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PROGRAMS REVAP and WEVAP for Estimating Areal Evapotranspiration and Lake Evaporation from Climatological Observations

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Abstract

This report contains the necessary documentation for application of the computer programs REVAP and WEVAP. Estimates of areal evapotranspiration or lake evaporation for periods of 5 days to 1 month are made from routinely published records of air temperature, dew point temperature and sunshine duration. Both models are based on a complementary relationship between areal and potential evapotranspiration.

Details of preparation of the input card deck as well as a sample output are discussed. Included in the appendices are the FORTRAN program listing for Program REVAP and documentation of the comparable Hewlett-Packard HP-67 hand-held calculator program.

Résumé

Le présent rapport renferme tous les renseignements nécessaires à l'utilisation des programmes d'ordinateur REVAP et WEVAP. Les évaluations de l'évapotranspiration surfacique ou de l'évaporation des lacs, pour des périodes allant de 5 jours à 1 mois, sont établies à partir des relevés publiés régulièrement de la température de l'air, de la température du point de rosée et de la durée d'ensoleillement. Les deux modèles sont fondés sur le principe d'une relation complémentaire entre l'évapotranspiration surfacique et potentielle.

Le rapport donne les détails de la préparation du paquet de cartes entrée ainsi qu'un échantillon sortie. Sont fournis en annexe les instructions FORTRAN du programme REVAP et les renseignements sur un programme comparable pour la calculatrice Hewlett-Packard HP-67.

1.0 INTRODUCTION

Program REVAP is the latest in a series of computer models for estimating areal evapotranspiration for periods of 5 days to 1 month from routinely published records of air temperature, dew point temperature and sunshine duration. Like the previous models, it is based on the concept of a complementary relationship between areal and potential evapotranspiration. The concept permits areal evapotranspiration to be estimated by its effects on the temperature and humidity of the overpassing air, which in turn are reflected in the estimates of potential evapotranspiration, thereby avoiding the complexities of the soil-plant system and the need for locally calibrated coefficients. As a consequence, the results are verifiable so that errors in the associated assumptions and empirical relationships can be detected and corrected by progressive testing over an ever-widening range of environments. The most recently published application of this methodology (Morton 1978) provides good agreement with corresponding long-term water budget estimates of areal evapotranspiration for 122 river basins in Canada, Ireland, Kenya and the southern United States. However, further testing in the Sahel region of northern Nigeria, where the average annual rainfall exceeds 650 mm, gave estimates of areal evapotranspiration that were significantly negative during the 5-month season when there is practically no rain. Program REVAP is for a revised model that corrects the source of these unrealistic results and incorporates certain conceptual improvements.

The complementary relationship between areal and potential evapotranspiration also provides a basis for estimating lake evaporation from climatological data observed in the land environment. This requires only minor modifications to the areal evapotranspiration model. With no routine observations of the significant seasonal heat-storage changes that occur in lakes, the short-term estimates become realistic only when accumulated to provide annual totals. The most recently published version of the model (Morton 1979) provides good agreement with corresponding water budget estimates for Lake Hefner in Oklahoma, the Salton Sea and Silver Lake in California, Pyramid and Winnemucca Lakes in Nevada, Lake Ontario in New York and Ontario and Dauphin Lake in Manitoba. Program WEVAP is for a revised model that incorporates the conceptual improvements used in the formulation of Program REVAP, thereby increasing confidence in the world-wide applicability of the resultant lake evaporation estimates.

The purpose of this report is to provide a complete documentation of the data requirements and operation of Programs REVAP and WEVAP prior to publication in the scientific literature of the conceptual and experimental bases for the models. The basic assumptions, concepts, sources of information and results of the verification procedure are discussed herein only insofar as they represent significant changes to the most recently published versions of the models (Morton 1978, 1979). For more

details the reader is advised to watch for the forthcoming publications.

The areal evapotranspiration and lake evaporation models have been programmed for the Hewlett-Packard HP-9100A desk calculator (with the HP-9101A extended memory) and for the HP-67 hand-held calculator. Documentation for the HP-67 program is included as Appendix III and documentation for the HP-9100A program can be supplied on request.

2.0 Terminology

The equation describing the complementary relationship is expressed as follows:

$$ET + ETP = 2 ETW$$

in which

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

ETP = potential evapotranspiration = the evapotranspiration that would occur from saturated surfaces as estimated from a solution of the energy balance and vapour transfer equations using radiation absorption, heat transfer and vapour transfer characteristics that are compatible with the plant, soil and snow cover of the surrounding area.

ETW = wet environment evapotranspiration = the evapotranspiration that would occur from an existing or hypothetical large area with saturated surfaces, i.e. with no limits on the availability of water for evapotranspiration.

The terminology is illustrated in Figure 1, which shows the workings of the complementary relationship under conditions of constant radiant energy supply. When there is no water available for evapotranspiration (extreme left of Fig. 1), ET = 0 and ETP is at its maximum rate of 2ETW. As the water supply to the soil-plant system increases (moving to the right in Fig. 1), the ET increases, resulting in a decrease in ETP of the same magnitude. Equilibrium is reached when there is no restriction on the water made available to the soil-plant system and ET = ETP = ETW. Thus, the potential evapotranspiration under completely humid conditions is equal to one half the potential evapotranspiration under completely arid conditions. It should be noted that neither ET nor the availability of water are known, but that both ETP and ETW can be estimated from

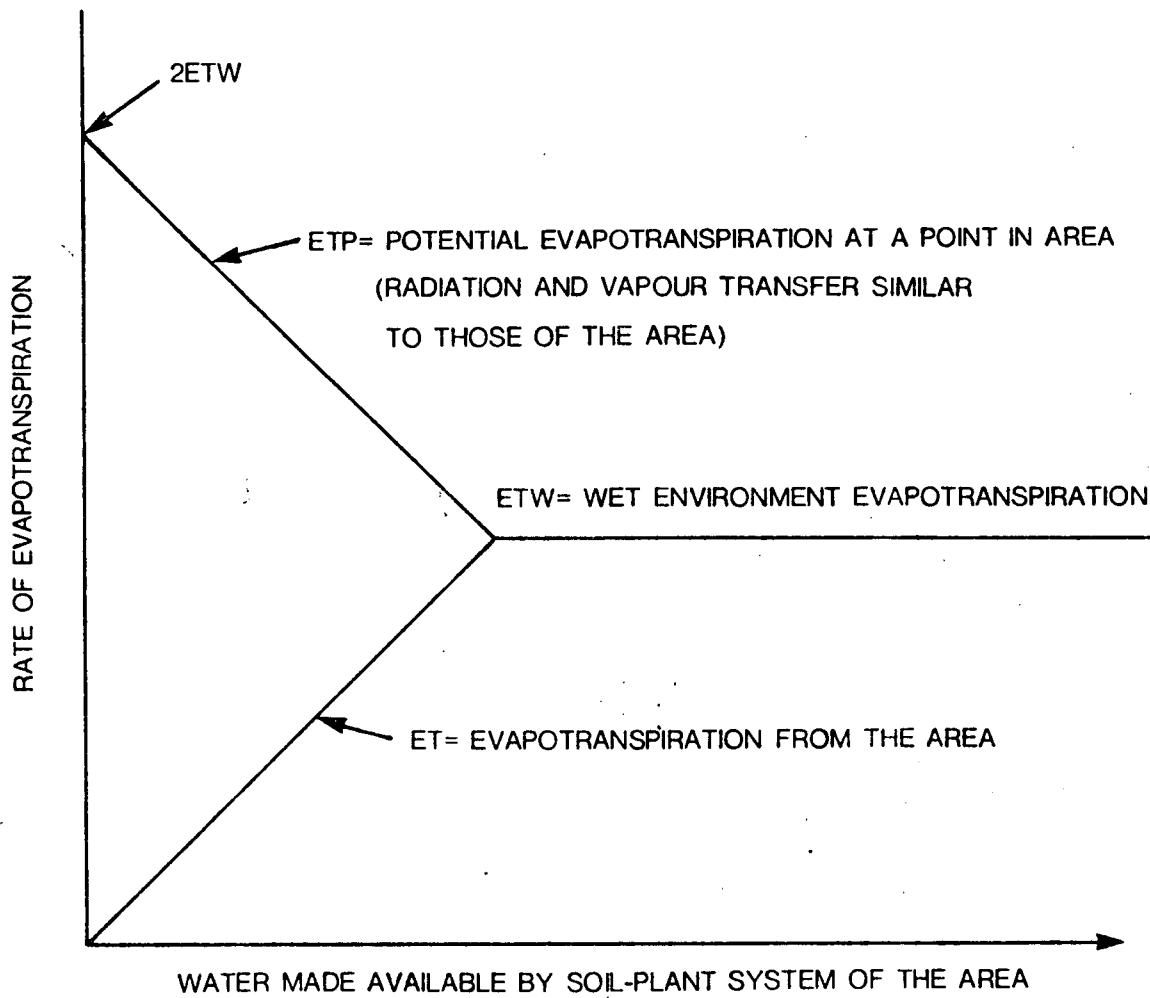


Figure 1. Schematic representation of the complementary relationship for areal evapotranspiration.

routine climatological observations. Therefore, the complementary relationship is used in the following form:

$$ET = 2ETW - ETP$$

The complementary relationship takes into account the differences between the lake and land environments and therefore can be used to estimate lake evaporation from routine climatological observations in the land environment. A schematic representation of this relationship and the terminology used in Program WEVAP are illustrated in Figure 2 in which:

EP = potential evaporation = the evaporation computed from a solution of the energy balance and vapour transfer equations using radiation absorption, heat transfer and vapour transfer characteristics that are compatible with a water surface. As the input data are normally observed in the land environment, EP is the evaporation at the upwind edge of the lake.

EW = lake evaporation = evaporation from a body of water so large that the effects of the shoreline transition are negligible. It is similar to ETW except for the effects of differences in the radiation absorption, heat transfer and vapour transfer characteristics between land and lake.

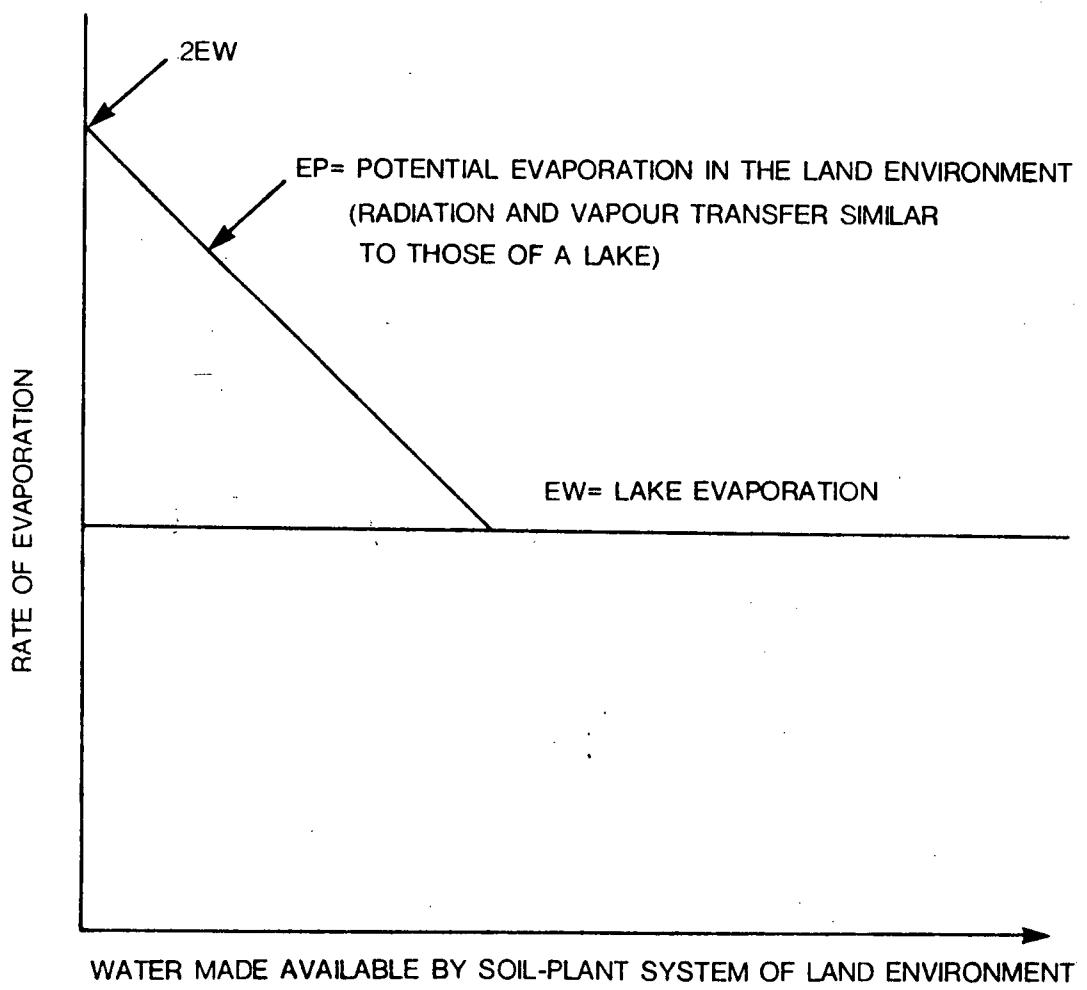


Figure 2. Schematic representation of the complementary relationship for lake evaporation.

Figure 2 shows what happens under conditions of constant radiant energy supply. As there is no lack of water on a lake, the value of EW remains constant, however, the value of EP responds in a complementary way to changes in water made available by the soil-plant system in the land environment. Thus, in a completely dry land environment the value of EP is twice EW, whereas in a completely wet environment the value of EP is equal to EW. Such large changes in EP (and in the evaporation at the upwind shoreline) have negligible effects unless the shoreline transition of approximately 300 metres (Morton 1979) is a large part of the lake area.

3.0 Conceptual Improvements

Programs REVAP and WEVAP differ from the most recently published applications of the complementary relationship (Morton 1978, 1979) in a number of ways. Some differences, such as those pertaining to estimates of net radiation and the effects of atmospheric stability and pressure on the vapour transfer coefficient, are relatively minor and will be discussed in forthcoming scientific publications; however, those involving estimates of potential evapotranspiration, wet environment evapotranspiration and calibration are more important and they are discussed briefly below.

Potential evapotranspiration is estimated from a solution of the energy balance and vapour transfer equations. This can be done by analytical, graphical or iterative techniques. Analytical solutions are accurate only under relatively humid conditions where the potential evapotranspiration equilibrium temperature is near the air temperature; graphical solutions are not suitable to computer applications; and published iterative solutions require an excessive number of computations to achieve the necessary accuracy. The most recently published applications of the complementary relationship (Morton 1978, 1979) used an analytical solution similar to the Kohler and Parmele (1967) version of the Penman equation. Program REVAP incorporates a new and improved technique which, by using certain aspects of the analytical procedure, produces numerical accuracy within four iterations.

In a rationalization of the complementary relationship Morton (1971) showed that the potential evapotranspiration equilibrium temperature produced by such a solution tends to remain constant with respect to availability of water for areal evapotranspiration. Therefore, the use of the equilibrium temperature to provide the conservative temperature effect required for estimates of the wet environment areal evapotranspiration eliminates the need for the complicated and questionable temperature adjustments used previously (Morton 1978, 1979).

In the most recently published applications of the complementary relationship (Morton 1978, 1979) the calibration started with educated assumptions concerning the nature of the wet environment areal evapotranspiration (ETW) and ended with estimates of the vapour transfer coefficient and two coefficients used in estimating advection energy. In contrast, the calibration of Programs REVAP and WEVAP starts with educated assumptions about the vapour transfer coefficient and ends with estimates of coefficients needed to determine the dry environment potential evapotranspiration (which by definition is twice the wet environment areal evapotranspiration). The resultant estimates of ETW include any effects of advection energy. The calibration used climatological data from the arid areas of Nigeria, the Sudan, and the states of Washington, Arizona and Texas. There were 154 station-months with precipitation low enough that it could be assumed equal to the areal evapotranspiration, and these were used to derive the following regression equation:

$$2ETW = 28 + 2.40 * DP * RTP \quad (r = 0.998)$$

in which DP is the Penman weighting factor (i.e. the ratio of the slope of the saturation vapour pressure curve to the sum of the slope and the psychrometric constant) and RTP is the net radiation for the land surface. Both DP and RTP are at the potential evapotranspiration equilibrium temperature.

The same methodology and data were used to calibrate the lake evaporation model with the vapour transfer coefficient reduced by 11% to make it more compatible with the roughness of a water surface. The results are as follows:

$$2EW = 26 + 2.24 * DP * RP \quad (r = 0.998)$$

in which DP is the Penman weighting factor and RP is the net radiation for the water surface, both at the potential evaporation equilibrium temperature.

4.0 Limitations

Programs REVAP and WEVAP are designed for world-wide application without local optimization of coefficients; however, such widespread use is subject to the following limitations:

- 1) They cannot be applied to time intervals shorter than 5 days.
- 2) They cannot be applied near sharp environmental discontinuities.
- 3) Climatological input must be from a station in surroundings representative of the area of interest.
- 4) Program REVAP cannot be used to predict the effects of natural or man-made changes in land use or climate.
- 5) Program WEVAP cannot provide realistic short-term or seasonal estimates of evaporation from lakes of any depth.

More details on these and other limitations have been published elsewhere (Morton 1978, 1979)

5.0 Computer Program Operation

The only differences between Programs REVAP and WEVAP are in the equations that have already been discussed and in the estimates of albedo, emissivity and vapour transfer coefficient; therefore, it is easy and convenient to combine them into one computer program. The combined program is referred to as Program REVAP and all the necessary changes are made automatically when the program control variable is specified as either "REVAP" or "WEVAP". This section deals with the organization of input data required to operate the computer program REVAP and the form of output to be expected.

5.1 Program Language

Program REVAP has been used successfully on the Control Data Corp. CDC CYBER 74 with the NOS/BE (Network Operating System/Batch Environment) operating system at the Department of Energy, Mines and Resources, Ottawa. It is written in the FORTRAN EXTENDED language and requires about 40 000 (octal) words of program storage space. While execution time will vary according to size of data base, 5 years of monthly records require approximately 0.40 sec of execution time.

The FORTRAN program listing and list of variables appear in Appendixes I and II respectively. Documentation and program listing for the Hewlett-Packard HP-67 hand-held calculator are found in Appendix III.

5.2 Options

As mentioned in Section 5.0, Program REVAP can be used to provide estimates of either areal evapotranspiration or lake evaporation. There are four other options available that are controlled by input control parameters.

- 1) The air and dew point temperatures can be in either Fahrenheit or Celsius units.
- 2) The average air temperature input can be replaced by both the average maximum and average minimum air temperatures if convenient.
- 3) Global radiation observations (expressed in langleyes per day) can replace the ratios of observed to maximum possible sunshine duration as input if necessary or convenient.
- 4) If required, the program can provide a summary of results in the form of a tabulation showing the averages of the monthly and annual values of net radiation, potential evapotranspiration and areal evapotranspiration or their Program WEVAP equivalents.

5.3 Structure

REVAP is structured to handle primarily monthly climatic observations of dew point temperature, air temperature and sunshine duration. Calculations can be performed for only a single station, or many stations at a time. For time periods of a fraction of a month, only the value of the number of periods in each month (m) needs to be changed, and all other changes outlined by Morton (1978, 1979) will be made automatically. To accept weekly data, equation 69 (Morton 1978) should be used, with the period number (I) equal to the number of days from the beginning of the calendar year to the middle day of the week in question (using a February of 28.5 days) and with m equal to $(29.5 + I/270)$ or 30.4, whichever is smaller.

5.3.1 Data Input

Data input requirements consist of three sections:
(1) program control card, (2) station identification card, and
(3) station climatological data. Details of the data input format are summarized in Table 1. A sample data deck is found in Figure 3.

The program control card consists of two input variables (PROGRM, MEANS) which define the model type to be used in the program, and whether or not a station summary is desired. The proper form of input is as follows:

Table 1
SUMMARY OF DATA INPUT REQUIREMENTS

INPUT DESCRIPTION	UNITS	VARIABLE NAME IN PROGRAM	COLUMN NOS. (INCLUSIVE)	READ FORMAT	EXAMPLE
(1) PROGRAM CONTROL CARD					
1. MODEL TYPE	-	PROGRM	1-5	A5	REVAP
2. MONTHLY SUMMARY?	-	MEANS	6-10	I5	1
(2) STATION IDENTIFICATION CARD					
1. STATION NAME	-	NAME	1-20	5A4	WHITE RIVER
2. LATITUDE	degrees	PHID	21-25	F5.2	48.60
3. NO. PERIODS/MONTH	-	M	30	I1	1
4. STARTING MONTH NUMBER	-	STRTMN	31-32	I2	01
5. YEAR OF 1ST RECORD	years	YEAR	36-39	I4	1965
6. AVG. ATMOSPHERIC PRESSURE	mb	P	40-47	F8.2	969.20
7. AVG. ANNUAL PRECIPITATION	mm	PPN	50-54	F5.0	678.
8. NO. OF DATA RECORDS	-	NN	55-57	I3	12
9. INPUT PARAMETER IT	-	IT	58-59	I2	01
10. INPUT PARAMETER FORM	-	FORM	60-61	I2	01
11. INPUT PARAMETER IS	-	IS	62-63	I2	0
(3) CLIMATOLOGICAL DATA (FORM = 1)					
1. AVG. DEW POINT TEMPERATURE	°F or °C	TD	1-9	F9.4	-3.5
2. IS IT AN ESTIMATE?	-	C1	10	I1	0
3. AVG. AIR TEMPERATURE	°F or °C	T	11-19	F9.4	-1.9
4. IS IT AN ESTIMATE?	-	C2	20	I1	0
5. SUNSHINE DURATION	ratio or langley/day	S	21-29	F9.4	0.39
6. IS IT AN ESTIMATE?	-	C3	30	I1	0
(FORM = 2)					
1. AVG. DEW POINT TEMPERATURE	°F or °C	TD	1-9	F9.4	-3.5
2. IS IT AN ESTIMATE?	-	C1	10	I1	0
3. AVG. MAXIMUM TEMPERATURE	°F or °C	TA1	11-19	F9.4	10.0
4. IS IT AN ESTIMATE?	-	C2	20	I1	0
5. AVG. MINIMUM TEMPERATURE	°F or °C	TA2	21-29	F9.4	-5.0
6. IS IT AN ESTIMATE?	-	C3	30	I1	0
7. SUNSHINE DURATION	ratio or langley/day	S	31-39	F9.4	0.39
8. IS IT AN ESTIMATE?	-	C4	40	I1	0

① PROGRAM CONTROL CARD

REVAP 1

② STATION IDENTIFICATION CARD

③ STATION CLIMATOLOGICAL DATA

AVERAGE DEW POINT TEMPERATURE	AVERAGE AIR TEMPERATURE	SUNSHINE DURATION
-03.5	-01.9	.39
02.2	08.5	.41
22.5	32.1	.51
37.5	48.8	.48
43.5	54.5	.56
47.2	54.4	.48
48.0	54.4	.44
41.0	44.9	.26
34.0	38.2	.21
20.0	23.7	.20
15.0	15.6	.12

Figure 3. Sample data deck.

1. (i) (PROGRM = REVAP) for the selection of the areal evapotranspiration model.
 - (ii) (PROGRM = WEVAP) for the selection of the lake evaporation model.
-
2. (i) (MEANS = 1) generates a station monthly summary if the station data is in the form of complete years.
 - (ii) (MEANS = 0 or blank) suppresses the station monthly summary.

This card must appear first in the data deck.

The second card type, the station identification card, must precede all of the climatological data for that particular station. Besides providing the station name and location, there are input control parameters included to describe the format of the climatological data to be entered. For each station card the following information is required:

- 1) Station name (20 characters).
- 2) Latitude of the station in degrees (negative in the southern hemisphere).
- 3) The number of time periods in each month (restricted to 0, 1, 2, 3, 5 and 6 where 0 = 1 = monthly data).
- 4) The month number of the first data record (i.e. September = 9).
- 5) The year of the first data record.

- 6) The station's average atmospheric pressure in millibars.
- 7) The station's average annual precipitation in millimetres.
- 8) The number of data records for the station.
- 9) Input control parameters.
 - A. i) (IT = 0 or blank) Temperature data is in degrees Celsius.
 - ii) (IT = 1) Temperature data is in degrees Fahrenheit.
 - B. i) (FORM = 1) Average air temperature consists of a single value.
 - ii) (FORM = 2) Average air temperatures are to be calculated; air temperatures consist of average of minimum and maximum air temperatures (i.e. two values are to be read in).
 - C. i) (IS = 0 or blank) Ratios of observed to maximum possible sunshine duration are entered.
 - ii) (IS = 1) Global radiation data are entered.

The last card type is composed of the station climatological data. Depending upon the selection of input control parameters as outlined previously, there will be one data card for each time period providing the following information:

- 1) Average dew point temperature.
- 2) Average air temperature.
- 3) The ratio of observed to maximum possible sunshine duration, or the observed global radiation.

If any data have been estimated, a "1" (one) may be entered in a column beside the value (please refer to Table 1 for the exact location) so that an "E" will appear beside the estimated value in the output. The data deck should not contain any blank cards. If more than one station is being used in the program, the second station identification card should come immediately after the last climatological data card for the previous station. The program will continue to read data until an EOF or blank card is encountered.

5.3.2 Sample Output

The climatological data from the input cards appear as output, with an "F" appearing on temperature headings if the temperature data are in degrees Fahrenheit and an "E" indicating that the data were estimated. If a station summary was requested, it will appear on the page following the station data. A sample of the output produced from the sample input deck, with an additional four years of data as input, is found in Figures 4a and 4b.

WHITE RIVER		PHID= 48.60		P= 969.2		PPN= 678.			
MN	YR	TDF	TF	S	RTM	ETPM	ETM		
JAN	1965	-4.2	-2.4	.300	-24.	-5.	-5.		
FEB	1965	-3.5	-1.9	.390	-13.	-4.	-4.		
MAR	1965	2.2	8.5	.410	-6.	3.	3.		
APR	1965	22.5	32.1	.510	90.	71.	47.		
MAY	1965	37.5	46.8	.480	118.	123.	65.		
JUNE	1965	43.5	54.5	.560	147.	147.	95.		
JULY	1965	47.2	54.4	.480	130.	119.	97.		
AUG	1965	48.0	54.4	.440	95.	95.	73.		
SEPT	1965	41.0	44.9	.260	46.	44.	43.		
OCT	1965	34.0	38.2	.210	10.	21.	21.		
NOV	1965	24.0	23.7	.200	-22.	-2.	-2.		
DEC	1965	15.0	15.6	.120	-28.	-9.	-9.		
JAN	1966	-8.0	-6.9	.240	-24.	-3.	-3.		
FEB	1966	5.5	7.7	.250	-17.	-4.	-4.		
MAR	1966	13.2	17.2	.330	-1.	3.	3.		
APR	1966	25.2	30.2	.270	53.	39.	39.		
MAY	1966	31.2	40.6	.430	109.	95.	62.		
JUNE	1966	48.2	57.4	.510	138.	138.	97.		
JULY	1966	54.5	61.8	.580	152.	145.	123.		
AUG	1966	51.8	57.3	.390	90.	91.	75.		
SEPT	1966	43.0	48.8	.460	56.	63.	62.		
OCT	1966	34.0	37.9	.200	8.	19.	19.		
NOV	1966	17.2	18.7	.090	-26.	-7.	-7.		
DEC	1966	3.8	6.5	.230	-27.	-5.	-5.		
JAN	1967	-3.0	0.0	.340	-25.	-4.	-4.		
FEB	1967	-9.0	-7.0	.470	-11.	-3.	-3.		
MAR	1967	8.5	12.1	.380	-1.	2.	2.		
APR	1967	24.0	31.0	.430	67.	53.	46.		
MAY	1967	30.5	41.1	.460	116.	103.	63.		
JUNE	1967	49.0	57.5	.430	121.	125.	86.		
JULY	1967	51.8	59.3	.400	113.	120.	85.		
AUG	1967	49.5	55.1	.470	102.	95.	82.		
SEPT	1967	43.2	51.1	.460	55.	77.	33.		
OCT	1967	33.8	38.8	.270	16.	29.	23.		
NOV	1967	19.0	21.6	.100	-25.	-5.	-5.		
DEC	1967	10.8	12.8	.180	-28.	-7.	-7.		
JAN	1968	-2.8	.4	.260	-25.	-4.	-4.		
FEB	1968	-4.2	.5	.350	-15.	-1.	-1.		
MAR	1968	14.8	18.7	.280	-3.	3.	3.		
APR	1968	27.2	34.7	.360	63.	57.	37.		
MAY	1968	35.0	46.8	.330	83.	105.	37.		
JUNE	1968	48.2	53.8	.380	108.	107.	77.		
JULY	1968	53.2	59.3	.490	134.	123.	111.		
AUG	1968	50.2	57.3	.520	110.	112.	83.		
SEPT	1968	49.5	54.6	.340	58.	66.	49.		
OCT	1968	39.2	43.2	.220	13.	25.	20.		
NOV	1968	24.2	22.9	.160	-24.	-4.	-4.		
DEC	1968	4.5	7.5	.210	-28.	-5.	-5.		
JAN	1969	5.2	7.1	.210	-26.	-6.	-6.		
FEB	1969	3.8	6.8	.430	-15.	-3.	-3.		
MAR	1969	6.2	10.9	.430	-3.	2.	2.		
APR	1969	24.8	33.3	.430	76.	64.	42.		
MAY	1969	33.8	45.7	.420	105.	113.	52.		
JUNE	1969	42.8	50.5	.230	84.	89.	55.		
JULY	1969	51.0	60.6	.570	148.	155.	106.		
AUG	1969	54.2	62.2	.550	116.	129.	87.		
SEPT	1969	44.0	48.4	.380	56.	55.	49.		
OCT	1969	32.0	39.9	.190	7.	16.	16.		
NOV	1969	22.5	25.7	.170	-22.	-2.	-2.		
DEC	1969	8.8	11.4	.110	-29.	-6.	-6.		

MONTHLY TOTALS AVERAGED OVER 5 YEARS

MN	RTM	ETPM	ETM
JAN	-24.8	-4.4	-4.4
FEB	-14.2	-3.0	-3.0
MAR	-2.8	2.6	2.6
APR	69.8	56.8	42.2

MAY	106.2	107.8	55.8
JUNE	119.6	121.2	82.0
JULY	135.4	132.4	104.4

AUG	102.6	104.4	80.0
SEPT	54.2	61.0	43.2
OCT	10.8	22.0	20.6

NOV	-23.8	-4.0	-4.0
DEC	-28.0	-6.4	-6.4

YEARLY	505.0	590.4	413.0
TOTAL			

Figure 4. Sample output.

References

Control Data Corporation. FORTRAN version 4 reference manual, 1977: Publ. No. 60497800.

Kohler, M.A. and Parmele, L.H. 1967. Generalized estimates of free-water evaporation. Water Resour. Res. 3: 996-1005.

Morton, F.I. 1978. Estimating evapotranspiration from potential evaporation: Practicality of an iconoclastic approach. J. Hydrol. 38: 1-32.

Morton, F.I. 1979. Climatological estimates of lake evaporation. Water Resour. Res. 15(1): 64-76.

Morton, F.I. 1971. Catchment evaporation and potential evaporation - further development of a climatologic relationship. J. Hydrol. 12: 81-99.

PROGRAM REVAP (INPUT,OUTPUT,TAPE1=INPUT)

5 C THIS PROGRAM IS A COMBINATION OF BOTH THE AREAL EVAPOTRANSPIRATION
 C AND LAKE EVAPORATION MODELS DEVELOPED BY DR. F.I. MORTON, N.H.R.I.,
 C ENVIRONMENT, CANADA.
 C BY SELECTING THE PROPER INPUT PARAMETER, PROGRAM REVAP PROVIDES AN
 C ESTIMATE OF EITHER AREAL EVAPOTRANSPIRATION OR LAKE EVAPORATION
 C BASED ON ROUTINE CLIMATOLOGICAL OBSERVATIONS.
 10 C DATA INPUT REQUIREMENTS INCLUDE:
 C FOR EACH STATION-LATITUDE, AVERAGE ATMOSPHERIC PRESSURE, AVERAGE ANNUAL
 C PRECIPITATION
 C FOR EACH TIME PERIOD- AIR TEMPERATURE, DEW POINT TEMPERATURE,
 C RATIO OF OBSERVED TO MAXIMUM POSSIBLE SUNSHINE DURATION

15

		***** LIST OF TERMS *****	*****
20	C PHID	= LATITUDE - NEGATIVE IN SOUTHERN HEMISPHERE	DEGREES
	C PHI	= LATITUDE - NEGATIVE IN SOUTHERN HEMISPHERE	RADIANS
	C P	= AVERAGE ATMOSPHERIC PRESSURE	MB
	C PPN	= AVERAGE ANNUAL PRECIPITATION	MM
	C TDF	= DEW POINT TEMPERATURE	DEGREE F
	C TF	= AIR TEMPERATURE	DEGREE F
25	C S	= RATIO OF OBSERVED TO MAXIMUM POSSIBLE SUNSHINE DURATION	
	C MONNUM	= MONTH NO STARTING WITH 1 FOR JANUARY	
	C N	= NUMBER OF DAYS IN MONTH	DAYS
	C TD	= DEW POINT TEMPERATURE	DEGREE C
	C T	= AIR TEMPERATURE	DEGREE C
30	C ALPHA(J)	= CONSTANT IN COMPUTATION OF VAPOUR PRESSURE	DEGREE C
	C BETA(J)	= CONSTANT IN COMPUTATION OF VAPOUR PRESSURE	MB/DEGREE C
	C GAMMA(J)	= SENSIBLE HEAT TRANSFER COEFFICIENT	W/(M^2*MB)
	C FTZ(J)	= VAPOUR TRANSFER COEFFICIENT * STABILITY FACTOR	W-DAYS/MM
	C L(J)	= LATENT HEAT	
35	C (J)	= 1 WHEN T IS GREATER THAN OR EQUAL TO ZERO	
	C (J)	= 2 WHEN T IS LESS THAN ZERO	
	C V	= SATURATION VAPOUR PRESSURE AT T	MB
	C VD	= SATURATION VAPOUR PRESSURE AT TD	MB
40	C DELTA	= SLOPE OF SATURATION VAPOUR PRESSURE CURVE AT T	MB/DEGREE C
	C DFLP	= SLOPE OF SATURATION VAPOUR PRESSURE CURVE AT TP	MB/DEGREE C
	C THETA	= DECLINATION OF SUN	RADIANS
	C OMEGA	= HALF THE ANGLE BETWEEN SUNRISE AND SUNSET	RADIANS
	C ZENA	= SOLAR ZENITH ANGLE	RADIANS
45	C CZENA	= COSINE OF THE SOLAR ZENITH ANGLE	
	C COSZ	= COSINE OF THE AVERAGE ANGULAR ZENITH DISTANCE OF THE SUN	
	C NETA	= RADIUS VECTOR OF SUN	
	C GE	= EXTRA-ATMOSPHERIC GLOBAL RADIATION	W/(M^2*M)
	C AZZ	= SNOW FREE-CLEAR SKY ALBEDO WHEN SUN IS AT ZENITH	
	C AZ	= CLEAR SKY ALBEDO WHEN SUN IS AT ZENITH	
50	C AO	= CLEAR SKY ALBEDO	
	C A	= AVERAGE ALBEDO	
	C DUST	= TURBIDITY COEFFICIENT	
	C W	= PRECIPITABLE WATER VAPOUR	MM
	C TAUT	= TRANSMITTANCY FOR DIRECT HEAM SOLAR RADIATION	
55	C TAUa	= PARTIAL TRANSMITTANCY DUE TO ABSORPTION ALONE	
	C GO	= CLEAR SKY GLOBAL RADIATION	W/(M^2*M)
	C G	= INCIDENT GLOBAL RADIATION	W/(M^2*M)

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	C R	= NET LONG WAVE RADIATION AT T	W/(M^2M)
60	C /FTA	= STABILITY FACTOR	
	C FT	= VAPOUR TRANSFER COEFFICIENT	W/(M^2MB)
	C LAMDA	= HEAT TRANSFER COEFFICIENT	MB/(DEGREE C)
	C TP	= POTENTIAL EVAPORATION EQUILIBRIUM TEMPERATURE	DEGREE C
	C TDEL	= TEMPERATURE INCREMENT FOR CALCULATING TP	DEGREE C
	C DP	= PENMAN WEIGHTING FACTOR	W/(M^2M)
65	C RT	= NET RADIATION AT T	W/(M^2M)
	C RTP	= NET RADIATION AT TP	W/(M^2M)
	C ETP	= POWER EQUIVALENT OF POTENTIAL EVAPOTRANSPIRATION	W/(M^2M)
	C ET	= POWER EQUIVALENT OF EVAPOTRANSPIRATION	W/(M^2M)
70	C ETW	= POWER EQUIVALENT OF WET ENVIRONMENT EVAPOTRANSPIRATION	W/(M^2M)
	C RTM	= EVAPORATION EQUIVALENT OF RT	MM
	C FTPM	= POTENTIAL EVAPOTRANSPIRATION FOR TIME PERIOD	MM
	C FTM	= EVAPOTRANSPIRATION FOR TIME PERIOD	MM
	C RWM	= EVAPORATION EQUIVALENT OF WATER SURFACE NET RADIATION AT T	MM
	C EPM	= POTENTIAL EVAPORATION	MM
75	C EWM	= LAKE EVAPORATION	0 MM

***** SPECIFICATION STATEMENTS *****

80 INTEGER STRTMN,YEAR,FORM,C1,C2,C3,C4,PLENGTH
 REAL LAMDA,NETA,LNX,LNY
 REAL ALPHA(2),BETA(2),GAMMA(2),FTZ(2),L(2)
 DIMENSION TETH(12),TETPH(12),TRTM(12)
 85 DIMENSION MON(12)*N(12),NAME(5),HEADNG(3)
 DATA N/31,28,31,30,31,30,31,31,30,31,30,31/
 DATA MON/3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,4HJUNE,4HJULY,3HAUG,4HSEPT,
 * 3HOCT,3HNOV,3HDEC/

***** INPUT DATA *****

C CONTROL CARD DEFINING PROGRAM REVAP OR WEVAP IS READ

95 C READ 1, PROGRAM,MEANS
 CS TRACE

100 C IF MEANS=0 * NO MONTHLY SUMMARY IS TO BE OUTPUT AT END
 C IF MEANS=1 * TABLE OF MONTHLY MEANS IS TO BE OUTPUT

IF (MEANS .NE. 0) MEANS=1
 IF (PROGRAM .NE. 5HREVAP) GOTO 8

105 C AS DIFFERENCES BETWEEN THE AREAL EVAPOTRANSPIRATION MODEL AND THE
 C LAKE EVAPORATION MODEL EXIST IN ONLY A FEW CALCULATIONS, THEY WILL BE
 C ACCOUNTED FOR BY INITIALIZING THE RELEVANT CONSTANTS AT THIS STAGE IN THE
 C PROGRAM. THE REMAINDER OF THE PROGRAM PERFORMS CALCULATIONS USING THE
 C VARIABLE NAMES ASSOCIATED WITH THE AREAL EVAPOTRANSPIRATION MODEL.

110 C
 C
 C CONSTANTS FOR THE AREAL EVAPOTRANSPIRATION MODEL ARE INITIALIZED

```

115      SBD = 20.88/10.***8
          FZ = 28.
          DV1=1.
          DV2=0.
          CONST1=14.
120      CONST2=1.20
          HEADNG(1)=3HRTM
          HEADNG(2)=4HETPM
          HEADNG(3)=3HETM
          GOTO 10
125      A IF (PROGRAM .NE. SHREVAP) GOTO 9

```

C CONSTANTS FOR THE LAKE EVAPORATION MODEL ARE INITIALIZED

```

130      SE = 5.5/10.***8
          SBD = 22.0/10.***8
          FZ = 25.
          DV1=0.
          DV2=1.
          CONST1=13.
135      CONST2=1.12
          HEADNG(1)=3HRWM
          HEADNG(2)=4H_EPM
          HEADNG(3)=3HEWM
          GOTO 10

```

C AN ERROR MESSAGE IS PRINTED IF THERE IS A MISTAKE IN THE PROGRAM NAME

```

9 PRINT 11
STOP
145

```

C VARIABLES FOR MONTHLY MEANS ARE INITIALIZED

```

150      10 DO 25 I=1,12
          25 TETM(I)=TETPM(I)=THTM(I)=0.0

```

C STATION NAME AND INPUT PARAMETERS ARE READ

```

30 READ 24,NAME,PHID,M,STRTMN,YEAR,P,PPN,NN,IT,FORM,IS
155      C A CHECK FOR END OF DATA IS MADE

```

```

      IF (EOF(1)) 555.31,555
      31 IF (YEAR .EQ. 0) GOTO 555
160

```

C ECHO STATION INPUT DATA AND SET UP OUTPUT LABELS

```

      PRINT 13, NAME,PHID,P
      IF (PPN .NE. 0) PRINT 27, PPN
165      IF (FORM .EQ. 1.AND.IT.EQ.0) PRINT 14, (HEADNG(I),I=1,3)
          IF (FORM.EQ.1.AND.IT.EQ.1) PRINT 144,(HEADNG(I),I=1,3)
          IF (FORM .EQ. 2.AND.IT.EQ.0) PRINT 114,(HEADNG(I),I=1,3)
          IF (FORM,EQ.2.AND.IT.EQ.1) PRINT 1144,(HEADNG(I),I=1,3)
          IF (M .EQ. 0) M=1
          NN=NN/M

```

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C***** CONSTANTS *****

175 C INITIALIZATION OF TEMPERATURE DEPENDENT CONSTANTS
C FOR TEMPERATURE > 0K = 0 DEG. CELSIUS

ALPHA(1)=17.27

BETA(1) =237.3

180 GAMMA(1)=0.66*P/1013.
FTZ(1) = FZ * SORT(1013./P)
L(1)=28.5

185 C FOR TEMPERATURE < 0 DEG. CELSIUS

ALPHA(2)=21.88

BETA(2) =265.5

190 GAMMA(2)=0.66*P/(1013.*1.15)
FTZ(2) = 1.15*FZ * SORT(1013./P)
L(2)=28.5*1.15

PI=3.141592654

195 C CONVERT LATITUDE FROM DEGREES TO RADIANS

PHI=PHID*PI/180.

C BEGINNING OF STATION DATA LOOP

200 33 00 60 I=1.NN

C ESTABLISH THE MONTH NO.(1 TO 12)

205 MONNUM = MOD((MOO)(I,12)+STRTMN-1),12
IF (MONNUM .EQ. 0) MONNUM=12

C BEGINNING OF LOOP FOR READING DATA AND PERFORMING CALCULATIONS.
C INPUT PARAMETER M SPECIFIES THE NO. OF TIMES THIS LOOP IS REPEATED.

210 DO 59 II=1,M

C MONTH AND YEAR OF DATA RECORD IS PRINTED

215 IF (II .EO. 1) PRNT 23, MON(MONNUM),YEAR
IF (II .GT. 1) PRNT 26, II
01=02=03=04=1H
IF (FORM .EQ. 2) GOTO 40

220 C FORM=1!READ AND PRINT DEW POINT,S,AND AVERAGE TEMPERATURE

READ 12, TD,C1,T,C2,S,C3
IF (C1 .NE. 0) 01=1ME
IF (C2 .NE. 0) 02=1ME
IF (C3 .NE. 0) 03=1HF
PRNT 15, TD,01,T,02,S,03
IF (IT .EO. 0) GOTO 50

C CONVERT TEMPERATURE TO DEGREES CELSIUS IF IT=1

```

230      TD = (TD-32.)*5./9.
          T=(T-32.)*5./9.
          GOTO 50

```

235 C FORM=21 READ AND PRINT DEW POINT, S, MAX. AND MIN. TEMPERATURES

```

40 READ 112, TD,C1,TA1,C2,TA2,C3,S,C4
240      IF (C1 .NE. 0) 01=1HE
          IF (C2 .NE. 0) 02=1HE
          IF (C3 .NE. 0) 03=1HE
          IF (C4 .NE. 0) 04=1HE
          PRINT 115, TD,01,TA1,02,TA2,03,S,04
          IF (IT .EQ. 0) GOTO 45

```

245 C TEMPERATURE CONVERTED TO DEGREES CELSIUS IF IT=1

```

        TD = (TD -32.)*5./9.
        TA1 = (TA1-32.)*5./9.
        TA2 = (TA2-32.)*5./9.

```

28 C CALCULATE AVERAGE TEMPERATURE FOR THE PERIOD

45 T = (TA1+TA2)/2.

255 C SELECT PROPER J FOR CONSTANTS (J=2 FOR TEMP. < 0 DEGREES CELSIUS)

```

50 J=1
      IF (T .LT. 0.) J=2

```

260 ***** CALCULATIONS *****

265 C SATURATION VAPOUR PRESSURES AT AIR AND DEW POINT TEMPERATURES

```

        V = 6.11*EXP(ALPHA(J) * T/(T+BETA(J)))
        VD=6.11*EXP(17.27*TD/(TD+237.3))

```

C RATE OF CHANGE OF VAPOUR PRESSURE W.R.T. TEMPERATURE (DELTA)

270 DELTA = ALPHA(J)*BETA(J)*V/(T+BETA(J))**2

275 C ALLOW FOR PERIOD LENGTHS OF FRACTIONS OF A MONTH WHEN CALCULATING
C THE DECLINATION OF THE SUN(THETA) AND RADIUS VECTOR OF THE SUN(NETA)

```

        FMM=FLOAT((MONNUM-1)*M+II)
        PERIOD = (FMM + 0.5*FLOAT(M-1))/FLOAT(M)
        TT = 23.2
        IF (M .GT. 1) TT=23.4
        THETA=TT*PI/180.*SIN((29.5*PERIOD-94.)*PI/180.)
        NETA=1.+SIN((29.5*PERIOD-106.)*PI/180.)/60.

```

C SOLAR ZENITH ANGLE (ZENA)

285 CZENA = COS(PHI - THETA)

IF (CZENA .LT. 0.001) CZENA = 0.001
 ZENA = ARCCOS(CZENA)

C NO. OF DEGREES THE EARTH ROTATES BETWEEN SUNRISE AND NOON (OMEGA)
 290 ACOM = 1. - CZENA/COS(PHI)/COS(THETA)
 IF (ACOM.LT.-1.) ACOM=-1.

C CALCULATE THE ARCCOSINE OF ACOM
 295 OMEGA=ARCCOS(ACOM)

C COSINE OF THE AVERAGE ANGULAR ZENITH DISTANCE OF THE SUN (COSZ)
 300 COSZ = CZENA + (SIN(OMEGA)/OMEGA-1.) * COS(PHI) * COS(THETA)

C THE EXTRA-ATMOSPHERIC GLOBAL RADIATION(GE)
 305 GE=1354.*COSZ*OMEGA/(PI*NETA*NETA)

C CLEAR SKY, SNOW FREE ALBEDO WHEN SUN IS AT THE ZENITH (AZZ)
 310 AZZ=(0.26-0.00012*SQRT(P/1013.)*PPN*(1.+ABS(PHID)/42.0
 *(PHID/42.0)**2))+DV1+0.05*DV2

C CONSTRAINT FOR AZZ WHICH MAY APPLY DURING WET SEASON IN DRY AREA
 315 IF(AZZ.GT.((0.91-VD/V)/2.)) AZZ=((0.91-VD/V)/2.)

C TWO FURTHER CONSTRAINTS FOR AZZ
 320 IF(AZZ.GT.0.17) AZZ=0.17
 IF(AZZ.LT.(0.11*DV1+0.05*DV2)) AZZ=0.11*DV1+0.05*DV2

C WEIGHTING FACTOR FOR THE EFFECT OF SNOW ON ALBEDO (ARAT)
 325 VPDL=V-VD
 IF(VPDL.LT.0.0) VPDL=0.0
 IF(VPDL.GT.1.0) VPDL=1.0
 ARAT=1.-VPDL*VPDL

C CLEAR SKY ALBEDO WITH SUN AT ZENITH (AZ)
 330 AZ=AZZ*ARAT*(0.34-AZZ)

C CLEAR SKY ALBEDO (A0)
 335 A0 = AZ*(EXP(1.08)-EXP((ZENA)*2.16/PI)*(COS(ZENA)*2.16/
 *PI*SIN(ZENA)))/(1.473*(1.-SIN(ZENA)))

C PRECIPITABLE WATER VAPOUR (W)
 340 W=VD/(1.49*T/129.)

TST = 21. - T
 IF (TST .LT. 0.0) TST = 0.0
 IF (TST .GT. 5.0) TST = 5.0

345

C TURRIDITY COEFFICIENT (DUST)

350

C TRANSMITTANCY OF CLEAR SKIES TO DIRECT BEAM SOLAR RADIATION (TAUT)

355

DUSTT=0.083*(DUST/COSZ)**0.9
 WVT=0.029*(W/COSZ)**0.6
 LNX = (-0.089*(P/(COSZ*1013.))**0.75 - DUSTT - WVT)
 IF (LNX .LT. -675.) LNX=-675.
 TAUT=EXP(LNX)

360

C PARTIAL TRANSMITTANCY DUE TO ABSORPTION ALONE (TAUA)

365

WVA = SORT(WVT/10.)
 IF (WVA .GT. WVT) WVA = WVT
 LNY = -DUSTT/2. - WVA
 IF (LNY .LT. -675.) LNY = -675.
 TAUA=EXP(LNY)

30

C CLEAR SKY GLOBAL RADIATION (G0)

370

C INCIDENT GLOBAL RADIATION (G)

375

G = G0*S + (0.08+0.3*S)*(1.-S)*GE
 IF (IS ,EQ, 0) GOTO 55
 C IF IS=1 ESTIMATE THE SUNSHINE DURATION RATIO (S) FROM
 C THE GIVEN VALUE OF INCIDENT GLOBAL RADIATION

380

G = S/2.064
 S = 0.53*G/(G0-0.47*G)
 IF (S .GT. 1.) S=1.
 IF (S .LT. 0.) S=0.

385

55 AK = T + 273.

C WEIGHTING FACTOR FOR THE EFFECT OF CLOUDS ON ATMOSPHERIC RADIATION(ATM)

390

ATM = 10.* (VD/V - S - 0.42)
 IF (ATM .LT. 0.) ATM = 0.
 IF (ATM .GT. 1.) ATM = 1.

395

C PROPORTIONAL INCREASE IN ATMOSPHERIC RADIATION DUE TO CLOUDS (RHO)

RHO = 0.18*1013./H*(ATM*SQRT(1.-S)*(1.-ATM)*(1.-S)**2)

C NET LONG-WAVE RADIATION LOSS AT T (B)

B = SB + AK**4* (1.-(0.71 + 0.007*VD*P/1013.)*(1.+RHO))
 IF (A.LT.0.05*SB*AK**4) B=0.05*SB*AK**4

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400

C ESTIMATE THE AVERAGE ALBEDO (A)

$$A = A0 * (S + (1. - ZENA * 180. / PI / 330.) * (1. - S))$$

405

C CALCULATE THE NET RADIATION AT T (RT)

$$RT = (1. - A) * G - B.$$

C STABILITY FACTOR (ZETA)

410

$$EE = FT2(J) * (V - VD)$$

$$RTC = RT$$

$$TF = (RTC * LT * 0.) RTC = 0.$$

415

$$ZETA = 1. / (0.28 * (1. - VD / V) + FZ / 28. * DELTA * RTC / GAMMA(J) / EE)$$

$$IF (ZETA .LT. 1.) ZETA = 1.$$

C VAPOUR TRANSFER COEFFICIENT (FT)

$$FT = FT2(J) / ZETA$$

420

C HEAT TRANSFER COEFFICIENT (LAMDA)

$$LAMDA = GAMMA(J) + SBD * (T + 273.) ** 3 / FT$$

425

C ITERATIVE PROCEDURE FOR COMPUTING POTENTIAL EVAPOTRANSPIRATION

C BY COMBINING THE ENERGY BUDGET AND VAPOUR TRANSFER EQUATIONS.

C THE ITERATION CONTINUES UNTIL THE INCREMENT (TDEL) OF THE POTENTIAL

C EVAPOTRANSPIRATION EQUILIBRIUM TEMPERATURE (TP) IS < 0.01 DEGREES C.

430

$$VP = V$$

$$TP = T$$

$$DELP = DELTA$$

$$200 TDEL = (RT / FT + VD + LAMDA * (T - TP) - VP) / (DELP + LAMDA)$$

$$TP = TP + TDEL$$

435

$$VP = 6.11 * EXP(ALPHA(J) * TP / (TP * BETA(J)))$$

$$DELP = ALPHA(J) * BETA(J) * VP / (TP * BETA(J)) ** 2$$

$$IF (ABS(TDEL) - 0.01) 201,200,200$$

440

C PENMAN WEIGHTING FACTOR (DP)

$$201 DP = DELP / (DELP + GAMMA(J))$$

C POWER EQUIVALENT OF POTENTIAL EVAPOTRANSPIRATION (ETP)

445

$$FTP = RT - FT * LAMDA * (TP - T)$$

C NET RADIATION AT TP (RTP)

450

$$RTP = ETP + FT * GAMMA(J) * (TP - T)$$

C POWER EQUIVALENT OF WET ENVIRONMENT EVAPOTRANSPIRATION (ETW)

455

$$ETW = CONST1 * CONST2 * DP * RTP$$

$$IF (ETW .LT. ETP / 2.) ETW = ETP / 2.$$

$$IF (ETW .GT. ETP) ETW = ETP$$

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C POWER EQUIVALENT OF EVAPOTRANSPIRATION (ET)

460 ET=2.*ETH-DV1*ETP-DV2*ETH

C CHANGE THE NO. OF DAYS IN FEBRUARY TO 29 IF IT IS A LEAP YEAR

IF(MOD(YEAR,4).EQ.0.AND.MOD(YEAR,400).NE.0) N(2)=29

465 C MULTIPLY BY THE PERIOD LENGTH AND DIVIDE BY THE LATENT HEAT OF
 C VAPOURIZATION (OR SUBLIMATION) TO OBTAIN THE EVAPORATION EQUIVALENT
 C OF THE EVAPOTRANSPIRATION, POTENTIAL EVAPOTRANSPIRATION AND NET RADIATION
 C FOR THE PERIOD.

470 PLNGTH=N(MONNUM)
 IF(M.GT.1) PLNGTH=30/M
 IF(M.GT.1.AND.II.EQ.M) PLNGTH=N(MONNUM)-PLNGTH*(M-1)
 ETM=FLOAT(PLNGTH)*ET/L(J)
 475 ETPM=FLOAT(PLNGTH)*ETP/L(J)
 RTM=FLOAT(PLNGTH)*RT/L(J)

N(2)=28

480 C ROUND OFF THE VALUES USING THE ROUND FUNCTION

ETM=ROUND(ETM)
 ETPM=ROUND(ETPM)
 RTM=ROUND(RTM)

485 C OUTPUT THE EVAPOTRANSPIRATION, POTENTIAL EVAPOTRANSPIRATION AND NET
 C RADIATION FOR THE PERIOD.

PRINT 29, RTM, ETPM, ETM

490 C TOTALS FOR MONTHLY MEANS ARE KEPT FOR STATION SUMMARY (IF MEANS=1).

51 TETM(MONNUM) = TETM(MONNUM) + ETM
 TETPM(MONNUM) = TETPM(MONNUM) + ETPM

495 TRTM(MONNUM) = TRTM(MONNUM) + RTM

59 CONTINUE

500 C CHANGE THE YEAR DATE IF THE MONTH NUMBER IS 12(DEC.)

IF (MONNUM .LT. 12) GOTO 60

YEAR = YEAR + 1

60 CONTINUE

505 ***** SET UP OUTPUT FOR STATION SUMMARY *****

IF (MEANS .EQ. 0) GOTO 10
 MEAN = MOD(NN/M,12)

IF (MEAN .NE. 0) GOTO 10

510 MEAN = NN/M/12
 ETMSYR=ETPM5YR=RTM5YR=0.0

DO 70 I=1,12

515 TETM(I) = TETM(I)/MEAN
 TETPM(I) = TETPM(I)/MEAN
 TRTM(I) = TRTM(I)/MEAN

520 ETMSYR = ETMSYR + TETM(I)
 ETPMSYR = ETPMSYR + TETPM(I)
 RTMSYR = RTMSYR + TRTM(I)

70 CONTINUE

C OUTPUT STATION SUMMARY

525 PRINT 28
 PRINT 16, MEAN
 PRINT 17, (HEADNG(I), I=1:3)
 PRINT 18, (MON(I), TRTM(I), TETPM(I), TETM(I), I=1:12)
 PRINT 19
 PRINT 20
 PRINT 21, RTMSYR, ETPMSYR, ETMSYR
 PRINT 22

535 C RETURN TO BEGINNING TO READ ANOTHER STATIONS DATA

GOTO 10

555 STOP

540 C***** FORMAT STATEMENTS *****
 1 FORMAT(A5,I5)
 11 FORMAT("1", "PROGRAM NAME INCORRECTLY SPECIFIED")
 12 FORMAT(3(F9.4,1I))
 112 FORMAT(4(F9.4,1I))
 13 FORMAT("1", 1X, 5A4, "PHID=", F6.2, 6X, "PB", F7.1)
 14 FORMAT(2X, "MN", YR", 7X, "TD", 7X, "T", 8X, "S", T53+A3,
 * 6X, A4, 5X, A3)
 114 FORMAT(2X, "MN", YR", 5X, "TDF", 5X, "TA1F", 4X, "TA2F", 6X, "S", T53+A3,
 * 6X, A4, 5X, A3)
 144 FORMAT(2X, "MN", YR", 7X, "TDF", 7X, "TF", 8X, "S", T53+A3,
 * 6X, A4, 5X, A3)
 114 FORMAT(2X, "MN", YR", 5X, "TD", 6X, "TA1", 5X, "TA2", 7X, "S", T53+A3,
 * 6X, A4, 5X, A3)
 15 FORMAT(1H0, 12X, 2(F7.1+A1, 2X), F7.3, A1)
 115 FORMAT(1H0, 12X, 3(F5.1, A1, 2X), F7.3, A1)
 16 FORMAT(" ", 10X, "MONTHLY TOTALS AVERAGED OVER ", 12, " YEARS")/
 17 FORMAT(" ", 10X, " MN", 12X, A3, 9X, 44+10X, A3//)
 18 FORMAT(" ", 10X, A4, 6X, F8.1, 5X, F8.1, 5X, F8.1//)
 19 FORMAT(" ", 10X, 7A, 3(4A, 9("=")))
 20 FORMAT(" ", 10X, "AVERAGE")
 21 FORMAT(" ", 10X, "YEARLY", 3X, 3(F9.1, 4X))
 22 FORMAT(" ", 10X, "TOTAL")
 23 FORMAT(1X, A5, 1X, I4)
 24 FORMAT(5A4, F5.2, 4X, 11, 12, 3X, I4, F8.2, 2X, F5.0, 1X, 4[2])
 26 FORMAT(2X, I1)
 27 FORMAT(1H0, T55, "PPN", F5.0)
 28 FORMAT(1H1//////////)
 29 FORMAT(1H0, T50, 3(F7.0, 2X))

FUNCTION ROUND 74/74 OPT=1

FTN 4.6+446

14/08/8 14.08.59

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```
1      REAL FUNCTION ROUND(X)
X1=FLOAT(IFIX(X))
REM=ABS(X-X1)*10.
IF(X<=0.0) GO TO 10
I=IFIX(REM)/5
SIGN=X/ABS(X)
ROUND=X1+SIGN*FLOAT(I)
RETURN
10 ROUND=0.0
10 RETURN
END
```

FUNCTION ARCCOS 74/74 OPT=1

FTN 4.6+446

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```
1      REAL FUNCTION ARCCOS(Y)
PI=3.141592654
IF(Y) 100,101,102
100 ARCCOS=PI-ATAN(SQRT((1.-Y**2)/Y**2))
5      RETURN
101 ARCCOS=PI/2.
RETURN
102 ARCCOS=ATAN(SQRT((1.-Y**2)/Y**2))
10 RETURN
END
```

Appendix II
Complete List of Variables Used
in Program REVAP

APPENDIX II

COMPLETE LIST OF VARIABLES USED IN PROGRAM REVAP

VARIABLE

<u>NAME</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
A	Average albedo	
ACOM	Cosine of OMEGA	
AK	Air temperature	(°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 when sun is at zenith	
AZZ	Snow-free, clear sky albedo when sun is at the zenith	
A0	Clear sky albedo	
B	Net long wave radiation loss at T	(Wm ⁻²)
BETA	Constant in computation of vapour pressure	(°C)
CONST1	Constant term used in calculating ETW or EW	(Wm ⁻²)
CONST2	Constant coefficient for calculating ETW or EW	

COSZ	Cosine of the average angular zenith distance of the sun	
CZENA	Cosine of the solar zenith angle	
C1,C2,C3,C4	Alpha-numerics used to indicate an estimated value	
DELTA	Slope of the saturation vapour pressure curve at T	(mb°C ⁻¹)
DELP	Slope of the saturation vapour pressure curve at TP	(mb°C ⁻¹)
DP	Penman weighting factor	
DUST	Turbidity coefficient	
DUSTT	Intermediate calculation used to estimate TAUT	
DV1	Dummy variable (DV1 = 0 for WEVAP; DV1 = 1 for REVAP)	
DV2	Dummy variable (DV2 = 1 for WEVAP; DV2 = 0 for REVAP)	
EE	Vapour transfer coefficient x stability factor x vapour pressure deficit	(Wm ⁻²)
EPM	Potential evapotranspiration for time period	(mm)
ET	Power equivalent of evapotranspiration	(W m ⁻²)
ETM	Evapotranspiration for time period	(mm)
ETM5YR	Sums evapotranspiration for all the station data	(mm)
ETP	Power equivalent of potential evapotranspiration	(Wm ⁻²)

ETPM	Potential evapotranspiration for time period (mm)	
ETPM5YR	Sums potential evapotranspiration for all the station data	(mm)
ETW	Wet environment evapotranspiration	(Wm ⁻²)
EWM	Lake evaporation for time period	(mm)
FMM	Intermediate calculation for period length	
FORM	Input control parameter for no. of temperature readings	
FT	Vapour transfer coefficient	(Wm ⁻² mb ⁻¹)
FTZ(J)	Vapour transfer coefficient x stability factor	(Wm ⁻² mb ⁻¹)
FZ	Coefficient used in computing FTZ(J) and ZETA (FZ = 28.0 for REVAP; FZ = 25.0 for WEVAP)	(Wm ⁻² mb ⁻¹)
G	Incident global radiation	(Wm ⁻²)
GAMMA(J)	Sensible heat transfer coefficient	(mb°C ⁻¹)
GE	Extra-atmospheric global radiation	(Wm ⁻²)
GO	Clear sky global radiation	(Wm ⁻²)
HEADNG(3)	Variable for REVAP or WEVAP headings	
I	Integer counter for station loop and initializations	
II	Integer counter for the no. of periods per month	
IS	Control parameter for sunshine duration	
IT	Control parameter for temperature data	

J	J = 1 for $T \geq 0^{\circ}\text{C}$	
	J = 2 for $T < 0^{\circ}\text{C}$	
L(J)	Latent heat of vaporization (or sublimation)	(W-days mm^{-1})
LAMDA	Heat transfer coefficient	$\text{mb}^{\circ}\text{C}^{-1}$
LNX	Used as argument in calculating TAUT	
LNY	Used as argument in calculating TAUA	
M	No. of time periods per month	
MEAN	No. of years of data	
MEANS	Control parameter for station summary	
MN	Short form for month used as heading	
MONNUM	No. of month (1 to 12)	
N(12)	Array containing no. of days per month	(days)
NAME	Station name	
NETA	Radius vector of sun	
NN	Total no. of records	
OMEGA	Half the angle between sunrise and sunset	(radians)
01,02,03,04	Variables used to indicate an estimated input	
P	Average atmospheric pressure	(mb)
PERIOD	Intermediate calculation for THETA and NETA	
PHI	Latitude	(radians)
PHID	Latitude	(degrees)
PI	Constant = 3.141592654	
PLENGTH	Length of time period	(days)

PPN	Average annual precipitation	(mm)
PROGRM	Program control variable for REVAP or WEVAP	
RHO	Proportional increase in atmospheric radiation due to clouds	
RT	Net radiation at temperature T	(Wm ⁻²)
RTC	RT constrained for use in ZETA estimates	(Wm ⁻²)
RTM	Evaporation equivalent of net radiation for time period	(mm)
RTM5YR	Sum of RTM for all the station data	(mm)
RTP	Net radiation at temperature TP	(Wm ⁻²)
RWM	Evaporation equivalent of water surface net radiation at T	(mm)
S	Ratio of observed to maximum possible sunshine duration	
SB	Surface emissivity x Stefan-Boltzmann constant	(Wm ^{-2 °K-4})
	= 5.22 x 10 ⁻⁸ for REVAP	
	= 5.5 x 10 ⁻⁸ for WEVAP	
SBD	4 x SB	(Wm ^{-2 °K-4})
	= 20.88 x 10 ⁻⁸ for REVAP	
	= 22.0 x 10 ⁻⁸ for WEVAP	
STRTMN	The first month no. of the stations' data	
T	Average air temperature	(°F or °C)

TAUA	Partial transmittancy due to absorption alone	
TAUT	Transmittancy for direct solar radiation	
TA1	Average maximum air temperature	(°C)
TA1F	Average maximum air temperature	(°F)
TA2	Average minimum air temperature	(°C)
TA2F	Average minimum air temperature	(°F)
TD	Average dew point temperature	(°C)
TDF	Average dew point temperature	(°F)
TETM(I)	Total monthly ETM for station summary	(mm)
TETPM(I)	Total monthly ETPM for station summary	(mm)
THETA	Declination of the sun	(radians)
TP	Potential evapotranspiration equilibrium temperature	(°C)
TRTM(I)	Total monthly RTM for station summary	(mm)
TST	Weighting factor for the effects of temperature on turbidity	
TT	Adjustment for time periods shorter than a month	
V	Saturation vapour pressure at T	(mb)
VD	Saturation vapour pressure at TD	(mb)
VP	Saturation vapour pressure at TP	(mb)
VPDL	Vapour pressure deficit	(mb)
W	Precipitable water vapour	(mm)

WVA	Intermediate part of equation for estimating TAUA
WVT	Intermediate part of equation for estimating TAUT
YEAR	Year of climatological observation
YR	Short form for year used as heading
ZENA	Solar zenith angle
ZETA	Stability factor

Appendix III
Areal Evapotranspiration and Lake Evaporation
Programs for Hewlett-Packard HP-67 Hand-Held
Calculator

APPENDIX III

AREAL EVAPOTRANSPIRATION AND LAKE EVAPORATION PROGRAMS FOR HEWLETT-PACKARD HP-67 HAND-HELD CALCULATOR

Preliminary

1. Put programs on cards. Program I occupies both sides of a card, while Programs II, III and IV each occupy only one side of a card. (See program listings starting on page 52)
2. Put program constants on a data card so that they can be loaded into storage registers 10 to 19 inclusive.

Storage Register	Constant
10	237.3
11	17.27
12	28.00
13	0.66
14	28.50
15	265.5
16	21.88
17	28.00 x 1.15
18	0.66 ÷ 1.15
19	28.50 x 1.15

For each set of computations

3. Load program constants into storage registers 10 to 19 inclusive from the data card.
4. Load the station latitude, ϕ , (in degrees) into storage register A.
5. Load the ratio of atmospheric pressure at the station to that at sea level (p/p_s) into storage register B. If pressure observations are available, divide the average by 1013 mbar. If not, use the station altitude in metres above sea level (H) in the following equation:

$$\frac{p}{p_s} = \left\{ 1 - \frac{0.0065H}{288} \right\}^{5.256}$$

6. Load the snow-free zenith albedo (a_{zz}) into storage register C. This is computed using the long-term average precipitation in millimetres per year (P) in:

$$a_{zz} = 0.26 - 0.00012P \left(\frac{p}{p_s} \right)^{0.5} \left[1 + \left| \frac{\phi}{42} \right| + \left(\frac{\phi}{42} \right)^2 \right] \leq 0.17$$

The constraint is applied before a_{zz} is stored in register C. Further constraints are applied in the program, one of which ensures that a_{zz} will not be lower than 0.11. For estimating lake evaporation the value of a_{zz} is 0.05.

7. Load the product of the emissivity and the Stefan-Boltzmann constant into storage register D. For estimating areal evapotranspiration the value is $5.22 \times 10^{-8} \text{ Wm}^{-2} (\text{°K})^{-4}$ and for estimating lake evaporation the value is $5.50 \times 10^{-8} \text{ Wm}^{-2} (\text{°K})^{-4}$.

Note: The contents of storage registers A, B, C and D and 10 to 19 inclusive remain unchanged while the program is working so that they only need to be loaded once.

For each individual computation

8. Load Program I from card.

9. Enter monthly values of dew point temperature ($^{\circ}\text{C}$), air temperature ($^{\circ}\text{C}$), month number and sunshine duration ratio in automatic storage registers T,Z, Y and X respectively.

10. Press Key A.

11. When program stops, enter the number of days in the month (it automatically goes into register X) and then press Key R/S.

12. While Program I is working, put card for Program II in card reader slot. It will load automatically and continue the computations when Program I is finished.

13. While Program II is working, put card for Program III in card reader slot.
14. While Program III is working, put card for Program IV in card reader slot.
15. The first flashing result during the execution of Program IV is the net radiation in mm of evaporation equivalent, the second is the potential evapotranspiration (or potential evaporation) in mm and the third is the areal evapotranspiration (or lake evaporation) in mm. These quantities are also stored in registers 8, 4 and 0 respectively.

Notes(1) The computations for any one month can be continuous with automatic loading of Programs II, III and IV. If for some reason (forgetfulness being the most common) the automatic loading does not take place, the program card in question can be loaded manually and the computation continued by pressing Key A.

(2) The program can be modified to use global radiation observations as input in place of the sunshine duration ratio by changing steps 080 to 098 of Program II as shown in Table III-1. The quantity 2.064 (steps 080 to 084) converts langleyes per day to watts per square metre. If global radiation is measured in MJ/m²/day, replace 2.064 by .0864.

- (3) Table III-2 shows the changes necessary to adapt the HP-67 areal evapotranspiration model to produce estimates of lake evaporation.
- (4) To handle period lengths of fractions of a month the HP-67 program requires a slight modification to the form of input of the "month number" and the number of days in each period. Instead of inputting the "month number" as in step 8, the value i should be input as calculated in the following equation:

$$i = (I + 0.5(m-1))/m$$

where m is the number of periods per month and $I = 1$ for the first period in January and $I = 12 m$ for the last period in December. The value of m is restricted to $m = 1, 2, 3, 5, 6$ to avoid large absolute and percentage variations in the length of the last period in a month. Thus, for the input of the number of days in a period (step 10), there will be a constant number of days for the first $m - 1$ periods in a month, while the last m th period will vary in length depending on the month. Furthermore, step 049 in PROGRAM I should be changed from a "2" to a "4" to obtain more accurate average values of the declination of the sun.

Table III-2
CHANGES REQUIRED TO OBTAIN LAKE EVAPORATION
ESTIMATES INSTEAD OF AREAL EVAPOTRANSPIRATION ESTIMATES

PROGRAM AND STEP NUMBER	FOR AREAL EVAPOTRANSPIRATION ESTIMATES		FOR LAKE EVAPORATION ESTIMATES	
	KEY ENTRY	KEY CODE	KEY ENTRY	KEY CODE
PROGRAM I				
141	.	83	RCL C	34 13
142	9	09	STO 8	33 08
143	1	01	RCL 9	34 09
144	RCL 4	34 04	3	03
145	RCL 6	34 06	3	03
146	÷	81	0	00
147	-	51	÷	81
148	2	02	h RCI	35 34
149	÷	81	+	61
150	RCL C	34 13	h STI	35 33
151	g x>y	32 81	.	83
152	h x \odot y	35 52	2	02
153	.	83	5	05
154	1	01	STO 9	33 09
155	1	01	.	83
156	g x≤y	32 71	2	02
157	h x \odot y	35 52	8	08
158	STO 8	33 08	STO ÷ 9	33 81 09
PROGRAM II				
099	RCL 9	34 09	h RCI	35 34
100	3	03	h RCI	35 34
101	3	03	f INT	31 83
102	0	00	h STI	35 33
103	÷	81	-	51
PROGRAM III				
081	STO 9	33 09	STOx9	33 71 09
PROGRAM IV				
085	4	04	2	02
086	0	00	4	04
089	8	08	6	06
098	RCL 4	34 04	2	02
099	-	51	÷	81

(5) To handle weekly or other irregular periods the same procedure can be used with I equal to the number of days from the beginning of the calendar year to the middle day of the period (using a February of 28.5 days) and with m equal to $(29.5 + I/270)$ or 30.4, whichever is smaller.

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11			h R↓	35 53	
	STO 0	33 00			f COS	31 63	
	h R↓	35 53			g x≤y	32 71	
	R/S	84		060	h x= y	35 52	
	STO 1	33 01			STO 7	33 07	
	h R↓	35 53			h R↑	35 54	
	STO 2	33 02			-	51	
	h R↓	35 53			STO E	33 15	
	STO 3	33 03			h LST x	35 82	
010	f x<0	31 71			g x≤y	32 71	
	h SF 2	35 51 02			ENTER↑	41	
	h R↓	35 53			÷	81	
	1	01			h LST x	35 82	
	0	00		070	h x= y	35 52	
	h ST I	35 33			CHS	42	
	h R↓	35 53			g COS⁻¹	32 63	
	f GSB B	31 22 13			f SIN	31 62	
	STO 4	33 04			h LST x	35 82	
	1	01			g D→R	32 73	
020	6	06			STO 8	33 03	
	h F? 2	35 71 02			÷	81	
	h ST I	35 33			X	71	
	f DSZ	31 33			RCL E	34 13	
	RCL 3	34 03		080	+	61	
	f GSB B	31 22 12			STO E	33 13	
	STO 6	33 06			RCL 8	34 03	
	X	71			h π	35 73	
	÷	81			÷	91	
	X	71			X	71	
030	h 1/x	35 62			RCL Z	34 02	
	STO 5	33 05			1	31	
	2	02			2	71	
	9	09			-	51	
	.	83		090	f SIN	31 62	
	5	05			6	03	
	STO × 2	33 71 02			0	09	
	9	09			÷	81	
	4	04			1	01	
	STO -2	33 51 02			3	03	
040	EEX	43		100	5	05	
	CHS	42			4	04	
	3	03			X	71	
	RCL A	34 11			STO 2	33 02	
	RCL Z	34 02			1	01	
	f SIN	31 62			•	S3	
	2	02			0	00	
	3	03			8	03	
	.	53			g e ^x	32 52	
	2	02		110	•	83	
050	X	71			0	00	
	-	51			1	01	
	h LST x	35 82			2	02	
	f COS	31 63					
	RCL A	34 11					
	f COS	31 63					
	X	71					

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A	B	C	D	E	F	G	H	I	J

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
	STO 8	33 08			RCL 8	34 08	
	RCL 7	34 07		170	.	83	
	9 COS ⁻¹	32 63			3	03	
	STO 9	33 09			4	04	
	X	71			-	51	
	9 e ^x	32 52			X	71	
	RCL 7	34 07			RCL 8	34 08	
120	RCL 8	34 08			+	61	
	h 1/x	35 62			STO x 7	33 71 07	
	9 D→R	32 73			2	02	
	÷	81			1	01	
	RCL 9	34 09		180	RCL 3	34 03	
	F SIN	31 62			9 X>Y	32 81	
	STO 8	33 08			ENTER↑	41	
	+	61			-	51	
	X	71			5	05	
130	-	51			9 X>Y	32 81	
	1	01			h X=F	35 52	
	RCL 8	34 08			RCL B	34 12	
	-	51			1	01	
	÷	81			-	51	
	1	01		190	X	71	
	·	83			9 e ^x	32 52	
	4	04			RCL E	34 15	
	7	07			9 X ²	32 52	
	3	03			5	05	
	÷	81			X	71	
140	STO 7	33 07			·	83	
	·	33			5	05	
	9	09			X	71	
	1	01			h LST x	35 82	
	RCL 4	34 04		200	+	61	
	RCL 6	34 06			X	71	
	÷	81			RCL E	34 15	
	-	51			h PAUSE	35 72	
	2	02			R/S	34	
	÷	81			f LBL B	31 25 12	
150	RCL C	34 13			STO 9	33 09	
	9 X>Y	32 81			RCL (i)	34 24	
	h X≥Y	35 52			+	61	
	·	83			h LST x	35 82	
	1	01		210	f ISZ	31 34	
	1	01			RCL (i)	34 24	
	9 X≤Y	32 71			X	71	
	h X≥Y	35 52			h R↑	35 54	
	STO 8	33 08			÷	51	
	RCL 6	34 06			9 e ^x	35 52	
160	RCL 4	34 04			6	06	
	9 X>Y	32 81		220	·	83	
	ENTER↑	41			1	01	
	-	51			1	01	
	9 X ²	32 52			X	71	
	1	01			h RTN	35 22	
	9 X≤Y	32 71					
	ENTER↑	41					
	-	51					

LABELS					FLAGS		SET STATUS		
A	B	C	D	E	0		FLAGS	TRIG	DISP
a	b	c	d	e	1		ON OFF		
0	1	2	3	4	2		0 <input type="checkbox"/> <input checked="" type="checkbox"/>	DEG <input type="checkbox"/>	FIX <input type="checkbox"/>
5	6	7	8	9	3		1 <input type="checkbox"/> <input type="checkbox"/>	GRAD <input type="checkbox"/>	SCI <input type="checkbox"/>
							2 <input type="checkbox"/> <input checked="" type="checkbox"/>	RAD <input type="checkbox"/>	ENG <input type="checkbox"/>
							3 <input type="checkbox"/> <input type="checkbox"/>		

REVAP - PROGRAM I (continued)

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	+ LBL A	31 25 11			STO ÷ B	33 81 08	
	.	81			÷	81	
	.	83			9 e ^x	32 52	
	9	09		060	RCL B	34 08	
	h y ^x	35 63			CHS	42	
	8	08			9 e ^x	32 52	
	3	03			X	71	
	X	71			h LST Z	35 82	
	STO 8	33 08			h LST X	35 82	
010	2	02			RCL 7	34 07	
	÷	81			X	71	
	RCL B	34 12			1	01	
	RCL E	34 15			+	61	
	÷	81		070	1	01	
	.	83			h R↑	35 54	
	7	07			-	51	
	5	05			X	71	
	h y ^x	35 63			X	71	
	8	08			+	61	
020	9	09			RCL Z	34 02	
	X	71			X	71	
	STO+B	33 61 08			STO E	33 15	
	h R↓	35 53			RCL O	34 00	
	RCL 3	34 03		080	X	71	
	1	01			RCL O	34 00	
	2	02			.	83	
	9	09			3	03	
	÷	81			X	71	
	.	83			.	83	
030	4	04			0	00	
	9	09			5	08	
	+	61			+	61	
	h 1/x	35 62			RCL Z	34 02	
	RCL 4	34 04		090	X	71	
	X	71			1	01	
	RCL E	34 15			RCL O	34 00	
	÷	81			-	51	
	.	83			STO E	33 15	
	6	06			X	71	
040	h y ^x	35 63			+	61	
	2	02			STO B	33 08	
	9	09			RCL E	34 15	
	X	71			RCL 9	34 00	
	STO+B	33 61 08		100	3	03	
	EEX	43			3	03	
	2	02			0	00	
	9 x > y	32 81			÷	81	
	GTO Z	22 02			X	71	
	X	71			1	01	
050	f √x	31 54			-	51	
	h R↑	35 54			RCL 7	34 07	
	f LBL Z	31 25 02			X	71	
	h R↓	35 53			1	01	
	+	61		110	+	61	
	EEX	43			STO X 8	33 71 08	
	3	03			h PAUSE	35 72	

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A	B	C	D	E	F				

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11			STO 7	33 07	
	RCL 4	34 04			2	02	
	RCL 6	34 06			7	07	
	÷	81		060	3	03	
	RCL E	34 15			+	61	
	+	61			X	71	
	I	01			h LST Z	33 82	
	.	83			3	03	
	4	04			h YZ	35 63	
010	2	02			RCL D	34 14	
	9 x > y	32 81			X	71	
	ENTER ↑	41			STO O	33 00	
	-	51			X	71	
	.	83		070	STO + 8	33 61 08	
	I	01			4	04	
	9 x ≤ y	32 71			STO x 0	33 71 00	
	ENTER ↑	41			RCL 8	34 08	
	÷	81			F Z<0	31 71	
	RCL E	34 15			O	00	
020	f √x	31 54			F ISZ	31 34	
	RCL E	34 15			RCL (L)	34 24	
	3 x^2	32 54			RCL B	34 12	
	-	51			f √x	31 54	
	X	71		080	÷	81	
	RCL E	34 15			STO 9	33 09	
	3 x^2	32 54			RCL 6	34 06	
	+	61			RCL 4	34 04	
	RCL B	34 12			-	51	
	.	83			X	71	
030	I	01			÷	81	
	B	08			RCL 5	34 05	
	÷	81			f ISZ	31 34	
	∴	91			RCL (L)	34 24	
	I	01		090	RCL B	34 12	
	+	61			X	71	
	RCL 4	34 04			STO E	33 15	
	.	83			÷	81	
	O	00			X	71	
	O	00			RCL 4	34 04	
040	7	07			RCL 6	34 06	
	RCL B	34 12			÷	81	
	X	71			.	83	
	X	71			2	02	
	.	83		100	8	03	
	7	07			X	71	
	I	01			h LST Z	35 32	
	+	61			+	61	
	X	71			+	61	
	.	83			I	01	
050	9	09			9 x > y	32 81	
	5	05			h x ≠ y	35 52	
	9 x > y	32 71			STO x 9	33 71 09	
	h x ≠ y	35 52			RCL 8	34 08	
	I	01		110	RCL 9	34 02	
	-	51			STO ÷ 0	33 81 00	
	RCL 3	34 03			h PAUSE	35 72	

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A	B	C	D	E			I		

STEP	KEY ENTRY	KEY CODE	COMMENTS	STEP	KEY ENTRY	KEY CODE	COMMENTS	
001	F LBL A	31 25 11			1		01	
	:	81			9 X ≤ Y	32 71		
	STO + 4	33 61 04			GTO 3	22 03		
	RCL E	34 15		060	RCL 3	34 03		
	STO + 0	33 61 00			RCL 7	34 07		
	F ISZ	31 34			-	51		
	RCL (L)	34 24			RCL 9	34 09		
	STO ÷ 1	33 81 01			X	71		
	F DSZ	31 33			STO 2	33 02		
010	F DSZ	31 33			RCL 0	34 00		
	F DSZ	31 33			X	71		
	F LBL 3	31 25 03			RCL 8	34 08		
	RCL 4	34 04		070	+	61		
	RCL 6	34 06			STO 4	33 04		
	RCL 3	34 03			RCL 4	34 04		
	RCL 7	34 07			RCL 2	34 02		
	-	51			RCL E	34 15		
	RCL 0	34 00			X	71		
	X	71			-	51		
020	-	51			STO 6	35 06		
	-	51			RCL E	34 15		
	RCL 0	34 00			RCL 5	34 05		
	RCL 5	34 05			+	61		
	+	61		080	RCL 5	34 05		
	÷	81			÷	81		
	STO 2	33 02			÷	81		
	STO + 7	33 61 07			2	02		
	RCL 7	34 07			·	83		
	F DSZ	31 33			4	04		
030	RCL (i)	34 24			0	00		
	+	61			X	71		
	h LST X	35 82			2	02		
	F ISZ	31 34			8	08		
	RCL (i)	34 24		090	+	61		
	X	71			9 X ≤ Y	32 71		
	h LST X	35 82			h X ≠ Y	35 52		
	RCL 7	34 07			RCL 4	34 04		
	X	71			RCL 4	34 04		
	h R↑	35 54			+	61		
040	÷	81			9 X > Y	32 81		
	0 e^x	32 52			h X ≠ Y	35 52		
	6	06			RCL 4	34 04		
	.	83			-	51		
	!	01		100	RCL 1	34 01		
	!	01			STO x 4	33 71 04		
	X	71			STO x 8	33 71 08		
	STO 6	33 06			X	71		
	X	71			STO 2	33 02		
	÷	81			DSP 0	23 00		
050	X	71			RCL 8	34 08		
	h 1/x	35 62			f -x-	31 84		
	STO 5	33 05			RCL 4	34 04		
	RCL 2	34 02			f -x-	31 84		
	h ABS	35 64		110	RCL 2	34 02		
	.	83			f -x-	31 84		
	O	00			h RTN	35 22		

REGISTERS

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
A	B	C	D	E		I			