HYDROLOGICAL PROCEDURE NO. 17

ESTIMATING POTENTIAL EVAPOTRANSPIRATION USING THE PENMAN PROCEDURE (REVISED AND UPDATED)

1991

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

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Bahagian Pengairan dan Saliran
Kementerian Pertanian
Malaysia

ESTIMATING POTENTIAL EVAPOTRANSPIRATION USING THE PENMAN PROCEDURE (REVISED AND UPDATED)

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TABLE OF CONTENTS

Synopsis

This procedure is a revised and updated version of the Department of Irrigation and Drainage Hydrological Procedure No. 17 (1977) – "Estimating Potential Evapotranspiration using the Penman Procedure". The previous procedure recommended sunshine conversion coefficients 'a' to be 0.24 and 'b' to be 0.51, whereas for this updated version there are recommendations for average annual and monthly values of 'a' and 'b' for different parts of Peninsular Malaysia. The new sunshine conversion coefficients can be expected to give lower evapotranspiration (PE) estimates in the order of 3% to 13% less for most parts of Peninsular Malaysia. For greater accuracy in monthly PE estimates, the user is recommended to use the monthly sunshine conversion coefficients, as differences of up to ± 15% is possible as compared to the case where only the annual sunshine conversion coefficient is used. In addition to this, the list of albedo values for different surfaces is updated and the computer program is also modified to make it more versatile and user friendly.

1. INTRODUCTION

Evapotranspiration is the sum of evaporation and transpiration where evaporation being water evaporating from soils, water surfaces and plants and transpiration is water entering roots and used by or being transpired by the plant. The potential evapotranspiration is defined as the evapotranspiration that would occur if there is an adequate soil-moisture supply at all times.

Physiological and environmental factors controls the rate of evapotranspiration. The volume of water transpired by plants depends on the air temperature, humidity of the air, wind, solar radiation, behaviour of the plant stomata, leaf structure and density. Evaporation from the soil or leaf requires heat to convert liquid into vapour. So evaporation ceases if there is no heat.

2. EVAPOTRANSPIRATION EQUATIONS

The difficulties associated with direct field measurement of evapotranspiration has led to the development of evapotranspiration equations that can relate the evapotranspiration with some climatic data; notably Blaney-Morin (1942), Thornthwaite (1944), Penman (1948), Blaney-Criddle (1950), Halkias-Veihmeyer-Hendrickson (1955) and Hargreaves (1956). The 'Penman equation' is based on the most complete theoretical approach, reflecting that evapotranspiration is directly related to the amount of radiation energy gained by the evaporating surface.

3. THE PENMAN PROCEDURE

Penman's equations consisted of two terms: the energy or radiation term (heat is required for evaporation) and the aerodynamic or wind and humidity term (removal of vapour produced or drying power of the air) which then follows that the energy term predominates and the aerodynamic term is of less significance under calm weather conditions.

The equations then take the following form:

$$PE = \frac{\Delta H + \gamma f(u)(e_m - e_d)}{\Delta + \gamma} \quad ....(1)$$

where: PE = Potential Evapotranspiration in mm/day

H = Heat budget at evaporating surface in equivalent evaporation in mm/day

f(u) = Wind-related function

$(e_m - e_d)$ = Difference between the saturation vapour pressure at mean air temperature and the saturation vapour pressure at mean dew point temperature, both in mm Hg (month).

Δ = Slope of saturation vapour pressure curve of air at absolute temperature T_m, in mm Hg/°C.

γ = Psychrometric constant, 0.49 mm Hg/°C.

3.1 Net Radiation (R_n) or heat budget (H)

The amount of energy or extra terrestrial radiation (Figure 1) reaching the outer limit of the atmosphere (R_a) is dependent on latitude and the time of year only. The amount of solar radiation (R_s) that penetrates the atmosphere and reaches the ground is much less than R_a and is largely dependent on cloud cover. It can be estimated by the empirical formula:-

$$R_s = R_a \left(a + b \frac{n}{N}\right)$$

where a, b = empirical constants converting sunshine hours to short wave radiation.

n = actual duration of bright sunshine in hours for day (month)

N = maximum possible mean daily duration of bright sunshine in hours

A part of R_s is reflected by the evaporating surface as shortwave radiation.

The net amount R_{ns} of shortwave radiation retained at the evaporating surface is:-

$$R_{ns} = R_s (1-r) = R_a (1-r) \left(a+b \frac{n}{N}\right) \quad \text{..... (2)}$$

where r = reflection coefficient or albedo

Some of the net incoming shortwave radiation R_{ns} is reradiated (day and night) as longwave radiation, and the process is most rapid during cloudless and dry weather. The atmosphere itself reradiates but is normally less than the upcoming longwave earth radiation. Empirically, the net outward longwave radiation, R_{nl} can be computed from:

$$R_{nl} = \gamma T_m^4 (0.56 - 0.092 \sqrt{e_d}) \left(0.1 + 0.9 \frac{n}{N}\right) \quad \text{..... (3)}$$

where T_m = mean air temperature in degrees absolute (°K) for day (month)

e_d = saturation vapour pressure in mm Hg at mean dew point temperature for the same period.

γ = Lummer and Pringsheim constant, 117.74×10^{-9}gm. cal/cm²/°K^{-4}

Total net radiation is then $R_n = R_{ns} - R_{nl}$ ..... (4)

Radiation when converted into heat can be related to the energy required to evaporate water from an open surface and is given as equivalent evaporation in mm/day i.e.

H (Heat budget) $= \frac{R_n}{L}$ where $L = 75.56 - 0.0581\, T_m$

3.1.1 Sunshine conversion coefficients 'a' and 'b'

The previous procedure has only a single set of sunshine conversion co-efficients (assumed to be applicable for the whole country i.e. 'a' = 0.24 and 'b' = 0.51) due to limited availability of solar radiation (R_s) and actual sunshine hours (n) data at that time.

In this updated procedure 14 years of such daily meteorological data i.e. 1975 to 1988 from 15 Malaysian Meteorological Service (MMS) stations (Figure 2) are used in the correlation analysis. By correlating the daily values of R_s/R_a against n/N, the respective average annual and monthly sunshine conversion coefficients 'a' and 'b' are obtained as shown in Appendixes 1a & 1b.

The monthly correlation coefficients, R, obtained are quite good ranging from 0.71 to 0.94 and similar to the findings of Hu and Lim (1983) who use meteorological data from 1975 to 1980. The new 'a + b' ranging from 0.64 to 0.74 are generally lower at 1.3% to 15% compared to the old 'a + b' (at 0.75).

To see the effect of a lower 'a' and 'b' on the estimation of PE, runs are made using selected MMS stations and compared with the situation where old 'a' and 'b' are utilised. As expected, the annual PE's obtained are lower, ranging from 3% (50mm) to 13% (200mm) less, while the monthly PE's exhibit differences of up to ± 15% (± 15mm).

3.1.2 Albedo or reflection coefficient (r)

Albedo of the evaporating surface is the ratio of the amount of solar radiation reflected by the surface to the amount incident on it. It is a sensitive parameter in the radiation equation and according to Scarf (1976), an albedo error of 0.01 gives rise to an error of 22mm in the annual evaporation (approx. 1.5%). Albedo values from different investigators both local and foreign are presented in Appendix 4.

3.2 Drying power of the air, i.e. f(u) * ($e_m - e_d$)

Removal of water vapour produced from the surface into the atmosphere is determined by wind and humidity effects as discussed in the following sections.

3.2.1 Wind function f(u) and wind conversion

In this publication the effect of wind on PE has been defined as:

$$f(u) = 0.35\ (1 + 0.526\ U_2) \qquad \ldots\ldots (5)$$

where U_2 is mean wind velocity in m/sec for day (month) at two metres above ground level.

Wind recorded at other heights (h) may be converted to the two metres elevation using either:

(a) the Hellman equation (cit. Toebes and Ouryvaev: 1971)

$$\frac{U_h}{U_2} = 0.3 + 0.844 \log_{10} (h + 4.75)$$

or (b) the logarithmic equation (cit. Ven Te Chow)

$$U_2 = U_h \frac{(\log 2)}{(\log h)}$$

where U_h and U_2 are wind velocities (m/sec.) at heights h and 2 metres respectively.

Because of the low wind profiles, the logarithmic conversion is considered more appropriate for Malaysian conditions.

3.2.2 Saturation vapour pressure deficit ($e_m - e_d$)

PE is also affected by air humidity. Humidity is expressed as saturation vapour pressure deficit ($e_m - e_d$).

Saturation vapour pressure may be calculated using the empirical equations:

$$e_m = e^{(21.0287 - 5326.43/T_m)}$$

and $$e_d = e^{(21.0287 - 5326.43/T_d)}$$

or alternatively, $e_d = e_m \times RH$ (when Td is not available)

where e is the expotential function (2.7183), T_m is the mean air temperature in °K, T_d the mean dew point temperature in °K, and RH the mean relative humidity.

3.3 Psychrometric constant (γ) and slope of the saturation vapour pressure curve ($\triangle$)

The psychrometric "constant" is dependent on atmospheric pressure and varies with altitude. For sea level and an altitude of 3000m the psychrometric constant is 0.51 and 0.35mm Hg/°C respectively. The value of γ is non-sensitive and for the normal working range of $0.51 > \gamma > 0.35$ effects a maximum error to PE of less than 1%. Corrections for γ are not necessary and a constant value of 0.49 mm Hg/°C is assumed.

The slope of the saturation vapour pressure curve, △ in mm Hg/°C is represented by the following equation:-

$$\triangle = \frac{5326.4}{T_m^2} e_m$$

4. CALCUI ATION PROCEDURE

Calculation procedure is best explained by way of actual example. Tabulated below are the mean monthly climate data observed for January 1987 at Kota Bahru Airport, at latitude approximately 6°N.

Mean air temperature	= 25.8°C
Mean relative humidity (RH)	= 79%
Mean sunshine hours	= 6.6 hours/day
Mean wind velocity	= 4.2 m/s at 14.0 m above ground level

The annual and monthly sunshine conversion coefficients 'a' and 'b' for the various climate stations are given in Appendices 1a & 1b. Tables showing mean daily extraterrestrial radiation (R_a) and maximum possible duration of bright sunshine (N) for Malaysia are given in Appendices 2 and 3 respectively. Albedo and saturation vapour pressure are given in Appendices 4 and 5.

4.1 Data preparation

From the appropriate appendix it is found that:

a = 0.22 }
b = 0.42 } (Corresponding to month of January)

R_a = 785 gm. cal/cm²/day (corresponding to January and 6°N)

N = 11.8 hours (corresponding to January and 6°N)

e_m = 24.83 mm Hg (corresponding to mean air temperature 25.8°C)

e_d = 19.62 mm Hg (i.e. $e_d = e_m \times RH$ or alternatively if T_d is available instead of RH, then look up Appendix 5 for e_d corresponding to mean dew point temperature, T_d in °C).

U_2 = 1.10 m/sec at 2m (converted from 4.2m/sec at 14.0m)

r = 0.23 (corresponding to cover for crops)

T_m = 25.8 + 273.16 = 298.96°K

4.2 Heat budget at evaporating surface (H)

Substituting the appropriate values into equation (2), (3) and (4) and calculating section by section gives:-

(a) $R_{ns} = R_a\left(a + b\frac{n}{N}\right)(1-r)$

$= 785\left(0.22 + 0.42 \times \frac{6.6}{11.8}\right)(1-0.23)$

$= 275.0$ gm cal/cm²/day

(b) $R_{nl} = \gamma T_m^4 (0.56 - 0.092\sqrt{e_d})\left(0.1 + 0.9\frac{n}{N}\right)$

$= 117.74 (10^{-9}) (298.96)^4 (0.56 - 0.092\sqrt{19.62})\left(0.1 + 0.9 \times \frac{6.6}{11.8}\right)$

$= 86.54$ gm. cal/cm²/day

(c) $R_n = R_{ns} - R_{nl} = 275.0 - 86.54$

$= 188.46$ gm. cal/cm²/day

(d) Convert R_n to equivalent evaporation in mm/day

i.e. $H = \frac{R_n}{L} = \frac{188.46}{58.19}$ = **3.24 mm/day**

where $L = 75.56 - 0.0581\ T_m = 75.56 - 0.0581\ (298.96) = 58.19$

4.3 **Drying power of air: $f(u) * (e_m - e_d)$**

Substituting the appropriate values into equation (5) and multiplying into $(e_m - e_d)$ gives $f(u) * (e_m - e_d) = 0.35\ (1 + 0.526 \times 1.10)\ (24.83 - 19.62)$

= **2.88 mm/day**

4.4 **Potential evapotranspiration (PE)**

Combining the results of section 4.2 and 4.3, the potential evapotranspiration according to equation (1) is:-

$$PE = \frac{1.479\ \mathbf{(3.24)} + 0.49\ \mathbf{(2.88)}}{1.479 + 0.49}$$

= **3.15 mm/day**

$$\text{where } \triangle = \frac{5326.4 \times e_m}{T_m^{\ 2}} = \frac{5326.4 \times 24.83}{(298.96)^2} = 1.479 \text{ mm Hg/°C}$$

Thus the total evapotranspiation for the month of January is estimated at 3.15 mm/day x 31 days

= **98 mm**

5. PROGRAMMED CALCULATION

A computer program (PEN 91. FOR) is developed for the Penman equations. The Hargreaves equation is also included for comparison purposes. The program supplied in a diskette with this publication is written in Fortran VII and can be run on personal micro computers. A listing of the program is shown in Appendix 6. Data input sequence are shown in Appendix 7. The procedures for using the program is as shown in Appendix 8. An example of the output is shown in Appendix 9.

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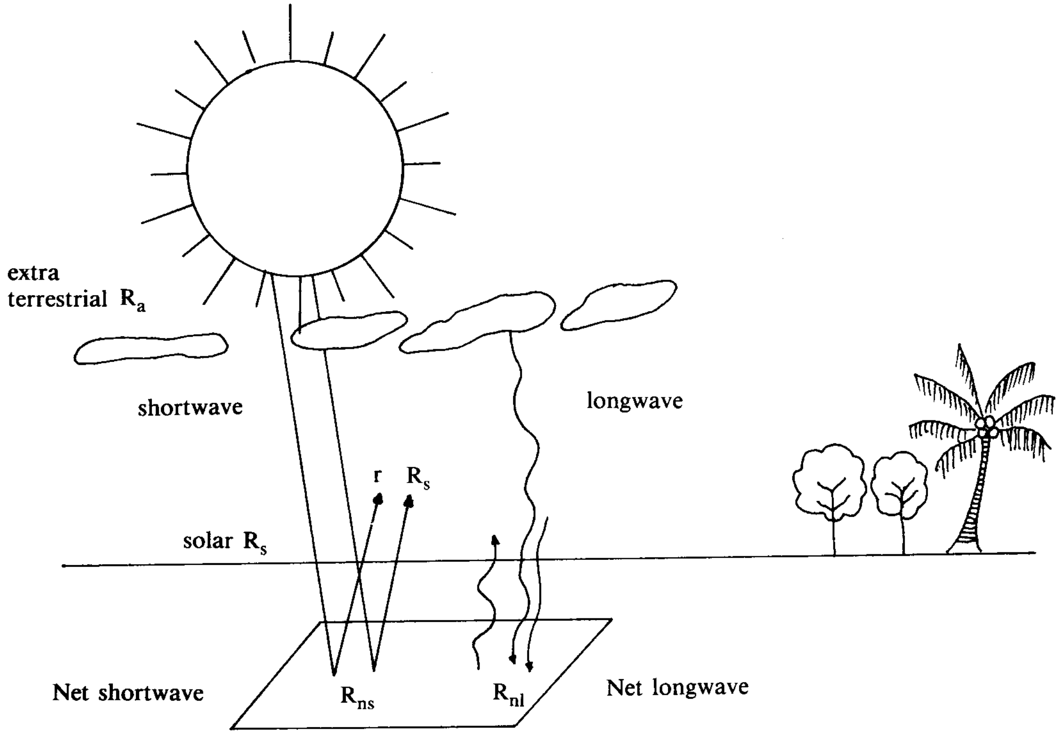

Net radiation R_n = net solar radiation R_{ns} − net longwave radiation R_{nl}

$$= (1-r)\,R_s - R_{nl}$$

FIGURE 1. ILLUSTRATION OF THE RADIATION BALANCE (After Doorenbos and Pruitt)

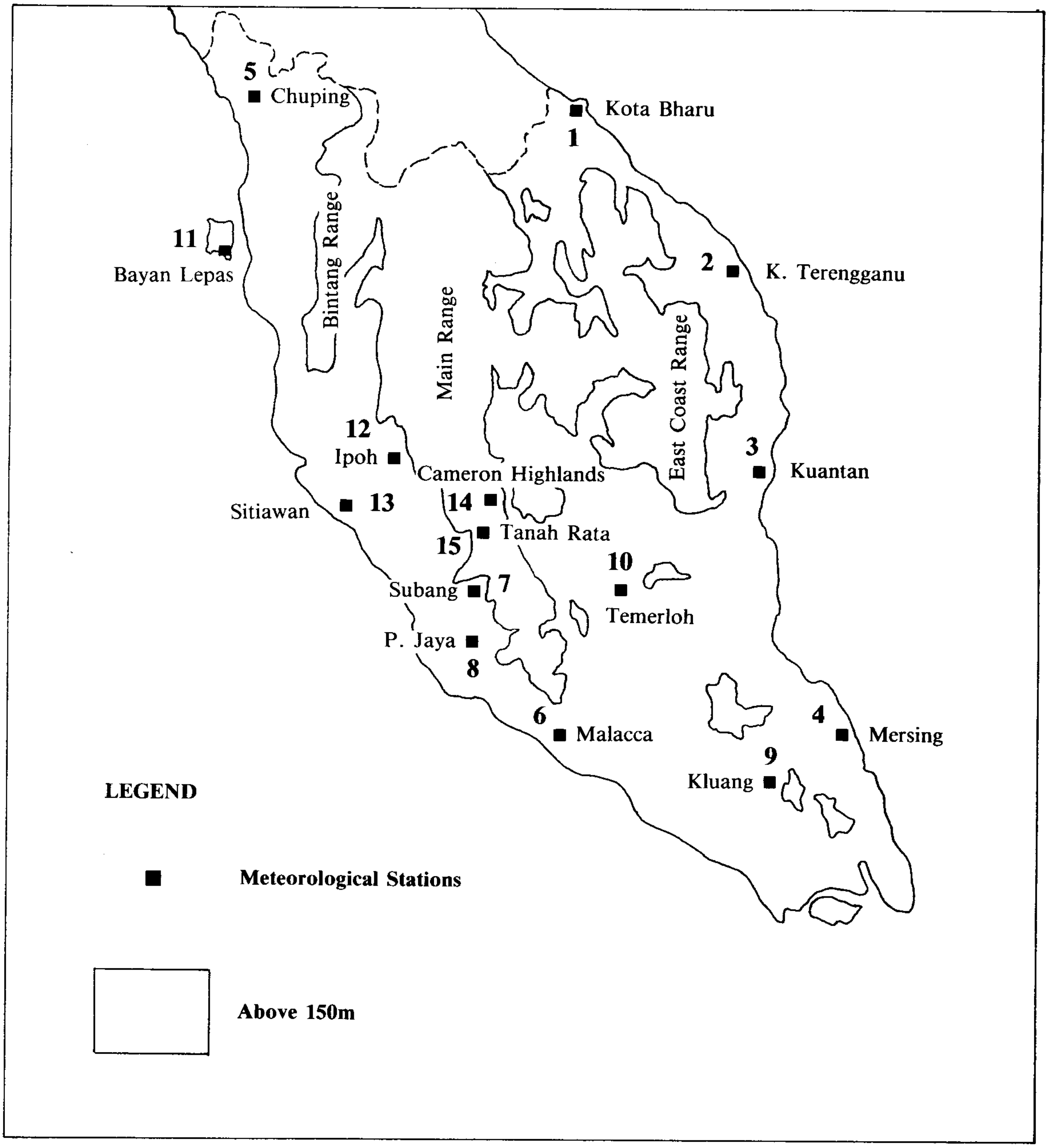

FIGURE 2. LOCATION OF METEOROLOGICAL STATIONS

APPENDIX 1a.

ANNUAL SUNSHINE CONVERSION COEFFICIENTS 'a' & 'b' FOR VARIOUS METEOROLOGICAL STATIONS IN PENINSULAR MALAYSIA.

	Station Name (Number)	Latitude	a	b	Period
1.	Kota Bharu (48615)	06° 10'N	0.24	0.41	1975 – 88
2.	Kuala Terengganu (48619)	05° 23'N	0.24	0.48	1976 – 84
3.	Kuantan (48657)	03° 47'N	0.26	0.40	1979 – 88
4.	Mersing (48674)	02° 27'N	0.24	0.49	76 – 78/82 – 88
5.	Chuping (41630)	06° 29'N	0.25	0.47	1980 – 88
6.	Malacca (48665)	02° 16'N	0.25	0.43	1976 – 88
7.	Subang (48647)	03° 07'N	0.25	0.39	1975 – 88
8.	Petaling Jaya (48648)	03° 06'N	0.26	0.41	1976 – 88
9.	Kluang (48672)	02° 01'N	0.25	0.45	1977 – 88
10.	Temerloh (48653)	03° 28'N	0.27	0.41	1979 – 88
11.	Bayan Lepas (48601)	05° 18'N	0.26	0.45	1975 – 88
12.	Ipoh (48625)	04° 34'N	0.27	0.44	1976 – 88
13.	Sitiawan (48620)	04° 13'N	0.26	0.42	1976 – 88
14.	Cameron Highlands (48632)	04° 28'N	0.20	0.48	1985 – 88
15.	Tanah Rata (48631)	04° 28'N	0.24	0.50	1976 – 84

Average annual for Peninsular Malaysia		0.25	0.44

Note: Numbering of meteorological station according to MMS.

APPENDIX 1b. MONTHLY SUNSHINE CONVERSION COEFFICIENTS 'a' & 'b' AND CORRELATION COEFF. R, FOR METEOROLOGICAL STATIONS LISTED IN APPENDIX 1a

Station	Kota Bharu			K. Terengganu			Kuantan			Mersing			Chuping		
Latitude	06° 10'N			05° 23'N			03° 47'N			02° 27'N			06° 29'N		
Longitude	102° 17'E			103° 06'E			103° 13'E			103° 50'E			100° 16'E		
Height	4.6m			5.2m			15.3m			43.6m			21.7m		
Month	a	b	R	a	b	R	a	b	R	a	b	R	a	b	R
Jan	0.22	0.42	0.85	0.24	0.48	0.88	0.24	0.42	0.93	0.21	0.59	0.94	0.24	0.45	0.86
Feb	0.25	0.40	0.85	0.25	0.47	0.84	0.25	0.38	0.91	0.27	0.50	0.93	0.27	0.42	0.78
Mar	0.22	0.45	0.83	0.19	0.52	0.79	0.24	0.43	0.91	0.29	0.44	0.87	0.22	0.49	0.87
Apr	0.24	0.39	0.72	0.24	0.47	0.85	0.24	0.39	0.88	0.27	0.44	0.82	0.22	0.47	0.86
May	0.26	0.39	0.82	0.25	0.47	0.88	0.27	0.39	0.89	0.24	0.50	0.86	0.25	0.47	0.74
Jun	0.27	0.36	0.88	0.27	0.43	0.87	0.29	0.35	0.84	0.23	0.47	0.84	0.34	0.36	0.77
Jul	0.27	0.35	0.71	0.28	0.42	0.86	0.29	0.36	0.88	0.25	0.45	0.87	0.27	0.52	0.84
Aug	0.29	0.36	0.86	0.27	0.45	0.85	0.30	0.34	0.90	0.27	0.41	0.79	0.30	0.45	0.73
Sep	0.28	0.38	0.86	0.25	0.49	0.87	0.27	0.38	0.89	0.24	0.47	0.73	0.22	0.60	0.76
Oct	0.24	0.44	0.85	0.23	0.48	0.93	0.27	0.39	0.88	0.22	0.53	0.76	0.22	0.49	0.77
Nov	0.17	0.52	0.88	0.16	0.55	0.92	0.22	0.46	0.89	0.20	0.53	0.84	0.20	0.42	0.78
Dec	0.17	0.48	0.86	0.19	0.56	0.90	0.20	0.49	0.86	0.18	0.54	0.78	0.22	0.47	0.93
Average	0.24	0.41		0.24	0.48		0.26	0.40		0.24	0.49		0.25	0.47	

APPENDIX 1b. MONTHLY SUNSHINE CONVERSION COEFFICIENTS 'a' & 'b' AND CORRELATION COEFF. R, FOR METEOROLOGICAL STATIONS LISTED IN APPENDIX 1a

Station	Malacca			Subang			Petaling Jaya			Kluang			Temerloh		
Latitude	02° 16'N			03° 07'N			03° 06'N			02° 01'N			03° 28'N		
Longitude	102° 15'E			101° 33'E			101° 39'E			103° 19'E			102° 23'E		
Height	8.5m			16.5m			45.7m			38.1m			39.1m		
Month	a	b	R	a	b	R	a	b	R	a	b	R	a	b	R
Jan	0.25	0.43	0.90	0.24	0.40	0.71	0.26	0.42	0.86	0.23	0.50	0.92	0.25	0.44	0.93
Feb	0.24	0.43	0.91	0.24	0.42	0.88	0.25	0.42	0.89	0.26	0.46	0.91	0.27	0.41	0.91
Mar	0.24	0.44	0.90	0.24	0.41	0.75	0.23	0.46	0.85	0.23	0.51	0.92	0.25	0.45	0.81
Apr	0.24	0.42	0.90	0.24	0.39	0.84	0.25	0.40	0.87	0.23	0.47	0.85	0.26	0.41	0.88
May	0.23	0.44	0.90	0.25	0.40	0.77	0.26	0.41	0.88	0.26	0.43	0.80	0.29	0.41	0.86
Jun	0.25	0.41	0.90	0.29	0.31	0.80	0.27	0.36	0.84	0.25	0.42	0.86	0.28	0.36	0.80
Jul	0.25	0.43	0.92	0.26	0.39	0.87	0.25	0.42	0.85	0.26	0.40	0.74	0.27	0.40	0.85
Aug	0.24	0.44	0.89	0.26	0.38	0.83	0.27	0.38	0.80	0.24	0.45	0.85	0.29	0.35	0.78
Sep	0.26	0.42	0.89	0.24	0.41	0.77	0.27	0.37	0.82	0.26	0.42	0.81	0.26	0.41	0.71
Oct	0.24	0.45	0.76	0.25	0.41	0.74	0.26	0.43	0.87	0.27	0.44	0.86	0.29	0.38	0.75
Nov	0.25	0.40	0.89	0.24	0.40	0.85	0.25	0.41	0.82	0.25	0.45	0.87	0.23	0.47	0.81
Dec	0.26	0.42	0.92	0.25	0.39	0.73	0.27	0.39	0.79	0.24	0.50	0.92	0.24	0.43	0.81
Average	0.25	0.43		0.25	0.39		0.26	0.41		0.25	0.45		0.27	0.41	

APPENDIX 1b. MONTHLY SUNSHINE CONVERSION COEFFICIENTS 'a' & 'b' AND CORRELATION COEFF. R, FOR METEOROLOGICAL STATIONS LISTED IN APPENDIX 1a

Station	Bayan Lepas			Ipoh			Sitiawan			Cameron Highlands			Tanah Rata		
Latitude	05° 18'N			04° 34'N			04° 13'N			04° 28'N			04° 28'N		
Longitude	100° 16'E			101° 06'E			100° 42'E			101° 23'E			101° 22'E		
Height	2.8m			39.0m			7.0m			1471.0m			1545.0m		
Month	a	b	R	a	b	R	a	b	R	a	b	R	a	b	R
Jan	0.28	0.42	0.90	0.28	0.41	0.87	0.26	0.43	0.87	0.28	0.45	0.89	0.23	0.50	0.89
Feb	0.29	0.39	0.72	0.25	0.47	0.88	0.20	0.50	0.86	0.14	0.61	0.94	0.21	0.54	0.89
Mar	0.29	0.39	0.75	0.26	0.45	0.86	0.28	0.38	0.82	0.23	0.45	0.89	0.20	0.56	0.89
Apr	0.23	0.48	0.77	0.24	0.47	0.87	0.26	0.39	0.86	0.17	0.50	0.91	0.22	0.49	0.81
May	0.25	0.45	0.89	0.28	0.45	0.86	0.27	0.41	0.80	0.25	0.40	0.75	0.23	0.53	0.87
Jun	0.26	0.41	0.89	0.29	0.40	0.87	0.26	0.40	0.88	0.22	0.43	0.85	0.27	0.46	0.83
Jul	0.25	0.43	0.84	0.29	0.41	0.82	0.27	0.41	0.85	0.20	0.50	0.88	0.26	0.50	0.88
Aug	0.25	0.46	0.87	0.29	0.42	0.81	0.29	0.37	0.84	0.20	0.48	0.83	0.27	0.48	0.87
Sep	0.23	0.53	0.89	0.28	0.41	0.82	0.27	0.41	0.88	0.18	0.50	0.86	0.24	0.52	0.86
Oct	0.23	0.50	0.86	0.27	0.44	0.83	0.26	0.43	0.85	0.17	0.51	0.81	0.24	0.51	0.87
Nov	0.24	0.46	0.88	0.26	0.42	0.85	0.25	0.42	0.89	0.21	0.41	0.80	0.25	0.45	0.80
Dec	0.28	0.43	0.92	0.25	0.52	0.92	0.26	0.48	0.92	0.17	0.53	0.72	0.26	0.50	0.90
Average	0.26	0.45		0.27	0.44		0.26	0.42		0.20	0.48		0.24	0.50	

APPENDIX 2: MEAN DAILY EXTRATERRESTRIAL RADIATION (Ra) IN LANGLEYS (gm. cal/cm²/day)
(after Angott; Smithsonian Meteorolotical Tables: 1958)

Latitude	Month											
North	J	F	M	A	M	J	J	A	S	O	N	D
1	833	858	878	881	811	814	800	824	892	863	864	820
2	824	852	877	883	817	823	806	830	891	858	854	810
3	814	846	876	887	825	831	815	834	891	853	845	798
4	804	840	875	890	832	839	823	839	890	848	836	786
5	794	833	874	893	839	847	830	843	889	842	827	774
6	785	826	873	896	845	856	837	848	888	835	818	762

APPENDIX 3: MEAN POSSIBLE DAILY DURATION OF BRIGHT SUNSHINE (N) IN HOURS

(after Thornthwaite and Mather 1957)

Latitude	Month											
North	J	F	M	A	M	J	J	A	S	O	N	D
1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
2	12.1	12.1	12.1	12.1	12.2	12.2	12.1	12.1	12.1	12.1	12.0	12.0
3	12.0	12.0	12.0	12.1	12.2	12.2	12.2	12.1	12.1	12.1	12.0	12.0
4	12.0	12.0	12.0	12.2	12.3	12.4	12.2	12.2	12.1	12.0	12.0	11.8
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.2	12.1	12.0	11.9	11.8
6	11.8	11.9	12.0	12.2	12.3	12.5	12.3	12.2	12.1	12.0	11.9	11.7

APPENDIX 4: TABLE OF ALBEDO VALUES (r) FOR VARIOUS SURFACES

Surface	Investigators	Albedo	Albedo
Open Water	Wiesner (1970): Dependent on angle of incidence	0.04 – 0.39	0.07
	E.A.A.F.R.O. (1962): For sunken pan	0.09	
	Stanhill et. al. (1966): For lake in Israel	0.11	
	USGS (1954): For sun altitudes above 55; Lake Hefner Studies	0.05 – 0.07	
Grass	E.A.A.F.R.O. (1962)	0.21	
	Angstrom (1925)	0.22 – 0.33	
	Budyko (1956)	0.15 – 0.25	0.21
	Barry and Chambers (1966)	0.22 – 0.26	
	Baumgartner (1967)	0.23	
	Weisner (1970)	0.26	
	Stanhill et.al. (1966)	0.20	
	Sutton (1953)	0.25 – 0.33	
	Monteith and Szeicz (1961)	0.25 – 0.27	
	Van Wijk (1963)	0.16 – 0.27	
	Ling and Robertson (1982)*	0.16 – 0.28	
	Tan and Rajaratnam (1975)	0.20	
Tropical Forest	Pinker et.al. (1980): For forest in Thailand	0.12	0.12
	Shuttleworth et.al. (1984)	0.12 – 0.13	
Crops	Budyko (1956)	0.10 – 0.25	0.23
	Monteith (1959)	0.25 – 0.27	
	Barry and Chambers (1956)	0.24 – 0.25	
	Baumgartner (1967)	0.20	
	Wiesner (1970)	0.26	
Towns	Barry and Chambers	0.17	0.17
Legumes	Ling and Robertson (1982)*	0.17 – 0.28	0.21
Oil Palm	Ling and Robertson (1982)*	0.12 – 0.25	0.18
Cocoa	Ling and Robertson (1982)*	0.13 – 0.25	0.19

*Experiments conducted at Tun Razak Agricultural Research Centre, Jerantut, Pahang.

APPENDIX 5: SATURATION VAPOUR PRESSURE in mm Hg

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	9.19	9.25	9.31	9.37	9.44	9.50	9.56	9.63	9.69	9.75
11	9.82	9.88	9.95	10.01	10.08	10.14	10.21	10.28	10.35	10.42
12	10.48	10.55	10.62	10.69	10.76	10.83	10.90	10.98	11.05	11.12
13	11.19	11.27	11.34	11.41	11.49	11.56	11.64	11.71	11.39	11.86
14	11.94	12.02	12.10	12.17	12.25	12.33	12.41	12.49	12.57	12.65
15	12.74	12.82	12.90	12.98	13.07	13.15	13.23	13.32	13.40	13.49
16	13.58	13.66	13.75	13.84	13.93	14.01	14.10	14.19	14.28	14.37
17	14.47	14.56	14.65	14.78	14.84	14.93	15.02	15.20	15.21	15.31
18	15.41	15.50	15.60	15.70	15.80	15.90	16.00	16.10	16.20	16.30
19	16.40	16.51	16.61	16.71	16.80	16.92	17.03	17.13	17.24	17.35
20	17.46	17.57	17.67	17.78	17.89	18.00	18.12	18.23	18.34	18.45
21	18.57	18.68	18.80	18.91	19.03	19.15	19.27	19.38	19.50	19.62
22	19.74	19.86	19.98	20.10	20.23	20.35	20.48	20.60	20.73	20.86
23	20.98	21.11	21.24	21.37	21.50	21.63	21.76	21.89	22.03	22.16
24	22.29	22.43	22.56	22.69	22.84	22.97	23.11	23.25	23.39	23.53
25	23.67	23.82	23.96	24.10	24.25	24.39	24.54	24.69	24.84	24.98
26	25.13	25.28	25.43	25.58	25.74	25.89	26.04	26.20	26.35	26.51
27	26.67	26.82	26.98	27.14	27.30	27.46	27.63	27.79	27.96	28.12
28	28.28	28.45	28.62	28.79	28.96	29.13	29.30	29.47	29.64	29.81
29	29.99	30.17	30.34	30.52	30.70	30.88	31.06	31.24	31.42	31.60
30	31.78	31.97	32.16	32.34	32.53	32.72	32.91	33.10	33.29	33.48

APPENDIX 6: LISTING OF PROGRAM

```
C
C ***********************************************************
C*
C*
C*                  PROGRAM PEN91. FOR
C*
C*             Water Resources Assessment Section,
C*                     Hydrology Branch,
C*            Department of Irrigation and Drainage,
C*                         Malaysia
C*                           1991
C*
C ***********************************************************
C
C
C ***********************************************************
C ***********************************************************

C       PROGRAM CALCULATES MONTHLY EVAPOTRANSPIRATION USING:
      - (A) PENMAN EQUATIONS AND (B) HARGREAVES EQUATION
C         WIND VELOCITY CORRECTION EQUATION: U2 = U(ANHT)*(LOG 2/LOG
C       (ANHT)) U2 = METRES/SEC @ 2M HEIGHT, U(ANHT) = METRES/SEC @
C       ANHT M HEIGHT UP TO 1974 MMS WIND VEL. IS IN KNOTS (1 KNOT = 0.5147
C       M/S) THEREFORE VELOCITY CORRECTION, WFAC = 0.5147*LOG 2/LOG
C       (ANHT) = 0.357/LOG(ANHT) AFTER 1974 MMS WIND VEL. IS IN M/S WFAC =
C       LOG 2/LOG(ANHT)=0.693/LOG(ANHT) THEREFORE IN THIS PROGRAMME
C       WIND(J) IS IN KNOTS UP TO 1974 AND AFTER 1974 ALSO FOLLOWING MMS
C       PUBLICATION, TEMP(J) IS ENTERED AS DEGREES F AND AS DEGREES C
C       AFTER 1974

        DIMENSION IRA(6,12), SMAX(6,12), HFACT(6,12), ALB(9), SUN(12),
      *TMEAN(12), RH(12), WIND(12), IEVAP(15,12,3), JEVAP(15,12), ITOT(15,3),
      *JTOT(15), NDAY(12), MTOT(12,3), NTOT(12), NAME(20), MBIG(12,3),
      *MSMALL(12,3), NBIG(12), NSMALL(12), LTOT(3), KK(12)
        DIMENSION VALB(9)
        DIMENSION A(12), B(12)
        CHARACTER NFILE(12)*1, CNFILE*12
        CHARACTER RSTN(5)*1, STSITE(10)*1, SSITE*10
        CHARACTER VLSITE(10)*1, VSITE*10, FRAD*10, FBSS*10
        CHARACTER *45 SURFACE(9), NAMESF(9)
        CHARACTER *3 KODA(9), EXSURF(9)
        CHARACTER *10 OUTNAME, SCALE
        CHARACTER *1 UJI, CHOALB, CSCALE, YN, CHTDAB
        CHARACTER *50 TAJUK, CETAK
        CHARACTER *4 MONTH(12), TEST
        INTEGER STNO, NAME, SITN, IER, P1, P2, CHOICE
        INTEGER PILIH, LS(15), guard
C       EQUIVALENCE (CNFILE, NFILE)
        EQUIVALENCE (STSITE(1), SSITE), (VLSITE(1), VSITE)
        DATA NDAY/31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31/
C          DATA MONTH/'Jan.', 'Feb.', 'Mac.', 'Apr.', 'May.', 'Jun.', 'Jul.', 'Aug.',
```

```
C      –                 'Sep.', 'Oct.', 'Nov.', 'Dec.'/
        MONTH (1)= 'Jan.'
        MONTH (2)= 'Feb.'
        MONTH (3)= 'Mac.'
        MONTH (4)= 'Apr.'
        MONTH (5)= 'May'
        MONTH (6)= 'Jun.'
        MONTH (7)= 'Jul.'
        MONTH (8)= 'Aug.'
        MONTH (9)= 'Sep.'
        MONTH (10)= 'Oct.'
        MONTH (11)= 'Nov.'
        MONTH (12)= 'Dec.'
C
C
C
C       READ IN STATION IDENTIFICATION
C
        OPEN (10, FILE = 'IN.DAT', STATUS = 'OLD')
C
        write (*,595)
  595   format ('List of output filename:')
 9999   READ (10,300) RSTN
  300   FORMAT(5A1)
  101   FORMAT(A)
        SCALE = 'M/S'
C
        STSITE (1) = 'S'
        VLSITE (1) = 'V'
        DO 214 IJ = 1,5
            STSITE (IJ+1) = RSTN(IJ)
            VLSITE (IJ+1) = RSTN(IJ)
  214   CONTINUE
        STSITE (7) = '.'
        VLSTITE (7) = '.'
        STSITE (8) = 'D'
        VLSITE (8) = 'D'
        STSITE (9) = 'A'
        VLSITE (9) = 'A'
        STSITE (10) = 'T'
        VLSITE (10) = 'T'
C
        OPEN (2, FILE = SSITE)
        OPEN (3, FILE = 'ALBEDO.DAT')
        OPEN (4, FILE = VSITE)
        OPEN (7, FILE = 'RAD1.DAT')
        OPEN (8, FILE = 'BSS.DAT')
        OPEN (9, FILE = 'FACT.DAT')
C
C       READ RADIATION DATA
          DO 77 I = 1,10
              READ (7,*,END = 216) (IRA(I,J), J = 1,12)
              READ (8,*) (SMAX(I,K), K = 1,12)
              READ (9,*) (HFACT(I,L), L = 1,12)
   77       CONTINUE
C           STNO = STATION NUMBER
C           NAME = STATION NAME
C           LATD = LATITUDE IN DEGREES
```

```
C           LATM = LATITUDE IN MINUTES
C           LOND = LONGITUDE IN DEGREES
C           LONM = LONGITUDE IN MINUTES
C           LEV = STATION ELEVATION
C           ANHT = HEIGHT ABOVE GROUNDLEVEL AT WHICH WIND VELOCITY
C    -                IS MEASURED
C
  216   JM=0
        DO 111 II = 1,50
            JM = JM+1
            READ (3,2112, END = 215) KODA(JM), NAMESF(JM), VALB(JM)
C           WRITE(*,2122)JM,NAMESF(JM),VALB(JM)
 2112       FORMAT (A3, 1X,A30,F4.3)
  111   CONTINUE
C
  215   READ (10,4002)CHOALB
 4002   FORMAT(A)
          IF (CHOALB.EQ.'Y'.OR.CHOALB.EQ.'y') THEN
            READ (10,*) JUM
            READ (10,*) (LS(JIK), JIK = 1, JUM)
          ELSE
            READ (10,*) JUM
            DO 4004 MN = 1, JUM
              READ (10,*) ALB (MN)
              READ (10,4007) SURFACE(MN)
 4007         FORMAT(A)
 4004       CONTINUE
          ENDIF
        READ (4,*) (A(JJ), JJ=1,12)
        READ (4,*) (B(JJ), JJ=1,12)
C
C
        IF (CHOALB.EQ.'Y'.OR.CHOALB.EQ.'y') THEN
          DO 1000 IJI=1, JUM
            DO 1001 IJJ=1,JM
              IF (LS(IJI).EQ.IJJ) THEN
                SURFACE(IJI)=NAMESF(LS(IJI))
                ALB(IJI)=VALB(LS(IJI))
              ENDIF
 1001       CONTINUE
 1000     CONTINIUE
        ENDIF
C
C
        AA=0.0
        BB=0.0
        DO 213 LL=1,12
        AAA=AA+A(LL)
        BB=BB+B(LL)
  213   CONTINUE

        AYEAR=AA/12
        BYEAR=BB/12
C
        READ(10,*)CHOICE
C
            IF (CHOICE.EQ.1) THEN
                P1=1
                P2=1
```

```
          ELSE
               IF (CHOICE.EQ.2) THEN
               P1=2
               P2=2
          ELSE
               P1=1
               P2=2
            ENDIF
          ENDIF
C
        DO 1010 PILIH=P1, P2
          LU=PILIH+12
          READ(10,2)OUTNAME
          write(*,3)outname
3         format('      ',a)
          OPEN(LU,FILE=OUTNAME,STATUS='NEW')
C
          READ(2,94,END=99)STNO,NAME,LATD,LATM,LOND,LONM,LEV,ANHT
94        FORMAT(I5,2X,20A2,1X,I2,I2,IX,I3,I2,IX,I4,F5.2)

C       INITIALISE FIRST YEAR OF DATA AND LATITUDE

          READ(2,95)II
95        FORMAT(I4)

C       CHOOSE DEW POINT TEMPERATURE (DEGREES CELCIUS) OR RELATIVE
C       HUMID (%)

          READ(2,4002)TEST
          K=LATD+(LATM+30)/60
          KTOT=0
C
          DO 20 I=I,15
            JTOT(I)=0
          DO 20J=1,12
            NTOT(J)=0
            NBIG(J)=0
            NSMALL(J)=500
            JEVAP(I,J)=0
          DO 20 N=1,JUM
            LTOT(N)=0
            ITOT(I,N)=0
            MTOT(J,N)=0
            MBIG(J,N)=0
            MSMALL(J,N)=500
            IEVAP(I,J,N)=0
20          CONTINUE
C       READ IN CLIMATE DATA
C         SITN = STATION NUMBER
C         IY = YEAR
C         SUN(J)=MEAN DAILY SUNSHINE HOURS
C         TMEAN(J)= MEAN DAILY TEMPERATURE IN DEGS. F UP TO 1974,DEGS.C
C         RH(J) = MEAN RELATIVE HUMIDITY (%)
C         WIND(J) = MEAN DAILY WIND VELOCITY IN KNOTS UP TO 1974, IN M/S A
C         READ IN CLIMATE DATA FOR FIRST FOUR MONTHS
C

            DO 50 J=1,12
50          KK(J)=0
```

```
12      READ(2,96,END = 13)SITN,IY,(SUN(J),TMEAN(J),RH(J),WIND(J),J = 1
96      FORMAT(I5,I4,1X,4(4F4.1))

C       TEST FOR INCOMPATIBLE DATA
C           READ IN CLIMATE DATA FOR REMAINING EIGHT MONTHS

                READ(2,97) (SUN(J),TMEAN(J),RH(J),WIND(J),J = 5,12)
97              FORMAT(10X,4(4F4.1)/10X,4(4F4.1))
                I = IY - II + 1
                NDAY(2) = 28
                IF(MOD(IY,4).EQ.0)NDAY(2) = 29

                DO 5J = 1,12
                    KK(J) = KK(J) + 1

                    IF(TMEAN(J).NE.0) THEN

C       CALCULATE MEAN DAILY TEMPERATURE IN DEGREES ABSOLUTE (K) TMAB
C
                        IF(IY.LE.1974) THEN
                            TMAB = ((TMEAN(J) - 32)*5.0/9.0) + 273.16
                          ELSE
                            TMAB = TMEAN(J) + 273.16
                        ENDIF

C       CALCULATE LATENT HEAT OF VAPORISATION, HLAT

                        HLAT = 75.56 - 0.0581*TMAB

C       CALCULATE SATURATION VAPOUR PRESSURE AT MEAN DAILY TEMP, EM

                        EM = EXP(21.0287 - 5326.43/TMAB)

C       CALCULATE MEAN DEW POINT TEMPERATURE IN DEGREES ABSOLUTE (K),
C       TD AND SATURATION VAPOUR PRESSURE AT MEAN DEW POINT TEMP, ED

                        IF (TEST.EQ.'RH      ') THEN
                            ED = EM*(RH(J)/100)
                        ENDIF

                        IF (TEST.EQ.'TDAB') THEN
                            TDAB  =  RH(J)  +  273.16
                            ED  =  EXP(21.0287 - (5326.43/TDAB))
                        ENDIF

                        IF(IY.LE.1974) THEN
                            WFAC = 0.357/ALOG(ANHT)
                        ELSE
                            WFAC = 0.693/ALOG(ANHT)
                        ENDIF

                        CWIND = WIND(J)*WFAC
                        EA = (EM - ED)*(1 + 0.526*CWIND)*0.35
                        TT = TMAB/100.
                        DELTA = 0.53264*EM/TT**2
                        SSR = SUN(J)/SMAX(K,J)
                        RB = 11.774*(0.56 - 0.092*SQRT(ED))*(0.1 + 0.9*SSR)*TT**4
```

```
                  IF (PILIH.EQ.1) THEN
                       RC = IRA(K,J)*(AYEAR + BYEAR*SSR)
                  ELSE
                       RC = IRA(K,J)*(A(J) + B(J)*SSR)
ENDIF
IE = I
C
C
                  DO 6 N = 1,JUM
                       RD = RC*(1 + ALB(N))
                       HEAT = (RD - RB)/HLAT
                       EVAP = (DELTA*HEAT + 0.49*EA)/(DELTA + 0.49)
                       IEVAP(I,J,N) = EVAP*NDAY(J) + 0.5
                       IF(IEVAP(I,J,N).GT.MBIG(J,N)MBIG(J,N))MBIG(J,N) =
                         IEVAP(I,J,N
                       IF(IEVAP(I,J,N).LT.MSMALL(J,N))MBIG(J,N) = IEVAP(I
                       ITOT(I,N) = ITOT(I,N) + IEVAP(I,J,N)
                       MTOT(J,N) = MTOT(J,N) + IEVAP(I,J,N)
   6              CONTINUE

C     COMPUTER HARGREAVES EVAPOTRANSPIRATION FOR GRASSLAND
C     HEVAP = MONTHLY GRASSLAND EVAPORATION IN MM
C     TMEAN(J) = MEAN DAILY TEMPERATURE IN DEGREES FAHRENHEIT
C     HFACT(K,J) = FACTOR BASED ON LATITUDE AND LENGTH OF SUNSHINE
        DAY,
C     RH(J) = MEAN RELATIVE HUMIDITY (%)

                       IF(IY.GT.1974) TMEAN(J) = TMEAN(J)*9.0/5.0 + 32
                       HEVAP = 4.0 + 0.16*TMEAN(J)*HFACT(K,J)*SQRT
                         (100 - RH(J))
                       JEVAP(I,J) = HEVAP + 0.5
                       IF(JEVAP(I,J).GT.NBIG(J))NBIG(J) = JEVAP(I,J)
                       IF(JEVAP(I,J).LT.NSMALL(J))NSMALL(J) = JEVAP(I,J)
                       JTOT(I) = JTOT(I) + JEVAP(I,J)
                       NTOT(J) = NTOT(J) + JEVAP(I,J)
                  ELSE
                       KK(J) = KK(J) - 1
                       JEVAP(I,J) = 0
C                 DO 16 N = 1,JUM
                       IEVAP(I,J,N) = 0
16                CONTINUE
              ENDIF
5           CONTINUE

            GO TO 12
13          TRY = IE

            DO 21 J = 1,12
                 NTOT(J) = NTOT(J)/KK(J) + 0.5
                 KTOT = KTOT + NTOT(J)
            DO 21 N = 1,JUM
                 MTOT(J,N) = MTOT(J,N)/KK(J) + 0.5
                 LTOT(N) = LTOT(N) + MTOT(J,N)
21          CONTINUE

            TANUK = 'HYDROLOGY BRANCH, D.I.D. MALAYSIA'

            WRITE(LU,205(TAJUK)
205         FORMAT(/15X,A)
```

```
C         PRINT TITLE

                WRITE(LU,202)STNO,NAME,LATD,LATM,LOND,LONM,LEV
202             FORMAT(///9X,'STATION NO:',I5,
     */9X,'STATION NAME:',20A2,'LAT:',I2,'D',I3,'M N',
*         2X,'LONG:',I4,'D',I3,'M E',2X,'ELEV:',I4,1X,'M ABOVE M.S.L.

C
       C
                IF (PILIH.EQ.2) THEN
                    WRITE(LU,2001)(MONTH(I),I=1,12)
2001                FORMAT(/,9X,'MONTHLY SUNSHINE CONVERSION
     -              COEFFICIENTS US,10X,'Month',1X,12(3X,A4))
                    WRITE(LU,2002) (A(J),J=1,12)
2002                FORMAT(12X,'a',3X,12F7.2)
                    WRITE(LU,2003) (B(K),K=1,12)
2003                FORMAT(12X,'b',3X,12F7.2)
                ELSE
                    AVEAA=AA/12
                    AVEBB=BB/12
                    WRITE(LU,2004)
2004                FORMAT(/,8X,'ANNUAL SUNSHINE CONVERSION
     -              COEFFICIENTS US
                    WRITE(LU,2005)AVEAA,AVEBB
2005                FORMAT(/14X, 'A = ',F7.2,/14X,'B = ',F7.2)
                ENDIF

                DO 7 N=1,JUM
                    WRITE(LU,203)SURFACE(N),ALB(N)
203                 FORMAT(/9X,'PENMAN EVAPOTRANSPIRATION:',A,22X,
     -              'ALBEDO:'

C           PRINT ARRAYS

                    WRITE(LU,206)
206                 FORMAT(/9X,'YEAR',6X,'JAN',4X,'FEB',4X,'MAR',4X,'APR',
      *             4X,'JUN',4X,'JUL',4X,'AUG',4X,'SEP',4X,'OCT',4X,'NOV',
      *             4X,'DEC',6X,'TOTAL',/)
C
C
                    DO 8 I=1,IE
                        IX=III+I-1
                        WRITE(LU,207)IX,(IEVAP(I,J,N),J=1,12),ITOT(I,N)
8                   CONTINUE

207       FORMAT(9X,I4,6X,I3,11(4X,I3),6X,I4,'MM')
          WRITE(LU,201)MSMALL(J,N),J=1,12)
210                 FORMAT(/7X,'MINIMUM',5X,I3,11(4X,I3)
                    WRITE(LU,209) (MTOT(J,N),J=1,12),LTOT(N)
209                 FORMAT(7X,'AVERAGE',5X,I3,11(4X,I3),6X,I4,'MM')
                    WRITE(LU,211) (MBIG(J,N),J=1,12)
211                 FORMAT(7X,'MAXIMUM',5X,I3,11(4X,I3))
7               CONTINUE

C         PRINT TITLE FOR HARGREAVES DATA

          WRITE(LU,208)
208             FORMAT(//9X,'HARGREAVES EVAPOTRANSPIRATION:
     -          GRASSLAND')
```

```
C       PRINT ARRAY

              WRITE(LU,206)
C
C
              DO 9 I=1,IE
                 IX=II+I-1
                 WRITE(LU,207)IX,(JEVAP(I,J),J=1,12),JTOT(I)
9       CONTINUE

C
C
              WRITE(LU,210) (NSMALL(J),J=1,12)
              WRITE(LU,209) (NTOT(J),J=1,12),KTOT
              WRITE(LU,211) (NBIG(J),J=1,12)
99            IF (PILIH.GT.1) GOTO 30
              REWIND 2
1010     CONTINUE
  30     CLOSE (2)
         CLOSE (3)
         CLOSE (4)
         CLOSE (7)
         CLOSE (8)
         CLOSE (9)
   2     FORMAT(A)
         READ(10,2)YN
         IF (YN.EQ.'Y'.OR.YN.EQ.'y') GOTO 9999
         STOP
        END
```

APPENDIX 7: DATA INPUT SEQUENCE

1. **Station Identification (I5, 2X, 20A2, 1X, I2, I2, 1X, I3, I2, 1X, I4, F5.2)**

Columns 1 – 5 : Station Number
6 – 7 : Blanks
8 – 47 : Station Name
48 : Blank
49 – 50 : Latitude in degrees
51 – 52 : Latitude in minutes
53 : Blank
54 – 56 : Longitude in degrees
57 – 58 : Longitude in minutes
59 : Blank
60 – 63 : Station elevation (m)
64 – 68 : Height above ground level at which wind velocity is measured (m)

2. **Initialisation of Job (I4)**

Initialise first year of data

3. **Relative Humidity (RH) or Dew Point Temperature (TDAB) Input (I4)**

Columns 1 – 4 : Relative Humidity (RH) or Mean Dew Point Temperature (TDAB)

4. **Climate Data (15, 14, 1x, 4 (4F4.1)**

Columns 1 – 5 : Station Number
6 – 9 : Year
10 : Blank
11 – 14 : Mean daily sunshine hours (hrs)
15 – 18 : Mean daily temperatures (°C)
19 – 22 : Mean relative humidity (%) or Mean Dew Point Temperature (°C)
23 – 26: Mean daily wind velocity (m/s)
27 – 30: Mean daily sunshine hours (hrs)
31 – 34: Mean daily temperatures (°C)
35 – 38: Mean relative humidity (%) or Mean Dew Point Temperature (°C)
39 – 42 : Mean daily wind velocity (m/s)
43 – 46: Mean daily sunshine hours (hrs)
47 – 50: Mean daily temperatures (°C)
51 – 54: Mean relative humidity (%) or Mean Dew Point Temperature (°C)
55 – 58: Mean daily wind velocity (m/s)
59 – 62: Mean daily sunshine hours (hrs)
63 – 66: Mean daily temperatures (°C)
67 – 70: Mean relative humidity (%) or Mean Dew Point Temperature (°C)
71 – 74: Mean daily wind velocity (m/s)

Example of Data Input Sequence (S48647. dat)

1. Station Identification (I5, 2X, 20A2, 1X, I2, I2, 1X I3, I2, 1X, I4, F5.2)

Stn. No.	STATION NAME	Lat. Deg. & Min.	Long. Deg. & Min.	Elev ab. msl	Anem. Ht. (m)
48647	KUALA LUMPUR: SUBANG INTER. AIRPORT	0307	10133	17	19.00

2. **Initialise Year (I4)**

   1976

3. **Relative Humidity (RH) or Mean Dew Point Temperature (TDAB) Input (I4)**

   RH

4. **Climate Data Input (I5,I4,1X,4(4F4.1))**

```
Stn.  Year   (n) (°C)   RH (m/s) etc...
No.
4864719761  6.725.282.2  0.9  7.126.179.6  1.3  6.526.184.1  1.3  6.526.287.4  0.9
4864719762  7.126.783.4  0.7  6.226.284.0  0.9  6.726.285.2  0.7  6.726.082.7  1.0
4864719763  5.026.285.1  1.1  4.825.887.9  0.8  4.525.887.4  0.9  5.225.786.0  0.9
4864719771 etc.
```

APPENDIX 8: PROCEDURES IN OPERATING THE HP.17 COMPUTER PROGRAM (PEN91.FOR):-

1. Input the Station Number (e.g. 48647 for Subang International Airport).
2. Input the listed or desired albedo values for the different type of surfaces.
3. Input the number of surface/surfaces.
4. Input the sunshine conversion coefficients 'a' and 'b' (annual, monthly or both) for the selected stations.
5. Input the output filename to be screened or printed (e.g. Subang or 48647).
6. Input any other station/stations desired.
7. Get output filename.
8. Screen or print output filename.

An example of the output is as shown in Appendix 9.

SAMPLE OF SCREEN INTERACTION

(a) Type in **PEN91**

(b) Introduction On The Screen:

ASSALAMUALAIKUM WR. WB./GREETINGS

This improved program on
Estimating Potential Evapotranspiration
using the Penman Procedure of H.P. No. 17
(Revised and Updated 1991)
was developed collaboratively by
the Water Resources Assessment Section and
Computer Application Section of
Hydrology Branch
Department of Irrigation and Drainage (D.I.D.) Malaysia
Ministry of Agriculture
50626 Kuala Lumpur.

Please strike any key when ready....

(c) User Data Input (Menu Driven) on Screen:

********** HP-17 **********

What is your station number?: 48647

CODE	EXISTING SURFACE	ALBEDO VALUE
1	– OPEN WATER	0.07
2	– GRASS	0.21
3	– TROPICAL RAIN FOREST	0.12
4	– CROPS	0.23
5	– TOWNS	0.17
6	– LEGUMES	0.21
7	– OIL PALM	0.18
8	– COCOA	0.19

Do you wish to use the existing albedo value? : (Y/N) y

Number of surfaces? : 1

List your surface (Use CODE Display on screen)

Write in one line (Horizontal) : 4

Which value of the sunshine conversion coefficients of A and
B do you want?

1 – Annual
2 – Monthly
3 – Annual and Monthly Output 1

Annual Output Filename
subang.out

Do you wish to process another station? : (Y/N) n

APPENDIX 9: SAMPLE OUTPUT OF PROGRAM PEN 91.FOR

HYDROLOGY BRANCH, D.I.D. MALAYSIA
STATION NO: 48647
STATION NAME: KUALA LUMPUR SUBANG INTERNAT. AIRPORT LAT: 3D 7M N LONG: 101D 33M E ELEV: 17M ABOVE M.S.L.

ANNUAL SUNSHINE CONVERSION COEFFICIENTS USED:-

a = .25
b = .39

PENMAN EVAPOTRANSPIRATION: OPEN WATER **ALBEDO: .07**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	120	125	134	130	130	119	123	127	121	115	109	110	1463 MM
1977	121	108	141	142	130	119	131	115	126	124	113	122	1492 MM
1978	122	124	134	134	123	126	120	121	127	124	112	114	1481 MM
1979	130	125	143	131	135	122	116	133	129	125	110	124	1523 MM
1980	123	124	166	157	131	121	127	115	125	125	109	107	1530 MM
1981	105	118	151	132	120	135	128	141	118	123	113	114	1498 MM
1982	120	119	132	128	123	125	129	117	128	123	116	111	1471 MM
1983	128	133	154	139	130	127	128	120	118	128	117	99	1521 MM
1984	107	103	132	130	127	125	120	132	132	121	112	107	1448 MM
1985	126	115	127	131	127	134	125	130	129	122	113	114	1493 MM
MINIMUM	105	103	127	128	120	119	116	115	118	115	109	99	
AVERAGE	120	119	141	135	127	125	124	125	125	123	112	112	1488 MM
MAXIMUM	130	133	166	157	135	135	131	141	132	128	117	124	

PENMAN EVAPOTRANSPIRATION: GRASS **ALBEDO: .21**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	99	103	111	108	107	99	102	105	101	96	91	91	1213 MM
1977	100	90	117	118	108	99	109	96	105	103	94	101	1240 MM
1978	101	103	111	111	103	105	100	101	106	104	94	95	1234 MM
1979	108	103	119	109	112	101	97	110	108	104	92	102	1265 MM
1980	102	103	141	134	109	101	105	96	104	104	91	90	1280 MM
1981	88	98	125	110	100	112	106	117	98	103	94	95	1246 MM
1982	100	99	110	107	103	104	108	98	107	102	96	93	1227 MM
1983	106	110	128	116	108	106	106	100	99	107	98	83	1267 MM
1984	90	86	110	109	106	104	100	109	110	101	93	89	1207 MM
1985	105	95	106	109	106	111	103	108	107	101	94	95	1240 MM
MINIMUM	88	86	106	107	100	99	97	96	98	96	91	83	
AVERAGE	99	99	117	113	106	104	103	104	104	102	93	93	1237 MM
MAXIMUM	108	110	141	134	112	112	109	117	110	107	98	102	

PENMAN EVAPOTRANSPIRATION: CROPS **ALBEDO: .23**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	96	100	108	105	104	96	99	102	98	93	88	89	1178 MM
1977	97	87	114	115	105	96	105	94	102	100	91	98	1204 MM
1978	98	100	108	108	100	102	97	98	103	101	91	92	1198 MM
1979	104	100	116	106	109	98	94	107	105	101	89	99	1228 MM
1980	99	100	138	131	106	98	102	94	101	101	88	87	1245 MM
1981	85	95	121	107	97	109	103	113	96	100	92	92	1210 MM
1982	97	96	107	104	100	101	104	96	104	99	93	90	1191 MM
1983	103	107	125	113	105	103	103	97	96	103	95	81	1231 MM
1984	87	84	106	105	103	101	97	106	107	98	91	86	1171 MM
1985	102	93	103	106	103	108	100	105	104	99	91	92	1206 MM
MINIMUM	85	84	103	104	97	96	94	94	96	93	88	81	
AVERAGE	96	96	114	110	103	101	100	101	101	99	90	90	1201 MM
MAXIMUM	104	107	138	131	109	109	105	113	107	103	95	99	

HARGREAVES EVAPOTRANSPIRATION: GRASSLAND

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	116	120	122	105	121	111	112	124	115	104	98	103	1351 MM
1977	115	111	139	130	119	109	126	119	124	115	101	114	1422 MM
1978	118	117	117	116	117	124	122	133	126	120	100	107	1417 MM
1979	124	115	138	117	132	113	115	128	126	120	100	108	1436 MM
1980	117	117	136	121	118	114	122	117	117	118	95	108	1400 MM
1981	112	113	139	115	107	124	125	145	115	119	108	116	1438 MM
1982	124	114	120	112	115	114	126	125	123	111	96	108	1388 MM
1983	125	121	138	131	118	121	122	118	112	122	109	107	1444 MM
1984	108	99	119	116	120	120	113	132	130	120	100	104	1381 MM
1985	126	105	126	116	116	135	127	135	123	117	96	104	1426 MM
MINIMUM	108	99	117	105	107	109	112	117	112	104	95	103	
AVERAGE	118	113	129	117	118	118	121	127	121	116	100	107	1405 MM
MAXIMUM	126	121	139	131	132	135	127	145	130	122	109	116	

HYDROLOGY BRANCH, D.I.D. MALAYSIA

STATION NO: 48647
STATION NAME: KUALA LUMPUR SUBANG INTERNAT. AIRPORT LAT: 3D 7M N LONG: 101D 33M E ELEV: 17M ABOVE M.S.L.

MONTHLY SUNSHINE CONVERSION COEFFICIENTS USED:-

Month	Jan.	Feb.	Mac.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
a	.24	.24	.24	.24	.25	.29	.26	.26	.24	.25	.24	.25
b	.40	.42	.41	.39	.40	.31	.39	.38	.41	.41	.40	.39

PENMAN EVAPOTRANSPIRATION: OPEN WATER **ALBEDO: .07**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	118	126	133	126	131	119	126	128	120	118	107	110	1462 MM
1977	119	108	141	138	132	119	134	117	125	126	111	122	1492 MM
1978	120	126	133	130	124	125	123	122	127	127	110	114	1481 MM
1979	129	127	143	127	137	121	119	134	128	128	108	123	1524 MM
1980	121	126	166	153	132	121	129	117	124	128	107	107	1531 MM
1981	103	119	152	128	121	131	131	141	117	125	111	114	1493 MM
1982	119	121	132	125	124	124	132	119	127	126	114	111	1474 MM
1983	126	136	155	135	131	126	130	122	117	131	115	99	1523 MM
1984	105	103	131	127	128	124	123	133	132	123	110	106	1445 MM
1985	125	116	126	127	128	130	127	131	128	124	111	114	1487 MM
MINIMUM	103	103	126	125	121	119	119	117	117	118	107	99	
AVERAGE	118	120	141	131	128	124	127	126	124	125	110	112	1486 MM
MAXIMUM	129	136	166	153	137	131	134	141	132	131	115	123	

PENMAN EVAPOTRANSPIRATION: GRASS **ALBEDO: .21**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	97	105	111	105	109	98	104	106	100	98	89	91	1213 MM
1977	99	90	117	115	109	99	111	98	104	105	92	101	1240 MM
1978	99	105	111	108	104	104	102	102	106	106	92	94	1233 MM
1979	106	105	119	106	114	101	99	111	107	107	90	102	1267 MM
1980	100	104	141	131	110	101	108	98	104	106	89	89	1281 MM
1981	86	99	126	107	101	109	109	117	98	105	93	95	1245 MM
1982	98	100	110	104	104	103	110	100	106	104	94	93	1226 MM
1983	104	113	129	113	109	105	108	102	98	109	96	83	1269 MM
1984	88	86	109	105	107	103	102	110	110	103	92	89	1204 MM
1985	103	96	105	106	107	108	106	109	107	103	92	95	1237 MM
MINIMUM	86	86	105	104	101	98	99	98	98	98	89	83	
AVERAGE	98	100	117	110	107	103	105	105	104	104	91	93	1237 MM
MAXIMUM	106	113	141	131	114	109	111	117	110	109	96	102	

PENMAN EVAPOTRANSPIRATION: CROPS

ALBEDO: .23

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	94	102	107	102	105	95	101	102	98	95	86	88	1175 MM
1977	96	88	114	112	106	96	108	95	101	102	90	98	1206 MM
1978	97	101	108	105	101	101	99	99	103	103	89	92	1198 MM
1979	103	102	116	103	110	98	96	108	104	103	87	99	1229 MM
1980	97	101	138	127	107	98	105	95	101	103	86	87	1245 MM
1981	83	96	122	104	98	106	106	114	95	102	90	92	1208 MM
1982	95	97	107	101	101	100	107	97	103	101	92	90	1191 MM
1983	101	109	125	110	106	102	105	99	95	106	93	81	1232 MM
1984	85	84	106	102	104	100	99	107	107	100	89	86	1169 MM
1985	100	93	102	103	104	105	103	106	104	101	90	92	1203 MM
MINIMUM	83	84	102	101	98	95	96	95	95	95	86	81	
AVERAGE	95	97	114	106	104	100	102	102	101	101	89	90	1201 MM
MAXIMUM	103	109	138	127	110	106	108	114	107	106	93	99	

HARGREAVES EVAPOTRANSPIRATION: GRASSLAND

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1976	116	120	122	105	121	111	112	124	115	104	98	103	1351 MM
1977	115	111	139	130	119	109	126	119	124	115	101	114	1422 MM
1978	118	117	117	116	117	124	122	133	126	120	100	107	1417 MM
1979	124	115	138	117	132	113	115	128	126	120	100	108	1436 MM
1980	117	117	136	121	118	114	122	117	117	118	95	108	1400 MM
1981	112	113	139	115	107	124	125	145	115	119	108	116	1438 MM
1982	124	114	120	112	115	114	126	125	123	111	96	108	1388 MM
1983	125	121	138	131	118	121	122	118	112	122	109	107	1444 MM
1984	108	99	119	116	120	120	113	132	130	120	100	104	1381 MM
1985	126	105	126	116	116	135	127	135	123	117	96	104	1426 MM
MINIMUM	108	99	117	105	107	109	112	117	112	104	95	103	
AVERAGE	118	113	129	117	118	118	121	127	121	116	100	107	1405 MM
MAXIMUM	126	121	139	131	132	135	127	145	130	122	109	116	