HYDROLOGICAL PROCEDURE NO. 20

# HYDROLOGICAL ASPECTS OF AGRICULTURAL PLANNING AND IRRIGATION DESIGN

1978

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

Hydrological Procedure No. 20

# HYDROLOGICAL ASPECTS OF AGRICULTURAL PLANNING AND IRRIGATION DESIGN

1978

BAHAGIAN PARIT DAN TALIAIR
KEMENTERIAN PERTANIAN, MALAYSIA.

# ACKNOWLEDGEMENTS

The work reported on here has been carried out by the Hydrology Branch of the Drainage and Irrigation Deparment (D.I.D.) of the Ministry of Agriculture, in association with the Department of Agriculture, Federal Land Development Authority (Felda), Malaysian Agricultural Research and Development Institute (MARDI) and Rubber Research Institute (R.R.I.). The use of data supplied by these agencies is gratefully acknowledged.



Price:- $10

*Published by and obtainable from:*

THE PUBLICATIONS UNIT,
MINISTRY OF AGRICULTURE,
JALAN SWETTENHAM,
KUALA LUMPUR,
MALAYSIA.

# HYDROLOGICAL ASPECTS
# OF
# AGRICULTURAL PLANNING
# AND
# IRRIGATION DESIGN

Contributors:-

M.A.W. Taylor, S. Thirugnanasambanthar & D.C. Still

Prepared in consultation with Dr. Chan Yik Kuan,
Dr. Erh Koon Tee, Messrs Goh Kiam Seng, Tan Chin Feaw,
F. Scarf, Ling Ah Hong & Soong Ngin Kwi.

DRAINAGE AND IRRIGATION DIVISION
MINISTRY OF AGRICULTURE, MALAYSIA.
1978

# SYNOPSIS

The procedure outlines the statistical analysis of effective rainfall and explains the water accounting simulation model of a water-soil-crop system. For the cultivation of an upland crop at any given location in Peninsular Malaysia, the procedure provides the methodology to obtain the following:-

(i) the preferred planting date
(ii) whether crop can be grown under rainfed conditions
(iii) the monthly crop water requirements
(iv) the monthly crop water deficits
(v) the probability of the day being 'dry' for each day of the year.

As the procedure is based on the statistical analysis of the past rainfall data, care should be taken in the use of the results because of their stochastic nature.

Due to lack of precise information on crop water requirements under local conditions, data from overseas publications have been used. However, this data could be replaced as and when local experimental data are available.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

## 1. INTRODUCTION

### 1.1. General

The accelerated development of agriculture and industry has caused increasing water demands which in turn has necessitated the optimisation of the use of water. As a first step in optimisation, best use of rainfall should be made in agriculture. This was difficult to achieve, due to lack of hydrometeorological data in a form suitable for use by planners, designers and operational personnel in agricultural projects. An attempt is made here not only to overcome this deficiency, but also to provide a methodology that optimises the use of rainfall for the cultivation of upland crops.

### 1.2 Objective

The main objective of this procedure is to determine the likelihood that crop water requirements can be satisfied wholly by rainfall and to determine monthly irrigation water requirements in cases where rainfall is insufficient to meet crop demands. This procedure is expected to provide information for the planners, at the planning stage of agricultural and irrigation development. As large amount of data are available on wet padi crop cultivation, this procedure will therefore be confined to the annual and biannual upland crops. It must be emphasised here, that this procedure is confined only to the objective mentioned above and does not include other aspects of agricultural planning such as market supply, farming practises, economics, etc.

## 2. CROP PRODUCTION SYSTEM

### 2.1 General

Any crop production system consists of three main components namely crop, soil and climate. Unlike factors related to soil and crop, factors related to climate cannot be easily modified or controlled. The most important aspect of climate is rainfall. In tropical countries a large portion of the water requirement for crop production is supplied by rainfall.

In the following three sections, brief discussions on rainfall, soil and crop characteristics pertaining to effective rainfall are given. Effective rainfall is defined as that which is useful or useable in any phase of the crop production (FAO, 1974).

### 2.2 Rainfall Characteristics

The factors that are related to the usefulness of rainfall for crop growth are the amount, intensity, frequency and distribution over area as well as time. A well distributed rainfall in frequent light showers is more useful than rain in heavy downpours.

### 2.3 Soil Characteristics

Soil acts as a reservoir of moisture for crop growth but it has a definite and limited water intake rate and holding capacity. The rainfall available for crop growth will therefore depend on soil properties.

### 2.4 Crop Characteristics

The water requirement of any crop is influenced by the degree of ground cover, rooting depth and stage of growth. Rainfall is most effective during the vegetative growth period. However, it is less effective during flowering and pre-harvesting periods.

### 2.5 Analysis of water-soil-crop system

Two techniques are normally used for analysing the water-soil-crop system. One is the statistical analysis of rainfall [Manning (1950), Kowal and Knabe (1972), Panabokke and Walgama (1974), Coligado et al (1968)] and the other is the system simulation [Robertson (1970), Wickham (1973), Richard and Fitzgerald (1972), Van den Eelaart (1972)]. As both these techniques have been shown to be applicable in Malaysia [Wycherley (1967) and Heiler (1973)] they have been adopted in the procedure. Theory and application of these techniques are described in the following sections.

## 3. STATISTICAL ANALYSIS OF RAINFALL DATA

### 3.1 General

The statistical analysis of rainfall data involves determining both the chance variation of rainfall for specific times of the year and the variation of rainfall through the year. The chances of the expected rainfall exceeding or falling short of a certain amount can be quantified and hence the risk of having either too much or too little water for a specified crop could be determined.

In the analysis of rainfall data, two factors have to be defined. One is the unit interval of time on which to base the analysis and the other is the portion of the rainfall that is considered to be effective.

The unit interval of time depends on the sensitivity of the soil-crop system to periods of moisture excess or deficit. ***As the procedure is confined to upland crops, it is assumed that there is no water-logging in the cultivated areas due to rainfall and all excess water is drained by gravity.*** Hence the unit interval of time would have to be based on the period of moisture deficit. The period of tolerance of many upland crops to moisture deficit under local conditions is generally about one week. Hence the unit interval of time chosen in the procedure is one week.

The second factor to be considered is the portion of rainfall that is effective. Rainfall which is stored within the root zone is considered effective. Rainfall that evaporates before reaching the crop or soil and that which contributes to drainage is not effective. A comprehensive discussion of effective rainfall and methods of determining the portion of total rainfall that is effective is given by FAO (1974). Of the methods reviewed, the empirical approach is considered to be very practical and sufficiently accurate for application to agricultural planning. Empirical methods generally assume a certain percentage of the total rainfall to be effective, based on daily, monthly or seasonal totals. In this procedure daily rainfall within the range of 5 to 50 mm is considered to be effective. This means that up to 50 mm of rain per day can be absorbed by the soil within the crop root zone (which for upland crops chosen is about 0.6 metre), regardless of the antecedent soil moisture level. The upper limit of 50 mm is suggested by Oldeman (1974) as being the effective soil moisture capacitv for most upland soils in the tropics.

The greater the number of years of rainfall data used, the better the result will be and in this regard, a minimum of 15 years is recommended.

### 3.2 Theory

The calendar year is divided into 51 weeks of 7 days, and one week of either 9 days for a leap year or 8 days for a non-leap year, for the purpose of computing weekly rainfall statistics. Year by year daily effective rainfalls are totalled for each week. For a particular week, the effective rainfall totals of all the recorded years are fitted with a probability distribution by the method of least squares. The effective rainfall for a selected risk level is computed from the theoretical distribution. A normal distribution is assumed since this has been found to give a satisfactory fit to the observed rainfall data.

The method of fitting the normal distribution to the data follows that of Baier and Russelo (1968) and is described as follows. To linearise the normal distribution the following transformation is used:

$$Z = \frac{X - U}{V}$$

where Z = normal random variable with mean zero and variance 1.
X = sample value
U = sample mean

$$V = \text{sample standard deviation}$$
$$\text{hence } VZ = X - U$$
$$X = U + VZ \quad \dots \quad \dots \quad \dots \quad (3.1)$$

Equation (3.1) is solved for U and V by linear regression of the dependent variable X on the independent variable Z. The value of Z for each sample value of X is computed as follows. The sample values are arranged in increasing order of size, assigned a rank starting with 1 for the smallest value, and the cumulative probability computed from equation (3.2)

$$P_i = \frac{m}{N+1} \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.2)$$

where $P_i$ = cumulative probability of value being X

N = total number of sample values

m = sample rank

For each $P_i$, the corresponding value of Z is found from the table of values for standard normal distribution. Sample values of zero are discarded in the regression analysis since the distribution is not considered for negative effective rainfall.

The method is illustrated for week 6 (Feb. 5th–11th) at D.I.D. Rainfall Station number 1632095, having rainfall records for the period 1950 to 1975. The weekly effective rainfalls for each year, weekly effective rainfalls in ascending order, the cumulative probabilities and the corresponding Z values are given in Table 3.1. The sample values and the fitted regression line are

Table 3:1 Rainfall Analysis
for week 6
at D.I.D. Station Number 1632095

| Year | Effective Rainfall (mm) | Effective Rainfall (mm) in ascending order | Rank M | Cumulative Probability $P_i$(%) | Normal Random variable Z |
|---|---|---|---|---|---|
| 1950 | 50 | 0 | 1 | — | — |
| 1951 | 13 | 0 | 2 | — | — |
| 1952 | 88 | 0 | 3 | — | — |
| 1953 | 43 | 0 | 4 | — | — |
| 1954 | 15 | 7 | 5 | 19 | −0.88 |
| 1955 | 96 | 12 | 6 | 22 | −0.77 |
| 1956 | 96 | 13 | 7 | 26 | −0.64 |
| 1957 | 46 | 15 | 8 | 30 | −0.52 |
| 1958 | 26 | 15 | 9 | 33 | −0.44 |
| 1959 | 12 | 18 | 10 | 37 | −0.33 |
| 1960 | 15 | 21 | 11 | 41 | −0.23 |
| 1961 | 71 | 26 | 12 | 44 | −0.15 |
| 1962 | 7 | 26 | 13 | 48 | −0.05 |
| 1963 | 28 | 28 | 14 | 52 | 0.05 |
| 1964 | 76 | 28 | 15 | 56 | 0.15 |
| 1965 | 26 | 43 | 16 | 59 | 0.23 |
| 1966 | 28 | 46 | 17 | 63 | 0.33 |
| 1967 | 0 | 50 | 18 | 67 | 0.44 |
| 1968 | 21 | 50 | 19 | 70 | 0.52 |
| 1969 | 0 | 63 | 20 | 74 | 0.64 |
| 1970 | 63 | 71 | 21 | 78 | 0.77 |
| 1971 | 0 | 76 | 22 | 81 | 0.88 |
| 1972 | 18 | 88 | 23 | 85 | 1.04 |
| 1973 | 50 | 90 | 24 | 89 | 1.23 |
| 1974 | 0 | 96 | 25 | 93 | 1.48 |
| 1975 | 90 | 96 | 26 | 96 | 1.76 |

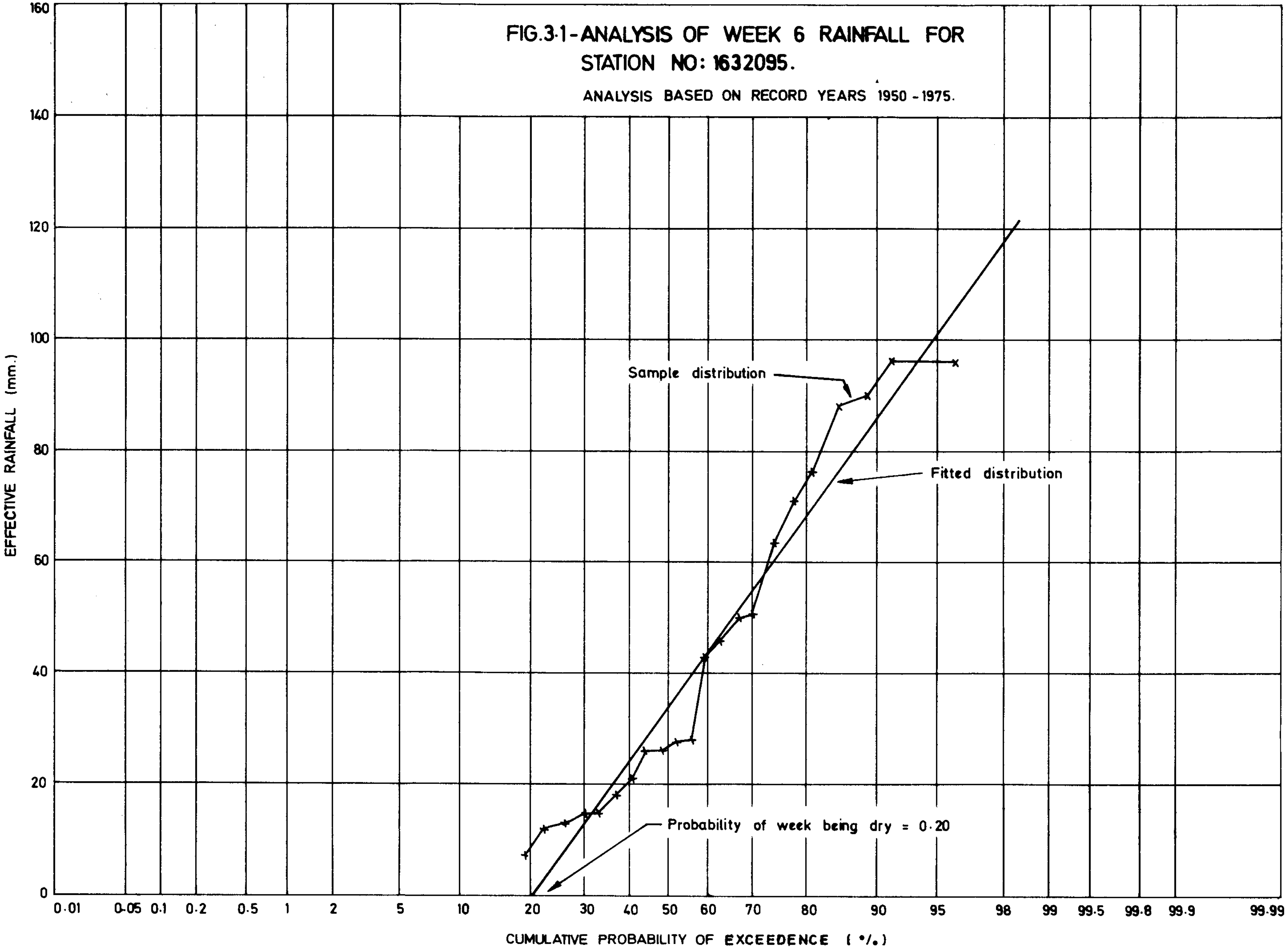



FIG.3·1-ANALYSIS OF WEEK 6 RAINFALL FOR STATION NO: 1632095.

ANALYSIS BASED ON RECORD YEARS 1950 - 1975.

shown in Fig. 3.1. The probability of the week being dry, is obtained by reading the value at the point where the regression line meets the x-axis (this value could be verified with the value given for week 6 in Table 3.3).

The effective rainfall for probability levels of 10% to 90% in steps of 10% for each week are listed in Table 3.3. A computer programme (TPSTAT) has been prepared to analyse daily rainfall data by the above method. A listing and explanation of the programme are given in Appendix A.

## 3.3 Application

### 3.3.1 General

The analytical technique described in section 3.2 gives the weekly effective rainfall that can be expected for a specified risk level and the risk of the week being dry for any week of the year. Crop water requirements can be estimated using evaporation data and crop factors for any location in Peninsular Malaysia (please see section 4.2.1).

The planner's primary concern is to find out whether the rainfall could fully satisfy the water requirements of a selected crop, in an area selected for development, for a given risk level. The following steps should be followed to get this information:

(i) Select rainfall station in or around the area chosen for development, having long continuous daily rainfall records (a minimum of 15 years of records is recommended). The selection must be done so that the chosen rainfall station is representative of the area.
(ii) Run TPSTAT programme for the selected rainfall station.
(iii) Select from Table 3.2 the recommended rainfall probability level for the crop to be grown.
(iv) From the output of programme TPSTAT, plot on graph paper weekly effective rainfalls for the probability level chosen in (iii). If probability level chosen is 80%, then also plot weekly effective rainfall for probability of 60%.
(v) Select evaporation station in or around the area chosen for development. The selected station must be representative of the area. If such a station does not exist a map of grassland evaporation for Peninsular Malaysia [Scarf (1976)] can be used and annual value interpolated for the location of the area. Using annual grassland evaporation value

Table 3.2: Recommended Rainfall Probability Levels (80% and 60%) for Upland Crops

| PROBABILITY LEVEL | |
|---|---|
| 80% | 60% |
| Cabbage | Maize |
| Lettuce | Soyabean |
| Cucumber | Sorghum |
| Tomato | Groundnuts |
| Mustard (Sawi) | Tapioca |
| Water Melon | Pineapple |
| Tobacco | Sweet Potato |
| Long Beans | Sugarcane |
| Onion | Ginger |
| | Brinjal |
| | Chilli |
| | Ladies Finger |

*Note:* ***This table is based on the cost of production and sensitivity to moisture stress and is only a general guide.***

(obtained for chosen evaporation station or by interpolation) and crop coefficients (Table C.1), determine weekly crop water requirements.

(vi) Plot this crop water requirement on graph paper on the same scale as that of weekly effective rainfalls as in (iv).

(vii) Transfer the plotting done in (vi) to a tracing paper.

(viii) Match the plot on the tracing paper with that obtained in (iv), such that the best fit is obtained. The planting and harvesting dates can then be read off from (iv).

### 3.3.2 Worked Examples

#### 3.3.2.1 *Example 1*

To determine whether (a) lowland cabbage, (b) maize (grain), (c) groundnuts, can be grown in Batu Pahat area in West Johore (Latitude 1° 40′ 20″N, Longitude 103° 15′ 00″E) under rainfed conditions and select the suitable planting dates.

(a) ***lowland cabbage***

Step 1. Selection of rainfall station

Using "Hydrological Data, Rainfall Records for Peninsular Malaysia 1970–1975" (D.I.D., 1977), D.I.D. rainfall station at Parit Bantang Duku, Batu Pahat (station number 1632095) having continuous daily rainfall records from 1950 to 1975 is chosen.

Step 2. Running of programme TPSTAT

TPSTAT programme is run using daily rainfall records for the station (please see Appendix A for details). The output obtained is shown as Table 3.3.

Step 3. Selection of rainfall probability level

From Table 3.2, the rainfall probability level for lowland cabbage is 80 %.

Step 4. Plotting of weekly effective rainfall

Weekly effective rainfalls for 80 % and 60 % levels corresponding to weeks 1 to 52 are obtained from Table 3.3 and plotted on a graph paper (number of weeks on x-axis and effective rainfall on y-axis).

Step 5. Calculation of weekly crop water requirements

Using D.I.D. Water Resources Publication No. 5 (Scarf, 1976) the nearest evaporation station at Parit Botak (station number 130) is selected. From Table 4.1 the mean annual grassland evaporation for this station is 1388 mm.

Weekly grassland evapotranspiration is 1388/52 = 26.7 mm. From Table C. 1, for cabbage the following time ratios of crop and corresponding crop coefficients are obtained:

| Time ratio of crop | Crop coefficient |
|---|---|
| 0.00 | 0.64 |
| 0.63 | 0.95 |
| 0.88 | 0.95 |
| 1.00 | 0.80 |

Crop duration is 80 days (Table C.1)

The number of days corresponding to the time ratios of the crop are obtained by multiplying them by the crop duration (80 days) and are converted to weeks by dividing by 7 and rounding up. The weekly crop water requirements are obtained by multiplying the corresponding crop

## TABLE 3.3: OUTPUT OF PROGRAMME TPSTAT FOR D.I.D. STATION NUMBER 1632095

STATION NUMBER 1632095
RECORD PERIOD ANALYSED 1950 TO 1975
EFFECTIVE WEEKLY RAINFALL(MM) FOR A GIVEN RISK(PERCENT)
LIMITS OF EFFECTIVE DAILY RAINFALL 5 TO 50 MM

| WEEK | LOWEST OBSERVED | RAIN(MM) FOR RISK OF EXCEDENCE(PERCENT) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | HIGHEST OBSERVED | RISK OF WEEK BEING WET | DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 7 | 21 | 33 | 46 | 59 | 75 | 97 | 140 | 75 | 25 |
| 2 | 0 | 0 | 0 | 5 | 20 | 33 | 47 | 62 | 79 | 103 | 132 | 73 | 27 |
| 3 | 0 | 0 | 0 | 0 | 1 | 20 | 39 | 60 | 85 | 119 | 159 | 60 | 40 |
| 4 | 0 | 0 | 0 | 0 | 0 | 11 | 28 | 47 | 70 | 101 | 132 | 56 | 44 |
| 5 | 0 | 0 | 0 | 7 | 19 | 31 | 42 | 54 | 69 | 89 | 124 | 75 | 25 |
| 6 | 0 | 0 | 1 | 14 | 24 | 34 | 44 | 55 | 68 | 86 | 96 | 80 | 20 |
| 7 | 0 | 0 | 0 | 4 | 17 | 30 | 42 | 56 | 72 | 94 | 133 | 72 | 28 |
| 8 | 0 | 0 | 11 | 25 | 37 | 48 | 59 | 71 | 85 | 104 | 124 | 86 | 14 |
| 9 | 0 | 0 | 0 | 6 | 19 | 31 | 43 | 57 | 72 | 93 | 163 | 74 | 26 |
| 10 | 0 | 0 | 4 | 18 | 30 | 42 | 53 | 65 | 79 | 99 | 138 | 82 | 18 |
| 11 | 0 | 0 | 10 | 23 | 34 | 44 | 55 | 66 | 79 | 98 | 123 | 86 | 14 |
| 12 | 0 | 0 | 15 | 29 | 41 | 52 | 64 | 76 | 90 | 110 | 151 | 88 | 12 |
| 13 | 0 | 0 | 18 | 35 | 48 | 61 | 74 | 88 | 105 | 127 | 170 | 88 | 12 |
| 14 | 0 | 6 | 27 | 42 | 54 | 66 | 77 | 90 | 105 | 126 | 141 | 92 | 8 |
| 15 | 0 | 6 | 26 | 41 | 54 | 65 | 77 | 89 | 104 | 125 | 162 | 92 | 8 |
| 16 | 0 | 7 | 23 | 35 | 45 | 54 | 64 | 74 | 86 | 102 | 109 | 93 | 7 |
| 17 | 5 | 2 | 21 | 35 | 47 | 59 | 70 | 82 | 96 | 115 | 185 | 90 | 10 |
| 18 | 0 | 0 | 3 | 12 | 19 | 26 | 33 | 40 | 49 | 61 | 76 | 83 | 17 |
| 19 | 0 | 0 | 0 | 12 | 23 | 34 | 44 | 56 | 69 | 87 | 134 | 79 | 21 |
| 20 | 0 | 0 | 0 | 13 | 24 | 35 | 46 | 57 | 71 | 90 | 152 | 79 | 21 |
| 21 | 0 | 0 | 6 | 17 | 26 | 35 | 43 | 52 | 63 | 78 | 100 | 85 | 15 |
| 22 | 0 | 0 | 0 | 14 | 28 | 40 | 52 | 65 | 81 | 103 | 154 | 79 | 21 |
| 23 | 0 | 0 | 0 | 2 | 11 | 19 | 28 | 36 | 47 | 61 | 95 | 72 | 28 |
| 24 | 0 | 0 | 0 | 8 | 20 | 31 | 42 | 54 | 68 | 88 | 128 | 76 | 24 |
| 25 | 0 | 0 | 0 | 5 | 21 | 35 | 49 | 64 | 82 | 107 | 167 | 73 | 27 |
| 26 | 0 | 0 | 0 | 10 | 22 | 34 | 45 | 57 | 72 | 92 | 138 | 77 | 23 |
| 27 | 0 | 0 | 0 | 0 | 17 | 32 | 47 | 64 | 83 | 110 | 171 | 70 | 30 |
| 28 | 0 | 0 | 1 | 14 | 24 | 35 | 45 | 55 | 68 | 86 | 123 | 81 | 19 |
| 29 | 0 | 0 | 0 | 14 | 25 | 36 | 47 | 58 | 72 | 91 | 123 | 80 | 20 |
| 30 | 0 | 0 | 3 | 17 | 29 | 39 | 50 | 62 | 75 | 94 | 140 | 82 | 18 |
| 31 | 0 | 0 | 0 | 6 | 18 | 29 | 40 | 51 | 65 | 85 | 154 | 75 | 25 |
| 32 | 0 | 0 | 10 | 20 | 29 | 37 | 45 | 54 | 64 | 78 | 117 | 87 | 13 |
| 33 | 0 | 0 | 3 | 16 | 28 | 39 | 49 | 61 | 75 | 93 | 124 | 82 | 18 |
| 34 | 0 | 0 | 0 | 6 | 18 | 30 | 42 | 54 | 69 | 90 | 126 | 74 | 26 |
| 35 | 0 | 0 | 13 | 22 | 30 | 37 | 45 | 53 | 62 | 75 | 82 | 90 | 10 |
| 36 | 0 | 0 | 10 | 20 | 29 | 37 | 45 | 54 | 64 | 78 | 113 | 87 | 13 |
| 37 | 0 | 0 | 0 | 2 | 16 | 28 | 41 | 55 | 71 | 94 | 143 | 71 | 29 |
| 38 | 0 | 0 | 0 | 1 | 12 | 22 | 32 | 43 | 56 | 74 | 101 | 71 | 29 |
| 39 | 0 | 0 | 4 | 18 | 30 | 42 | 53 | 65 | 79 | 99 | 123 | 82 | 18 |
| 40 | 0 | 0 | 0 | 12 | 22 | 31 | 40 | 49 | 61 | 77 | 90 | 80 | 20 |
| 41 | 0 | 0 | 0 | 19 | 36 | 53 | 69 | 86 | 107 | 135 | 236 | 79 | 21 |
| 42 | 0 | 0 | 3 | 20 | 34 | 48 | 61 | 76 | 93 | 117 | 157 | 81 | 19 |
| 43 | 0 | 2 | 21 | 35 | 46 | 57 | 67 | 79 | 92 | 111 | 131 | 91 | 9 |
| 44 | 0 | 0 | 8 | 26 | 42 | 56 | 70 | 86 | 104 | 129 | 160 | 83 | 17 |
| 45 | 0 | 0 | 17 | 29 | 39 | 49 | 59 | 69 | 81 | 98 | 136 | 90 | 10 |
| 46 | 7 | 8 | 25 | 38 | 49 | 59 | 69 | 80 | 93 | 110 | 144 | 93 | 7 |
| 47 | 7 | 3 | 19 | 30 | 40 | 49 | 58 | 67 | 79 | 94 | 131 | 91 | 9 |
| 48 | 0 | 0 | 4 | 24 | 42 | 57 | 73 | 91 | 111 | 139 | 199 | 82 | 18 |
| 49 | 0 | 0 | 0 | 0 | 17 | 34 | 50 | 68 | 90 | 119 | 156 | 69 | 31 |
| 50 | 0 | 0 | 11 | 28 | 42 | 56 | 69 | 83 | 100 | 123 | 150 | 85 | 15 |
| 51 | 0 | 1 | 17 | 30 | 40 | 50 | 59 | 70 | 82 | 99 | 129 | 90 | 10 |
| 52 | 0 | 0 | 7 | 24 | 38 | 52 | 65 | 79 | 97 | 120 | 168 | 83 | 17 |

coefficients by the weekly grassland evapotranspiration (26.7 mm). The converted number of weeks and the corresponding water requirements are given below:

| Age of cabbage (weeks) | Water requirement (mm) |
|---|---|
| 0 | 17 |
| 7 | 25 |
| 10 | 25 |
| 11 | 21 |

The water requirements for weeks in between those given above are obtained by linear interpolation.

Step 6. Plotting of weekly crop water requirements

The weekly water requirements of lowland cabbage are plotted on a graph paper to same scale as the plot in step 4.

Step 7. Transferring to tracing paper

The plot obtained in step 6 is transferred to a tracing paper.

Step 8. Matching of plots

The tracing from step 7 is superimposed on the plot from step 4, such that the best fit is obtained with the 80% effective rainfall probability level. It is important to ensure that the 80% effective rainfall at least satisfies the water requirements of the initial and development stages (please see Fig. 4.2) of lowland cabbage.

The best fit for lowland cabbage using rainfall records of station no. 1632095 is shown in Fig. 3.2.

It can be observed from Fig. 3.2, that the water requirements of the initial and development stages of cabbage are generally satisfied by the 80% probability level. However, the 60% probability level over satisfies the water requirement for both these stages and generally satisfies the water requirement for the mid and late seasons.

Hence, it is possible to grow lowland cabbage in Batu Pahat area under rainfed conditions.

The planting date from Fig. 3.2 is the beginning of 11th week i.e. 11th March.

(b) ***maize (grain)***

The rainfall probability level for maize (grain) is 60% (Table 3.2). The time ratios of the crop and corresponding crop coefficients obtained from Table C.1 are given below:

| Time ratio of crop | Crop coefficient |
|---|---|
| 0.00 | 0.64 |
| 0.44 | 1.05 |
| 0.76 | 1.05 |
| 1.00 | 0.55 |

Crop duration is 110 days (Table C.1)

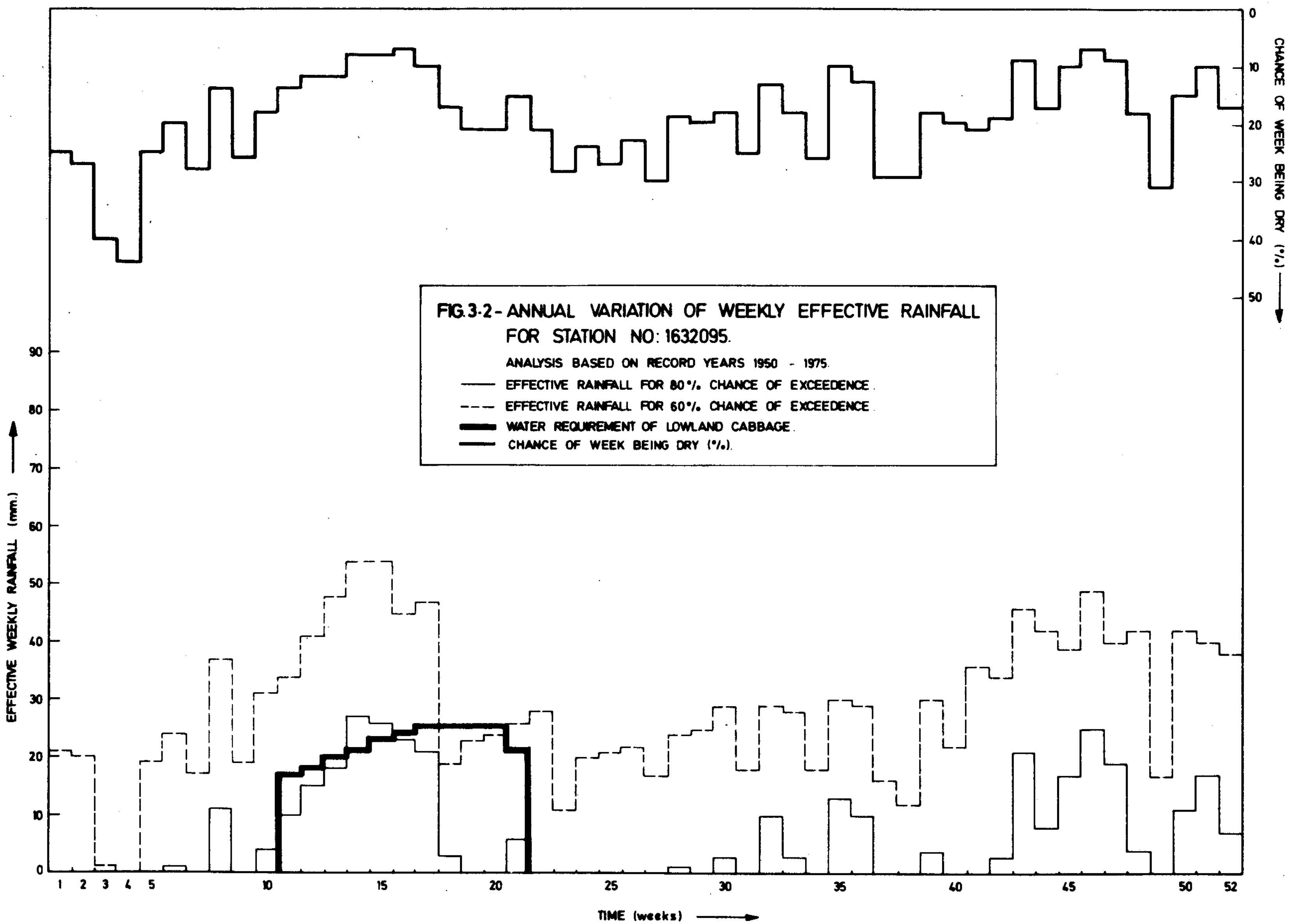



FIG. 3-2 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 1632095.

The number of weeks corresponding to the time ratios of crop and water requirements are given below:

| Age of maize (weeks) | Water requirement (mm) |
|---|---|
| 0 | 17 |
| 7 | 28 |
| 12 | 28 |
| 16 | 15 |

The best fit for maize using rainfall records of D.I.D. station number 1632095 is shown in Fig. 3.3.

It is possible to grow maize (grain) in Batu Pahat area under rainfed conditions.

The earliest planting date from Fig. 3.3 is the beginning of the 5th week i.e. 29th of January.

Note: The crop can also be planted any time between 5th and 8th week and also at the beginning of 39th week.

(c) ***groundnuts***

The rainfall probability level for groundnuts is 60% (Table 3.2). The time ratios of the crop and corresponding crop coefficients obtained from Table C.1 are given below:

| Time ratio of crop | Crop coefficient |
|---|---|
| 0.00 | 0.64 |
| 0.46 | 0.95 |
| 0.81 | 0.95 |
| 1.00 | 0.55 |

Crop duration is 110 days (Table C.1)

The number of weeks corresponding to the time ratios of the crop and water requirements are given below:

| Age of groundnuts (weeks) | Water requirement (mm) |
|---|---|
| 0 | 17 |
| 7 | 25 |
| 13 | 25 |
| 16 | 15 |

The best fit for groundnuts using rainfall records of D.I.D. station number 1632095 is shown in Fig. 3.4.

It is possible to grow groundnuts in Batu Pahat area under rainfed conditions.

The earliest planting date from Fig. 3.4 is the beginning of 5th week i.e. 19th of January.

Note: The crop can also be planted anytime between 5th and 8th week and also at the beginning of 39th week.

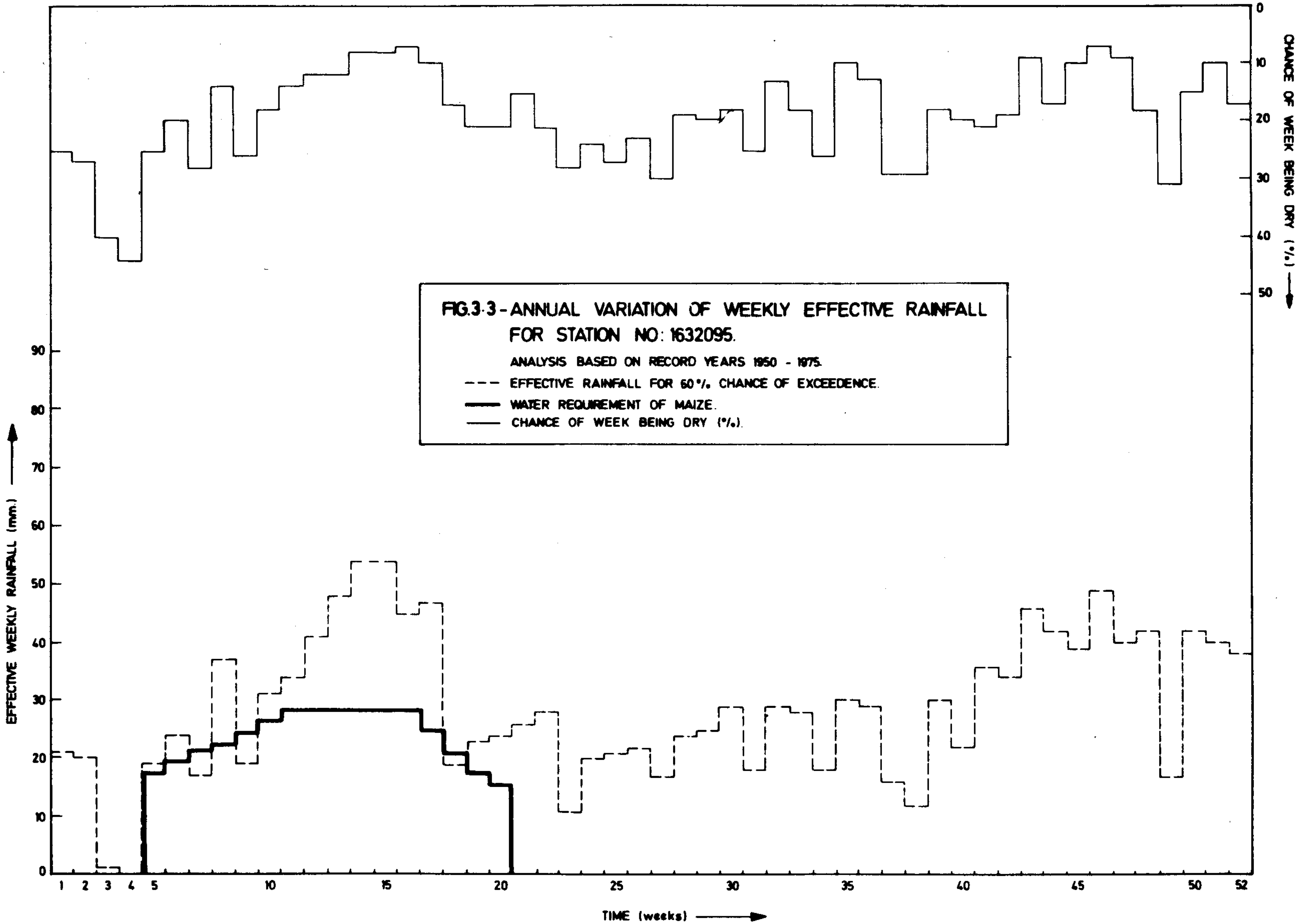


FIG.3·3 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 1632095.
ANALYSIS BASED ON RECORD YEARS 1950 - 1975.
EFFECTIVE RAINFALL FOR 60 % CHANCE OF EXCEEDENCE.
WATER REQUIREMENT OF MAIZE.
CHANCE OF WEEK BEING DRY (%).
EFFECTIVE WEEKLY RAINFALL (mm.)
CHANCE OF WEEK BEING DRY (%)
TIME (weeks)
0
10
20
30
40
50
60
70
80
90
1
2
3
4
5
10
15
20
25
30
35
40
45
50
52

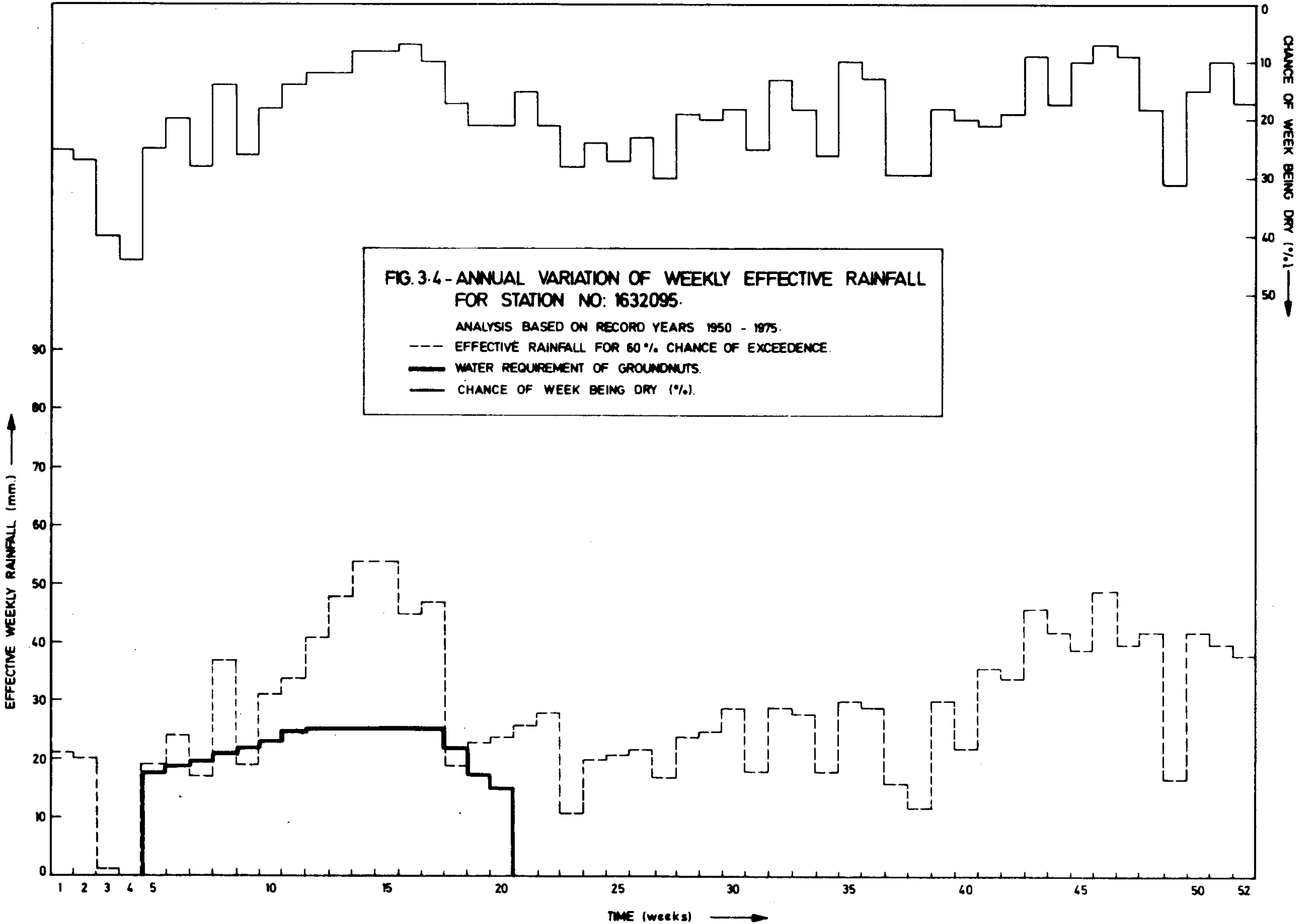



FIG. 3.4 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 1632095.

3.3.2.2 *Example 2*

To determine whether (a) water melon, (b) maize (grain), (c) groundnuts, can be grown in Endau area (Latitude 2° 36′ 35″N, Longitude 103° 37′ 50″E) under rainfed conditions and select the suitable planting dates.

(a) ***Water Melon***

Following the same procedure as in Example 1, TPSTAT programme is run using daily rainfall records of D.I.D station number 2636169 (please see Table 3.4). Adopting the grassland evaporation data for evaporation station number 2636370, the water requirement curve for water melon is superimposed on the weekly effective rainfall graph. The best fit is shown in Fig. 3.5.

It can be observed from Fig. 3.5, that the water requirements of the initial and development stages of water melon are generally satisfied by the 80% probability level. The 60% probability level over satisfies the water requirement for both these stages and generally satisfies the water requirement for the mid and late seasons.

Hence it is possible to grow water melon in Endau area under rainfed conditions.

The planting date from Fig. 3.5 is the beginning of 43rd week i.e. 22nd October.

Note: The crop is not normally grown in this area during the period suggested, because of the monsoon which frequently causes crop damage. However the crop is often planted from the 12th week. This planting date is based on 60% probability level.

(b) ***Maize (grain)***

The best fit for maize is shown in Fig. 3.6.

This shows that it is possible to grow maize (grain) in Endau area under rainfed conditions.

The planting date from Fig. 3.6 is the beginning of the 17th week i.e. 23rd April.

Note: Although the water requirement of the crop can be met from 36th week onwards, this crop is not recommended for this period because of the monsoon.

(c) ***Groundnuts***

The best fit for groundnuts is shown in Fig. 3.7.

This shows that it is possible to grow groundnuts in Endau area under rainfed conditions.

The planting date from Fig. 3.7 is the beginning of the 17th week i.e. 23rd April.

Note: Although the water requirement of the crop can be met from 36th week onwards, this crop is not recommended for this period because of the monsoon.

3.3.2.3 *Example 3*

To determine whether (a) tobacco, (b) maize (grain), (c) groundnuts, can be grown in Kuala Brang area (Latitude 5° 04′ 15″N, Longitude 103° 00′ 50″E) under rainfed conditions and select the suitable planting dates.

(a) ***Tobacco***

Following the same procedure as in Example 1, TPSTAT programme is run using daily rainfall records of D.I.D. station number 5030039 (please see Table 3.5). Adopting the grassland evaporation data for evaporation station number 0482, the water requirement curve for tobacco is superimposed on the weekly effective rainfall graph. The best fit is shown in Fig. 3.8.

# TABLE 3.4: OUTPUT OF PROGRAMME TPSTAT FOR D.I.D. STATION NUMBER 2636169

STATION NUMBER 2636169
RECORD PERIOD ANALYSED 1953 TO 1974
EFFECTIVE WEEKLY RAINFALL(MM) FOR A GIVEN RISK(PERCENT)
LIMITS OF EFFECTIVE DAILY RAINFALL 5 TO 50 MM

| WEEK | LOWEST OBSERVED | RAIN(MM) FOR RISK OF EXCEDENCE(PERCENT) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | HIGHEST OBSERVED | RISK OF WEEK BEING WET | DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 29 | 56 | 81 | 105 | 132 | 164 | 207 | 261 | 79 | 21 |
| 2 | 0 | 0 | 0 | 20 | 57 | 82 | 111 | 143 | 181 | 234 | 275 | 75 | 25 |
| 3 | 0 | 0 | 0 | 0 | 21 | 42 | 64 | 87 | 114 | 151 | 178 | 69 | 31 |
| 4 | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 51 | 77 | 112 | 160 | 55 | 45 |
| 5 | 0 | 0 | 0 | 0 | 11 | 25 | 39 | 54 | 71 | 96 | 136 | 67 | 33 |
| 6 | 0 | 0 | 0 | 0 | 13 | 28 | 42 | 57 | 75 | 100 | 130 | 68 | 32 |
| 7 | 0 | 0 | 0 | 0 | 22 | 43 | 63 | 85 | 112 | 148 | 203 | 69 | 31 |
| 8 | 0 | 0 | 0 | 0 | 4 | 23 | 41 | 60 | 84 | 116 | 153 | 62 | 38 |
| 9 | 0 | 0 | 0 | 0 | 0 | 14 | 32 | 52 | 75 | 108 | 150 | 58 | 42 |
| 10 | 0 | 0 | 0 | 0 | 0 | 15 | 31 | 48 | 69 | 97 | 131 | 59 | 41 |
| 11 | 0 | 0 | 0 | 0 | 11 | 29 | 48 | 67 | 91 | 123 | 222 | 65 | 35 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 41 | 80 | 133 | 161 | 43 | 57 |
| 13 | 0 | 0 | 0 | 0 | 17 | 35 | 53 | 73 | 96 | 128 | 172 | 68 | 32 |
| 14 | 0 | 0 | 0 | 0 | 12 | 24 | 35 | 48 | 62 | 82 | 92 | 69 | 31 |
| 15 | 0 | 0 | 0 | 0 | 11 | 22 | 33 | 45 | 59 | 78 | 109 | 69 | 31 |
| 16 | 0 | 0 | 0 | 3 | 9 | 15 | 20 | 27 | 34 | 44 | 50 | 74 | 26 |
| 17 | 0 | 0 | 1 | 11 | 19 | 27 | 34 | 42 | 52 | 65 | 82 | 81 | 19 |
| 18 | 0 | 0 | 0 | 11 | 21 | 31 | 40 | 51 | 63 | 80 | 108 | 79 | 21 |
| 19 | 0 | 0 | 0 | 5 | 17 | 29 | 40 | 52 | 67 | 87 | 103 | 73 | 27 |
| 20 | 0 | 0 | 3 | 18 | 31 | 43 | 54 | 67 | 82 | 103 | 168 | 82 | 18 |
| 21 | 0 | 0 | 9 | 18 | 25 | 32 | 39 | 46 | 55 | 67 | 90 | 88 | 12 |
| 22 | 0 | 0 | 0 | 4 | 12 | 21 | 29 | 38 | 48 | 63 | 74 | 73 | 27 |
| 23 | 5 | 0 | 10 | 18 | 26 | 32 | 39 | 46 | 55 | 66 | 122 | 88 | 12 |
| 24 | 0 | 0 | 0 | 11 | 23 | 33 | 44 | 56 | 69 | 88 | 92 | 78 | 22 |
| 25 | 0 | 0 | 0 | 10 | 19 | 28 | 36 | 46 | 57 | 72 | 119 | 79 | 21 |
| 26 | 0 | 0 | 1 | 12 | 21 | 30 | 38 | 48 | 59 | 74 | 88 | 81 | 19 |
| 27 | 0 | 0 | 7 | 17 | 26 | 34 | 42 | 51 | 62 | 76 | 87 | 85 | 15 |
| 28 | 0 | 0 | 0 | 11 | 23 | 33 | 43 | 54 | 68 | 86 | 95 | 79 | 21 |
| 29 | 0 | 0 | 9 | 19 | 28 | 36 | 44 | 52 | 63 | 77 | 96 | 87 | 13 |
| 30 | 0 | 9 | 23 | 32 | 41 | 48 | 56 | 64 | 74 | 87 | 96 | 94 | 6 |
| 31 | 0 | 0 | 0 | 0 | 7 | 16 | 26 | 36 | 48 | 65 | 116 | 66 | 34 |
| 32 | 0 | 0 | 0 | 6 | 14 | 21 | 28 | 36 | 45 | 57 | 64 | 77 | 23 |
| 33 | 0 | 0 | 0 | 17 | 32 | 46 | 60 | 75 | 93 | 118 | 185 | 79 | 21 |
| 34 | 0 | 0 | 9 | 18 | 26 | 33 | 41 | 49 | 58 | 71 | 84 | 87 | 13 |
| 35 | 0 | 0 | 0 | 3 | 15 | 26 | 38 | 50 | 65 | 85 | 118 | 72 | 28 |
| 36 | 0 | 7 | 18 | 26 | 32 | 38 | 44 | 51 | 59 | 69 | 72 | 94 | 6 |
| 37 | 0 | 0 | 0 | 6 | 19 | 32 | 44 | 57 | 72 | 93 | 130 | 74 | 26 |
| 38 | 0 | 0 | 12 | 24 | 34 | 43 | 52 | 62 | 74 | 90 | 103 | 88 | 12 |
| 39 | 0 | 0 | 5 | 20 | 32 | 43 | 55 | 67 | 82 | 101 | 123 | 83 | 17 |
| 40 | 0 | 0 | 0 | 8 | 20 | 32 | 43 | 56 | 70 | 91 | 129 | 75 | 25 |
| 41 | 0 | 0 | 1 | 13 | 23 | 32 | 41 | 51 | 62 | 78 | 110 | 81 | 19 |
| 42 | 0 | 0 | 9 | 21 | 31 | 40 | 50 | 60 | 72 | 88 | 108 | 86 | 14 |
| 43 | 6 | 4 | 21 | 32 | 42 | 51 | 60 | 70 | 82 | 98 | 118 | 92 | 8 |
| 44 | 30 | 19 | 43 | 60 | 74 | 88 | 101 | 115 | 132 | 156 | 221 | 95 | 5 |
| 45 | 0 | 0 | 8 | 31 | 49 | 66 | 84 | 102 | 125 | 155 | 236 | 83 | 17 |
| 46 | 0 | 11 | 29 | 43 | 55 | 65 | 76 | 87 | 101 | 120 | 128 | 94 | 6 |
| 47 | 10 | 20 | 43 | 60 | 74 | 87 | 100 | 114 | 131 | 154 | 210 | 95 | 5 |
| 48 | 0 | 32 | 55 | 72 | 87 | 100 | 113 | 128 | 145 | 168 | 160 | 97 | 3 |
| 49 | 0 | 0 | 20 | 52 | 79 | 105 | 130 | 158 | 190 | 235 | 325 | 85 | 15 |
| 50 | 9 | 15 | 58 | 89 | 115 | 139 | 163 | 189 | 220 | 262 | 302 | 92 | 8 |
| 51 | 10 | 10 | 44 | 69 | 89 | 109 | 128 | 149 | 174 | 208 | 240 | 92 | 8 |
| 52 | 0 | 0 | 41 | 77 | 108 | 136 | 165 | 196 | 232 | 282 | 372 | 88 | 12 |

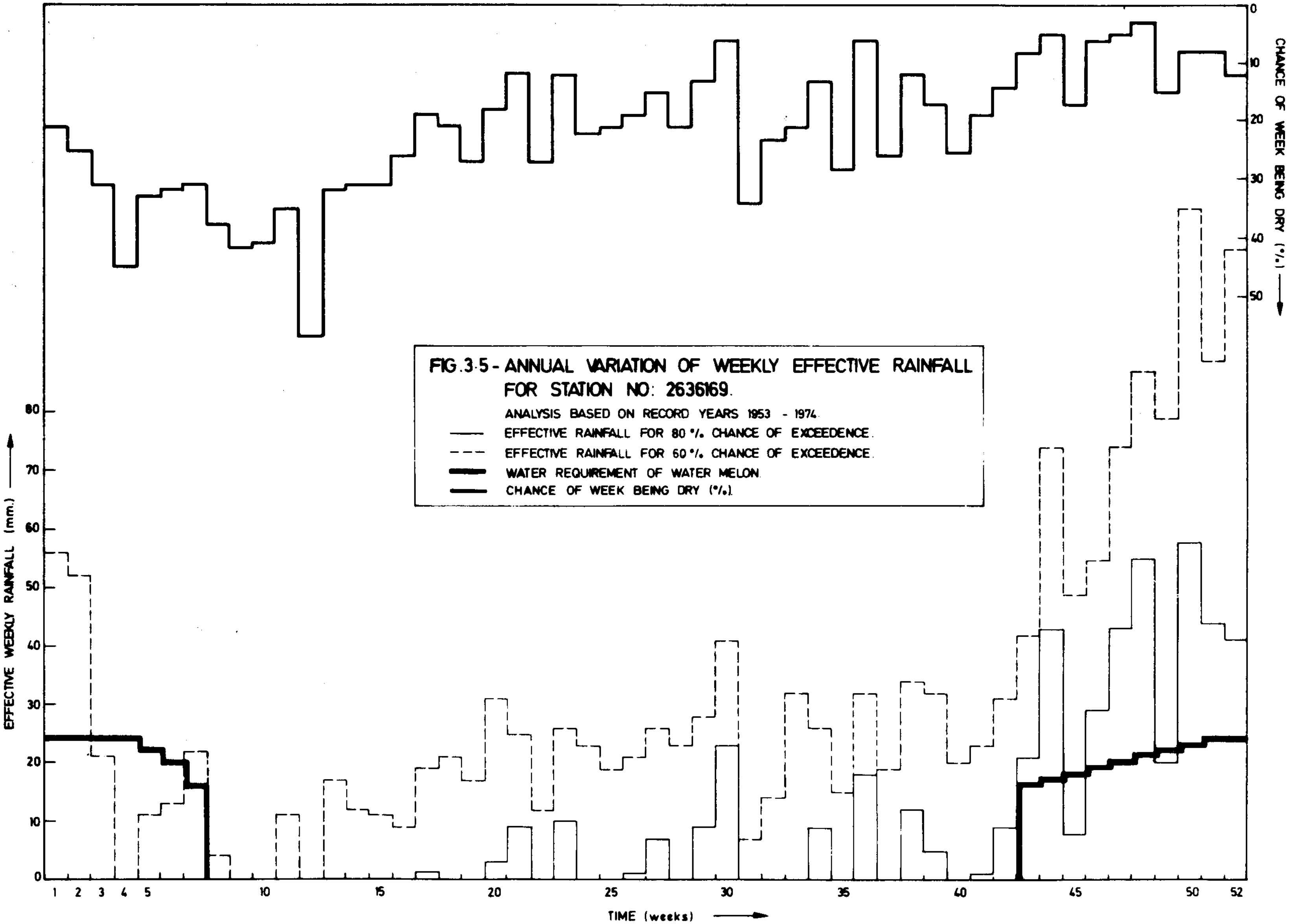



FIG.3.5 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 2636169.

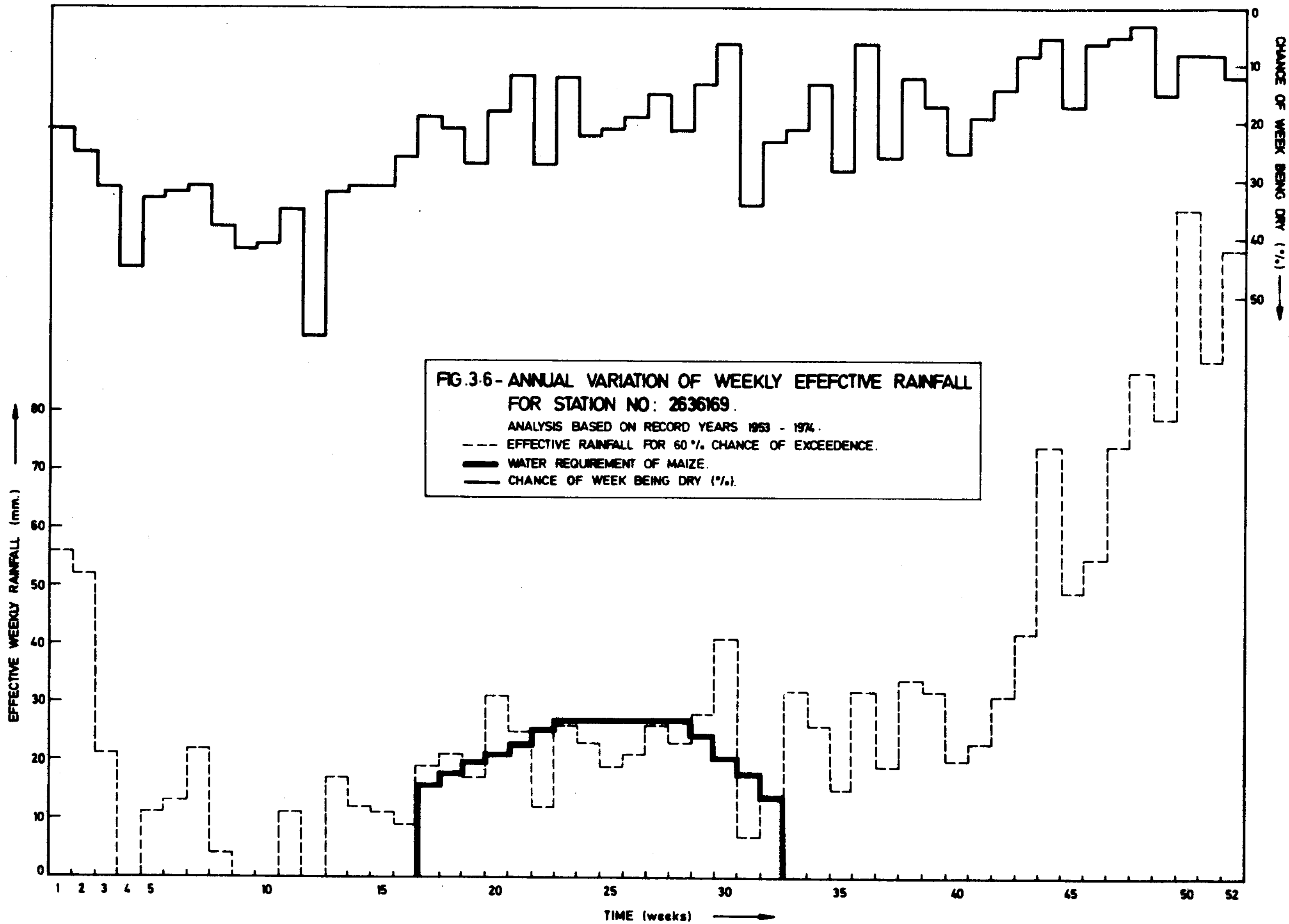



FIG. 3.6 - ANNUAL VARIATION OF WEEKLY EFEFCTIVE RAINFALL FOR STATION NO: 2636169.

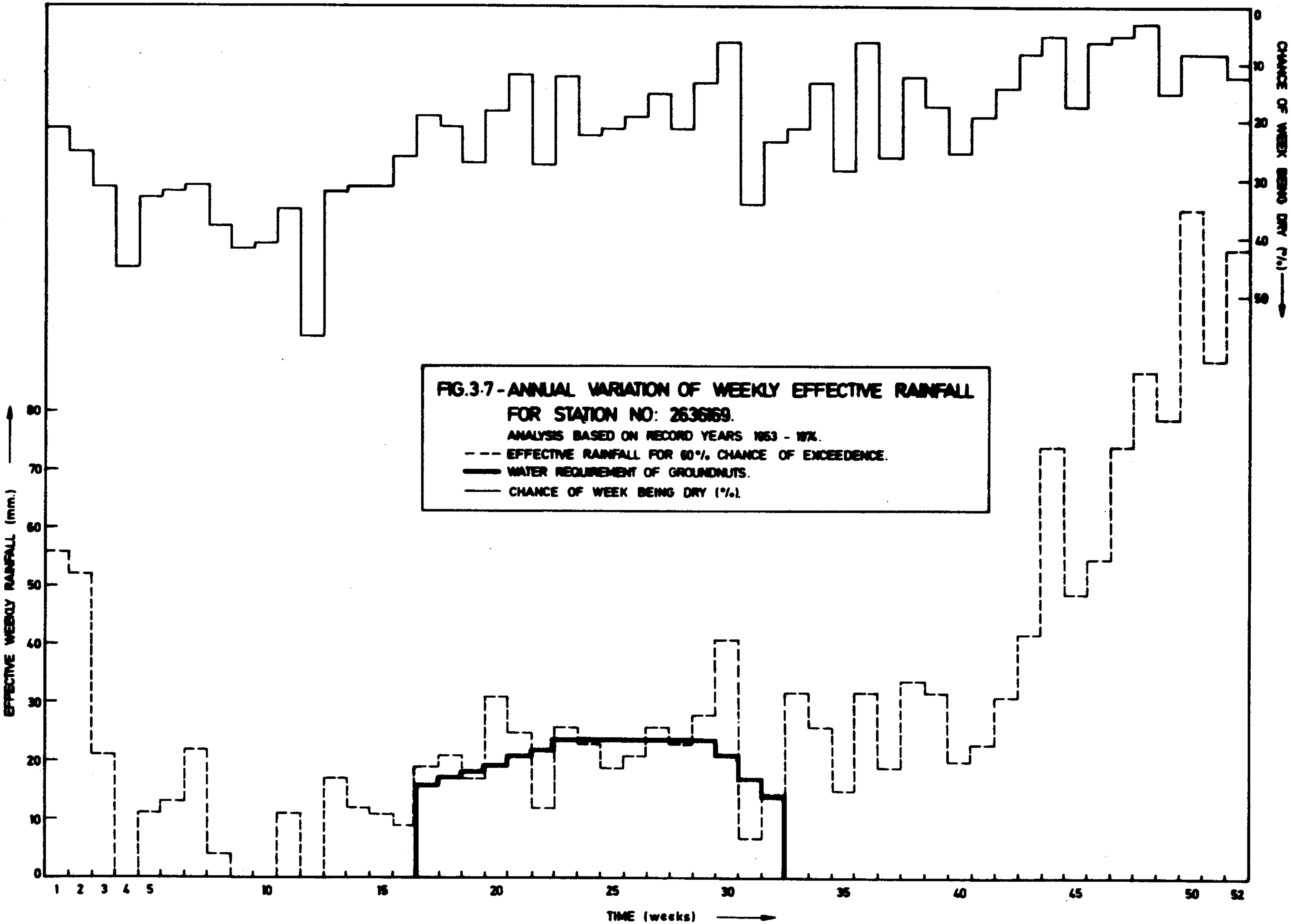



FIG.3.7 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 2636169.

## TABLE 3.5: OUTPUT OF PROGRAMME TPSTAT FOR D.I.D. STATION NUMBER 5030039

STATION NUMBER 5030039
RECORD PERIOD ANALYSED 1959 TO 1975
EFFECTIVE WEEKLY RAINFALL (MM) FOR A GIVEN RISK (PERCENT)
LIMITS OF EFFECTIVE DAILY RAINFALL 5 TO 50 MM

| WEEK | LOWEST OBSERVED | RAIN(MM) FOR RISK OF EXCEDENCE(PERCENT) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | HIGHEST OBSERVED | RISK OF WEEK BEING WET | DRY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 29 | 59 | 86 | 114 | 144 | 179 | 228 | 275 | 78 | 22 |
| 2 | 0 | 0 | 0 | 0 | 20 | 54 | 89 | 126 | 170 | 230 | 282 | 65 | 35 |
| 3 | 0 | 0 | 0 | 1 | 21 | 40 | 59 | 79 | 103 | 136 | 186 | 70 | 30 |
| 4 | 0 | 0 | 0 | 0 | 0 | 17 | 38 | 60 | 87 | 124 | 163 | 58 | 42 |
| 5 | 0 | 0 | 0 | 0 | 6 | 17 | 27 | 38 | 51 | 69 | 99 | 66 | 34 |
| 6 | 0 | 0 | 0 | 0 | 6 | 21 | 37 | 53 | 73 | 99 | 152 | 64 | 36 |
| 7 | 0 | 0 | 0 | 0 | 29 | 55 | 81 | 109 | 143 | 189 | 243 | 70 | 30 |
| 8 | 0 | 0 | 0 | 0 | 10 | 25 | 40 | 57 | 77 | 104 | 137 | 66 | 34 |
| 9 | 0 | 0 | 0 | 0 | 0 | 15 | 33 | 51 | 74 | 104 | 130 | 58 | 42 |
| 10 | 0 | 0 | 0 | 5 | 16 | 27 | 37 | 48 | 62 | 80 | 134 | 74 | 26 |
| 11 | 0 | 0 | 0 | 0 | 0 | 4 | 19 | 36 | 56 | 84 | 150 | 52 | 48 |
| 12 | 0 | 0 | 0 | 0 | 0 | 4 | 18 | 33 | 51 | 76 | 96 | 52 | 48 |
| 13 | 0 | 0 | 0 | 10 | 22 | 33 | 44 | 56 | 70 | 89 | 102 | 77 | 23 |
| 14 | 0 | 0 | 0 | 0 | 8 | 26 | 44 | 63 | 85 | 116 | 136 | 64 | 36 |
| 15 | 0 | 0 | 0 | 0 | 0 | 11 | 24 | 37 | 53 | 75 | 104 | 59 | 41 |
| 16 | 0 | 0 | 0 | 0 | 0 | 3 | 13 | 24 | 37 | 55 | 69 | 53 | 47 |
| 17 | 0 | 0 | 0 | 0 | 0 | 7 | 18 | 30 | 44 | 63 | 86 | 56 | 44 |
| 18 | 0 | 0 | 0 | 10 | 24 | 37 | 50 | 65 | 82 | 105 | 139 | 76 | 24 |
| 19 | 0 | 0 | 0 | 14 | 25 | 36 | 47 | 59 | 72 | 91 | 110 | 80 | 20 |
| 20 | 0 | 0 | 0 | 14 | 26 | 38 | 49 | 61 | 76 | 96 | 123 | 80 | 20 |
| 21 | 0 | 2 | 11 | 18 | 23 | 29 | 34 | 39 | 46 | 55 | 58 | 91 | 9 |
| 22 | 7 | 0 | 12 | 21 | 28 | 35 | 42 | 49 | 57 | 69 | 84 | 90 | 10 |
| 23 | 0 | 0 | 4 | 12 | 19 | 25 | 31 | 38 | 46 | 57 | 62 | 84 | 16 |
| 24 | 0 | 0 | 13 | 25 | 34 | 43 | 52 | 61 | 73 | 88 | 107 | 89 | 11 |
| 25 | 0 | 0 | 12 | 23 | 33 | 41 | 50 | 59 | 70 | 85 | 93 | 88 | 12 |
| 26 | 0 | 0 | 3 | 19 | 32 | 43 | 55 | 68 | 84 | 105 | 138 | 82 | 18 |
| 27 | 0 | 0 | 3 | 19 | 32 | 43 | 55 | 68 | 83 | 104 | 114 | 82 | 18 |
| 28 | 0 | 0 | 0 | 9 | 21 | 32 | 43 | 55 | 69 | 88 | 91 | 76 | 24 |
| 29 | 0 | 1 | 15 | 26 | 35 | 43 | 51 | 60 | 70 | 84 | 101 | 90 | 10 |
| 30 | 0 | 0 | 3 | 14 | 24 | 33 | 42 | 52 | 64 | 80 | 113 | 82 | 18 |
| 31 | 0 | 3 | 13 | 21 | 27 | 33 | 39 | 45 | 53 | 63 | 66 | 92 | 8 |
| 32 | 0 | 0 | 14 | 27 | 38 | 48 | 58 | 69 | 82 | 100 | 127 | 88 | 12 |
| 33 | 0 | 0 | 0 | 17 | 37 | 56 | 75 | 95 | 119 | 152 | 267 | 77 | 23 |
| 34 | 0 | 0 | 18 | 34 | 46 | 58 | 70 | 83 | 98 | 119 | 135 | 89 | 11 |
| 35 | 6 | 9 | 24 | 36 | 45 | 54 | 63 | 72 | 84 | 99 | 102 | 94 | 6 |
| 36 | 0 | 20 | 40 | 54 | 66 | 77 | 88 | 100 | 115 | 134 | 147 | 96 | 4 |
| 37 | 6 | 4 | 25 | 40 | 53 | 65 | 77 | 89 | 105 | 125 | 136 | 91 | 9 |
| 38 | 0 | 7 | 29 | 44 | 57 | 69 | 82 | 95 | 110 | 132 | 149 | 92 | 8 |
| 39 | 0 | 10 | 26 | 38 | 48 | 57 | 66 | 76 | 88 | 105 | 126 | 94 | 6 |
| 40 | 0 | 0 | 0 | 15 | 36 | 55 | 73 | 94 | 118 | 151 | 177 | 76 | 24 |
| 41 | 18 | 10 | 33 | 51 | 65 | 79 | 92 | 107 | 124 | 148 | 213 | 93 | 7 |
| 42 | 0 | 18 | 35 | 48 | 59 | 68 | 78 | 89 | 102 | 119 | 155 | 96 | 4 |
| 43 | 12 | 10 | 34 | 52 | 67 | 81 | 95 | 111 | 128 | 153 | 197 | 93 | 7 |
| 44 | 0 | 0 | 35 | 62 | 85 | 106 | 126 | 149 | 176 | 212 | 268 | 90 | 10 |
| 45 | 9 | 0 | 23 | 44 | 62 | 78 | 95 | 113 | 134 | 163 | 221 | 88 | 12 |
| 46 | 10 | 12 | 35 | 51 | 66 | 79 | 92 | 106 | 123 | 146 | 158 | 93 | 7 |
| 47 | 8 | 5 | 41 | 68 | 90 | 111 | 131 | 154 | 180 | 216 | 244 | 91 | 9 |
| 48 | 0 | 0 | 41 | 75 | 104 | 131 | 158 | 187 | 221 | 269 | 314 | 89 | 11 |
| 49 | 17 | 22 | 57 | 83 | 105 | 125 | 146 | 168 | 193 | 229 | 247 | 94 | 6 |
| 50 | 13 | 21 | 57 | 83 | 105 | 125 | 145 | 167 | 193 | 229 | 245 | 94 | 6 |
| 51 | 0 | 4 | 36 | 60 | 80 | 98 | 117 | 137 | 161 | 193 | 219 | 91 | 9 |
| 52 | 7 | 5 | 54 | 90 | 121 | 149 | 177 | 207 | 243 | 292 | 313 | 91 | 9 |

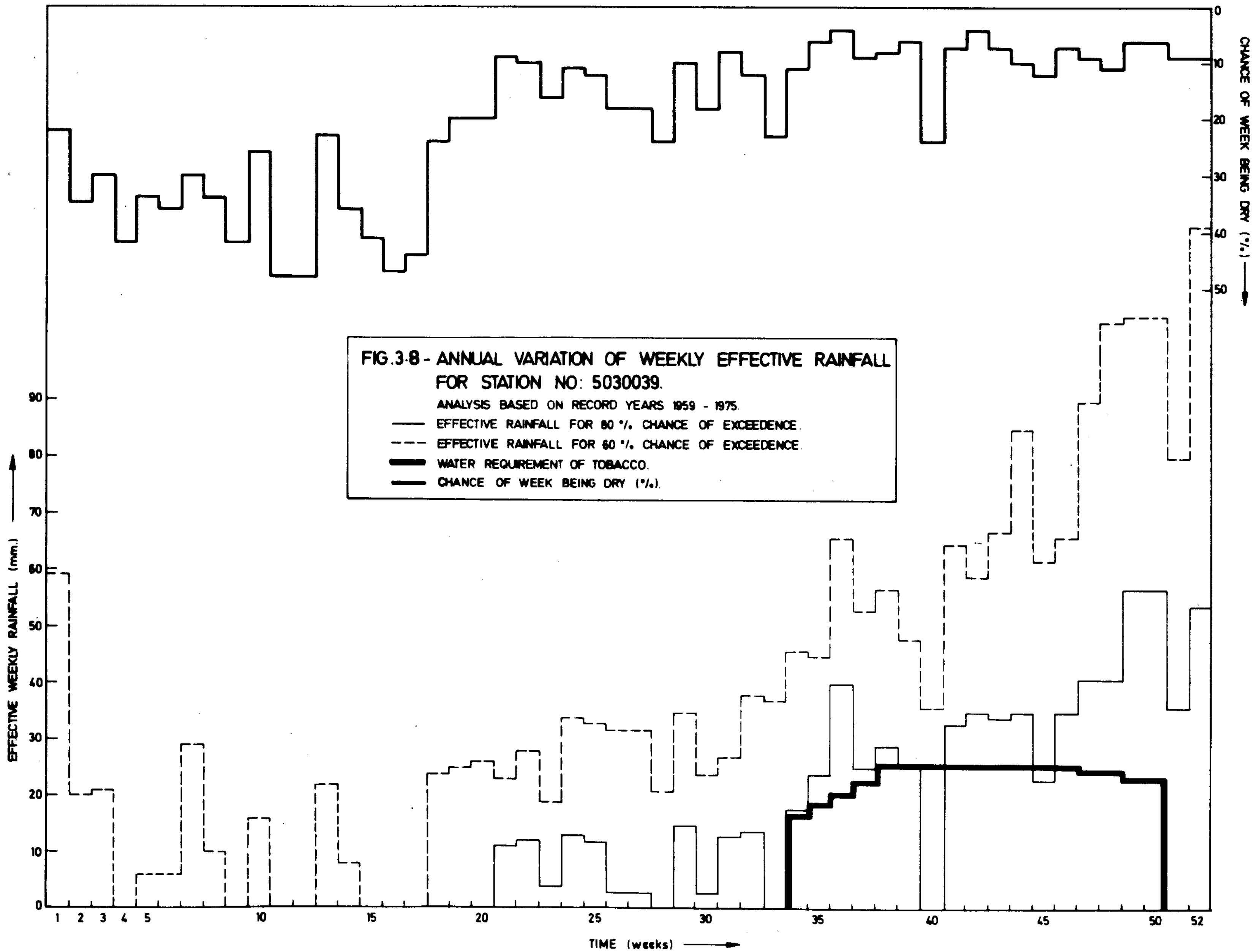



FIG.3.8 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 5030039.

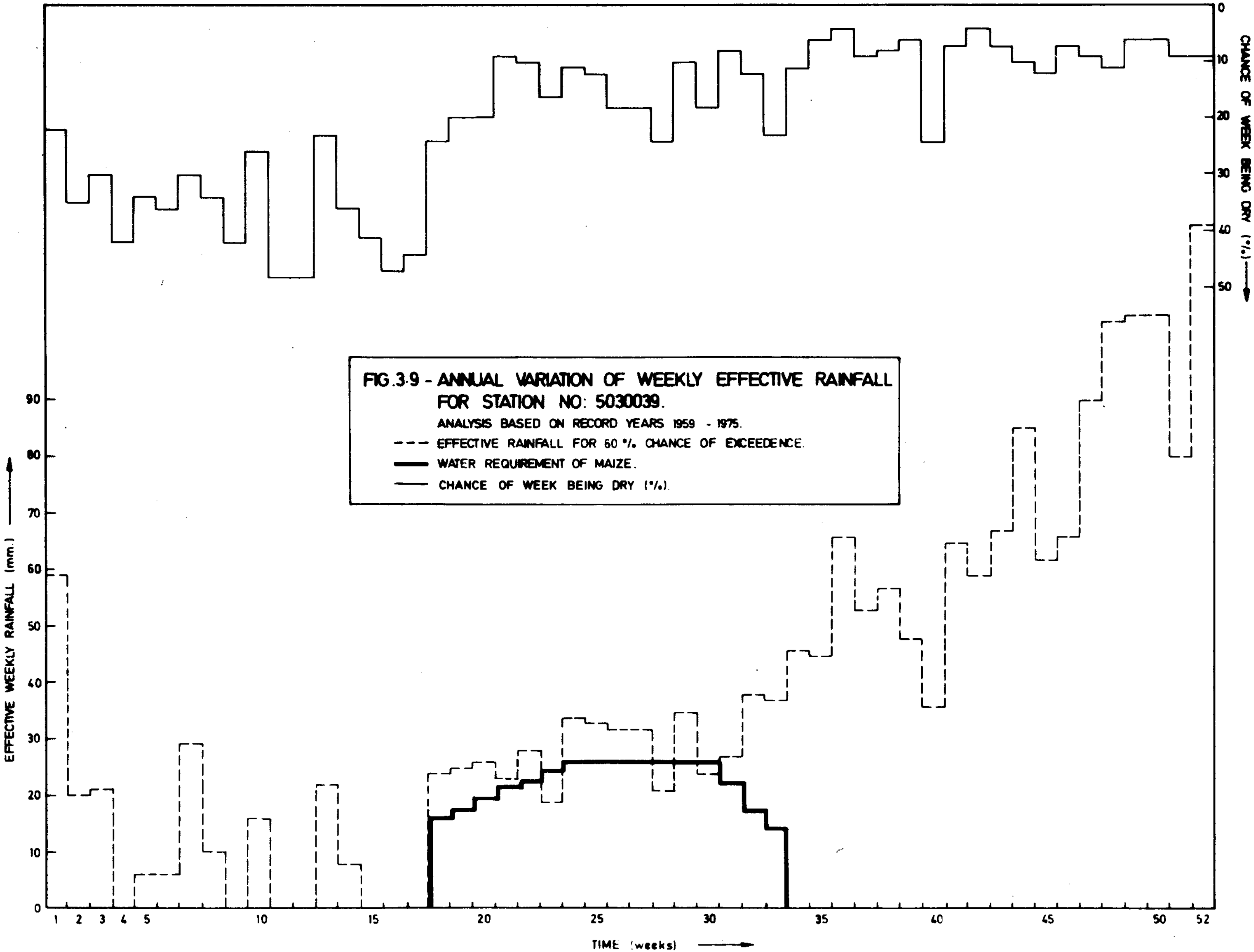



FIG. 3.9 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 5030039.

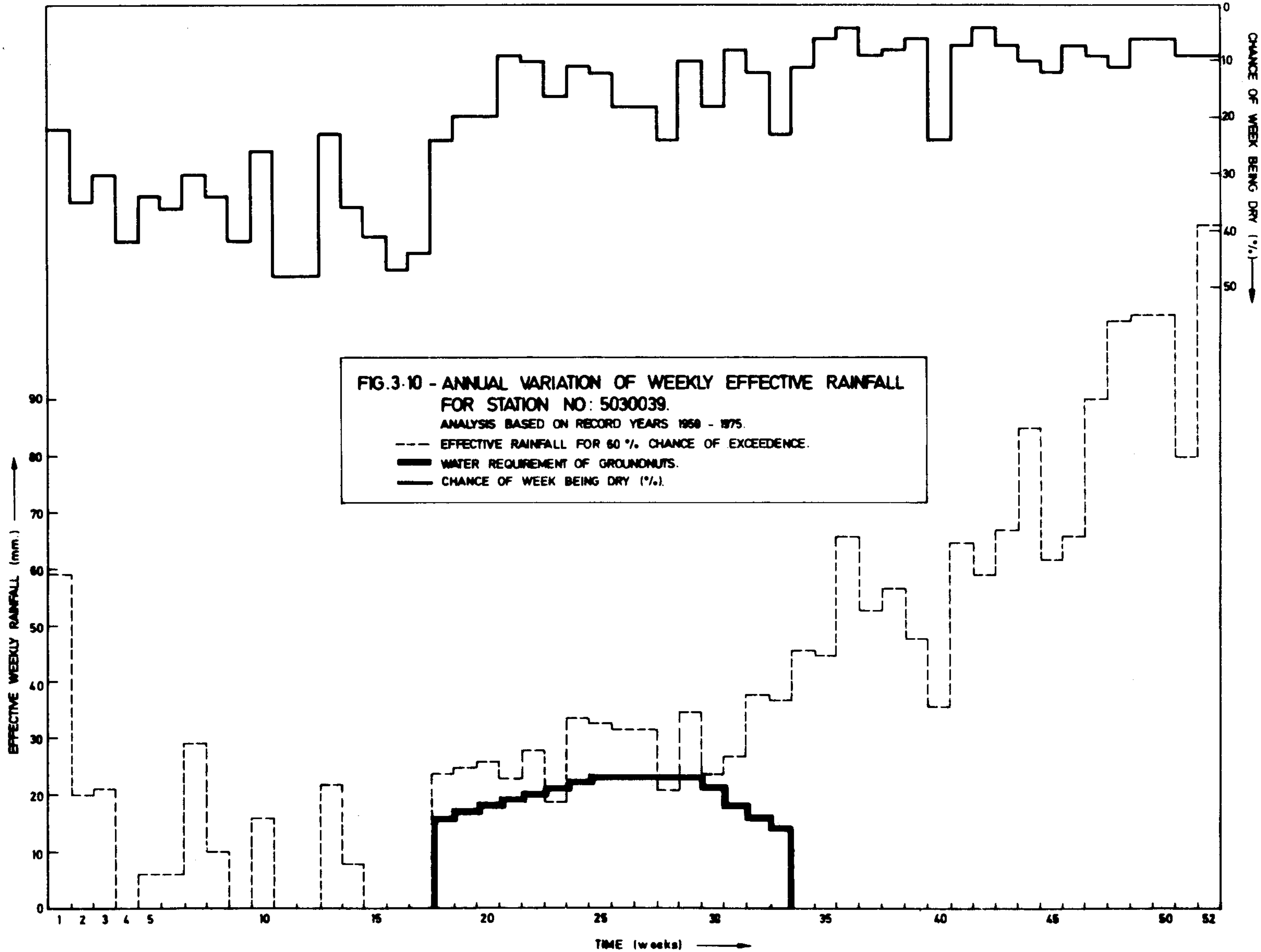



FIG.3.10 - ANNUAL VARIATION OF WEEKLY EFFECTIVE RAINFALL FOR STATION NO: 5030039.

It can be observed in Fig. 3.8, that the water requirements of tobacco is completely satisfied by the 80 % effective rainfall except during the 40th week and 45th week. However, the 60 % probability level over satisfies the water requirement of tobacco.

Hence it is possible to grow tobacco in Kuala Brang area under rainfed conditions.

The planting date from Fig. 3.8 is the beginning of 34th week i.e. 20th August.

Note: The crop is not normally grown in this area during the period suggested, because of the monsoon which frequently causes crop damage. However, the crop is often planted from the 18th week. This planting date is based on 60 % probability level.

(b) *Maize (grain)*

The best fit for maize is shown in Fig. 3.9. This shows that it is possible to grow maize (grain) in Kuala Brang area under rainfed conditions.

The planting date from Fig. 3.9 is the beginning of 18th week, i.e. 30th April.

Note: Although the water requirement of the crop can be met anytime after the 18th week, it is not recommended to be grown during the monsoon period.

(c) *Groundnuts*

The best fit for groundnuts is shown in Fig. 3.10. This shows that it is possible to grow groundnuts in Kuala Brang area under rainfed conditions.

The planting date from Fig. 3.10 is the beginning of 18th week i.e. 30th of April.

Note: Although the water requirement of the crop can be met anytime after the 18th week, it is not recommended to be grown during the monsoon period.

# 4. WATER-SOIL-CROP SIMULATION MODEL

## 4.1 General

Simulation of the water-soil-crop system is basically a water budgeting procedure in which rainfall is added to a storage component and evapotranspiration and drainage are subtracted according to certain rules. The simulation model may be run with or without irrigation input to simulate irrigated or non-irrigated situations respectively. The output from the model is analysed statistically on a monthly basis. The simulation technique is very useful for agricultural planning in that the model output can provide such information as the magnitude of crop water deficits, the number of drought days, the number of irrigation applications required and the corresponding amount of irrigation water to be supplied to the crop.

## 4.2 The Model

A conceptual model of the water-soil-crop system is shown in Fig. 4.1. The model uses a daily water balance approach to determine the change in soil moisture status resulting from daily rainfall and crop evapotranspiration.

In the model, rainfall is added to the soil moisture status existing at the end of the previous day. If the soil moisture storage capacity is exceeded the excess is regarded as a combination of surface and subsurface drainage and the soil is regarded as saturated within the effective rooting depth of the crop. The amount of crop evapotranspiration, which is related to the degree of soil saturation, is then subtracted from the new soil moisture value to yield the day's final soil moisture status. If the soil moisture status falls below a certain critical level a drought day is defined and an irrigation input is scheduled. In such a case sufficient irrigation water is applied to restore the soil to storage capacity.

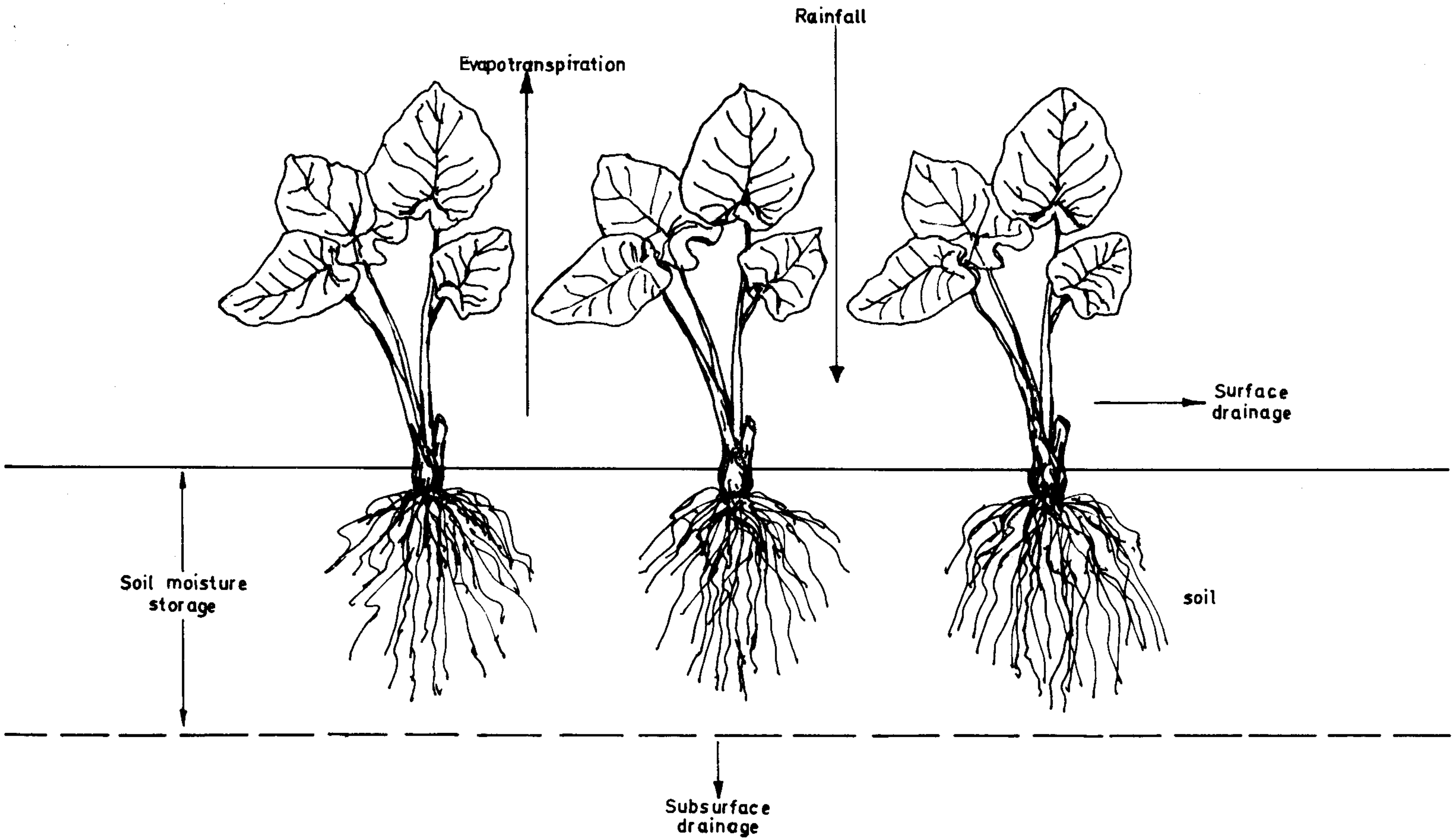



FIG. 4.1 - CONCEPTUAL MODEL OF WATER-SOIL-CROP SYSTEM.

Apart from rainfall input the other two main components of the model are soil moisture storage and evapotranspiration. The development of crop evapotranspiration rates is explained in paragraph 4.2.1 and the soil moisture model is detailed under paragraph 4.2.2.

### 4.2.1 Crop Evapotranspiration

#### 4.2.1.1 Introduction

In any study of crop water requirements one of the major problems is to estimate actual crop evapotranspiration. For this study, the formulae of Penman or Hargreaves, or evaporimeter data are used to estimate the reference crop evapotranspiration (ETO). This reference value, ETO, is defined as "the rate of evapotranspiration from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (FAO, 1975). To account for the effect of individual crop characteristics on crop water requirements, crop coefficients are required to relate ETO to crop evapotranspiration.

#### 4.2.1.2 Method

Climate is the most important factor determining the amount of water lost by evapotranspiration from crops. Evapotranspiration for a given crop is also determined by the crop itself and its growth characteristics. To calculate the crop evapotranspiration the approach adopted in "FAO Irrigation and Drainage Paper No. 24: Crop Water Requirements" (1975) is used since it is the most comprehensive and up-to-date publication on this subject. The FAO approach is to relate magnitude and variation of evapotranspiration to climatic factors to obtain evapotranspiration values for a grass cover reference crop.

On the basis of available climatic data for Peninsular Malaysia, Radiation and modified Penman's methods (FAO, 1975) were used to calculate ETO values. The values obtained were compared with those obtained by Scarf (1976) who used Penman's and Hargreaves' formula as well as evaporimeter records in his study of evapotranspiration in Peninsular Malaysia. It was found that values of ETO obtained using Penman's and Hargreaves' Methods gave better correlation with the pan evaporimeter data than the Radiation and modified Penman's methods. Hence Scarf's ETO values were utilised in this study.

These values of ETO are related to the crop evapotranspiration by the following equation:

$$ET(Crop) = K \times ETO \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (4.1)$$

where, K is the crop coefficient

ET (Crop) is "the potential evapotranspiration of a disease-free crop, growing in a large field (one or more hectares) under optimal soil conditions including sufficient water and fertility and achieving full production potential of that crop under the given growing environment"(FAO, 1975).

#### 4.2.1.3 Spatial variability of ETO

As shown in paragraph 4.2.1.2, ET(Crop) is a function of both K and ETO. Scarf (1976) has computed ETO values for 100 climatological and US class A (black painted) pan stations throughout Peninsular Malaysia and these values are presented in Table 4.1. In his study Scarf found that maximum evapotranspiration occurs along the foothills of the mountain blocks and decreases towards the coast and that evapotranspiration also decreases markedly with increasing elevation.Because of such spatial variations in grassland potential evapotranspiration it is necessary to adopt monthly ETO data from the nearest climatological or US class A (black painted) pan station for calculation of ET(Crop) values.

The daily values of ETO in each month are obtained by dividing the monthly value by the number of days in that month.

## TABLE 4.1: MONTHLY GRASSLAND POTENTIAL EVAPORATION DATA FOR PENINSULAR MALAYSIA

HYDROLOGY BRANCH JPT MALAYSIA

GRASS EVAPORATION

| SITE NO | SITE NAME | ST | LAT | LONG | ELEV | MD | NY | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0614 | KANGAR | PS | 6 26 | 100 12 | 3 | H | 11 | 114 | 121 | 143 | 128 | 121 | 108 | 112 | 116 | 111 | 109 | 101 | 104 | 1388 MM |
| 6401308 | JPT, KANGAR | PS | 6 27 | 100 11 | 3 | AP | 14 | 134 | 147 | 167 | 145 | 119 | 102 | 105 | 107 | 101 | 99 | 93 | 102 | 1421 MM |
| 6397311 | PG. MATSIRAT, P. LANGKAWI | KD | 6 21 | 99 44 | 5 | AP | 13 | 151 | 152 | 164 | 132 | 111 | 104 | 106 | 105 | 104 | 98 | 106 | 126 | 1459 MM |
| 0602 | PULAU LANGKAWI | KD | 6 19 | 99 51 | 4 | H | 2 | 125 | 130 | 138 | 134 | 121 | 110 | 110 | 118 | 111 | 110 | 102 | 118 | 1427 MM |
| 6204323 | PETAK UJIAN, JITRA | KD | 6 16 | 100 25 | 5 | AP | 11 | 139 | 154 | 167 | 142 | 125 | 108 | 112 | 115 | 113 | 108 | 99 | 109 | 1491 MM |
| 6203324 | TELAGA BATU | KD | 6 15 | 100 22 | 4 | AP | 8 | 139 | 146 | 161 | 139 | 123 | 106 | 118 | 116 | 107 | 106 | 103 | 119 | 1483 MM |
| 0619 | PEDU DAM | KD | 6 14 | 100 46 | 59 | H | 7 | 117 | 123 | 142 | 137 | 126 | 118 | 122 | 124 | 115 | 113 | 103 | 103 | 1443 MM |
| 6207332 | PEDU DAM | KD | 6 14 | 100 46 | 59 | AP | 7 | 164 | 166 | 178 | 143 | 122 | 104 | 116 | 117 | 108 | 105 | 100 | 118 | 1541 MM |
| 0620 | ALOR STAR, K. BATAS AIRPORT | KD | 6 12 | 100 25 | 5 | P | 11 | 117 | 119 | 138 | 137 | 122 | 115 | 116 | 117 | 114 | 107 | 102 | 102 | 1406 MM |
| 0635 | GAJAH MATI | KD | 6 10 | 100 33 | 15 | H | 7 | 122 | 126 | 149 | 133 | 133 | 122 | 127 | 129 | 119 | 117 | 107 | 112 | 1496 MM |
| 6105337 | GAJAH MATI | KD | 6 10 | 100 32 | 15 | AP | 8 | 134 | 149 | 164 | 142 | 119 | 100 | 111 | 111 | 103 | 101 | 96 | 108 | 1438 MM |
| 0638 | MUDA DAM | KD | 6 7 | 100 51 | 110 | H | 7 | 111 | 116 | 139 | 128 | 131 | 113 | 115 | 114 | 105 | 95 | 96 | 92 | 1355 MM |
| 6108301 | MUDA DAM | KD | 6 7 | 100 51 | 110 | AP | 7 | 155 | 159 | 173 | 144 | 121 | 112 | 121 | 121 | 112 | 104 | 88 | 119 | 1529 MM |
| 0553 | SALA KANAN | KD | 5 58 | 100 24 | 15 | H | 7 | 114 | 115 | 136 | 121 | 110 | 103 | 111 | 111 | 103 | 100 | 95 | 96 | 1315 MM |
| 0549 | BATU SEKETUL | KD | 5 58 | 100 48 | 76 | H | 4 | 118 | 120 | 142 | 134 | 119 | 112 | 127 | 112 | 114 | 113 | 96 | 98 | 1405 MM |
| 5903351 | KUALA SALA | KD | 5 58 | 100 22 | 3 | AP | 10 | 149 | 144 | 154 | 129 | 117 | 108 | 113 | 118 | 108 | 101 | 102 | 114 | 1457 MM |
| 5904352 | SIMPANG TIGA, SG RIMAU | KD | 5 55 | 100 26 | 3 | AP | 8 | 135 | 142 | 155 | 140 | 129 | 113 | 130 | 124 | 118 | 112 | 106 | 112 | 1516 MM |
| 0548 | CHAROK PADANG | KD | 5 48 | 100 43 | 31 | H | 7 | 122 | 127 | 148 | 145 | 144 | 135 | 139 | 141 | 134 | 132 | 120 | 120 | 1607 MM |
| 0545 | BALING | KD | 5 41 | 100 55 | 54 | H | 11 | 129 | 128 | 153 | 140 | 142 | 134 | 137 | 142 | 132 | 131 | 117 | 119 | 1604 MM |
| 0543 | SUNGAI PATANI | KD | 5 39 | 100 30 | 8 | H | 11 | 123 | 126 | 146 | 136 | 136 | 129 | 134 | 137 | 128 | 124 | 111 | 112 | 1542 MM |
| 0540 | KULIM | KD | 5 23 | 100 33 | 32 | H | 11 | 119 | 121 | 138 | 125 | 125 | 121 | 125 | 127 | 119 | 117 | 106 | 107 | 1450 MM |
| 0542 | BUMBONG LIMA | PW | 5 37 | 100 28 | 4 | H | 2 | 109 | 105 | 126 | 119 | 122 | 111 | 119 | 122 | 107 | 109 | 96 | 104 | 1349 MM |
| 5504332 | BUMBONG LIMA | PW | 5 33 | 100 26 | 4 | AP | 8 | 142 | 151 | 158 | 129 | 127 | 109 | 122 | 116 | 114 | 113 | 105 | 116 | 1502 MM |
| 0537 | BUTTERWORTH | PW | 5 28 | 100 23 | 2 | H | 6 | 117 | 116 | 133 | 124 | 120 | 115 | 122 | 124 | 110 | 112 | 102 | 106 | 1401 MM |
| 0538 | BUKIT MERTAJAM | PW | 5 22 | 100 28 | 14 | H | 11 | 122 | 122 | 144 | 131 | 131 | 128 | 130 | 128 | 126 | 122 | 111 | 113 | 1508 MM |
| 0533 | PENANG HILL | PG | 5 25 | 100 16 | 732 | H | 11 | 88 | 86 | 100 | 86 | 82 | 79 | 81 | 80 | 74 | 76 | 69 | 74 | 975 MM |
| 0537 | PENANG TOWN | PG | 5 25 | 100 19 | 5 | H | 11 | 125 | 127 | 144 | 133 | 126 | 122 | 124 | 125 | 116 | 115 | 109 | 114 | 1480 MM |
| 0530 | PENANG, BAYAN LEPAS AIRPORT | PG | 5 18 | 100 16 | 3 | P | 11 | 124 | 121 | 139 | 133 | 120 | 117 | 117 | 117 | 113 | 109 | 108 | 109 | 1427 MM |
| 0520 | PARIT BUNTAR | PK | 5 8 | 100 30 | 3 | H | 11 | 111 | 109 | 124 | 120 | 125 | 118 | 123 | 126 | 126 | 122 | 112 | 111 | 1427 MM |
| 0505 | LENGGONG | PK | 5 6 | 100 58 | 101 | H | 11 | 127 | 129 | 151 | 134 | 134 | 124 | 131 | 136 | 131 | 129 | 116 | 113 | 1555 MM |
| 5006321 | JPT, BUKIT MERAH | PK | 5 2 | 100 39 | 3 | AP | 10 | 134 | 131 | 141 | 128 | 129 | 131 | 134 | 134 | 117 | 122 | 113 | 117 | 1531 MM |
| 0503 | BAGAN SERAI | PK | 5 1 | 100 32 | 3 | H | 11 | 111 | 113 | 126 | 119 | 124 | 123 | 122 | 127 | 122 | 119 | 110 | 107 | 1423 MM |
| 0445 | MAXWELLS HILL | PK | 4 52 | 100 48 | 1036 | H | 11 | 55 | 61 | 66 | 62 | 64 | 64 | 67 | 70 | 66 | 64 | 55 | 56 | 750 MM |
| 0446 | TAIPING | PK | 4 52 | 100 44 | 18 | H | 11 | 118 | 117 | 131 | 118 | 122 | 124 | 127 | 129 | 121 | 124 | 106 | 108 | 1445 MM |
| 0447 | KUALA KANGSAR | PK | 4 46 | 100 56 | 39 | H | 11 | 127 | 127 | 147 | 138 | 135 | 132 | 133 | 138 | 130 | 128 | 117 | 117 | 1569 MM |
| 0419 | TANJUNG RAMBUTAN | PK | 4 40 | 101 10 | 70 | H | 11 | 130 | 128 | 151 | 141 | 142 | 133 | 140 | 144 | 136 | 136 | 124 | 122 | 1627 MM |
| 0418 | IPOH AIRPORT | PK | 4 34 | 101 6 | 39 | P | 11 | 117 | 115 | 135 | 129 | 122 | 119 | 119 | 119 | 118 | 112 | 105 | 102 | 1412 MM |
| 0417 | BATU GAJAH | PK | 4 28 | 101 2 | 34 | H | 7 | 121 | 122 | 138 | 133 | 131 | 125 | 129 | 135 | 132 | 127 | 115 | 113 | 1521 MM |
| 0416 | PARIT | PK | 4 26 | 100 54 | 19 | H | 4 | 119 | 116 | 140 | 127 | 125 | 116 | 119 | 122 | 122 | 125 | 109 | 109 | 1449 MM |
| 0460 | N. E. B. JOR | PK | 4 22 | 101 20 | 604 | H | 2 | 103 | 103 | 118 | 102 | 93 | 97 | 106 | 106 | 102 | 99 | 88 | 88 | 1205 MM |
| 0414 | KAMPAR | PK | 4 18 | 101 9 | 37 | H | 11 | 119 | 117 | 137 | 128 | 129 | 125 | 130 | 137 | 132 | 132 | 116 | 114 | 1516 MM |
| 0410 | SITIAWAN | PK | 4 13 | 100 4 | 7 | P | 11 | 112 | 111 | 129 | 126 | 119 | 115 | 114 | 116 | 115 | 109 | 102 | 100 | 1368 MM |
| 0413 | TAPAH | PK | 4 12 | 101 16 | 35 | H | 7 | 123 | 119 | 142 | 134 | 130 | 126 | 133 | 134 | 133 | 129 | 116 | 116 | 1535 MM |
| 0407 | TELOK ANSON | PK | 4 2 | 101 1 | 3 | H | 11 | 124 | 118 | 140 | 128 | 128 | 124 | 127 | 135 | 131 | 130 | 115 | 111 | 1511 MM |
| 3710306 | BAGAN TERAP | SR | 3 44 | 101 5 | 3 | AP | 12 | 120 | 123 | 138 | 125 | 121 | 111 | 116 | 121 | 118 | 119 | 108 | 104 | 1424 MM |
| 0340 | TANJUNG MALIM | SR | 3 41 | 101 31 | 43 | H | 7 | 116 | 115 | 138 | 128 | 128 | 124 | 129 | 130 | 131 | 127 | 118 | 112 | 1496 MM |
| 3609313 | SUNGEI BESAR | SR | 3 40 | 100 59 | 3 | AP | 11 | 121 | 123 | 139 | 130 | 128 | 126 | 127 | 131 | 118 | 122 | 113 | 109 | 1487 MM |
| 0327 | KUALA KUBU BARU | SR | 3 34 | 101 39 | 61 | H | 11 | 123 | 115 | 136 | 131 | 128 | 122 | 127 | 132 | 128 | 129 | 117 | 119 | 1507 MM |
| 3516322 | KUALA KUBU BARU | SR | 3 34 | 101 40 | 90 | AP | 13 | 153 | 136 | 135 | 110 | 118 | 114 | 111 | 108 | 110 | 104 | 104 | 122 | 1425 MM |
| 0325 | TANJUNG KARANG | SR | 3 30 | 101 12 | 2 | H | 7 | 105 | 105 | 121 | 113 | 112 | 107 | 109 | 117 | 113 | 112 | 101 | 98 | 1313 MM |

STATE CODE: PS-PERLIS; KD-KEDAH; PW-PROVINCE WELLESLEY; PG-PENANG; PK-PERAK; SR-SELANGOR; MA-MELAKA
NS-NEGRI SEMBILAN; JH-JOHOR; PH-PAHANG; TR-TRENGGANU; KN-KELANTAN

METHOD CODE (MD): P-PENMAN; H-HARGREAVES; AP-CLASS A EVAPORATION PAN (BLACK PAINTED C. I.)

ELEV: ELEVATION IN METRES

NY: NUMBER OF YEARS OF RECORDS

## TABLE 4.1 (CONTD.)

### HYDROLOGY BRANCH JPT MALAYSIA

GRASS EVAPORATION

| SITE NO | SITE NAME | ST | LAT | LONG | ELEV | MD | NY | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0312 | KEPONG | SR | 3 14 | 101 38 | 67 | H | 11 | 118 | 118 | 134 | 125 | 121 | 133 | 114 | 119 | 115 | 119 | 107 | 107 | 1410 MM |
| 0311 | BUKIT NANAS | SR | 3 9 | 101 42 | 30 | H | 2 | 128 | 129 | 145 | 120 | 126 | 128 | 129 | 149 | 132 | 141 | 117 | 124 | 1568 MM |
| 3117370 | JPT, AMPANG, KUALA LUMPUR | SR | 3 9 | 101 45 | 46 | AP | 10 | 125 | 128 | 143 | 133 | 130 | 117 | 122 | 123 | 112 | 116 | 110 | 110 | 1469 MM |
| 0310 | SUBANG INT. AIRPORT K.L. | SR | 3 7 | 101 33 | 16 | P | 11 | 109 | 109 | 126 | 121 | 117 | 111 | 112 | 113 | 113 | 111 | 103 | 98 | 1343 MM |
| 0306 | KLANG HIGH SCHOOL | SR | 3 3 | 101 27 | 10 | H | 11 | 119 | 117 | 134 | 123 | 122 | 115 | 118 | 128 | 119 | 121 | 112 | 108 | 1436 MM |
| 0300 | KAJANG | SR | 3 0 | 101 47 | 40 | H | 11 | 126 | 122 | 144 | 131 | 130 | 120 | 125 | 131 | 124 | 127 | 120 | 119 | 1519 MM |
| 0258 | ONE FATHOM BANK LIGHTHOUSE | SR | 2 53 | 100 59 | 21 | H | 7 | 77 | 84 | 104 | 100 | 90 | 91 | 101 | 102 | 85 | 96 | 87 | 90 | 1107 MM |
| 0248 | JELEBU, KUALA KELAWANG | NS | 2 57 | 102 4 | 137 | H | 11 | 118 | 114 | 131 | 127 | 126 | 119 | 122 | 127 | 126 | 129 | 117 | 118 | 1474 MM |
| 0246 | AYER HITAM, BAHAU | NS | 2 56 | 102 24 | 55 | H | 2 | 120 | 110 | 142 | 127 | 136 | 125 | 129 | 139 | 133 | 132 | 116 | 118 | 1527 MM |
| 0244 | KUALA PILAH | NS | 2 44 | 102 15 | 107 | H | 11 | 120 | 120 | 135 | 127 | 127 | 121 | 117 | 128 | 128 | 127 | 113 | 111 | 1474 MM |
| 0241 | SEREMBAN | NS | 2 43 | 101 56 | 64 | H | 11 | 126 | 124 | 143 | 132 | 131 | 120 | 122 | 127 | 126 | 128 | 119 | 117 | 1515 MM |
| 0240 | PORT DICKSON | NS | 2 32 | 101 48 | 9 | H | 11 | 119 | 115 | 132 | 125 | 121 | 115 | 119 | 123 | 124 | 124 | 113 | 117 | 1447 MM |
| 0219 | TAMPIN | NS | 2 28 | 102 14 | 61 | H | 11 | 121 | 120 | 137 | 123 | 120 | 111 | 114 | 118 | 122 | 124 | 112 | 109 | 1431 MM |
| 0210 | MALACCA AIRPORT | MA | 2 16 | 102 15 | 7 | P | 11 | 116 | 114 | 128 | 124 | 116 | 108 | 108 | 110 | 112 | 112 | 104 | 100 | 1352 MM |
| 0205 | MERLIMAU ENGLISH SCHOOL | MA | 2 9 | 102 26 | 3 | H | 11 | 117 | 115 | 130 | 118 | 109 | 105 | 110 | 113 | 114 | 115 | 111 | 111 | 1368 MM |
| 0216 | SEGAMAT | JH | 2 30 | 102 49 | 29 | H | 11 | 118 | 120 | 139 | 133 | 123 | 117 | 120 | 128 | 127 | 130 | 117 | 111 | 1483 MM |
| 0206 | TANGKAK | JH | 2 16 | 102 32 | 30 | H | 7 | 123 | 124 | 140 | 127 | 115 | 110 | 114 | 121 | 122 | 129 | 116 | 116 | 1457 MM |
| 2125342 | KESANG TASEK | JH | 2 9 | 102 32 | 5 | AP | 13 | 116 | 110 | 127 | 115 | 116 | 107 | 109 | 112 | 111 | 109 | 103 | 101 | 1331 MM |
| 0204 | MUAR | JH | 2 3 | 102 34 | 6 | H | 11 | 121 | 116 | 132 | 119 | 114 | 107 | 119 | 122 | 122 | 119 | 114 | 110 | 1415 MM |
| 0143 | AYER HITAM | JH | 1 56 | 103 11 | 37 | H | 6 | 114 | 116 | 136 | 126 | 122 | 114 | 121 | 113 | 116 | 131 | 118 | 113 | 1440 MM |
| 0140 | SUNGAI SUDAH | JH | 1 54 | 102 43 | 2 | H | 6 | 117 | 114 | 132 | 121 | 120 | 114 | 116 | 118 | 118 | 123 | 114 | 113 | 1420 MM |
| 1829378 | BATU PAHAT | JH | 1 51 | 102 56 | 4 | AP | 9 | 115 | 117 | 123 | 120 | 120 | 112 | 121 | 116 | 108 | 116 | 100 | 109 | 1377 MM |
| 0134 | LAYANG LAYANG | JH | 1 49 | 103 28 | 30 | H | 2 | 111 | 104 | 122 | 111 | 113 | 103 | 114 | 118 | 111 | 121 | 110 | 104 | 1342 MM |
| 0130 | PARIT BOTAK | JH | 1 43 | 103 5 | 5 | H | 6 | 123 | 110 | 130 | 117 | 115 | 108 | 114 | 117 | 109 | 122 | 111 | 112 | 1388 MM |
| 0115 | PONTIAN KECIL | JH | 1 29 | 103 23 | 5 | H | 11 | 108 | 103 | 116 | 106 | 108 | 102 | 109 | 105 | 109 | 109 | 101 | 99 | 1275 MM |
| 0117 | JOHOR BHARU | JH | 1 28 | 103 45 | 15 | H | 11 | 112 | 103 | 117 | 108 | 107 | 98 | 104 | 109 | 108 | 114 | 107 | 105 | 1292 MM |
| 1437316 | JPT, JOHOR BHARU | JH | 1 29 | 103 45 | 30 | AP | 14 | 107 | 105 | 116 | 100 | 102 | 94 | 101 | 100 | 101 | 105 | 93 | 90 | 1214 MM |
| 0118 | KONG KONG | JH | 1 36 | 103 49 | 38 | H | 6 | 109 | 105 | 124 | 110 | 108 | 102 | 108 | 108 | 108 | 118 | 105 | 96 | 1301 MM |
| 0120 | KOTA TINGGI | JH | 1 44 | 103 54 | 9 | H | 11 | 118 | 116 | 131 | 122 | 123 | 112 | 114 | 118 | 120 | 124 | 114 | 111 | 1423 MM |
| 0230 | MERSING | JH | 2 27 | 103 50 | 45 | P | 11 | 121 | 121 | 137 | 131 | 121 | 113 | 110 | 114 | 118 | 115 | 103 | 97 | 1401 MM |
| 2636370 | ENDAU | JH | 2 39 | 103 37 | 4 | AP | 14 | 104 | 111 | 135 | 125 | 118 | 105 | 111 | 109 | 110 | 105 | 90 | 90 | 1313 MM |
| 2734383 | PAYA SEPAYANG | PH | 2 44 | 103 28 | 6 | AP | 14 | 94 | 101 | 116 | 118 | 117 | 107 | 112 | 114 | 112 | 109 | 95 | 91 | 1286 MM |
| 0378 | PEKAN | PH | 3 29 | 103 24 | 4 | H | 2 | 102 | 94 | 121 | 114 | 119 | 104 | 120 | 119 | 109 | 113 | 102 | 93 | 1310 MM |
| 3533302 | PAHANG TUA | PH | 3 34 | 103 21 | 5 | AP | 14 | 110 | 108 | 131 | 126 | 130 | 124 | 120 | 126 | 121 | 116 | 100 | 99 | 1411 MM |
| 0360 | KAMPONG AWAH | PH | 3 35 | 102 30 | 30 | H | 7 | 108 | 115 | 136 | 130 | 131 | 120 | 126 | 131 | 127 | 126 | 115 | 112 | 1477 MM |
| 0320 | BENTONG | PH | 3 31 | 101 55 | 97 | H | 11 | 114 | 114 | 134 | 133 | 137 | 127 | 129 | 136 | 134 | 131 | 122 | 115 | 1526 MM |
| 0335 | RAUB | PH | 3 47 | 101 51 | 158 | H | 7 | 113 | 112 | 133 | 130 | 129 | 122 | 127 | 131 | 129 | 129 | 115 | 101 | 1471 MM |
| 3818354 | RAUB | PH | 3 48 | 101 51 | 185 | AP | 8 | 107 | 109 | 126 | 120 | 114 | 114 | 121 | 113 | 104 | 106 | 95 | 101 | 1330 MM |
| 0420 | CAMERON HIGHLANDS T. RATA | PH | 4 28 | 101 23 | 1471 | P | 10 | 78 | 79 | 92 | 86 | 79 | 79 | 80 | 78 | 79 | 76 | 71 | 68 | 945 MM |
| 0461 | KUALA TAHAN | PH | 4 23 | 102 24 | 610 | H | 2 | 110 | 87 | 134 | 123 | 127 | 114 | 117 | 125 | 120 | 118 | 103 | 103 | 1381 MM |
| 0363 | SUNGAI TEKAM | PH | 3 50 | 102 34 | 76 | H | 2 | 122 | 108 | 133 | 134 | 132 | 123 | 130 | 133 | 130 | 125 | 108 | 114 | 1492 MM |
| 0380 | KUANTAN AIRPORT | PH | 3 47 | 103 13 | 15 | P | 11 | 102 | 105 | 123 | 123 | 116 | 111 | 114 | 115 | 116 | 107 | 92 | 84 | 1308 MM |
| 0381 | BUKIT GOH | PH | 3 52 | 103 16 | 15 | H | 7 | 103 | 108 | 128 | 118 | 124 | 115 | 124 | 125 | 121 | 126 | 105 | 94 | 1391 MM |
| 0382 | SUNGAI LEMBING | PH | 3 55 | 103 2 | 70 | H | 11 | 108 | 107 | 130 | 130 | 131 | 122 | 128 | 132 | 129 | 127 | 111 | 101 | 1456 MM |
| 0464 | SUNGAI BAGING | PH | 4 4 | 103 23 | 4 | H | 7 | 100 | 101 | 122 | 116 | 122 | 111 | 113 | 120 | 114 | 118 | 94 | 89 | 1320 MM |
| 0465 | KEMAMAN | TR | 4 14 | 103 27 | 3 | H | 11 | 102 | 101 | 119 | 118 | 121 | 111 | 117 | 121 | 117 | 117 | 99 | 94 | 1337 MM |
| 0476 | DUNGUN | TR | 4 46 | 103 25 | 3 | H | 8 | 99 | 94 | 125 | 116 | 118 | 111 | 112 | 116 | 114 | 115 | 96 | 93 | 1309 MM |
| 4734379 | DUNGUN | TR | 4 46 | 103 25 | 6 | AP | 10 | 125 | 127 | 152 | 143 | 135 | 115 | 121 | 128 | 119 | 117 | 97 | 105 | 1484 MM |
| 0482 | JERANGAU | TR | 4 59 | 103 9 | 30 | H | 11 | 93 | 94 | 111 | 118 | 120 | 114 | 115 | 119 | 116 | 111 | 87 | 80 | 1278 MM |
| 0590 | KUALA TRENGGANU | TR | 5 20 | 103 8 | 35 | P | 11 | 108 | 111 | 133 | 138 | 128 | 119 | 118 | 119 | 120 | 111 | 95 | 92 | 1392 MM |
| 5725306 | KG. RAJA BESUT | TR | 5 48 | 102 34 | 4 | AP | 6 | 97 | 113 | 124 | 137 | 128 | 119 | 116 | 118 | 116 | 106 | 89 | 89 | 1352 MM |
| 5823301 | TIGA DAERAH | KN | 5 52 | 102 19 | 20 | AP | 13 | 101 | 109 | 135 | 145 | 130 | 112 | 115 | 120 | 116 | 108 | 94 | 90 | 1375 MM |
| 0665 | KOTA BHARU AGR. STATION | KN | 6 3 | 102 17 | 5 | H | 7 | 101 | 103 | 128 | 127 | 133 | 122 | 128 | 125 | 121 | 113 | 94 | 84 | 1379 MM |
| 6021341 | PASIR MAS PUMPHOUSE | KN | 6 3 | 102 10 | 10 | AP | 8 | 103 | 117 | 134 | 132 | 113 | 132 | 111 | 110 | 112 | 107 | 93 | 82 | 1346 MM |
| 0670 | KOTA BHARU P. CHEPA AIRPORT | KN | 6 10 | 102 17 | 5 | P | 11 | 114 | 116 | 139 | 145 | 132 | 123 | 122 | 124 | 125 | 114 | 97 | 95 | 1446 MM |

STATE CODE: PS-PERLIS; KD-KEDAH; PW-PROVINCE WELLESLEY; PG-PENANG; PK-PERAK; SR-SELANGOR, MA-MELAKA
NS-NEGRI SEMBILAN, JH-JOHOR; PH-PAHANG; TR-TRENGGANU; KN-KELANTAN

METHOD CODE (MD): P-PENMAN; H-HARGREAVES; AP-CLASS A EVAPORATION PAN (BLACK PAINTED C. I.)
ELEV: ELEVATION IN METRES NY: NUMBER OF YEARS OF RECORDS

4.2.1.4 **Crop coefficients (K)**

Factors affecting the value of the crop coefficient K are mainly the crop characteristics, planting date, growth stages, length of growing season and climatic conditions. During the early growth stage of the crop, the frequency of rain or irrigation is also of particular importance.

Crop characteristics are a major factor in the relationship between ET (Crop) and ETO. The variations in characteristics between major groups of crops are due to differences in plant mechanisms for resisting transpiration, in crop heights, in crop roughness and reflection, and in crop ground cover. The crop planting date will affect the length of the growing season, the rate of crop development to full ground cover and onset of maturity.

ET (Crop) is the sum of transpiration by the crop and evaporation from the soil surface. During full ground cover, evaporation is negligible. However during the early growing period, evaporation from the soil surface may be considerable, particularly when the soil surface is wet for most of the time. Hence there is a great range of K values during early season growth due to alternating dry and wet soil surface conditions. The method used to estimate K during this period is a modification of the suggested approach outlined by FAO (1975), and is discussed in Appendix C.4.

4.2.1.5 **Adopted crop coefficient values**

Although considerable crop development and production research is currently being carried out in Malaysia there appears to be little or no published data on crop coefficients and evapotranspiration of local upland crops. A detailed review of local and overseas literature yielded very little useable data on tropical and sub-tropical crop water requirements. In view of this it was decided to use the crop coefficient values compiled by FAO (1975) for various field and vegetable crops. In that publication the growing season is divided into 4 stages–initial, crop development, mid-season and late season–and the crop coefficient curve is simplified to 4 straight lines (Fig. 4.2). For this study four characteristic points (Fig. 4.2) were chosen to represent this curve for input into the computer programme TSMAY. A detailed description of the data processing of these crop coefficient curves is given in Appendix C.

4.2.2 **Daily Water Balance**

Having developed the daily pattern of potential crop evapotranspiration the remaining component to be considered is the soil moisture storage. Once this is defined the daily water balance model can be operated.

The soil moisture storage component in the model represents the effective soil moisture storage capacity which is the maximum volume of water that can be stored within the crop root zone and that is available to the crop. The water held in the soil at moisture levels higher than field capacity and lower than permanent wilting point is considered to be not available to the crop. Field capacity is defined (Veihmeyer & Hendricksen, 1933) as the soil moisture at 1/3 bar* and the permanent wilting point as the soil moisture at 15 bar (Richards & Weaver, 1943). Strictly speaking the permanent wilting point is a function of both the crop and soil type but for the purposes of this study it is defined as a function of the soil type only. For sandy soils the field capacity might be justly defined as the soil moisture at 1/10 bar (USBR, 1948).

By subtracting the soil moisture level at permanent wilting point from that at field capacity the water holding capacity of the soil is obtained. Values of water holding capacity for a number of common Peninsular Malaysian soil series are listed in Table 4.2. ***It should be noted that no attempt has been made in this procedure to match crop type with the soil type and therefore expert advice should be sought as to which crops are suitable for growing in the given soil.***

To calculate the effective soil moisture storage capacity, the available water holding capacity is multiplied by the effective rooting depth of the crop. ***Although, the effective rooting depth depends on the type of crop, soil type and other factors, a value of 0.6 metre has been adopted in***

*one bar equals the pressure exerted by a 1000 cm water column

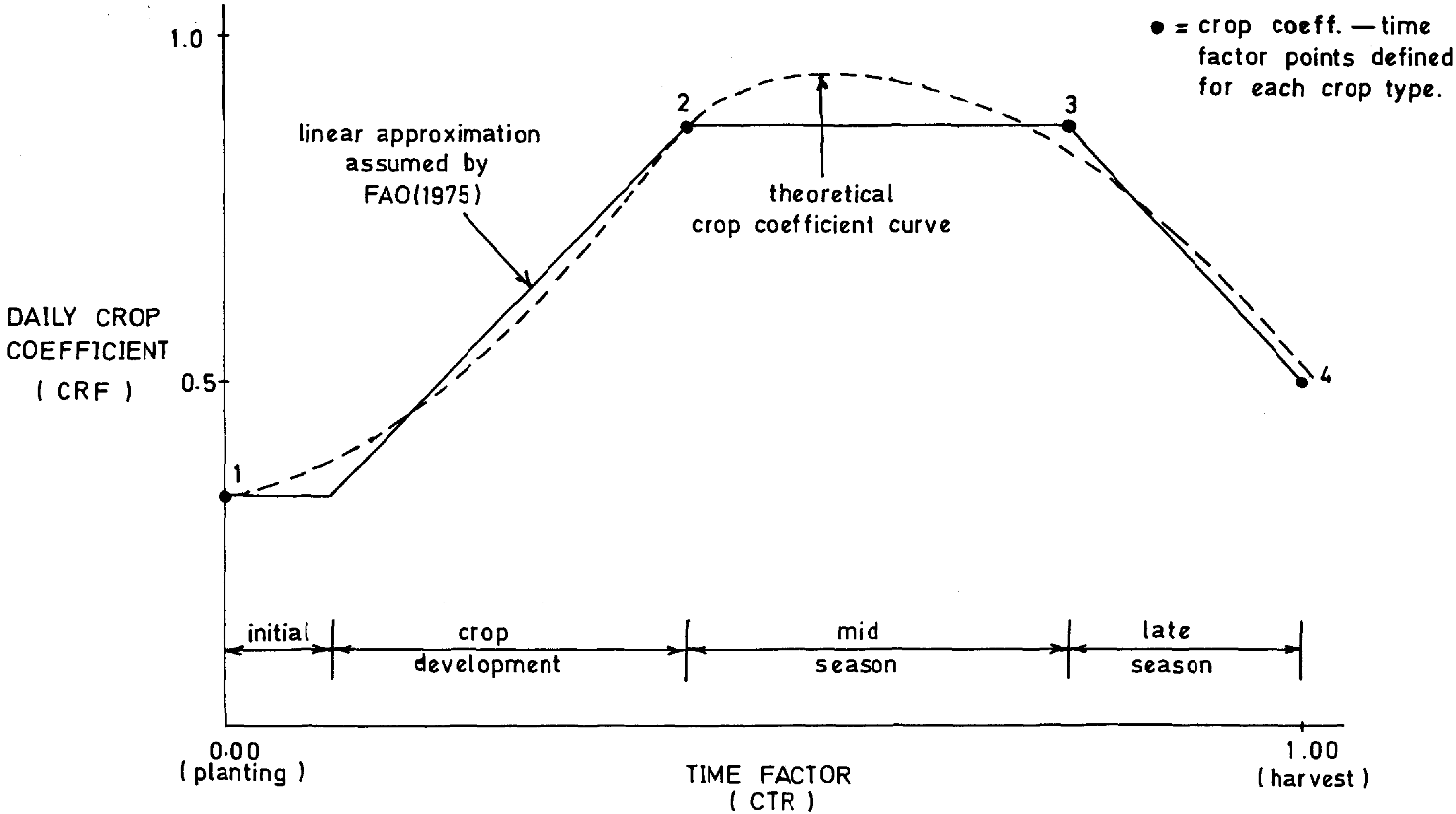


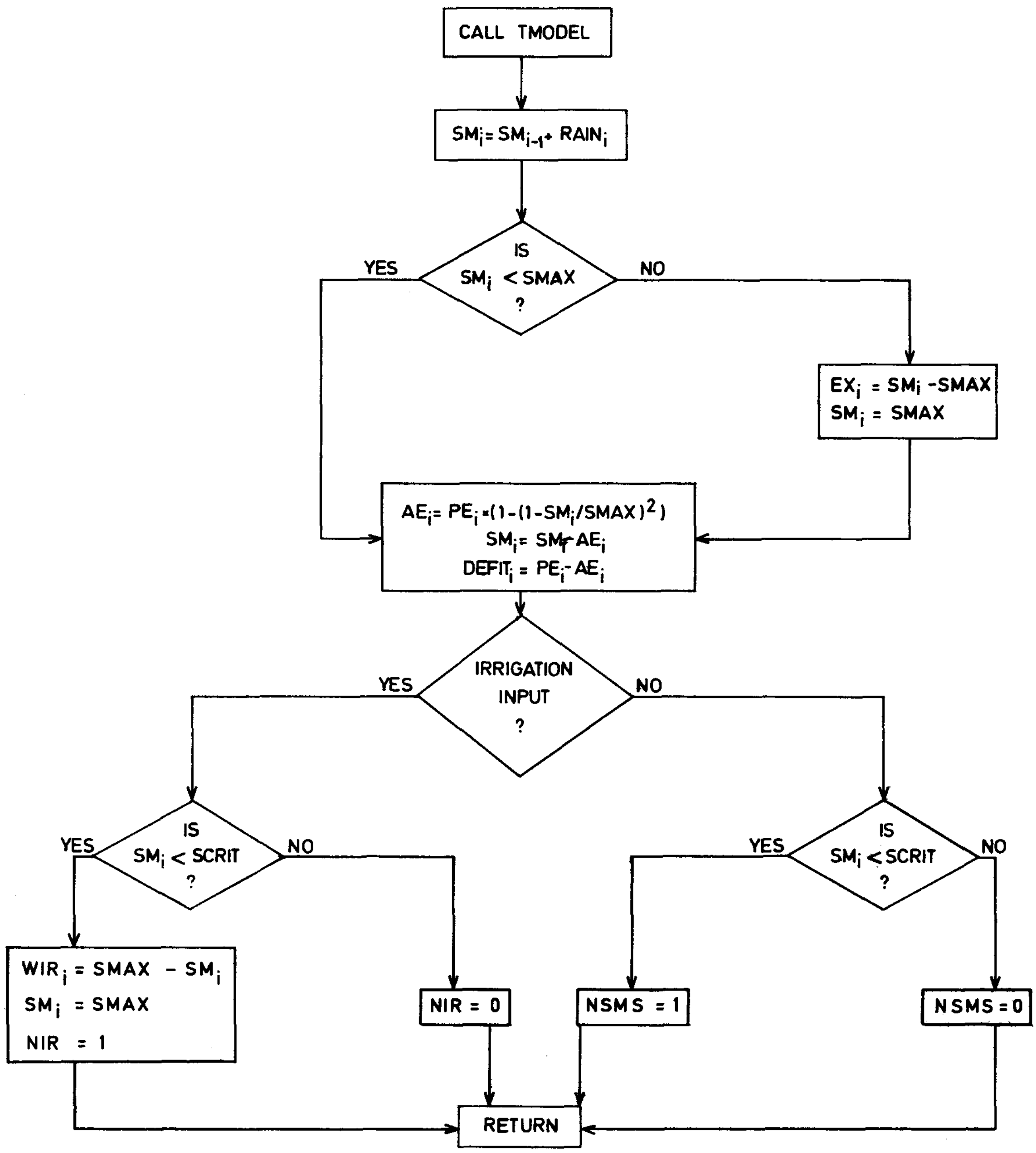

FIGURE 4.2 : A TYPICAL CROP COEFFICIENT CURVE

***the procedure.*** If, however, a precise value of the effective rooting depth can be obtained, then this value can be used as input (please see para C.2).

Table 4.2: Available Water Holding Capacity Values for some Peninsular Malaysia Soils

| Soil Series | Soil Type | Field Capacity Defined at | Wilting point Defined at | Available Water Holding Capacity (mm/metre depth of soil) | Critical Soil Moisture Level (mm/metre depth of soil) |
|---|---|---|---|---|---|
| AKOB | fine sandy loam | 1/3 BAR | 15 BAR | 204.0 | 102.0 |
| BATU ANAM | silty clay | 1/3 BAR | 15 BAR | 77.6 | 38.8 |
| BUNGOR | fine sandy clay loam | 1/3 BAR | 15 BAR | 135.9 | 67.9 |
| CHEMPAKA | silty clay | Salter–Williams Formula 1967 | | 172.8 | 86.4 |
| DURIAN | clay loam | 1/3 BAR | 15 BAR | 105.6 | 52.8 |
| HARIMAU | sandy loam | 1/3 BAR | 15 BAR | 143.0 | 71.5 |
| HOLYROOD | loamy sand | 1/3 BAR | 15 BAR | 100.9 | 50.5 |
| JEMPOL | clay | 1/3 BAR | 15 BAR | 135.0 | 67.5 |
| JERANGAU | sandy clay | 1/3 BAR | 15 BAR | 81.3 | 40.7 |
| KIAU | clay | 1/3 BAR | 15 BAR | 38.0 | 19.0 |
| KULAI | clay | 1/3 BAR | 15 BAR | 97.3 | 48.7 |
| LANGKAWI | silty clay | 1/3 BAR | 15 BAR | 45.5 | 22.8 |
| LUNAS | sandy clay | 1/3 BAR | 15 BAR | 46.1 | 23.1 |
| LUNDANG | sandy clay loam | Salter–Williams Formula 1967 | | 168.4 | 84.2 |
| MELAKA | clay loam | 1/3 BAR | 15 BAR | 108.6 | 54.3 |
| MANIK | clay loam | 1/3 BAR | 15 BAR | 94.7 | 47.4 |
| MASAI | clay | 1/3 BAR | 15 BAR | 99.5 | 49.8 |
| MUNCHONG | silty clay loam | 1/3 BAR | 15 BAR | 150.0 | 75.0 |
| POHOI | clay | 1/3 BAR | 15 BAR | 134.7 | 67.3 |
| RENGAM | sandy clay loam | 1/3 BAR | 15 BAR | 133.5 | 66.8 |
| SEGAMAT | clay | 1/3 BAR | 15 BAR | 52.5 | 26.3 |
| SELANGOR | clay | 1/3 BAR | 15 BAR | 353.0 | 176.5 |
| SENAI | clay | 1/3 BAR | 15 BAR | 103.1 | 51.6 |
| SERDANG | sandy loam | 1/3 BAR | 15 BAR | 37.4 | 18.7 |
| SITIAWAN | silty loam | 1/3 BAR | 15 BAR | 113.6 | 56.8 |
| SOGOMANA | silty clay | 1/3 BAR | 15 BAR | 83.3 | 41.7 |
| TAI TAK | clay loam | 1/3 BAR | 15 BAR | 71.4 | 35.7 |
| TAMPOI | sandy loam | 1/3 BAR | 15 BAR | 21.4 | 10.7 |
| TELEMONG | fine sandy loam | Salter–Williams Formula 1967 | | 147.5 | 73.8 |
| TOK YONG | clay loam | Salter–Williams Formula 1967 | | 148.4 | 74.2 |
| ULU TIRAM | sandy clay loam | 1/3 BAR | 15 BAR | 60.4 | 30.2 |
| YONG PENG | clay | 1/3 BAR | 15 BAR | 126.9 | 63.4 |

(The above information is a summary of data obtained from a number of different publications and also from personal communications)




DEFINITION OF SYMBOLS :-

$RAIN_i$ = Rainfall on day i .

$SM_{i-1}$ = Soil moisture status at the end of the previous day .

$SM_i$ = Soil moisture status on day i .

SMAX = Effective soil moisture storage capacity.

SCRIT = Critical soil moisture level.

$EX_i$ = Water excess on day i .

$PE_i$ = Potential evapotranspiration on day i .

$AE_i$ = Actual evapotranspiration on day i .

$DEFIT_i$ = Water deficit on day i .

$WIR_i$ = Amount of irrigation water applied on day i .

NIR = Integer variable which returns one if an irrigation application is made and zero otherwise.

NSMS = Integer variable which returns soil moisture status at end of day - one for drought day, zero otherwise.

FIG. 4.3 : SIMPLIFIED FLOW CHART OF THE DAILY WATER BALANCE MODEL

A simplified flow chart of the model operating procedure is shown in Fig. 4.3. Firstly the day's rainfall (RAIN) is added to the soil moisture status existing at the end of the previous day. The soil moisture level is then tested against the effective soil moisture capacity (SMAX). If it exceeds the defined capacity then a water excess (EX) is defined which is a combination of surface and subsurface drainage, and the soil (within the effective rooting depth of the crop) is regarded as fully saturated. Having thus defined the soil moisture level following the rainfall input, the model now reduces the soil moisture level by subtracting the evapotranspiration component.

The evapotranspiration component of the model assumes a non-linear rate of evapotranspiration which is dependent on the soil moisture level. This is in accordance with current theory that as the soil moisture level drops it becomes increasingly difficult for the plant to extract water. The equation expressing the relationship between evapotranspiration and soil moisture is:

$$AE = [1 - (1 - S/SMAX)^2]PE \quad \ldots \quad \ldots \quad \ldots \quad (4.2)$$

where AE = daily actual evapotranspiration

S = soil moisture status

SMAX = effective soil moisture storage capacity

PE = daily potential evapotranspiration

The boundary conditions are AE equal to zero when S is zero, and AE equal to PE when S equals SMAX. The potential evapotranspiration is the maximum rate of evapotranspiration when there is no moisture stress in the soil. If there is no irrigation input the final soil moisture status for the day is defined by subtracting the actual evapotranspiration (AE) from the rainfed soil moisture level.

When simulating irrigated conditions, irrigation (WIR) is applied to bring the soil moisture level back to field capacity when the moisture level drops to a critical percentage of the effective soil moisture storage capacity, SMAX. This is the critical soil moisture level, SCRIT below which crop yield would be affected. Hagan and Stewart (1972) compiled a comprehensive list of allowable soil moisture depletion levels of different crops. However, for this study a single SCRIT value of 50% × SMAX has been adopted for all soil-crop combinations. This value is commonly used by irrigation engineers.

The drought day is defined as a day on which soil moisture is below the critical soil moisture level (SCRIT).

Water deficit is defined as the additional water required for the crop to transpire at a potential rate with zero moisture stress. This is expressed as:

$$DEFIT = PE - AE. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4.3)$$

where DEFIT = water deficit.

In this study the model output is being analysed on a monthly basis and consists of:-

(a) Monthly summary of daily water balance (Table 4.3)

(b) Frequency of drought days for each month of the year (Table 4.4)

(c) Monthly crop water deficits for specified probability levels (Table 4.5)

(d) Frequency of irrigation required for each month of the year (Table 4.6)

A computer programme TSMAY has been prepared to do the simulation and statistical analysis. A listing and description of the programme is given in Appendix B.

## TABLE 4.3: SAMPLE OUTPUT FROM PROGRAMME TSMAY

( SUMMARY OF DAILY WATER BALANCE FOR JUN )

| YEAR | RAIN (MM) | EVAPOTRANS. (MM) | DRAINAGE (MM) | CROP WATER DEFICIT(MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS(MM) | MONTHLY WATER BALANCE(MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1953 | 179 | 90.6 | 85.2 | 3.9 | 0 | 0.0 | 0 | 76.8 | 3.3 |
| 1954 | 176 | 85.3 | 109.3 | 4.2 | 0 | 0.0 | 0 | 42.9 | -18.6 |
| 1955 | 156 | 90.9 | 41.5 | 6.4 | 2 | 0.0 | 0 | 70.2 | 23.8 |
| 1956 | 97 | 87.1 | 17.3 | 11.9 | 8 | 0.0 | 0 | 63.6 | -6.6 |
| 1957 | 190 | 95.6 | 84.3 | 3.1 | 0 | 0.0 | 0 | 76.8 | 10.9 |
| 1958 | 104 | 88.7 | 0.0 | 11.3 | 0 | 0.0 | 0 | 71.5 | 15.4 |
| 1959 | 185 | 89.0 | 66.6 | 11.0 | 10 | 0.0 | 0 | 72.4 | 30.4 |
| 1960 | 226 | 98.9 | 112.8 | 1.2 | 0 | 0.0 | 0 | 76.8 | 14.7 |
| 1961 | 99 | 96.2 | 11.1 | 3.8 | 0 | 0.0 | 0 | 48.9 | -8.3 |
| 1962 | 94 | 91.2 | 0.9 | 8.9 | 2 | 0.0 | 0 | 49.1 | 2.2 |
| 1963 | 147 | 93.4 | 56.8 | 6.4 | 0 | 0.0 | 0 | 70.2 | -2.8 |
| 1964 | 181 | 94.2 | 81.7 | 5.9 | 3 | 0.0 | 0 | 51.3 | 5.9 |
| 1965 | 95 | 85.9 | 3.6 | 13.2 | 5 | 0.0 | 0 | 66.9 | 5.8 |
| 1966 | 124 | 94.0 | 44.6 | 4.5 | 0 | 0.0 | 0 | 43.3 | -14.4 |
| 1967 | 138 | 96.5 | 65.7 | 3.2 | 0 | 0.0 | 0 | 45.6 | -23.8 |
| 1968 | 77 | 94.7 | 2.9 | 5.0 | 0 | 0.0 | 0 | 45.6 | -20.2 |
| 1969 | 136 | 94.7 | 55.4 | 4.7 | 0 | 0.0 | 0 | 53.0 | -13.4 |
| 1970 | 213 | 98.5 | 135.9 | 1.7 | 0 | 0.0 | 0 | 55.6 | -20.9 |
| 1971 | 197 | 94.8 | 99.6 | 4.0 | 0 | 0.0 | 0 | 64.7 | 3.1 |
| 1972 | 110 | 96.5 | 38.9 | 3.7 | 0 | 0.0 | 0 | 51.6 | -24.9 |
| 1973 | 313 | 98.4 | 218.9 | 1.7 | 0 | 0.0 | 0 | 72.6 | -3.9 |
| 1974 | 155 | 98.8 | 55.2 | 1.4 | 0 | 0.0 | 0 | 63.7 | 2.0 |

# TABLE 4.4 : SAMPLE OUTPUT FROM PROGRAMME TSMAY

( FREQUENCY ANALYSIS OF DROUGHT DAYS FOR STATION 5030039 )

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 94 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 76 | 24 | 24 | 24 | 18 | 12 | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 65 | 35 | 35 | 35 | 35 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 24 | 24 | 18 | 18 | 18 | 18 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 |
| 5 | 76 | 24 | 24 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 6 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## TABLE 4.5: SAMPLE OUTPUT FROM PROGRAMME TSMAY

(FREQUENCY ANALYSIS OF MONTHLY CROP WATER DEFICIT FOR STATION 5030039)

| MONTH | SMALLEST | CROP WATER DEFICIT(MM) FOR RISK OF EXCEDENCE(%) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | | LARGEST | MEAN | S.D. | SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 2 | 0. | 0.63 | 2.05 |
| 2 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 4 | 5 | 0 | 9 | 2. | 2.34 | 2.75 |
| 3 | 0 | 0 | 0 | 2 | 4 | 5 | 7 | 8 | 10 | 13 | 0 | 21 | 5. | 5.98 | 1.61 |
| 4 | 0 | 0 | 1 | 4 | 7 | 9 | 11 | 14 | 17 | 21 | 0 | 28 | 9. | 9.19 | 1.08 |
| 5 | 0 | 0 | 0 | 1 | 2 | 4 | 5 | 7 | 9 | 12 | 0 | 22 | 4. | 6.10 | 2.08 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 2 | 0. | 0.55 | 3.29 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0. | 0.30 | 3.56 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.23 | 2.78 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.11 | 2.88 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.15 | 3.70 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.00 | 2.21 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.01 | 1.63 |

## TABLE 4.6: SAMPLE OUTPUT FROM PROGRAMME TSMAY

(FREQUENCY ANALYSIS OF IRRIGATION APPLICATIONS FOR STATION 2636169)

AMOUNT OF IRRIGATION WATER PER APPLICATION 40. MM

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 |
|---|---|---|---|
| 1 | 82 | 18 | 0 |
| 2 | 100 | 0 | 0 |
| 3 | 50 | 50 | 5 |
| 4 | 73 | 27 | 0 |
| 5 | 86 | 14 | 0 |
| 6 | 95 | 5 | 0 |
| 7 | 82 | 18 | 0 |
| 8 | 100 | 0 | 0 |
| 9 | 100 | 0 | 0 |
| 10 | 100 | 0 | 0 |
| 11 | 100 | 0 | 0 |
| 12 | 100 | 0 | 0 |

## 5. APPLICATION TO AGRICULTURAL PLANNING

The water-soil-crop system can be simulated over the period for which records are available for any soil and crop type. The water deficit and the drought days over a month provide a measure of the magnitude and duration respectively of agricultural drought for a particular soil-crop combination. Hence the severity of agricultural drought for a specified risk level can be assessed. Knowing the soil and crop characteristics it can be estimated whether rainfall is sufficient to satisfy crop water requirements and the month of the year that certain agricultural activities are favoured.

If irrigation is required, the analysis of irrigation frequencies provides information on the amount of irrigation water that is needed for a given risk level. This is extremely important since the adequacy of available water resources to meet this demand must be determined in the planning stages.

TSMAY is the computer programme which simulates the water-soil-crop system. Since the programme is designed to analyse either the severity of agricultural drought or the required frequency of irrigation, it is desirable that the most suitable planting date be chosen, such that the crop water requirements are satisfied as much as possible by the rainfall pattern. That is, the planting date developed from the TPSTAT analysis (paragraph 3.3) should be used as input into TSMAY. ***It should be noted that this analysis is only concerned with satisfying the water requirements of the crop and assumes that there is adequate drainage. It does not take into account the effect of prolonged excessive rainfall.*** For example, crops such as tobacco and leafy vegetables are particularly sensitive to heavy rainfall at harvest time.

The running of programme TSMAY, as supplementary to TPSTAT, involves the following steps:

(i) The rainfall station and length of records as used in TPSTAT are utilised again.

(ii) The monthly grassland potential evapotranspiration data for the same evaporation station chosen for the TPSTAT analysis is used (paragraph 3.3.2).

(iii) The values of available water holding capacity and critical soil moisture level have to be obtained by testing the soil of the locality. If this is not possible the values may be obtained from Table 4.2.

(iv) Using the planting dates obtained from the TPSTAT analysis (paragraph 3.3.2), a crop pattern can be determined. This crop pattern must not exceed one calender year, that is, 366 days.

(v) The above data is prepared on punch cards and the programme TSMAY is then run as outlined in Appendices B and C. TSMAY should be run first without irrigation input to determine the severity of agricultural drought under rain-fed conditions. This will indicate whether irrigation is needed since irrigation is scheduled whenever a drought day is defined.

(vi) TSMAY output includes the following:

- (a) annual crop coefficient pattern (Table C.2)
- (b) monthly summary tables of daily water balance (Table 4.3)
- (c) totals of rainfall, irrigation, drainage and evapotranspiration for the period of analysis
- (d) frequency analysis of monthly drought days (Table 4.4) and of monthly crop water deficit (Table 4.5)

(vii) TSMAY can be run a second time using the irrigation input to carry out a frequency analysis of monthly irrigation applications. The output includes (a), (b) and (c) as outlined in Step (vi) while (d) is the frequency analysis of monthly irrigation applications (Table 4.6).

## 5.1 Worked Examples

### 5.1.1 *Example 1*

To determine the extent of monthly crop water deficit and frequency of monthly drought days for Lowland cabbage cultivated in Batu Pahat area, Western Johore (Latitude 1 40′ 20″N, Longitude 103 15′ 00″E).

Step 1. As for the TPSTAT analysis (Example 1, 3.3.2.1) the same rainfall records of D.I.D. rainfall station number 1632095 at Parit Bantang Duku, Batu Pahat are used.

Step 2. As for the TPSTAT analysis (Example 1, 3.3.2.1) evaporation station number 130 at Parit Botak is used to provide the monthly grassland potential evapotranspiration data.

Step 3. With reference to the Reconnaissance Soil Map of Peninsular Malaysia (1968) the Selangor series of soil (Table 4.2) is selected as the representative soil in the Batu Pahat area.

Step 4. From the TPSTAT analysis results (Example 1, 3.3.2.1) the recommended planting date is 12th March.

Step 5. As outlined in Appendix B and Appendix C (C.3) the above evapotranspiration, soil and crop data are punched on computer cards. The punched format of the cards is shown in Table 5.1. Programme TSMAY is run first without irrigation input.

Step 6. TSMAY output are as follows:-

(a) model parameters printout (Table 5.2).

(b) twelve monthly summary tables of daily water balance (typical monthly summary, Table 5.3).

(c) frequency analysis of monthly crop water deficit (Table 5.4).

(d) monthly drought days (Table 5.5).

Tables 5.4 and 5.5 reveal that the combination of suitable distribution of rainfall and the very high water holding capacity of the Selangor soil series has resulted in negligible monthly crop water deficits and nil drought days. There is thus no need to run TSMAY under irrigation input since the crop appears to be completely satisfied by the local rainfall.

### 5.1.2 *Example 2(A)*

To determine the extent of monthly crop water deficit and frequency of monthly drought days for groundnuts cultivated in the Endau area, Pahang Tenggara (Latitude 2 36′ 35″N, Longitude 103° 37′ 50″E).

Step 1. As for the TPSTAT analysis (Example 2, 3.3.2.2) the same rainfall records of D.I.D. rainfall station number 2636169 at Endau Agricultural Centre, Endau are used.

Step 2. As for the TPSTAT analysis (Example 2, 3.3.2.2) evaporation station number 2636370 at Endau is used to provide the monthly grassland potential evapotranspiration data.

Step 3. With reference to the Reconnaissance Soil Map of Peninsular Malaysia (1968) the Rengam series of soil (Table 4.2) is selected as the representative soil in the Endau area.

Step 4. From the TPSTAT analysis results (Example 2, 3.3.2.2) the recommended planting date is 23rd April.

Step 5. As outlined in Appendix B and Appendix C (C.3) the above evapotranspiration, soil and crop data are punched on computer cards. The punched format of the cards is shown in Table 5.6. Programme TSMAY is run first without irrigation input.

E.D.P. Section,
Hydrology Branch,
D.I.D. Headquarters.

# TABLE 5.1 CODING FORM

L—J.C.K., K.L.

| | | | | |
|---|---|---|---|---|
| PROGRAM | TSMAY | PUNCHING INSTRUCTIONS | GRAPHIC | PAGE OF |
| PROGRAMMER | DEPARTMENT OF IRRIGATION AND DRAINAGE | | PUNCH | DATE |

```
(a)  FOR NO IRRIGATION INPUT

CARD 1   SOIL TYPE-SELANGOR SERIES    FC@1/3 BAR  WP@15BAR353.0176.5
CARD 2                     160.0
CARD 3       130           12311013017115108114117109122111112
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6     90   80   70   60   50   40   30   20   10
CARD 7   LOWLAND CABBAGE                   31203 80

(b)  FOR IRRIGATION INPUT

CARD 1   SOIL TYPE-SELANGOR SERIES    FC@113 BAR  WP@15BAR353.0176.5
CARD 2                     160.01
CARD 3       130           1231 101130117115108114117109122111112
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6   LOWLAND CABBAGE                   31203 80
```

## TABLE 5.2: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 1

( DAILY WATER BALANCE SIMULATION FOR STATION 16920 '5' )

MODEL PARAMETERS

SOIL TYPE-SELANGOR SERIES FC@1/3 BAR WP@15BAR
AVAILABLE WATER IN MILLIMETRES PER METRE OF SOIL 353.0 MM
CRITICAL SOIL MOISTURE CAPACITY IN MILLIMETRES PER METRE OF SOIL 176.5 MM

MONTHLY POTENTIAL GRASSLAND EVAPOTRANSPIRATION(MM)

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 123 | 110 | 130 | 117 | 115 | 108 | 114 | 117 | 109 | 122 | 111 | 112 |

RAINFALL CONVERSION FACTOR 0.2540

## TABLE 5.3: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 1

( SUMMARY OF DAILY WATER BALANCE FOR APR )

| YEAR | RAIN (MM) | EVAPOTRANS. (MM) | DRAINAGE (MM) | CROP WATER DEFICIT(MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS(MM) | MONTHLY WATER BALANCE(MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1950 | 264 | 109.4 | 158.2 | 0.0 | 0 | 0.0 | 0 | 204.5 | -3.4 |
| 1951 | 193 | 104.0 | 99.6 | 0.2 | 0 | 0.0 | 0 | 193.3 | -10.6 |
| 1952 | 289 | 105.6 | 199.0 | 0.2 | 0 | 0.0 | 0 | 188.9 | -15.0 |
| 1953 | 309 | 108.8 | 192.7 | 0.0 | 0 | 0.0 | 0 | 208.1 | 8.3 |
| 1954 | 320 | 105.6 | 225.7 | 0.1 | 0 | 0.0 | 0 | 196.6 | -11.3 |
| 1955 | 576 | 108.4 | 471.0 | 0.0 | 0 | 0.0 | 0 | 200.8 | -3.1 |
| 1956 | 576 | 109.4 | 474.0 | 0.0 | 0 | 0.0 | 0 | 200.8 | -7.1 |
| 1957 | 231 | 102.8 | 126.1 | 0.2 | 0 | 0.0 | 0 | 204.5 | 2.3 |
| 1958 | 284 | 103.8 | 189.3 | 0.3 | 0 | 0.0 | 0 | 199.5 | -8.4 |
| 1959 | 447 | 108.4 | 338.8 | 0.1 | 0 | 0.0 | 0 | 204.5 | -0.2 |
| 1960 | 188 | 109.4 | 81.7 | 0.0 | 0 | 0.0 | 0 | 205.2 | -2.7 |
| 1961 | 257 | 109.9 | 154.2 | 0.0 | 0 | 0.0 | 0 | 200.8 | -7.0 |
| 1962 | 255 | 108.4 | 150.0 | 0.1 | 0 | 0.0 | 0 | 204.5 | -3.4 |
| 1963 | 195 | 78.9 | 104.2 | 0.5 | 0 | 0.0 | 0 | 204.5 | 12.5 |
| 1964 | 397 | 110.0 | 294.4 | 0.0 | 0 | 0.0 | 0 | 197.3 | -6.7 |
| 1965 | 148 | 99.4 | 41.4 | 0.3 | 0 | 0.0 | 0 | 204.0 | 7.2 |
| 1966 | 307 | 108.2 | 174.1 | 0.1 | 0 | 0.0 | 0 | 204.9 | 19.7 |
| 1967 | 159 | 102.1 | 51.2 | 0.2 | 0 | 0.0 | 0 | 197.7 | 6.3 |
| 1968 | 263 | 108.2 | 148.5 | 0.3 | 0 | 0.0 | 0 | 199.1 | 6.7 |
| 1969 | 226 | 106.8 | 115.6 | 0.2 | 0 | 0.0 | 0 | 204.5 | 4.4 |
| 1970 | 377 | 108.4 | 267.1 | 0.0 | 0 | 0.0 | 0 | 204.5 | 2.4 |
| 1971 | 143 | 95.4 | 76.8 | 0.6 | 0 | 0.0 | 0 | 178.9 | -28.9 |
| 1972 | 93 | 101.7 | 0.0 | 3.4 | 0 | 0.0 | 0 | 170.9 | -8.4 |
| 1973 | 148 | 104.5 | 43.1 | 0.7 | 0 | 0.0 | 0 | 204.5 | 0.6 |
| 1974 | 312 | 90.9 | 187.4 | 0.4 | 0 | 0.0 | 0 | 197.7 | 33.8 |
| 1975 | 328 | 100.6 | 240.3 | 1.8 | 0 | 0.0 | 0 | 192.1 | 38.0 |

## TABLE 5.4: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 1

(FREQUENCY ANALYSIS OF MONTHLY CROP WATER DEFICIT FOR STATION 1632095)

| MONTH | SMALLEST | CROP WATER DEFICIT(MM) FOR RISK OF EXCEDENCE(%) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | . | LARGEST | MEAN | S. D. | SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 6 | 0 | 17 | 2. | 3. 53 | 4. 39 |
| 2 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 0 | 14 | 2. | 3. 42 | 2. 64 |
| 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 0 | 5 | 1. | 1. 47 | 2. 57 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 3 | 0. | 0. 71 | 3. 55 |
| 5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 0 | 6 | 1. | 1. 32 | 2. 95 |
| 6 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 3 | 0 | 7 | 1. | 1. 75 | 2. 72 |
| 7 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 6 | 0 | 10 | 2. | 3. 16 | 2. 24 |
| 8 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 4 | 0 | 9 | 1. | 2. 09 | 2. 83 |
| 9 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 0 | 5 | 1. | 1. 46 | 2. 75 |
| 10 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 4 | 0 | 9 | 1. | 2. 13 | 3. 10 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0. | 0. 38 | 3. 73 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 5 | 0. | 1. 05 | 4. 34 |



## TABLE 5.5: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 1

(FREQUENCY ANALYSIS OF DROUGHT DAYS FOR STATION 1632095)

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 96 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2 | 96 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 |
| 3 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*E.D.P. Section,*
*Hydrology Branch,*
*D.I.D. Headquarters.*

# TABLE 5.6 CODING FORM

L—J.C.K., K.L.

| PROGRAM | TSMAY | PUNCHING INSTRUCTIONS | GRAPHIC | PAGE OF |
|---|---|---|---|---|
| PROGRAMMER | DEPARTMENT OF IRRIGATION AND DRAINAGE | | PUNCH | DATE |

```
        C Statement Number | Cont 6 | STATEMENT 8 ... 72 | Identification and Sequence No 73-80

          (a) FOR NO IRRIGATION INPUT

CARD 1    SOIL TYPE-RENGAM   SERIES    FC@1/3 BAR  WP@15BAR133.5 66.8
CARD 2                   65.0
CARD 3   2636370        104111135125118105111109110105 90 90
CARD 4   0.254
CARD 5    JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6      90   80   70   60   50   40   30   20   10
CARD 7    GROUNDNUTS                   102304110

          (b) FOR IRRIGATION INPUT

CARD 1    SOIL TYPE-RENGAM   SERIES    FC@1/3 BAR  WP@15BAR133.5 66.8
CARD 2                   65.01
CARD 3   2636370        104111135125118105111109110105 90 90
CARD 4   0.254
CARD 5    JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6    GROUNDNUTS                   102304110
```

Step 6. TSMAY output are as follows:-

(a) twelve monthly summary tables of daily water balance (typical monthly summary, Table 5.7).

(b) frequency analysis of monthly crop water deficit (Table 5.8).

(c) monthly drought days (Table 5.9).

Tables 5.8 and 5.9 show that the crop water requirements for groundnuts are quite well satisfied for the planting date of 23rd April. The worst crop water deficit is 19 mm (in May 1963, please see Table 5.7) and the largest probability of at least one drought day is 32%, also in the month of May. This means that approximately once in three years there is the likelihood of the crop suffering from critical moisture stress on at least one day within the month of May. For the same month, the likelihood of 4 or more drought days is 23% (or once in every 4 years). For the following months of June and July the probability of at least two drought days is 27% and 36% respectively. Thus, there is a need to run TSMAY under irrigation input since the crop of groundnuts does not have its water requirements quite satisfied by the local rainfall. [TSMAY is then tested with irrigation input, see Example 2(B)].

*Example 2(B)*

To determine the frequency of monthly irrigation applications for groundnuts cultivated during a drier season in the Endau area, Pahang Tenggara (Latitude 2° 36′ 35″N, Longitude 103° 37′ 50″E).

Step 1, 2 and 3 are the same as in Example 2(A).

Step 4. From TPSTAT analysis results (Fig. 3.7) a poor planting date is judged to be at the beginning of the 4th week, i.e. 22nd January.

Step 5. The punched format of the input cards is shown in Table 5.10. Programme TSMAY is to be run with irrigation input and therefore Step 6 is not followed.

Step 7. TSMAY output are as follows:-

(a) twelve monthly summary tables of daily water balance (typical monthly summary, Table 5.11).

(b) frequency analysis of monthly irrigation applications (Table 5.12).

While Table 5.12 shows that there is a high probability of requiring at least one irrigation application in the months of March and April (82% and 59% respectively) the likely need for two or more applications is much less (23% and 18% respectively).

Note: As a comparison of the probabilities of irrigation between the best planting date and another planting date in a drier season, TSMAY is run with the planting date from Example 2(A). The results are shown in Table 5.13 and it can be seen that the probability of one irrigation application is 23% in June and 45% in July.

### 5.1.3 *Example 3(A)*

To determine the extent of monthly crop water deficit and frequency of monthly drought days for maize cultivated in the Kuala Brang area, Trengganu Tengah (Latitude 5° 04′ 15″N, Longitude 103° 00′ 50″E).

Step 1. As for the TPSTAT analysis (Example 3, 3.3.2.3) the same rainfall records of D.I.D. rainfall station number 5030039 at Kuala Brang Hospital, Kuala Brang are used.

## TABLE 5.7: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (A)

( SUMMARY OF DAILY WATER BALANCE FOR MAY )

| YEAR | RAIN (MM) | EVAPOTRANS (MM) | DRAINAGE (MM) | CROP WATER DEFICIT(MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS(MM) | MONTHLY WATER BALANCE(MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1953 | 120 | 101.7 | 8.0 | 3.3 | 0 | 0.0 | 0 | 73.5 | 11.0 |
| 1954 | 237 | 103.8 | 132.5 | 1.4 | 0 | 0.0 | 0 | 61.5 | 1.4 |
| 1955 | 179 | 99.7 | 82.4 | 4.1 | 0 | 0.0 | 0 | 46.3 | -2.5 |
| 1956 | 100 | 93.9 | 0.0 | 11.5 | 4 | 0.0 | 0 | 70.2 | 7.0 |
| 1957 | 138 | 85.8 | 26.8 | 15.7 | 11 | 0.0 | 0 | 65.9 | 25.8 |
| 1958 | 192 | 98.8 | 68.7 | 3.6 | 1 | 0.0 | 0 | 56.1 | 25.2 |
| 1959 | 67 | 95.0 | 0.0 | 10.5 | 2 | 0.0 | 0 | 42.1 | -27.7 |
| 1960 | 165 | 107.3 | 68.2 | 0.8 | 0 | 0.0 | 0 | 62.1 | -10.2 |
| 1961 | 297 | 108.6 | 199.9 | 0.9 | 0 | 0.0 | 0 | 57.2 | -11.3 |
| 1962 | 167 | 94.7 | 98.0 | 3.1 | 0 | 0.0 | 0 | 46.9 | -25.4 |
| 1963 | 159 | 70.1 | 38.4 | 19.5 | 15 | 0.0 | 0 | 73.0 | 50.8 |
| 1964 | 149 | 79.2 | 74.5 | 3.2 | 0 | 0.0 | 0 | 45.4 | -4.1 |
| 1965 | 138 | 106.5 | 14.5 | 1.7 | 0 | 0.0 | 0 | 61.1 | 17.9 |
| 1966 | 149 | 97.6 | 63.3 | 1.3 | 0 | 0.0 | 0 | 57.7 | -11.6 |
| 1967 | 175 | 94.5 | 73.0 | 1.4 | 0 | 0.0 | 0 | 69.4 | 7.5 |
| 1968 | 227 | 107.5 | 108.5 | 1.7 | 0 | 0.0 | 0 | 65.8 | 11.9 |
| 1969 | 323 | 99.5 | 189.4 | 7.1 | 4 | 0.0 | 0 | 66.4 | 34.1 |
| 1970 | 138 | 94.8 | 39.2 | 3.1 | 0 | 0.0 | 0 | 76.5 | 4.2 |
| 1971 | 145 | 82.5 | 31.9 | 7.5 | 4 | 0.0 | 0 | 61.5 | 31.3 |
| 1972 | 166 | 101.0 | 57.9 | 2.8 | 0 | 0.0 | 0 | 76.4 | 8.0 |
| 1973 | 204 | 105.1 | 95.0 | 2.7 | 0 | 0.0 | 0 | 76.5 | 4.1 |
| 1974 | 236 | 104.6 | 137.0 | 2.3 | 0 | 0.0 | 0 | 61.8 | -5.1 |

## TABLE 5.8: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (A)

(FREQUENCY ANALYSIS OF MONTHLY CROP WATER DEFICIT FOR STATION 2636169 )

| MONTH | SMALLEST | CROP WATER DEFICIT(MM) FORRISK OF EXCEDENCE(%) | | | | | | | | | LARGEST | | MEAN | S.D. | SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | | | | | |
| 1 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 3 | 4 | 6 | 0. | 10 | 2. | 3.06 | 2.06 |
| 2 | 0 | 0 | 0 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 0 | 17 | 4. | 4.65 | 1.74 |
| 3 | 0 | 0 | 2 | 5 | 8 | 10 | 13 | 16 | 19 | 24 | 0 | 34 | 10. | 10.49 | 1.17 |
| 4 | 0 | 0 | 1 | 4 | 6 | 9 | 11 | 14 | 17 | 21 | 0 | 26 | 9. | 9.68 | 0.96 |
| 5 | 0 | 0 | 1 | 2 | 4 | 5 | 6 | 8 | 9 | 11 | 0 | 19 | 5. | 5.08 | 1.76 |
| 6 | 1 | 1 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 10 | 0 | 13 | 6. | 3.56 | 0.94 |
| 7 | 0 | 0 | 1 | 3 | 5 | 6 | 8 | 9 | 11 | 13 | 0 | 17 | 6. | 5.74 | 0.91 |
| 8 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 4 | 0 | 6 | 2. | 1.79 | 2.47 |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 1. | 0.72 | 1.59 |
| 10 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 3 | 0 | 8 | 1. | 1.82 | 4.37 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.06 | 0.68 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.14 | 3.30 |

## TABLE 5.9: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (A)

( FREQUENCY ANALYSIS OF DROUGHT DAYS FOR STATION 2636169 )

PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN

| MONTH | PROBABILITY(%) OF BEING ZERO | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 82 | 18 | 18 | 18 | 14 | 9 | 9 | 9 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 73 | 27 | 23 | 23 | 23 | 18 | 14 | 14 | 14 | 14 | 9 | 5 | 5 | 5 | 5 | 5 | 5 |
| 3 | 50 | 50 | 50 | 50 | 50 | 45 | 41 | 36 | 36 | 27 | 27 | 27 | 23 | 23 | 23 | 23 | 23 |
| 4 | 55 | 45 | 36 | 36 | 36 | 32 | 32 | 32 | 27 | 27 | 23 | 23 | 23 | 23 | 23 | 23 | 18 |
| 5 | 68 | 32 | 27 | 23 | 23 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 5 | 5 | 5 | 5 | 0 |
| 6 | 73 | 27 | 27 | 18 | 14 | 14 | 9 | 9 | 9 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 55 | 45 | 36 | 32 | 27 | 27 | 27 | 23 | 18 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 95 | 5 | 5 | 5 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 95 | 5 | 5 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| MONTH | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 14 | 14 | 9 | 9 | 9 | 5 | 0 | 0 | 0 | 0 | 0 |
| 4 | 18 | 18 | 18 | 18 | 18 | 18 | 14 | 14 | 5 | 5 | 5 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

E.D.P. Section,
Hydrology Branch,
D.I.D. Headquarters.

## TABLE 5.10 CODING FORM

L—J.C.K., K.L.

| PROGRAM | TSMAY | PUNCHING INSTRUCTIONS | GRAPHIC | PAGE OF |
|---|---|---|---|---|
| PROGRAMMER | DEPARTMENT OF IRRIGATION AND DRAINAGE | | PUNCH | DATE |

Columns: C / Statement Number (1–5), Cont. (6), STATEMENT (7–72), Identification and Sequence No (73–80)

```
       (a)  FOR NO IRRIGATION INPUT

CARD 1   SOIL TYPE-RENGAM   SERIES   FC@1/3 BAR  WP@15BAR133.5 66.6
CARD 2                          65.0
CARD 3  263637 0              10411113512511810511110911010 5 90 90
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6     90   80   70   60   50   40   30   20   10
CARD 7   GROUNDNUTS                   10220111 0

       (b)  FOR IRRIGATION INPUT

CARD 1   SOIL TYPE-RENGAM   SERIES   FC@1/3 BAR  WP@15BAR133.5 66.8
CARD 2                          65 01
CARD 3  263637 0              10411113512511810511110911010 5 90 90
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6   GROUNDNUTS                   10220111 0
```

# TABLE 5.11: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (B)

( SUMMARY OF DAILY WATER BALANCE FOR APR )

| YEAR | RAIN (MM) | EVAPOTRANS (MM) | DRAINAGE (MM) | CROP WATER DEFICIT (MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS (MM) | MONTHLY WATER BALANCE (MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1953 | 151 | 109.3 | 90.2 | 5.9 | 0 | 41.9 | 1 | 63.3 | -6.2 |
| 1954 | 69 | 108.4 | 14.1 | 6.8 | 0 | 41.2 | 1 | 59.8 | -12.0 |
| 1955 | 219 | 111.4 | 144.8 | 3.8 | 0 | 41.2 | 1 | 46.1 | 4.2 |
| 1956 | 123 | 111.6 | 8.7 | 2.8 | 0 | 0.0 | 0 | 64.4 | 2.8 |
| 1957 | 43 | 108.7 | 1.5 | 6.4 | 0 | 41.1 | 1 | 50.0 | -25.9 |
| 1958 | 30 | 104.6 | 4.5 | 10.6 | 0 | 82.6 | 2 | 76.1 | 4.2 |
| 1959 | 185 | 110.4 | 86.7 | 4.8 | 0 | 0.0 | 0 | 64.7 | -11.2 |
| 1960 | 212 | 110.4 | 92.2 | 4.0 | 0 | 0.0 | 0 | 73.7 | 10.0 |
| 1961 | 234 | 112.5 | 128.0 | 2.6 | 0 | 0.0 | 0 | 70.2 | -5.8 |
| 1962 | 172 | 109.5 | 67.7 | 5.7 | 0 | 0.0 | 0 | 67.1 | -4.7 |
| 1963 | 33 | 107.0 | 17.8 | 8.2 | 0 | 80.9 | 2 | 49.4 | -10.3 |
| 1964 | 90 | 108.5 | 33.0 | 5.9 | 0 | 41.2 | 1 | 70.4 | -9.7 |
| 1965 | 57 | 106.4 | 1.5 | 8.7 | 0 | 40.9 | 1 | 46.5 | -9.4 |
| 1966 | 103 | 106.6 | 8.6 | 8.6 | 0 | 0.0 | 0 | 56.4 | -11.8 |
| 1967 | 90 | 108.3 | 14.2 | 6.8 | 0 | 41.2 | 1 | 58.1 | 9.6 |
| 1968 | 127 | 107.8 | 51.4 | 6.6 | 0 | 40.4 | 1 | 80.1 | 8.3 |
| 1969 | 47 | 105.8 | 40.7 | 9.3 | 0 | 174.0 | 3 | 70.2 | 25.2 |
| 1970 | 319 | 111.5 | 210.2 | 3.6 | 0 | 0.0 | 0 | 73.5 | -2.4 |
| 1971 | 24 | 104.9 | 13.9 | 10.3 | 0 | 126.4 | 3 | 73.5 | 32.2 |
| 1972 | 172 | 107.2 | 54.9 | 7.2 | 0 | 0.0 | 0 | 70.4 | 10.7 |
| 1973 | 92 | 110.5 | 25.1 | 4.7 | 0 | 41.2 | 1 | 74.2 | -1.8 |
| 1974 | 189 | 113.5 | 73.3 | 1.7 | 0 | 0.0 | 0 | 69.8 | 2.7 |

## TABLE 5.12: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (B)

( FREQUENCY ANALYSIS OF IRRIGATION APPLICATIONS FOR STATION 2636169 )

AMOUNT OF IRRIGATION WATER PER APPLICATION 40. MM

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 | 3 |
|---|---|---|---|---|
| 1 | 82 | 18 | 0 | 0 |
| 2 | 73 | 27 | 0 | 0 |
| 3 | 18 | 82 | 23 | 0 |
| 4 | 41 | 59 | 18 | 9 |
| 5 | 95 | 5 | 0 | 0 |
| 6 | 95 | 5 | 0 | 0 |
| 7 | 100 | 0 | 0 | 0 |
| 8 | 100 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 |
| 10 | 95 | 5 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 |

## TABLE 5.13: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 2 (B) – USING PLANTING DATE FROM EXAMPLE 2 (A)

( FREQUENCY ANALYSIS OF IRRIGATION APPLICATIONS FOR STATION 2636169 )

AMOUNT OF IRRIGATION WATER PER APPLICATION 40. MM

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 |
|---|---|---|---|
| 1 | 82 | 18 | 0 |
| 2 | 82 | 18 | 0 |
| 3 | 55 | 45 | 5 |
| 4 | 68 | 32 | 0 |
| 5 | 86 | 14 | 0 |
| 6 | 77 | 23 | 0 |
| 7 | 55 | 45 | 0 |
| 8 | 95 | 5 | 0 |
| 9 | 100 | 0 | 0 |
| 10 | 95 | 5 | 0 |
| 11 | 100 | 0 | 0 |
| 12 | 100 | 0 | 0 |

Step 2. As for the TPSTAT analysis (Example 3, 3.3.2.3) evaporation station number 482 at Jerangau is used to provide the monthly grassland potential evapotranspiration data.

Step 3. With reference to the Reconnaissance Soil Map of Peninsular Malaysia (1968) the Akob series of soil (Table 4.2) is selected as the representative soil in the Kuala Brang area.

Step 4. From the TPSTAT analysis results (Example 3, 3.3.2.3) the recommended planting date is 30th April.

Step 5. As outlined in Appendix B and Appendix C (C.3) the above evapotranspiration, soil and crop data are punched on computer cards. The punched format of the cards is shown in Table 5.14. Programme TSMAY is run first without irrigation input.

Step 6. TSMAY output are as follows:-

(a) twelve monthly summary tables of daily water balance (typical monthly summary, Table 5.15).
(b) frequency analysis of monthly crop water deficit (Table 5.16).
(c) monthly drought days (Table 5.17).

The two latter tables show that the maize crop water requirements are quite satisfied by the rainfall pattern and the water holding capacity of the Akob soil series. Table 5.17 shows there is an 18 % probability of the maize crop suffering from critical moisture stress on at least 9 days in May and 5 days in June.

***Example 3(B)***

To determine the extent of monthly crop water deficit and frequency of monthly drought days for maize cultivated during a drier season in the Kuala Brang area, Trengganu Tengah (Latitude 5° 04′ 15″N, Longitude 103° 00′ 50″E).

Step 1, 2 and 3 are the same as in Example 3(A)

Step 4. From TPSTAT analysis results (Fig. 3.9) a poor planting date is judged to be at the beginning of the 8th week, i.e. 18th February.

Step 5. The punched format of the input cards is shown in Table 5.18. Programme TSMAY is run first without irrigation input.

Step 6. TSMAY output are as follows:-

(a) twelve monthly summary tables of daily water balance (typical monthly summary, Table 5.19).
(b) frequency analysis of monthly crop water deficit (5.20).
(c) monthly drought days (5.21).

A comparison of these latter two tables with Tables 5.16 and 5.17 shows the marked increase in monthly crop water deficits and number of drought days for the earlier planting date. Table 5.21 shows there is a 24 % probability (i.e. once in every four years) of maize suffering from critical moisture stress on at least 22 days in April and 19 days in May.

## 6. APPLICATION TO IRRIGATION DESIGN

The results obtained from the simulation studies can be utilised for preliminary design of irrigation schemes. The information required in the design stage is:

(i) the peak demand for supplementary irrigation water
(ii) the associated risk of the crop water requirements exceeding the design capacity.

*E.D.P. Section,*
*Hydrology Branch,*
*D.I.D. Headquarters.*

# TABLE 5.14 CODING FORM

L—J.C.K., K.L.

| PROGRAM | TSMAY | PUNCHING INSTRUCTIONS | GRAPHIC | PAGE OF |
|---|---|---|---|---|
| PROGRAMMER | DEPARTMENT OF IRRIGATION AND DRAINAGE | | PUNCH | DATE |

Statement Number (C, 1–5) | Cont (6) | STATEMENT (7–72) | Identification and Sequence No (73–80)

```
        C    6 8      15  20   25   30   35   40   45   50   55   60   65   72 73 76 80
          (a)  FOR NO IRRIGATION INPUT

CARD 1   SOIL TYPE-AKOB     SERIES    FC@1/3 BAR  WP@15BAR204.0102.0
CARD 2                  110.0
CARD 3      482         93 94111118120114115119116111 87 80
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6     90   80   70   60   50   40   30   20   10
CARD 7   MAIZE  (GRAIN)                  23004110

          (b)  FOR IRRIGATION INPUT

CARD 1   SOIL TYPE-AKOB     SERIES    FC@1/3 BAR  WP@15BAR204.0102.0
CARD 2                  110.01
CARD 3      482         93 94111118120114115119116111 87 80
CARD 4  0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6   MAIZE  (GRAIN)                  23004110
```

## TABLE 5.15: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (A)

( SUMMARY OF DAILY WATER BALANCE FOR MAY )

| YEAR | RAIN (MM) | EVAPOTRANS. (MM) | DRAINAGE (MM) | CROP WATER DEFICIT(MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS(MM) | MONTHLY WATER BALANCE(MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1959 | 66 | 89. 6 | 0. 0 | 11. 5 | 0 | 0. 0 | 0 | 70. 8 | -23. 5 |
| 1960 | 301 | 110. 6 | 194. 5 | 0. 2 | 0 | 0. 0 | 0 | 115. 1 | -3. 6 |
| 1961 | 189 | 95. 4 | 94. 5 | 1. 6 | 0 | 0. 0 | 0 | 118. 8 | 0. 1 |
| 1962 | 93 | 96. 2 | 24. 0 | 1. 9 | 0 | 0. 0 | 0 | 82. 5 | -27. 0 |
| 1963 | 114 | 59. 1 | 0. 0 | 25. 3 | 26 | 0. 0 | 0 | 103. 9 | 55. 0 |
| 1964 | 75 | 91. 4 | 0. 0 | 18. 3 | 1 | 0. 0 | 0 | 63. 6 | -15. 7 |
| 1965 | 336 | 112. 0 | 228. 5 | 0. 3 | 0 | 0. 0 | 0 | 111. 0 | -4. 0 |
| 1966 | 372 | 108. 7 | 276. 2 | 0. 3 | 0 | 0. 0 | 0 | 103. 4 | -12. 8 |
| 1967 | 208 | 106. 5 | 70. 5 | 1. 7 | 0 | 0. 0 | 0 | 102. 7 | 31. 0 |
| 1968 | 178 | 109. 2 | 73. 2 | 0. 3 | 0 | 0. 0 | 0 | 115. 1 | -3. 6 |
| 1969 | 111 | 87. 9 | 0. 0 | 12. 4 | 9 | 0. 0 | 0 | 85. 4 | 23. 6 |
| 1970 | 321 | 105. 5 | 191. 5 | 1. 6 | 0 | 0. 0 | 0 | 118. 8 | 24. 1 |
| 1971 | 171 | 94. 0 | 14. 1 | 16. 3 | 11 | 0. 0 | 0 | 108. 4 | 63. 4 |
| 1972 | 208 | 89. 0 | 95. 6 | 5. 6 | 0 | 0. 0 | 0 | 105. 8 | 23. 4 |
| 1973 | 87 | 96. 0 | 4. 0 | 2. 2 | 0 | 0. 0 | 0 | 89. 7 | -12. 2 |
| 1974 | 175 | 107. 2 | 85. 1 | 0. 8 | 0 | 0. 0 | 0 | 98. 4 | -17. 3 |
| 1975 | 201 | 110. 5 | 84. 0 | 0. 3 | 0 | 0. 0 | 0 | 105. 8 | 6. 7 |

## TABLE 5.16: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (A)

( FREQUENCY ANALYSIS OF MONTHLY CROP WATER DEFICIT FOR STATION 5030039 )

| MONTH | SMALLEST | CROP WATER DEFICIT(MM) FORRISK OF EXCEDENCE(%) 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | | LARGEST | MEAN | S. D. | SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0. | 0. 45 | 1. 98 |
| 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 1. | 0. 73 | 1. 78 |
| 3 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 4 | 5 | 0 | 6 | 2. | 2. 38 | 0. 86 |
| 4 | 0 | 0 | 0 | 2 | 4 | 5 | 7 | 8 | 10 | 13 | 0 | 18 | 5. | 5. 73 | 1. 44 |
| 5 | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 16 | 0 | 25 | 6. | 7. 82 | 1. 38 |
| 6 | 0 | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 14 | 0 | 28 | 5. | 7. 58 | 2. 47 |
| 7 | 0 | 0 | 0 | 0 | 3 | 6 | 9 | 12 | 16 | 22 | 0 | 53 | 6. | 12. 61 | 3. 88 |
| 8 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 4 | 5 | 6 | 0 | 15 | 2. | 3. 78 | 3. 70 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0. 21 | 2. 74 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0. | 0. 28 | 3. 86 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0. 02 | 2. 23 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0. 07 | 1. 54 |

## TABLE 5.17: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (A)

(FREQUENCY ANALYSIS OF DROUGHT DAYS FOR STATION 5030039 )

PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN

| MONTH | PROBABILITY(%) OF BEING ZERO | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 94 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 71 | 29 | 24 | 18 | 18 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 76 | 24 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 |
| 6 | 82 | 18 | 18 | 18 | 18 | 18 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 88 | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| 8 | 94 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*E.D.P. Section,*
*Hydrology Branch,*
*D.I.D. Headquarters.*

# TABLE 5.18 CODING FORM

L—J.C.K., K.L.

| PROGRAM | TSMAY | PUNCHING INSTRUCTIONS | GRAPHIC | PAGE | OF |
|---|---|---|---|---|---|
| PROGRAMMER | DEPARTMENT OF IRRIGATION AND DRAINAGE | | PUNCH | DATE | |

Columns: C, Statement Number (1–5), Cont (6), STATEMENT (7–72), Identification and Sequence No (73–80)

```
  (a)  FOR NO IRRIGATION INPUT

CARD 1   SOIL TYPE-AKOB           SERIES     FC@1/3 BAR  WP@15BAR204.0102.0
CARD 2                       110.0
CARD 3       482             93 941111181201141151191161111 87 80
CARD 4   0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6      90   80   70   60   50   40   30   20   10
CARD 7   MAIZE  (GRAIN)                        218021110

  (b)  FOR IRRIGATION INPUT

CARD 1   SOIL TYPE-AKOB           SERIES     FC@1/3 BAR  WP@15BAR204.0102.0
CARD 2                       110.01
CARD 3       482             93 94 1111812011411511911161111 87 80
CARD 4   0.254
CARD 5   JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
CARD 6   MAIZE (GRAIN)                         218021110
```

## TABLE 5.19: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (B)

( SUMMARY OF DAILY WATER BALANCE FOR APR.)

| YEAR | RAIN (MM) | EVAPOTRANS. (MM) | DRAINAGE (MM) | CROP WATER DEFICIT(MM) | DROUGHT DAYS | IRRIGATION (MM) | IRRIGATION APPLICATIONS | SOIL MOISTURE STATUS(MM) | MONTHLY WATER BALANCE(MM) |
|---|---|---|---|---|---|---|---|---|---|
| 1959 | 74 | 109.6 | 18.8 | 13.6 | 6 | 0.0 | 0 | 65.2 | -53.7 |
| 1960 | 174 | 114.5 | 5.5 | 8.9 | 5 | 0.0 | 0 | 110.6 | 54.5 |
| 1961 | 230 | 122.2 | 109.0 | 1.0 | 0 | 0.0 | 0 | 118.3 | -0.6 |
| 1962 | 64 | 102.5 | 0.0 | 20.6 | 8 | 0.0 | 0 | 75.6 | -38.3 |
| 1963 | 29 | 69.7 | 0.0 | 53.5 | 29 | 0.0 | 0 | 26.5 | -40.5 |
| 1964 | 39 | 102.9 | 0.0 | 20.5 | 8 | 0.0 | 0 | 45.2 | -63.0 |
| 1965 | 211 | 118.6 | 71.4 | 4.6 | 0 | 0.0 | 0 | 91.5 | 21.9 |
| 1966 | 76 | 105.4 | 0.0 | 17.8 | 7 | 0.0 | 0 | 80.1 | -28.4 |
| 1967 | 55 | 80.4 | 0.0 | 42.8 | 27 | 0.0 | 0 | 41.6 | -25.0 |
| 1968 | 150 | 82.2 | 0.0 | 41.2 | 22 | 0.0 | 0 | 117.8 | 68.1 |
| 1969 | 54 | 84.2 | 0.0 | 39.0 | 18 | 0.0 | 0 | 26.0 | -30.1 |
| 1970 | 216 | 119.7 | 141.1 | 3.5 | 0 | 0.0 | 0 | 74.2 | -44.6 |
| 1971 | 5 | 70.2 | 0.0 | 53.0 | 23 | 0.0 | 0 | 21.2 | -64.3 |
| 1972 | 163 | 113.2 | 67.2 | 10.2 | 2 | 0.0 | 0 | 58.0 | -17.3 |
| 1973 | 54 | 103.2 | 0.0 | 20.0 | 10 | 0.0 | 0 | 68.3 | -48.6 |
| 1974 | 338 | 122.6 | 209.3 | 0.6 | 0 | 0.0 | 0 | 112.1 | 6.1 |
| 1975 | 201 | 117.9 | 90.3 | 5.3 | 0 | 0.0 | 0 | 77.8 | -6.6 |

## TABLE 5.20: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (B)

( FREQUENCY ANALYSIS OF MONTHLY CROP WATER DEFICIT FOR STATION 5030039 )

| MONTH | SMALLEST | CROP WATER DEFICIT(MM) FORRISK OF EXCEDENCE(%) | | | | | | | | | | LARGEST | MEAN | S.D. | SKEW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0. | 0.52 | 2.01 |
| 2 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 0 | 4 | 1. | 1.20 | 1.74 |
| 3 | 0 | 0 | 1 | 3 | 5 | 7 | 8 | 10 | 12 | 15 | 0 | 19 | 7. | 6.71 | 1.22 |
| 4 | 0 | 0 | 6 | 12 | 16 | 21 | 25 | 30 | 36 | 44 | 0 | 53 | 21. | 18.12 | 0.70 |
| 5 | 0 | 0 | 1 | 7 | 12 | 17 | 22 | 27 | 33 | 42 | 0 | 62 | 17. | 19.20 | 1.07 |
| 6 | 0 | 0 | 0 | 0 | 1 | 3 | 4 | 5 | 7 | 9 | 0 | 18 | 3. | 4.86 | 2.63 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 3 | 4 | 0 | 11 | 1. | 2.73 | 4.09 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 4 | 0. | 1.08 | 3.27 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.24 | 2.73 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0. | 0.33 | 3.85 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.02 | 2.16 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0. | 0.03 | 1.55 |

# TABLE 5.21: OUTPUT FROM PROGRAMME TSMAY FOR EXAMPLE 3 (B)

( FREQUENCY ANALYSIS OF DROUGHT DAYS FOR STATION 5080039 )

| MONTH | PROBABILITY(%) OF BEING ZERO | PROBABILITY(%) OF BEING GREATER THAN OR EQUAL TO NUMBER SHOWN 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 71 | 29 | 29 | 24 | 24 | 24 | 18 | 18 | 18 | 12 | 12 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 29 | 71 | 71 | 65 | 65 | 65 | 59 | 53 | 47 | 35 | 35 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 24 | 24 | 24 | 24 | 18 | 12 | 12 | 12 | 12 | 6 | 6 | 0 | 0 |
| 5 | 53 | 47 | 47 | 41 | 41 | 41 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 29 | 29 | 24 | 24 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 12 | 6 | 6 | 6 |
| 6 | 82 | 18 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 94 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 94 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The peak water requirement governs the capacity of the hydraulic components of the irrigation system such as pumps, pipes, channels etc. On most irrigation schemes, it is uneconomical to provide facilities to irrigate the total area simultaneously and hence the water application is staggered according to a planned operational sequence. The peak water requirement therefore depends on the time available between successive irrigations, the total area to be irrigated and the amount of water per irrigation application.

The area to be irrigated is fixed, and the amount of irrigation water per application depends on the crop, growth stages and soil type (in terms of the simulation model this is equal to half the effective soil moisture storage capacity). The time available between successive irrigations may be approximately determined from the analysis of monthly irrigation frequencies as:

$$T_a = \frac{30}{n} \qquad \ldots \quad \ldots \quad \ldots \quad .. \quad (6.1)$$

where $T_a$ = average time available between successive irrigation applications (days) for a given risk level.

n = monthly irrigation frequency for a given risk level.

The average water requirement for the month is then:

$$q = \frac{AI}{T_a \times 8640} \qquad \ldots \quad \ldots \quad .. \quad (6.2)$$

where q = average water requirement for the month for a given risk level (cumecs)

A = total irrigation area (hectares)

I = irrigation water per application (mm)

Allowance is made for conveyance and application losses by an efficiency factor

$$\text{i.e. } q_c = \frac{100A\ I}{8640T_a e_f} \qquad \ldots \quad \ldots \quad .. \quad (6.3)$$

where $q_c$ = required irrigation system capacity (cumecs) for a given risk level.

$e_f$ = irrigation system efficiency (%)

Substituting for $T_a$ for equation (6.1) gives

$$q_c = \frac{4\ AIn}{e_f} \times 10^{-4} \qquad \ldots \quad \ldots \quad .. \quad (6.4)$$

Since n varies from month to month, the month with the highest value of n determines the irrigation system capacity.

Equation (6.4) does not account for the variability of rainfall and soil moisture status over the irrigated area. Both these factors upset the schedule of irrigation. In the demand system, water is only applied when the soil moisture is depleted to a predetermined level (in this case 50% of the effective soil moisture storage capacity) and irrigation is interrupted when the soil moisture depletion is satisfied by rainfall.

In practice irrigation is usually applied before the soil moisture drops to the critical level. Since the whole area cannot be irrigated simultaneously, the schedule must allow sufficient time to irrigate the whole area before the soil moisture on any portion of the area drops to the critical level. This means, the frequency of irrigation (n) will increase and the irrigation water per application (I) will be less than the difference between the effective soil moisture storage capacity and the critical soil moisture level i.e. when n increases I decreases. Hence in equation 6.4 the value of $q_c$ is not affected appreciably. Therefore equation 6.4 can be used to estimate the peak flow rate and the associated risk level for the design of irrigation schemes.

# 7. DISCUSSION & CONCLUSION

## 7.1 Discussion

As stated in section 1.2 (Objective) this procedure is only an aid to agricultural planners and should not be regarded as a day to day operational model because results obtained are based on statistical analysis of past annual records. Both programmes TPSTAT and TSMAY are designed to analyse continuous complete annual records and not instantaneous daily values.

Computer programme TPSTAT is the statistical analysis of the weekly rainfall totals obtained from daily effective rainfall. Although, the effective rainfall range adopted in the procedure is 5–50 mm, it is possible to run the TPSTAT programme with any other desired range (please see Appendix A). The programme allows normal or log-normal distribution to be used for the statistical analysis. However, normal distribution is preferred because of its superior fit to the sample values.

The choice of recommended rainfall probability level for the cultivation of upland crops (Table 3.2) is based on the cost of production and sensitivity to moisture stress. Table 3.2 is only a general guide to agricultural planners and does not take into consideration the various farm management practices.

The crop coefficient curve is developed from crop time ratios, crop coefficients [Table C.1 (FAO, 1975)] and the reference crop potential evapotranspiration, ETO [Table 4.1 (Scarf, 1976)]. The FAO values having been developed from overseas research, may not represent the values for crops grown under local conditions. However, these values are used due to lack of local experimental data. The weekly value of ETO is obtained by dividing the average annual value by the number of weeks in a year. This has been found to be sufficiently accurate because of the little variation in the monthly ETO values. The crop water requirement curve is defined by four characteristic points with linear relationship between successive points. Although, this is not true under actual growing conditions, it is satisfactory for the matching of crop water requirement with the TPSTAT analysis.

In existing agricultural areas this TPSTAT method can be used to check whether the planting date practised makes best use of the available rainfall, for a given crop. However, a realistic planting date can be obtained only if the chosen rainfall and evaporation stations are representative of the area.

In the TSMAY daily water balance model, the available soil water holding capacity and critical soil moisture level are decisive factors in the determination of the daily water deficit and definition of a drought day. The soil data obtained from publications, internal reports, etc. show a wide variation in the values of available soil water holding capacity, for the same soil series. Table 4.2, gives the adjusted values based on experience and judgement of the soil scientists involved in the preparation of this procedure.

Due to the wide variation in the values of available soil water holding capacity and the lack of local experimental data on crop water requirement, it is essential that the procedure results be compared with field data such as soil moisture infiltration rate, soil moisture depletion rate, frequency and depth of supplementary irrigation water, etc., from on-going projects.

## 7.2 Conclusion

It has been shown that by using statistical analysis of rainfall (TPSTAT) together with water-soil-crop simulation model (TSMAY), it is possible to find the most suitable planting date and to determine crop water requirements and irrigation demand for upland crops in Peninsular Malaysia.

To improve the results of the procedure, the following recommendations are made:-

(1) Research should be directed towards the determination of crop coefficients for local upland crops, and towards the identification of the growth stages most sensitive to moisture stress.

(2) Every effort should be made to collect additional data on moisture characteristics of Malaysian soils and on establishing a uniformity in the classification of local soil series.

(3) Due to insufficient core storage of the computer used, only monthly output of TSMAY is provided. To provide better presentation of the values of crop water deficit and irrigation demand, it is recommonded to get the output on a weekly basis, as in TPSTAT.

## REFERENCES

Baier, W. and Russelo, D.A. (1968), "A Computer Program for estimating risks of irrigation requirements from climatic data", Tech, Bul. 59, Agrometeorology Section, Plant Research Institute, Research Branch, Canada Department of Agriculture.

Cawangan Ekonomi, (1974), "Anggaran Kos Pengeluaran dan Pendapatan Jenis-Jenis Tanaman dan Ternakan", Bil. 2., Institiut Penyelidekan dan Kemajuan Pertanian Malaysia (MARDI).

Coligado, M.C. et al (1968), "Risk Analyses of Weekly Climatic Data for Agricultural and Irrigation Planning, Swift Current, Saskatachewan", Tech. Bul. 43, Agrometeorology Section, Plant Research Institute, Research Branch, Canada Department of Agriculture.

Department of Agriculture (1968), "Reconnissance Soil Map of Peninsular Malaysia."

Drainage and Irrigation Department (1977), "Hydrological Data, Rainfall Records (1970–75)". Ministry of Agriculture, Peninsular Malaysia.

FAO (1974), "Effective Rainfall in Irrigation Agriculture", Irrigation and Drainage Paper 25, Food and Agricultural Organization of the United Nations, Rome.

FAO (1975), "Guidelines for Predicting Crop Water Requirements", Irrigation and Drainage Paper 24, Food and Agricultural Organization of the United Nations, Rome.

Hagan, R.M. and Stewart, J.I. (1972), "Water Deficits–Irrigation Design and Programming", J. Irrig. and Drain. Div., Proc. ASCE.

Heiler, T.D. (1973), "Prospects and Planning for Upland Crop Irrigation in West Malaysia," National Seminar on Water Management at Farm Level, Alor Star, Malaysia.

Kowal, J.M. and Knabe, D.T. (1972), "An Agroclimatological Atlas of the Northern States of Nigeria with Explanatory Notes", Ahmadu Bello University, Samaru–Jaria, Nigeria.

Liew Chong Hwa (1976), "Costing for Vegetables per Acre", Farm Management Section Extension Branch, Department of Agriculture, Kuala Lumpur.

Manning, H.L. (1950), "Confidence limits of Expected Monthly Rainfall", J. Agric. Sci. 40.

Oldeman, L.R. (1974), "An Agro-climatic Classification for Evaluation of Cropping Systems in Southeast Asia", paper presented at "International Experts Consultation on the Use of Improved Technology for Food Production in Rainfed Areas of Tropical Asia", Hyderabad, Khoon Kaen, Kuala Lumpur 24 Nov.–13 Dec.

Panabokke, C.R. and Walgama, A. (1974), "The Application of Rainfall Confidence Limits to Crop Water Requirements in Dry Zone Agriculture"; paper prepared in the Land Use Division, Irrigation Department, Sri Lanka.

Richard, D.S. and Fitzgerald, P.D. (1972), "An Evapotranspiration Model for Water Balance and Irrigation Research", Winchmore Irrigation Research Station, Ministry of Agriculture and Fisheries, Ashburton, New Zealand.

Richards, L.A. and Weaver, L.R. (1943), "Fifteen atmosphere–percentage as related to the permanent wilting percentage". Soil Science 56: 331–339.

Robertson, G.W. (1970), "Rainfall and Soil Water Variability with Reference to Land Use Planning", Technical Series No. 1, UDC 551: 5: 63, issued by the WMO/UNDP Project "Meteorological Training and Research, Manila", Philippines Weather Bureau, Department of Meteorology, University of the Philippines.

Salter, P.J. and Goode, J.E. (1967), "Crop responses to water at different stages of growth". Commonwealth Agricultural Bureaux, England.

Scarf, F. (1976), "Evaporation in Peninsular Malaysia". Drainage and Irrigation Department, Ministry of Agriculture, Peninsular Malaysia. Water Resources Publication No. 5.

Tang Loon Boon (1976), "Production Cost of Miscellaneous Agricultural Commodities", Federal Agricultural Marketing Authority, Ministry of Agriculture, Malaysia.

U.S. Bureau of Reclamation (1948), "Land Classification Report".

Van de Eelaart, A.I.J. (1972), "An Agroclimatological Study in Thailand", Land Classification Division, Department of Land Development and FAO, Thailand, paper presented at Second Asean Soil Conference, Kuala Lumpur.

Veihmeyer, V.I. and Hendricksen, A.H. (1933), "Some plant and soil moisture relations". Amer. Soil Survey Assoc. Bul. 15.

Walpole, R.E. (1973), "Introduction of Statistics", The Macmillan Company, New York/Collier-Macmillan Publishers, London.

Wickham, T. (1973), "A Low-Cost Technology for Improved Irrigation of Lowland Rice", National Seminar on Water Management at Farm Level, Alor Star, Malaysia.

Wycherley, P.R. (1967), "R.R.I.M. Planting Manual No. 12, Rainfall Probability Tables for Malaysia", Rubber Research Institute of Malaya publication.

# APPENDICES

# APPENDICES

Two main computer programmes have been developed for analysing weekly rainfall statistics (TPSTAT) and for simulating the water-soil-crop system (TSMAY). These two programmes call a number of supporting subroutine programmes. All programmes have been written in FORTRAN IV for the Nova 1220 minicomputer at the Drainage and Irrigation Department.

Daily rainfall records for all the rainfall stations in Peninsular Malaysia operated by the D.I.D. are stored on a computerised data storage-retrieval system (TIDEDA). Because of the existing storage structure of the data bank, rainfall data are extracted in a series of records over the period of observation. These records must be merged to give a continuous period of record as required by the programmes TPSTAT and TSMAY. A flow chart of the sequence of operation is shown in Fig. A.1. All the necessary system and FORTRAN programmes are loaded on disc pack 16 of the Nova machine. TPSTAT is described in Appendix A, TSMAY in Appendix B, CROP subroutine in Appendix C and remaining subroutines in Appendix D.

## APPENDIX A

PROGRAMME TPSTAT

This programme computes weekly effective rainfall totals for each week of the year for specified probability levels. The statistical methodology is explained in section 3.2. Upon initialization, the programme requests the file name containing the daily rainfall data in compressed format. The file name is punched in through the teletype. Three cards are then read to complete the programme data requirements:

First card – Contains the limits within which the daily rainfall is considered effective, and the factor to convert the daily rainfall data to millimetre units. Card format is 2I5, F5.0.

Second card – Contains data transformation option. The first column contains 1 for no data transformation and 2 for a logarithmic data transformation. The next 20 columns are reserved for the description of the type of probability distribution i.e. normal or log-normal. The card format is I1, 10A2.

Third card – Contains percentage probability levels for which the expected weekly rainfall is computed. Nine probability levels (in decreasing order) are allowed and the card format is 9I3.

Output from the programme is a summary of the data and the statistical parameters for each week of the year, followed by a table listing the expected weekly rainfalls for each week of the year for the specified probability levels. The programme calls supporting sub-routines TORDER, TNORM, TREGRES, TSIZE and TSTATIS. A listing of the programme TPSTAT is given in Table A.1 and the flow chart in Fig. A.2.

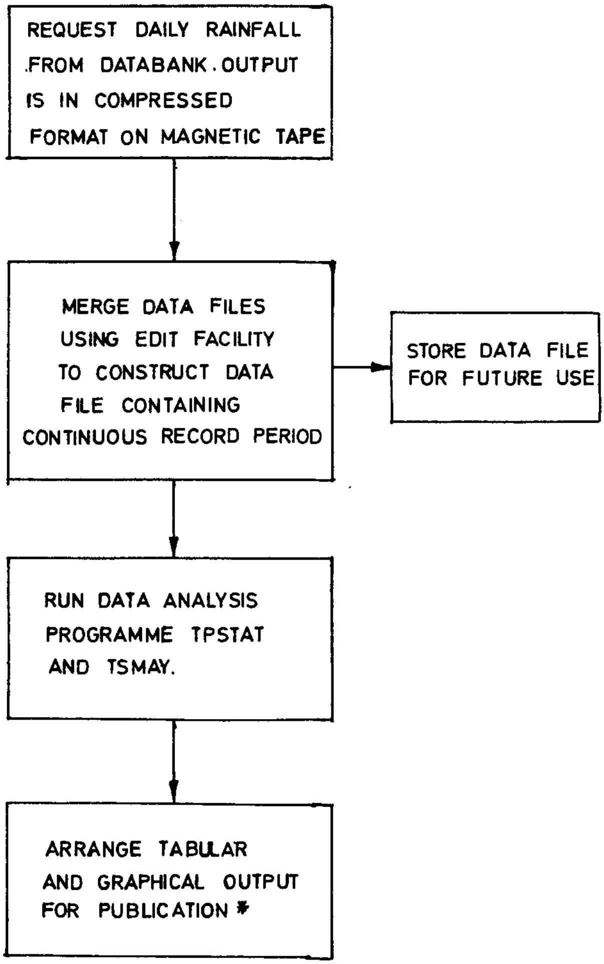



FIG. A.1 FLOW CHART FOR ANALYSIS OF DAILY RAINFALL DATA

( * THIS OPERATION IS DEPENDENT ON THE USER'S REQUIREMENT )

# TABLE A.1: LISTING OF PROGRAMME TPSTAT

```
      COMPILER NOSTACK
C     PROGRAM TPSTAT COMPUTES STATISTICS OF WEEKLY RAINFALL TOTALS
C     SUBROUTINES CALLED - TORDER, TNORM, TREGRES, TSIZE, TSTATIS
C     DEFINITION OF VARIABLE NAMES USED
C     IRR - WORKING ARRAY CONTAINING DAILY RAINFALL YEAR AT A TIME
C     IYR - ARRAY CONTAINING YEARS OF DATA
C     WRRAY - WORKING ARRAY CONTAINING WEEKLY RAINFALL
C     ORDER - WORKING ARRAY CONTAINING NON ZERO WEEKLY RAINFALL
C             ARRANGED IN ORDER OF INCREASING SIZE
C     CUMP - WORKING ARRAY CONTAINING CUMULATIVE PROBABILITY OF NON ZERO
C            WEEKLY RAINFALL
C     SNDEV - WORKING ARRAY CONTAINING STANDARD NORMAL DEVIATES CORRESPONDING
C             TO VALUES OF CUMP
C     RMEAN - ARRAY CONTAINING MEAN OF WEEKLY RAINFALLS
C     RSTD - ARRAY CONTAINING STANDARD DEVIATION OF WEEKLY RAINFALLS
C     DRYP - ARRAY CONTAINING PROBABILITY OF A DRY WEEK
C     SMALL - ARRAY CONTAINING SMALLEST WEEKLY RAINFALL
C     BIG - ARRAY CONTAINING LAREST WEEKLY RAINFALL
C     ISELP - ARRAY CONTAINING SPECIFIED PROBABILITY LEVELS
C     Z - WORKING ARRAY CONTAINING S.N.D'S CORRESPONDING TO ISELP
C     ZO - ARRAY CONTAINING S.N.D'S FOR ZERO RAIN
C     SITE - ARRAY CONTAINING STATION IDENTIFICATION NUMBER
C     ID - WORKING ARRAY CONTAINING DAY ON WHICH RAIN OCCURED
C     IR - WORKING ARRAY CONTAINING RAIN WHICH OCCURED ON DAY ID
C     NPREC - WORKING ARRAY CONTAINING WEEKLY RAINFALL FOR SPECIFIED PROBABILITY
C             LEVELS
C     IMIN - MINIMUM EFFECTIVE RAIN(MM)
C     IMAX - MAXIMUM EFFECTIVE RAIN(MM)
C     FACTOR - CONVERSION FACTOR TO MM
C     INPUT DATA REQUIREMENTS ARE AS FOLLOWS:
C     $TTI - DISK FILE NAME CONTAINING DAILY RAINFALL IN COMPRESSED FORMAT
C     FIRST DATA CARD CONTAINS LIMITS WITHIN WHICH RAINFALL IS CONSIDERED
C         TO BE EFFECTIVE AND CONVERSION FACTOR TO MM
C     SECOND CARD CONTAINS DATA TRANSFORMATION OPTION -
C         1= NO DATA TRANSFORMATION
C         2= LOGARITHMIC DATA TRANSFORMATION
C     THIRD CARD CONTAINS SPECIFIED PROBABILITY LEVELS
      DIMENSION STN(7)
      DIMENSION IRR(366),IYR(50),ID(9),IR(9),CUMP(50) ,SITE(2),WRRAY(50)
      DIMENSION DRYP(52),ORDER(50),SNDEV(50),RMEAN(52),RSTD(52)
      DIMENSION SMALL(52),BIG(52),ISELP(9),Z(9),NPREC(9),TRANS(10),ZO(52),NFILE(10)
      INTEGER SITE,BIG,SMALL,TRANS
      REAL IRR
      TYPE'<15>','DATA FILE NAME ?<15>'
      READ(11,300)NFILE
300   FORMAT(10A2)
      KIER=1
      CALL OPEN(2,NFILE,2,IER)
      IF(IER.NE.1)WRITE(12,203)KIER,IER
203   FORMAT(1H1,10X,'**** FILE OPERATION',I2,'  ERROR CODE',I2)
      CALL OPEN(3,"TDATA",2,IER,2)
      KIER=2
      IF(IER.NE.1)WRITE(12,203)KIER,IER
      READ(9,101)IMIN,IMAX,FACTOR,ITRANS,TRANS,ISELP
101   FORMAT(2I5,F5.0/I1,10A2/9I3)
      KYR=0
1001  KYR=KYR+1
      DO 1 I=1,366
1     IRR(I)=0.
3     SITE(1)=LOC1
      SITE(2)=LOC2
      READ(2,100,END=1000)STN,IYR(KYR),NCARD,KEY,(ID(K),IR(K),K=1,9)
100   FORMAT(7A1,3I3,1X,9(I3,I4))
      IF(NCARD.EQ.0)GO TO 1000
      DO 2 I=1,9
      K=ID(I)
      IF(K.EQ.0)GO TO 2
      IRR(K)=IR(I)*FACTOR
2     CONTINUE
      IF(KEY.NE.NCARD)GO TO 3
C     COMPUTE WEEKLY RAINFALL TOTALS
      JS=1
      JE=7
      DO 4 I=1,52
      WRAIN=0.
      DO 5 J=JS,JE
C     TEST FOR RAIN GT. IMAX AND LT. IMIN
      IF(IRR(J).LT.IMIN)GO TO 5
```

```
      IF(IRR(J).GT.IMAX)GO TO 6
      WRAIN=WRAIN+IRR(J)
      GO TO 5
6     WRAIN=WRAIN+IMAX
5     CONTINUE
      IRAIN=WRAIN
      JS=I*7+1
      JE=JS+6
      IF(I.EQ.51)JE=JS+8
C     WRITE WEEKLY RAINFALL ON DISC FILE
      ILR=(KYR-1)*52+I
      CALL FSEEK(3,ILR)
4     WRITE BINARY(3)IRAIN
      GO TO 1001
1000  NYR=KYR-1
      WRITE(12,200)FACTOR,NYR,STN
200   FORMAT(1H1,10X,'FACTOR USED TO CONVERT RAINFALL UNITS TO MM =',F7.4/11X,
     1I4,' YEARS OF WEEKLY PRECIPITATION FOR STATION ',
     27A1,' STORED ON FILE TDATA')
      KIER=3
      CALL CLOSE(2,IER)
      IF(IER.NE.1)WRITE(12,203)KIER,IER
C     INITIALIZE TABLE OF CUMULATIVE PROBABILITIES
      CALL TNORM(A,B,1)
      DO 10 I=1,52
C     READ I-TH RECORD FOR EACH YEAR
      NRS=I
      NRE=NYR*52+NRS-1
      KYR=0
      DO 11 J=NRS,NRE,52
      KYR=KYR+1
      CALL FSEEK(3,J)
      READ BINARY(3)IRAIN
11    WRRAY(KYR)=IRAIN
C     LIST DATA
      IF(MOD(I,5).NE.0.AND.I.NE.1)GO TO 17
      WRITE(12,205)I,(WRRAY(J),J=1,NYR)
205   FORMAT(1H1,45X,'EFF.RAINFALL'//1X,'WEEK ',I2,10X,20F5.0/2(18X,20F5.0/))
      GO TO 18
17    WRITE(12,204)I,(WRRAY(J),J=1,NYR)
204   FORMAT(1H0,45X,'EFF.RAINFALL'//1X,'WEEK ',I2,10X,20F5.0/2(18X,20F5.0/))
18    CONTINUE
C     COMPUTE WEEKLY RAINFALL STATISTICS BY MOMENTS
      CALL TSTATIS(WRRAY,NYR,XMEAN,XSTD,XSKEW)
      CONTINUE
C     COMPUTE LARGEST AND SMALLEST VALUES
      CALL TSIZE(WRRAY,AS,NS,AB,NB,NYR)
      SMALL(I)=AS
      BIG(I)=AB
C     COMPUTE SAMPLE PROBABILITIES
      CALL TORDER(WRRAY,ORDER,NYR,CUMP)
C     SORT INTO NON-ZERO ARRAY
      NW=0
      DO 12 J=1,NYR
      IF(ORDER(J).EQ.0)GO TO 12
      NW=NW+1
      ORDER(NW)=ORDER(J)
      CUMP(NW)=CUMP(J)
12    CONTINUE
C     USE LOGARITHMIC TRANSFORMATION IF SPECIFIED
      IF(ITRANS.EQ.1)GO TO 15
      DO 16 J=1,NW
16    ORDER(J)=ALOG(ORDER(J))
15    CONTINUE
C     COMPUTE WEEKLY RAINFALL STATISTICS BY LEAST SQUARES
      DO 14 J=1,NW
      AC=CUMP(J)
      CALL TNORM(AC,ASN,2)
14    SNDEV(J)=ASN
      CALL TREGRES(SNDEV,ORDER,AY,BY,NW,CC)
      RMEAN(I)=AY
      RSTD(I)=BY
C     FIND PROBABILITY OF DRY WEEK
      ZO(I)=-AY/BY
      AZ=ZO(I)
      CALL TNORM(CPROB,AZ,3)
      DRYP(I)=CPROB
C     PRINT DISTRIBUTION PARAMETERS
      WRITE(12,206)RMEAN(I),RSTD(I),CC,DRYP(I),XMEAN,XSTD,XSKEW,TRANS
```

## TABLE A.1 (CONTD.)

```
206    FORMAT(1H0,45X,'DISTRIBUTION PARAMETERS'//5X,'BY LEAST SQUARES *',8X,'MEAN
      1=',F7.2,7X,'ST.DEV.=',F7.2,7X,'CORR.COEFF.=',F7.2/
      240X,'PROBABILITY OF DRY WEEK =',F6.2/11X,'BY MOMENTS *',8X,
      3'MEAN=',F7.2,7X,'ST.DEV.=',F7.2,7X,'SKEW=',F7.2/
      44X,'DISTRIBUTION TYPE *',10A2)
10     CONTINUE
C      PRINT TITLE OF OUTPUT TABLE
       WRITE(12,201)STN,IYR(1),IYR(NYR),IMIN,IMAX,(ISELP(J),J=1,9)
201    FORMAT(1H1, 9X,'STATION NUMBER',1X,7A1/10X,'RECORD PERIOD ANALYSED',
      13H 19,I2,6H TO 19,I2/10X,'EFFECTIVE WEEKLY RAINFALL (MM) FOR A GIVEN RISK(PERCENT)'
      2/10X,'LIMITS OF EFFECTIVE DAILY RAINFALL',I3,3H TO,I5,3H MM,
      3///10X,'WEEK',4X,'LOWEST',8X,'RAIN(MM) FOR RISK OF EXCEDENCE(PERCENT)',
      49X,'HIGHEST',5X,'RISK OF WEEK BEING'/17X,'OBSERVED',3X,9I5,7X,'OBSERVED',
      57X,'WET',7X,'DRY'/)
C      COMPUTE S.N.D. FOR SPECIFIED PROB. OF EXCEDENCE
       DO 20 J=1,9
       SPEXC=1.0-ISELP(J)*0.01
       CALL TNORM(SPEXC,AZ,2)
20     Z(J)=AZ
       DO 8 I=1,52
C      COMPUTE WEEKLY RAIN FOR SPECIFIED PROBABILITY OF EXCEDENCE
       DO 9 J=1,9
       IF(Z(J).GT.ZO(I))GO TO 19
C      SPECIFIED PROB. OF EXCEDENCE GT PROB. OF WET WEEK
       RPREC=0.
       GO TO 9
19     RPREC=RMEAN(I)+RSTD(I)*Z(J)
C      TEST WHETHER DATA TRANSFORMATION USED
       IF(ITRANS.EQ.2)RPREC=EXP(RPREC)
9      NPREC(J)=RPREC+0.5
C      PRINT OUT ONE LINE OF TABLE
       NDRYP=DRYP(I)*100.0+0.5
       NWETP=100-NDRYP
8      WRITE(12,202)I,SMALL(I),NPREC,BIG(I),NWETP,NDRYP
202    FORMAT(11X,I2,6X,I3,6X,9I5,9X,I3,10X,I3,7X,I3)
       KIER=4
       CALL CLOSE(3,IER)
       IF(IER.NE.1)WRITE(12,203)KIER,IER
       KIER=5
       CALL DFILW("TDATA",IER)
       IF(IER.NE.1)WRITE(12,203)KIER,IER
       END
```

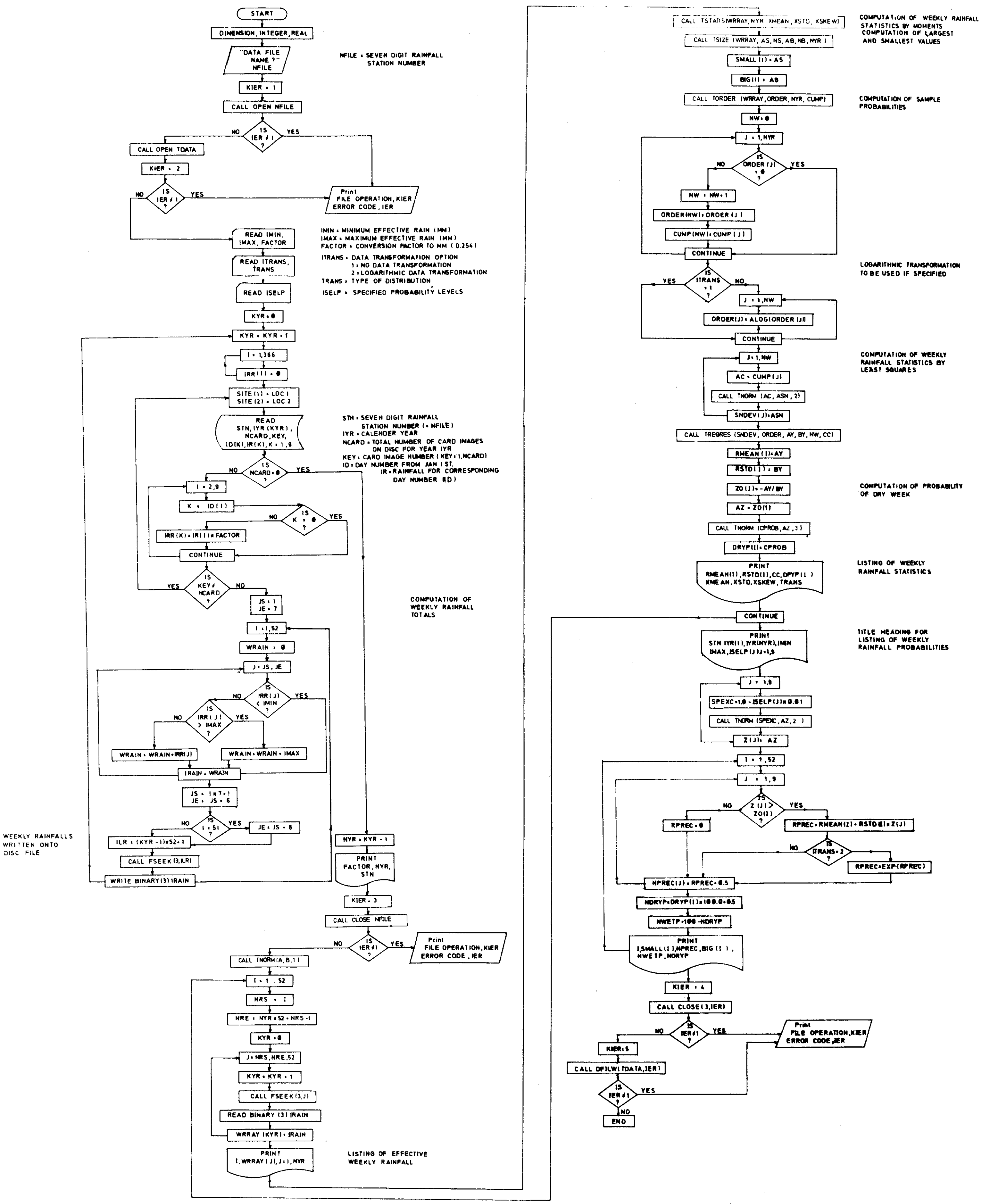



FIG. A.3: FLOW CHART FOR PROGRAMME TPSTAT

# APPENDIX B

## PROGRAMME TSMAY

This programme computes a frequency analysis of drought days, water deficits and irrigation applications for a specified set of soil and crop parameters. The simulation theory is explained in section 4.2. Input to the programme is requested upon initialising the programme and consists of the disc file name containing the daily rainfall data and five data cards (or six cards if irrigation input is not required). The disc file name is entered through the teletype. The data cards are:

| | |
|---|---|
| First card | – Contains the following soil parameters: name of soil series (including the pressure levels used in defining Field Capacity and Wilting Point), available water holding capacity, critical soil moisture level defining agricultural drought. Card format is 25A2, 2F5.1. |
| Second card | – Contains initial soil moisture level, and an integer value specifying the mode of simulation. A value of 1 requests irrigation input during simulation and a value of 0 requests no irrigation input during simulation. Card format is 15X, F5.0, I2. |
| Third card | – Contains monthly potential grassland evapotranspiration for each month of the year in millimetres. Card format is 15X, 12I3. |
| Fourth card | – Contains factor to convert the rainfall units to millimetres. Card format is F10.0. |
| Fifth card | – Contains the months of the year for labelling output. The first three letters of each month are punched in 3 columns with 1 blank column between months. |
| Sixth card | – Contains percentage probability levels for which crop water deficit is computed. Nine probability levels (in decreasing order) are allowed and card format is 9I5. This card is not required if the program is run with the irrigation option. |

(Note: For format of crop data input cards, please see Appendix C.3)

Output from the programme is a monthly summary of the daily water balance for all the years analysed. If the irrigation option is set to 1, a table of irrigation frequencies for each month of the year is printed. If the non-irrigated option is run, the programme prints two tables; one showing monthly crop water deficits for each month for the specified probability levels, and the second table showing a frequency analysis of drought days for each month of the year. The programme calls supporting subroutines OCROP, OTSTATIS, OTSIZE, OTMODEL, OTNORM (the first letter "O" indicates the subroutines are overlaid). A listing of programme TSMAY is in Table B.1 and the flow chart in Fig. B.1.

# TABLE B.1 : LISTING OF PROGRAMME TSMAY

```
      *COMPILER NOSTACK
C      TSMAY
C      ALL  SUBROUTINES ARE OVERLAID
C      SOIL  MOISTURE ANALYSIS PROGRAM
C      SUBROUTINES CALLED OTSTATIS,OTSIZE,OTMODEL,OTNORM,OCROP
C      INPUT DATA REQUIREMENTS ARE :
C      $TTI - DISK FILE NAME CONTAINING DAILY RAINFALL DATA IN COMPRESSED FORMAT
C      CARD 1 - SOIL  PARAMETERS
C                SOIL  TYPE WITH FIELD CAPACITY @ 1/3 BAR OR @
C                1/10 BAR, AND WILTING POINT @ 15 BAR (EXPRESSED AS PERCENTAGE
C                 MOISTURE RETENTION ON DRY WEIGHT BASIS)
C                SMAXPM=AVAILABLE WATER IN MM/M OF SOIL  (CALCULATED FROM
C                (FC%-WP%)*10*BULK DENSITY
C                SCRPM=CRITICAL  SOIL  MOISTURE CAPACITY IN MM/M
C                 OF SOIL  (EQUALS 50% OF SMAXPM)
C      CARD 2 - MODEL  PARAMETERS
C               SMI - INITIAL  SOIL  MOISTURE LEVEL WITHIN ROOTING DEPTH
C               IRI =1 FOR IRRIGATION INPUT
C                   =0 FOR NO IRRIGATION INPUT
C      CARD 3 - MONTHLY POTENTIAL  GRASSLAND EVAPOTRANSPIRATION
C      CARD 4 - FACTOR TO CONVERT RAINFALL  UNITS TO MM
C      CARD 5 - MONTHS OF THE YEAR
C      CARD 6 - SELECTED PROBABILITY LEVELS FOR WHICH CROP WATER DEFICIT IS
C               COMPUTED (NOT REQUIRED IF IRI IS SET TO 1)
C      INPUT DATA REQUIREMENTS FOR SUBROUTINE OCROP
C      $TTI - NUMBER OF PLANTING DATES PER YEAR
C      ONE CARD FOR EACH PLANTING DATE,GIVING CROP TYPE,PLANTING DATE,CROP LENGTH
       EXTERNAL  OCROP,OTSTATIS,OTNORM,OTSIZE,OTMODEL
       COMMON /NDM/NDAY(12),EFAC(366),KIN(4),KSEC(4),NC,ROOTDP(22)
       COMMON /ERA/INTVL(32)
       DIMENSION IRR(366),IYR(40),ID(9),IR(9),SITE(2),Z(10),JPE(12),
      1MONTH(12,2),ISELP(9),BIG(12),SMALL(12),RMEAN(12),STD(12),SKEW(12),
      2IRAIN(40,12),EVAP(40,12),EXCES(40,12),WDEF(40,12),NDD(40,12),
      3WIRI(40,12),NIA(40,12),SMS(40,12),CSMS(40,12),NCLASS(12,32),
      4IRISK(32),ARRAY(40),NDEV(10),NFILE(10),SOIL(25)
       INTEGER MONTH,SITE,BIG,SMALL
       DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
       DATA INTVL/0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,
      121,22,23,24,25,26,27,28,29,30,31/
       JCHAN=1
       TYPE "DATA FILE NAME (RAINFALL STATION NUMBER) ?<15>"
       READ(11,300)NFILE
300    FORMAT(10A2)
       READ(9,80)SOIL,SMAXPM,SCRPM
80     FORMAT(25A2,2F5.1)
       READ(9,101)SMI,IRI,(JPE(I),I=1,12),FACTOR
101    FORMAT(15X,F5.0,I2/15X,12I3/F10.0)
       READ(9,61)((MONTH(I,J),J=1,2),I=1,12)
 61    FORMAT(24A2)
       IF(IRI.EQ.0)READ(9,102)ISELP
102    FORMAT(9I5)
       CALL  OVOPN(JCHAN,"TSMAY.OL",IERR)
       CALL  OVLOD(JCHAN,OCROP,0,IERR)
       CALL  CROP
C      OPEN DISK FILE CONTAINING DAILY RAINFALL  DATA
       KIER=1
       CALL  OPEN(2,NFILE,2,IER)
       IF(IER.NE.1)WRITE(12,222)KIER,IER
222    FORMAT(1H1,10X,'****FILE OPERATION',I4,' ERROR CODE=',I4)
       REWIND 2
       SM=SMI
1001   KYR=KYR+1
       DO 1  I=1,366
1      IRR(I)=0
C      READ AND STORE ONE YEARS DATA
4      SITE(1)=LOC1
       SITE(2)=LOC2
       READ(2,100,END=1000)LOC1,LOC2,IYR(KYR),NCARD,KEY,(ID(K),IR(K),K=1,9)
100    FORMAT(I4,4I3,1X,9(I3,I4))
       IF(NCARD.EQ.0)GO TO 1000
       DO 3 I=1,9
       K=ID(I)
       IF(K.EQ.0)GO TO 3
       IRR(K)=IR(I)
3      CONTINUE
       IF(KEY.NE.NCARD)GO TO 4
C      TEST FOR LEAP YEAR
       NDAY(2)=28
       LPYR=IYR(KYR)+1900
```

# TABLE B.1 (CONTD.)

```
      IF((MOD(LPYR,4)).EQ.0)NDAY(2)=29
      K=0
C     COMMENCE YEARLY DO LOOP
      DO 6 I=1,12
C     CONVERT MONTHLY POTENTIAL GRASSLAND EVAPORATION (JPE) TO DAILY VALUES(ETO)
      JE=NDAY(I)
      ETO=1.0*JPE(I)/JE
      SRAIN=0.
      DO 5 J=1,JE
      K=K+1
C     MATCHING OF CROP PERIOD WITH CROP EFFECTIVE ROOTING DEPTHS
      IF(K.LT.KIN(1).OR.K.GE.KIN(NC))GO TO 40
      NL=NC-1
      DO 50 N=1,NL
      NM=N+1
      IF(K.GE.KIN(N).AND.K.LT.KIN(NM))GO TO 52
50    CONTINUE
52    RDP=ROOTDP(N)
      GO TO 43
40    RDP=ROOTDP(NC)
43    SMAX=RDP*SMAXPM
      SCRIT=RDP*SCRPM
      RAIN=IRR(K)*FACTOR
C     ADJUSTMENT OF 'DCROP' DEVELOPED DAILY CROP COEFFICICIENTS FOR EARLY CROP
C     GROWTH STAGES WHEN CROP HAS NOT REACHED FULL GROUND COVER CONDITION
      IF(EFAC(K).GT.0.95)GO TO 46
      L=L+1
      IF(RAIN.GT.1.0.OR.NIR.EQ.1)L=0
      DO 47 N=1,NC
      IF(K.GE.KIN(N).AND.K.LT.KSEC(N))GO TO 48
      M=K+366
      IF(M.GE.KIN(N).AND.M.LT.KSEC(N))GO TO 48
      GO TO 47
48    IF(L-1)44,44,45
44    EFAC(K)=0.94
      GO TO 47
45    ALPHA=1.4-0.056*ETO
      PHA=L
      EFAC(K)=ALPHA-0.35*ALOG(PHA)
47    CONTINUE
C     DPE EQUALS THE DAILY POTENTIAL CROP EVAPOTRANSPIRATION
46    DPE=EFAC(K)*ETO
C     DAILY WATER BALANCE
      CALL OVLOD(JCHAN,OIMODEL,0,IERR)
      CALL TMODEL(SMAX,SCRIT,SM,DPE,RAIN,AE,EX,DEFIT,NSMS,WIR,NIR,IRI)
C     ACCUMULATE MONTHLY TOTALS
      SRAIN=SRAIN+RAIN
      NDD(KYR,I)=NDD(KYR,I)+NSMS
      NIA(KYR,I)=NIA(KYR,I)+NIR
      EVAP(KYR,I)=EVAP(KYR,I)+AE
      EXCES(KYR,I)=EXCES(KYR,I)+EX
      WDEF(KYR,I)=WDEF(KYR,I)+DEFIT
5     WIRI(KYR,I)=WIRI(KYR,I)+WIR
      IRAIN(KYR,I)=SRAIN
C     STORE SOIL MOISTURE STATUS AND COMPUTE MONTHLY WATER BALANCE
      SMS(KYR,I)=SM
      CSMS(KYR,I)=SRAIN+WIRI(KYR,I)-EXCES(KYR,I)-EVAP(KYR,I)
      TRAIN=TRAIN+SRAIN*0.001
      TEVAP=TEVAP+EVAP(KYR,I)*0.001
      TEXCES=TEXCES+EXCES(KYR,I)*0.001
6     TWIRI=TWIRI+WIRI(KYR,I)*0.001
      GO TO 1001
1000  NYR=KYR-1
      CALL CLOSE(2,IER)
      KIER=2
      IF(IER.NE.1)WRITE(12,222)KIER,IER
C     CHECK FOR CONTINUITY
      BALANCE=(TRAIN+TWIRI-TEXCES-TEVAP)*1000.0+SMI-SM
C     LIST INPUT DATA
      WRITE(12,200)SITE,SOIL,SMAXPM,SCRPM,((MONTH(I,J),J=1,2),I=1,12)
     1,JPE,FACTOR
200   FORMAT(1H1,29X,'DAILY WATER BALANCE SIMULATION FOR STATION ',I4,I3//
     11H0,9X,"MODEL PARAMETERS"//10X,25A2/10X,"AVAILABLE WATER IN MILLIME",
     2"TRES PER METRE OF SOIL ",F5.1," MM",/10X,"CRITICAL SOIL MOISTURE ",
     3"CAPACITY IN MILLIMETRES PER METRE OF SOIL ",F5.1," MM",///10X,
     4'MONTHLY POTENTIAL GRASSLAND EVAPOTRANSPIRATION(MM)'//
     511X,12(2A2,4X),///7X,12F8.0///
     610X,'RAINFALL CONVERSION FACTOR'F10.4)
C     LIST WATER BALANCE SUMMARY
```

## TABLE B.1 (CONTD.)

```
      DO 7 I=1,12
      WRITE(12,201)(MONTH(I,J),J=1,2)
201   FORMAT(1H1,29X,'SUMMARY OF DAILY WATER BALANCE FOR ',2A2///10X,
     1'YEAR',7X,'RAIN  EVAPOTRANS  DRAINAGE  CROP WATER   DROUGHT  IRRIGATION
     2 IRRIGATION   SOIL  MOISTURE  MONTHLY WATER'/21X,'(MM)       (MM)',8X,4H(MM),
     3 4X,'DEFICIT(MM)    DAYS',7X,'(MM)      APPLICATIONS    STATUS(MM)',5X,
     4 'BALANCE(MM)'//)
      DO 7 J=1,NYR
7     WRITE(12,202)IYR(J),IRAIN(J,I),EVAP(J,I),EXCES(J,I),WDEF(J,I),NDD(J,I),
     1WIRI(J,I),NIA(J,I),SMS(J,I),CSMS(J,I)
202   FORMAT(10X,2H19,I2,6X,I5,4X,F6.1,6X,F6.1,5X,F6.1,7X,I2,7X,F6.1,9X,I2,10X,
     1F6.1,9X,F6.1)
      WRITE(12,203)SMI,TRAIN,TWIRI,TEXCES,TEVAP,SM,BALANCE
203   FORMAT(1H1,9X,'INITIAL SOIL MOISTURE LEVEL ',F7.3,3H MM/10X,'TOTAL RAIN'
     118X,F7.3,2H M/10X,'TOTAL IRRIGATION',12X,F7.3,2H M/10X,'TOTAL DRAINAGE',
     214X,F7.3,2H M/10X,'TOTAL EVAPOTRANSPIRATION' ,4X,F7.3,2H M/10X,
     3'FINAL SOIL MOISTURE LEVEL',3X,F7.3,3H MM///10X,'UNACCOUNTED WATER',
     48X,F9.3,3H MM)
      IF(IRI.EQ.1)GO TO 8
C     STATISTICAL ANALYSIS OF MONTHLY CROP WATER DEFICIT
      DO 9 I=1,12
      DO 10 J=1,NYR
10    ARRAY(J)=WDEF(J,I)
C     FIND LARGEST AND SMALLEST VALUES
      CALL OVLOD(JCHAN,OTSIZE,0,IERR)
      CALL TSIZE(ARRAY,SMLL,NS,BG,NB,NYR)
      SMALL(I)=SMLL
      BIG(I)=BG
C     COMPUTE MEAN,STANDARD DEVIATION AND SKEW BY MOMENTS
      CALL OVLOD(JCHAN,OTSTATIS,0,IERR)
      CALL TSTATIS(ARRAY,NYR,XMEAN,XSD,XSKEW)
      RMEAN(I)=XMEAN
      STD(I)=XSD
9     SKEW(I)=XSKEW
C     COMPUTE CLASS TOTALS OF DROUGHT DAYS
      DO 11 I=1,12
      DO 11 J=1,NYR
      DO 12 K=1,32
      IF(NDD(J,I).EQ.INTVL(K))GO TO 11
12    CONTINUE
11    NCLASS(I,K)=NCLASS(I,K)+1
      GO TO 14
8     CONTINUE
C     COMPUTE CLASS TOTALS OF IRRIGATION APPLICATIONS
      DO 15 I=1,12
      DO 15 J=1,NYR
      DO 16 K=1,32
      IF(NIA(J,I).EQ.INTVL(K))GO TO 15
16    CONTINUE
15    NCLASS(I,K)=NCLASS(I,K)+1
14    CONTINUE
C     FIND MAXIMUM NON-ZERO CLASS
      KMAX=0
      DO 17 I=1,12
      DO 17 K=1,32
      IF(NCLASS(I,K).EQ.0)GO TO 17
      IF(K.LE.KMAX)GO TO 17
      KMAX=K
17    CONTINUE
      IF(IRI.EQ.1)GO TO 18
C     INITIALIZE TABLE OF STANDARD NORMAL DEVIATES
      CALL OVLOD(JCHAN,OTNORM,0,IERR)
      CALL TNORM(CPROB,SNDEV,1)
C     COMPUTE AND LIST CROP WATER DEFICITS FOR SPECOFIED PROBABILITY LEVELS
      WRITE(12,204)SITE
204   FORMAT(1H1,///30X,'FREQUENCY ANALYSIS OF MONTHLY CROP WATER ',
     1'DEFICIT FOR STATION ',I4,I3///)
      WRITE(12,212)ISELP
212   FORMAT(///10X,"MONTH  SMALLEST      CROP WATER DEFICIT(MM) FOR",
     2'RISK OF EXCEEDENCE(%)',10X,'LARGEST',10X,'MEAN    S.D.    SKEW'/25X,10I6,//)
C     COMPUTE STANDARD NORMAL DEVIATES FOR SPECIFIED PROBABILITY LEVELS
      DO 19 J=1,9
      CPROB=1.0-ISELP(J)/100.0
      CALL TNORM(CPROB,SNDEV,2)
19    Z(J)=SNDEV
      DO 20 I=1,12
      DO 21 J=1,9
      NDEV(J)=RMEAN(I)+STD(I)*Z(J)+0.5
      IF(NDEV(J).LT.0)NDEV(J)=0
```

## TABLE B.1: (CONTD.)

```
21      CONTINUE
20      WRITE(12,205)I,SMALL(I),NDEV,BIG(I),RMEAN(I),STD(I),SKEW(I)
205     FORMAT(11X,I4 ,4X,11I6,I9,9X,F5.0,2F7.2)
        WRITE(12,206)SITE
  206 FORMAT(1H1,///,29X,"FREQUENCY ANALYSIS OF DROUGHT DAYS",
     1" FOR STATION ",I4,I3///)
        GO TO 22
18      AMOUNT=SMAX-SCRIT
        WRITE(12,207)SITE,AMOUNT
207     FORMAT(1H1,29X,'FREQUENCY ANALYSIS OF IRRIGATION APPLICATIONS FOR STATION
     1',I4,I3///10X,'AMOUNT OF IRRIGATION WATER PER APPLICATION',F5.0,3H MM///)
   22   WRITE(12,208)(INTVL(K),K=2,KMAX)
208     FORMAT(///10X,'MONTH',5X,'PROBABILITY(%)',6X,'PROBABILITY(%) ',
     1'OF BEING ',
     1'GREATER THAN OR EQUAL TO NUMBER SHOWN'/20X,'OF BEING ZERO  ',
     216I5/38X,15I5)
        WRITE(12,210)
210     FORMAT(1H0)
        DO 23 I=1,12
C       COMPUTE PROBABILITY OF BEING ZERO
        IRISK(1)=NCLASS(I,1)*100.0/NYR+0.5
C       COMPUTE PROBABILITY OF BEING GREATER THAN OR EQUAL TO
        ACLASS=NCLASS(I,1)
        DO 24 K=2,KMAX
        IRISK(K)=100.-100.*ACLASS/NYR+0.5
24      ACLASS=ACLASS+NCLASS(I,K)
23      WRITE(12,209)I,(IRISK(K),K=1,KMAX)
209     FORMAT(11X,I4,10X,I3,7X,16I5/38X,15I5)
        CALL CLOSE(JCHAN,IERR)
        END
```

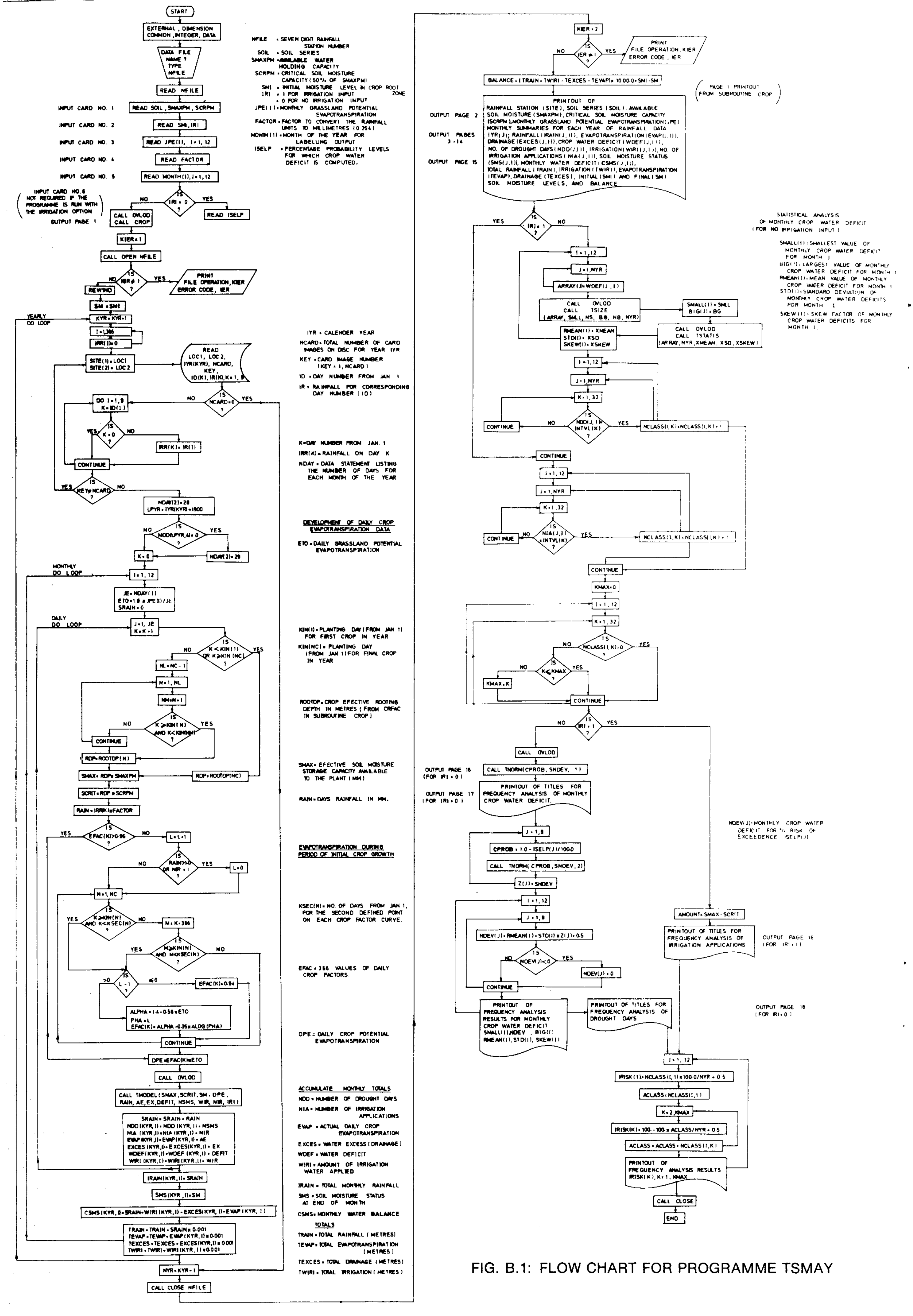



FIG. B.1: FLOW CHART FOR PROGRAMME TSMAY

# APPENDIX C

## SUBROUTINE CROP

### C.1 General description

Given the simplified crop factor patterns as defined by FAO (1975) the subroutine CROP develops daily crop coefficient values for the calender year. This daily pattern is compiled from input data consisting of:-

(i) a disc file, CRFAC which contains a listing of crop coefficient characteristics for 20 upland crops.

(ii) punched card input of number and types of crops to be planted, their planting dates, and crop durations. The total duration of crops must not exceed one calender year, that is, 366 days.

### C.2 Storage of crop coefficients

Crop coefficients are stored under the disc file CRFAC as a two dimensional array containing crop coefficient and corresponding time ratio. This time ratio is obtained by dividing the age of the crop by the total time of the growing period. This is to facilitate contraction or expansion, time-wise, of the crop coefficient curve to allow for varying crop growing periods.

Data is transferred to the disc file CRFAC from cards prepared in the following format:

| | | | |
|---|---|---|---|
| FIRST CARD | – cols 1– 2, | JCMAX = Total number of crop types being stored | (I2) |
| OTHER CARDS | – cols 1–40, | crop description | (20A2) |
| (number equal | cols 41–42, | KROP(J) = Crop identity number | (I2) |
| to JCMAX) | cols 43–46, | CTR(J,K) = Time ratio of crop | (F4.2) |
| | cols 47–50, | CRF(J,K) = corresponding crop coefficient | (F4.2) |
| | cols 51–74, | Three repeats of CTR, CRF | (6F4.2) |
| | col 75, | Blank | (1X) |
| | cols 76–79, | ROOTDP(J) = crop rooting depth (metres) | (F4.2) |

CTR (J, 1), CRF (J, 1) and CTR (J, 4), CRF (J, 4) are the crop time ratios and coefficients corresponding to the start (ie. CTR (J, 1) = 0.00) and end (ie. CTR (J, 4) = 1.00) respectively of the growing cycle. CTR (J, 2), CRF (J, 2) and CTR (J, 3), CRF (J, 3,) are selected to define the "mid-season" portion of the crop coefficient curve.

Table C.1 reproduces the contents of the current CRFAC.

### C.3 Scheduling of daily crop coefficients

To develop the daily pattern of crop coefficients, individual crop data must be provided to match CRFAC. This data includes number of crops within the year, the crop types, their planting dates and crop growing periods. In scheduling the crops it must be remembered that the crop pattern must not exceed one calender year (ie. 366 days). Therefore for such upland crops as tapioca, sugar cane, and bananas, all of whose cropping patterns exceed one year, the programmer must define only one year's growth cycle.

The individual crop data input has the following format:-

(i) The number of planting dates per year (NC) must be typed in on request from the teletype.

(ii) Each crop input is via one computer card with the crop cards arranged in order of calender planting date. The number of cards must equal the stated number of planting dates. The card format is:-

| | | |
|---|---|---|
| cols 1–30, | Crop description, KRD(I, J) | (15A2) |
| cols 31–32, | Crop identity number in CRFAC,ICROP(I) | (I2) |
| cols 33–34, | Crop planting day, IPD(I) | (I2) |
| cols 35–36, | Crop planting month, IPM(I) | (I2) |
| cols 37–39, | Crop growing period, ICD(I) (in days) | (I3) |

TABLE C.1: Crop Coefficient Curve Data stored in Disk File 'CRFAC', including Crop Growing Periods

| Crop Type | Crop Identity Number | First Time Ratio | First Crop Coeff. | Second Time Ratio | Second Crop Coeff. | Third Time Ratio | Third Crop Coeff. | Fourth Time Ratio | Fourth Crop Coeff. | Crop Rooting Depth(m) | Crop Growing Period |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | KROP(J) | CTR(J, 1) | CRF(J, 1) | CTR(J, 2) | CRF(J, 2) | CTR(J, 3) | CRF(J, 3) | CTR(J, 4) | CRF(J, 4) | ROOTDP(J) | (Days) |
| Maize (Sweet) | 1 | 0.00 | 0.64 | 0.30 | 1.05 | 0.88 | 1.05 | 1.00 | 0.95 | 0.60 | 80 |
| Maize (Grain) | 2 | 0.00 | 0.64 | 0.44 | 1.05 | 0.76 | 1.05 | 1.00 | 0.55 | 0.60 | 110 |
| Crucifers (Cabbage, Cauliflower) | 2 | 0.00 | 0.64 | 0.63 | 0.95 | 0.88 | 0.95 | 1.00 | 0.80 | 0.60 | 80 |
| Cucumber (Fresh market) | 4 | 0.00 | 0.64 | 0.48 | 0.90 | 0.86 | 0.90 | 1.00 | 0.70 | 0.60 | 105 |
| Lettuce | 5 | 0.00 | 0.64 | 0.66 | 0.95 | 0.87 | 0.95 | 1.00 | 0.90 | 0.60 | 75 |
| Beans (Green) | 6 | 0.00 | 0.64 | 0.53 | 0.95 | 0.87 | 0.95 | 1.00 | 0.85 | 0.60 | 75 |
| Eggplant (Aubergine) | 7 | 0.00 | 0.64 | 0.54 | 0.95 | 0.82 | 0.95 | 1.00 | 0.80 | 0.60 | 140 |
| Melons | 8 | 0.00 | 0.64 | 0.55 | 0.95 | 0.82 | 0.95 | 1.00 | 0.65 | 0.60 | 120 |
| Onions (Dry) | 9 | 0.00 | 0.64 | 0.27 | 0.95 | 0.73 | 0.95 | 1.00 | 0.75 | 0.60 | 150 |
| Groundnuts | 10 | 0.00 | 0.64 | 0.46 | 0.95 | 0.81 | 0.95 | 1.00 | 0.55 | 0.60 | 110 |
| Sorghum (Late maturing) | 11 | 0.00 | 0.64 | 0.44 | 1.00 | 0.76 | 1.00 | 1.00 | 0.50 | 0.60 | 110 |
| Soyabeans | 12 | 0.00 | 0.64 | 0.35 | 1.00 | 0.82 | 1.00 | 1.00 | 0.45 | 0.60 | 90 |
| Chilli–Transplant | 13 | 0.00 | 0.64 | 0.52 | 0.95 | 0.84 | 0.95 | 1.00 | 0.80 | 0.60 | 125 |
| Tomato–Transplant | 14 | 0.00 | 0.64 | 0.56 | 1.05 | 0.92 | 1.05 | 1.00 | 0.60 | 0.60 | 110 |
| Tapioca (One year crop pattern) | 15 | 0.00 | 0.64 | 0.50 | 0.95 | 0.85 | 0.95 | 1.00 | 0.95 | 0.60 | 365 |
| Sweet potato–tuber | 16 | 0.00 | 0.64 | 0.42 | 1.05 | 0.77 | 1.05 | 1.00 | 0.70 | 0.60 | 130 |
| Mangkuang | 17 | 0.00 | 0.64 | 0.42 | 1.00 | 0.77 | 1.00 | 1.00 | 0.70 | 0.60 | 125 |
| Brinjals, Lady's Finger–Transplant | 18 | 0.00 | 0.64 | 0.52 | 0.95 | 0.84 | 0.95 | 1.00 | 0.80 | 0.60 | 125 |
| Sugar Cane–Ratoon crop | 19 | 0.00 | 0.64 | 0.33 | 1.00 | 0.83 | 1.05 | 1.00 | 0.60 | 0.60 | 365 |
| Tobacco–Transplant at 7 weeks | 20 | 0.00 | 0.64 | 0.27 | 1.00 | 0.73 | 1.00 | 1.00 | 0.95 | 0.60 | 120 |

Having provided the planting date and length of crop growing period the four characteristic points (CTR, CRF) defined in CRFAC can be allocated calender days for each crop. Linear interpolation is then used to determine the daily crop coefficients for the entire growing period (CROP flow chart Fig. C.1). In any cropping pattern there is a period between harvest and the next planting when the land is under fallow. To complete the required daily crop coefficient pattern for the full calender year, linear interpolation is again used to proportion daily crop coefficients between the final crop coefficient and next initial crop coefficient.

The resultant printout from subroutine CROP is the complete annual crop coefficient pattern (Table C.2). The listing of subroutine CROP is found in Table C.3.

### C.4 Alignment with programme TSMAY

As stated in paragraph 4.2.1.2, the daily crop potential evapotranspiration is equal to the product of daily crop coefficient and the grassland potential evapotranspiration. Having already obtained the year's listing of daily crop coefficients from subroutine CROP it would seem to be a simple matter to compute the corresponding daily crop potential evapotranspiration. This would be achieved via one of the TSMAY input cards containing the monthly grassland evapotranspiration data.

However the direct application of the daily crop coefficients generated by subroutine CROP would not account for the initial and crop development stages when the crop has not reached at least 80 percent ground cover. The initial bare soil conditions having considerable evaporation, was taken into account by adjusting the daily crop coefficients using Fig. C.2.

Since ETO values for Peninsular Malaysia vary between 3 and 5 mm/day, three equations were developed from Fig. C.2 relating crop coefficients to frequency of rainfall or irrigation for ETO values of 3, 4 and 5 mm. These equations are:

$$K = 1.23 - 0.35 \ln y \quad \text{for ETO} = 3 \text{ mm}$$

$$K = 1.18 - 0.35 \ln y \quad \text{for ETO} = 4 \text{ mm}$$

$$K = 1.12 - 0.35 \ln y \quad \text{for ETO} = 5 \text{ mm}$$

where K = daily crop coefficient

y = number of days since rain/irrigation

ETO = grassland potential evapotranspiration

By introducing a factor ALPHA, a single equation is developed for calculation of the crop coefficient:

$$K = \text{ALPHA} - 0.35 \ln y$$

where $\text{ALPHA} = 1.4 - 0.056 \times \text{ETO}$

This equation is then applied to each crop pattern to determine the daily crop coefficients during the initial and development crop stages. However if rainfall or irrigation occurred on that day or the previous day the daily crop coefficient is set equal to 0.94. This value is read from Fig. C.2 for ETO of 3 mm/day. For the remaining crop periods (mid and late season) the crop coefficients obtained in subroutine CROP are used directly to develop the daily crop evapotranspiration as shown in Fig. C.3.

The final form of the TSMAY-developed crop coefficient curve is shown in Fig. C.4.

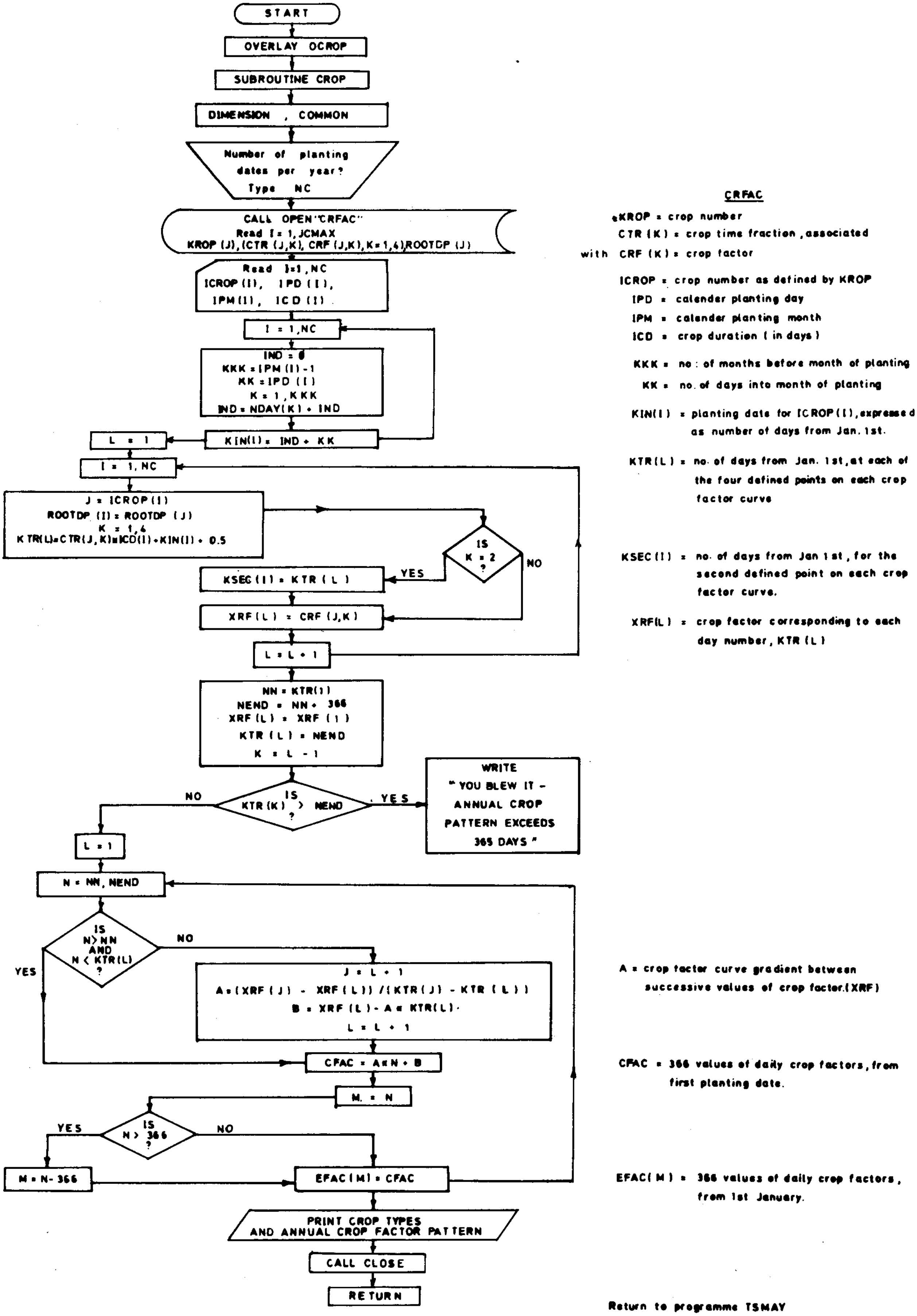



FIG. C.1: FLOW CHART FOR SUBROUTINE CROP

# TABLE C.2: OUTPUT FROM SUBROUTINE CROP

| CROP DESCRIPTION | PLANTING DATE | CROP DURATION |
|---|---|---|
| 3 LOWLAND CABBAGE | 12/ 3 | 80 |

ANNUAL CROP FACTOR PATTERN FOR 366 DAYS FROM JAN1

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 |
| 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.67 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 |
| 0.66 | 0.66 | 0.66 | 0.66 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| 0.65 | 0.65 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.65 | 0.65 | 0.66 | 0.66 | 0.67 | 0.68 | 0.68 | 0.69 | 0.70 |
| 0.70 | 0.71 | 0.71 | 0.72 | 0.73 | 0.73 | 0.74 | 0.75 | 0.75 | 0.76 | 0.76 | 0.77 | 0.78 | 0.78 | 0.79 | 0.80 | 0.80 | 0.81 | 0.81 | 0.82 |
| 0.83 | 0.83 | 0.84 | 0.84 | 0.85 | 0.86 | 0.86 | 0.87 | 0.88 | 0.88 | 0.89 | 0.89 | 0.90 | 0.91 | 0.91 | 0.92 | 0.93 | 0.93 | 0.94 | 0.94 |
| 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| 0.95 | 0.93 | 0.92 | 0.90 | 0.89 | 0.87 | 0.86 | 0.84 | 0.83 | 0.81 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.79 |
| 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.78 | 0.78 | 0.78 |
| 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |
| 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 |
| 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 |
| 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 |
| 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 |
| 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.69 | 0.69 |
| 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.68 | 0.68 | 0.68 | 0.68 |
| 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | | | | | | | | | | | | | | |

# TABLE C.3: LISTING OF SUBROUTINE CROP

```
      COMPILER NOSTACK
      OVERLAY OCROP
      SUBROUTINE CROP
C     SCHEDULES DAILY CROP EVAPORATION FROM 1JAN TO 31DEC
      COMMON /NDM/NDAY(12),FFAC(366),KIN(4),KSEC(4),NC,ROOTDP(22)
      DIMENSION ICROP(4),IPD(4),IPM(4),ICD(4),KROP(30),CTR(30,4),
     1CRF(30,4),KTR(730),XRF(730),KRD(4,15)
      TYPE "NUMBER OF PLANTING DATES PER YEAR"
      READ(11,903)NC
903   FORMAT(I1)
C     READ IN CROP FACTOR DATA
      CALL OPEN(3,"CRFAC",2,IER)
      READ(3,900)JCMAX
900   FORMAT(I2)
      DO 901 J=1,JCMAX
      READ(3,902,END=999)KROP(J),(CTR(J,K),CRF(J,K),K=1,4),ROOTDP(J)
  902 FORMAT(40X,I2,8F4.2,1X,F4.2)
901  CONTINUE
  999 DO 904 I=1,NC
      READ(9,905)(KRD(I,J),J=1,15),ICROP(I),IPD(I),IPM(I),ICD(I)
905   FORMAT(15A2,3I2,I3)
904    CONTINUE
C     INDEX DATES OF PLANTING ACCORDING TO NO. DAYS FROM START OF YEAR
      DO 906 I=1,NC
     IND=0
      KKK=IPM(I)-1
      KK=IPD(I)
      DO 907 K=1,KKK
907   IND=NDAY(K)+IND
906   KIN(I)=IND+KK
C     SCHEDULE DAILY CROP EVAPORATIONS FROM DATE OF PLANTING FIRST CROP
      L=1
      DO 908 I=1,NC
      J=ICROP(I)
      ROOTDP(I)=ROOTDP(J)
      DO 908 K=1,4
      KTR(L)=CTR(J,K)*ICD(I)+KIN(I)+0.5
      IF(K.EQ.2)KSEC(I)=KTR(L)
      XRF(L)=CRF(J,K)
908   L=L+1
      NN=KTR(1)
      NEND=NN+366
      XRF(L)=XRF(1)
      KTR(L)=NEND
      K=L-1
      IF(KTR(K).GT.NEND)WRITE(12,909)
909   FORMAT(//9X,"YOU BLEW IT-ANNUAL CROP PATTERN EXCEEDS 365 DAYS")
      L=1
      DO 911 N=NN,NEND
      IF(N.GT.NN.AND.N.LE.KTR(L))GO TO 912
      J=L+1
      A=(XRF(J)-XRF(L))/(KTR(J)-KTR(L))
      B=XRF(L)-A*KTR(L)
      L=L+1
912   CFAC=A*N+B
      M=N
      IF(N.GT.366)M=N-366
911   FFAC(M)=CFAC
      WRITE(12,913)
913   FORMAT(10X,"CROP DESCRIPTION",16X,"PLANTING DATE",4X,"CROP DURATION"/)
      DO 917 I=1,NC
917   WRITE(12,914)ICROP(I),(KRD(I,J),J=1,15),IPD(I),IPM(I),ICD(I)
914   FORMAT(6X,I2,2X,15A2,6X,I2,"/",I2,12X,I3)
      WRITE(12,915)
915   FORMAT(//6X,"ANNUAL CROP FACTOR PATTERN FOR 366 DAYS FROM JAN1")
      WRITE(12,916)(FFAC(M),M=1,366)
916   FORMAT(18(10X,20(F4.2,1X)/),10X,6(F4.2,1X))
      REWIND 3
      CALL CLOSE(3,IER)
      RETURN
      END
```

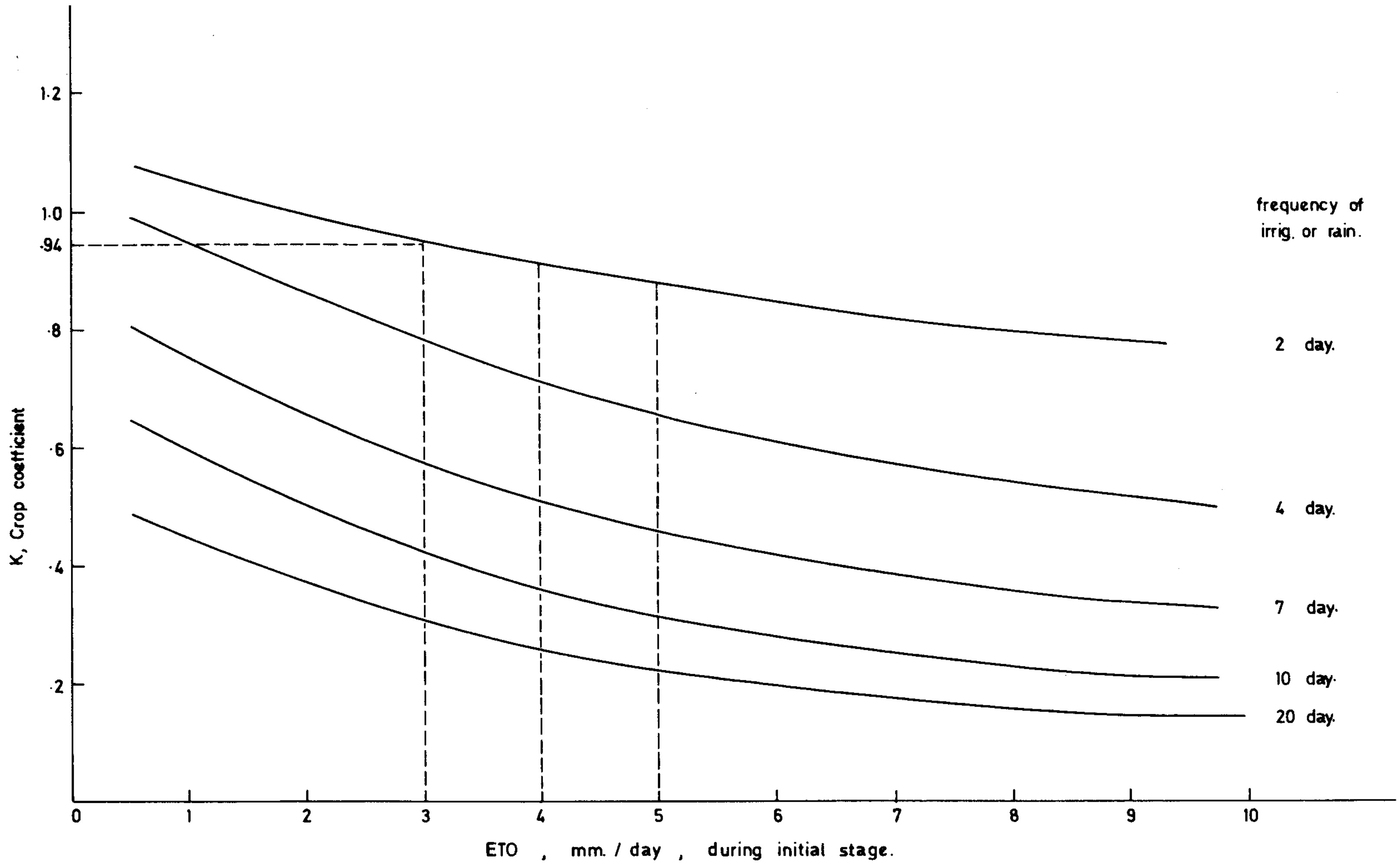



FIG. C.2 - AVERAGE K FOR INITIAL STAGE AS A FUNCTION OF AVERAGE ETO LEVEL (DURING INITIAL STAGE) AND FREQUENCY OF IRRIGATION OR OF SIGNIFICANT RAIN.
(Fig. 8, p. 64., F.A.O. (1975) reproduced.)

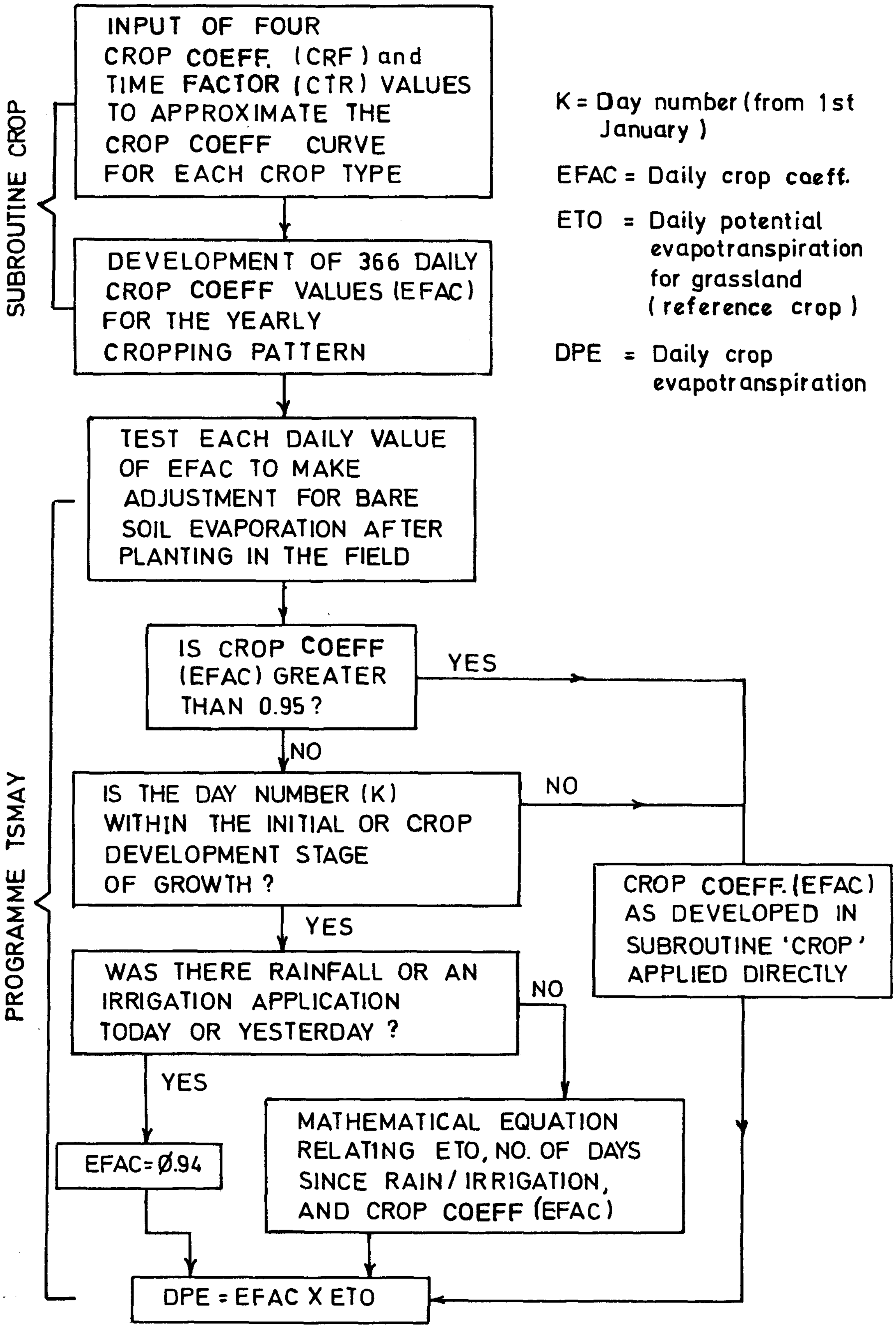



FIG C.3 : CALCULATION OF DAILY CROP EVAPOTRANS - PIRATION (DPE) FROM DAILY CROP COEFFICIENT (EFAC)

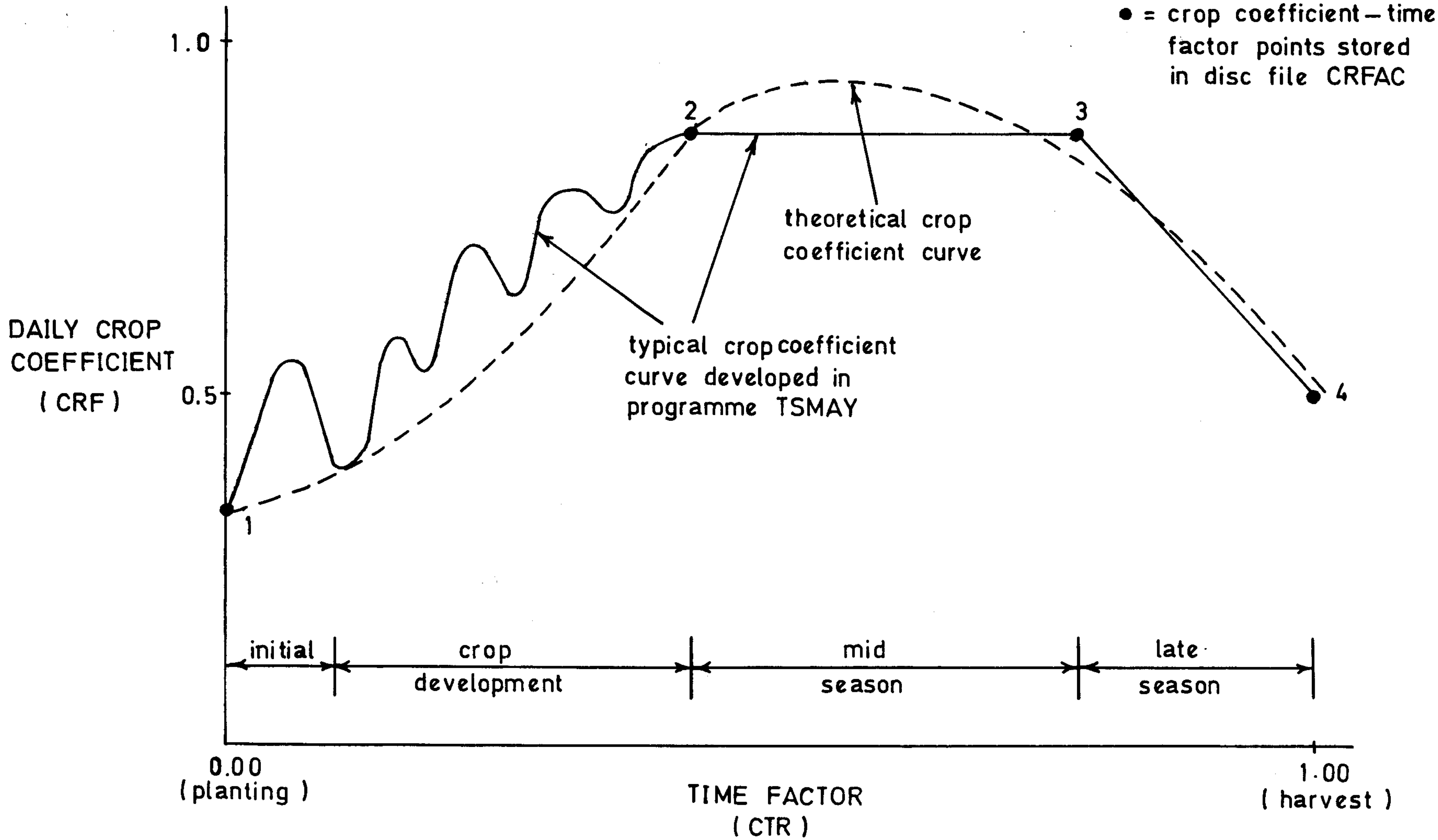



**FIG** C.4 : THE TSMAY-DEVELOPED CROP COEFFICIENT CURVE

## APPENDIX D

**SUBROUTINE** TSTATIS (X, N, XMEAN, XSTDEV, XSKEW)

This subroutine computes the mean, standard deviation and skew of a one-dimensional array by the method of moments. The arguments are as follows:-

X – one-dimensional array variable of size N
XMEAN – returns mean
XSTDEV – returns standard deviation
XSKEW – returns skew

A listing of TSTATIS is in Table D.1 and the flow chart in Fig. D.1.

**SUBROUTINE** TSIZE (X, SMALL, NS, BIG, NB, N)

This subroutine finds the largest and smallest elements in a one-dimensional array. The subroutine arguments are:

X – one-dimensional array variable of size N
SMALL – returns smallest element
NS – returns subscript value of smallest element
BIG – returns largest element
NB – returns subscript value of largest element

A listing of TSIZE is in Table D.2 and the flow chart in Fig. D.2.

**SUBROUTINE** TREGRES (X, Y, AY, BY, N, CC)

This subroutine computes simple linear regression by the method of least squares. The subroutine arguments are:

X – independent one-dimensional array variable of size N
Y – dependent one-dimensional array variable of size N
AY – returns regression intercept
BY – returns regression coefficient
CC – returns correlation coefficient

A listing of TREGRES is in Table D.3 and the flow chart in Fig. D.3.

**SUBROUTINE** TORDER (X, XO, N, CUMP)

This subroutine arranges the elements of a one-dimensional array in order of increasing size and computes the cumulative probability of each element. TORDER calls subroutine TSIZE. The subroutine arguments are:

X – one-dimensional array variable of size N, where N cannot exceed 50.
XO – one-dimensional array of size N which returns the elements of array X arranged in order of increasing size.
CUMP – one-dimensional array of size N which returns the cumulative probability of elements in array XO.

A listing of TORDER is in Table D.4 and the flow chart in Fig. D.4.

**SUBROUTINE** TNORM (CPROB, SNDEV, KODE)

This subroutine computes the standard normal deviate for a specified cumulative probability and vice-versa. The subroutine references disc file TAREA which stores the percentage areas under the standard normal distribution for values of the standard normal deviate between 0.00 and 3.49 in increments of 0.01. The subroutine arguments are:

CPROB – cumulative probability

## TABLE D.1: LISTING OF SUBROUTINE TSTATIS

```
      COMPILER NOSTACK
      OVERLAY OTSTATIS
      SUBROUTINE TSTATIS(X,N,XMEAN,XSTDEV,XSKEW)
C           THIS SUBROUTINE CALCULATES MEAN,STANDARD DEVIATION,SKEW OF
C           A SAMPLE
      DIMENSION X(1)
      K=0
      SUM=N
      SUM1=0.
      SUM2=0.
      SUM3=0.
      DO 1 I=1,N
      K=K+1
      SUM1=SUM1+X(I)
      SUM2=SUM2+X(I)**2
    1 SUM3=SUM3+X(I)**3
      XMEAN=SUM1/SUM
      XSTDEV=SQRT((SUM2-(XMEAN**2)*SUM)/(SUM-1.))
      A=0.
      B=0.
      A=(SUM**2)*SUM3-3.*SUM*SUM1*SUM2+2.*SUM1**3
      B=SUM*(SUM-1.)*(SUM-2.)*XSTDEV**3
      XSKEW=A/B
      RETURN
      END
```

## TABLE D.2: LISTING OF SUBROUTINE TSIZE

```
      COMPILER NOSTACK
      OVERLAY OTSIZE
      SUBROUTINE TSIZE(X,SMALL,NS,BIG,NB,N)
C     FINDS SMALLEST AND LARGEST ELEMENTS OF ARRAY X OF SIZE N
C     SMALL RETURNS SMALLEST ELEMENT
C     BIG RETURN SBIGGEST ELEMENT
C     NS RETURNS SMALLEST ELEMENT NUMBER
C     NB RETURNS BIGGEST ELEMENT NUMBER
      DIMENSION X(1)
      SMALL=X(1)
      BIG=X(1)
      NS=1
      NB=1
      DO 1 I=2,N
      IF(X(I).GE.SMALL)GO TO 2
      SMALL=X(I)
      NS=I
    2 CONTINUE
      IF(X(I).LE.BIG)GO TO 1
      BIG=X(I)
      NB=I
    1 CONTINUE
      RETURN
      END
```

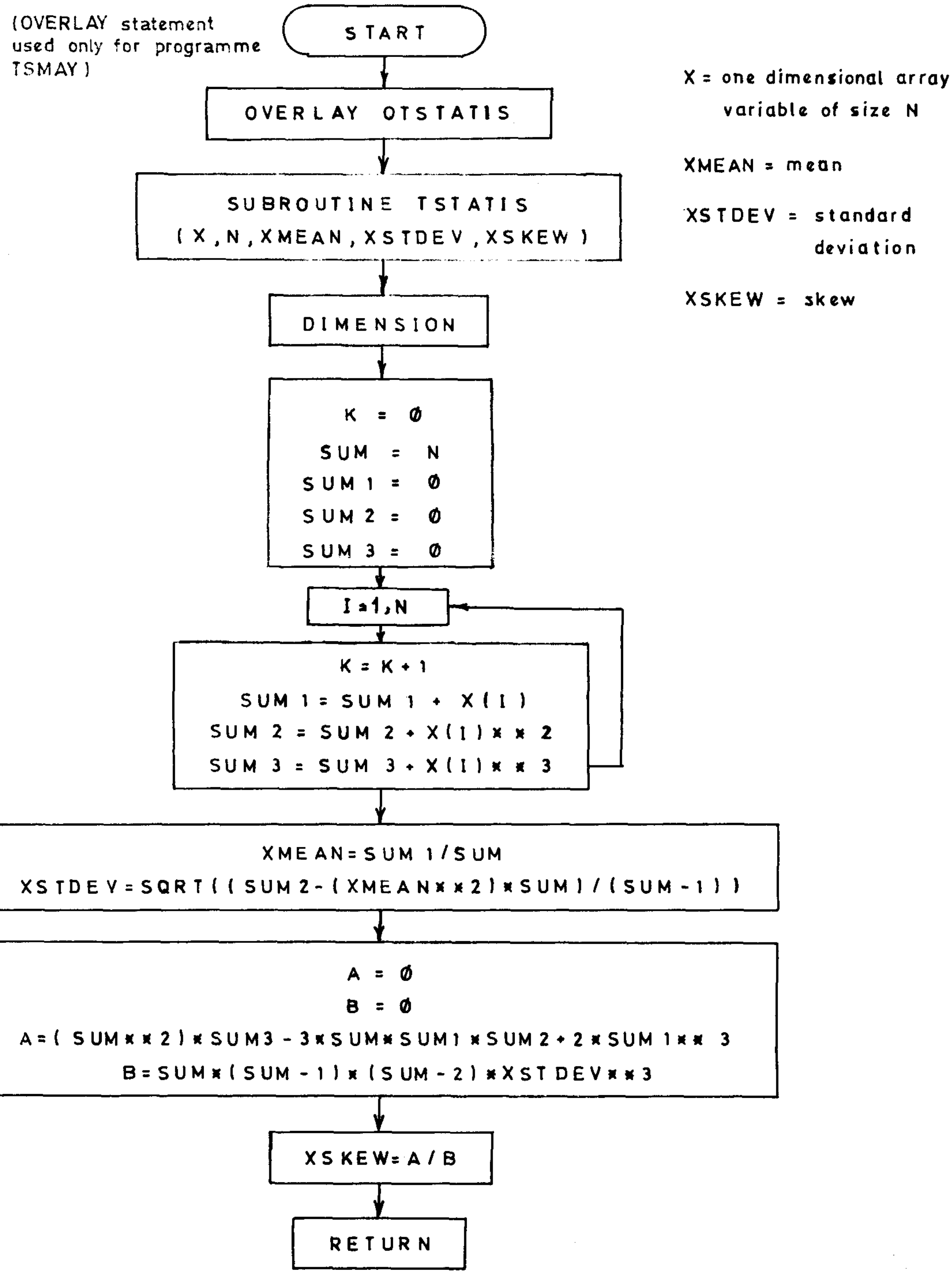



FIGURE D.1: FLOW CHART FOR SUBROUTINE TSTATIS

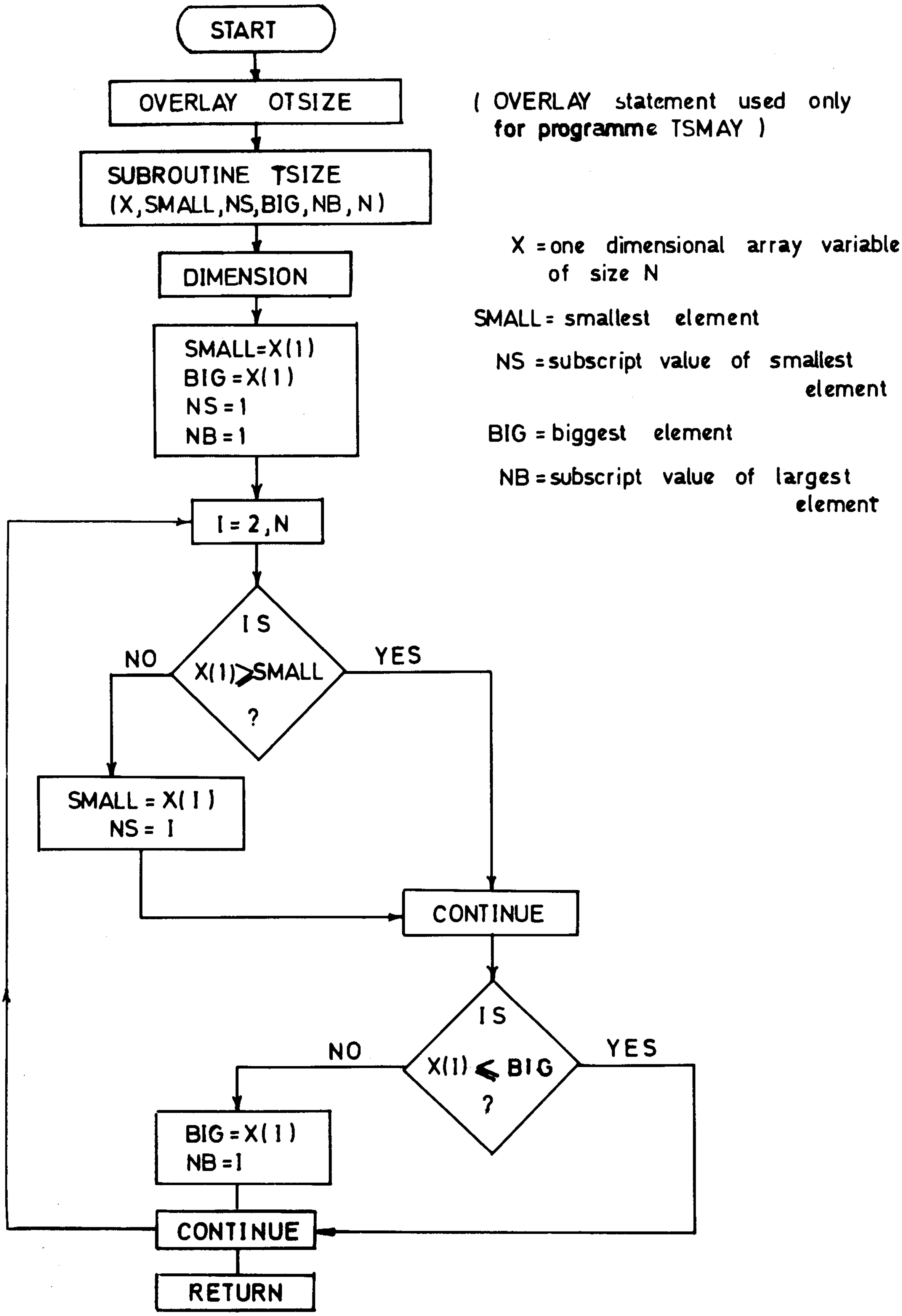



FIG D.2 : FLOW CHART FOR SUBROUTINE TSIZE

# TABLE D.3: LISTING OF SUBROUTINE TREGRES

```
      COMPILER NOSTACK
      SUBROUTINE TREGRES(X,Y,AY,BY,N,CC)
C     COMPUTES SIMPLE LINEAR REGRESSION BY LEAST SQUARES
C     Y=DEPENDENT ARRAY VARIABLE OF SIZE N
C     X=INDEPENDENT ARRAY VARIABLE OF SIZE N
C     AY=INTERCEPT     BY=REGRESSION COEFFICIENT     CC=CORRELATION COEFFICIENT

      DIMENSION X(1),Y(1)
      CC=0.
      SUM=N
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      SUM5=0.
      DO 3 I=1,N
      SUM1=SUM1+X(I)
      SUM2=SUM2+Y(I)
      SUM3=SUM3+X(I)**2
      SUM5=SUM5+Y(I)**2
    3 SUM4=SUM4+X(I)*Y(I)
      XBAR=SUM1/SUM
      YBAR=SUM2/SUM
      BY=(SUM4-SUM*XBAR*YBAR)/(SUM3-SUM*(XBAR**2))
      AY=YBAR-BY*XBAR
      XSD=SQRT((SUM3-(XBAR**2)*SUM)/(SUM-1.))
      YSD=SQRT((SUM5-(YBAR**2)*SUM)/(SUM-1.))
      CC=BY*XSD/YSD
      RETURN
      END
```

# TABLE D.4: LISTING OF SUBROUTINE TORDER

```
      COMPILER NOSTACK
      SUBROUTINE TORDER(X,XO,N,CUMP)
C     ARRANGES N ELEMENTS OF ARRAY X IN ORDER OF INCREASING SIZE AND
C     COMPUTES CUMULATIVE PROBABILITY OF EACH ELEMENT
C     CUMP RETURNS CUMULATIVE PROBABILITY
C     MAXIMUM NO OF ELEMENTS = 50
C     MAXIMUM SIZE OF ELEMENT = 0.99E+09
      DIMENSION X(1),XO(1),XWORK(50),CUMP(1)
C     SUBROUTINES CALLED - TSIZE
      DO 1 I=1,N
1     XWORK(I)=X(I)
      T=N+1
      DO 2 I=1,N
      CALL TSIZE(XWORK,SMALL,NS,BIG,NB,N)
      XO(I)=SMALL
      XWORK(NS)=+1.0E+09
      TT=I
2     CUMP(I)=TT/T
      RETURN
      END
```

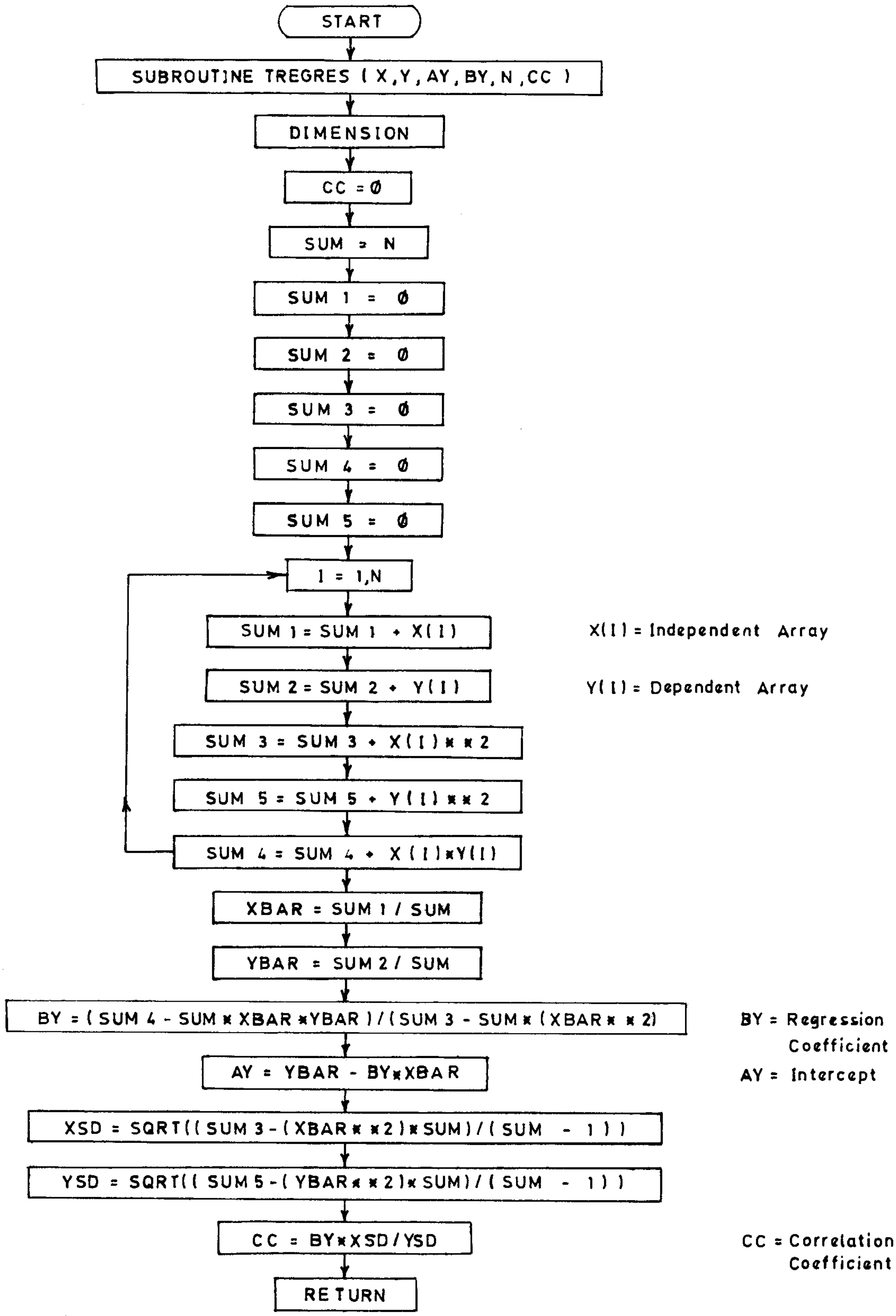



FIGURE D.3: FLOW CHART FOR SUBROUTINE TREGRES

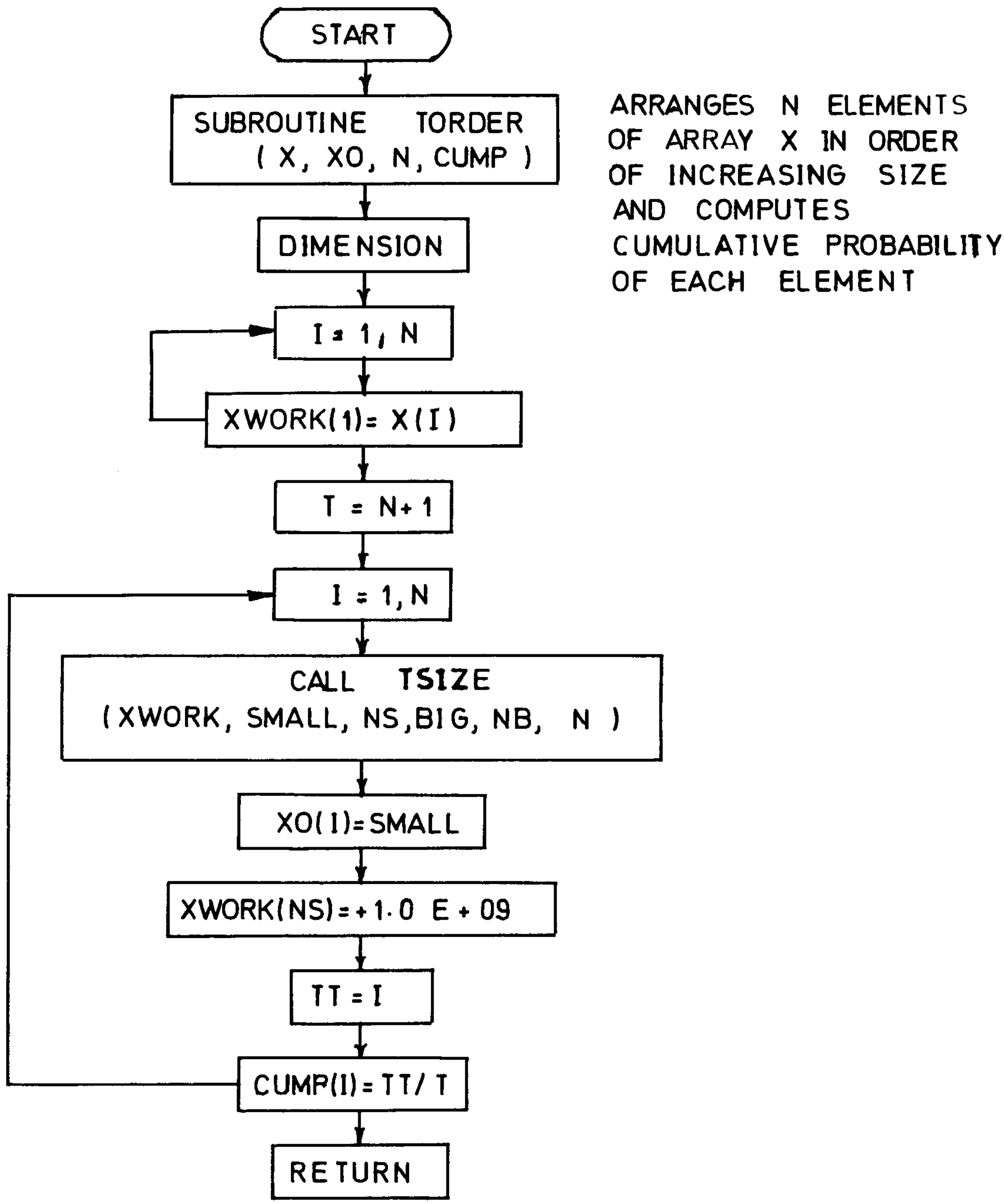



FIG. D.4 : FLOW CHART FOR SUBROUTINE TORDER

SNDEV – standard normal deviate
KODE – integer variable which must take one of the following values:
1, to initialise and list the table of cumulative probabilities by reading from disc file TAREA.
2, to compute SNDEV for a specified CPROB, file read suppressed.
3, to compute CPROB for a specified SNDEV, file read suppressed.

A listing of TNORM is in Table D.5 and the flow chart in Fig. D.5.

**SUBROUTINE** TMODEL (SMAX, SCRIT, SM, PE, RAIN, AE, EX, DEFIT, NSMS, WIR, NIR, IR)

This subroutine computes the daily water balance for the soil moisture simulation model according to the operational sequence shown in Fig. 4.3. The subroutine arguments are:

SMAX – effective soil moisture storage capacity (mm)
SCRIT – critical soil moisture level below which plant yield suffers (mm)
SM – returns daily soil moisture level (mm)
PE – daily potential crop evapotranspiration (mm)
RAIN – daily rainfall (mm)
AE – returns daily actual evapotranspiration (mm)
EX – returns daily water excess (mm)
DEFIT – returns daily water deficit (mm)
NSMS – integer variable which returns soil moisture status at end of day: one for drought day, zero otherwise.
WIR – returns daily irrigation water application
NIR – integer variable which returns one if an irrigation application is made and zero otherwise.
IR – integer variable specifying the mode of simulation: one for irrigation input and zero for no irrigation input.

A listing of TMODEL is in Table D.6 and the flow chart in Fig. D.6.

# TABLE D.5: LISTING OF SUBROUTINE TNORM

```
      COMPILER NOSTACK
      OVERLAY OTNORM
      SUBROUTINE TNORM(CPROB,SNDEV,KODE)
C     FINDS STANDARD NORMAL DEVIATE FOR SPECIFIED CUMULATIVE PROBABILITY
C     AND VICE-VERSA
C     CPROB= CUMULATIVE PROBABILITY
C     SNDEV=STANDARD NORMAL DEVIATE
C     SET KODE=1 TO INITIALIZE TABLE OF CUM PROBS. FROM DIBC&FILE&TAREA&
C               =2 TO LOCATE SNDEV FOR SPECIFIED CPROB,FILE READ SUPRESSED
C               =3 TO LOCATE CPROB FOR SPECIFIED SNDEV,FILE READ SUPRESSED
      DIMENSION IX(35,10),TITLE(66)
      INTEGER TITLE
      IF(KODE.EQ.2)GO TO 7
      IF(KODE.EQ.3)GO TO 10
C     INITIALIZE TABLE OF CUM PROBS.
      CALL OPEN(4,'TAREA',2,IER)
      IF(IER.NE.1)WRITE(12,200)IER
200   FORMAT(10X,'FILE OPEN ERROR CODE =',I5)
      READ(4,300,END=66)TITLE,((IX(I,J),J=1,10),I=1,35)
300   FORMAT(2(33A2/),35(10I5/))
66    WRITE(12,203)TITLE,((IX(I,J),J=1,10),I=1,35)
203   FORMAT(1H1,2(10X,33A2,/)//35(10X,10I5,/))
      CALL CLOSE(4,IER)
      IF(IER.NE.1)WRITE(12,202)IER
202   FORMAT(10X,'FILE CLOSE ERROR CODE =',I5)
      RETURN
C     TEST FOR CPROB GT OR LT 0.5000
7     K=1
      TPROB=CPROB
      IF(CPROB.GE.0.5000)GO TO 1
      TPROB=1.0-CPROB
      K=-1
C     LOCATE STANDARD NORMAL DEVIATE
1     RI=0.0
      RJ=0.0
      DO 2 I=1,35
      DO 2 J=1,10
      RX=IX(I,J)*0.0001
      IF(TPROB.LT.RX)GO TO 3
      RI=I
2     RJ=J
3     IF(RI.EQ.0.0.OR.RJ.EQ.0.0)GO TO 4
      IF(RI.EQ.35.0.AND.RJ.EQ.10.0)GO TO 4
      GO TO 5
4     WRITE(12,201)
201   FORMAT(1H0,10X,'CUMULATIVE PROBABILITY OUTSIDE RANGE 0.0003 TO 0.9998')
      RETURN
5     RI=RI-1.0
      RJ=RJ-1.0
      SNDEV=RI/10.0+RJ/100.0
      IF(K.EQ.-1)SNDEV=-SNDEV
      RETURN
C     LOCATE CUMULATIVE PROBABILITY
10    Z=SNDEV
      K=1
      IF(Z.GT.0.)GO TO 11
      K=-1
      Z=-Z
11    I=Z*10.
      J=(Z*10.-I)*10.+1.
      I=I+1
      IF(I.LE.35.AND.J.LE.10)GO TO 9
      WRITE(12,201)
      RETURN
9     CPROB=IX(I,J)*0.0001
      IF(K.EQ.-1)CPROB=1.0-CPROB
      RETURN
      END
```

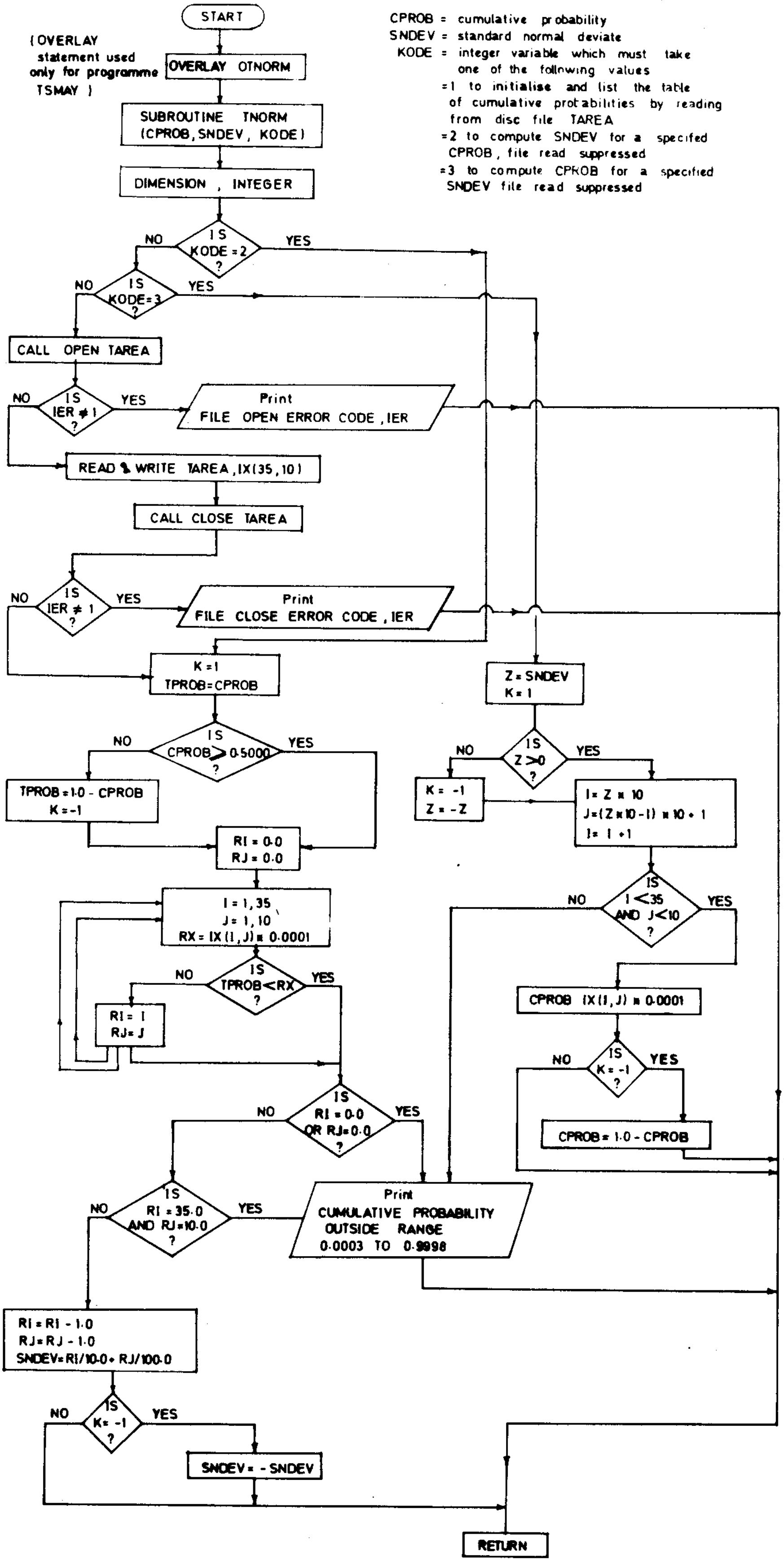
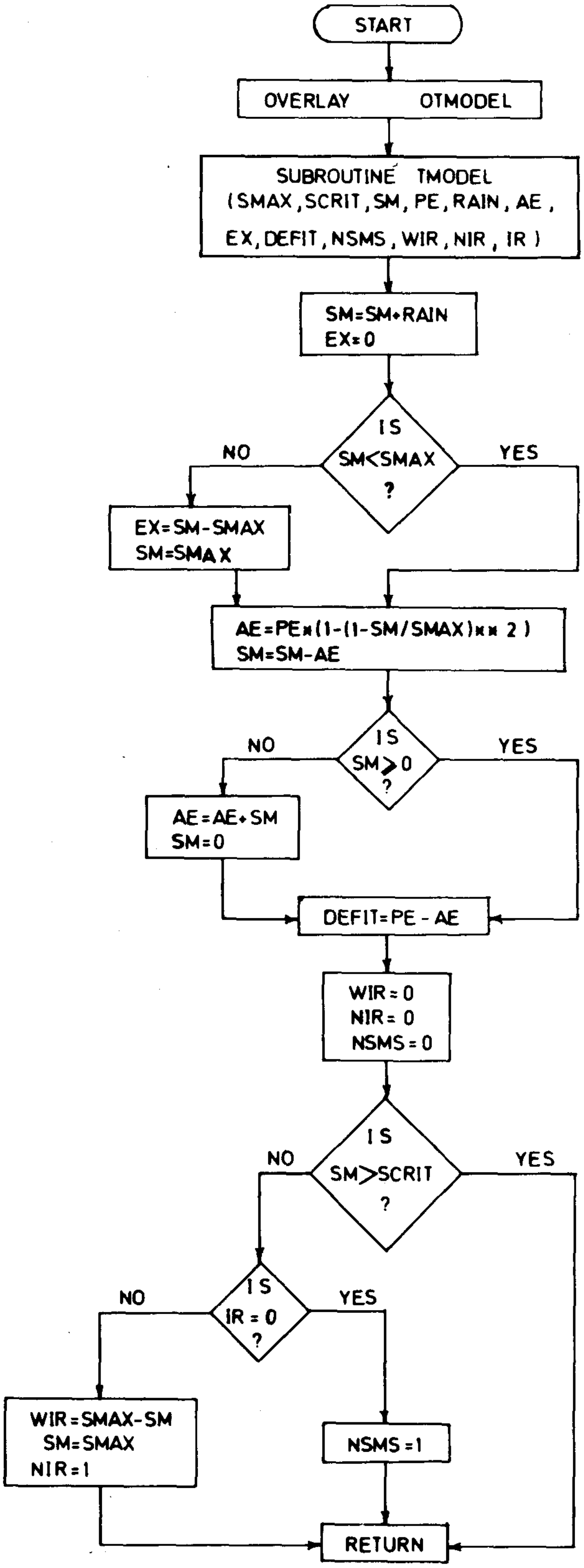



FIG D.5: FLOW CHART FOR SUBROUTINE TNORM

# TABLE D.6: LISTING OF SUBROUTINE TMODEL

```
      COMPILER NOSTACK
      OVERLAY OTMODEL
      SUBROUTINE TMODEL(SMAX,SCRIT,SM,PE,RAIN,AE,EX,DEFIT,NSMS,WIR,NIR,IR)
C     COMPUTES DAILY WATER BALANCE
C     SMAX=SOIL MOISTURE STORAGE CAPACITY AVAILABLE TO THE PLANT (SMAX
C      EQUALS SMAXPM MULTIPLIED BY ROOT DEPTH)
C     SCRIT=CRITICAL SOIL MOISTURE LEVEL BELOW WHICH PLANT YIELD SUFFERS
C     RAIN=DAILY RAINFALL
C     PE=DAILY POTENTIAL CROP EVAPOTRANSPIRATION (EQUALS CROP FACTOR
C      MULTIPLIED BY GRASSLAND POTENTIAL EVAPOTRANSPIRATION)
C     SM=CURRENT SOIL MOISTURE STATUS
C     AE RETURNS DAILY EVAPOTRANSPIRATION
C     EX RETURNS DAILY WATER EXCESS
C     WIR RETURNS DAILY IRRIGATION WATER
C     NIR RETURNS 1 FOR IRRIGATION APPLICATION
C                 0 FOR NO IRRIGATION APPLICATION
C     NSMS RETURNS 1 FOR SOIL MOISTURE BELOW SCRIT
C                  0 FOR SOIL MOISTURE ABOVE SCRIT
C     DEFIT RETURNS DAILY PLANT WATER DEFICIT
C     IR=1 FOR IRRIGATION INPUT
C        0 FOR NO IRRIGATION INPUT
C     ADD DAILY RAIN
      SM=SM+RAIN
      EX=0.
      IF(SM.LT.SMAX)GO TO 3
      EX=SM-SMAX
      SM=SMAX
C     SUBTRACT DAILY EVAPOTRANSPIRATION
C     AE IS COMPUTED AS A FUNCTION OF SM ASSUMING THAT THE % REDUCTION
C     OF AE INCREASES AS THE SQUARE OF THE % SM DEPLETION
3     AE=PE*(1.-(1.-SM/SMAX)**2)
      SM=SM-AE
      IF(SM.GE.0)GO TO 7
      AE=AE+SM
      SM=0.
7     DEFIT=PE-AE
      WIR=0.
     NIR=0
      NSMS=0
      IF(SM.GT.SCRIT)GO TO 6
C     SOIL MOISTURE LEVEL LESS THAN SCRIT
      IF(IR.EQ.0)GO TO 5
      WIR=SMAX-SM
      SM=SMAX
      NIR=1
      GO TO 6
5     NSMS=1
6     RETURN
      END
```




( OVERLAY statement used only for programme TSMAY )

SMAX = effective soil moisture storage capacity available to the plant (mm)

SCRIT = critical soil moisture level below which plant yield suffers (mm)

SM = daily soil moisture level (mm)

PE = daily potential crop evapotranspiration (mm)

RAIN = daily rainfall (mm)

AE = daily actual crop evapotranspiration (mm)

EX = daily water excess (mm)

DEFIT = daily water deficit (mm)

NSMS = integer variable which returns soil moisture status at end of day = one for drought day, zero otherwise

WIR = daily irrigation water application

NIR = integer variable which returns one if an irrigation application is made and zero otherwise

IR = integer variable specifying the mode of simulation = one for irrigation input and zero for no irrigation input.

FIG D.6: FLOW CHART FOR SUBROUTINE TMODEL

# AGRICULTURAL PLANNING & IRRIGATION DESIGN

## REQUEST FORM

[This form should be perfected in conjunction with D.I.D. Hydrological Procedure No. 20 'Hydrological Aspects of Agricultural Planning & Irrigation Design' (1978)].

| |
|---|
| .................................................. <br> (See Note 1 & 2, page II) |

1. Name of Agency/Individual making the request ..............................................................................

2. Address ..............................................................................................................................

..............................................................................................................................

| | | | | |
|---|---|---|---|---|
| 3. Area planned for Agricultural Development | (i) Name <br> ...................... | (ii) Extent (Hectares) <br> ...................... | (iii) Latitude <br> ° ′ ″ <br> ...................... | (iv) Longtude <br> ° ′ ″ <br> ...................... |
| 4. Name(s) of upland crop(s) intended for cultivation. | (i) <br> .................................................. | | (ii) <br> ...................... | (iii) <br> ...................... |

5. Hydrology Branch, Drainage and Irrigation Department will be responsible for selecting the necessary rainfall station

6. **Evaporation data**

Can you provide monthly evaporation data of a station representative of the area.

| YES | NO |
|---|---|
| Enclose records and give details of the station. | Which evaporation station given in Fig. 1 of D.I.D. Water Resources Publication 5, you would suggest for use in the analysis. |
| (i) Name:- <br> (ii) Latitude:- <br> (iii) Longitude:- <br> (iv) Elevation (MSL):- <br> (v) Agency collecting data:- <br> (vi) Type of equipment used:- <br> (vii) Remarks:- | (i) Name:- <br> (ii) Station Number:- <br> (or would you suggest to use Fig. 7 of the publication) <br> I suggest to use/not to use Fig. 7 <br> (strike which ever is not applicable) <br> (iii) Remarks:- |

7. **Soil Data**

Can you provide available water holding capacity of the soil (mm/metre depth of soil) representative of the area.

| YES | NO |
| --- | --- |
| (i) Available water holding capacity ........................................ mm/m<br>(ii) Name of soil series ....................................<br>(iii) Analysis done by (name).....................................................<br>(iv) Method used in analysis...........................<br>(v) Remarks: | Which soil series will you recommend from those given in Table 4.2.<br>(i) Name of soil series ...................................<br>Do you wish to suggest any other available water holding capacity other than given in Table 4.2.<br>(i) Available water holding capacity<br>..........................................................<br>(ii) Remarks:- |

8. **Crop water requirement**

Can you provide water requirement, on a weekly basis of the crop(s) chosen, for the life span of the crop.

| YES | NO |
| --- | --- |
| (i) Enclose weekly crop water requirements of the crop(s).<br>(ii) Brief description of experimental technique adopted:-<br>(iii) Remarks:- | Crop coefficients given in Table C.1. will be used.<br>Do you wish to make any change in the crop coefficients in the Table, if so state:<br>(i) Changes in Crop Coefficients<br>1. 2. 3. 4.<br>(ii) Remarks:- |

9. **Any Other General Remarks**

(i) If you do not agree with the probability level chosen for the crop in Table 3.2 and you wish the programme TPSTAT to be run with another probability level, then give the value here............

(ii) ..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

Note 1:—If best planting date is only requested, write 'RUN TPSTAT ONLY' in the column provided in the top right hand corner and note that soil data (7) is not necessary.

Note 2:—If all the out put is requested, sections 1 to 9 should be duly perfected and column provided in the top right hand corner should be completed by writing 'RUN TPSTAT AND TSMAY'.

(This form should be perfected and returned with the necessary data to the

Director-General,
Drainage & Irrigation Department,
Swettenham Road,
Kuala Lumpur 01-02.)

I agree to pay all the costs involved in running the programme and getting the necessary out put as requested by me.

Signature:........................................................ Designation:......................................................

Name: .......................................................... Date: ..........................................................

## HYDROLOGICAL PROCEDURES PUBLISHED

| | | | Price |
|---|---|---|---|
| No. 1 | – | Estimation of the Design Rainstorm (1973) ... ... ... ... ... | $8.00 |
| No. 2 | – | Water Quality Sampling for Surface Water (1973) ... ... ... | $3.00 |
| No. 3 | – | A General Purpose Event Water-Level Recorder Capricorder Model 1598 (1973) ... ... ... ... ... ... ... ... | $5.00 |
| No. 4 | – | Magnitude and frequency of floods in Peninsular Malaysia (1974). ... ... ... ... ... ... ... ... | $6.00 |
| No. 5 | – | Rational method of flood estimation for rural catchments in Peninsular Malaysia (1974)... ... ... ... | $3.00 |
| No. 6 | – | Hydrological station numbering system (1974) ... ... ... | $3.00 |
| No. 7 | – | Hydrological Station Registers (1974).. ... ... ... ... | $5.00 |
| No. 8 | – | Field Installation and Maintenance of Capricorder 1599 (1974) | $5.00 |
| No. 9 | – | Field Installation and Maintenance of Capricorder 1598 Digital Event Water Level Recorder (1974). ... ... ... | $5.00 |
| No. 10 | – | Stage-Discharge Curves (1977).. ... ... ... ... ... | $5.00 |
| No. 11 | – | Design Flood Hydrograph Estimation for Rural Catchments in Peninsular Malaysia (1976) ... ... ... ... ... | $5.00 |
| No. 12 | – | Magnitude and Frequency of Low Flows in Peninsular Malaysia (1976). ... ... ... ... ... ... ... ... | $5.00 |
| No. 13 | – | The Estimation of Storage-Draft Rate Characteristics for Rivers in Peninsular Malaysia (1976) ... ... ... ... ... | $5.00 |
| No. 14 | – | Graphical Recorders–Instructions for Chart Changing and Annotation (1976) ... ... ... ... ... ... | $5.00 |
| No. 15 | – | River Discharge Measurement by Current Meter (1976) ... ... | $5.00 |
| No. 16 | – | Flood Estimation for Urban Areas in Peninsular Malaysia (1976) | $5.00 |
| No. 17 | – | Estimating Potential Evapotranspiration Using the Penman Procedure (1977) ... ... ... ... ... ... ... | $5.00 |
| No. 18 | – | Hydrological Design of Agriculture Drainage Systems (1977) | $5.00 |
| No. 19 | – | The Determination of Suspended Sediment Discharge (1977) | $5.00 |