.	239.	138.
1936	OCT	1	31	30.0	53.9	.840	89.	155.	83.
1936	NOV	1	30	21.0	41.8	.900	45.	78.	44.
1936	DEC	1	31	22.0	33.3	.560	4.	25.	20.

IV.1 PYRAMID LAKE – CRWE OPTION

PYRAMID LAKE

MONTHLY TOTALS AVERAGED OVER 2 YEARS

MONTH	NET RAD.	WET SURFACE EVAP. PAN-SIZE	LAKE-SIZE
JAN	11.5	32.0	23.5
FEB	44.0	60.0	38.5
MAR	126.5	128.5	87.5
APR	177.0	186.0	130.5
MAY	234.5	255.5	181.5
JUNE	234.5	300.5	201.0
JULY	230.5	340.0	213.0
AUG	199.0	325.5	190.0
SEPT	152.0	254.0	140.5
OCT	92.0	152.0	82.0
NOV	39.0	64.0	38.0
DEC	4.5	25.0	20.0
TOTAL OF MONTHLY AVERAGES	1545.0	2123.0	1346.0

```
                 FILE TAPE1 USED AS INPUT FOR CRWE MODEL ESTIMATES OF
            -----WET SURFACE EVAPORATION FOR PYRAMID LAKE--------------
     COLUMN 00000000011111111112222222222333333333344444444445555555555
     NUMBER 12345678901234567890123456789012345678901234567890123456789
              PYRAMID LAKE        40.00  1160.00    0. 61.0      3500.
             2411111001
             1 11935 1
              25.0        33.8        .570
              26.0        39.6        .580
              23.0        37.9        .760
              29.0        47.7        .710
              31.0        55.6        .790
              34.0        67.1        .960
              37.0        69.4        .920
              37.0        72.2        .970
              33.0        67.1        .940
              28.0        49.9        .870
              23.0        35.3        .680
              23.0        33.8        .570
              25.0        38.0        .510
              26.0        36.0        .570
              25.0        44.8        .780
              29.0        52.6        .850
              31.0        57.6        .890
              38.0        64.6        .770
              41.0        74.3        .890
              38.0        71.4        .880
              32.0        61.6        .920
              30.0        53.9        .840
              21.0        41.8        .900
              22.0        33.3        .560
```

IV.2 PYRAMID LAKE — CRLE OPTION WITHOUT ANTECEDENT INFORMATION

PYRAMID LAKE PHID= 40.00 ALTI= 1160.0 DA= 61.0 SALT= 3500.00

YEAR	MONTH	STARTDAY	LENGTH	TDF	TF	S	HADD	NET RAD.	EVAPORATION POTENT.	EVAPORATION LAKE	GW(W/M*M)
1935	JAN	1	31	25.0	33.8	.570	0.00	168.	103.	100.	85.92
1935	FEB	1	28	26.0	39.6	.580	0.00	107.	98.	72.	119.21
1935	MAR	1	31	23.0	37.9	.760	0.00	73.	90.	55.	198.91
1935	APR	1	30	29.0	47.7	.710	0.00	47.	88.	49.	241.37
1935	MAY	1	31	31.0	55.6	.790	0.00	46.	109.	58.	296.97
1935	JUNE	1	30	34.0	67.1	.960	0.00	60.	160.	81.	339.10
1935	JULY	1	31	37.0	69.4	.920	0.00	100.	223.	114.	316.20
1935	AUG	1	31	37.0	72.2	.970	0.00	141.	293.	149.	291.80
1935	SEPT	1	30	33.0	67.1	.940	0.00	173.	283.	160.	241.35
1935	OCT	1	31	28.0	49.9	.870	0.00	209.	206.	151.	177.66
1935	NOV	1	30	23.0	35.3	.680	0.00	214.	136.	128.	109.21
1935	DEC	1	31	23.0	33.8	.570	0.00	206.	125.	121.	77.58

**** GLBGN = 248.2737 **** GLEND = 248.2777

MONTHLY TOTALS AVERAGED OVER 1 YEARS

MONTH	NET RAD.	EVAPORATION POTENT.	EVAPORATION LAKE
JAN	168.0	103.0	100.0
FEB	107.0	98.0	72.0
MAR	73.0	90.0	55.0
APR	47.0	88.0	49.0
MAY	46.0	109.0	58.0
JUNE	60.0	160.0	81.0
JULY	100.0	223.0	114.0
AUG	141.0	293.0	149.0
SEPT	173.0	283.0	160.0
OCT	209.0	206.0	151.0
NOV	214.0	136.0	128.0
DEC	206.0	125.0	121.0
TOTAL OF MONTHLY AVERAGES	1544.0	1914.0	1238.0

```
        FILE TAPE1 USED AS INPUT FOR CRLE MODEL ESTIMATES OF
   _____LAKE_EVAPORATION_FOR_PYRAMID_LAKE____________________
COLUMN 00000000011111111112222222222333333333344444444445555555555
NUMBER 12345678901234567890123456789012345678901234567890123456789
         PYRAMID LAKE         40.00  1160.00    0. 61.0      3500.
        1211211001
        1 11935 1
          25.0        33.8         .570
          26.0        39.6         .580
          23.0        37.9         .760
          29.0        47.7         .710
          31.0        55.6         .790
          34.0        67.1         .960
          37.0        69.4         .920
          37.0        72.2         .970
          33.0        67.1         .940
          28.0        49.9         .870
          23.0        35.3         .680
          23.0        33.8         .570

        FILE TAPE3 RESULTING FROM THE CRLE MODEL ESTIMATES OF
   _____LAKE_EVAPORATION_FOR_PYRAMID_LAKE____________________
COLUMN 00000000011111111112222222222333333333344444444445555555555
NUMBER 12345678901234567890123456789012345678901234567890123456789
        248.2777
         77.5783
        109.2100
        177.6567
        241.3504
        291.8038
        316.1976
        339.1048
        296.9652
        241.3709
        198.9111
        119.2077
         85.9173
```

IV.3 PYRAMID LAKE – CRLE OPTION WITH ANTECEDENT INFORMATION

PYRAMID LAKE		PHID= 40.00	ALTI= 1160.0	DA= 61.0	SALT=	3500.00	NET	EVAPORATION		
YEAR	MONTH	STARTDAY	LENGTH	TDF	TF	S	HADD	RAD.	POTENT.	LAKE	GW(W/M*M)
1936	JAN	1	31	25.0	38.0	.510	0.00	169.	126.	106.	79.92
1936	FEB	1	29	26.0	36.0	.570	0.00	114.	85.	72.	118.36
1936	MAR	1	31	25.0	44.8	.780	0.00	67.	106.	59.	201.86
1936	APR	1	30	29.0	52.6	.850	0.00	39.	93.	49.	270.43
1936	MAY	1	31	31.0	57.6	.890	0.00	41.	110.	57.	319.26
1936	JUNE	1	30	38.0	64.6	.770	0.00	71.	162.	84.	299.59
1936	JULY	1	31	41.0	74.3	.890	0.00	111.	256.	131.	307.24
1936	AUG	1	31	38.0	71.4	.880	0.00	151.	292.	155.	276.19
1936	SEPT	1	30	32.0	61.6	.920	0.00	175.	249.	150.	245.37
1936	OCT	1	31	30.0	53.9	.840	0.00	199.	221.	153.	173.54
1936	NOV	1	30	21.0	41.8	.900	0.00	196.	168.	128.	130.21
1936	DEC	1	31	22.0	33.3	.560	0.00	200.	123.	117.	76.86

**** GLBGN = 248.2777 **** GLEND = 243.6892

MONTHLY TOTALS AVERAGED OVER 1 YEARS

	NET	EVAPORATION	
MONTH	RAD.	POTENT.	LAKE
JAN	169.0	126.0	106.0
FEB	114.0	85.0	72.0
MAR	67.0	106.0	59.0
APR	39.0	93.0	49.0
MAY	41.0	110.0	57.0
JUNE	71.0	162.0	84.0
JULY	111.0	256.0	131.0
AUG	151.0	292.0	155.0
SEPT	175.0	249.0	150.0
OCT	199.0	221.0	153.0
NOV	196.0	168.0	128.0
DEC	200.0	123.0	117.0
TOTAL OF MONTHLY AVERAGES	1533.0	1991.0	1261.0

```
                FILE TAPE1 USED AS INPUT FOR CRLE MODEL ESTIMATES OF
            -----LAKE EVAPORATION FOR PYRAMID LAKE--------------------
COLUMN       000000000111111111122222222223333333333444444444455555555555
NUMBER      _1234567890123456789012345678901234567890123456789012345678 9
               PYRAMID LAKE           40.00  1160.00    0. 61.0      3500.
             1211311001
             1 11936 1
               25.0       38.0        .510
               26.0       36.0        .570
               25.0       44.8        .780
               29.0       52.6        .850
               31.0       57.6        .890
               38.0       64.6        .770
               41.0       74.3        .890
               38.0       71.4        .880
               32.0       61.6        .920
               30.0       53.9        .840
               21.0       41.8        .900
               22.0       33.3        .560
```

```
                FILE TAPE2 USED AS INPUT FOR CRLE MODEL ESTIMATES OF
            -----PYRAMID LAKE EVAPORATION---------------------------
COLUMN       000000000111111111122222222223333333333444444444455555555555
NUMBER      _1234567890123456789012345678901234567890123456789012345678 9
             248.2777
              77.5783
             109.2100
             177.6567
             241.3504
             291.8038
             316.1976
             339.1048
             296.9652
             241.3709
             198.9111
             119.2077
              85.9173
```

```
                FILE TAPE3 RESULTING FROM THE CRLE MODEL ESTIMATES OF
            -----LAKE EVAPORATION FOR PYRAMID LAKE--------------------
COLUMN       000000000111111111122222222223333333333444444444455555555555
NUMBER      _1234567890123456789012345678901234567890123456789012345678 9
             243.6892
              76.8592
             130.2077
             173.5429
             245.3713
             276.1851
             307.2438
             299.5899
             319.2640
             270.4344
             201.8553
             118.3553
              79.9220
```

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
A	AVERAGE ALBEDO	
ACOM	COSINE OF OMEGA	
ACOMA	COSINE OF OMEGAA	
AK	ABSOLUTE AVERAGE AIR TEMPERATURE	DEG.K
ALPHA(J)	CONSTANT IN COMPUTATION OF VAPOUR PRESSURE	
ARAT	WEIGHTING FACTOR FOR THE EFFECT OF SNOW ON ALBEDO	
ATM	WEIGHTING FACTOR FOR THE EFFECT OF CLOUDS ON ATMOSPHERIC RADIATION	
AZ	CLEAR SKY ALBEDO IF SUN WERE AT ZENITH	
AZZ	SNOW-FREE, CLEAR SKY ALBEDO IF SUN WERE AT ZENITH	
AZZZ	INTERMEDIATE STEP IN COMPUTATION OF AZZ	
A0	CLEAR SKY ALBEDO	
B	NET LONG WAVE RADIATION LOSS WITH SURFACE AT T	W/M**2
BETA(J)	CONSTANT IN COMPUTATION OF VAPOUR PRESSURE	DEG.C
CONST1	CONSTANT USED IN CALCULATING ETW	W/M**2
CONST2	CONSTANT USED IN CALCULATING ETW	
CONV	CONSTANT FOR CONVERSION FROM DEGREES TO RADIANS	RAD/DEG.
COSZ	COSINE OF THE AVERAGE SOLAR ZENITH DISTANCE	
CZENA	COSINE OF NOON SOLAR ZENITH DISTANCE	
CZENAA	COSINE OF NOON SOLAR ZENITH DISTANCE PLUS 0.005	
C1, C2, C3	ALPHA-NUMERIC VALUE. BLANK INDICATES AN ACTUAL OBSERVATION, AND "E" AN ESTIMATED VALUE	
DA	AVERAGE DEPTH OF THE LAKE	M
DAY	FIRST DAY OF THE PERIOD AS A CALENDAR DAY	
DELP	SLOPE OF THE SATURATION VAPOUR PRESSURE CURVE AT TP	MB/DEG.C
DELTA	SLOPE OF THE SATURATION VAPOUR PRESSURE CURVE AT T	MB/DEG.C

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
DUST	TURBIDITY COEFFICIENT	
DUSTT	INTERMEDIATE STEP IN CALCULATION OF TAUT	
EE	FTZ(J) * (V - VD)	W/M**2
ET	POWER EQUIVALENT OF AREAL EVAPOTRANSPIRATION, LAKE-SIZE WET SURFACE EVAPORATION OR LAKE EVAPORATION	W/M**2
ETMM	ET IN EVAPORATION UNITS	MM
ETNYR	SUM OF MONTHLY VALUES OF ETMM	MM
ETP	POWER EQUIVALENT OF POTENTIAL EVAPOTRANSPIRATION, PAN-SIZE WET SURFACE EVAPORATION OR POTENTIAL EVAPORATION	W/M**2
ETPMM	ETP IN EVAPORATION UNITS	MM
ETPNYR	SUM OF MONTHLY VALUES OF ETPMM	MM
ETW	POWER EQUIVALENT OF WET ENVIRONMENT AREAL EVAPOTRANSPIRATION, LAKE-SIZE WET SURFACE EVAPORATION OR LAKE EVAPORATION	W/M**2
FRACT	FRACTIONAL COMPONENT OF DELAY TIME	MONTH
FT	VAPOUR TRANSFER COEFFICIENT	W/M**2/MB
FTZ(J)	VAPOUR TRANSFER COEFFICIENT * STABILITY FACTOR	W/M**2/MB
FZ	COEFFICIENT USED IN COMPUTING FTZ(J)	W/M**2/MB
G	INCIDENT GLOBAL RADIATION	W/M**2
GAMMA(J)	SENSIBLE HEAT TRANSFER COEFFICIENT	MB/DEG.C
GE	EXTRA-ATMOSPHERIC GLOBAL RADIATION	W/M**2
GL	IF LK = 0 OR LK = 1, GL = ABSORBED GLOBAL RADIATIONS(GW) IF LK = 2 OR LK = 3, GL = AVAILABLE SOLAR & WATER-BORNE ENERGY	W/M**2
GLB	GL AT THE BEGINNING OF THE PRESENT MONTH	W/M**2
GLBGN	GL AT THE BEGINNING OF THE FIRST PERIOD	W/M**2
GLE	GL AT THE END OF THE PRESENT MONTH	W/M**2
GLEND	GL AT THE END OF THE LAST PERIOD	W/M**2

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
GW	IF LK = 0 OR LK = 1, GW = ABSORBED GLOBAL RADIATION IF LK = 2 OR LK = 3, GW = SOLAR & WATER-BORNE ENERGY INPUT	W/M**2
GWT	DELAYED SOLAR & WATER-BORNE ENERGY	W/M**2
GO	CLEAR SKY GLOBAL RADIATION	W/M**2
HADD	WATER-BORNE ENERGY INPUT TO LAKE (CAN BE IGNORED IF HADD IS ZERO)	W/M**2
I	SUBSCRIPT	
II	SUBSCRIPT	
INDEX	IF INDEX = 1, MONTHLY STRUCTURE IS USED IF INDEX = 2, MONTHLY STRUCTURE WITH M PERIODS PER MONTH IS USED IF INDEX = 3, UNEQUAL TIME PERIOD STRUCTURE IS USED (I.E. 5 DAY, 16 DAY, 9 DAY,ETC...) IF INDEX = 4, EQUAL TIME PERIOD STRUCTURE IS USED (I.E. WEEKLY) *NOTE WHEN LK > 1 INDEX MUST BE EQUAL TO 1	
INTE	INTEGER VALUE OF THE DELAY TIME	MONTH
INT1	INTEGER VALUE OF THE DELAY TIME PLUS 1	MONTH
IP	CONTROL STATION PARAMETER FOR STATION ALTITUDE IF IP = 0, P IS THE AVERAGE ATMOSPHERIC PRESSURE AT STATION IF IP = 1, P IS THE ALTITUDE OF STATION ABOVE MEAN SEA LEVEL	 MB M
IS	CONTROL PARAMETER FOR INSOLATION DATA. IF IS = 0, S IS THE SUNSHINE DURATION RATIO IF IS = 1, S IS THE SUNSHINE DURATION IF IS = 2, S IS THE INCIDENT GLOBAL RADIATION IF IS = 3, S IS THE INCIDENT GLOBAL RADIATION	 HOUR/DAY LY/DAY MJ/M**2/DAY
ISUM	CONTROL PARAMETER FOR STATION SUMMARY. IF ISUM = 0, TABULATION OF MONTHLY TOTALS AVERAGED OVER NYR YEARS IS NOT LISTED IF ISUM = 1, TABULATION OF MONTHLY TOTALS AVERAGED OVER NYR YEAR IS LISTED (NYR MUST BE AN INTEGER)	
IT	CONTROL PARAMETER FOR TEMPERATURE DATA. IF IT = 0, T IS AIR TEMPERATURE IN CELSIUS IF IT = 1, T IS AIR TEMPERATURE IN FAHRENHEIT	 DEG.C DEG.F
IV	CONTROL PARAMETER FOR HUMIDITY DATA. IF IV = 0 AND IT = 0, TD IS THE DEW POINT IF IV = 0 AND IT = 1, TD IS DEW POINT IF IV = 1, TD IS VAPOUR PRESSSURE AT THE DEW POINT IF IV = 2, TD IS RELATIVE HUMIDITY	 DEG.C DEG.F MB RATIO

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
I1	MONTH THAT IS INT1 MONTHS BEFORE THE PRESENT MONTH IN THE TGW TABLE	MONTH
J	INDEX FOR THE SELECTION OF CONSTANTS THAT DEPEND ON WHETHER THE TEMPERATURE IS ABOVE, AT OR BELOW FREEZING J = 1, IF T IS GREATER THAN OR EQUAL TO 0 C J = 2, IF T IS LESS THAN 0 C	
JULBP	BEGINNING OF THE PERIOD AS A JULIAN DAY	DAY
JULDAY	REAL VALUE OF JULIAN PLUS REAJUL (SEE DEFINITIONS BELOW)	DAY
JULEND	LAST DAY OF THE PERIOD AS A JULIAN DAY	DAY
JULIAN	COUNTER FOR JULIAN DAY	DAY
K	STORAGE ROUTING CONSTANT	MONTH
LAMDA	HEAT TRANSFER COEFFICIENT	MB/DEG.C
LENGTH	LENGTH OF THE PERIOD	DAY
LIMITL	NUMBER OF LINES PRINTED PER PAGE	LINES/PAGE
LK	CONTROL PARAMETER FOR SELECTION OF MODEL OPTION IF LK = 0, AREAL EVAPOTRANSPIRATION(CRAE) OPTION IS SELECTED IF LK = 1, WET SURFACE EVAPORATION(CRWE) OPTION IS SELECTED IF LK = 2, LAKE EVAPORATION(CRLE) OPTION WITH NO PREVIOUS GW INPUT IS SELECTED IF LK = 3, LAKE EVAPORATION(CRLE) OPTION WITH PREVIOUS GW INPUT IS SELECTED	
LNX	USED AS ARGUMENT IN CALCULATION OF TAUT	
LNY	USED AS ARGUMENT IN CALCULATION OF TAUA	
LT	DELAY TIME	MONTH
LTHEAT	LATENT HEAT OF VAPORIZATION(OR SUBLIMATION)	W-DAY/MM
M	NUMBER OF TIME PERIODS PER MONTH IN A MONTHLY STRUCTURE. IF INDEX.NE.2 THEN M = 1	
MM	NUMBER OF ITERATIONS NEEDED TO COMPUTE TGL (USED ONLY FOR LAKE EVAPORATION) IF LK = 2, THEN MM = 3 IF LK = 3, THEN MM = 1	
MON	TABLE FOR THE NAMES OF THE MONTHS	

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
MONTH	NUMBER FOR MONTH DURING WHICH THE PERIOD BEGINS.	MONTH
MSD	MAXIMUM POSSIBLE SUNSHINE DURATION	HOUR/DAY
N	TABLE FOR THE LENGTHS OF THE MONTHS	DAY
NETA	RADIUS VECTOR OF THE EARTH'S ORBIT AROUND THE SUN	
NINPUT	COUNTER FOR RAW DATA INPUT	
NN	TOTAL NUMBER OF TIME PERIODS	
NNFR	COUNTER USED ALSO AS A SUBSCRIPT	
NNTO	COUNTER USED ALSO AS A SUBSCRIPT	
NOLINE	LINE COUNTER FOR PAGE PRINTOUT	
NOPAGE	PAGE COUNTER FOR STATION PRINTOUT	
NTIME	COUNTER FOR PERIODS IN A MONTH	
NYR	NUMBER OF YEARS OF DATA	
OMEGA	HALF THE ANGLE THE EARTH ROTATES BETWEEN THEORETICAL SUNRISE AND THEORETICAL SUNSET	RADIANS
OMEGAA	HALF THE ANGLE THE EARTH ROTATES BETWEEN APPARENT SUNRISE AND APPARENT SUNSET	RADIANS
ORB1	INTERMEDIATE STEP IN CALCULATION OF ORB2	
ORB2	INTERMEDIATE STEP IN CALCULATION OF THETA AND NETA	
P	SEE CONTROL PARAMETER IP	
PHI	LATITUDE	RADIANS
PHID	LATITUDE IN DECIMAL DEGREES	DEGREES
PI	CONSTANT = 3.141592654	
PPN	AVERAGE ANNUAL PRECIPITATION	MM/YR
PW	USED TO KEEP THE ORIGINAL VALUE OF P FOR PRINTOUT	
REAJUL	ADJUSTMENT TO THE INTEGER VALUE OF THE JULIAN DAY IF MONTH = 1 OR 2, THEN REAJUL = 0.0 IF MONTH > 2 AND IT IS A LEAP YEAR, THEN REAJUL = -0.5 IF MONTH > 2 AND IT IS NOT A LEAP YEAR, THEN REAJUL = 0.5	

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
REMAIN	NUMBER OF DAYS IN LAST PERIOD OF MONTH (USED ONLY WHEN INDEX = 2)	DAY
RHO	PROPORTIONAL INCREASE IN ATMOSPHERIC RADIATION DUE TO CLOUDS	
RT	NET RADIATION CORRESPONDING TO SOIL-PLANT SURFACES AT T, NET RADIATION CORRESPONDING TO WET SURFACE AT T OR NET AVAILABLE ENERGY CORRESPONDING TO LAKE SURFACE AT T	W/M**2
RTC	RT CONSTRAINED FOR USE IN ZETA ESTIMATES	W/M**2
RTMM	RT IN EVAPORATION UNITS	MM
RTNYR	SUMS OF MONTHLY VALUES OF RTMM	MM
RTP	NET RADIATION CORRESPONDING TO SOIL-PLANT SURFACES AT TP, NET RADIATION CORRESPONDING TO TP OR NET AVAILABLE ENERGY CORRESPONDING TO TP	W/M**2
S	SEE CONTROL PARAMETER IS	
SALT	TOTAL DISSOLVED SOLIDS OR SALINITY	PPM
SB	SURFACE EMISSIVITY * STEFAN-BOLTZMAN CONSTANT SB = 5.22/10**8 IF LK = 0 SB = 5.5 /10**8 IF LK > 0	W/M**2/K**4
SITE	STATION NAME	
SLT	SOFT WATER DELAY TIME	MONTH
STRTDY	STARTING DAY OF THE CURRENT PERIOD	DAY
STRTMN	STARTING MONTH OF THE CURRENT PERIOD	MONTH
STRTYR	STARTING YEAR OF THE CURRENT PERIOD. FOR ANY INPUT VALUE EQUAL TO OR EXCEEDING 9900 THE PROGRAM PRINTS AVYR FOR AVERAGE YEAR	YEAR
SW	USED TO KEEP ORIGINAL VALUE OF S FOR PRINTOUT	
T	AVERAGE AIR TEMPERATURE(SEE OPTION IT)	DEG.C OR DEG.F
TAUA	PART OF TAUT THAT IS RESULT OF ABSORPTION	
TAUT	TRANSMITTANCY OF CLEAR SKIES TO DIRECT BEAM SOLAR RADIATION	
TC1,TC2,TC3	TABLES OF C1, C2,C3	
TD	SEE CONTROL PARAMETER IV	DAY
	TABLE OF VARIABLE DAY	

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
TDEL	CORRECTION FOR TP IN THE ITERATION PROCESS	DEG.C
TDW	USED TO KEEP ORIGINAL VALUE OF TD FOR PRINTOUT	
TETM	MONTHLY TOTAL OF ETMM FOR STATION SUMMARY	MM
TETPM	MONTHLY TOTAL OF ETPMM FOR STATION SUMMARY	MM
TGL	TABLE OF VARIABLE GL	W/M**2
TGW	GW VALUES WITH SUBSCRIPT OF 13 FOR FIRST MONTH, WITH VALUES SUBSCRIPTED FROM 1 TO 12 FOR THE PRECEDING YEAR, FROM 13 TO 24 FOR THE FIRST YEAR AND 25 TO NN + 12 FOR ANY SUBSEQUENT YEARS. IF VALUES FOR PRECEDING YEAR ARE NOT AVAILABLE, THE VALUES FOR THE STARTING YEAR ARE USED TWICE WITH SUBSCRIPTS FROM 1 TO 12 AND 13 TO 24	W/M**2
THADD	TABLE OF VARIABLE HADD	
THETA	DECLINATION OF SUN	RADIANS
TJ	TABLE OF VARIABLE J	
TLENGT	TABLE OF VARIABLE LENGTH	DAY
TMONTH	TABLE OF VARIABLE MONTH	MONTH
TP	POTENTIAL EVAPOTRANSPIRATION EQUILIBRIUM TEMPERATURE, PAN-SIZE WET SURFACE EQUILIBRIUM TEMPERATURE OR POTENTIAL EVAPORATION EQUILIBRIUM TEMPERATURE	DEG.C
TRTM	MONTHLY TOTAL RTMM FOR STATION SUMMARY	MM
TS	TABLE OF VARIABLE S	
TST	WEIGHTING FACTOR FOR EFFECTS OF TEMPERATURE ON TURBIDITY	
TSW	TABLE OF VARIABLE SW	
TT	TABLE OF VARIABLE T	DEG.C OR DEG.F
TTDW	TABLE OF VARIABLE TDW	
TTW	TABLE OF VARIABLE TW	DEG.C OR DEG.F
TV	TABLE OF VARIABLE V	MB
TVD	TABLE OF VARIABLE VD	MB

LIST OF VARIABLE NAMES USED IN THE PROGRAM

VARIABLE	DEFINITION	UNIT
TW	USED TO KEEP ORIGINAL VALUE OF T FOR PRINT OUT	DEG.C OR DEG.F
TYEAR	TABLE OF VARIABLE YEAR	YEAR
V	SATURATION VAPOUR PRESSURE AT T	MB
VD	SATURATION VAPOUR PRESSURE AT DEW POINT	MB
VP	SATURATION VAPOUR PRESSURE AT TP	MB
VPDL	VAPOUR PRESSURE DEFICIT	MB
W	PRECIPITABLE WATER VAPOUR	MM
WVA	INTERMEDIATE STEP IN COMPUTATION OF TAUA	
WVT	INTERMEDIATE STEP IN COMPUTATION OF TAUT	
YEAR	YEAR IN WHICH CLIMATOLOGICAL OBSERVATION WAS MADE	YEAR
YR	SHORT FORM FOR YEAR USED AS HEADING	DAY
ZENA	NOON SOLAR ZENITH DISTANCE	RADIANS
ZETA	STABILITY FACTOR	