ESTIMATION OF THE EFFECT OF IRRIGATION ON ANNUAL RECHARGE AT THE KANO PROJECT AREA OF KANO RIVER BASIN

BY

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DECLARATION

The work reported in this thesis was carried out by me under the supervision of Dr. L.I.O. Odigie. The work has not been previously published or accepted elsewhere for the award of any degree.

All works and ideas other than mine have been fully acknowledge.

HUSSAINI AHMED DAURA

December, 1991.

DEDICATION

This project is dedicated to my

dear mother,

Mrs. HASANA AHMED RUFA'I

CERTIFICATION

This thesis entitled "Estimation of the effect of irrigation on annual recharge at the Kano Project Area of Kano river basin" by Hussaini Ahmed Daura meets the regulations governing the award of the degree of Master of Engineering(Water Resources And Enviromental Engineering) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

This study was carried out to investigate and quantify the effect of irrigation on annual recharge at the Kano project area of Kano river Project. The soil moisture deficit model was used in estimating the recharge and its sensitivity to data and model parameters was investigated.

The mean annual recharge for the whole area was estimated at 101.1 mm. In the irrigated areas, the mean annual recharge was 262.1 mm, out of which an average 172.6 mm comes from irrigation.

The sensitivity analysis has shown the model to be sensitive to variations in rainfall and potential evapotranspiration.

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CHAPTER ONE INTRODUCTION

1.1 Objective

The aim of this study is to investigated and quantify the effect of irrigation on annual recharge at the Kano project area of Kano river project.

1.2 General

Recharge is the amount of water that infiltrates the soil to replendish the groundwater reservoir. It occurs naturally from rainfall, rivers and lakes. Human action in the form of irrigation, artificial reservoirs and recharge wells also induce recharge. In the former case it is termed "natural recharge" while in latter "artificial recharge".

Natural recharge can be "direct" or "indirect". Direct recharge is that occurring from rainfall as it infiltrates the soil at the point where the rain falls, while indirect recharge is that occurring after the rainfall has turned into runoff in streams, depressions or local areas of concentration.

1.3 Justification

The decade 1970-80 saw a rapid rise of irrigation practice in the savannah zone of this country. One of the earliest irrigation scheme in this region is the "Kano River Project", about 24 KM south of Kano city. The project was established to harness the water resources of the Kano river and, if properly managed, can irrigate an estimated area of 62,000 hectares.

As the scheme progressed towards its target, however,

its effects on the moisture regime in the area began to manifest itself in the form of rising water tables. An investigation showed that water tables, which never existed withing 1.5m below the ground level before the project started, are now found withing 0-60 cm below the ground at the peak of the rains and upto 40 cm below the ground during the irrigation season. (Nwa, 1982)

As the rising water tables indicate increased recharge, an estimate of the recharge together with whatever effect the irrigation may have on it will give an insight into the problem and thereby help in finding a lasting solution.

Hence this study will ultimately, it is hoped, help in realizing greater yields from crops through an efficient management of the water resources.

.4 Outline of work

The soil moisture deficit model, based on the work of Penman (1949) and Grindley (1967), is used in this study for the estimation of the recharge. For the estimate, the area is divided into three zones based on geological and physical properties of the soils in the area and irrigation practice. The first zone consist of the areas with deep soils developed for irrigation, the second consist of the areas with deep soils but not developed for irrigation and the third zone consist of areas with shallow soils unsuitable for irrigation. The estimates from the three zones are later combined by weighting areally to give the estimate for the whole area.

Rainfall data (1973-1984) for the area was obtained from Institute of Agricultural Research's(IAR) meteorological station at Kadawa. The potential evapotranspiration for the same period was computed using Penmans (1948) equation with data obtained from Kano Airport. Runoff coefficient was computed from runoff data of the Kano river, obtained from Water Resources and Engineering Construction Agency(WRECA), Kano. Root constants and maximum soil moisture deficit were calculated for crops grown in the area and these are weighted areally using landuse data for the area obtained from NEDECCO and Hadejia Jama'are river Basin Development Authority(HJRBDA).

The Estimate is carried out by a computer program based on a sub-routine developed for the model by Odigie (1984). A sensitivity analysis is finally carried out for each of the zones to determine the sensitivity of the estimate to model and input parameters.

CHAPTER 2

LITERATURE REVIEW

2.1 Water Balance Equation

Direct recharge can be estimated from the equation,

$$Drec\ t = Pt - Rt - ETat + St \qquad 2.1$$

where,

Drec t = direct recharge in time interval t

Pt = precipitation in time interval t

Rt = runoff in time interval t

ETat = evapotranspiration in time interval t

St = change in soil moisture storage over t

The method is simple but it is difficult to estimate the actual evapotranspiration ETa. Also when applied over large areas , the assumption uniform soil conditions and landuse introduces errors in the soil moisture storage and holding capacities.

To avoid difficulties in estimating the change in soil moisture stotage S, an annual time interval is sometimes used when St is assumed to be negligible.

The method was used by Kowal and Knabe (1972) to prepare annual water budgets for Nothern Nigerian, using a time (t) of ten days. No account was made of direct runoff while evapotranspiration is assumed to take place at the potential rate, calculated from Penmans (1948) equation. Their results for Kano , near the study area, is as follows:-

Soil moisture storage	Mean annual recharge
101.6 mm	216.4 mm

These will be compared and discussed with the results of the study in chapter 6.

2.2 Soil Moisture Profile

Direct recharge can be estimated by measuring the moisture content of the soil at suitable intervals over the root zone depth. The measurement is carried out at regular time intervals at different points in the area of study using soil tensiometers, neutron probes or electrical sensors. Water in excess of field capacity of the soil beyond the root zone is assumed to be recharge and the recharge rate is calculated from moisture gradients in the soil.

The method is accurate but due to the hetrogenity of the soil, it is necessary to carry out measurements at sufficient number of points to ensure good areal estimate. This coupled with the cost of equipment and other problems inherent and associated with instrumentation , makes it expensive to use for large areas where it may prove difficult to carry out measurement at sufficient number of points. Also the measurements have to be carried out for long periods to get long term results.

2.3

LYSIMETERS

Lysimeters, packed with the soils of the area of study and planted with similar vegetation can be used to estimated direct recharge . Any excess moisture from precipitation that is enough to satisfy the evaporative demand of the plants and the moisture holding capacity of the packed soils, percolates downwards and is collected at the bottom of the lysimeter. This is measured by volume or weighing and represents the direct recharge.

The method avoids the difficulty of estimating actual evapotranspiration, but despite this lysimeters have the following disadvantages :-

1 Their small size restricts root development and introduces edge effects.

2 The re-packed soils within them have been disturbed so that root development and water flow through them may no longer be natural.

3 The surrounding vegetation is not usually the same as that in the lysimeter. Thus it may no longer represent a larger area of the same vegetation within it.

4 The allowance of free drainage by lysimeters does not represent the natural soil conditions.

5 They are expensive to construct and operate and require a long time to allow the vegetation planted on them to stabilize.

Kitching et al (1977) used two sophisticated lysimeters to measure the recharge to the Bunter sandstone aquifer in England. Their result was 175 % higher than that calculated using Penman-Grindley model.

Holmes and Colville (1970) used lysimeter for estimation of recharge to the Gambier plains, south Australia. Their result was 58 % higher than those found by Allison and Hughes (1974) who used tritium profiles of the same site for their estimate.

2.4 Tracers

Direct recharge can be estimated indirectly by measuring the rate of groundwater movement or age by means of tracers. The tracers are either naturally present in the groundwater or may be introduced artificially into the ground. In either case the concentration of the tracer is monitored by measurement from samples taken from boreholes or at points situated at down-gradient.

2.4.1 Natural Tracers :- Natural ions such as chloride or bromide are relatively innert and so can be used for monitoring the movement of water from surface to water table. (Williamson and Lawrence 1981).

The method of Schoeller (1955) has been used to estimate recharge to fractured rock aquifers in Australia. The equation for computing recharge is :-

$$(P-Q)Cp = CgR - CdR \qquad 2.2$$

where, P - precipitation

Q = runoff

R = recharge

Cp =ion concentration in rainfall

Cg = ion concentration in groundwater

Cd = ion concentration due to leaching

The method often gives lower values of recharge compared with other methods.

Dincer et al (1974) used natural tritium profiles to estimate recharge through sand dunes in Saudi Arabia. Smith et al (1970), Vogel et al (1974) have all used natural tritium in estimating recharge.

2.4.2 Artificial tracers :- Artificial tritium, introduced into the atmosphere by thermo-nuclear explosions (since 1953) or alternatively injected into the ground, affords a means of estimating recharge by determining the tritium profiles. The profile is determined by measurement of tritium concentration from core samples taken at intervals over the depth of soil.

Studies by Zimmermann et al (1976) showed that groundwater recharge process is essentially a piston-like propagation of soil water through the unsaturated zone and developed a model for estimating recharge from tritium profiles based on this deduction.

Bredenkamp et al (1980) used tritium profiles to estimate recharge to dolomitic aquifer in South Africa. The result is 30.0 ± 5 mm annually and represents 5.4 % of the precipitation.

Athavale et al (1980) developed a method for estimating recharge by injecting artificial tritium into the soil and determining the profile. He calculated recharge from the formulae :-

$$Wh = (Md/(100 + Md))\ wn$$

where, Wh = recharge per cubic cm of soil

Md = dry weight percent of soil

w = wet bulk density of soil

n = displacement of tracer from injection site determined from tritium profile.

The method is technically intensive requiring skilled manpower and expensive equipment.

.5 Soil Moisture Balance Models

Direct recharge can be estimated by the use of conceptual models in which input in the form of rainfall or snowmelt is passed through various processes and storages to produce output in the form of runoff, evapotranspiration and recharge. Records of spring flow, river flow and well hydrographs are used to control the model parameters.

For accurate results, such models require long records of climatic data and good knowledge of the soil/ geological

properties of the area of study. Because of this and the diversity of the soils, vegetation and climate, few models have found application beyond the areas they were developed for.

2.6 The Soil Moisture Deficit Model

This model was developed from the works of Penman (1949) and Grindley (1967), and estimates recharge through the top soil by a process involving the calculation of soil moisture deficit (SMD) and actual evapotranspiration .

After any rainfall event, the amount of water that goes into soil moisture storage (potential recharge) is the balance after runoff and evapotranspiration have been deducted from rainfall. This can be expressed as :-

$$S = P - Ep - RO \qquad 2.4$$

where, S = change in soil moisture storage

P = rainfall / precipitation

Ep = evapotranspiration

RO = runoff

If S is negetive, it means there is an increase in SMD where'as a positive value of S indicates potential recharge. The evapotranspiration Ep depends on the moisture conditions in the soil, the type of vegetation and weather conditions. When the soil is at field capacity, the evapotranspiration Ep equals the potential evapotranspiration, PE, calculated from Penmans (1948) equation or determined from lysimeters. Thus :-

$$S = P - PE - RO \qquad 2.5$$

If the soil is not replendish by fresh rain, evapotranspiration will continue at the potential rate and the SMD increases until it reaches a certain value called "root constant", RC, which depends on the type of vegetation cover. The root constant represents the amount of moisture readily available to the plants. (Penman, 1949).

At this stage evapotranspiration ceases to take place at the potential rate. The actual change in storage is reduced to a certain fraction, F, of the potential change in storage.

Thus :-

$$S = F\,(P - PE - RO) \qquad 2.6$$

If the actual evapotranspiration is represented by AE, equation 2.6 can be written as :-

$$S = P - AE - RO \qquad 2.7$$

From equations 2.6 and 2.7 ,

$$AE = (1 - F)\,(P - RO) + F(PE) \qquad 2.8$$

The factor F is the slope of the drying curve of the soil and equation 2.8 is used to determine the actual evapotranspiration in the SMD model. For example, when P and RO are both equal to zero and SMD > RC,

$$AE = F(PE) \qquad 2.9$$

A detailed description of other situations that arise is given in the next chapter.

Penman (1950) performed computation of water balances in Stour chalk catchment in England over a 15 year period. He estimated mean monthly and annual change in storage (i.e.

recharge) using conventional values of root constants and maximum soil moisture deficit. By comparing his results with changes in water levels, he concluded that the estimate give a good picture of changes in storage in the catchment.

Grindley (1967) performed calculations of soil moisture deficits over Great Britain using the results of Penmans studies (1949-50). From his results, he produced a map of SMD over Great Britain for use as aid in flood warnings.

Llyod et al (1966) used the SMD model to estimate recharge in north eastern Jordan. He used a ten day time step and also showed how the results vary with time step used and maximum SMD values.

Headworth (1970) used the SMD model to estimate recharge to the chalk aquifer in southern England and demonstrated that the model fails to reproduce long term runoff from the aquifer. He showed that the root constant has to be reduced to 25 mm instead of the conventional 75.mm in order to reproduce long term runoff.

Rushton and Fox (1976) showed that in order to simulate well hydrographs in the Lincolnshire limestone aquifer of eastern England, recharge must occur during summer months, when the SMD is positive. They introduced the concept of "rapid recharge" which the attribute to rapid water transfer through fissues. Although their concept produced the right results, it may be limited to their area.

Rushton and Ward (1979) carried out a study of north Lincolnshire limestone aquifer in England and showed that

the conventional model fails reproduce summer recharge as indicated by well hydrographs. They modified the model using the "rapid recharge" concept in which a certain fraction of effective or actual precipitation or a combination of both enters directly as recharge. after several trials, they obtained satisfactory results when 10 % of effective plus 10 % of actual precipitation greater than 6 mm is allowed to enter the aquifer as rapid recharge.

Howard and Llyod (1979) used the conventional model to estimate recharge to north Lincolnshire Aquifer and showed the sensitivity of the recharge estimates to variations in various model parameters. They demonstrated that the best results are obtained when a daily time interval is used.

Hadgraft and Volker (1980) described a model which they used to estimate recharge to the Burdekin delta aquifer, Queensland, Australia. The mode of computation differs substantially from the normal SMD model. PE is calculated from a formulae developed by Boughton (1966) in his studies of rainfall-runoff relations. Recharge is calculated from a formulae based on "intuitive" reasoning. This lack of physical basis and the fact that the formulae for computing PE was developed for ronoff estimation, makes the model unsuitable for general use.

Henry and Palmer (1980) used a model to estimate recharge to Callide valley in central Queensland, Australia. The model used two stores, the capillary store and gravity store, which are replendished from rainfall or irrigation

and deplated by consumptive use and recharge. The authors did not give the details of the process but claimed that the models results were satisfactory.

Odigie (1984) used the SMD model to estimate direct recharge to the great limestone aquifer in south England. He recommends the use of root constants and maximum SMD values consistent with soil and plant properties rather than conventional values. He also showed how the use of areally weighted root constants and maximum SMD gives nearly the same results as the individual root constants and maximum SMD, whilst resulting in great savings in computer time and space.

Anyaeche (1985) used the SMD model after Odigie (1984) to estimate direct recharge into the upper zone of lake Chad basin aquifer. He used daily time step and areally weighted root constants and maximum SMD.

Oluremi (1985) estimated direct recharge to the Sokoto Rima river basin using the SMD model after Odigie. He used also daily time step and areally weighted root constants and maximum SMD.

From the discussion and the availability of data in the area of study, the SMD model is the best method for use in this study.

CHAPTER 3

THE SOIL MOISTURE DEFICIT MODEL

The soil moisture deficit (SMD) model is based on the process of moisture movement in the soil-plant-atmosphere system. The model estimates recharge by a process involving the calculation of SMD and the use of a number of criteria to determine actual evaporation and incidence of recharge.

3.1 Available Water

The available water, Am, in a given depth of soil Ds is defined as the difference between moisture content at field capacity and permanent wilting point.

$$Am = (Mfc - Mwp) \times Ds/100 \qquad 3.1$$

where, Am = available water

Mfc= moisture content at field capacity

Mwp= moisture content at permanent wilting point

The SMD in a given soil depth is any deficit below the available moisture. The maximum SMD or D, expressed as an equivalent rainfall, is the amount of water a given plant can abstract from the soil moisture before it permanently wilts and dies. It is made up of available water within the root zone and the contribution through capillary rise and vapour movement from zones deeper than the root zone.

The root constant, RC, is that amount of available soil moisture expressed as an equivalent rainfall which a plant can abstract from the soil without difficulty in order to

satisfy evaporative demand.

3.2 Availavility of Soil Water

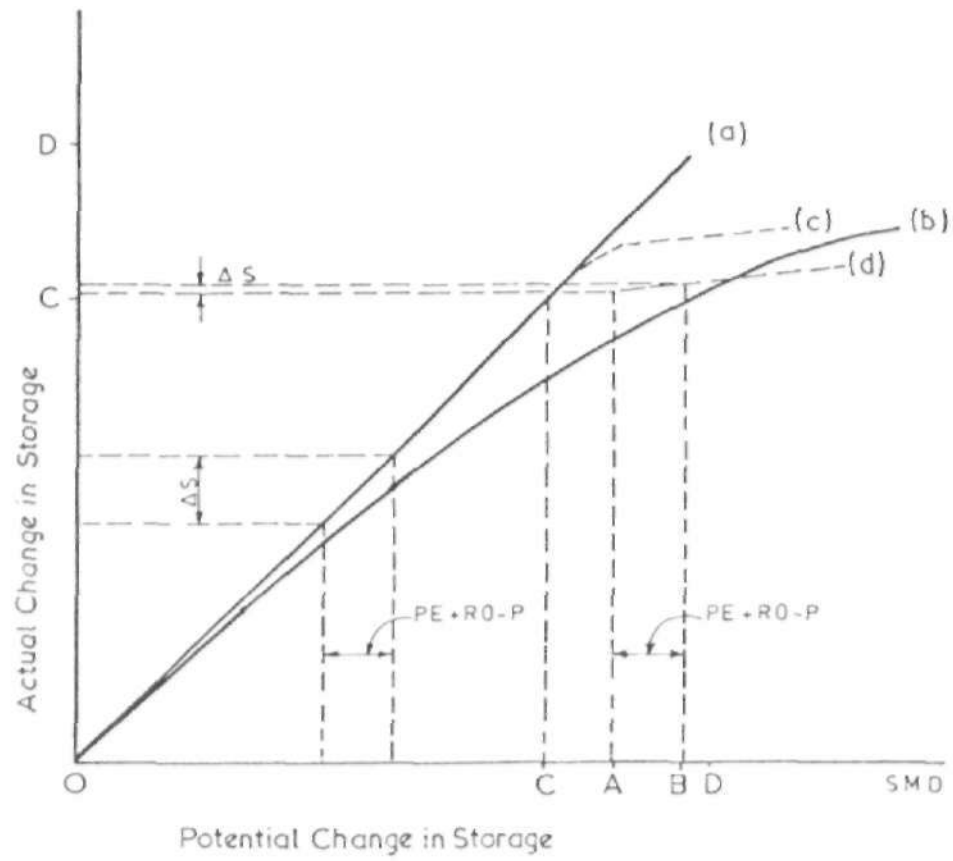
The availability of soil water in the soil is represented in a simplified form by the soil's drying curve, of which there are several proposals. Some of these are shown in fig. 3.1 .

a) Equal availability curve :- This curve was proposed by Veihmeyer and Hendrickson (1927, 1949, 1950, 1955) and claims that soil water is equally available throughout the defined limits of soil wetness. This means that plant functions are unaffected by any decrease in soil moisture until permanent wilting point is reached. at this point, the functions are abruptly reduced and the plant dies.

b) Gradually decreasing availability curve :- Richards and Wadleigh (1952), using field evidence, proposed that the availability of soil water to plants decreases with soil wetness. This implies that the plant may suffer water stress and reduced activity before the permanent wilting point is reached.

c) Equal availability followed by decreasing availability: Here it is stipulated that there exist a critical point between field capacity and permanent wilting point. Above this point, water is equally available to plants and below it, water availability decreases. This proposal was futher modified by Penman (1949) who stipulated that below the critical point and for 25 mm, the decrease in availability of water is gradual and beyond that it is very high with a

FIG 3.1 DRYING CURVES FOR A VEGETATED SOIL (Oliggie.1984)



(a) Veihmeyer

(b) Richardson and Wedleigh

(c) Penman

(d) Rushton and Ward

slope of 8 to 10 percent. This concept is shown in curve c.

Rushton and Ward (1979) Penman's concept and suggested that beyond the critical point, the availavility of soil water decreases suddenly at a very high rate. This concept is represented by the curve d.

This last proposal is used in the SMD model because it is easy to incoporate in a computer program.

3.3 Model's Description

The process of estimating the recharge is represented in the subroutine flow chart shown in fig. 3.2, by Odigie (1984) . The estimate is carried out on a one day time step and the mode of computation depends on the value of soil moisture deficit (SMD) along the drying curve. The SMD at the beginning of the day assumes the value of SMD at the end of the previous day. It normally varies from zero at field capacity to the maximum SMD (D), but can exceed D due to change in landuse; e.g. harvest.

Priority for satisfying evaporation is from rainfall. The effect of folliage interception is taken care of by not allowing for direct runoff whenever the rainfall is less than the potential evapotranspiration, PE. The computation is carried out for the following four states / conditions :-

i) $SMD = 0$

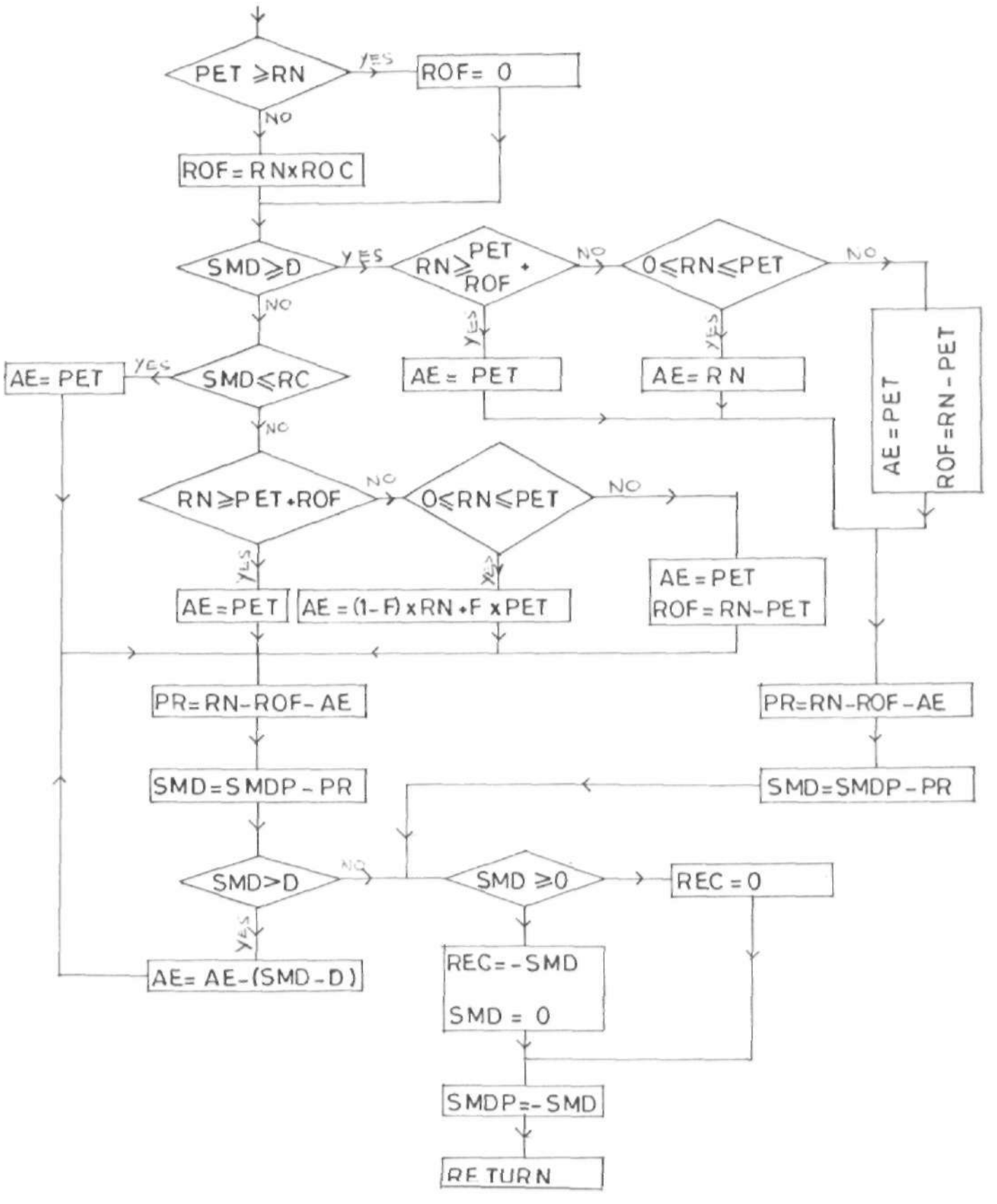
ii) $0 < SMD \leq RC$

iii) $RC < SMD \leq D$

iv) $SMD > D$

Figure 3.2

Flow chart of subroutine used in calculation of recharge (odigie 1984)



i) SMD = 0

In this state, the soil is saturated and the plants have no difficulty in abstracting moisture from it. Thus actual evapotranspiration (AE) is equal to the potential rate (PE). Two cases arise depending on the value of the rainfall, P.

a) P ≥ PE = RO

b) P < PE = RO

In the first case, there is the possibility of excess rainfall infiltrating as recharge. The potential recharge, PR is given by :-

PR = P - RO - AE 3.2

PR , to some extent, determines the incidence of recharge. For this case , evaporation takes place at the potential rate and so, AE = PE . Substituting for AE in the above equation gives :-

PR = P - RO - PE 3.3

Therefore PR is either positive or zero depending on the value of P.

For the second case (b), PR is negative. The potential recharge is the amount of water that goes into soil moisture storage to make up for any deficit. The deficit at the end of one time step is given by :-

SMD = SMDP - PR 3.4

where, SMDP is the SMD at the beginning of the day. SMDP is also the SMD at the end of the previous day. If PR is zero, then no moisture is added or removed from the soil, i.e. SMD

remains constant and recharge is zero. If PR is positive, equation 3.4 gives :-

SMD = -PR

The negative SMD is excess soil moisture above field capacity and this percolates to recharge groundwater. Therefore the recharge (Rech), is given by :-

Rech = -SMD 3.5

Substituting for SMD in equation 3.5, we get :-

Rech = PR

After the percolation of excess moisture, the SMD becomes zero again. If PR is negative as in case (b), the SMD increases above zero by amount equal to PR. Evaporative demand is satisfied from two sources namely, rainfall and soil moisture storage.

ii) $0 < SMD \leq RC$

In this condition also, evaporation takes place at the potential rate, i.e. AE = PE. Three cases may arise :-

a) P = RO + PE i.e. PR = 0

b) P < RO + PE i.e. PR is -ve

c) P > RO + PE i.e. PR is +ve

Any change in the SMD with respect to the magnitude and sign of PR is as described previously (i.e. for SMD = 0). Only in the third case, c, is there a possibility of recharge if PR exceeds SMDP.

iii) $RC < SMD \leq D$

The evaporation and flow process is complex in this condition and the interpretation can only be regarded as

simplifications of the dominant processes. The three situations that may arise are :-

a) $P > PE + RO$ i.e. PR is +ve

b) $0 \leq P \leq PE$ PR is -ve

c) $PE < P < PE + RO$ PR = 0

In the second case (b), the computed SMD may exceed D. There is a provision in the model to correct the SMD by reducing the actual evaporation, AE, by an amount equal to (D - SMD) and recalculating the SMD with the new AE.

iv) SMD > D

This condition is brought about by change in landuse such as harvesting. After harvest, D is lowered abruptly and may be lower than the SMD accumulated during the growing season. In this condition, evaporative demand is satisfied only from rainfall. The SMD either remains constant or falls depending on the value of P, until it becomes lower than D. The two cases that may arise are :-

a) $0 < P \leq PE + RO$ i.e. PR = 0

b) $P > PE + RO$ i.e. PR is +ve

Thus in the model, recharge may take place only in conditions (i) and (ii) if SMD is zero.

CHAPTER 4

THE STUDY AREA

4.1 The Kano river river project was initiated by the Kano state government in 1970 and covers a gross area of 93,000 hectares about 24 km south of Kano city. The project was planned to be executed in two phases and in the first phase, a gross area of 52,000 hectares called the "Kano Project Area" is to be brought under irrigation. It is bounded in the north, west and south by the Kano river and in the south east by the rocky inselberges near Rano (NEDECCO). It lies approximately between lattitudes 8° 30' E and 90° 40' E, and longitudes 11° 30' N and 12° 03' N.

4.2 Topography

The area is part of the Kano Zaria plains, a vast, almost flat peneplain extending from Sokoto to lake Chad. The landscape varies from flat to gently sloping with outcrops of rocky inselberges mainly in the southern parts. It varies in height from 520 m to 430 m above sea level and generally slopes towards the north east. Several shallow valleys and deep gulleys drain the area via the Kano river. (NEDECCO 1974)

4.3 Geology and Soils

NEDECCO (1974) described the area as a portion of a dissected peneplain developed on the crystalline pre-cambrian rocks of the basement complex. The main rock types are granite gneisses and schist, complex glimerschist and quartzites. The top of the basement complex is deeply

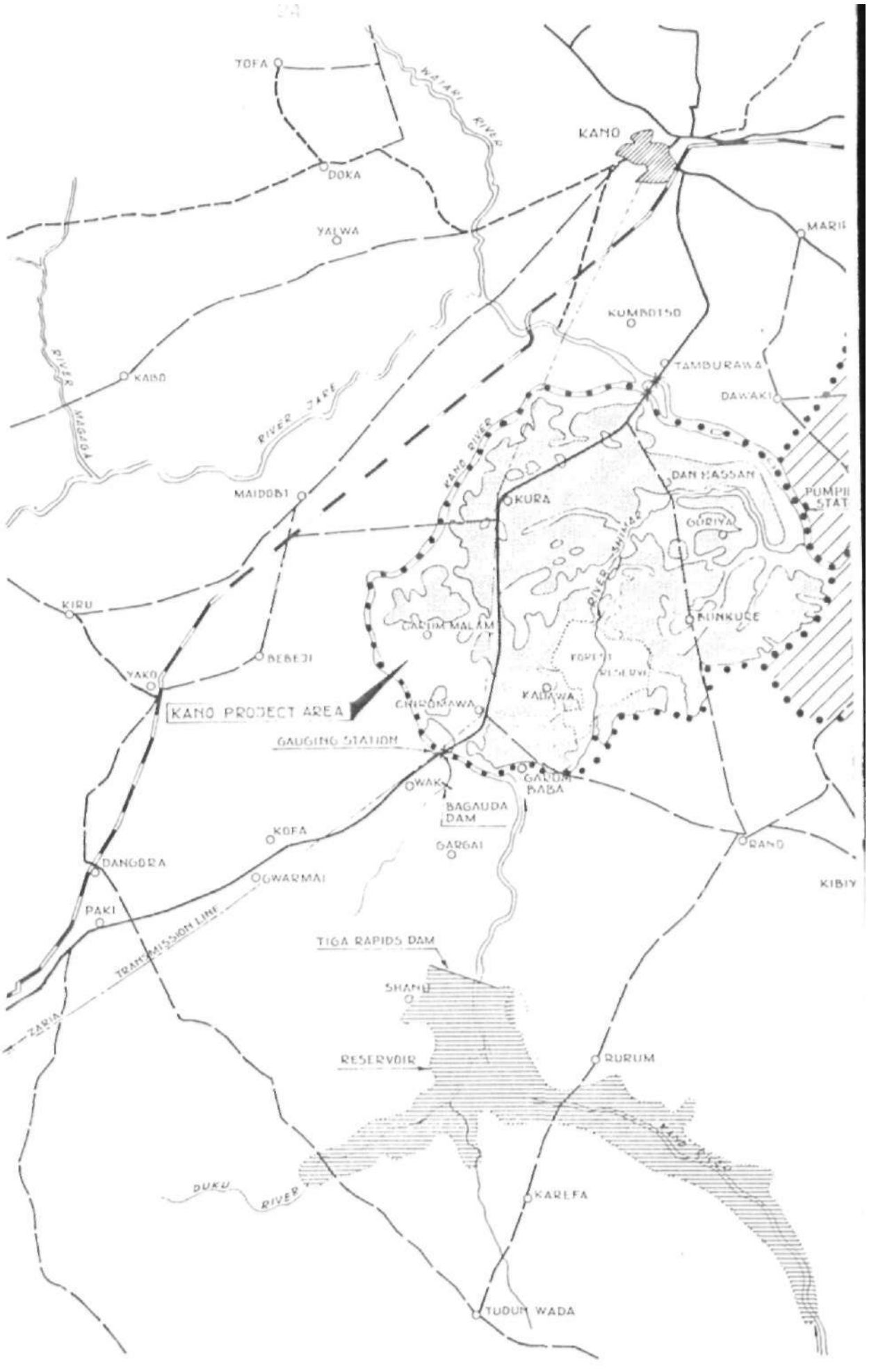


FIG.4.1 The Kano Project Area | INDEX (1974)

weathered and on this weathered zone, a lateritic iron pan layer has developed. In many places this layer has been eroded and laterization is restricted to the top layer of the weathered zone.

A top layer (0.3m - 6m) of unconsolidated materials of various compositions overlies the laterite. These consist of older alluvial/ colluvial complex and younger aeolian deposits. Soils of the area are divided into three classes according to their physiography :-

i) Soils of the upland plain (P)

ii) Soils of higher terrace (HT)

iii) Soils of lower terrace (LT)

Two subclasses are also recognized :-

1) Well drained soils (a)

2) Poorly drained soils (b)

Further subdivision is based on soil depth. The presence of iron-pan in the soils is indicated by the letter "1".

Figure 4.2 shows the cross sections of the landforms while table 4.1 shows their composition.

4.4 Climate

The climate is typical of the sudan savannah zone of

SCHEMATIC CROSS-SECTIONS

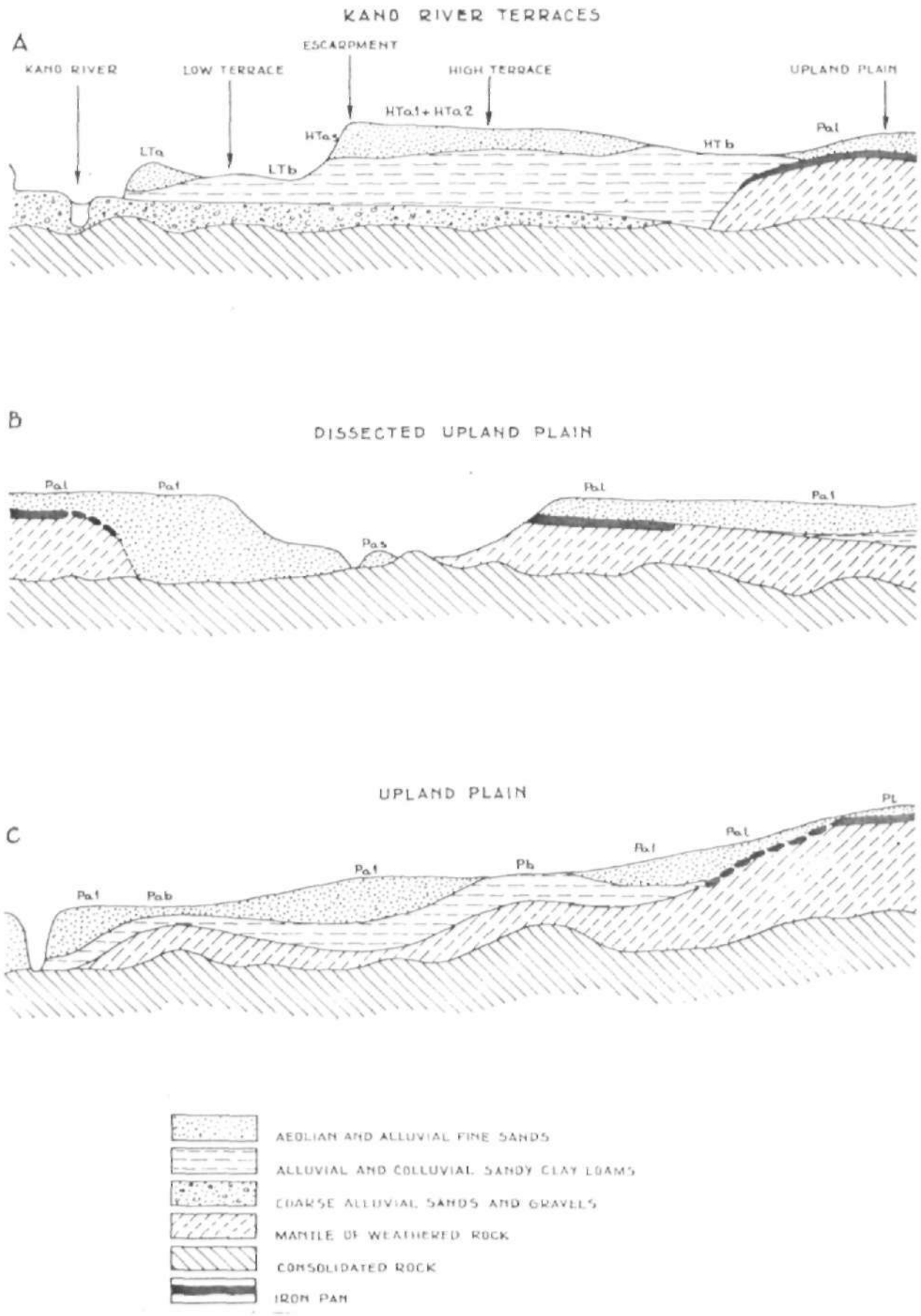


FIG.4.2 Cross-Sections of Landforms

nothern Nigeria. Three seasons can be distinguished:-

the cool dry season	october-march
the hot dry season	march-may
the warm rainy season	june-september

The cool dry season is characterized by dry harmattan

Table 4.1 Landform units in the Kano Project Area.

Landform	Geomorphology	Parent material
Upland Plain	Peneplain of the pre-cambrian basement complex	Unconsolidated material of aeolic/alluvial/colluvial origin over weathered and solid metamorphic rocks; mainly gneisses,schist and quartzites
Higher Terrace	Pleistocene alluvial terrace	Alluvial with aeolic component, mainly sands, loams and clay
Lower Terrace	Holocene allivial terrace and recent flood plain.	Alluvial sands, clay and some gravel

winds from the Sahara. Temperature varies from 15°c to 31.7°c, with lowest in december/january and highest in october and march. There is very little, if any, rainfall during this season. It averages about 11 mm for the whole period (October - March). Relative humidity is low at an average of 36 %.

During the hot dry season, the direction of wind

changes from northeast - southwest to southwest - northeast, and temperature rises with a maximum of 37.1°c. Rainfall, mainly in May, averages to 68 mm, while the average relative humidity is 37%.

The warm rainy season is characterized by cloud carrying winds from the Atlantic. Temperature ranges from 21.0°c to 31.9°c with lowest in July/August. Rainfall averages to about 550 mm with peaks in July or August. The relative humidity is 76% on the average with a peak of 90% in July and August.

Potential evapotranspiration in the area varies from 3100 mm to 6100 mm with peak rate in April/May and lowest in January and August.

4.5 Vegetation

The vegetation consist of mixture of grasses and fire resistant trees and shrubs. Most of the original vegetation has been altered through cultivation practices, bush burning and grazing. The residual vegetation can be grouped into the following:-

i) The cultivated parkland: this consist of areas under permanent cultivation. Only very few trees are left standing or planted.

ii) Open savannah woodland :- this is more or less the natural savannah although bush burning and grazing have altered the natural pattern.

iii) Low shrubland :- this is located in poorly drained areas and eroded bedlands along streams and gullies. These

areas are extensively grazed.

4.6 Landuse

The area is intensively cultivated, with landuse of about 90% in the soils of the upland plain. The main crops grown are sorghum, millet, groundnut and cowpeas. Others are cotton, maize and vegetables. (NEDECCO 1974).

The traditional cropping pattern is :-

sorghum 35%

millet 25%

groundnut 20%

cowpeas 10%

others 10% (NEDECCO 1972)

This pattern has changed in the areas developed for irrigation where the major crops grown are now wheat, tomatoes and maize during the irrigation season.

4.7 Irrigation

The water for irrigation comes from Tiga reservoir (2.1x 1000 million cubic meters capacity) completed in 1975. The conveyance system consist of main canal, branch canals, lateral canals night storage reservoirs, distributary canals and field channels. Water flows continiously for 24 hours upto the night storage reservoirs. The distributary canals and field channels recieve water from the night storage reservoirs during the day time when farmers use siphons to irrigate their farms.

Irrigation normally commences in November and ends in March/April. The major crops irrigated are wheat, tomatoes

and maize. Since the project began, the net area irrigated has risen to about 13,000 hectares per annum.

CHAPTER 5

SOURCES OF DATA

5.1 Rainfall data was obtained from I.A.R.'s meteorological station at Kadawa. The data covers the period 1973 - 1984. Potential evapotranspiration for the same period was computed using Penman's (1948) equation with data obtained from Kano airport. Although 24 kms away from the area, it is considered adequate.

Soil map of the area was from NEDECCO's report "Kano River Project" (1974). Further data on hydrological properties of the soil were obtained from I.A.R.'s publication "Progress Report on Irrigation Research Programme" (1982-83).

The data on landuse was obtained from Hadejia Jama'are river basin development authority and also from NEDECCO. Hydrographs of Kano river were obtained from WRECA, Kano, while water table hydrographs for a limited period (1978-1981) were after Nwa (1982). Data on irrigation water requirments and irrigation efficiencies were after NEDECCO who estimated them from short experiences at the Kadawa pilot scheme (1970-73).

5.2 Model Parameters

For the recharge estimation, the area was divided into three zones based soil properties and irrigation practice.

The first zone (Zone I) consist of areas with deep soils developed for irrigation. This consist mainly of the Upland plain soils except the soil unit P1, underlain by

iron pan. The remaining areas with deep soils that are yet to be developed for irrigation are grouped into Zone II. The third zone, Zone III, consist of areas with shallow soils, predominantly the soil unit P1. These areas were considered unsuitable for irrigation and were not developed for it.

The areas belonging to each zone are inter-mixed, i.e., none of the zones is a single block of area. The difference between Zone I and Zone II is that the former is irrigated while the latter is not.

5.3 Maximum SMD (D)

The available water for each of the soil units in the area was computed using equation 3.1. The moisture contents at field capacity and permanent wilting point were obtained from I.A.R.'s publication "Progress report on irrigation research programme" (1982-83). Only values for the soils of the upland plain (72 % of the area) are available. For the remaining soils, estimates were made from FAO (1979) "Yield Response to Water".

The available water for each zone is found by weighting that of the individual soil units in the zone. The root depth of the various crops grown were then determined for each month after planting, throughout the growing season. The estimates were after Lungley D.R. (1973). The maximum SMD for each crop in a particular month in a given zone is then computed by substituting the root depth and available water for that zone in equation 3.2. The maximum SMD for

the whole zone in the same month is then computed by weighting, areally, that of the individual crops grown in the zones as the landuse dictates.

In computing the maximum SMD for Zone III however, soil depth was used instead of root depth because of the shallowness of the soil in the zone.

5.4 Root Constants

Root constants (RC), given as fractions, (P), of maximum SMD, were obtained from FAO (1979), for the various crops at their different stages of growth. These were multiplied by the individual crop's maximum SMD, calculated previously, to get the individual crop's root constants. The root constant for the whole zone in a particular month was then computed by areal weighting as described previously for the maximum SMD.

The fractions P, known as soil water deplation factors, were obtained as follows :-

For each crop, the crop coefficient, Kx, for the different stages of growth (initial, vegetative, flowering, yielding and harvesting) were obtained from tables in FAO (1979). The crop coefficients are the computed on monthly basis by weighting those of the different stages that fall within that month depending on the period of each stage lapped in the month. This monthly Kx is then multiplied by the month's potential evapotranspiration, PE to obtain the crop's maximum evapotranspiration, ETM. Soil water deplation factors, P, are then obtained from tables, also in

FAO (1979), using the ETM.

5.5 Runoff Coefficient

The runoff coefficient (ROC) was determined from hydrographs of Kano river as follows :-

i) Hydrographs of Kano river, obtained from WRECA (1965-73), were separated into baseflow and direct runoff using one of the methods given by Linsley and Kolher in "Hydrology For Engineers", 1975.

ii) The areas of total hydrographs and baseflow were measured using a planimeter and converted to volume (cubic meters) using the scales of the hydrographs. The difference between the total hydrographs and baseflow gives the volume of direct runoff.

iii) The above procedure was repeated for each of the years (1965-73) and the mean volume of direct runoff was computed.

iv) The volume of mean annual rainfall upstream of the guaging station was determined from a map of the basin on which rainfall isohytes weere super-imposed. The procedure used is as follows:-

a) the areas of the basin upstream of the guaging point, between adjacent isohytes were measured until the whole basin was covered.

b) These areas were multiplied by means of the adjacent isohytes to get the volume of rainfall within each area.

c) the individual volumes were summed up to give the total mean annual volume of rainfall in the basin

upstream of the guaging point.

v) The mean volume of direct runoff was divided by the volume of the mean annual rainfall to give the runoff coefficient.

The maps used were obtained from "Land Resources Of Central Nigeria", volume 7; an Atlas of resources maps.

A value of 0.13 was obtained for the runoff coefficient. This is slightly higher than that obtained by United States Bureau of Rclamation (1968), which is 0.12.

5.6 Weighting Factors

These factors are used to obtain weighted recharge for the whole area from individual recharge estimates in each zone. The factor used for each zone is the ratio of the area of that zone to the total area. For Zone I, it is the ratio of the area irrigated to the total area. For each year, the factors for each zone are computed and used to obtain the weighted recharge estimates for the whole area.

5.7 The Computer Program

The program consist of a main program and a subroutine. The flow chart for the main program is shown in appendix I, while that of the subroutine was shown earlier in fig. 3.2.

The main program consist of four main DO loops, which are nested, and other DO loops that carry out elementary operations on arrays and output the results. Initially data common to all the zones i.e. F, and ROC are inputed and the main arrays used in computations cleared.

The first and outermost DO loop (zonal loop), DO NZN=1,3, then takes control and assigns the computations to each of the three zones in turn. For each zone, the SMD at the beginning of the period of study is read and then control passes to the second or yearly DO loop, DO I= 1,12. This loop carries the computatioms through each of the twelve years of study. For each year, monthly root constants and maximum SMD are inputed before control passes to the third or monthly DO loop, DO J= 1,12.

For each of the twelve months of study, this loop assigns the number of days in the month (M) and the daily rainfall and potential evapotranspiration data for the month are inputed. Control then passes to the fourth or daily DO loop, DO N= 1,M. This is the innermost DO loop and calls the subroutine for each day of the month to compute the recharge and sum up the daily estimates to give monthly estimates.

Upon exit from the daily DO loop, the monthly estimates are multiplied by a weighting factor to give weighted monthly estimates. The third or monthly DO loop then takes control and assigns the next month and so on, till the last month of the year. Upon exit from this loop, the recharge estimates for the twelve months are printed before control passes back to the second or yearly DO loop. This loop assigns the next year until the twelve years of study are covered.

Upon exit from this loop, average monthly and yearly

recharge estimates are computed and printed before the first, outermost or zonal DO loop takes control. It assigns the next zone until all the three zones are covered. Upon exit from this loop, the monthly weighted recharge estimates for the whole area are printed for the twelve years of study. Average monthly and yearly weighted recharge are then computed and printed.

5.8 Sensitivity Analysis

The sensitivity of the model to input data and model parameters was determined by varying the inputs/ model parameters and using the new values to estimate the recharge. The variations of inputs/ model parameters used are shown below :-

RN : ± 5%

PE : ± 6%

ROC : ± 50%

RC : ± 50%

D : ± 50%

F : + 200% , -70%

The difference between the new estimates and the original ones is used to compute the sensitivity ratio SNR, according to equation 5.1, below , after Odigie (1984)

$$SNR \quad \frac{NE - ME}{ME} \times 100 \times \frac{1}{PPV} \qquad 5.1$$

where,

NE = new estimate

ME = model estimate

PPV = percentage parameter variation

From the sensitivity ratios, the sensitivity of the model is determined according to the following four level:-

high		/SNR/ > 1.0
modderate	0.4 ≤	/SNR/ < 1.0
low	0.1 ≤	/SNR/ < 0.4
nil		/SNR/ < 0.1

(Odigie, 1984)

CHAPTER 6

RESULTS AND DISCUSSIONS

In this chapter, the results of the work are presented and discussed. Zone I is first treated followed by Zone II, Zone III and finaly the weighted results. The results of the sensitivity analysis are then presented before closing the chapter.

6.1 Zone I

Recharge for this zone comes from two sources :-

a) Rainfall in the summer months

b) Irrigation water applied to the fields during the cold season.

Table 6.1 shows the estimated recharge from both sources. Recharge takes place mainly in the rainy months of June to September and the irrigation season months of December to February. One exception was in the year 1979 when recharge occured in May. This is due to the high rainfall of 128 mm in the month (the highest of all the years). The distribution of rainfall within the month also count since in the years 1978 and 1980, the rainfall in May was also high (113mm and 120mm) and yet there was no recharge during the month in these years. This is more so when the initial soil moisture deficit (IMD) at the beginning of May in 1979 is higher than that in 1980 (69.1 vs 64.6).

Recharge in the month of June occured only in the years 1979, 1980 and 1982, amounting to 24.3mm, 1.5mm and 14.1mm respectively. The year 1979 has the highest rainfall for

TABLE 6.1 : MONTHLY AND ANNUAL RECHARGE ESTIMATE (MM) ZONE I

	1979		1980		1981		1982		1983		1984	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	17.6	101.1	17.6	101.1	22.0	101.5	17.2	102.0	17.6	96.2	19.5	98.5
Feb	0.0	97.8	0.0	97.6	0.0	100.2	0.0	76.8	0.0	87.3	0.0	109.0
Mar	0.0		0.0		0.0		0.0		0.0		0.0	
Apr	76.1		76.9		80.4		73.6		74.1		73.5	
May	68.6	5.0	64.6		55.5		61.8		64.8		50.5	
Jun	19.3	24.3	25.4	1.5	25.4		38.4	14.1	47.5		25.4	
Jul	16.3	64.0	34.9		23.3	15.3	35.9	7.2	38.9		40.0	
Aug	6.6	34.2	14.3	185.5	10.0	4.5	61.3		51.5	47.2	29.4	
Sep	19.1	17.5	5.1		10.2	29.7	8.1	20.6	14.7		56.4	
Oct	68.4		71.0		68.9		75.3		68.0		69.8	
Nov	85.7		88.1		87.2		91.8		85.4		85.4	
Dec	29.3	10.5	28.8	12.5	32.2	32.8	22.9	40.6	27.0		27.0	
TOTAL		354.0		398.1		284.0		261.3		230.7		207.5

Imd = initial soil moisture deficit. Rech = recharge.

TABLE 6.1 : MONTHLY AND ANNUAL RECHARGE ESTIMATE (MM) ZONE I

	1973		1974		1975		1976		1977		1978	
Month	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	94.9		51.0	26.0	40.6	42.4	16.4	101.2	18.4	98.5	18.0	100.2
Feb	94.9		0.0	53.4	0.0	49.6	0.0	91.1	0.0	101.6	0.0	96.0
Mar	94.9		0.0		0.0		0.0		0.0		0.0	
Apr	94.9		67.9		68.0		76.8		76.7		76.9	
May	94.9		66.6		67.1		74.1		73.8		74.3	
Jun	94.9		53.6		28.8		34.5		64.6		25.4	
Jul	63.4	48.9	44.6	25.3	31.2	8.5	31.2		37.7		33.3	78.5
Aug	1.3	88.3	18.5	6.0	0.0	18.5	56.6	12.1	56.4	185.5	9.8	57.3
Sept	69.9		13.8		0.0	65.8	36.7		7.5	19.6	16.7	
Oct	72.9		60.2		47.7		45.3		71.4		70.2	
Nov	90.6		79.3		78.4		65.9		79.7		86.4	
Dec	29.2		28.1		29.3	13.4	29.5	5.7	29.3	8.6	29.6	9.4
Total		137.2		109.7		198.2		210.1		413.8		341.4

Imd = initial soil moisture deficit. Rech = recharge.

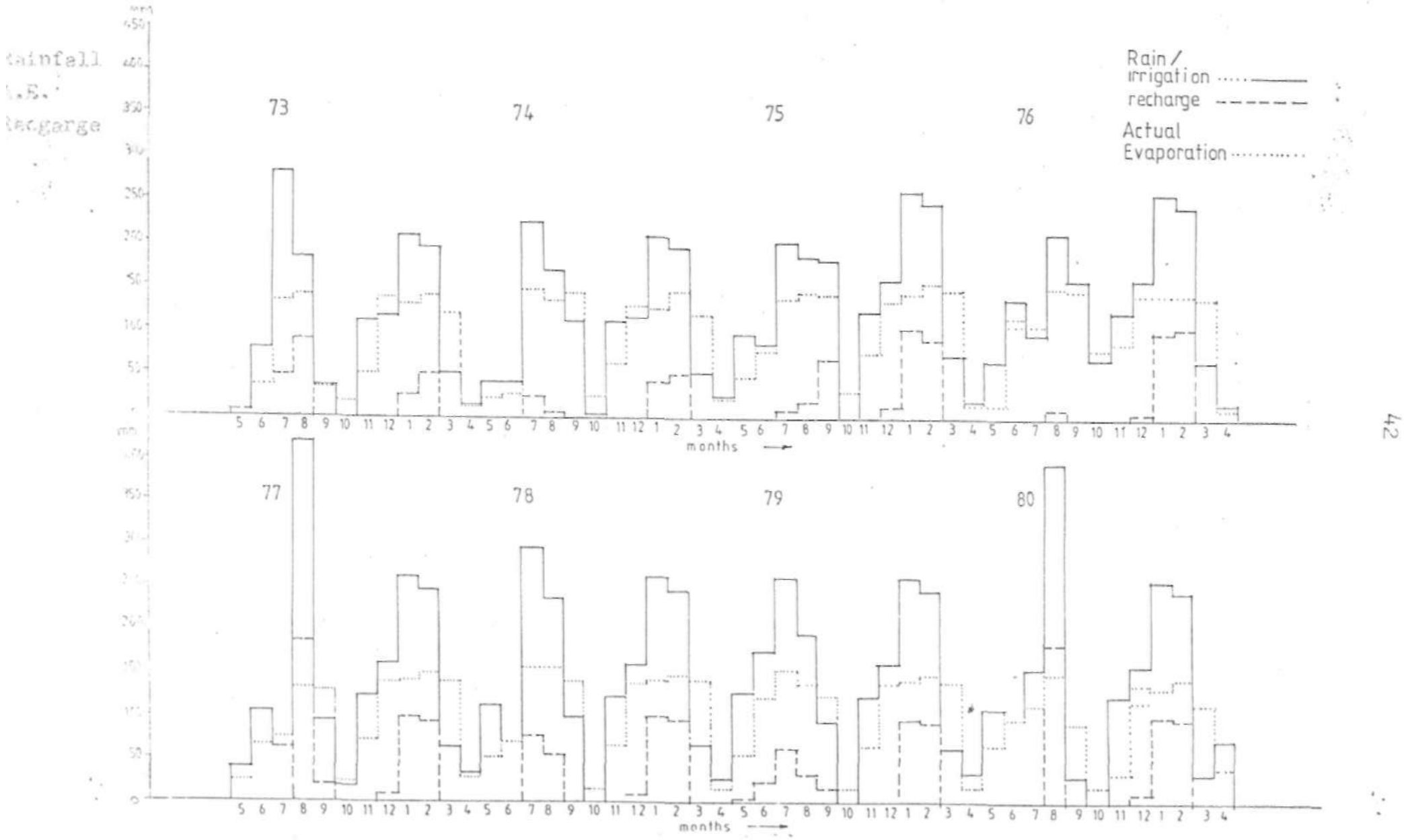


Figure 6.1: Comparision of rainfall, A.E. and recharge: ZONE 1

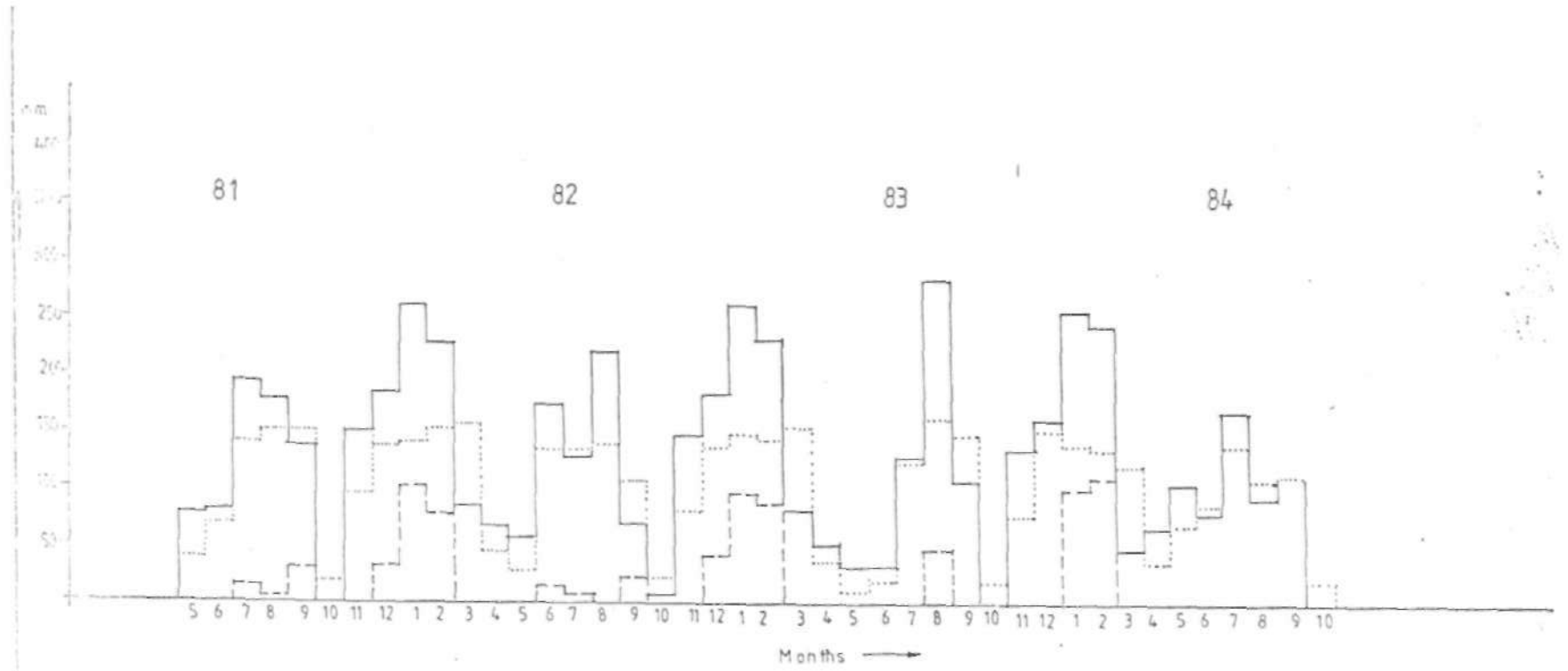


Figure 6:1 (con'd)

both May and June and consequently the lowest IMD in June. Therefore it is not suprising that it has the highest recharge in June. In 1980, the rainfall in May was also high giving rise to low IMD in June. This coupled with the fairly high rainfall of 102.0mm in June resulted in the occurence of the recharge. For 1982, the recharge can be attributed to the high rainfall of 170mm (second highest) in the month.

The bulk of the recharge in the rainy season occurs in July, August and September, with August having the highest amount followed by July. Together these months account for 99% of the recharge in the rainy seasons of all the years except 1979 and 1982 where they account for 80% and 66% respectively.

The month of July has a range of 0.0 - 78.5mm in recharge with an average of 20.6mm. In the month of August, the recharge is highest with a range of 0.0 - 185.5mm and an average of 53.2mm. This is because August has a low IMD coupled with the highest rainfall. Only in the years 1982 and 1984 was there no recharge in August. For 1984, this is due to the relatively low rainfall of 91.5mm in the month. In 1982 the distribution of the 220mm rainfall in the month was sparse coupled with the highest IMD of 61.1mm for the month. In the years i977 and 1980, the amount of recharge in August exceeded the actual evapotranspiration. This is due to the peak rainfall in August in these years (420mm and 397mm respectively).

The month of September has the lowest IMD among the wet season months. In the years 1977, 1979, 1981 and 1982 the rainfall in September is less than the actual evapotranspiration. Thus on "monthly" basis, it appears as if recharge has occured in the the month in these years despite the existance of SMD. However,if we look at the situation on a daily basis, it is possible for recharge to occur on some days (i.e. SMD = 0.0 on these days) and the cumulative sum of the SMD to be positive for the month. The same applies to the month of luly in 1982.

During the irrigation season, recharge occurs mainly the months of December, January and February. The recharge in these months shows a more or less regular pattern which can be attributed to the more regular pattern of water application for irrigation in these months. In November there is no recharge because of the high IMD carried over from the dry month of October. By the end of the month it is lowered to an average 26.3mm (from 76.5mm).

Recharge occurs in December, ranging from 0.0 - 40.6mm with an average of 11.1mm. But the bulk of the recharge in the irrigation season occurs in January and February with an average of 80.0mm for each of the months. This is about 93% of the total recharge in this season. For most of the years the actual recharge is, in fact, around 100mm except in the years 1974 and 1975 when it averages to 36.0mm in January and 51.0mm in February. These are the years in which irrigation commenced and the months had a higher IMD due to

lower water application.

The annual recharge in Zone I ranges from 105.2mm in 1973 to 413.8mm in1977 with an average of 262.2mm. An average 65% of the annual recharge occurs during the irrigation season, except in 1973 , when it was 100% from rainfall. Most of the variation in annual recharge is due to the variation in recharge during the rainy season which ranges from 0.0mm - 205.0mm with an average of 90.4mm. For the irrigation season, the range is 78.4mm - 234.5mm, with an average of 187.4mm.

6.2 Zone I Without Irrigation

In order to evaluate the effect of irrigation on recharge, the estimate was carried out for Zone I with irrigation during the dry season. As most of the land during this season is fallow, the root constants and maximum SMD during the dry season are assigned those values corresponding to fallow conditions.

The result of the estimate is shown in table 6.2, together with that of the case with irrigation for comparision. without irrigation, recharge occurs only in the rainy season months of June to September. For the month of June, recharge occurs only in the years 1979, 1980 and 1982 amounting to 24.2mm, 1.5mm and 13.3mm respectively. In July it varies from o.omm to 78.5mm with an average of 20.7mm. The peak occured in 1978 which also has the higest rainfall for July.

The month of August has the highest monthly recharge

TABLE 6.2 : COMPARISION OF IMD AND RECHARGE (MM). ZONE I

MONTH	Irrig. 1973		No Irrig. 1973		Irrig. 1974		No Irrig. 1974		Irrig. 1975		No Irrig. 1975	
	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	94.9		94.9		51.0	26.0	90.6		40.6	42.4	79.3	
Feb	94.9		94.9		0.0	52.4	90.6		0.0	49.6	79.3	
Mar	94.9		94.9		0.0		90.6		0.0		79.3	
Apr	94.9		94.9		67.9		90.6		68.0		79.3	
May	94.9		94.9		66.6		90.6		67.1		79.3	
Jun	94.9		94.9		53.6		77.5		28.8		41.0	
Jul	63.4	48.9	63.4	48.9	44.6	25.3	68.6	20.2	31.2	8.5	32.3	8.5
Aug	1.3	88.3	1.3	88.3	18.5	6.0	18.5	6.0	0.0	18.5	0.0	18.5
Sep	69.9		69.9		13.8		13.8		0.0	65.8	0.0	65.8
Oct	72.9		72.9		60.2		60.2		47.7		47.7	
Nov	90.6		90.6		79.3		79.3		78.4		78.4	
Dec	29.2		90.6		28.1		79.3		29.3	13.4	78.4	
TOTAL		137.2		137.2		109.7		26.2		198.2		92.8

Imd = initial soil moisture deficit. Rech = recharge.

TABLE 6.2 (CON'T) (mm)

MONTH	Irrig. 1976		No Irrig. 1976		Irrig. 1977		No Irrig. 1977		Irrig. 1978		No Irrig. 1978	
	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	16.4	101.2	78.4		18.4	98.5	65.9		18.0	100.2	79.7	
Feb	0.0	91.1	78.4		0.0	101.6	65.9		0.0	96.0	79.7	
Mar	0.0		78.4		0.0		65.9		0.0		79.7	
Apr	76.8		78.4		76.2		65.9		76.3		79.7	
May	74.1		78.4		73.3		65.9		73.8		79.7	
Jun	34.5		38.9		64.1		56.4	185.5	25.4		25.4	
Jul	31.2		31.1		37.7		37.7		33.3	78.5	33.3	78.5
Aug	56.6	12.1	56.6	12.1	56.4	185.5	56.4	185.5	9.8	57.3	9.8	57.3
Sep	36.7		36.7		7.5	19.6	7.5	19.6	16.7		16.7	
Oct	45.3		45.3		71.4		71.4		70.2		70.2	
Nov	65.9		65.9		79.7		86.9		86.9			
Dec	29.5	5.7	65.9		29.3	8.6	79.7		29.6	9.4	86.9	
TOTAL		210.1		12.1		413.8		205.1		341.3		135.8

Imd = initial soil moisture deficit. Rech = recharge.

TABLE 6.2 CON'T. (mm)

MONTH	Irrig. 1979 Imd	Irrig. 1979 Rech	No Irrig. 1979 Imd	No Irrig. 1979 Rech	Irrig. 1980 Imd	Irrig. 1980 Rech	No irrig. 1980 Imd	No irrig. 1980 Rech	Irrig. 1981 Imd	Irrig. 1981 Rech	No Irrig. 1981 Imd	No Irrig. 1981 Rech
Jan	17.6	101.1	86.9		17.6	101.1	85.7		22.0	101.5	88.1	
Feb	0.0	97.3	86.9		0.0	97.6	85.7		0.0	100.2	88.1	
Mar	0.0		86.9		0.0		85.7		0.0		88.1	
Apr	76.1		86.9		76.3		85.7		80.4		88.1	
May	68.6	5.0	82.5		64.0		76.0		55.5		63.1	
Jun	19.3	24.3	25.4	24.3	25.4	1.5	25.4	1.5	25.4		25.4	
Jul	16.3	64.0	16.3	64.0	34.9		34.9		23.3	15.3	23.3	15.3
Aug	6.6	34.2	6.6	34.2	14.3	185.4	14.3	185.4	10.0	4.5	10.0	4.5
Sep	9.1	17.5	9.1	17.5	5.1		5.1		10.2	29.7	10.2	29.7
Oct	68.4		68.4		71.0		71.0		68.9		68.9	
Nov	85.7		85.7		88.1		88.1		87.2		87.2	
Dec	29.3	10.5	85.7		28.8	12.5	88.1		32.2	32.2	87.2	
TOTAL		354.5		140.0		398.1		186.9		284.0		49.5

Imd = initial soil moisture deficit. Rech = recharge.

TABLE 6.2 CON'T. (mm)

MONTH	Irrig. 1982 Imd	Irrig. 1982 Rech	No Irrig. 1982 Imd	No Irrig. 1982 Rech	Irrig. 1983 Imd	Irrig. 1983 Rech	No Irrig. 1983 Imd	No Irrig. 1983 Rech	Irrig. 1984 Imd	Irrig. 1984 Rech	No Irrig. 1984 Imd	No Irrig. 1984 Rech
Jan	17.2	102.2	87.2		17.6	96.2	91.8		19.5	98.5	85.4	
Feb	0.0	76.8	87.2		0.0	87.3	91.8		0.0	109.0	85.4	
Mar	0.0		87.2		0.0		91.8		0.0		85.4	
Apr	0.0		87.2		74.1		91.8		73.5		67.2	
May	61.8		82.9		64.8		91.8		50.5		32.3	
Jun	38.4	14.1	59.5	13.3	47.5		74.5		25.4		40.0	
Jul	35.9	7.2	35.9	7.2	38.9		64.7		40.0		29.4	
Aug	61.3		61.3		51.5	**47.2**	51.5	47.2	29.4		56.4	
Sep	8.1	**20.6**	8.1	**20.6**	14.7		14.7		56.4		69.8	
Oct	75.3		75.3		68.0		68.0		69.8		85.4	
Nov	91.8		91.8		85.4		85.4		85.4			
Dec	22.9	40.6	91.8		27.0		85.4		27.0		-	
TOTAL		201.2		41.1		230.7		47.2		207.5		0.0

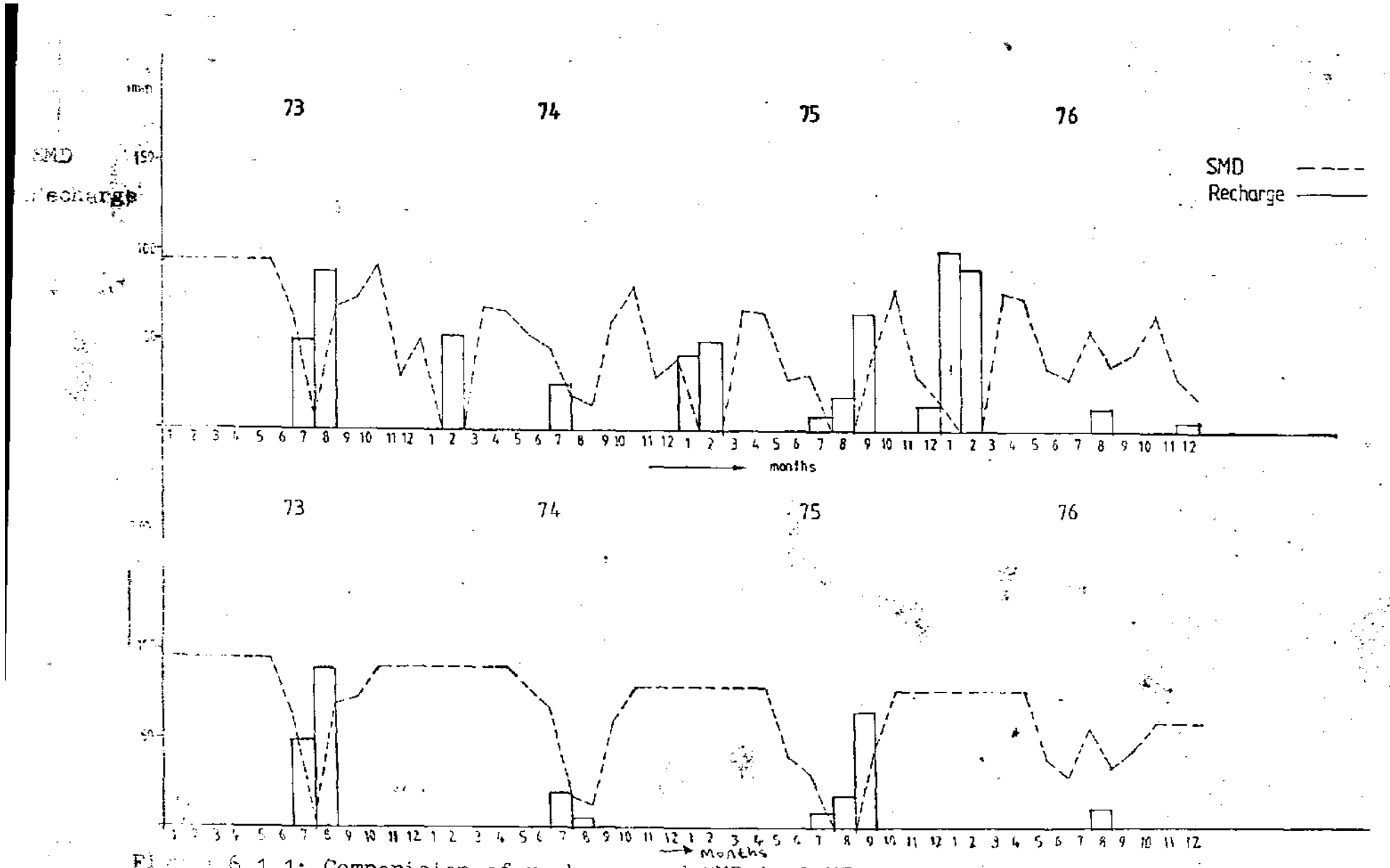
Imd = initial soil moisture deficit. **Rech = recharge.**

ranging from 0.0mm - 185.5mm, with an average of 54.1mm. The highest was in 1977 which had a peak rainfall of 420.0mm in august. Only in two of the years, 1982 and 1984, was there no recharge in August. In 1982, this is due to the high IMD of 61.0mm in the month (average IMD for August is 26.3mm) coupled with sparse distribution of rainfall. For 1984, the rainfall in August was relatively low at 91.0mm (average for August is 231.4mm) and together with the reasons above, resulted in zero recharge . In September , the last month of the rainy season, recharge ranges from 0.0mm - 65.8mm with an average of 12.3mm. This month also has the lowest IMD due to high recharge in the previous month, i.e, August.

The annual recharge varies from 0.0mm in 1984 to 205.1mm in 1977. Although not the year with the highest rainfall, about 56% of the annual rainfall of 739.3mm for the year fell in August. This lead to the highest recharge in the month as previously discussed. The year 1980 also has a high propotion of its annual rainfall in August (47%) and it has the second highest annual recharge. The zero annual recharge in 1984 is due to the low annual rainfall of 589.1mm and its sparse distribution from April to September.

.3 *Effect Of Irrigation*

The effect of on recharge irrigation can be seen from table 6.2 and figure 6.1.1. The main effect is the occurence of recharge in the dry season months of December - February. Under irrigation, the high SMD in October



Fi[illegible] 6.1.1: Comparision of recharge and SMD in ZONE 1, with (top) and without (bottom) irrigation

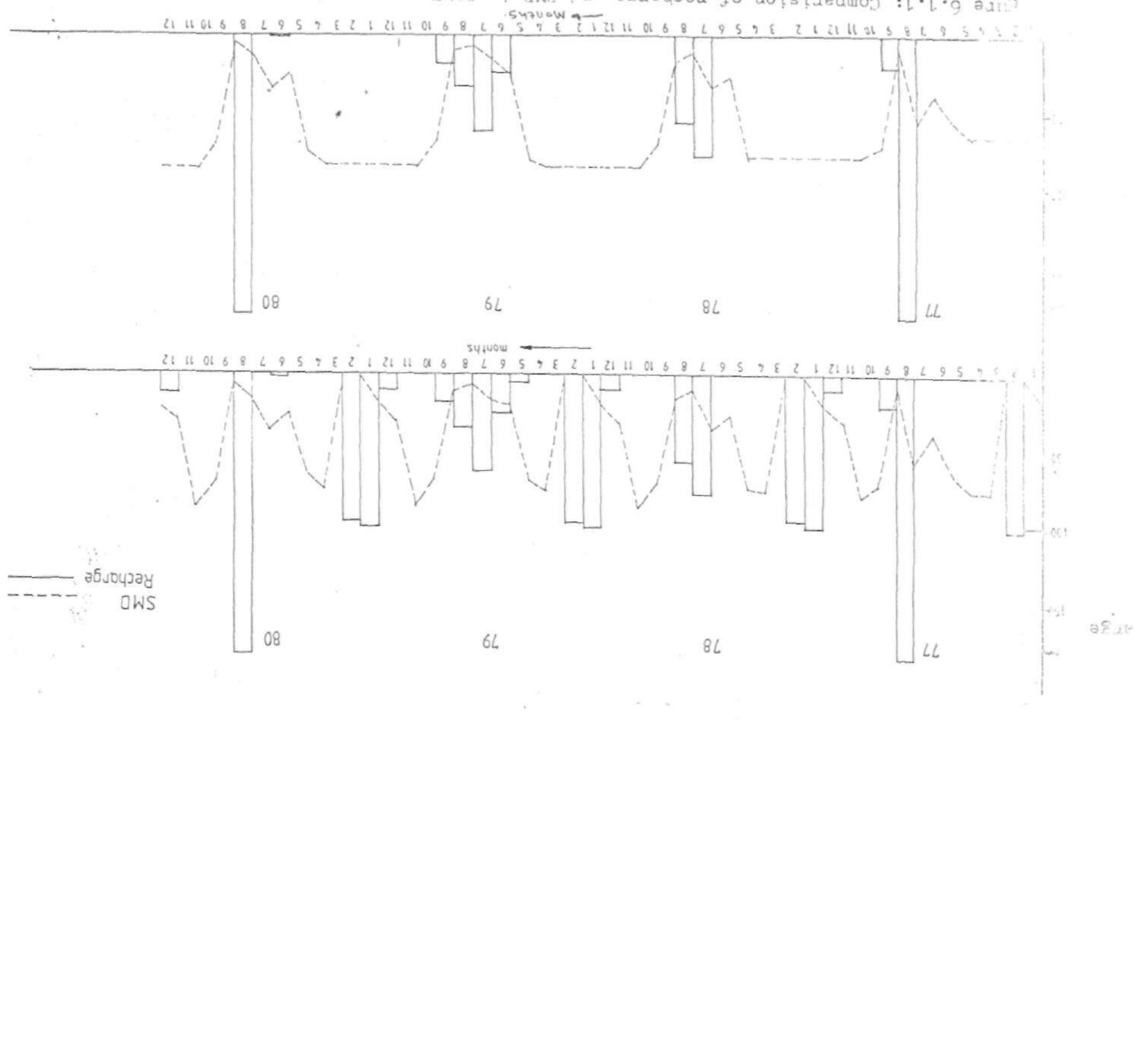


Figure 6.1.1: Comparision of recharge and SMD in ZONE 1, with (top) and without (bottom) irrigatio

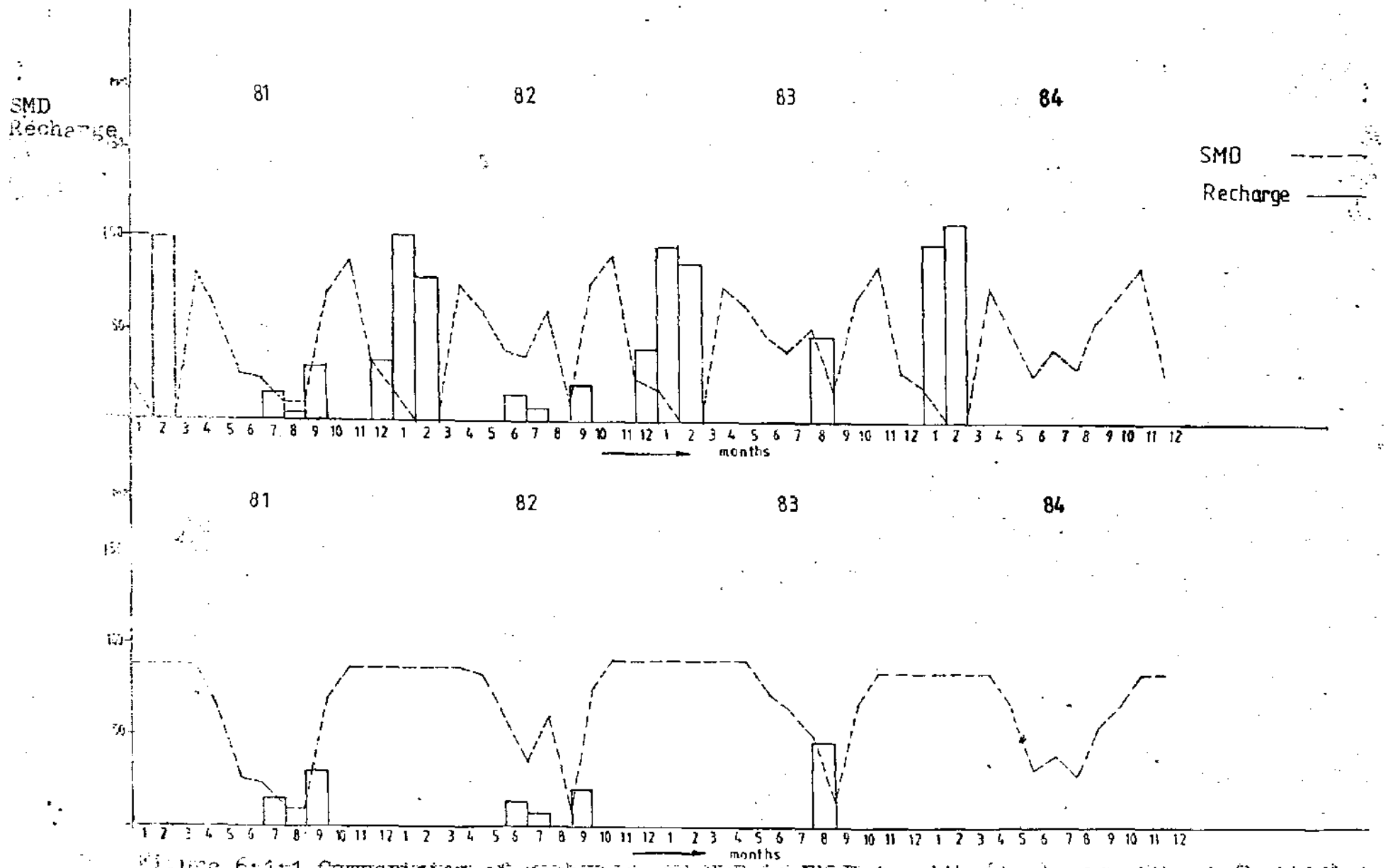


Figure 6:1:1 Comparision of recharge and SMD in ZONE 1, with (top) and without (bottom) irrigation.

rapidly drops in November and by December, the monthly recharge averages 11.1mm. Recharge is highest in January and February with an average of 80.7mm and 80.0mm respectively. During these month, the water application is at its highest and by the end of these months, the SMD is at its lowest.

In March the irrigation rate drops as crops approach harvesting stage and the SMD rises sharply again. The harvesting of crops in april Checks the rise (as D suddenly drops) but the SMD is then only slightly lower than that corresponding to the case without irrigation. This limits the effect of irrigation on recharge in the rainy months and mostly depends on distribution of rainfall events in the months of May, June and July.

In most of the years, the early rains are sparsely distributed such that the SMD for the irrigated and unirrigated conditions equalize in May and June before any recharge event occurs. Subsequent rainfall then have the same effect for both cases. If the first rains are heavy and steady however, the difference in SMD between the two conditions is translated into a difference in the first recharge event.

Thus in July 1974, recharge recharge for Zone I was higher by 5.1mm under irrigation than otherwise. Also in 1979 recharge occured in May, the only recharge event for the month in all the years, due to irrigation.

The annual recharge without irrigation is far less than

that with irrigation, due mainly to absence of recharge in the dry season. The average annual recharge is 262.0mm with irrigation and 89.5mm without irrigation. Thus an average of 172mm in recharge is contributed by irrigation annually in Zone I. In some of the years with low rainfall, over 90% of the recharge comes from irrigation. Table 6.3 shows a comparision for both cases.

The analysis of recharge in Zone I is shown in table 6.4. The actual evapotranspiratiion rises sharply from 564.0mm in 1973 to 1104.1mm in 1974. This is due to the higher irrigation for 1974 than 1973. Also from 1973 to 1975, there is an increase in soil moisture storage. From then onwards however, the change in soil moisture storage is slight and often alternating. Again this is explained by the rise in irrigation amountwhich rises from 1973 to 1976 and thereafter is more or less steady. the low amount of irrigation for 1984 is because the study ended with the end of the rainy season in October of the year and thus irrigations for November and December are not included. This also explains the sharp decrease in soil moisture storage in the year.

The highest number occurence of recharge (NDR) was in 1977 with 27 incidences. This year also has the highest annual recharge. But the year with the lowest NDR is not the one with lowest recharge. The average NDR is 17 with ten for the irrigation season and 7 for the rainy season.

TABLE 6.3: COMPARISION OF ANNUAL RECHARGE IN ZONE I. (mm)

YEAR	With Irrigation	Without Irrigation	Difference
1973	137.2	137.2	0.0
1974	109.7	26.2	83.5
1974	198.2	92.8	105.4
1976	210.1	12.1	198.0
1977	413.8	205.0	208.8
1978	341.3	135.8	205.5
1979	354.0	140.0	214.0
1980	398.1	186.9	211.2
1981	284.0	49.5	234.5
1982	261.2	41.0	220.2
1983	230.7	47.2	183.5
1984	207.5	0.0	207.5
AVERAGE	262.1	89.5	172.6

6.4 Zone II

Zone II areas suitable for irrigation but not yet developed for it. Thus recharge can occur only during the rainy season. Table 6.5 and 6.6 show the result of the estimate while a comparision of rainfall, actual evapotranspiratio and recharge is shown in figure 6.2.

The pattern is very similar to the result for the rainy season in Zone I. Recharge occurs mainly in the months of June to September. Unlike in Zone I, there is no recharge in the month of may, 1979. This is due to the higher IMD in May 1979 for Zone II which is carried over from October of the previous year. Likewise the smaller recharge in the month of June 1982 and July 1974 for Zone II is due to the higher IMD in these months than for Zone I. The month of August has the highest recharge, accounting for about 60% of the annual recharge.

The annual recharge varies from 0.0mm in 1984 to 205.1mm in 1977. However 1977 does not have the highest rainfall (1978, 1979 and 1980 all have higher amount of rainfall) but about 420.0mm or 56% of the total rainfall for the year occured in August, resulting in the highest recharge for the month. The only other year in which August has a high propotion of the rainfall is 1980 (47% of 832) and it has the second highest annual recharge.

The lack of recharge in 1984 is due to the low rainfall of 589.1mm in the year (average annual rainfallis 710mm) coupled with the fact that it is spread over six months,

TABLE 6.5 : MONTHLY AND ANNUAL RECHARGE ESTIMATES (MM) ZONE II

	1973		1974		1975		1976		1977		1978	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	94.9		90.6		79.3		78.4		65.9		79.7	
Feb	94.9		90.6		79.3		78.4		65.9		79.7	
Mar	94.9		90.6		79.3		78.4		65.9		79.7	
Apr	94.9		90.6		79.3		78.4		65.9		79.7	
May	94.9		90.6		79.3		78.4		65.9		79.7	
Jun	94.9		77.5		41.0		38.9		56.7		25.4	
Jul	63.4	54.5	68.6	20.2	32.3	8.5	31.1		37.7		33.3	78.5
Aug	1.3	88.3	18.5	6.0	0.0	18.5	56.6	12.1	56.4	185.5	9.8	62.5
Sep	69.9		13.8		0.0	65.8	36.7		7.5	19.6	21.9	
Oct	72.9		60.2		47.7		45.3		71.4		70.7	
Nov	90.6		79.3		78.4		65.9		79.7		86.9	
Dec	90.6		79.3		78.4		65.9		79.7		86.9	
TOTAL		142.8		26.2		92.8		12.1		205.1		141.0

Imd=initial soil moisture deficit. Rech=recharge

TABLE 6.5, CON'T. (mm)

	1979		1980		1981		1982		1983		1984	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	86.9		85.7		88.1		87.2		91.8		85.4	
Feb	86.9		85.7		88.1		87.2		91.8		85.4	
Mar	86.9		85.7		88.1		87.2		91.8		85.4	
Apr	86.9		85.7		88.1		87.2		91.8		85.4	
May	82.5		76.0		63.1		82.9		91.8		67.2	
Jun	25.4	24.3	25.4	1.5	25.4		59.5	13.3	74.5		32.3	
Jul	16.3	64.0	34.9	0.0	23.3	15.3	35.9	7.2	64.7		40.0	
Aug	6.6	34.2	14.3	185.4	10.0	9.5	61.3	0.0	51.5	47.2	29.4	
Sep	9.1	17.5	5.1		15.2	24.7	8.1	20.6	14.7		56.4	
Oct	68.4		71.0		68.9		75.3		68.0		69.8	
Nov	85.7		88.1		87.2		91.8		85.4		85.4	
Dec	85.7		88.1		87.2		91.8		85.4		85.4	
TOTAL		140.0		186.9		49.5		41.1		47.2		0.0

Imd=initial soil moisture deficit. Rech=recharge

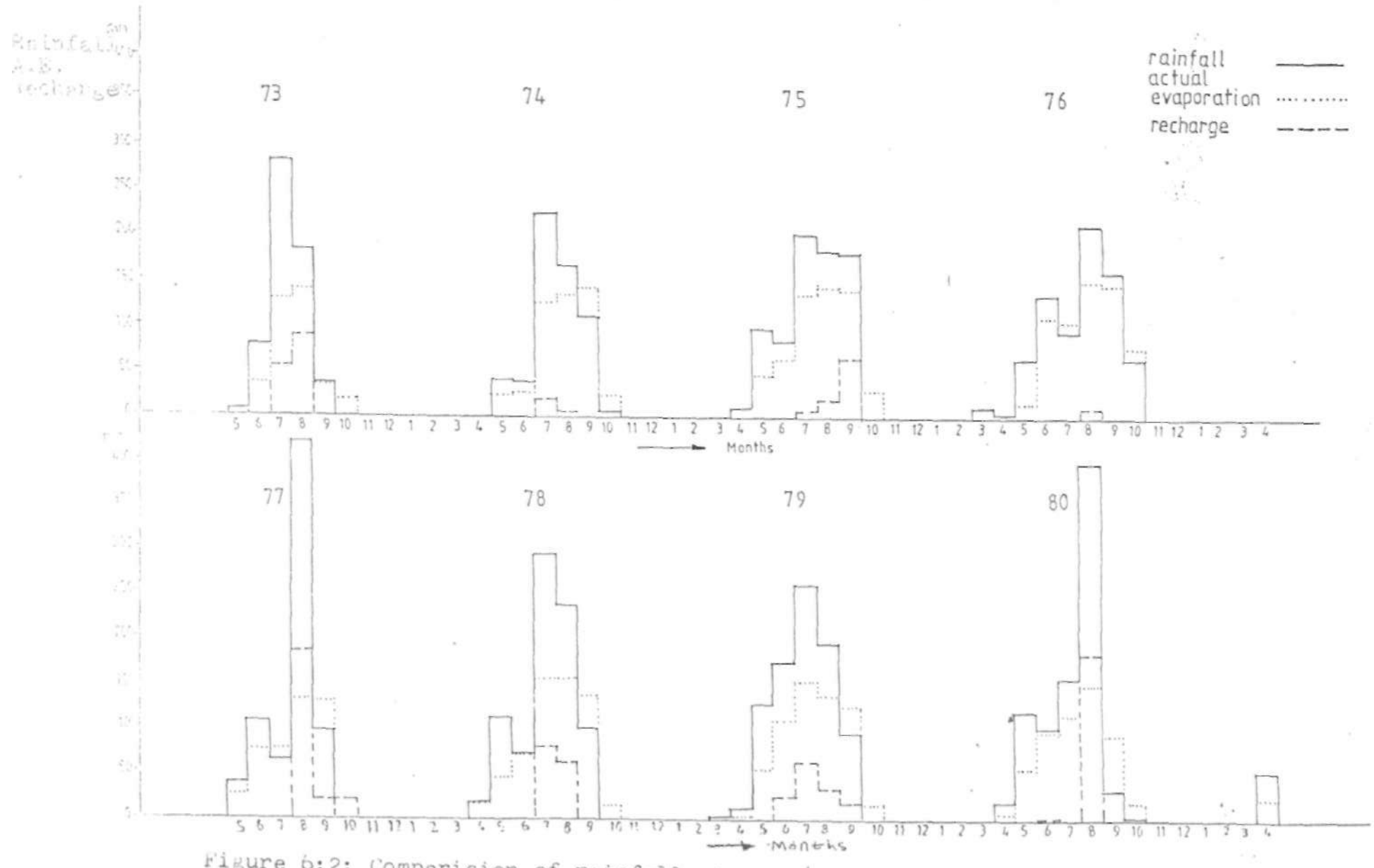


Figure 6:2: Comparision of rainfall, A.E. and recharge: ZONE 2

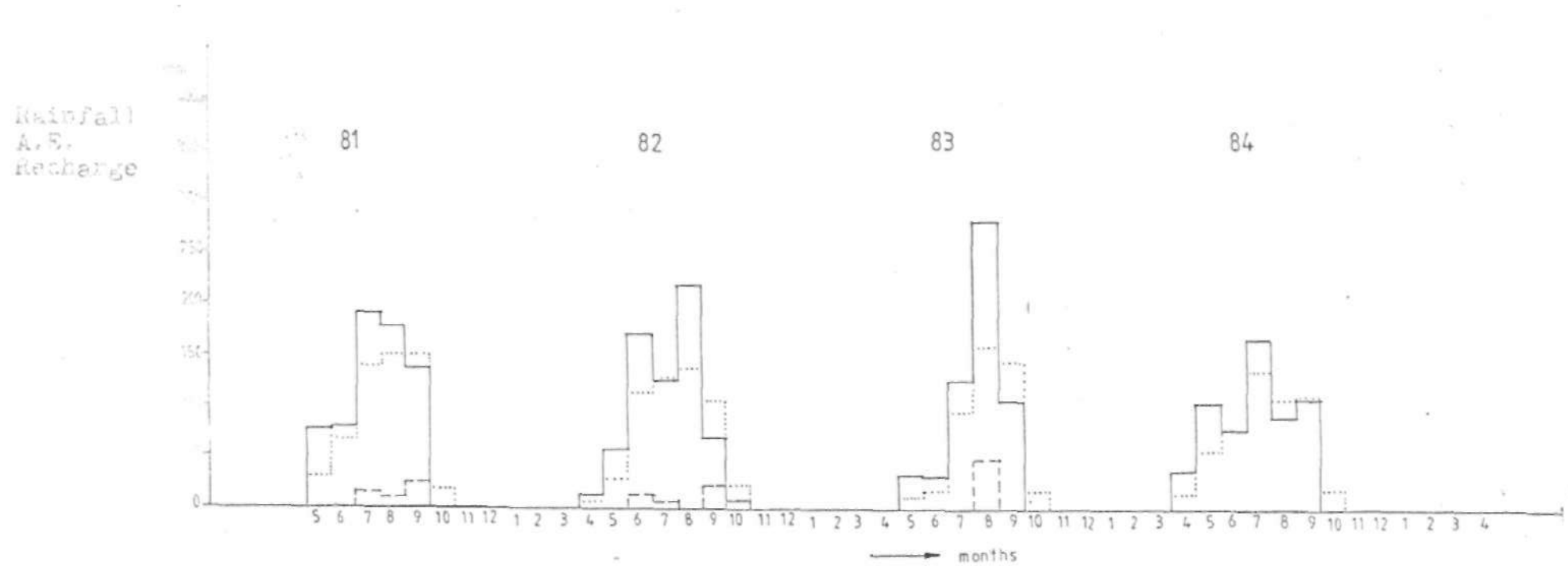


Figure 6:2 (con'd)

TABLE 6.6 : ANALYSIS OF ANNUAL RECHARGE, ZONE II (mm)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Average
RN	586.0	594.6	763.4	749.2	739.3	835.2	872.3	832.4	721.3	666.6	579.3	589.1	710.7
ROF	70.9	70.7	89.8	90.7	89.3	101.3	111.2	101.7	88.1	82.2	72.8	66.4	86.3
AE	368.0	486.4	580.0	633.8	458.7	600.1	619.7	546.3	588.9	547.9	452.8	525.6	533.5
S	4.3	11.3	0.9	12.5	-13.8	-7.2	1.2	-2.4	0.9	-4.6	6.4	2.8	0.8
Rec	142.8	26.2	92.8	12.1	205.0	141.0	140.1	186.9	49.2	41.0	47.2	0.0	90.4
NDR	11	4	12	2	17	7	12	11	7	3	5	0	7.7

RN= rainfall. ROF= runoff. AE= actual evapotranspiration.

S= change in soil moisture storage. Rec= recharge. NDR= No. of recharge incidences.

April - September. In that year, the months of April May and September all have higher than average rainfall while the months of June, July and August lower than average. The rainfall in August was 91.0mm, the lowest of all the years (for a month which has an average of 231mm rainfall).

The number of incidences of recharge is highest in 1977, which also has the highest recharge. Generally, the higher the NDR the higher the recharge.

6.5 Zone III

This zone consist of areas with shallow soils Unsuitable for irrigation. The results of the recharge estimates are shown in table 6.7 and table 6.8. The comparition of rainfall, actual evapotranspiration and recharge is shown in figure 6.3.

The estimates follow the general pattern described for Zone I and Zone II. However, because of the lower values of maximum SMD (D) and root constants (RC) in Zone III, the monthly recharge estimates tend to be higher. For examole, the average monthly recharge for July, August and September in Zone III are 30.6mm, 69.3mm and 14.9mm respectively while for Zone II, the corresponding are 20.7mm, 54.1mm and 12.3mm respectively. Also the lower values of RC and D resulted in more incidences of recharge in the month of october, 1976.

The average annual recharge of 122.7mm is higher than that of Zone II (90.4mm) and so is the number of incidencies, NDR (10.5 vs 7.6 yearly average). Actual

TABLE 6.7 : MONTHLY AND ANNUAL RECHARGE ESTIMATES (MM) ZONE III

	1973		1974		1975		1976		1977		1978	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	37.3		40.6		37.3		37.3		33.9		37.3	
Feb	37.3		40.6		37.3		37.3		33.9		37.3	
Mar	37.3		40.6		37.3		37.3		33.9		37.3	
Apr	37.3		40.6		37.3		37.3		33.9		37.3	
May	37.3		40.6		37.3		37.3	0.4	33.9		37.3	25.8
Jun	37.3		27.6		10.2		25.4		25.4		25.4	
Jul	22.7	73.6	34.6	43.9	34.9	26.6	33.7		35.5		35.5	85.8
Aug	1.3	88.3	18.5	13.5	0.0	27.4	37.9	38.6	38.1	216.2	9.8	70.7
Sep	39.1		13.8		0.0	65.8	34.0	4.1	7.5	19.6	21.9	
Oct	40.6		29.7		32.2		26.1	0.9	35.3		35.0	
Nov	40.6		37.3		37.3		33.9		37.3		37.3	
Dec	40.6		37.3		37.3		33.9		37.3		37.3	
TOTAL		147.7		57.4		119.8		44.0		235.8		182.3

Imd=initial soil moisture deficit. Rech= recharge.

TABLE 6.7, CON'T. (MM)

	1979		1980		1981		1982		1983		1984	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	37.3		37.3		38.3		38.4		38.9		35.7	
Feb	37.3		37.3		38.3		38.4		38.9		35.7	
Mar	37.3		37.3		38.3		38.4		38.9		35.7	
Apr	37.3		37.3		38.3		38.4		38.9		24.2	
May	32.9	15.0	27.7		25.4	6.7	34.0		38.9		24.2	
Jun	19.3	21.7	25.4		25.4		25.4	24.7	25.4		25.4	
Jul	16.3	75.7	35.5	4.4	23.5	36.6	34.1	16.5	31.8		36.6	4.0
Aug	6.6	55.2	0.0	199.6	10.0	14.5	39.2	28.1	29.3	79.6	7.4	
Sep	9.1	21.9	5.1		15.2	27.7	0.0	28.7	14.7		19.5	10.8
Oct	32.5		38.3		38.4		38.9		35.0		33.3	
Nov	37.3		38.3		38.4		38.9		35.7		35.7	
Dec	37.3		38.3		38.4		38.9		35.7		35.7	
TOTAL		189.5		204.0		85.5		98.0		79.6		14.8

Imd= initial soil moisture deficit. Rech= recharge.

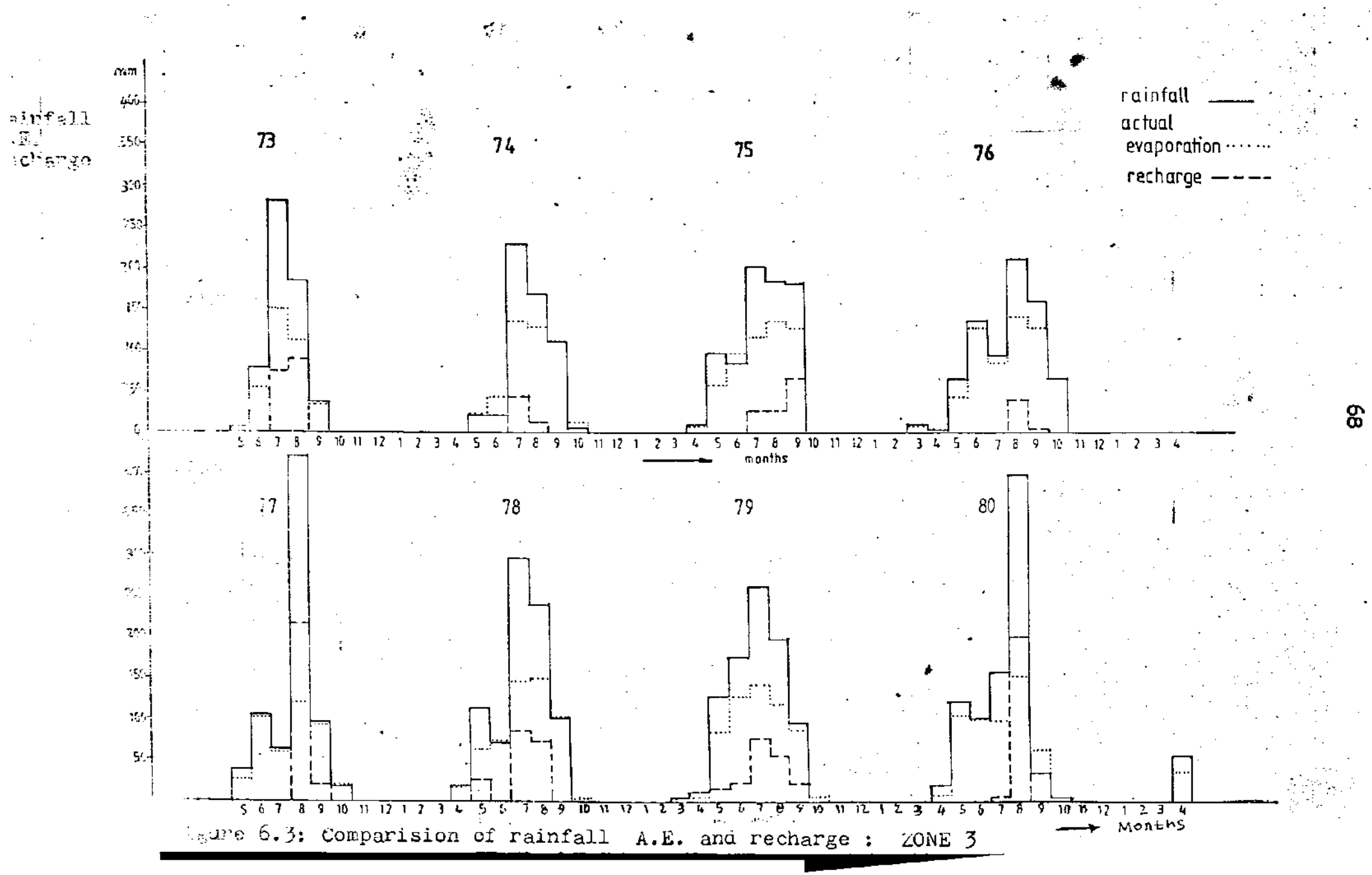


Figure 6.3: Comparision of rainfall A.E. and recharge : ZONE 3

Figure 6.3 (con't)

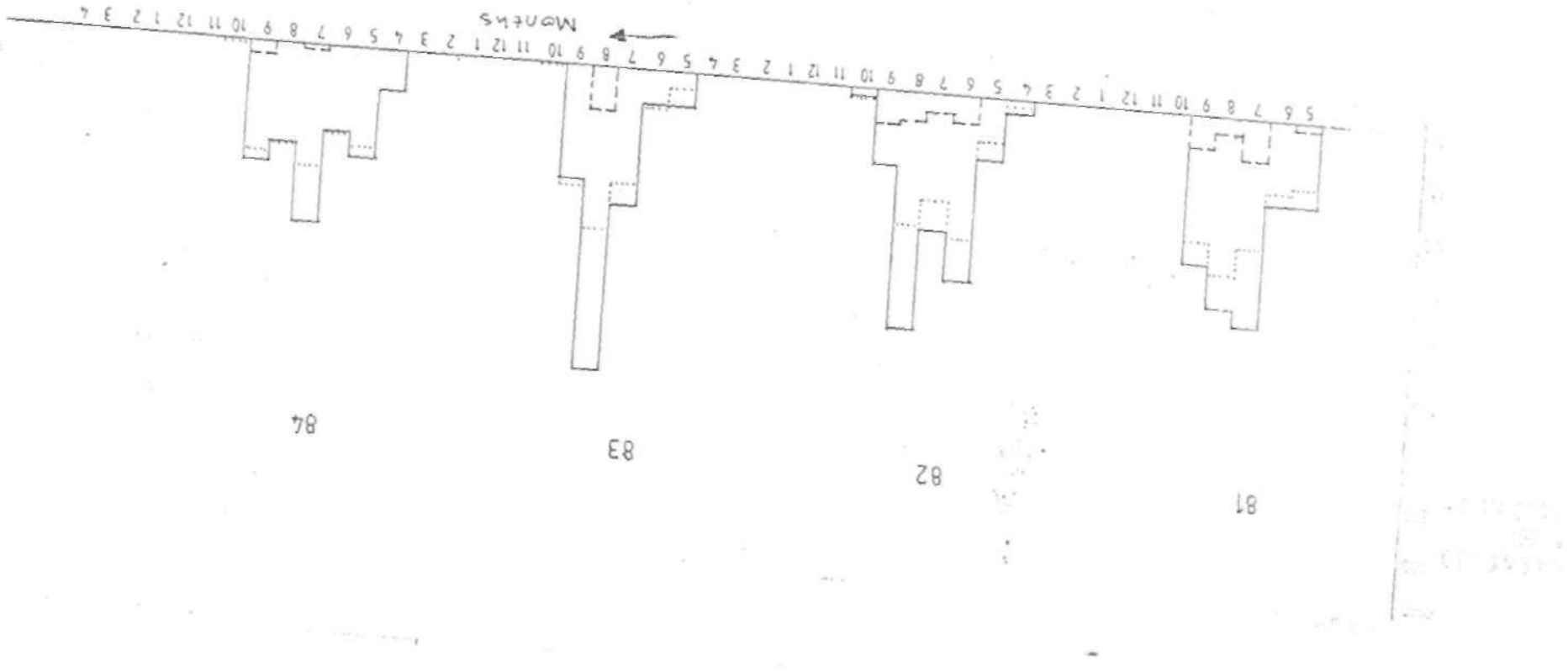


TABLE 6.8 : ANALYSIS OF ANNUAL RECHARGE, ZONE III. (mm)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Average
RN	586.0	594.6	763.4	749.2	739.3	835.2	872.3	832.4	721.3	666.6	579.3	589.1	710.7
ROF	70.9	70.7	89.2	90.7	89.4	101.3	111.2	101.7	88.1	82.2	72.8	66.4	86.2
AE	356.6	463.2	554.4	611.2	417.2	551.6	571.6	527.7	547.8	486.9	423.7	508.2	501.7
S	-3.3	3.3	0.0	3.4	-3.4	0.0	0.0	-1.0	-0.1	-0.5	3.2	-0.3	0.1
Rec	161.8	57.4	119.8	43.9	235.8	182.3	189.5	204.1	85.4	98.0	79.6	14.8	122.7
NDR	14	5	14	11	18	9	16	11	11	8	6	3	10.5

RN= rainfall. ROF= runoff. AE= actual evapotranspiration.

S= change in soil moisture storage. Rec= recharge. NDR= No. of recharge incidences.

evapotranspiration is lower for Zone III by about 6% than Zone II.

6.6 Weighted Recharge For The Whole Area.

The results of the estimated recharge for the whole area, computed by areal weighting are shown in tables 6.9 and 6.10. The comparision of rainfall, actual evapotranspiration and recharge is shown in figure 6.4.

Recharge occurs in every month except in October. The monthly recharge for the irrigation season months of November - April are, in the early years, much lower than those in the rainy season months. But the values increase steadly, due to the rise in areas irrigated, reaching the highest in 1983 -84. The monthly recharge for the rainy season months is very similar to those of the individual zones and follow the same pattern, with peaks in jyly and August. The annual recharge varies from 8.6mm in 1974 to 227.5mm in 1980 with an average of 116.0mm.

TABLE 6.9: WEIGHTED MONTHLY AND ANNUAL RECHARGE. (MM)

	1973		1974		1975		1976		1977		1978	
MONTH	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech	Imd	Rech
Jan	87.7		84.0	0.2	73.3	0.8	72.6	1.1	62.4	0.9	72.1	3.7
Feb	87.7		83.6	0.4	72.4	0.9	72.4	1.0	61.3	0.9	71.4	3.6
Mar	87.7		83.6		72.6		72.4		61.3		71.4	
Apr	87.7		84.1		73.8		73.3		62.0		74.3	
May	87.7		84.1		73.8		73.2		62.0		74.2	
Jun	87.7		71.1		36.4		37.2		52.8		25.4	
Jul	58.3	56.8	64.1	23.2	32.6	10.8	31.5		37.4		33.6	79.4
Aug	1.3	88.3	18.5	7.0	0.0	19.6	54.3	15.5	54.1	189.3	9.8	63.3
Sep	66.0		13.8		0.0	65.8	36.4	0.5	7.5	19.6	21.7	
Oct	68.9		56.3		45.9		42.8	0.1	66.8		66.2	
Nov	84.3		74.6		73.3		61.9		74.4		80.8	
Dec	83.8		73.1		72.7	0.1	61.6	0.1	72.5	0.3	80.0	0.1
TOTAL		145.1		30.8		98.1		18.3		211.0		153.4

Imd= initial soil moisture deficit. Rech= recharge.

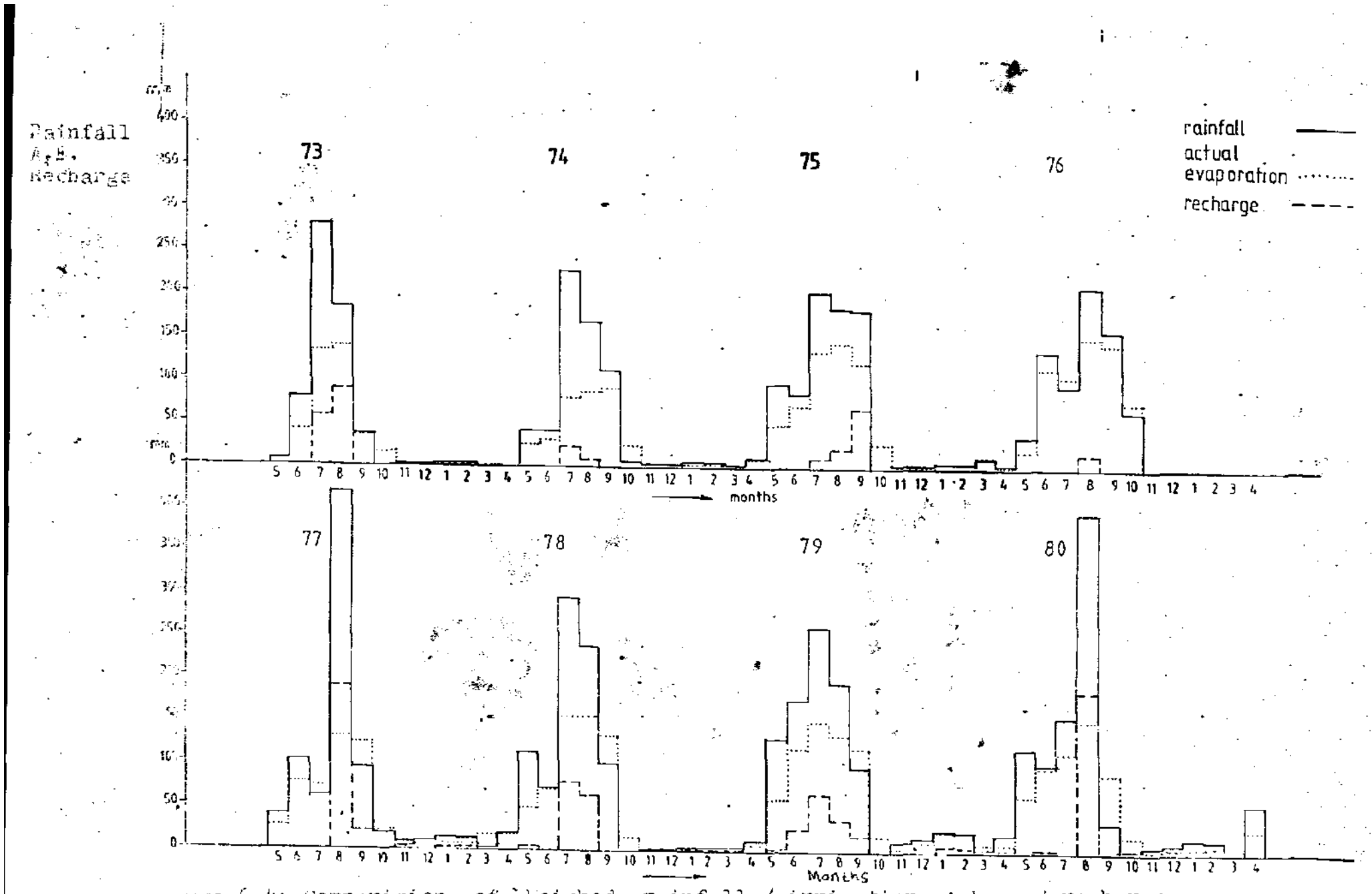


Fig 6.4: Comparision of weighed rainfall / irrigation A.E. and recharge

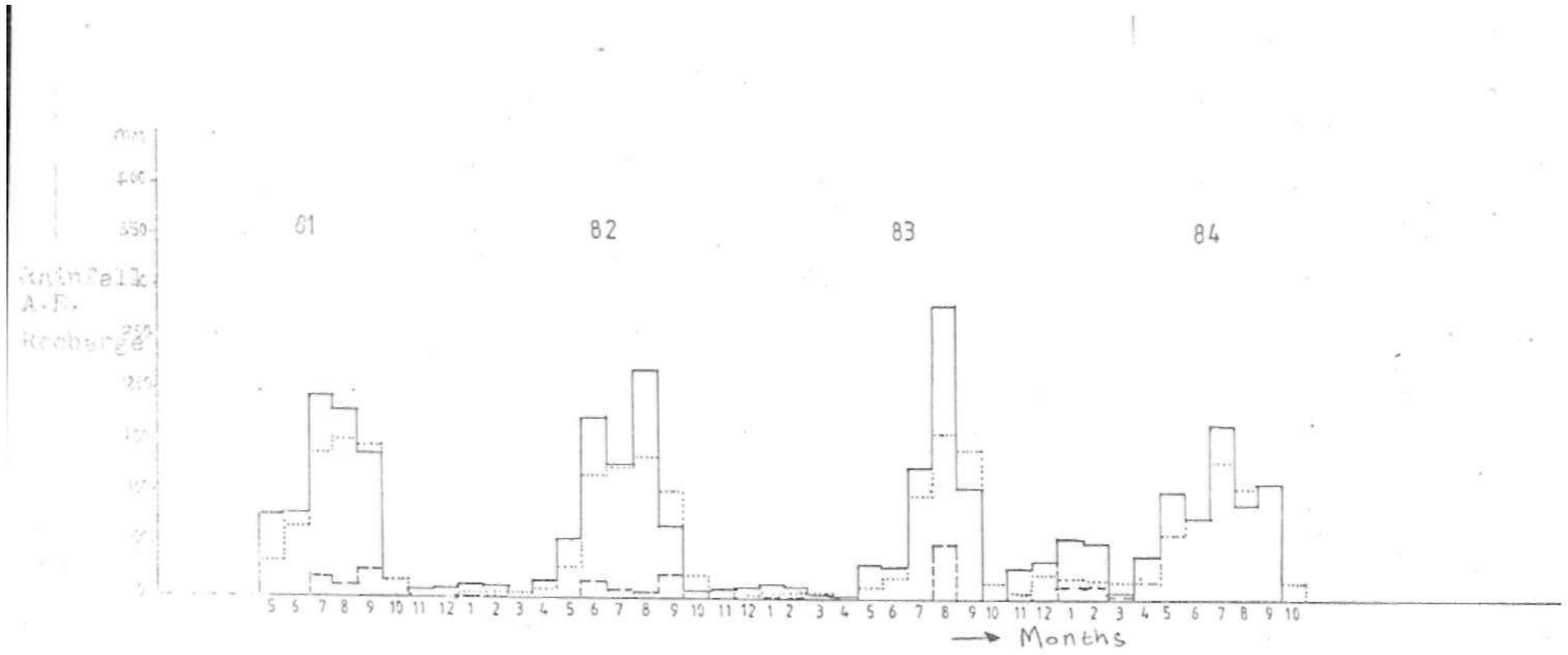


Figure 3.4 (con'd)

TABLE 6.10 : ANALYSIS OF WEIGHTED ANNUAL RECHARGE (mm).

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Average
Irg	1.8	8.0	11.6	9.1	16.0	25.1	23.3	45.3	30.7	29.3	62.4	82.4	28.8
RN	586.0	594.6	763.4	749.2	739.3	835.2	872.3	832.4	721.3	666.6	579.3	589.1	710.7
ROF	70.9	70.7	89.7	90.7	89.4	101.4	111.3	101.7	88.1	82.4	73.0	66.9	86.4
AE	368.1	490.4	586.8	638.1	465.5	613.3	630.8	578.5	601.1	562.4	498.4	585.0	551.5
S	3.7	10.7	0.7	11.2	-10.7	-7.8	4.3	-3.7	0.3	-3.7	13.0	-11.9	0.5
NDR	11.4	4.2	12.4	3.2	17.2	7.6	12.7	11.6	7.9	4.0	5.4	1.7	8.3

Irg= irrigation. RN= rainfall. ROF= runoff. AE= actual evapotranspiration.

S= change in soil moisture storage. Rec= recharge. NDR= No. of recharge incidences.

6.7 Sensitivity Analysis

The results of the sensitivity analysis carried out are shown in tables 6.12, 6.13, 6.14 and 6.15, representing zones I, II, III and weighted recharge estimates.

6.7.1 Rainfall/ irrigation :- The results show that the model is sensitive to rainfall/ irrigation as the ratios are higher than one. In the months of May and June, the recharge is small with the result that any change in the recharge is a high fraction of the original estimate. This results in the high ratios for the months. In the months of December, January and February in Zone I, and also in the month of August, the rainfall is higher than the potential evapotranspiration and the SMD is low. Thus evapotranspiration takes place at the potential raye and recharge is approximately equal to rainfall/ irrigation less the PE, IMD and runoff. Thus any change in rainfall/ irrigation changes the recharge by an equal amount and, since the recharge in these months is less than the rainfall, the sensitivity ratios are greater than one. The ratios for July and August in Zone III are lower than those in zones I and II due to the higher recharge in Zone III. The high value for October in Zone III is due to the low recharge in the month. The sensitivity of the annual recharge is also high.

6.7.2 Potential Evapotranspiration :- the sensitivity ratios for PE variation imply that the model is sensitive to it. The ratios are somewhat smaller than for rainfall. The

TABLE 6.11 : SENSITIVITY ANALYSIS ZONE I

Model	RN		PET		ROC		RC		D			F	
(mm)	+5%	-5%	+6%	-6%	+50%	-50%	+50%	-50%	+50%	-50%	UNL	+200%	-70%
80.7	93.2	67.5	70.8	90.2	80.7	80.7	70.3	85.3	80.7	81.8	80.7	80.3	80.8
80.0	90.7	69.2	71.9	88.0	80.0	80.0	80.0	83.4	80.0	80.0	80.0	80.0	80.0
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	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	0.9	0.0	0.1	0.6	0.0	1.2	0.0	4.7	0.2	0.6	0.0	0.2	0.5
3.3	4.9	2.6	3.0	3.7	2.3	5.3	2.0	12.5	3.3	9.7	3.1	2.8	4.2
20.6	25.9	15.7	17.7	24.3	13.5	28.1	14.2	34.7	20.6	28.6	15.5	19.6	21.0
53.2	63.0	44.4	47.1	60.0	40.7	67.6	45.5	69.1	53.2	60.3	51.2	53.0	53.8
12.8	15.4	9.8	10.2	15.0	8.4	16.3	10.6	14.6	12.8	13.4	12.8	12.6	12.8
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.1	18.3	5.1	5.8	17.0	11.1	11.1	2.6	30.5	11.1	20.0	11.1	10.1	11.6
262.1	312.2	214.3	226.7	299.0	236.7	290.4	225.2	335.3	261.9	294.4	254.4	258.5	264.6
					SENSITIVITY RATIOS								
	3.1	3.3	-2.0	-2.0	0.0	0.0	-0.3	-0.1	0.0	0.0	0.0	0.0	0.0
	2.7	2.7	-1.7	-1.7	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
	25.0	20.0	-12.5	-8.3	-2.0	-4.0	-2.0	-21.5	-1.0	-1.0	0.0	-0.3	-0.4
	9.7	4.2	-1.5	-2.0	-0.6	-1.21	-0.8	-5.6	0.0	-3.9	0.0	-0.1	-0.4
	5.2	4.8	-2.4	-3.0	-0.7	-0.7	-0.6	-1.4	0.0	-0.8	-0.0	-0.0	-0.0
	3.7	3.3	-1.9	-2.1	-0.5	-0.5	-0.3	-0.6	0.0	-0.3		0.0	0.0
	4.1	4.7	-3.4	-2.9	-0.7	-0.6	-0.3	-0.3	0.0	-0.1		0.0	0.0
	13.0	10.8	-8.0	-8.9	0.0	0.0	-1.5	-3.5	0.0	-1.6		0.0	0.0
	3.8	3.7	-2.3	-2.4	-0.2	-0.2	-0.3	-0.6	0.0	-0.3		0 .0	0.0

TABLE 6.12 : SENSITIVITY ANALYSIS ZONE 2

MONTH	Model (mm)	RN +5%	RN -5%	PET +6%	PET -6%	ROD +50%	ROD -50%	RC +50%	RC -50%	D +50%	D -50%	UNL	F +200%	F -70%
JAN														
FEB														
MAR														
APR														
MAY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.2
JUN	3.3	4.0	2.6	3.0	3.5	2.3	4.4	2.0	10.1	3.2	-0.1	0.0	2.8	3.6
JUL	20.7	25.9	15.7	17.8	24.2	13.6	28.0	14.7	34.9	20.7	0.0	10.4	19.6	21.5
AUG	54.1	63.8	44.9	47.6	61.1	41.1	68.5	45.9	69.9	54.1	0.0	40.8	53.9	54.6
SEP	12.3	15.0	9.7	10.2	14.6	8.4	15.9	10.6	14.4	12.3	13.0	11.7	12.1	12.4
OCT														
NOV														
DEC														
TOTAL	**90.4**	**108.7**	**72.9**	**78.5**	**103.4**	**65.4**	**116.9**	**73.3**	**131.0**	**90.3**	**117.9**	**62.8**	**88.4**	**92.3**

SENSITIVITY RATIOS

MONTH	RN +5%	RN -5%	PET +6%	PET -6%	ROD +50%	ROD -50%	RC +50%	RC -50%	D +50%	D -50%	UNL	F +200%	F -70%
JAN													
FEB													
MAR													
APR													
MAY													
JUN	4.2	4.2	-1.5	-1.0	-0.6	-0.7	-0.8	-4.1	-0.1	-4.1		-0.1	-0.1
JUL	5.0	4.8	-2.3	-2.8	-0.7	-0.7	-0.6	-1.4	0.0	-0.8		-0.0	-0.1
AUG	3.6	3.4	-2.0	-2.2	-0.5	-0.5	-0.3	-0.6	0.0	-0.3		0.0	0.0
SEP	4.4	4.2	-2.9	-3.1	-0.6	-0.6	-0.3	-0.3	0.0	-0.1		0.0	0.0
OCT													
NOV													
DEC													
TOTAL	4.1	3.9	-2.2	-2.4	-0.6	-0.6	**-0.4**	**-0.9**	**0.0**	**-0.6**		**-0.0**	**0.0**

Table 6.13 : SENSITIVITY ANALYSIS ZONE 3

MONTH	Model (mm)	RN +5%	RN -5%	PET +6%	PET -6%	ROD +50%	ROD -50%	RC +50%	RC -50%	D +50%	D -50%	UNL	F +200%	F -70%
JAN														
FEB														
MAR														
APR														
MAY	4.0	4.9	3.3	3.8	4.2	2.9	5.4	3.7	6.9	2.3	10.6	0.0	4.0	4.0
JUN	3.9	4.8	3.1	3.7	4.1	2.8	5.4	3.1	13.3	3.3	13.3	1.2	3.6	4.1
JUL	30.6	35.2	26.1	28.6	33.0	24.1	37.3	23.4	48.0	30.2	42.4	18.2	29.0	31.0
AUG	69.3	78.3	60.2	64.5	74.4	55.7	82.5	61.0	86.4	69.3	79.1	59.7	67.1	70.2
SEP	14.9	17.5	12.1	13.1	16.6	11.2	18.9	13.0	21.9	14.9	17.5	14.9	14.5	15.1
OCT	0.1	0.3	0.0	0.0	0.1	0.0	0.3	0.1	1.2	0.0	1.2	0.0	0.1	0.3
NOV														
DEC														
TOTAL	122.7	141.1	104.8	113.8	132.5	96.7	149.8	104.4	177.7	120.0	164.2	94.0	118.2	124.7

SENSITIVITY RATIOS

JAN												
FEB												
MAR												
APR												
MAY	4.5	3.5	-0.8	-0.8	-0.6	-0.7	-0.2	-1.5	-0.9	-3.3	0.0	0.0
JUN	4.6	4.1	-0.9	-0.9	-0.6	-0.8	-0.4	-4.8	-0.3	-4.8	0.0	-0.1
JUL	3.0	2.9	-1.1	-1.3	-0.4	-0.4	-0.5	-1.1	-0.0	-0.8	0.0	0.0
AUG	2.6	2.6	-1.2	-1.2	-0.4	-0.4	-0.2	-0.5	0.0	-0.3	0.0	0.0
SEP	3.5	3.8	-2.0	-1.9	-0.5	-0.5	-0.3	-0.9	0.0	-0.4	0.0	0.0
OCT	40.0	20.0	-16.7	0.0	-2.0	-4.0	0.0	-22.0	-2.0	-22.0	0.0	-2.9
NOV												
DEC												
TOTAL	3.0	2.9	-1.2	-1.3	-0.4	-0.4	-0.3	-0.9	-0.0	-0.7	0.0	0.0

TABLE 6.14: SENSITIVITY ANALYSIS FOR WEIGHTED RECHARGE

	Model	RN		PET		ROD		RC		D			F	
MONTH	(mm)	+5%	-5%	+6%	-6%	+50%	-50%	+50%	-50%	+50%	-50%	UNL	+200%	-70%
JAN	3.2	3.6	2.6	2.7	3.5	3.2	3.2	2.7	3.2	3.2	3.2	3.2	3.1	3.2
FEB	3.2	3.6	2.8	2.9	3.5	3.2	3.2	3.2	3.3	3.2	3.2	3.2	3.2	3.2
MAR	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
APR	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
MAY	0.5	0.6	0.4	0.5	0.5	0.4	0.7	0.5	2.5	0.3	5.1	0.0	0.5	0.7
JUN	3.3	4.2	2.6	3.1	3.6	2.4	4.6	2.2	10.5	3.2	10.4	0.2	2.9	3.7
JUL	21.9	27.0	17.0	19.1	25.3	14.9	29.2	15.8	36.5	21.9	31.0	11.5	20.8	22.7
AUG	56.0	65.6	46.8	49.7	62.7	42.9	76.2	47.8	71.9	56.0	63.4	43.3	55.5	56.5
SEP	12.7	15.3	10.0	10.5	14.9	8.8	16.3	10.9	15.3	12.7	13.6	12.1	12.4	12.7
OCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0
NOV	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
DEC	0.4	0.7	0.2	0.2	0.6	0.4	0.4	0.1	1.3	0.4	0.7	0.4	0.3	0.4
TOTAL	101.1	120.6	82.4	88.8	114.6	76.0	127.7	83.1	144.6	100.7	130.6	73.8	98.7	103.0

SENSITIVITY RATIOS

JAN	2.5	3.8	-2.6	-1.6	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0
FEB	2.5	2.5	-1.6	-1.6	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
MAR												
APR												
MAY	4.0	4.0	0.0	0.0	-0.4	-0.8	0.0	-8.0	-0.8	-18.4	0.0	-0.6
JUN	5.5	4.2	-1.0	-1.5	-0.6	-0.8	-0.7	-4.4	-0.1	-4.3	-0.1	-0.2
JUL	4.7	4.5	-2.1	-2.6	-0.6	-0.7	-0.6	-1.3	0.0	-0.8	-0.0	-0.1
AUG	3.4	3.3	-1.9	-2.0	-0.5	-0.7	-0.3	-0.6	0.0	-0.3	0.0	0.0
SEP	4.1	4.3	-2.9	-2.9	-0.6	-0.6	-0.3	-0.4	0.0	-0.1	0.0	0.0
OCT												
NOV												
DEC	15.0	10.0	-8.3	-8.3	0.0	0.0	-1.5	-4.5	0.0	-1.5	-0.1	0.0
TOTAL	3.9	3.7	-2.0	-2.2	-0.5	-0.5	-0.4	-0.9	0.0	-0.6	0.0	-0.0

RN: Rainfall/ Irrigation Application
PET: Potential Evapotranspiration
ROC: Runoff Coefficient
RC: Root Constant
D: Max. SMD
F: Drying curve slope

sensitivity ratios for May and June in Zone III are less than 1.0 because of higher recharge in both months in the zone.

6.7.3 Runoff Coefficient :- the results indicate that the model is moderately sensitive to the runoff coefficient. The higher values for the months of May in Zone I and october in Zone II is because of the little recharge in these months. The sensitivity of the annual recharge is low.

6.7.4 Root Constant :- The sensitivity of the model to root constant is generally low to moderate, but it is high in the months of May, June and July when the root constant is decreased. This is because the SMD is usually high in the months of May, June and early July and a decrease in the root constant results in appreciably lower SMD than normal, leading to higher recharge. The effect of rising the root constant does not appreciably increase the SMD in these months, which is already high. Therefore the effect on the recharge amount is less. The high sensitivity ratio of May in Zone I and October in Zone III is due to the reasons given earlier. The sensitivity of the annual recharge varies from low to moderate.

6.7.4 Maximum SMD (D) :- the sensitivity of the model to D is from nil to low, except in the months of May and June. This is because in these months, the SMD is close to D when variation in D has the greatest effect. The same applies for October in Zone III, but the high ratio is because of reasons given earlier. The sensitivity of the annual

recharge to D varies from nil to moderate.

6.7.5 Drying Curve Slope (F) :- the results show that the model is insensitive to F.

6.8 Validation

Comparision of the monthly recharge in Zone I with water table hydrographs is shown in figure 6.5. The hydrographs were obtained from measurements in tubes located at the Kadawa sector of the area (Nwa, 1982). Generally the water table begins to rise in June, and often sharply, and then less sharply reaching a peak in August. It then drops equally sharply at the end of August and then less sharply until December when it rises again to a smaller peak in February. From then it drops until June, with small rises only if there is recharge in April/ May.

The main feature of the graph is the greater response for recharge in the rainy months than in the irrigation months, even though the latter is higher. This is because the small areas irrigated are not in a single block and are pierced by unirrigared lands. Also they are stretched along the West Branch canal from Kadawa to Kura and beyond. Thus there is a high lateral flow to adjacent, unirrigated lands which recieve no water. The manner in which the water table drops sharply at the end of August or Fobruary indicates the high rate of spread of the water table. Since during the rainy season, the whole area and beyond recieve roughly equal rain (even though individual storms may occur only in

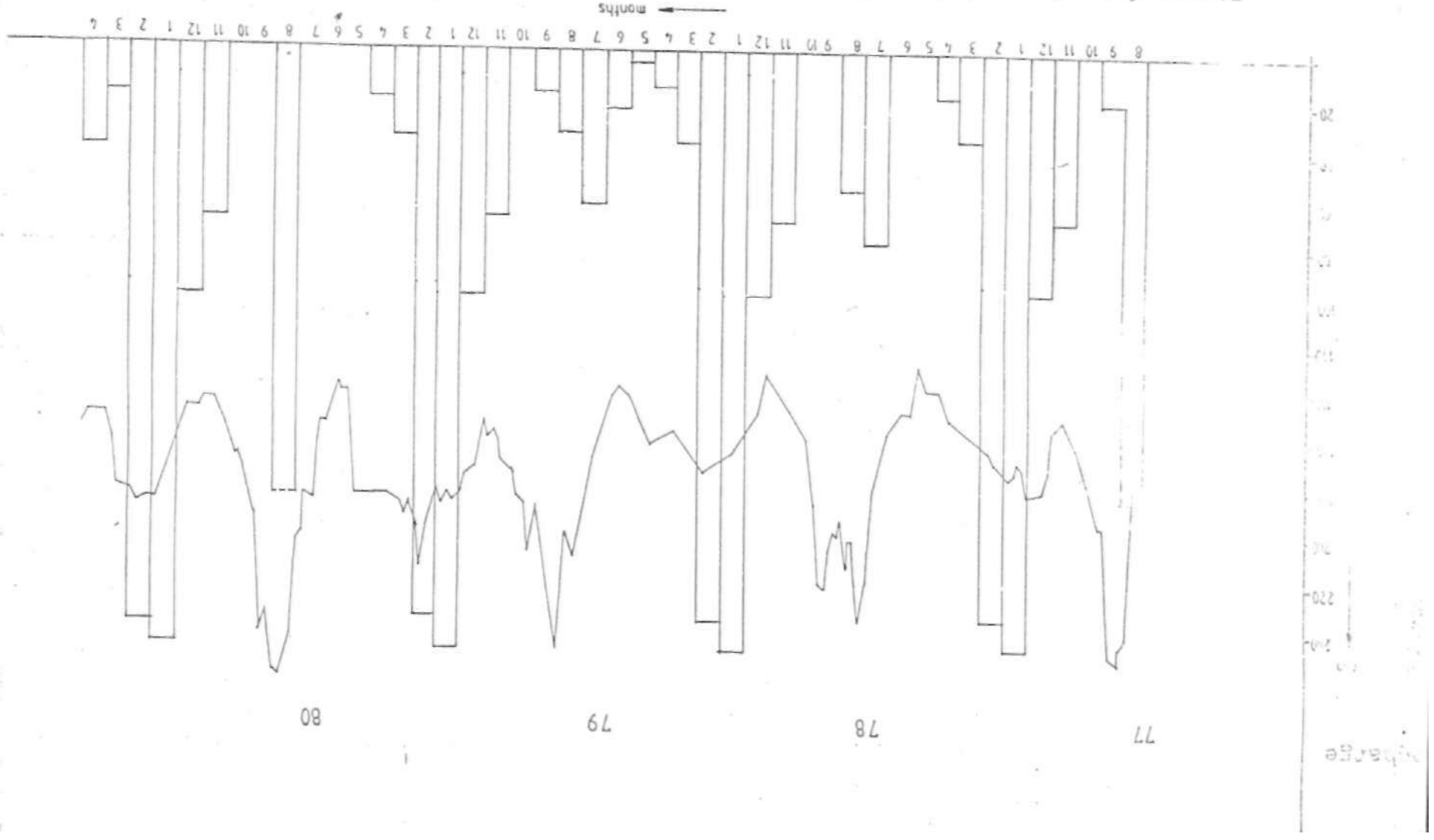


Figure 6.5: Comparision of monthly recharge in ZONE 1
with water table hydrographs

some parts) the response of the water table is higher.

The tendency of the water table to rise in the absence of recharge, as the case in June, 1978 and 1980 may indicate indirect recharge mechanisms.

6.9 Amount Of Recharge

An estimate of the recharge for the area by Kowal and Knabe (1972) was given in the literature review. This is compared with that of Zone II, where conditions are similar (i.e. no irrigation).

	Rainfall mm	Runoff mm	Actual evaporation	Recharge mm
Zone II estimate	710.7	86.3	533.5	90.4
Kowal & Knabe estimate	884.2	0.0	667.8	216.4

The reason for the big difference in recharge is due to:- 1) higher amount of rainfall for the period of study by Kowal and Knabe.

2) non consideration of runoff in the method used by Kowal and Knabe (even though they acknowledge that runoff may account for between 6 - 18% of rainfall) This results in a difference of 259.8mm in effective rainfall (i.e. rainfall minus runoff) with the result that the actual evaporation and recharge are larger by 134.3mm and 126.0mm, respectively for the period used by Kowal and Knabe.

CONCLUSION

From the results of this study, the direct recharge over the Kano Project Area is estimated at 101.1mm per annum. This is the average for the period of study and the annual recharge in the individual years ranges from 18.3mm to 211.0mm.

In the irrigated areas, the mean annual recharge is 262.1mm out of which an average 172.6mm comes from irrigation. It was found that most of the recharge due to irrigation occurs in the months of December to February and that recharge in the rainy season is mostly unaffected by irrigation. It is clear that as a greater proportion of the area comes under irrigation, the mean annual recharge is bound to rise.

From the results of the sensitivity analysis, the model was found to be sensitive to variations in rainfall and potential evapotranspiration. This is similar to the findings of Odigie (1984), who said

> "it is generally sensitive to input data, rainfall and potential evaporation"

The sensitivity of the model to root constants and maximum SMD is generally low to moderate, but high in months with high initial SMD(May, June). Again to quote Odigie,

> "The root constant effect only becomes important after the soil moisture deficit has built up sufficiently to cause a reduction in the rate of evaporation"

The model is moderately sensitive to runoff coefficient but insensitive to drying curve slope.

RECOMMENDATIONS

The effect of irrigation in the area is that drainage is now a problem in some parts of the area. To maximize the benefits of irrigation, it is recommended that :-

1) The authorities should try to improve water management by training farmers in the judicious use of water.

2) The authorities should make more efforts in measuring and recording flows in all the major canals. This will aid further research by giving actual water application in the irrigated areas. It would also lead to better control of the system.

3) measurement of soil moisture in the area should be initiated on a long term basis. This will provide an alternative and more accurate way of estimating the recharge. The use of tracers or lysimeters may be tried but the results are short term.

4) Further studies to determine the hydro-dynamic properties of the aquifer such as transmissibility and storage coefficient should be initiated as thse are essential for any drainage system to be evolved for the area.

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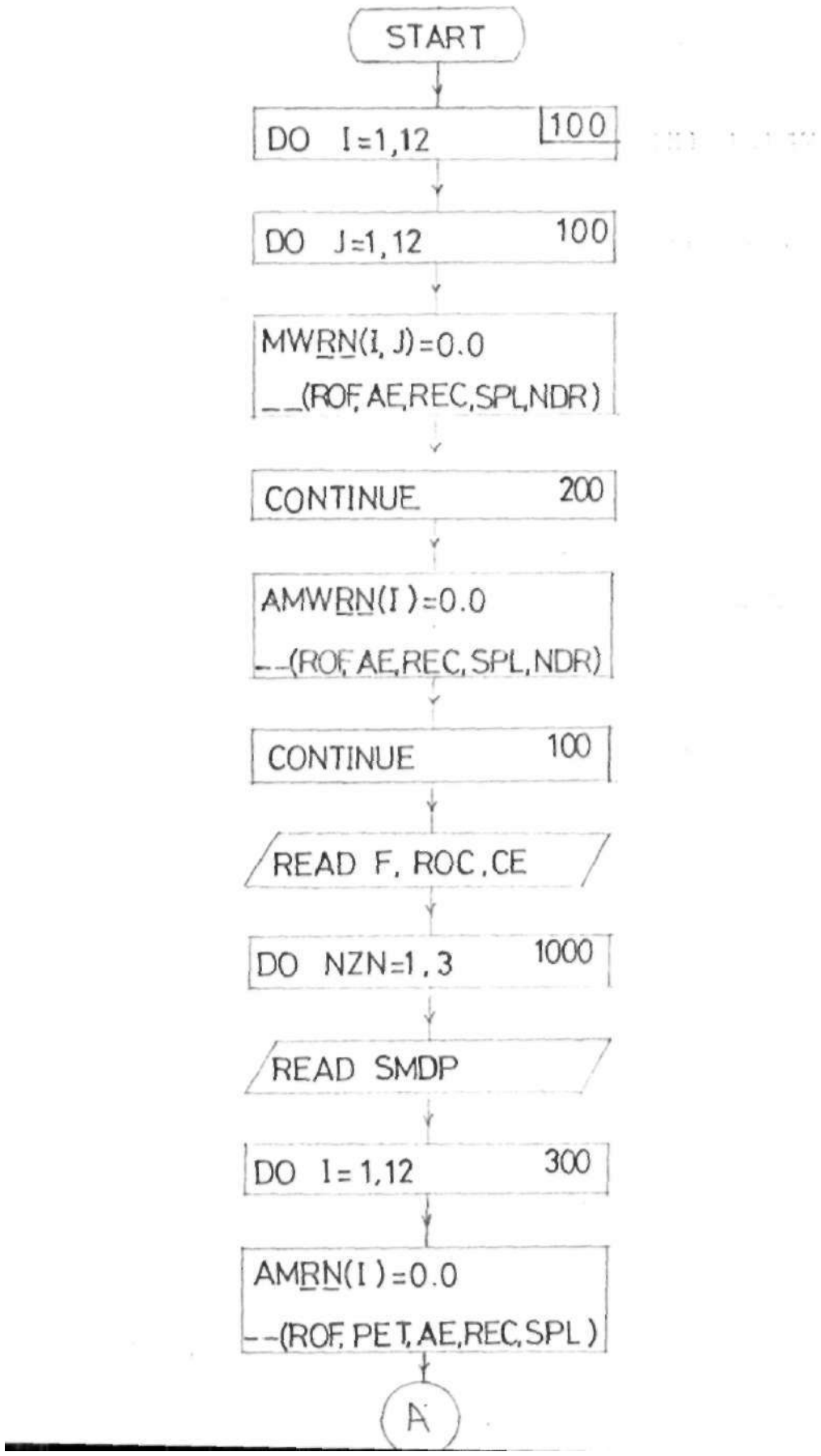
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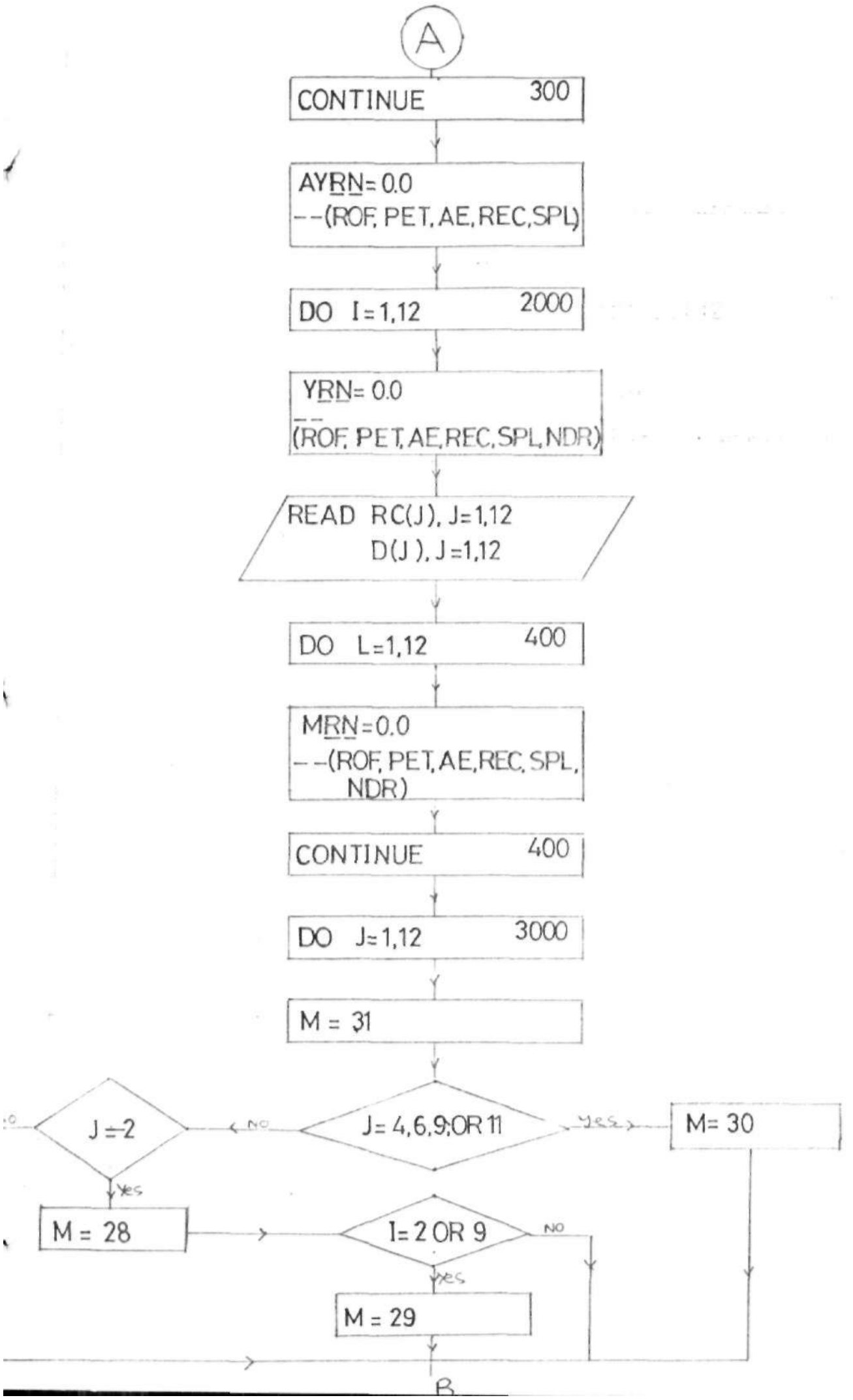
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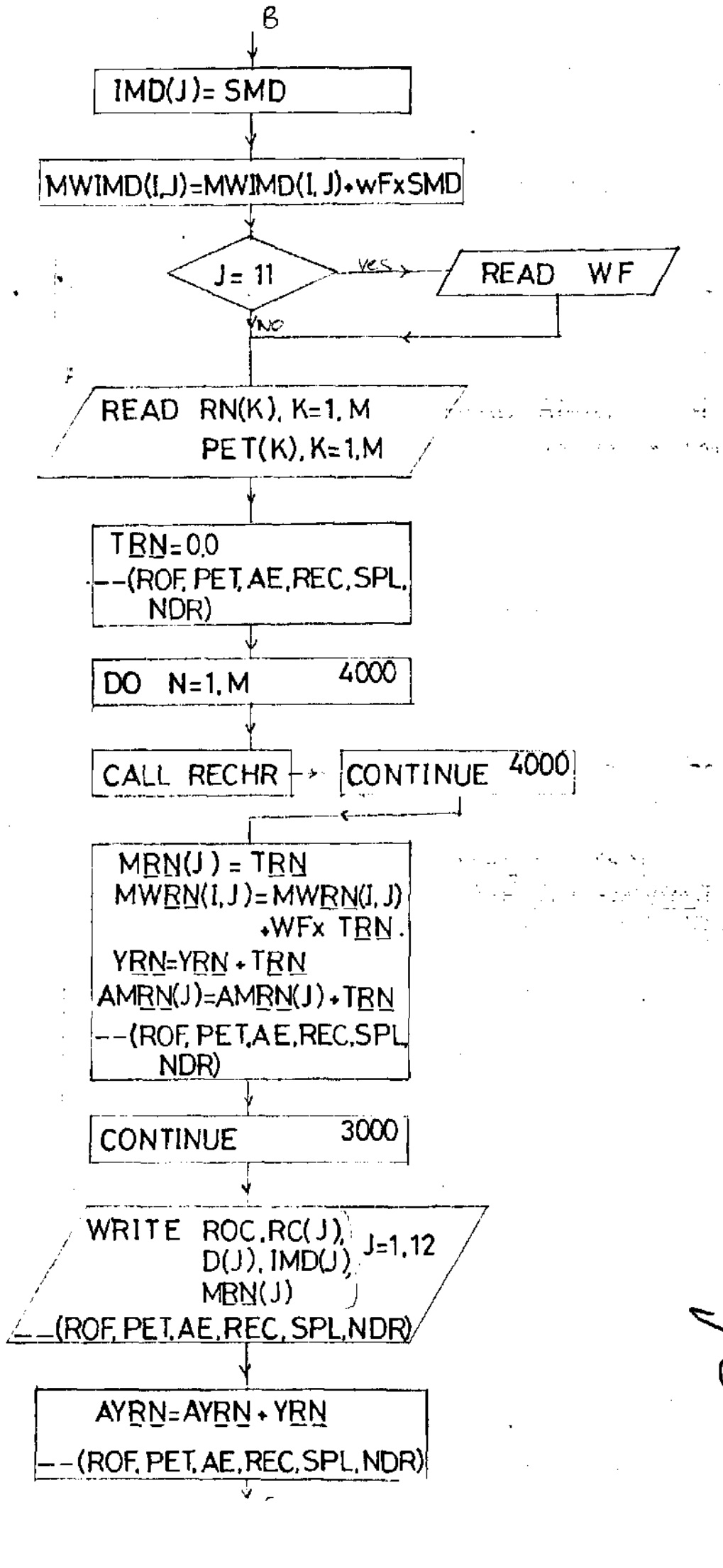
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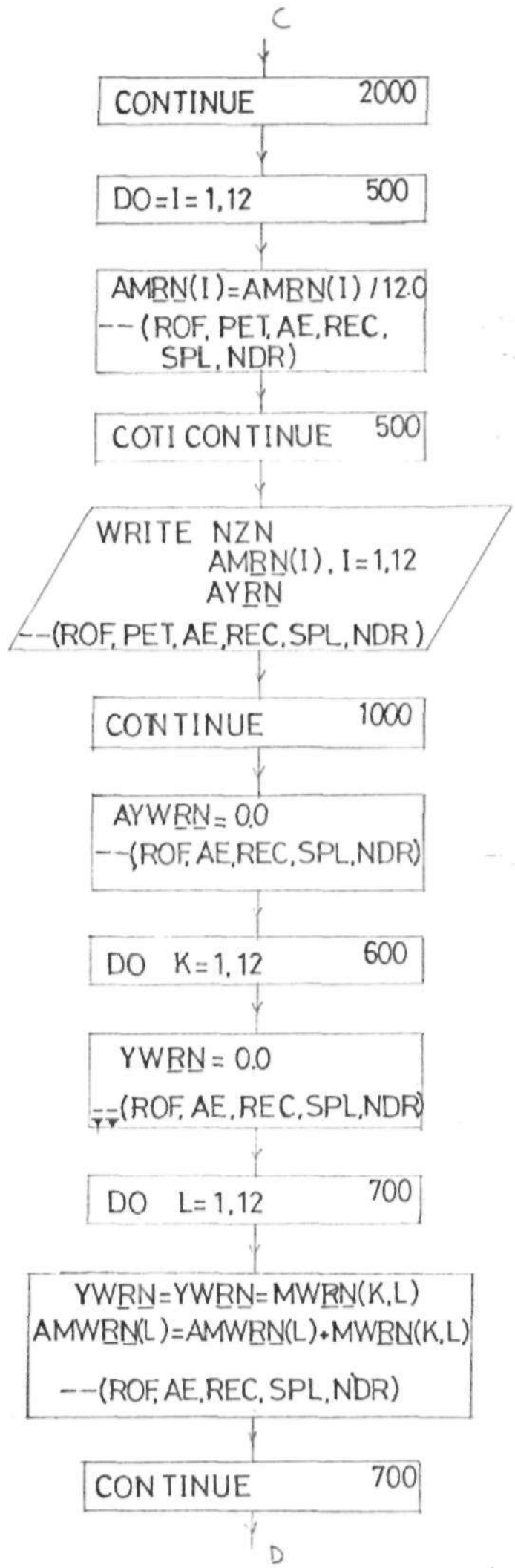
APPENDIX I

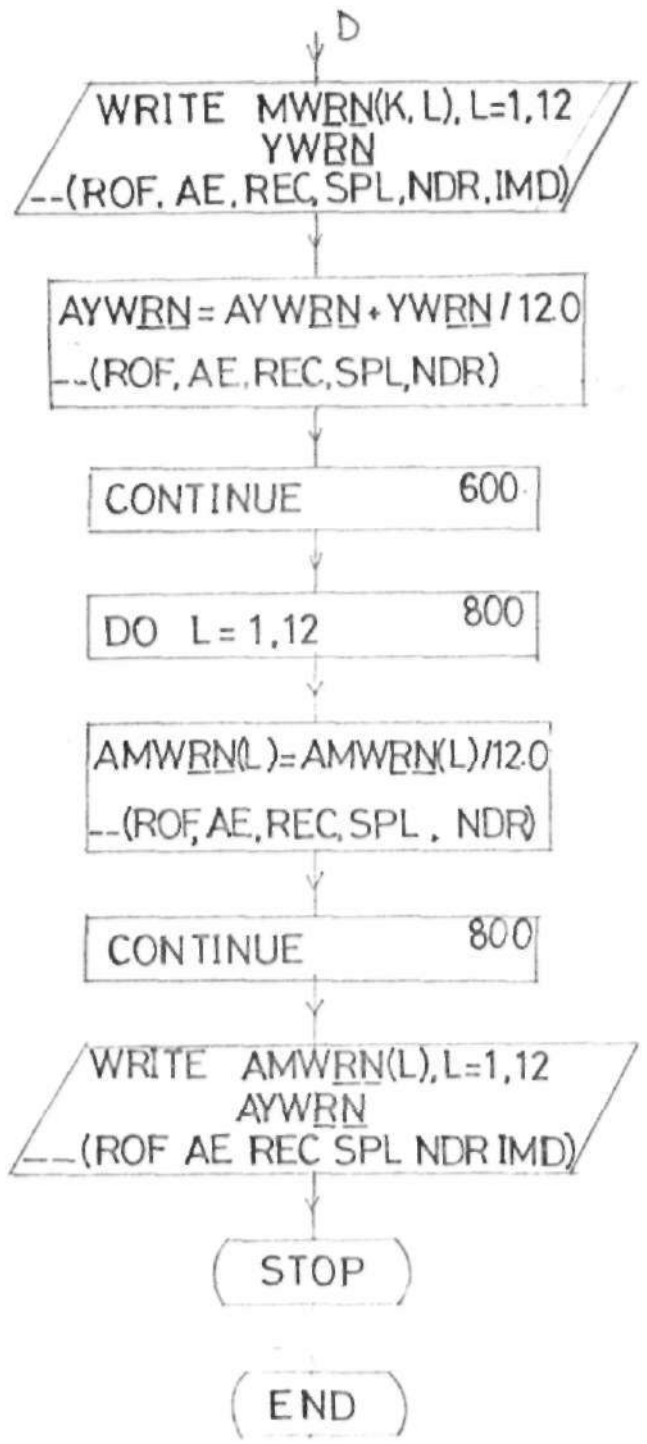
FLOW CHART FOR MAIN PROGRAM




A
CONTINUE 300
AYRN= 0.0
--(ROF, PET, AE, REC, SPL)
DO I=1,12 2000
YRN= 0.0
(ROF, PET, AE, REC, SPL, NDR)
READ RC(J), J=1,12
D(J), J=1,12
DO L=1,12 400
MRN=0.0
--(ROF, PET, AE, REC, SPL, NDR)
CONTINUE 400
DO J=1,12 3000
M = 31
J=2
NO
J= 4,6,9,OR 11
Yes
M= 30
Yes
M = 28
I= 2 OR 9
NO
Yes
M = 29
B


B
IMD(J)= SMD
MWIMD(I,J)=MWIMD(I, J)+wFxSMD
J= 11
YES
READ WF
NO
READ RN(K), K=1, M
PET(K), K=1,M
TRN=0.0
--(ROF, PET, AE, REC, SPL, NDR)
DO N=1, M 4000
CALL RECHR
CONTINUE 4000
MRN(J) = TRN
MWRN(I,J)=MWRN(I, J) +WFx TRN.
YRN=YRN + TRN
AMRN(J)=AMRN(J) + TRN
--(ROF, PET, AE, REC, SPL, NDR)
CONTINUE 3000
WRITE ROC, RC(J), D(J), IMD(J), MRN(J) J=1, 12
--(ROF, PET, AE, REC, SPL, NDR)
AYRN=AYRN + YRN
--(ROF, PET, AE, REC, SPL, NDR)


C
CONTINUE 2000
DO=I=1,12 500
AMRN(I)=AMRN(I)/12.0
--(ROF, PET, AE, REC, SPL, NDR)
COTI CONTINUE 500
WRITE NZN
AMRN(I), I=1,12
AYRN
--(ROF, PET, AE, REC, SPL, NDR)
CONTINUE 1000
AYWRN = 0.0
--(ROF, AE, REC, SPL, NDR)
DO K=1, 12 600
YWRN = 0.0
--(ROF, AE, REC, SPL, NDR)
DO L=1, 12 700
YWRN=YWRN=MWRN(K,L)
AMWRN(L)=AMWRN(L)+MWRN(K,L)
--(ROF, AE, REC, SPL, NDR)
CONTINUE 700
D


D
WRITE MWRN(K, L), L=1,12
YWRN
--(ROF, AE, REC, SPL, NDR, IMD)
AYWRN = AYWRN + YWRN / 12.0
--(ROF, AE, REC, SPL, NDR)
CONTINUE 600
DO L = 1,12 800
AMWRN(L) = AMWRN(L) / 12.0
--(ROF, AE, REC, SPL, NDR)
CONTINUE 800
WRITE AMWRN(L), L=1,12
AYWRN
--(ROF AE REC SPL NDR IMD)
STOP
END

```
C     THIS PROGRAM ESTIMATES RECHARGE OF GROUND WATER FROM DAILY
      RAINFALL AND EVAPOTRANSPIRATION DATA USING THE SOIL MOISTURE
      DEFICIT MODEL.

C
      DIMENSION RC(12),D(12),RN(31),PET(31),MREC(12),MRN(12),
      MROF(12)1,MPET(12),MAE(12),AMREC(12),AMRN(12),AMPET(12),
      AMROF(12,2AMAE(12),IMD(12),AMIMD(12),MNDR(12),MADR(12),
      AMNDR(12),
      3MWRN(12,12),MWROF(12,12),MWAE(12,12),MWREC(12,12),
      MWIMD(12,12),
      4MWNDR(,12,12),AMWRN(12),AMWROF(12),AMWAE(12),AMWREC(12),
      5AMWIMD(12),AMWNDR(12)
C
      COMMON RC,D,PET,RN,ROC,ROF,REC,I,J,N,SMD,SMDP,F,CE,NDR
C
      REAL IMD,MRN,MROF,MPET,MWRN,MWROF,MWAE,MWREC,MWIMD,MWNDR,MAE
      1,MREC
      INTEGER YNDR
C
C     THE MEANING OF THE ABOVE MODEL PARAMETERS ARE AS FOLLOWS :
C
C     F         DRYING CURVE SLOPE
C     ROC       RUNOFF COEFFICIENT
C     WF        WEIGHING FACTOR FOR ZONES
C     RC        ROOT CONSTANT
C     D         MAXIMUM SOIL MOISTURE DEFICIT
C     SMD       SOIL MOISTURE DEFICIT
C     SMDP      SOIL MOISTURE DEFICIT ON PREVIOUS DAY
C     RN        RAINFALL OR IRRIGATION
C     ROF       RUNOFF
C     PET       POTENTIAL EVAPOTRANSPIRATION
C     AE        ACTUAL EVAPOTRANSPIRATION
C     REC       RECHARGE
C     NDR       NUMBER OF INCIDENCES OF RECHARGE
C     IMD       SMD AT THE BEGINING OF THE MONTH
C     M..       MONTHLY..
C     MW..      MONTHLY WEIGHED..
C     AM..      AVERAGE MONTHLY..
C     AMW..     AVERAGE MONTHLY WEIGHED..
C     Y..       YEARLY..
C     YW..      YEARLY WEIGHED..
C     AY..      AVERAGE YEARLY..
C     AYW..     AVERAGE YEARLY WEIGHED..
C
C     CLEAR ALL WEIGHED ARRAYS
      DO 100 I=1,12
      DO 200 J=1,12
      MWRN(I,J)=0.0
      MWROF(I,J)=0.0
      MWAE(I,J)=0.0
      MWREC(I,J)=0.0
      MWNDR(I,J)=0.0
      MWIMD(I,J)=0.0
200   CONTINUE
      AMWRN(I)=0.0
      AMWROF(I)=0.0
      AMWAE(I)=0.0
      AMWREC(I)=0.0
      AMWIMD(I)=0.0
```

```
      AMWNOR(I)=0.0
  100 CONTINUE
C
C     INITIATE THE ZONAL DO LOOP
      DO 1000 NZN=1,3
C
C     INPUT THE VALUES OF F,ROC,SMDP
C
      READ(1,110) F,ROC,SMDP
  110 FORMAT(4F6.1)
      SMD=SMDP
      WF=400
      IF(NZN.EQ.2) WF=47120
      IF(NZN.EQ.3) WF=6830
C
C     CLEAR ALL ZONAL ARRAYS
C
      DO 300 I=1,12
      AMRN(I)=0.0
      AMPET(I)=0.0
      AMREC(I)=0.0
      AMAE(I)=0.0
      AMROF(I)=0.0
      AMIMD(I)=0.0
      MADR(I)=0
      AMNDR(I)=0.0
  300 CONTINUE
      AYRN=0.0
      AYPET=0.0
      AYROF=0.0
      AYAE=0.0
      AYREC=0.0
      AYNDR=0.0
C
C     INITIATE THE 12 YEAR DO LOOP
C
C     SET YEARLY SUMS TO ZERO
C
      DO 2000 I=1,12
      YRN=0.0
      YROF=0.0
      YAE=0.0
      YPET=0.0
      YREC=0.0
      YNDR=0.0
C
      IF(I.GT.1) GO TO 701
      IF(NZN.EQ.1) WRITE (6,102)
  102 FORMAT(1H ,/,4X,"ESTIMATE OF DIRECT RECHARGE AT KANO PROJECT
AREA
     1",/,4X,"OF KANO RIVER BASIN",/)
      WRITE(6,105) NZN
  105 FORMAT (/,40X,"ZONE",I2,/)
  701 CONTINUE
C
C     INPUT MONTHLY ROOT CONSTANTS AND MAXIMUM SMD
C
      READ(2,120) (RC(J),J=1,12)
      READ(3,120) (D(J),J=1,12)
  120 FORMAT(12F6.1)
```

```
C
C     CLEAR ALL MONTHLY ARRAYS
C
      DO 400 L=1,12
      MREC(L)=0.0
      MROF(L)=0.0
      MAE(L)=0.0
      MRN(L)=0.0
      MPET(L)=0.0
      MNDR(L)=0.0
  400 CONTINUE
C
C     INITIATE THE MONTHLY DO LOOP
C
      K1=12
      IF(I.EQ.12) K1=10
      DO 3000 J=1,K1
      GO TO 702
      GO TO (11,12,13,14,15,16,17,18,19,20,21,22),J
   11 M=31
      WRITE(6,115)
  115 FORMAT(///,4X,13H   JANUARY  )
      GO TO 23
   12 M=28
      IF(I.EQ.4.OR.I.EQ.9) M=29
      WRITE(6,125)
  125 FORMAT(1H1,4X,13H   FEBUARY  )
      GO TO 23
   13 M=31
      WRITE(6,135)
  135 FORMAT(1H1,4X,11H   MARCH  )
      GO TO 23
   14 M=30
      WRITE(6,145)
  145 FORMAT(1H1,4X,11H   APRIL  )
      GO TO 23
   15 M=31
      WRITE(6,155)
  155 FORMAT(1H1,4X,9H   MAY  )
      GO TO 23
   16 M=30
      WRITE(6,165)
  165 FORMAT(1H1,4X,10H   JUNE  )
      GO TO 23
   17 M=31
      WRITE(6,175)
  175 FORMAT(1H1,4X,10H   JULY  )
      GO TO 23
   18 M=31
      WRITE(6,185)
  185 FORMAT(1H1,4X,12H   AUGUST  )
      GO TO 23
   19 M=30
      WRITE(6,195)
  195 FORMAT(1H1,4X,15H   SEPTEMBER  )
      GO TO 23
   20 M=31
      WRITE(6,205)
  205 FORMAT(1H1,4X,13H   OCTOBER  )
      GO TO 23
```

```
 21   M=30
      WRITE(6,215)
 215  FORMAT(1H1,4X,14H    NOVEMBER  )
      GO TO 23
 22   M=31
      WRITE(6,225)
 225  FORMAT(1H1,4X,14H    DECEMBER  )
 702  CONTINUE
      M=31
      IF(J.EQ.4.OR.J.EQ.6.OR.J.EQ.9.OR.J.EQ.11) M=30
      IF(J.EQ.2) M=28
      IF(J.EQ.2.AND.I.EQ.4) M=29
      IF(J.RQ.2.AND.I.EQ.9) M=29
      IMD(J)=SMD
      MWIMD(I,J)=MWIMD(I,J)+WF/54350.0*SMD
      IF(J.EQ.11.) READ(7,130) WF
 130  FORMAT(7F.1)
C
C     INPUT     DAILY     RAINFALL/IRRIGATION     AND     POTENTIAL
EVAPOTRANSPIRATION
C
 23   READ(4,140) (RN(K),K=1,M)
      READ(5,140) (PET(K),K=1,M)
 140  FORMAT(16F5.1/16F5.1)
C
      TREC=0.0
      TPET=0.0
      TRN=0.0
      TROF=0.0
      TAE=0.0
      NDR=0.0
C
C     INITIATE THE DAILY DO LOOP
C
      DO 4000 N=1,M
      CALL                                                          RECHR
(RN,PET,ROC,F,D,RC,SMDP,SMD,AE,REC,PR,ROF,ERN,TREC,TRN,
     1TPET,TROF,TAE,CE,SPL,TSPL,NDR,I,J,N)
4000  CONTINUE
      MREC(J)=TREC
      MRN(J)=TRN
      MPET(J)=TPET
      MROF(J)=TROF
      MAE(J)=TAE
      MNDR(J)=NDR
      MWRN(I,J)=MWRN(I,J)+WF/54350.0*TRN
      MWROF(I,J)=MWROF(I,J)+WF/54350.0*TROF
      MWAE(I,J)=MWAE(I,J)+WF/54350.0*TRAE
      MWREC(I,J)=MWREC(I,J)+WF/54350.0*TREC
      MWNDR(I,J)=MWNDR(I,J)+WF/54350.0*FLOAT(NDR)
      YRN=YRN++TRN
      YPET=YPET+TPET
      YROF=YROF+TROF
      YAE=YAE+TAE
      YREC=YREC+TREC
      YNDR=YNDR+NDR
      AMRN(J)=AMRN(J)+TRN
      AMROF(J)=AMROF(J)+TROF
      AMPET(J)=AMPET(J)+TPET
      AMAE(J)=AMAE(J)+TAE
```

```
      AMREC(J)=AMAE(J)+TAE
      AMIMD(J)=AMIMD(J)+IMD(J)
      MADR(J)=MADR(J)+NDR
3000 CONTINUE
C
C     PRINT YEARLY SUMARY
C
      WRITE(6,235) I+1972
  235 FORMAT(1H ,//,50X,14HSUMARY : YEAR ,I4,//)
      IF(I.EQ.1) WRITE(6,245)
  245 FORMAT(1H0,20X,96H    JAN     FEB     MAR     APR     MAY     JUN
     1    JUL     AUG     SEP     OCT     NOV     DEC,5X,5HT0TAL,/)
      WRITE(6,255)
ROC,(RC(J),J=1,12),(D(J),J=1,12),(IMD(J),J=1,12)
  255 FORMAT(1X,18HRUNOFF           COEFFICIENT,3X,F6.3,/1X,13HROOT
CONSTANT,9X,1
                12F8.1,/,1X,7HMAX     SMD,15X12F8.1,/,1X,11HINITIAL
SMD,11X,12F8.1)
      WRITE(6,265)
(MRN(K),K=1,12),YRN,(MPET(K),K=1,12),YPET,(MROF(K),K=

11,12),YROF,(MAE(K),K=1,12),YAE,(MREC(K),K=1,12),YREC,(MNDR(K),K=
1,
     112),YNDR
  265 FORMAT(1H0,"RAINFALL/IRRIGATION
",2X,13F8.1,/,1X"P.EVAPOTRANSPIRA
                                                              1TION
",2X,13F8.1,/,1X,"RUNOFF",16X,13F8.1,/,1X,"A.EVAPOTRANSPIRAT
     2ION",2X,13F8.1,/,1X,"RECHARGE",14X,13F8.1,/,1X,"NO. OF DAYS
RECH"
     36X,13I8)
C
      AYRN=AYRN+YRN
      AYROF=AYROF+YROF
      AYPET=AYPET+YPET
      AYAE=AYAE+YAE
      AYREC=AYREC+YREC
      AYNDR=AYNDR+YNDR
2000 CONTINUE
C
      DO 500 I=1,12
      AV=12.0
      AMPET(I)=AMPET(I)/AV
      IF(I.GT.10) AV=11.0
      AMRN(I)=AMRN(I)/12.0
      AMROF(I)=AMROF(I)/12.0
      AMAE(I)=AMAE(I)/12.0
      AMREC(I)=AMREC(I)/12.0
      AMIMD(I)=AMIMD(I)/12.0
      AMNDR(I)=AMNDR(I)/12.0
  500 CONTINUE
C
      WRITE(6,275) NZN
      WRITE(6,285)
(AMRN(I),I=1,12),AYRN/12.0,(AMPET(I),I=1,12)AYPET/12.

10,(AMROF(I),I=1,12),AYROF/12.0,(AMAE(I),I=1,12),AYAE/12.0,(AMIMD
(I
```

```
2),I=1,12),(AMREC(I),I=1,12),AYREC/12.0,(AMNDR(I),I=1,12),AYNDR/1
2.
  275  FORMAT(1H  ,20X,"MEAN  MONTHLY  VALUES  FOR  THE  12  YEARS:
ZONE",I2//,2
     17X,"JAN      FEB      MAR      APR      MAY      JUN      JUL
AUG
     2  SEP      OCT      NOV      DEC     ","    TOTAL")
   285   FORMAT(1HO,//,23H   RAINFALL/IRRIGATION      ,13F8.1,/,23H
P.EVAPOTRANS
             1PIRAYION       ,13F8.1,/,7H   RUNOFF,16X,13F8.1,/,23H
A.EVAPOTRANSPIRATI
             2ON       ,13F8.1,/,12H   INITIAL   SMD,11X,13F8.1,/,"
RECHARGE",14X,13F8.1
     3,/," NO. DAYS OF RECHARGE",3X,13F8.1,///)
1000 CONTINUE
C
      AYWRN=0.0
      AYWROF=0.0
      AYWAE=0.0
      AYWREC=0.0
      AYWNDR=0.0
      DO 600 K=1,12
      YWRN=0.0
      YWROF=0.0
      YWAE=0.0
      YWREC=0.0
      YWNDR=0.0
C
      D0 700 L=1,12
      YWRN=YWRN+MWRN(K,L)
      YWROF=YWROF+MWROF(K,L)
      YWAE=YWAE+MWAE(K,L)
      YWREC=YWREC+MWREC(K,L)
      YWNDR=YWNDR+MWNDR(K,L)
      AMWRN(L)=AMWRN(L)+MWRN(K,L)
      AMWROF(L)=AMWROF(L)+MWROF(K,L)
      AMWAE(L)=AMWAE(L)+MWAE(K,L)
      AMWREC(L)=AMWREC(L)+MWAE(K,L)
      AMWNDR(L)=AMWNDR(L)+MWNDR(K,L)
      AMWIMD(L)=AMWIMD(L)+MWIMD(K,L)
 700 CONTINUE
C
      IF(K.EQ.1) WRITE(6,295)
 295 FORMAT(1H ,"      WEIGHTED VALUES FOR THE WHOLE ZONE"//,8X,"
JA
     1N      FEB      MAR      APR      MAY      JUN      JUL      AUG
SE
     2P      OCT      NOV      DEC     TOTAL")
      WRITE(6,305)(K+1972),(MWRN(K,L),L=1,12),YWRN,(MWROF(K,L),L=1
,12)

1,YWROF,(MWAE(K,L),L=1,12),YWAE,(MWREC(K,L),L=1,12),YWREC,(MWNDR(
     2K,L),L=1,12),YWNDR,(MWIMD(K,L),L=1,12)
 305 FORMAT(1H0,//,10X,I4//"    MWRN "13F8.1/,"  MWROF "13F8.1,/"
MW
      1AE "13F8.1,/"   MWREC "13F8.1,/"   MWNDR "13F8.1/"   MWIMD
"12F8.1)
      AYWRN=AYWRN+YWRN/12.0
      AYWROF=AYWROF+YWROF/12.0
```

```
      AYWAE=AYWAE+YWAE/12.0
      AYWREC=AYWREC+YWREC/12.0
      AYWNDR=AYWNDR+YWNDR/12.0
  600 CONTINUE
C
      AV=12.0
      DO 800 L=1,12
      IF(L.GT.10)AV=11.0
      AMWRN(L)=AMWRN(L)/AV
      AMWROF(L)=AMWROF(L)/AV
      AMWAE(L)=AMWAE(L)/AV
      AMWREC(L)=AMWREC(L)/AV
      AMWNDR(L)=AMWNDR(L)/AV
      AMWIMD(L)=AMWIMD(L)/AV
  800 CONTINUE
C
      WRITE(6,315)
(AMWRN(L),L=1,12),AYWRN,(AMWROF(L),L=1,12),AYWROF,

1(AMWAE(L),L=1,12),AYWAE,(AMWREC(L),L=1,12),AYWREC,(AMWIMD(L),L=
     21,12),(AMWNDR(L),L=1,12)AYWNDR
   315  FORMAT(1H  ,//"    MEAN  MONTHLY  WEIGHTED  VALUES"//,"    RN
"13F8.1
     1,/"    ROF   "13F8.1,/"  AE    "13F8.1,/"  REC   "13F8.1,/"  IMD
"
     212F8.1/"  NDR   "13F8.1)
C
      STOP
      END
C
C
      SUBROUTINE
RECHR(RN,PET,ROC,F,D,RC,SMDP,SMD,AE,REC,PR,ROF,ERN,
     1TREC,TRN,TROF,TAE,NDR,I,J,N)
      DIMENSION RN(31),PET(31),RC(12),D(12)
      ROF=ROC*RN(N)
      IF(J.GT.10.OR.J.LT.4) ROF=0.0
      IF(PET(N).GE.RN(N)) ROF=0.0
      ERN=RN(N)-ROF
      IF(SMD.GE.D(J)) GO TO 301
      IF(SMD.GE.RC(J)) GO TO 301
      AE=PET(N)
      IF((SMD+AE).GT.RC(J)) AE=(RC(J)-SMD)+F*(PET(N)-(RC(J)-SMD))
      GO TO 303
  301 IF(RN(N).GE.(PET(N)+ROF)) AE=PET(N)
      IF(RN(N).LE.PET(N)) AE=(1.0-F)*(RN(N)-ROF)+F*PET(N)
      IF(RN(N).LE.PET(N).AND.SMD.GE.D(J)) AE=RN(N)
      IF(RN(N).GE.PET(N).AND.RN(N).LT.(PET(N)+ROF)) GO TO 302
      GO TO 303
  302 AE=PET(N)
      ROF=RN(N)-PET(N)
  303 PR=RN(N)-ROF-AE
      SMD=SMDP-PR
      IF(SMDP.GE.D(J).OR.SMD.LE.D(J)) GO TO 304
      AE=AE-(SMD-D(J))
      GO TO 303
  304 IF(SMD.GE.0.0) REC=0.0
      IF(SMD.LT.0.0) GO TO 305
      GO TO 306
  305 REC=-SMD
```

```
      NDR=NDR+1
      SMD=0.0
306   SMDP=SMD
      TREC=TREC+REC
      TRN=TRN+RN(N)
      TPET=TPET+PET(N)
      TAE=TAE+AE
      GO TO 705
      IF(N.EQ.1) WRITE(6,235)
235   FORMAT(///,3X,94HDAY          RAINFALL      RUNOFF
     1EVAPOTRANSPIRATION    SOIL MOISTURE   RECHARGE     ,//,
     246X,18HPOTENTIAL    ACTUAL,4X,7HDEFICIT,//,3X,3HREC,/)
      WRITE(6,245)N,RN(N),ROF,PET(N),AE,SMD,REC
245   FORMAT(1H ,2X,I2,12X,F5.1,7X,F4.1,12X,F4.1,8X,F4.1,6X,
     1F6.2,10X,F4.1)
705   CONTINUE
      RETURN
      END
```