# THE HYDROLOGY OF SAMARU DAM CATCHMENT BASIN

BY

ANDREW OLUFEMI OMOLOKUN

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# THE HYDROLOGY OF SAMARU DAM CATCHMENT BASIN

## I N T R O D U C T I O N

### (A) PURPOSE

The major objective in this study was the determination of the hydrological balance of a small typical river basin in the North of Nigeria, near the Zaria City.

The study, which is one of the first of its kind in the area, will enable more accurate predictions to be made of the available water resources of the basin.

It will also provide a basis for future work in correlating the different components of the hydrological cycle and other current and future research work carried out by the University on the basin.

Catchment basin studies are a working tool needed to plan for soil and water conservation for the agricultural and economic growth of the area in particular and the nation as a whole.

## (B) THE IMPORTANCE OF WATER CONSERVATION IN THE ECONOMY OF NORTHERN NIGERIA

In the northern states of Nigeria, the dry and wet seasons are well-defined, and the pattern of crop production is dependent on the amount and distribution of rainfall.

In the southernmost part, where the rainfall is heavier and distributed over longer period, the staple crops are mainly roots, e.g., yams, cassava and sweat potatoes. The cash crops are mainly tree crops, e.g., coffee, palm products, shear of butter and cocoa. Owing to lower rainfall and a shorter growing season in the north, the food crops are dominated by grains, e.g., sorghum, millet, and the main cash crops are groundnuts and cotton. The subsidiary crops are rice, beans, vegetables and citrus fruits.

During the dry season cultivation is at a stand still, because of a physical lack of water. This period has also considerable influence on pastoral output which is an important part of the northern Nigerian economy. The livestock, which consists mainly of cattle, goats and sheep, lose weight during the dry season owing to lack of sufficient and balanced feeding. As a result, resistance to disease is decreased and their growth period to marketing is prolonged.

Therefore progress in agriculture and in industry demand adequate conservation and careful use of water resources. Use

of the conserved water will not only limit the risk of rainfed crop failures, but will also help to bring under cultivation large areas of land now lying waste. With a correct combination of land and water in space and time more food crops and agricultural raw materials - the basic necessities for an industrial growth will be produced year in and year out. It would also be possible to grow more than one crop per year in an area, or to extend the growing season and thus permit the introduction of new crops.

(C)
ABSTRACT

The hydrological characteristics of this small catchment basin which is essentially an agricultural land are described and the available climatic data examined. One of the methods by which climatic picture may be created is by the averages of the several climatic elements particularly thost. on precipitation and temperature. This picture is presented in the form of histograms. The analysis of the characteristics, origin and distribution of the important elements which comprise the climatic complex are presented.

During the rainy season the catchment basin is vegetative providing protection from the impact of rainfall for the soil. The soil cover and land use studies show that they are essential factors in analysing the hydrological components. Owing to the present system of land use, the observed surface runoff is low though the runoff potential on the basin is high.

Determination of the changes in ground water storage was accomplisaed from an adequate knowledge of the behaviour of the water-table in the basin. The dry and wet season contour maps prepared provide direct visual information relating to the slope of the water-table. Depth to dry season water table can be estimated at any point on the oatchment basin using a simple formula evolved. It is only during the dry season

that the entire population of Bomo village appreciate fully the ground water resources for their needs.

In solving the equation of the hydrologic equilibrium, advantage was taken of the basin' s ground water and climatic characteristics.

C O N T E N T S


Part I

THE ENVIRONMENTAL STUDY — Page

(A) Location 1

(B) Land Use 2

(C) Soils (i) General 5

(ii) Middle Slopes 7

(D) Climate - General 9

(i) Radiation 15

(ii) Evaporation and Transpiration 18

(iii) (a) Precipitation General 19

(b) Statistical Analysis 22

Part II

PHYSICAL AND HYDROLOGICAL PROPERTIES OF THE UPPER SLOPE SOILS

(A) Introduction 27

( ) Methods of Sampling 27

(C) Laboratory Analysis 28

(D) Results 29

Part III

SURVEY OF THE CATCHMENT AREA

(A) Methods of Survey 34

Page

(B) Results

I (i) Area 36

(ii) Basin Characteristics 36

II Land Use 38

(C) The Concentration Point 40

**Part IV**

GROUND WATER STUDY

(A) Setting 43

(B) General Pattern 44

(C) Water-table Gradients 45

(D) The Direction of Ground Water Flow 51

(E) Agricultural Significance 52

**Part V**

THE HYDROLOGICAL BALANCE OF THE CATCHMENT BASIN - 1968 HYDROLOGICAL YEAR

(A) Basic Hydrology 55

(B) Experiment Setup to Solve the Equation 56

(C) Assessment of Main Components of Hydrological Equation

(i) Mean Areal Depth of Precipitation 58

(ii) Ground Water 61

(iii) Evapotranspiration 62

(iv) Runoff 64

(a) Estimate of Discharge over the spillway 64

(b) Estimate of the change of storage in the lake 66

(D) Computation of Values and Conclusions 63

APPENDIX I Statistical Annual Series
Computation of Extreme Values 81

II Frequency and Return Period of Values of Annual Precipitation for Samaru - 1928 - 1967 84

III Soil Analysis 86

IV Analysis of the Hydrological Year Rainfall Over the Catchment 87

V Discharge and Water-Table Gradient Correlation Analysis 89

# PART I

## THE ENVIRONMENTAL STUDY

### (A) LOCATION

The experimental basin chosen for the study is a small one, but offers certain advantages as it comprises the upstream of a watershed. Part of the basin forms the main sites of the experimental farms of the Institute for Agricultural Research of Ahmadu Bello University. The basin is situated about three miles from the University on the Zaria - Shika road within longitude $7^{\circ}$ 38' 10" and $7^{\circ}$ 38' 30" and latitude $11^{\circ}$ 10' 20" and $11^{\circ}$ 12' 0" north (MAP SHEET I).

The basin is believed to be largely representative of the Loess Plain Soil Unit - (Lawes 1963) which extends over some 17,000 sq. miles in central parts of northern Nigeria and forms an important area for agricultural production. The Loess Plain Soil Unit is 1800 - 2400 feet above sea level, and consists mainly of rolling to gently undulating topography interrupted by occasional groups of granite inselbergs.

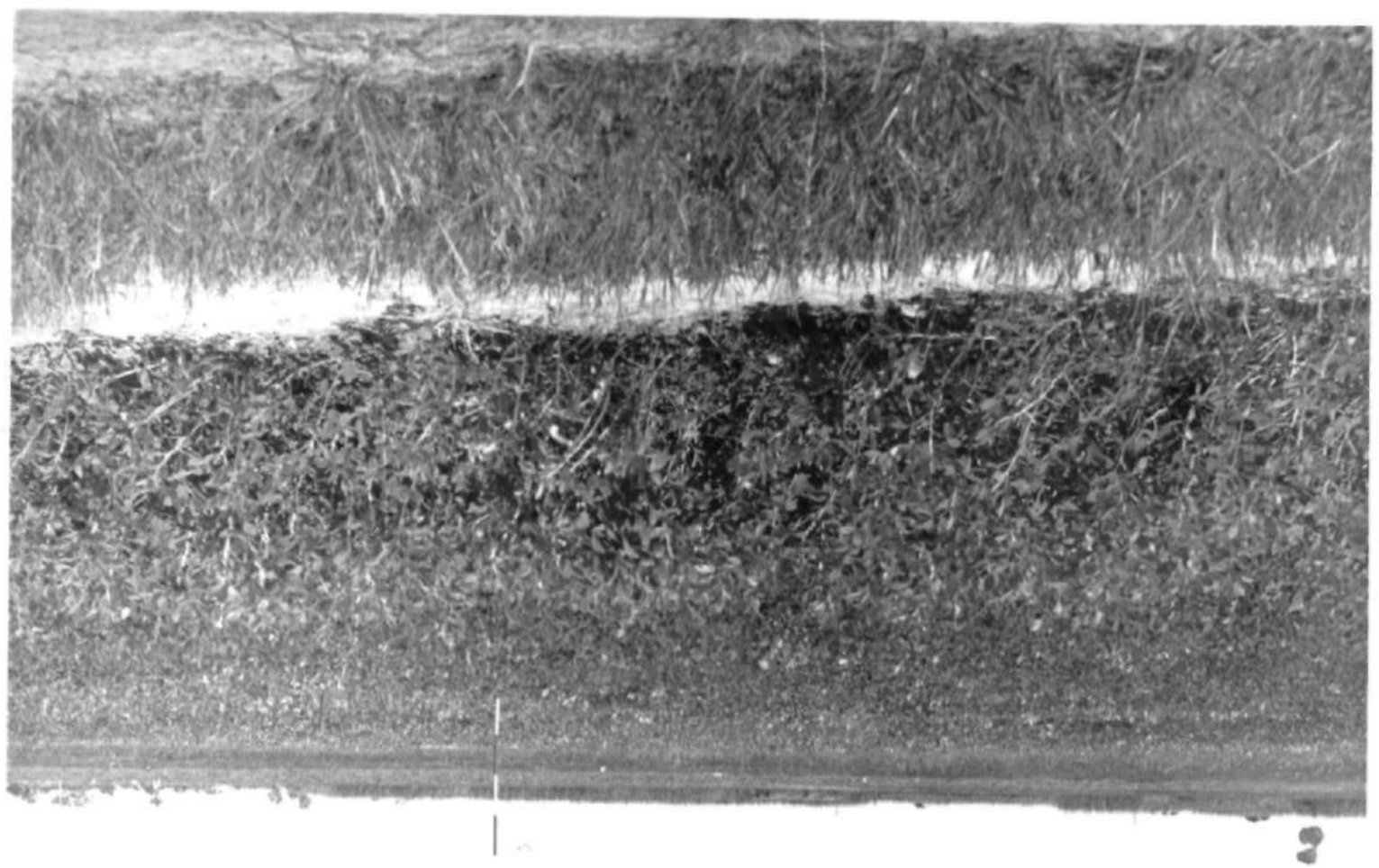
## (B) VEGETATION AND LAND USE

The natural vegetation of the area belongs to Northern Guinea Savanna zone described by Keay (1960) and consists of thickbarked trees and tall grasses growing in tussocks 1 or 2 feet apart, between which is bare ground. The common, thick-barked trees are Isoberlinia doka, Isoberlinia tomentosa, Menotes kerstingii and Uapaca samon.

The density of population varies considerably. Actual settlements have been largely determined by the accessibility of regular domestic water supplies chiefly from wells of moderate depth. Around Zaria and along the main roads settlements are dense and the land is almost permanently cultivated. Sorghum is the chief crop, whilst millet (Pennisetum species), groundnuts, cowpeas, cotton and some yams are grown in varying amounts. Almost all parts away from farm settlements are visited by the Fulanis with large heads of cattle.

Photograph I is a typical picture of the natural vegetation of the area around the basin when the ground has not been cultivated for a number of years. Within the basin the vegetation picture in modified by extensive cultivation (photo II). As a result it is far more open and degraded than the surrounding woodland.





II

(C) SOILS

(i) General

The soils have been formed by infilling of fine drift material onto a sedentary soil derived from Basement Complex formations. It has a high proportion of fine sand at or near the surface.

The geomorphology of this soil unit is complex owing to various aged ironpan formations and the partial masking of erosion surfaces of recent drift deposits. Profile descriptions of those soils together with their analytical data are given by Higgins (1963). The soils, reddish brown to greyish-brown, are fine grained containing about 50 per cent of fine sand in its upper layers. They are largely non-gravelly though iron-oxide concretions or broken up concretionary ironstone very often occurs in the upper layers of the upper slope soils.

The clay fraction, which as a rule increases in depth, consists of Kaolinite and oxides especially of iron and of micaceous clays. The molecular weight ratio $SiO_2/Al_2O_3$ is usually equal or greater than 2, whilst the $SiO_2/R_2O_3$ molecular weight is always below 2.

The base exchange capacity of the soil is low (4 - 9 me/100g) and the hydrogen ion ($H^+$) concentration varies from about pH 6 - 6.5 at the surface decreasing gradually with depth to about pH 5.0. Low carbon and nitrogen of about 0.6%

and 0.05% respectively for surface soils are typical. Below the transported material the subsoil becomes distinctly coarser. Under cultivation the soil surface forms a hard crust (hardpan) when exposed to rainfall and this impedes cultivation in succeeding years.

The coefficient of permeability or the hydraulic conductivity of the first 6" layer of the soil is presented in the Table A below (Kowal, 1967). The permeability of the soil profile down to the dry season water table of on average 16 feet was determined, using pumping test techniques, to be 10" per hour.

TABLE A

HYDRAULIC CONDUCTIVITY OF SOIL

| SOIL TREATMENT | HYDRAULIC CONDUCTIVITY (in / hr.) |
|---|---|
| Cotton with 5 tons FYM received annually | 5.1 |
| Cotton | 1.5 |
| Natural Vegetation | 1.2 |
| Grass fallow | 1.0 |
| Bare fallow plot | 0.4 |

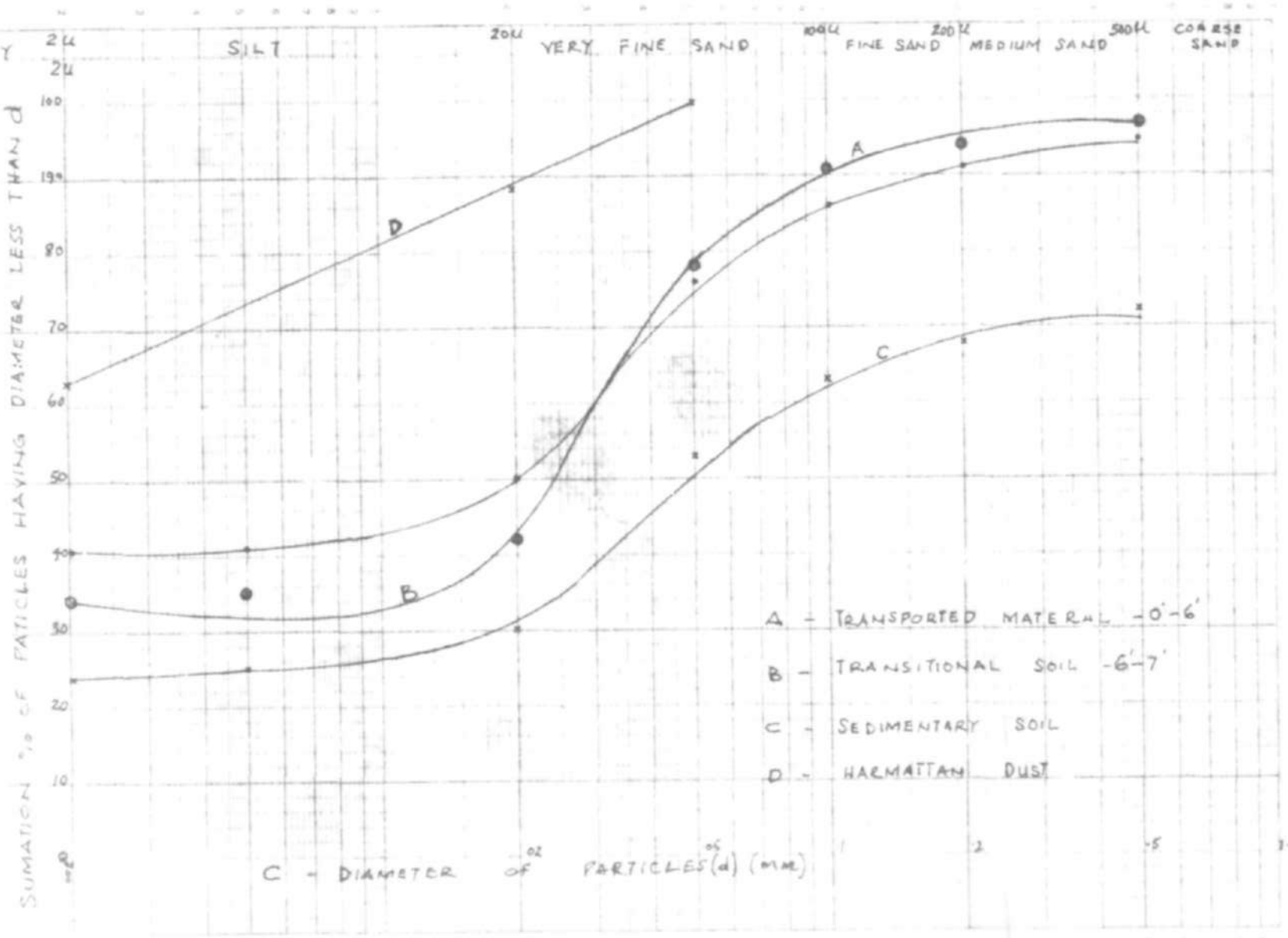
(C) (ii) MIDDLE SLOPES

Some physical and hydrological studies were carried out on the middle slope soils in 1967 by the Soil Science Section of the University. From the laboratory analysis of the soil samples it is observed that, from the surface to a depth of 5 feet which forms the base of the transported material, the soil is free of stones. The bulk of the materials lies between 2$\mu$ and 50 $\mu$ in diameter. In the upper 6 feet of the soil depth the clay percentage is low, probably owing to frequent cultivation. The clay fraction in the transported material increases with depth from 13% at the surface to about 40% at its base. The particle size distribution curves are as shown in Fig I.

The particle density increases with depth with values ranging from 2.63g/cc at the surface to 2.71g/cc, i.e., the sedentary soils values are above average. The total porosity decreases gradually with depth with values ranging from 46% to 34% corresponding to 5.6" to 4" per foot depth of soil respectively (Table IA). The storage capacity of the soil was calculated to be 33 inches from the surface to a depth of 17 feet.

FIG. 1

PARTICLE SIZE DISTRIBUTION CURVES - (MIDDLE SLOPES)



(D) CLIMATE

General

In the Koppen's classification, (Trewartha, 1954) the basin enjoys the Aw type of climate, i.e., there is marked wet and dry season with little variation between the maximum and the minimum temperature.

The rainy season normally begins in April and ends in early October. The moisture-laden wind (south west wind) predominates throughout the wet season. Fast moving dusty winds usually precede the start of the rains and the wind transported particles or nuclei, are only of the order of $10^{-3}$ to 10 microns in size and have an affinity for water (Chow, 1964). Condensation in the atmosphere takes place on these hygroscopic nuclei and the first rains are usually dirty due to the presence of the dust. In general, the rains occur at regular and frequent intervals after the last week of May with the heaviest and most continuous rainfall in August (Fig. 2,3). The end of rainy season, whether in September or October, is usually abrupt.

The dry season usually begins in October and is characterised by the east-west moving tornadoes. These severe line squalls are associated with the fluctuating northward and southward movements of the dry and stable Sahara air of anti-cyclonic origin arriving in Nigeria from north easternly

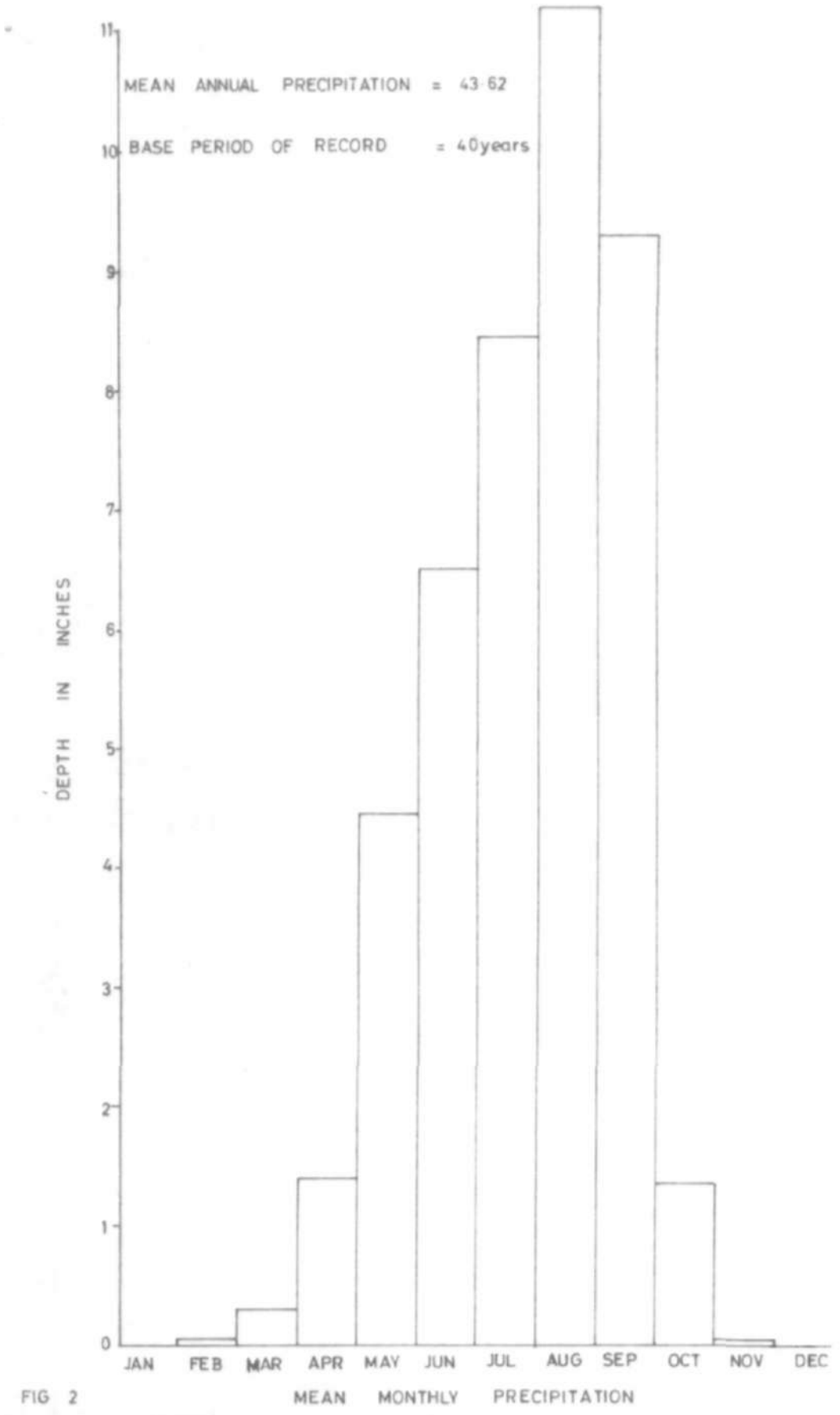

MEAN ANNUAL PRECIPITATION = 43·62
BASE PERIOD OF RECORD = 40years
DEPTH IN INCHES
0
1
2
3
4
5
6
7
8
9
10
11
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MEAN MONTHLY PRECIPITATION

FIG 2

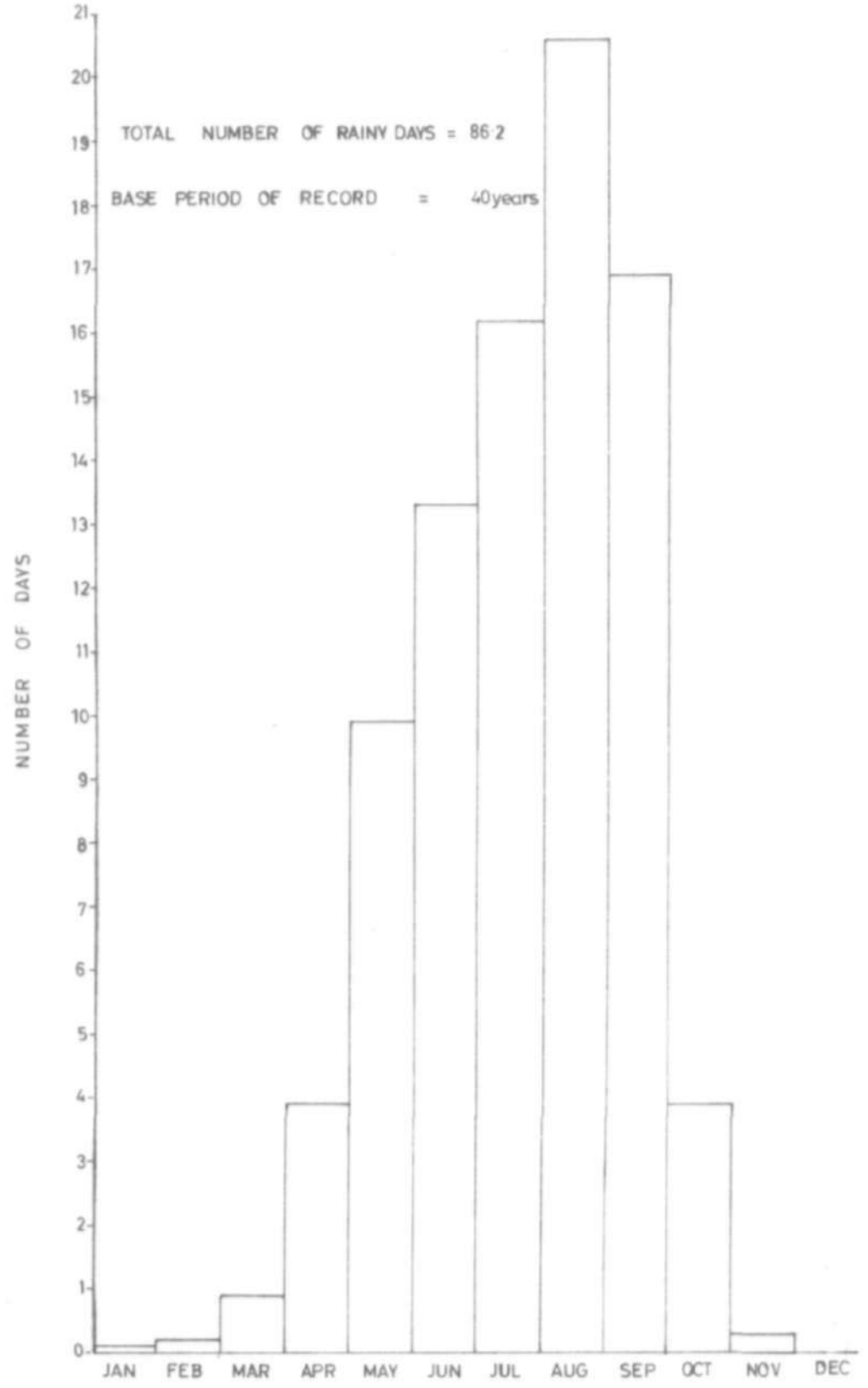



FIG 3 MEAN DAYS OF PRECIPITATION

direction, meeting the cooler, moist and unstable air from the southwest with its source over the Atlantic Ocean. This stable Sahara air or Harmattan wind is dusty and cold. The cold air is imported by the harmattan wind from north-east Africa which is invaded during winter by the cold Siberian Polar Air Mass. Cold evenings, nights and mornings, low visibility, low relative humidity, (Figs. 4, 5) are weather conditions associated with the true harmattan. The intensity of the weather conditions is a function of the strength of the wind which in turn depends to a great extent, on the severity of the frontal activities in some parts of its source. The low visibility is due to the density of the dust in the atmosphere and the strength of the harmattan wind. The harmattan blows throughout most of the dry season and usually finishes in February. The month of January can be relatively cool with morning temperatures as low as $46^{\circ}F$. During the later part of the dry season the temperature rapidly rises (Fig. 5) and it is hot throughout the day and night. The mean monthly temperature is $80^{\circ}F \pm 5^{\circ}F$.

The climatic elements are discussed as follows under three main headings:

(1) Radiation

(2) Evaporation and transpiration

(3) Precipitation.

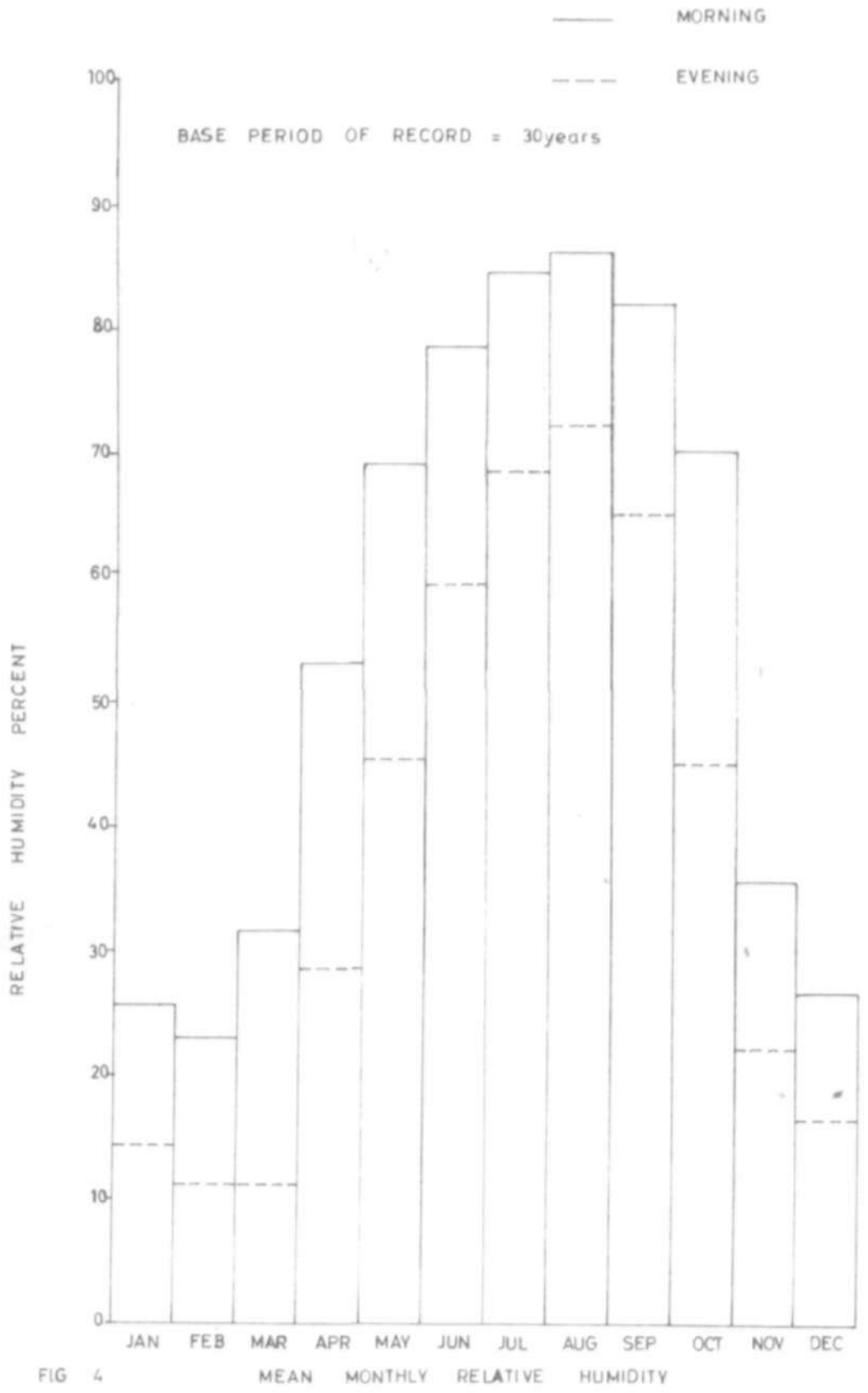



FIG 4 MEAN MONTHLY RELATIVE HUMIDITY

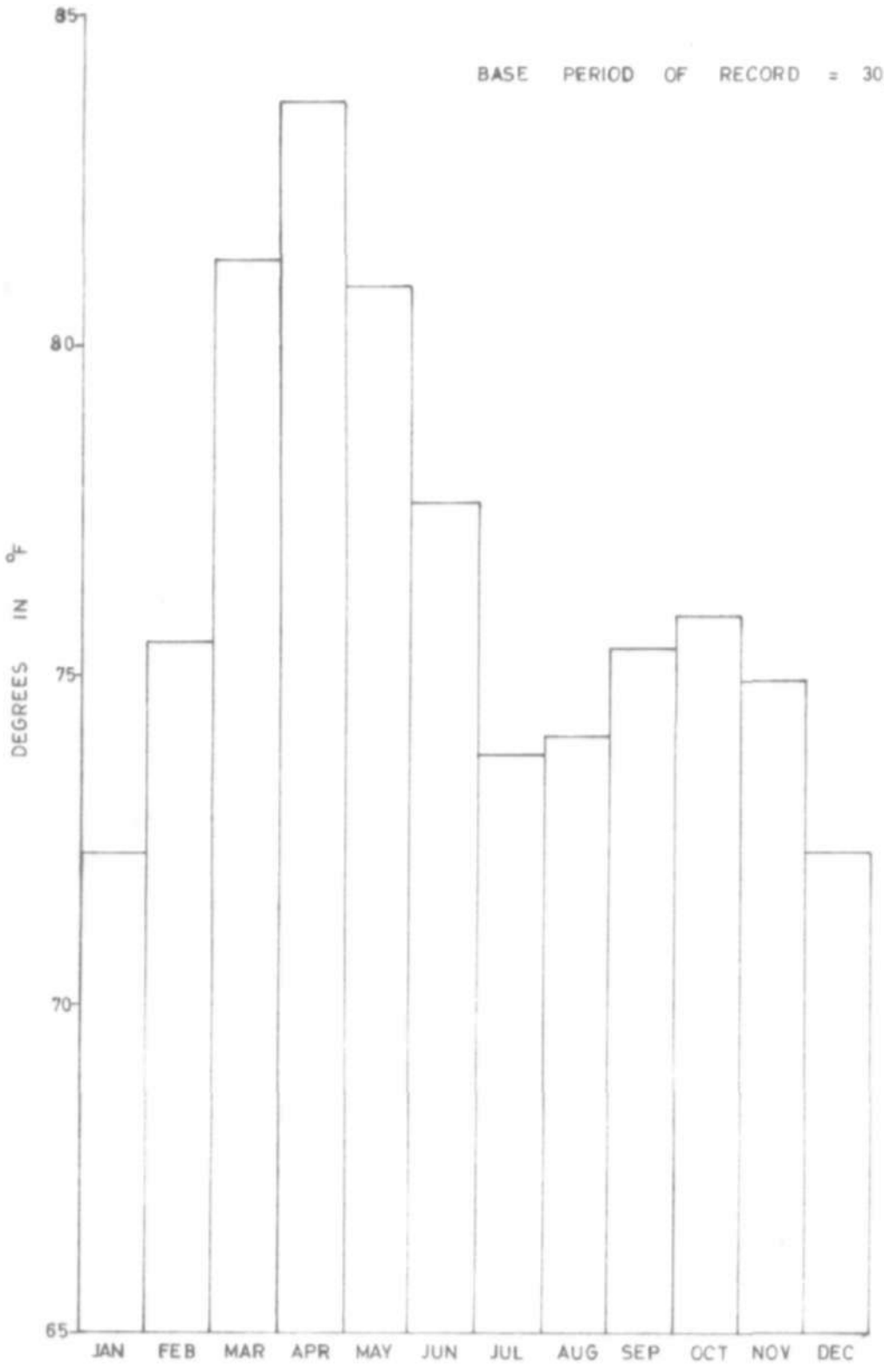



FIG 5 MEAN MONTHLY TEMPERATURE

(D) (i) RADIATION

The single noteworthy source of heat for the earths' atmosphere is the sun. The duration of bright sunshine is measured locally at Samaru using a Campbell-stokes Sunshine Recorder. The duration of bright sunshine is least in August and greatest from November to February (Fig. 6). Considerable importance is at present given to the measurements of total radiation by the use of a Kipp's solarimeter because potential evapotranspiration is easily calculated from the data. The measurements are in gram-calories $cm^{-2}$ per day. Fig. 7 , show, that the total radiation is low during the months of June to September.

Recently, measurements of the balance of short and long wave radiation or net radiation were made over various crop covers showing that net radiation is on the average about 55% of the total solar radiation (Davies, 1965). It is estimated that during the crops' growing period about 75% of the net radiation absorbed during the day time is used to evaporate water, whilst 5 - 10% goes into the sensible heat of the air and about 5% is being used in photosynthesis - (Kowal, 1968).

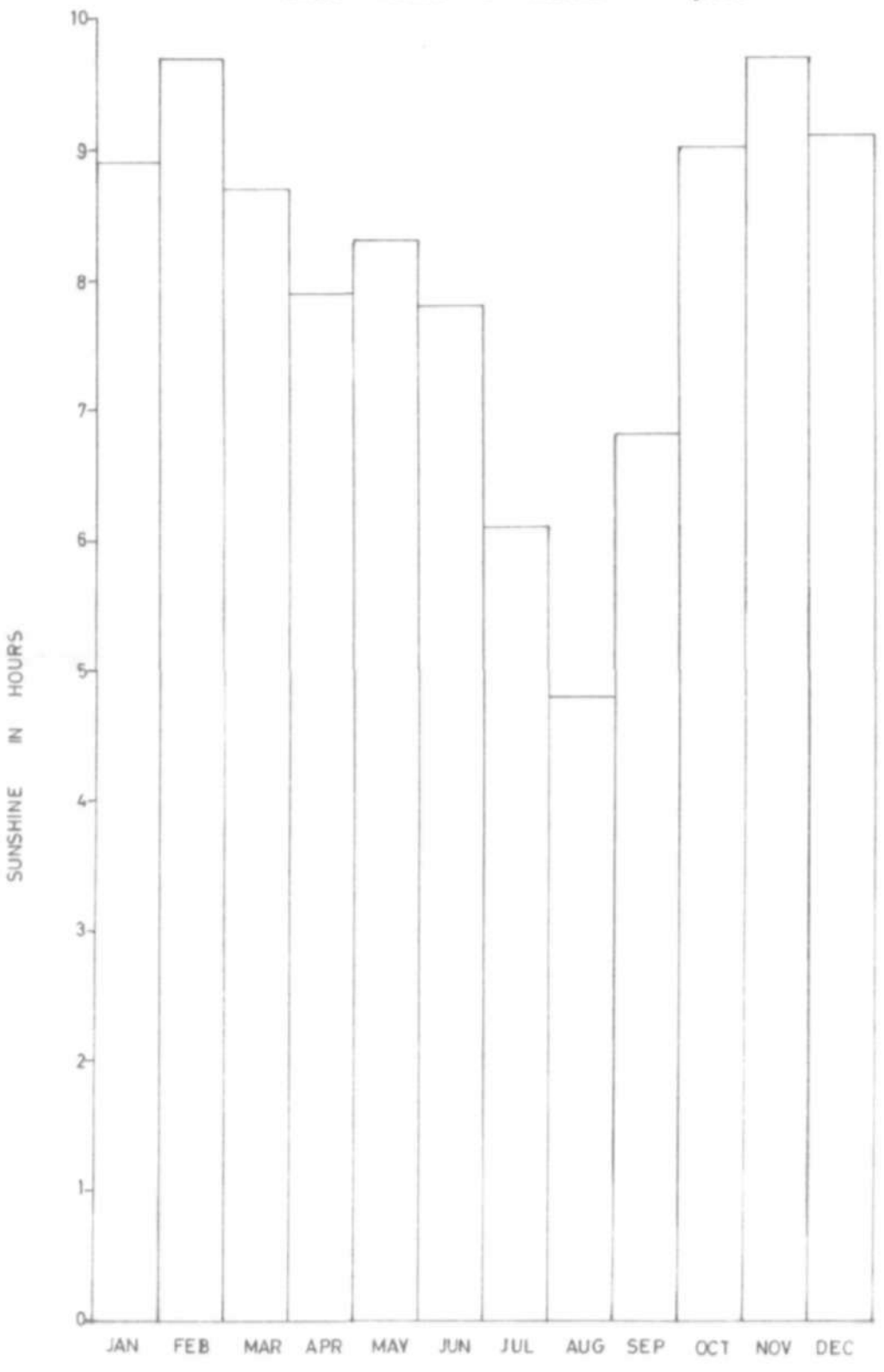
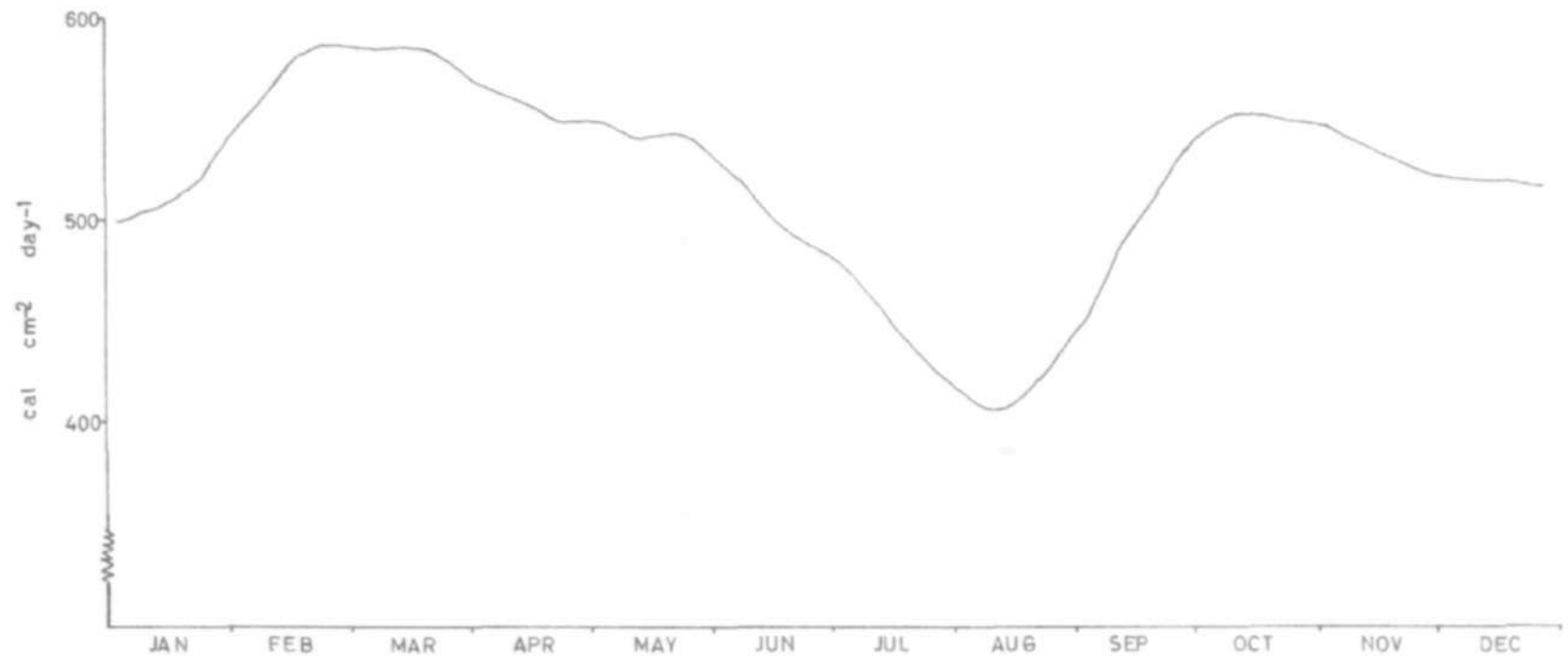



FIG 6 DAILY MEAN HOURS OF SUNSHINE

FIG 7 SOLAR RADIATION SAMARU

3 x 10 day moving averages



(D) (ii) EVAPORATION AND TRANSPIRATION

Free water on the surface of the land or vegetation will diminish in volume by the process of evaporation. The water is converted into vapour thus reducing the original water volume, but at the same time increasing the relative humidity of the atmosphere. The rate of evaporation depends upon several factors:

1. The intensity and duration of solar radiation
2. Rate of change of atmospheric and ground temperature.
3. The relative humidity of the atmosphere
4. Air stream (wind) velocity
5. The initial volume of water.

All plant growth has free water available for evaporation within the leaves stomata and this process is termed transpiration. The rate at which this water is turned into vapour depends upon the same factors and ordinary evaporation and on the rate at which the plant can extract water from the soil and make it available for transpiration.

Evaporation from free water surfaces can be as high as 2" per day and these measurements are made at the Samaru Meteorological Station using 'Piche' evaporimeters. Evaporation formulae have been developed by various workers among them Penman, whose formula is used in calculating potential evapotranspiration (Fig. 8). The actual evaporation will be

somewhat less than the potential owing to incomplete or varied vegetative cover or owing to the physical lack of water for evapotranspiration during the dry season. From the third period of May to the last period of September potential evapotranspiration is less than the rainfall (Fig. 8).

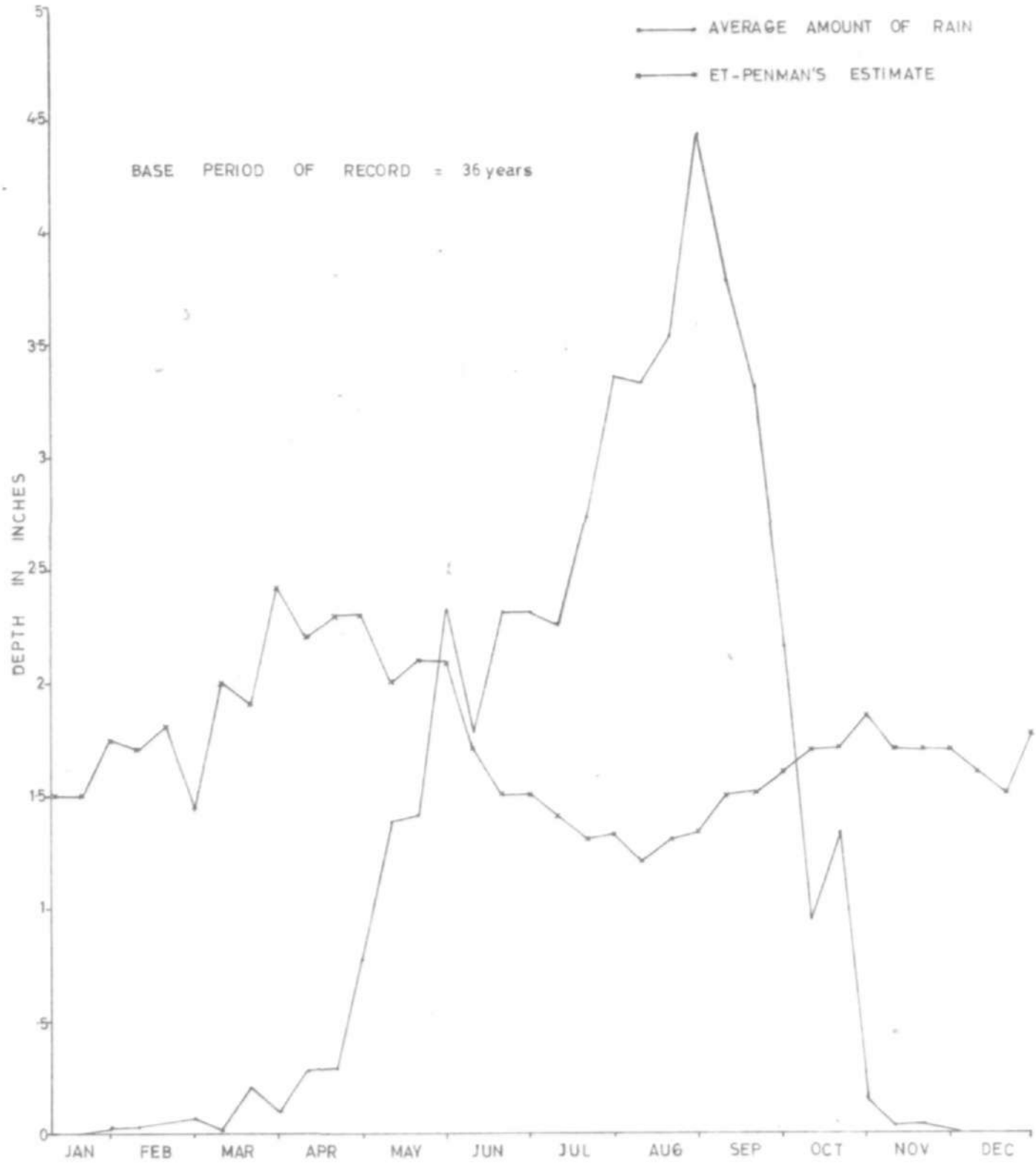
(D) (iii) PRECIPITATION

General

The daily amount of precipitation is measured in Samaru using the standard 5" diameter raingauge. The forty-year record available provides means of reliable analysis. The average annual amount of precipitation is 44" with a range from 58.34 inches in 1954 to 32.45 inches in 1961. The month of August usually has the highest rainfall, the amounts have varied from 21.24 inches in 1943 to 3.79 inches in 1967.

This wide variation in the amount of rainfall (Fig. 9) and the time the rainy season begins and ends is due to tropical climatic conditions. The beginning of the rainy season is defined when the accumulative rainfall just maintains evapotranspiration (Penman estimates) and the end when the evapotranspiration is not maintained. From the 41-year record (1928 - 68), on 82% of occasions the rainy season began in the second week of May and ended at the end of September, with the exceptions of 1954 and 1944. In 1944 the

FIG 8 A COMPARISON OF AVERAGE RAINFALL AND POTENTIAL EVAPOTRANSPIRATION



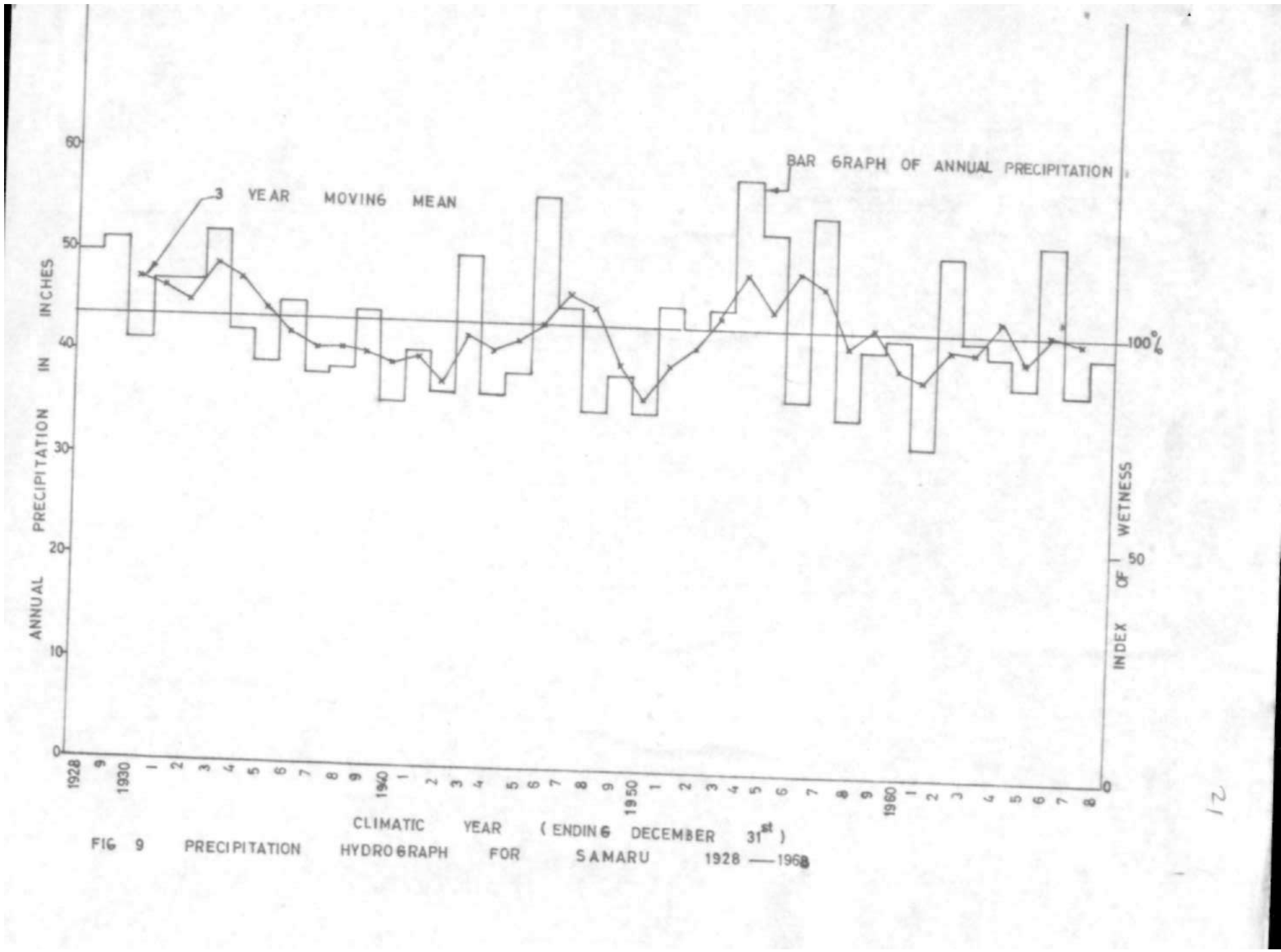



FIG 9 PRECIPITATION HYDROGRAPH FOR SAMARU 1928 — 1968

rainy season was from 21st May to 20th September (about 120 days ) whilst in 1954 the rainy season was from 1st April to 20th October, i.e., about 204 days.

(D) (iii)b STATISTICAL ANALYSIS

One important problem in hydrology is the interpretation of past records of a hydrologic event,, i.e., precipitation, in terms of the future probability of occurrence. This helps in assessing the susceptibility of soils to erosion, designing hydraulic structures and estimating irrigation needs.

In the statistical analysis, a forty-year precipitation record (1928 - 67) was used. The mean is 43.62" $\pm$ 2.1 inches. The coefficient of variation or the standard deviation of the indices of wetness is 15%. (See Appendix I for the computations.) In Appendix II the recurrence interval is shown as T and Hazen's method is used in the derivation of the frequency curve Fig. 10. The computation of frequency F is as shown in Appendix II.

For agricultural purposes the frequency and recurrence interval as analysed above are not accurate enough to assess longterm crop risks as there is an inherent skewness due to the non-uniformity of rainfall over short periods. A more accurate method is using Manning's method of 1 : 1 confidence limits of expected rainfall. In Manning's method, the inherent skewness

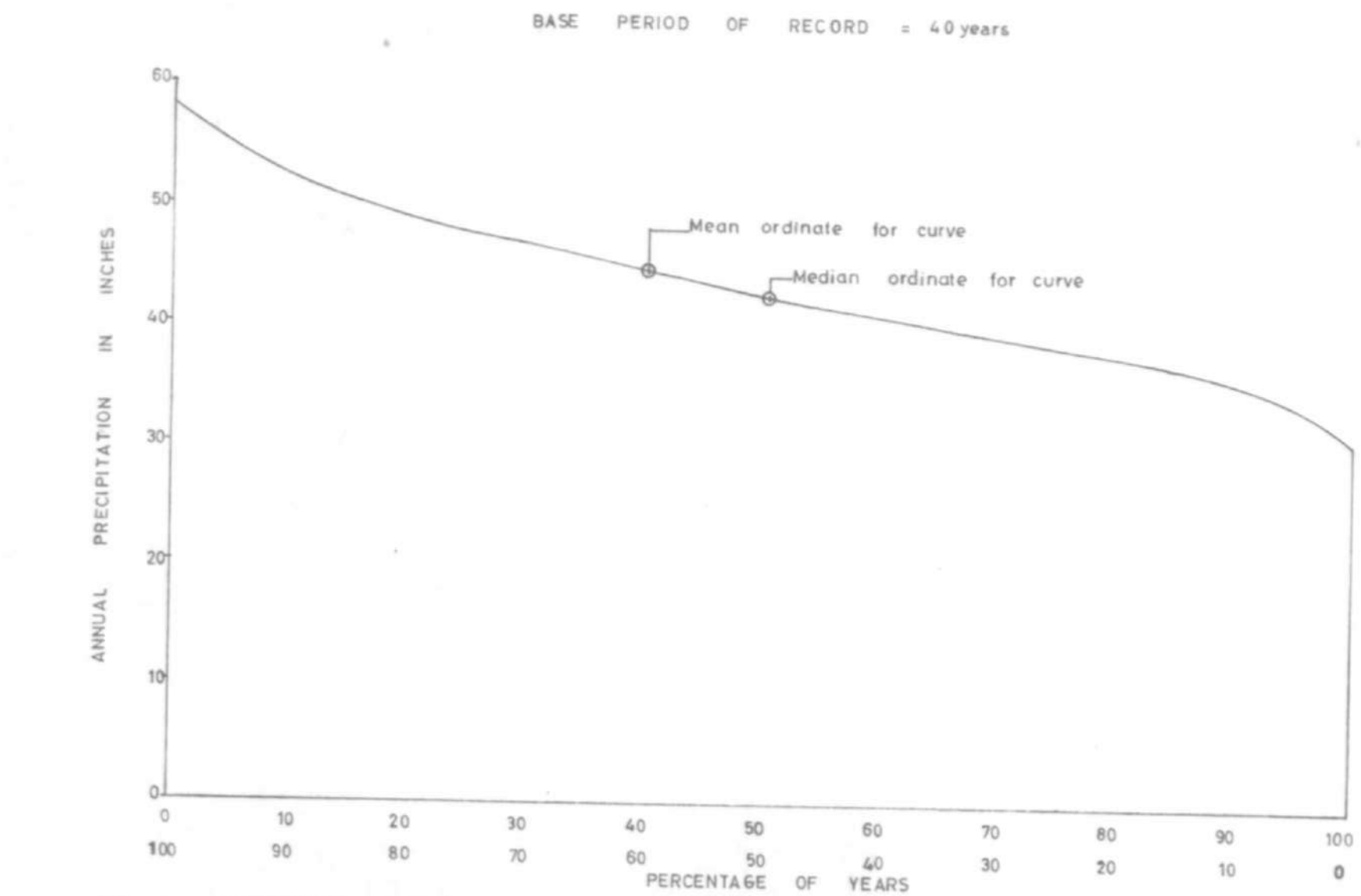



FIG 10 PRECIPITATION FREQUENCY CURVE FOR SAMARU USING HAZEN METHOD BASED ON 40 YEARS PERIOD 1928 - 1967

can be dealt with if the raw precipitation data are transformed by the addition of a constant and conversion to the logarithmic scale. Curves in Fig. 11 have been prepared using Manning's method - (Manning, 1956). Several conclusions can be drawn from these curves, but the most important one is that there is likely to be sufficient rainfall at the beginning of the planting periods and during the maturing periods of the crops. It is evident that water is not the limiting factor for the rainfed crop production in this area. However, there is the possibility that the uneven distribution of rainfall might give sub-optimal crop growth.

FIG 11 Samaru Rainfall

M Confidence limits of three weekly moving total

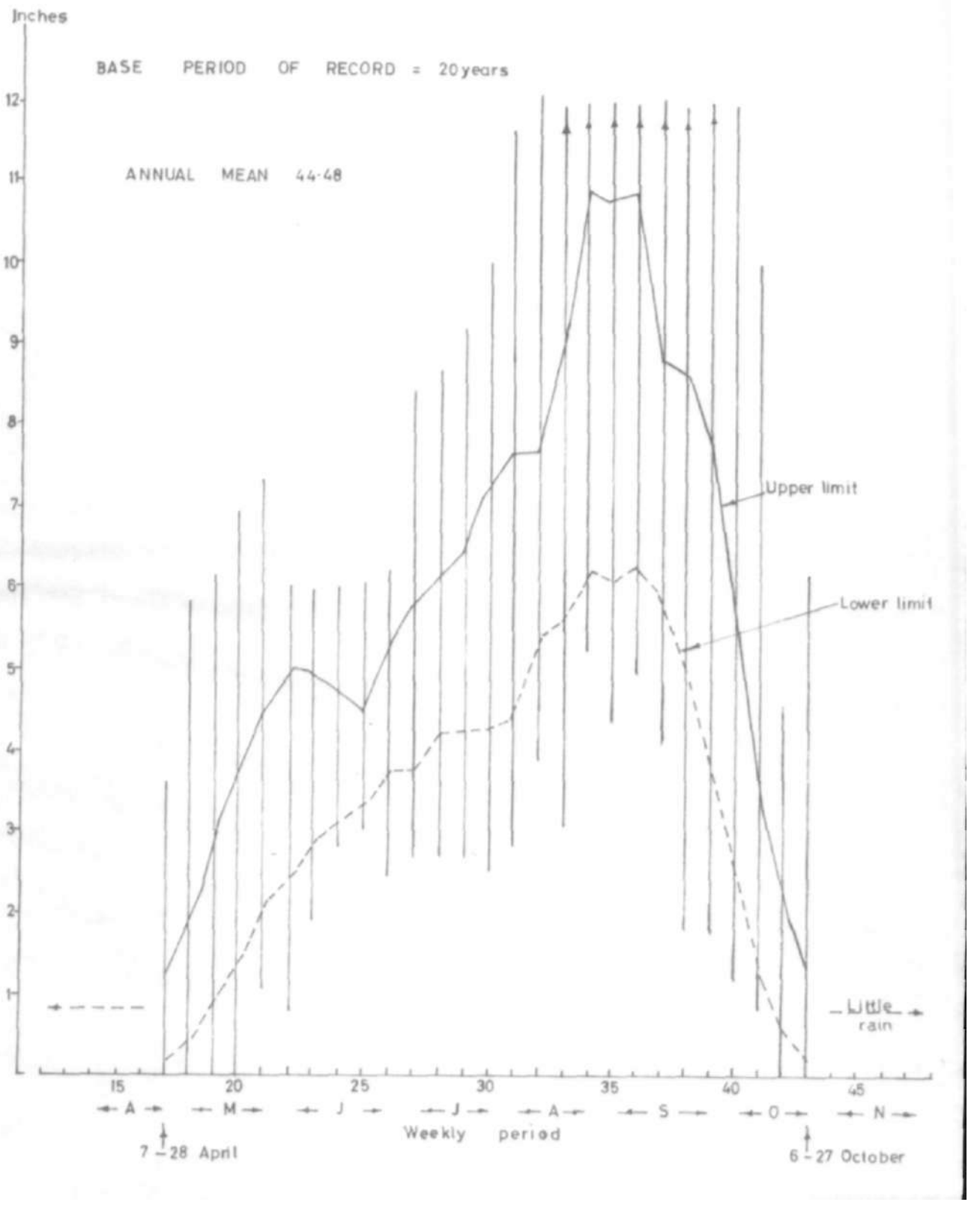


Table I

SOIL PROFILE SAMPLE AT 1 FOOT INTERVAL

1A MIDDLE SLOPE

| DEPTH | BULK DENSITY | PARTICLE DENSITY | TOTAL POROSITY |
|---|---|---|---|
| Feet | g/cc. | g/cc. | % |
| 0 - 1 | 1.52 | 2.63 | 42.3 |
| 1 - 2 | 1.45 | 2.64 | 45.9 |
| 2 - 3 | 1.48 | 2.65 | 44.2 |
| 3 - 4 | 1.55 | 2.66 | 41.8 |
| 4 - 5 | 1.58 | 2.66 | 40.6 |
| 5 - 6 | 1.58 | 2.67 | 40.9 |
| 6 - 7 | 1.59 | 2.67 | 40.5 |
| 7 - 8 | 1.55 | 2.68 | 42.2 |
| 8 - 9 | 1.60 | 2.68 | 40.3 |
| 9 - 10 | 1.63 | 2.69 | 39.4 |
| 10 - 11 | 1.64 | 2.70 | 39.3 |
| 11 - 12 | 1.70 | 2.70 | 37.1 |
| 12 - 13 | 1.72 | 2.71 | 36.6 |
| 13 - 14 | 1.75 | 2.72 | 35.7 |
| 14 - 15 | 1.77 | 2.71 | 34.7 |
| 15 - 16 | 1.78 | 2.71 | 34.1 |
| 16 - 17 | 1.78 | 2.70 | 34.1 |

# PART II

## PHYSICAL AND HYDROLOGICAL PROPERTIES OF THE UPPER SLOPE SOILS

### A. INTRODUCTION

The upper slope soils are not normally cultivated, but are frequented by the Fulanis with their large herds of cattle. A study of the laboratory analysis of the upper slope soil in conjunction with the middle slope soil (as discussed earlier (Part I, Cii) will provide more knowledge and understanding of the soil characteristics of the basin. The position of the trial pit is marked X on Map sheet II.

### B. METHODS OF SAMPLING

The undisturbed samples were taken at 1 foot intervals to a depth of 20 feet as the pit was excavated. The samples were taken by forcing stainless steel cylinders horizontally into the vertical face of the pit. The cylinders are 5 cm long, 5 cm in diameter with a volume of 100 $cm^3$ and opened at both ends with the sharper end as the cutting edge. Three samples were taken at each foot in a manner approximating the form of equilateral triangle, and excess soil was trimmed off with a knife.

(C) LABORATORY ANALYSIS

(i) PARTICLE SIZE DISTRIBUTION:- From each sample 50g of soild was used for this experiment. The Bouyocus method was followed, i.e., using the hydrometer. "CALGON" sodium hexameta phosphate $(NaPO_4)_n Na_2O$ was used as the chemical dispersion agent.

(ii) PORE SIZE DISTRIBUTION: Using a sand tension table and the procedure described by Varder Harst and Stokman, the water content at suction pressures or pF.0.4, 1.0, 1.5, 2.0, were determined on the undisturbed soil samples. Water content at pF 3.0 was determined using a "15 bar" ceramic plate extractor. The water content at pF 4.2 was determined by a pressure membrane apparatus with two layers of cellophane type PT 600 and 2mm soil.

(iii) PARTICLE DENSITY: A standard panchrometer method was employed using kerosine as the displacing liquid. The density of kerosine was maintained constant by carrying out the experiment in a controlled temperature in an air conditioned room.

(iv) BULK DENSITY: This was measured using the core method with 100 $cm^3$ cylinders.

(D) RESULTS

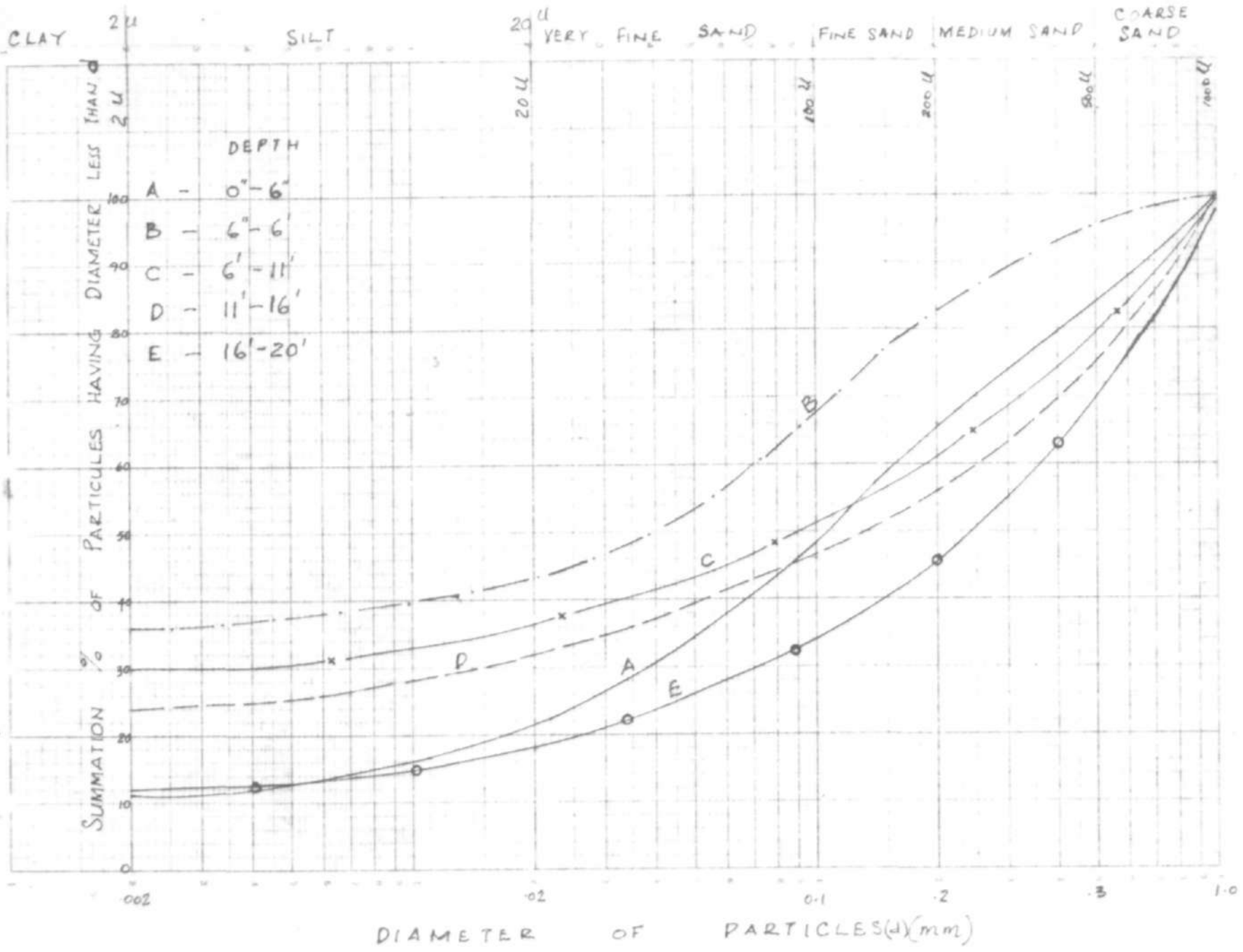
(i) PARTICLE SIZE DISTIBUTION: The upper 6 inch layer of the soil is low in clay percentage and consists of partially decomposed or matted plant residue of the past years. From 6 inch to 6 feet depth, which is believed to be the thickness of the drifted material, the soil is free from stones and gravel and the coarse sand percentage is high especially at the lower zones (Appendix III). The clay fraction is almost uniform and approximately 40%. The particle size distribution curve is as shown in Fig. 12. The soild in the lower sedentary part of the profile has a comparatively low clay content and a high proportion of coarse sand than the eaolian drift material. The bulk density is lower also due to the pronounced weathering (Table 1B).

(ii) PARTICLE DENSITY: The specific gravity of the transported material increases with depth with a value of 2.66g/cc at the surface to 2.69g/cc at the base. The average of this value is within the accepted value of 2.67g/cc. Below these levels the specific gravity is higher than normal with an average value of 2.70g/cc approximately, since this zone, i.e., from 6 feet to 20 feet consisted mainly of weathered granite - gneisses. (Klinkinberg, 1968)

(iii) TOTAL POROSITY: The total porosity percentage is calculated and presented in Table 1B. On average, the total

FIG 12

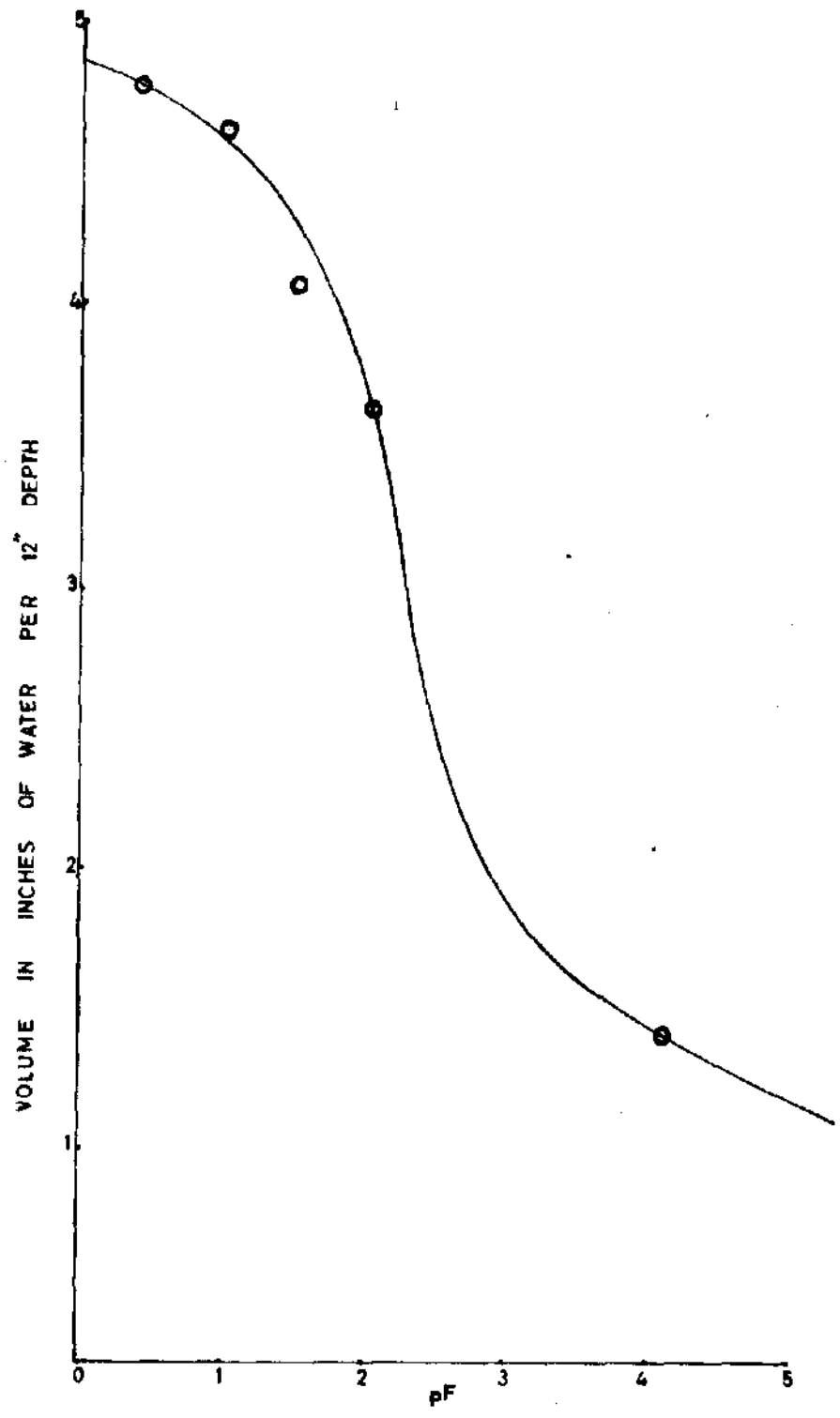
PARTICLE SIZE DISTRIBUTION CURVES (UPPER SLOPE)



porosity percentage for the upper slope soils is higher than the middle slope soils (Part I - C iii) as a result of the weathering of the upper slope soils. This indicates the degree of soil compaction as it represents the soil space occupied jointly by water and air. Generally the total porosity percentage of the top soils from the two examples is low. This is one of the contributing factors to the low rainfall acceptance into the soils and, as Lutz (1952) pointed out that the reduction in total porosity that accompanies compaction is usually at the expense of the macropores in the soil.

(iv) SOIL MOISTURE CHARACTERISTICS: Water is largely retained in the soil by surface tension. The pF curve (Fig.13) for the upper slope represents the amount of water available to plants at various energy levels and is also a measure of the relative ease with which plants can extract water from the soil. From the pF curve it is observed that the bulk of the soil water that can be extracted by plants is within the suction levels of pF 0 and pF 2.0 which may be assumed as the field capacity condition of the soil.

FIG 13 pF CURVE OF 12" DEPTH SOIL IN INCHES OF MOISTURE



SOIL PROFILE SAMPLE AT 1 FOOT INTERVAL

IB UPPER SLOPE

| DEPTH | BULK DENSITY | PARTICLE DENSITY | TOTAL POROSITY |
|---|---|---|---|
| Feet | g/cc. | g/cc. | % |
| 0 - 6" | 1.51 | 2.66 | 43.1 |
| 6"-12" | 1.45 | 2.67 | 45.6 |
| 1 - 2 | 1.43 | 2.68 | 46.5 |
| 2 - 3 | 1.41 | 2.69 | 47.5 |
| 3 - 4 | 1.39 | 2.69 | 48.2 |
| 4 - 5 | 1.42 | 2.69 | 47.1 |
| 5 - 6 | 1.51 | 2.69 | 43.9 |
| 6 - 7 | 1.55 | 2.71 | 42.9 |
| 7 - 8 | 1.42 | 2.72 | 46.4 |
| 8 - 9 | 1.45 | 2.72 | 46.9 |
| 9 - 10 | 1.49 | 2.72 | 45.4 |
| 10 - 11 | 1.49 | 2.71 | 45.2 |
| 11 - 12 | 1.51 | 2.71 | 44.2 |
| 12 - 13 | 1.51 | 2.70 | 44.3 |
| 13 - 14 | 1.49 | 2.69 | 44.6 |
| 14 - 15 | 1.48 | 2.68 | 45.0 |
| 15 - 16 | 1.48 | 2.68 | 44.5 |
| 16 - 17 | 1.48 | 2.67 | 44.6 |
| 17 - 18 | 1.43 | 2.67 | 46.1 |
| 18 - 19 | 1.38 | 2.67 | 47.8 |
| 19 - 20 | 1.36 | 2.66 | 48.8 |

# PART III

## SURVEY OF THE CATCHEMENT AREA

### (A) METHODS OF SURVEY

The area south of the 'EXISTING STATION BOUNDARY' (MAP SHEET II) was compiled from Samaru Sheet series 1:2400 Scale, obtained from the Soil Survey Section of the Institute for Agricultural Research, Ahmadu Bello University. The Samaru Sheet series 1:2400 scale was drawn and constructed by the Northern Nigeria Survey Department from the Photogrametric compilation by Fairey Air Surveys Ltd. of Canada in 1961. The ground control was by Northern Nigeria Surveys Department. The Series were printed and published by the Nigeria Federal Surveys Department in 1964.

An additional survey was carried out in May and early June 1968 to provide more details of the catchment area. The 'existing Station Boundary' (Map Sheet II) was used as the Base Line.

(i) On the Base Line perpendiculars were erected northward and southward at 1,000-foot interval, using a Kern [illegible] Theodolite, starting from point A in Map Sheet II and moving westward along the Base Line. Cross-sections of the area were carried beyond the catchment area and extensions of the cross-section lines were obtained using the 'Transit' method (Sandover, 1960). Raingauges and wells were located using

offsets from the cross-sections and by intersecting rays from two points on the cross-section lines when the wells and raingauges are more than 100 feet from the lines.

(ii) CHAINAGE: The ground does not slope uniformly. The horizontal projection of the Base line, the cross-section lines and offsets which lie along the sloping ground were determined by the Thomas method of 'stepping'. Linen tapes and ranging rods were used in the measurements. Reduced distances were set and pegged at 200-feet intervals along the cross-section lines.

(iii) LEVELLING: In the levelling process Northern Nigeria Surveys cadastral beacon no. 593 (secondary) with a value of 2267.95 feet above sea level was used as a reference. Readings along the cross-section lines were at 200 feet interval. The times of levelling were usually from 8.30 a.m. to 11.00 a.m. and 3.30 p.m. to 5.30 p.m. to avoid errors due to refraction.

(iv) CONTOURING: The first half of the map was prepared using a 5-feet contour interval and this was maintained in the second half. The contours were drawn by interpolation using the method of cross-sections. The ground levels of the wells and raingauges which are not on any cross-section lines were used as extra points in drawing the contours.

(B) RESULTS

I (i) AREA: The demarcation of the basin follows mostly the topographic ridges. In addition, on the spot check surveys were conducted to define the contributing areas. In some cases the main tracks act as the topographical divide of the surface drainage area. The catchment area as shown in Map II is 1574.27 acres (approximately 2.46 sq. miles).

(ii) BASIN CHARACTERISTICS: 9,600 feet constitute the longest axis of the basin and perpendicular to this axis, the maximum width is 11,700 feet. The shape of the basin approximates to a semi-circle with a shape index of 1.0

The land surface contains many local slope irregularities in various directions. Two topographical sections A and B on Map Sheet II are represented in Fig. 14 and the general slope varies from 1.11% to 1.82%. Using the total length of the contour lines, the catchment area and the contour interval (Chow, 1964) the average slope of the basin is 1.38 feet percent. From the writers observations this is slightly steeper than the general slopes for the sorrounding area, but it may be considered as approximating to the average slope of the catchment basins in the basement complex of the northern states of Nigeria.

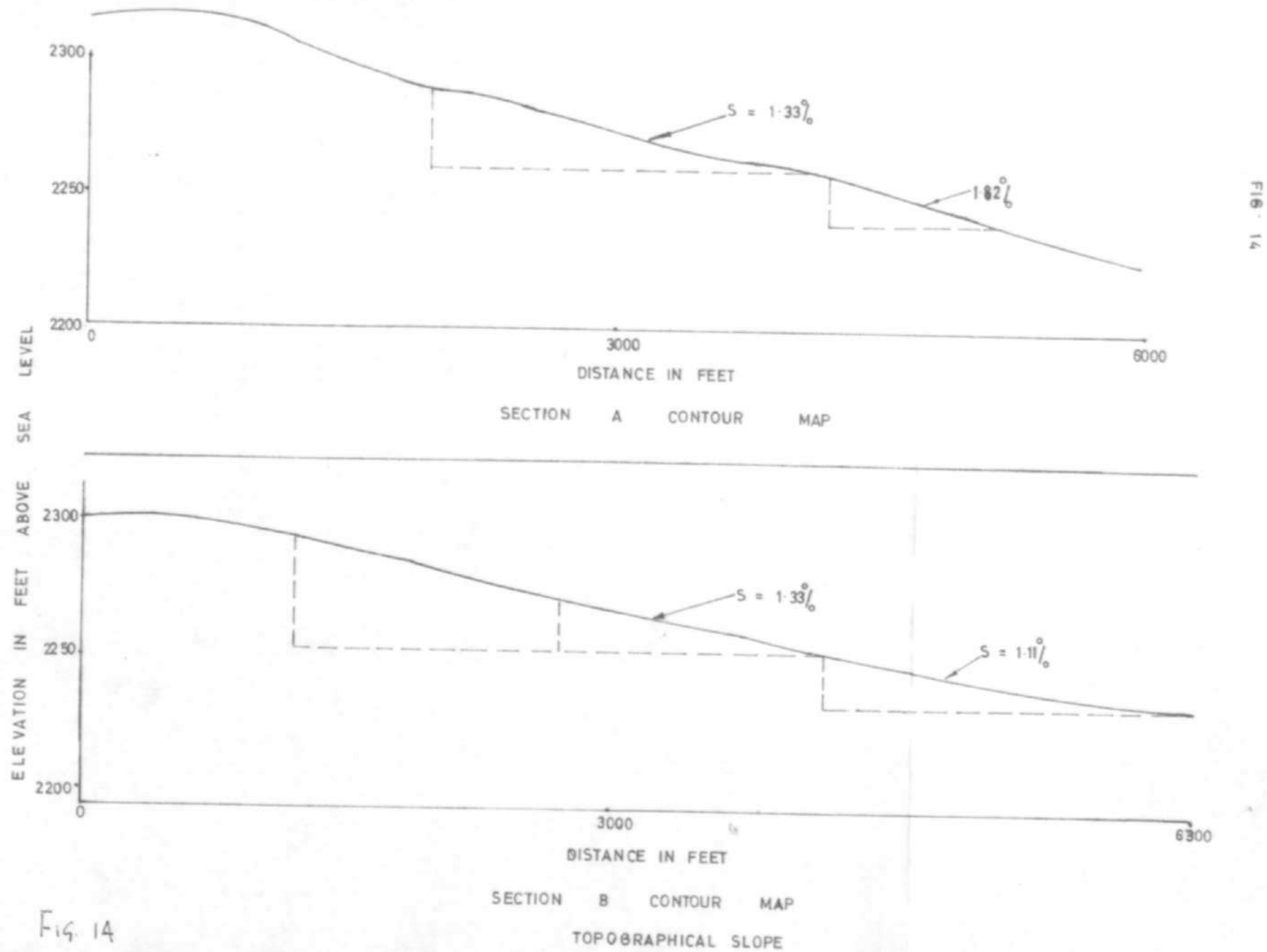



FIG - 14

Fig 14

TOPOGRAPHICAL SLOPE

## II LAND USE

The basin is mainly an agricultural area and exhibits good examples of old and modern farming methods. Map Sheet III shows the land use within the basin.

(i) 6.07% of the basin is the residential area for the senior staff of the Institute for Agricultural Research. It can be considered as a permanently built up area.

(ii) The lake, at spillway level (2229.58 feet) takes 2.76% of the basin's area. During the dry season the area is reduced to 28 acres which involves a water surface lowering of 4 feet. Apart from some small experimental irrigation areas during the dray season, there is little use for the lake except for recreation and aesthetic pleasure in the beauty of one of the rare expanses of water in this area.

(iii) The experimental fields take 22.40% of the total catchment area. During the rainy season cultivations, which are mechanised mainly, are for three main crops - cotton, sorghum and groundnut. These are the principal crops over much of northern Nigeria.

(iv) 46.57% or almost half of the basin area is used by the local people for farming and it includes the small village of Bomo. They are predominantly rainy season farmers and are grouped at one side of the experimental farm area. They still

cherish the old methods of farming and the chief crops are sorghum, groundnut and cassava. In some patches of land where the water-table is within 6 feet throughout the year sugar-cane is planted. Crops are grown on ridges made across the slopes. During the dry season area (iii) and (iv) are almost bare.

(v) 17.11% of the basin is agriculturally undeveloped by the University, and except for few acres of citrus orchard is uncultivated and has a perennial vegetation cover probably owing to its proximity to the lake. This area affords a good opportunity for expansion especially in the field of pilot irrigation schemes.

(vi) The remaining 5.09% of the basin is represented by uncultivated areas at higher elevations with widespread bare laterite surfaces, sparsely covered with small sized shrubs. Of this area, north of Bomo village 3.63% is occupied by the Fulani cattle men with their herds. This area affords easy movement for the herds during the wet season as it contains a well drained soil.

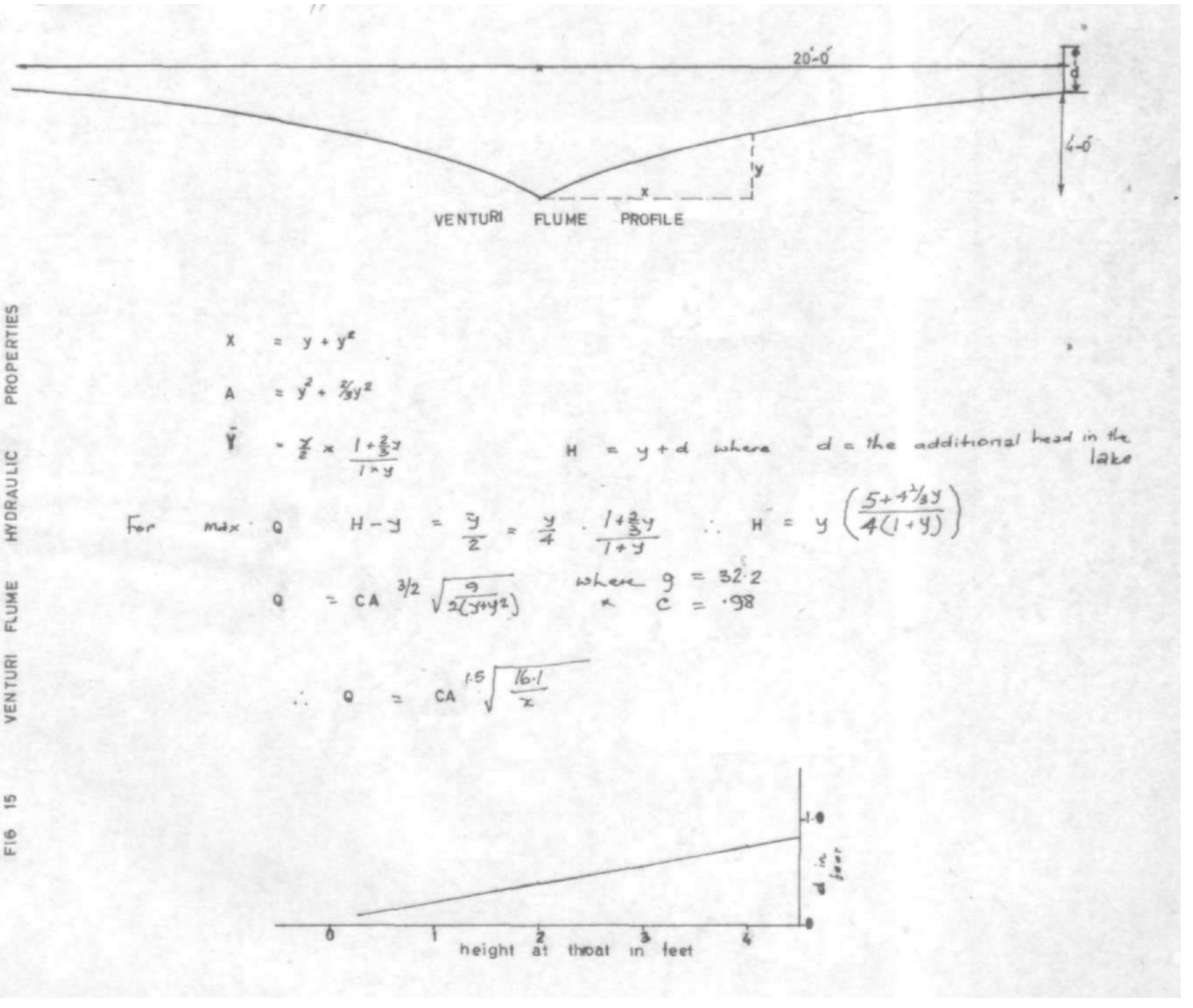
On the whole, cultivated farm land amounts to 66.97% of the basin's area. This is high in relation to other catchments in northern Nigeria. Lake and residential areas including Bomo village take 10.83% of the whole area, 22.20% or more than 1/5 of the whole area is uncultivated waiting for development. The

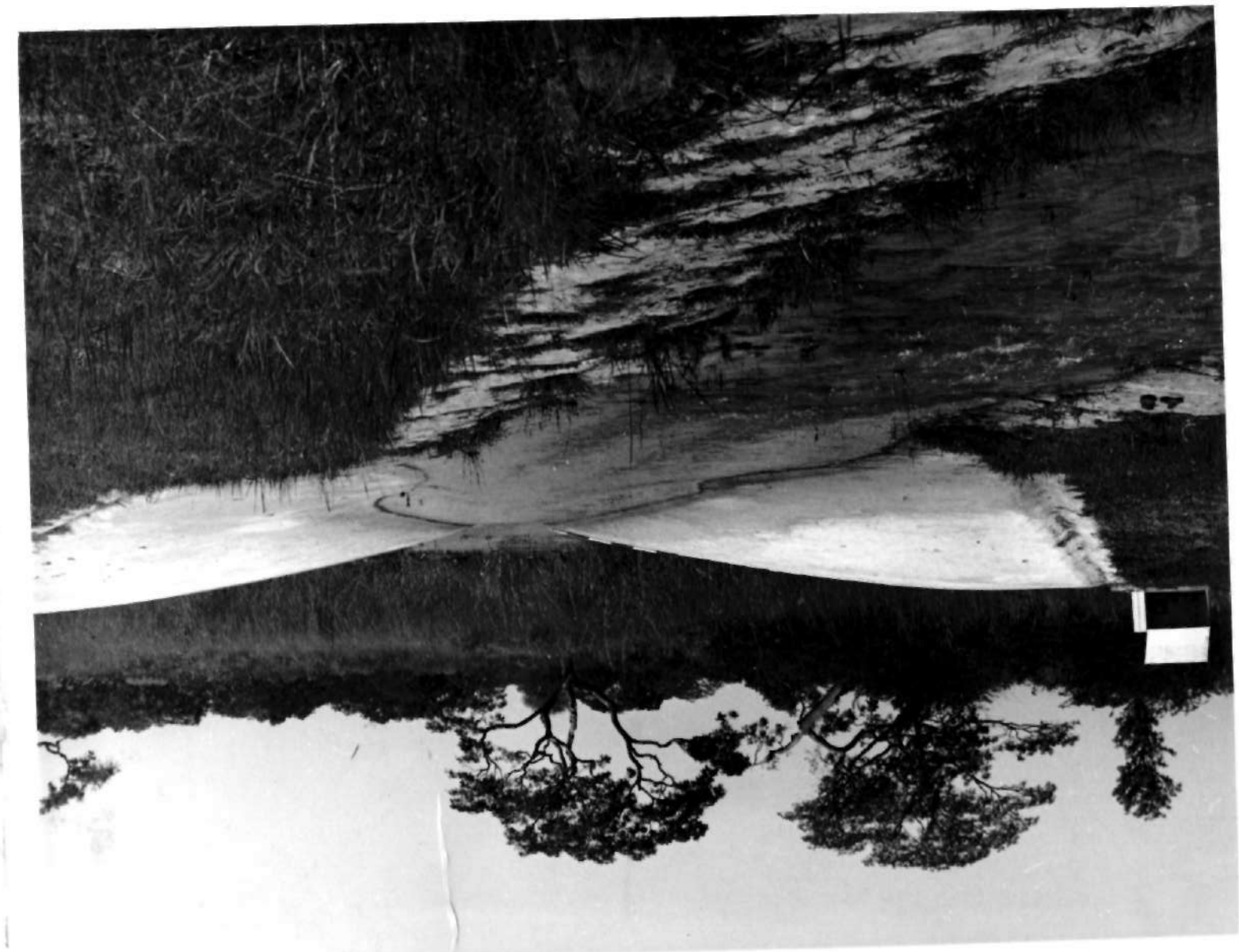
total available land area for agriculture is 80% if 10% is adjudged necessary for roads, footpaths and other necessary permanent structures.

(D) THE CONCENTRATION POINT

The water in the lake is retained by an earth dam with one spillway situated at the left edge of the embankment. The earth dam had its central core made from a puddled clay from the river bed. During the surveys drains and ditches behind the dam were found to be dry. During the wet season it is very difficult to assess the leakage as the entire area behind the dam is flooded partially owing to discharge from the spillway and the rise in level of another storage lake just a mile downstream. It may be assumed that if there is any leakage beneath the dam it would be very small and may be neglected.

The discharge measurements from the spillway are made using a Venturi flume designed by Naylor, (1965). In his design he adopted a profile given by $x = y + y^2$ (Fig. 15 and photograph III). At low flows the design gives the requisite sensitivity and in the extremes it becomes a $90^{\circ}$V section so that it gives an accuracy which is comparable at all flows. The stage is measured by an automatic recorder and a manometer. The downstream is grassed and at a gradient of roughly 0.5 feet percent.


20'-0"
d
4'-0"
y
x
VENTURI FLUME PROFILE
FIG 15 VENTURI FLUME HYDRAULIC PROPERTIES
$X = y + y^2$
$A = y^2 + \frac{2}{3}y^2$
$\bar{Y} = \frac{X}{2} \times \frac{1+\frac{2}{3}y}{1+y}$
$H = y + d$ where $d$ = the additional head in the lake
For max Q $H - y = \frac{y}{2} = \frac{y}{4} \cdot \frac{1+\frac{2}{3}y}{1+y}$ $\therefore H = y\left(\frac{5+4\frac{1}{3}y}{4(1+y)}\right)$
$Q = CA^{3/2}\sqrt{\frac{g}{2(y+y^2)}}$ where $g = 32.2$ & $C = .98$
$\therefore Q = CA^{1.5}\sqrt{\frac{16.1}{x}}$
1.0
d in feet
0
0
1
2
3
4
height at throat in feet



# PART IV

## GROUND WATER STUDY

### (A) SETTING

The pattern of groundwater movement in relation to the seasonal rainfall and to the topography of the catchment basin has been studied using a grid of observation wells randomly distributed over the catchment area (MAP SHEETS II - VII). The observation wells, thirty-two in number were constructed manually using a 4 inch diameter auger. Protection against caving and runoff entry was supplied by a fibre pipe collar of similar diameter - extending a minimum of 6 inches above the ground level. A wooden cap was used to prevent the entry of rainfall, trash and rodents.

The water-table heights were measured daily using a measuring tape. In addition to auger wells a 3 foot diameter well was constructed manually in the middle portion of the basin to provide a means of a detailed inspection of the soil profile and for pumping test data. An automatic depth recorder was installed at this well (L2W3) to give continuous records of changes in water-table levels.

The study covers a period of five years (1964 - 8) using data provided by the Soil Science Section of the Institute for Agricultural Research of the University. To correlate the changes in water-table heights with rainfall a grid of rainfall gauges was installed in the vicinity of each observation well.

(B) GENERAL PATTERN

The shape of the surface of the water-table of the catchment basin is similar to that of the ground surface except in the upper areas near the watershed ridge. The depth of the water-table varies in relation to topography and the seasons. Thus, in the dry season, the water-table in the valley bottom averages 1 foot below middle slopes and to 75 feet on the ridge.

The change in water-table depth is dependent on the equilibrium between precipitation on one hand and evapotranspiration and drainage on the other. Thus, there is little change in the dry season water-table depths under present patterns of land use since during the dry season most of the catchment area is bare fallow land which reduces evaporation from the deeper layers of soil profiles.

The rise in the water-table begins in the middle of July when cumulative rainfall is 18 $\pm$ 3 inches (Table II). This value, 18 inches is a rough measure of soil water deficit of the catchment basin which develops in the soil profiles during the dry season and of evapotranspiration which occurs from the beginning of rains to when the initial rise in water-table is detected. It also indicates that rainfall during the period (May - July) is in excess of evapotranspiration requirements to the extent that the complete recharge of the soil profile occurs by the end of this period.

The rise of the water-table is uneven during the rainy season depending on the amount and distribution of rainfall. The peak of the water-table level usually occurs in August or early September, i.e., almost conciding with the peak of rainfall. (Fig. 16, 18). The recession of water-table levels occurs rapidly after the end of rains in October. The duration of high water-table varies with season, but is principally a function of the magnitude of the hydraulic gradient which develops over and above the dry season water-table. The hydraulic gradients of the water table are discussed in the following section.

(C) WATER TABLE GRADIENTS

The elevation of the water-table in the catchment basin has been determined and shown as water-table contours (Map sheet IV and V). These maps provide direct visual information relating to the slope of the water-table and it is evident that these water table levels of the catchment basin can be described in terms of gradients especially when the lake is viewed as a big well with the ground water seeping into it radially, then the water-table acts as the draw - down curves. See Diagram I

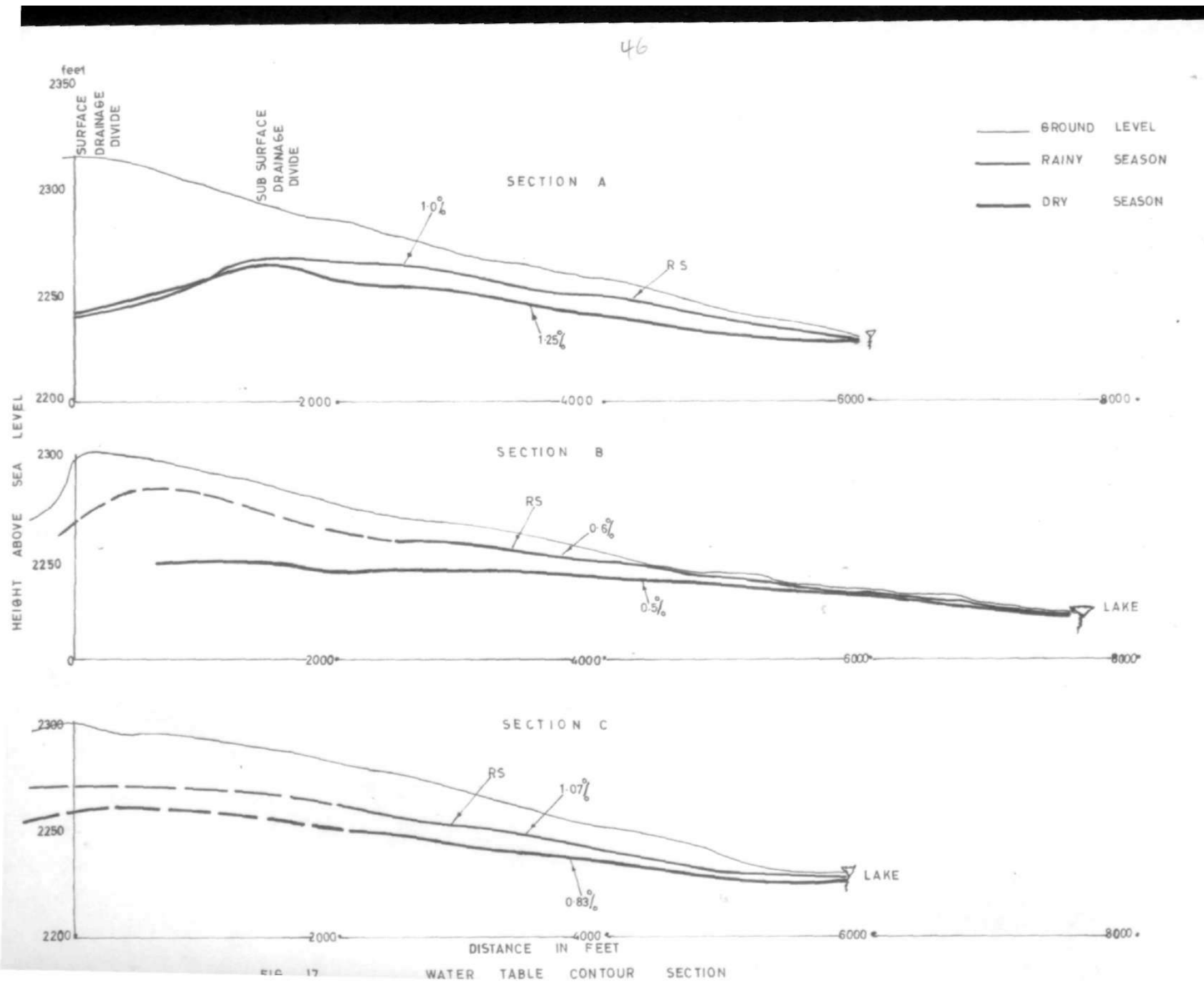
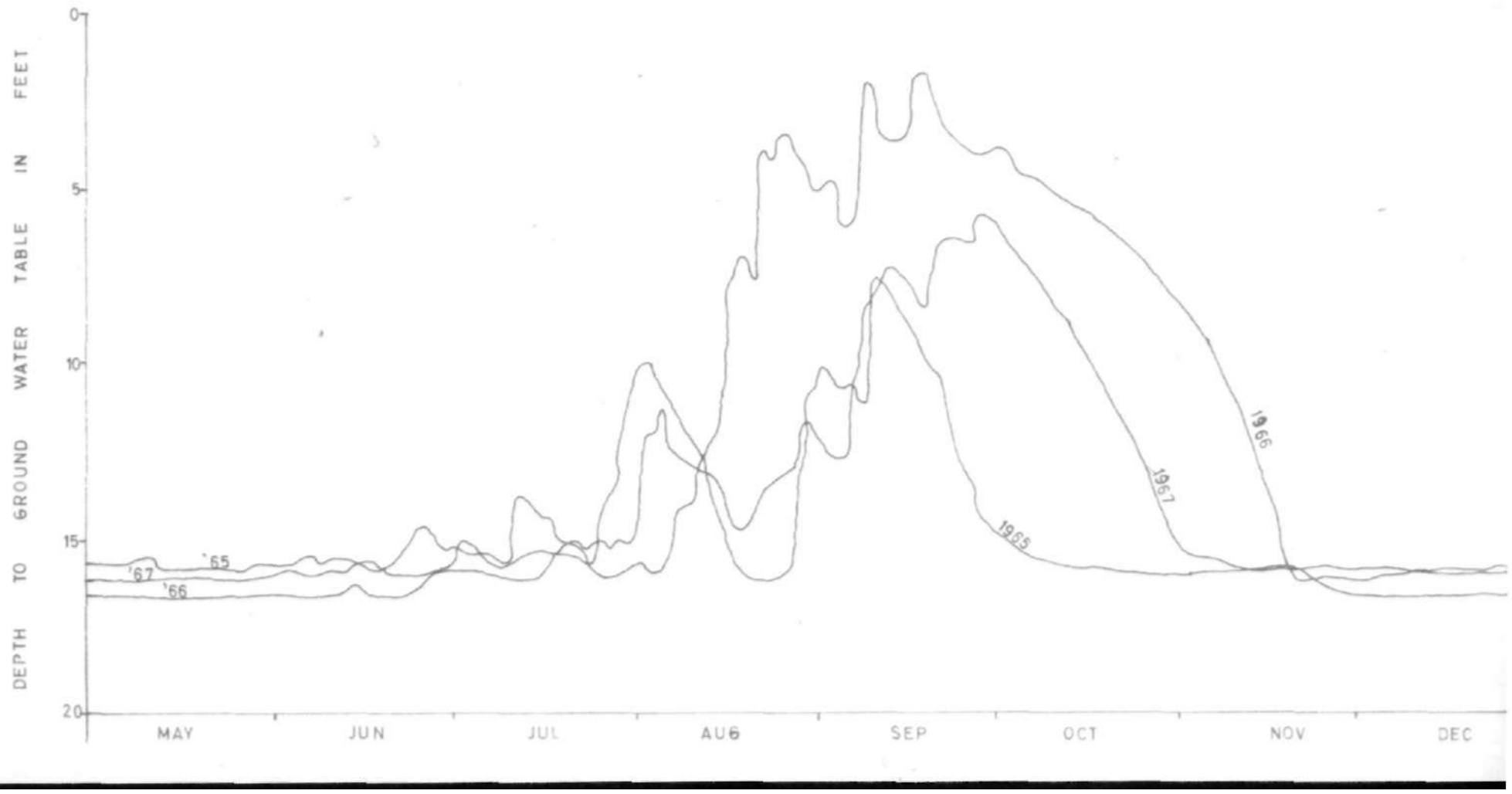



FIG. 17 WATER TABLE CONTOUR SECTION

FIG 18 AMPLITUTE OF WATER TABLE FLUCTUATIONS W4L2 (middle slope)



The dry season water table gradient is estimated along the main lines of the ground water flow in relation to the dry season lake level. The general average gradient is 0.63%. (Map sheets IV and V lines A, B, C, and fig.17). The dry season water table gradient in relation to the lake level at full capacity is 0.75%. The full capacity of the lake is considered to be when water ceases to flow from the lake. This also marks the end of groundwater see-page as the water table is almost at the dry season level. The average dry season water table gradient in relation to the full capacity of the lake and also in relation to the lake base capacity is 0.69%.

See **Diagram** II

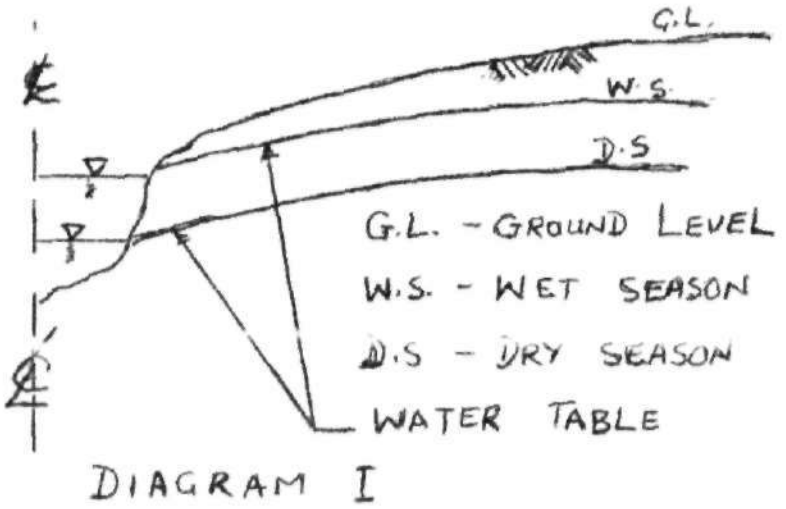



DIAGRAM I

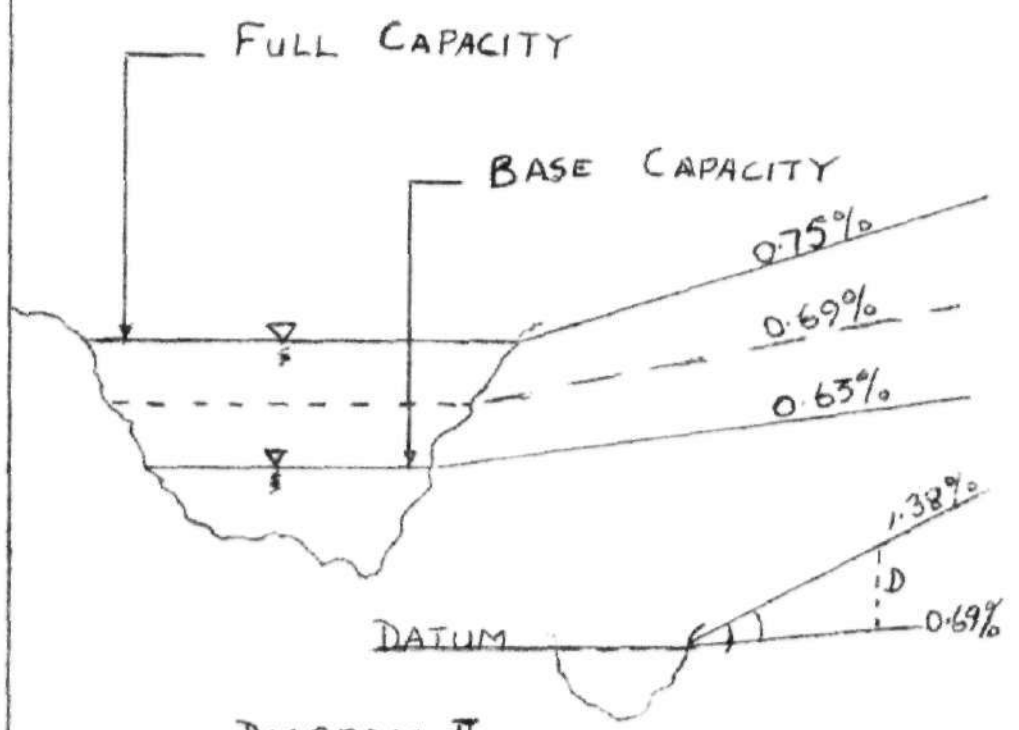



DIAGRAM II

The average topographical slope of the basin (as shown in Part III - B.ii) is 1.38%. Hence the average gradient of the dry season water table in relation to the average topographical slope is 1.38% - 0.69% = .69%. The depth (D) of the dry season water at any point in thecatchment basin can be estimated from this gradient and the shortest distance (L) from this point to the lake. The depth may be expressed simply as

$$D = \frac{0.69}{100} \times L \quad \text{or} \quad D = .0069L$$

The dimensions are in feet.

During the wet season the water-table builds up rapidly in response to the amount and distribution of rainfall causing seepage flows to appear at valley bottoms resulting in the flow of small streams. The pattern of fluctuations for the past years is illustrated in figure 18. From figure 17, the rainy season water table gradient in respect to lake level at full capacity ranges up the ground slope from 0.6% to 1.3%. The rainy season water table persists during the dry and average years from mid-July to end of September. In the case of wet years, e.g., 1966, the high water table persists from mid-July to end of October.

Fig. 18 A. also indicates that the subsurface drainage divide does not corresponds with the surface drainage divide and that at higher elevations the ground water drains to the

adjacent catchment basin. It is not possible to estimate from the available data the exact area difference determined from the divides but the subsurface drainage divide at one point is approximately 20% closer to the lake than the surface drainage divide on the same section line.

(D) THE DIRECTION OF GROUND WATER FLOW

The water table is regarded as a bounding flow surface and lines of under-ground flow must therefore parallel the water-table. Assuming that the atmospheric pressure (P) is zero, the fluid potential (he) in the Bernoulli equations (Todd, 1959).

$$he = \frac{P}{\gamma} + z = Z \quad \text{if } p = o$$

where Z is the elevation of the water-table above datum. Therefore the energy head or fluid potential is equal to the elevation of the water-table at any point in the catchment. As flows always take the shortest possible distance, the flow lines of the ground water are perpendicular to the Water table contours. In maps IV and V, flow lines are sketched perpendicular to the contours. It is observed, that like the surface drainage, the ground water flow is, in general, towards the lake.

## (E) AGRICULTURAL SIGNIFICANCE

Since the water-table flow surface in the catchment basin can be expressed in the form of a gradient and its direction of flow is towards the lake, the soil profiles in the lower slopes of the basin are saturated with water which will cause water - logged conditions. It has been estimated that the water table at 1.25% gradient (Map sheet VI) will ensure that for 40% of the catchment area, the water-table is situated approximately 5 feet below the ground surface over prolonged periods especially during a wet year.

The effect of the high water-table on the growth of crops and vegetation has not been studied and is largely a matter of speculation. However, it is well accepted fact that water logged conditions or the presence of a high water table not only interferes with soil aeration but has a depressing effect on the quality and quantity of available soil nutrients and on the health of crops. Fluctuations of ground water within the root zone of crops reduced the proportion ofboth oxygen and carbon-dioxide in the soil air and the rate of respiration of roots (Armstrong, 1967 ). Under prolonged high water table conditions asphyxiation and wilting occur. Water-logging favours the increase of divalent ions, particularly $Fe^{++}$ and $Mn^{++}$, concentrations of which in soil solutions may be toxic to plants.

Water-logged problems are usually solved by various drainage techniques. Due to the small size, and the topography of the areas concerned, the cost of any drainage technique may not be economically justified. If this is so, the use of the lower portion agriculturally is very limited. To compensate for the loss of this area agriculturally the writer suggests that fish culture be introduced into the lake. This is another economic "crop" capable of development on a large scale within the catchment basin.

Table II

WATER LEVEL RECORD - CONTROL WELL (L2W3)

| YEAR | PRECIPITATION | | COMMENCEMENT OF RISE WATER TABLE | | TOTAL PRECIPITATION CAUSING RISE (INCHES) | DECLINE TO USUAL ELEVATION | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| | TOTAL (INCHES) | INDEX (%) OF WETNESS | ELEVATION (FEET) | DATE | | ELEVATION (FEET) | DATE | |
| 1964 | 41.5 | 95 | 2243.20 | 17.7.64 | 15.3 | 2243.20 | 7.12.64 | Average Year |
| 1965 | 38.5 | 88 | 2243.20 | 26.7.65 | 18.0 | 2243.20 | 17.10.65 | Dry Year |
| 1966 | 52.5 | 120 | 2243.37 | 11.7.66 | 19.8 | 2243.37 | 12.12.66 | Wet Year |
| 1967 | 38.1 | 87 | 2243.37 | 15.5.67 | 15.9 | 2243.37 | 12.11.67 | Dry Year |
| 1968 | 39.34 | 90 | 2243.37 | 27.7.68 | 20.27 | 2243.34 | 5.10.68 | Average Year |

# PART V

## THE HYDROLOGICAL BALANCE OF THE CATCHMENT BASIN 1968 - HYDROLOGICAL YEAR

### (A) BASIC HYDROLOGY

The amount of rainfall is the result of combinations of hydrologic components in space and time. These components which move in a yearly cycle in response to the climate of the basin consists of three main phases (Butler, 1957).

(a) Evaporation from water, marsh, and soil surfaces and transpiration from plants.

(b) Precipitation as a result of evaporation and transpiration - carried over-land by wind.

(c) Runoff - both surface and subsurface of the precipitation into the Atlantic ocean from where water is mainly evaporated as sources of subsequent precipitation.

The hydrologic components grouped together into an equation is merely a statement of the law of conservation of matter and can be set out simply as $W_1 + R_{12} = T_{12} + E_{12} + W_2$ (Penman, 1955) where $W_1$ and $W_2$ represent the water content of soils and rocks at the beginning and end of the hydrological year respectively.

$R_{12}$= total rainfall during the hydrological year

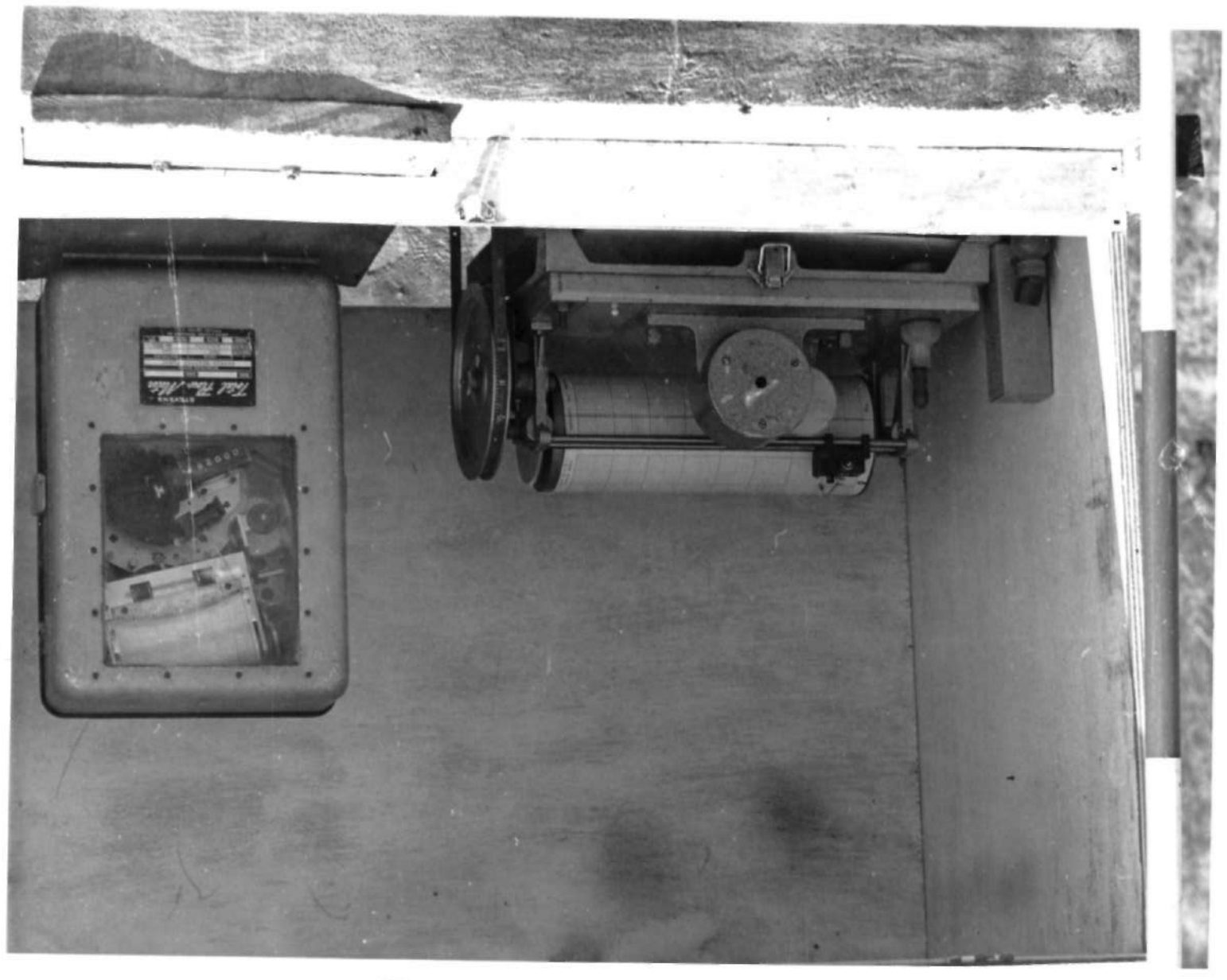
$E_{12}$= total evapotranspiration during the hydrological year

$r_{12}$= total runoff during the hydrological year.

(B) EXPERIMENTAL SET UP TO SOLVE THE EQUATION

The measurement of rainfall is one of the primary tasks when determining the hydrological balance of the catchment. This was measured using as many as 25 numbers of Australian type raingauges. The open end of these rain gauges were set 18" above ground level and they were positioned as shown on Map Sheet VII. The work was divided between two operatives and daily readings were taken between 9.00 a.m. and 10.00 a.m. Random checks were made to ensure that the operatives were performing their works effectively.

The catchment runoff discharge was determined from the head upstream of the venturi flume on the spillway. Adjacent to the venturi flume is a stilling well on which a stage recorder and a flow meter are mounted - (Photograph 4). A 3 inch diameter pipe connects the flume and the stilling well. The stage recorder and the flow meter were serviced and prepared for operation in June 1968 at least one month before discharge occurred over the spillway. Test runs were made, filling the well with water through the 3 inch diameter pipe to ensure that



the system was in working order. The flow meter and stage recorder provide a linear time integral of the hydrograph of total flow and stage respectively. The flow meter measure is in American gallons. In this study the stage records are used to determine the run off data. Frequent checks on the 3 inch diameter pipe were needed to ensure free flow of water to the stilling well.

(C) ASSESSMENT OF MAIN COMPONENTS OF HYDROLOGY EQUATION

$$W_1 + R_{12} = T_{12} + E_{12} + W_2$$

(i) MEAN AREAL DEPTH OF PRECIPITATION $R_{12}$: A study of the daily records of the 25 raingauge stations, revealed that rains have always fallen over the catchment almost at the same time, i.e., the whole catchment basin lies in the same storm path. It was further observed that the depth of daily precipitation varies very little from raingauge to raingauge - confirming that the variation in altitude of the raingauge stations, (which is small) has little effect on the catch. It can therefore be assumed that the precipitation distribution over the basin is homogenous and its annual depth may be represented with a high degree of accuracy, using the records of any of the raingauges or the single metereological station raingauge

near the catchment basin on which the previous rainfall analysis was based.

The monthly rainfall record for the 1968 hydrological year and the statistical analysis are as shown in appendix IV. The monthly variation in the distribution of rainfall over the catchment examined statistically shows that the coefficient of variation varied between 13% and 6% of the mean. The average depth of rainfall over the catchment basin was 39 39 $\pm$ 2.1 inches. The total number of significant rainy days was 77 as against the average of 86 days over forty years. The frequency analysis of daily rainfall within defined limits during the hydrological (1968) year rainy season is as shown below (Table B).

TABLE B

FREQUENCY ANALYSIS OF DAILY RAINFALL WITHIN DEFINED LIMITS

| MONTHS | Number of days with recorded amounts within the limits | | | | Number of occasions on which falls were | |
|---|---|---|---|---|---|---|
| | 0-.49 inches | .49-.99 inches | 1.0-1.49 inches | 1.50-2.00 inches | RECORDED | POSSIBLE |
| APRIL | 8 | 1 | - | - | 9 | 30 |
| May | 10 | 2 | 1 | - | 13 | 31 |
| JUNE | 9 | 2 | - | - | 11 | 30 |
| JULY | 6 | 5 | 3 | - | 14 | 31 |
| AUG. | 10 | 3 | 5 | - | 18 | 31 |
| SEPT. | 8 | 3 | 1 | - | 12 | 30 |
| TOTAL | 51 | 16 | 10 | - | 77 | |
| Percentage of recorded occasions of rain | 66% | 21% | 13% | 0% | 100% | |

Despite the previous assumption that the area was homogeneous with respect to rainfall it was thought worthwhile, computing the annual mean depth of precipitation using the Thiessen method. The Thiessen method gives weight to the areal distribution of stations, as it is assumed that the amount of precipitation at any station can be applied half way to the next in any direction (Butler, 1957). The effective area assumed to be controlled by each station is the area of the polygon thus formed around the station. Map sheet VII shows

the raingauge network with the raingauge stations as the polygon hubs.

The elevation of each station, its effective area, and the weighted precipitation for the month of March 1968 is as shown in Table III. The weighted precipitation for the whole year is as shown in Table IV to be 39.34 inches, which is $R_{12}$ for 1968 hydrological year.

(ii) GROUND WATER: In solving the hydrologic equation, advantage was taken of certain climatic and ground water characteristics of the catchment basin, such as constant level of dry season water table level and similar patterns of fluctuations during the rainy season (Table II and Figs 16, 18). The Hydrologic year may be taken as the period separating two consecutive initial upward movements of the water-table or could be assumed as the period between two consecutive dates when the water-table reaches its lowest level. The latter method is preferred to the former in that the total annual precipitation is within the period.

The 1967 water-table resumed its normal dry season level on 13th November 1967. For this paper, the hydrologic year (1968) started on 14th November, 1967, and ended on 5th October, 1968 when the 1968 water-table resumed the dry season water table level. As there was no change in ground water

storage and the soil moisture content reference is zero at beginning and end of period, $W_1$ and $W_2$ in the hydrologic equation as earlier, can safely be discarded. The hydrologic equation is reduced to the form

$$R_{12} = r_{12} + E_{12}$$

The initial rise in water table was observed to take place on July 27, 1968. Before this rise in the water-table, the soil profile to water table level must be at field capacity, as it is the gravitational water that recharges the dry season water table. The major source by which the soil water is lost is through evapotranspiration. The amount of rainfall needed to initiate the rise in the water table is a valid measure of soil moisture deficit due to evapotranspiration between the beginning of the hydrologic year and before the start of rise of water table level. The weighted depth of precipitation just before the rise of water was 20.27" (Table II). Hence part of $E_{12}$ is therefore determined.

(iii) EVAPOTRANSPIRATION $E_{12}$

Evapotranspiration which occured during the hydrological year is estimated from hydrologic equation i.e., as a difference between precipitation and spillway loss allowing for changes in storage capacity of the lake. However, the $E_{12}$ component may

be split into two parts $E_a$ and $E_b$ with $E_{12} = E_a + E_b$.

$E_a$ refers to evaporation and transpiration from the beginning of the hydrologic year to July 27th, 1968. This period included the dry season and early part of the growing season. It is therefore a measure of soil moisture deficit and evapotranspiration loss during the period. $E_a$ value is determined by observing the amount of cumulative rainfall required to cause a rise in the dry season water-table which occurred on the 27th July, 1968. From Table II the amount of precipitation recorded to that date was 20.27" = $E_a$.

$E_b$ represents the evaporation and transpiration from 28th July to 5th October, 1968. It is determined by difference between $E_{12}$ and $E_a$

$$\text{i.e. } E_b = E_{12} - E_a$$

However, an approximate estimate of $E_b$ may be made using the Kipp's solarimeter readings for the period. The total solarimeter readings from 28th July, to 5th October, a period of 70 days was 28,419 g/cal. $cm^{-2}$. Davies (1965) has shown that on the average, net radiation measured in West Africa is about 55% of the total solar radiation. The corresponding value of net radiation is 15,600 g/cal - $cm^{-2}$. Taking the latent heat of evaporation as 600 g/cal - $cm^{-3}$, then there was sufficient energy to evaporate about 260 cm or 10.10 inches of water

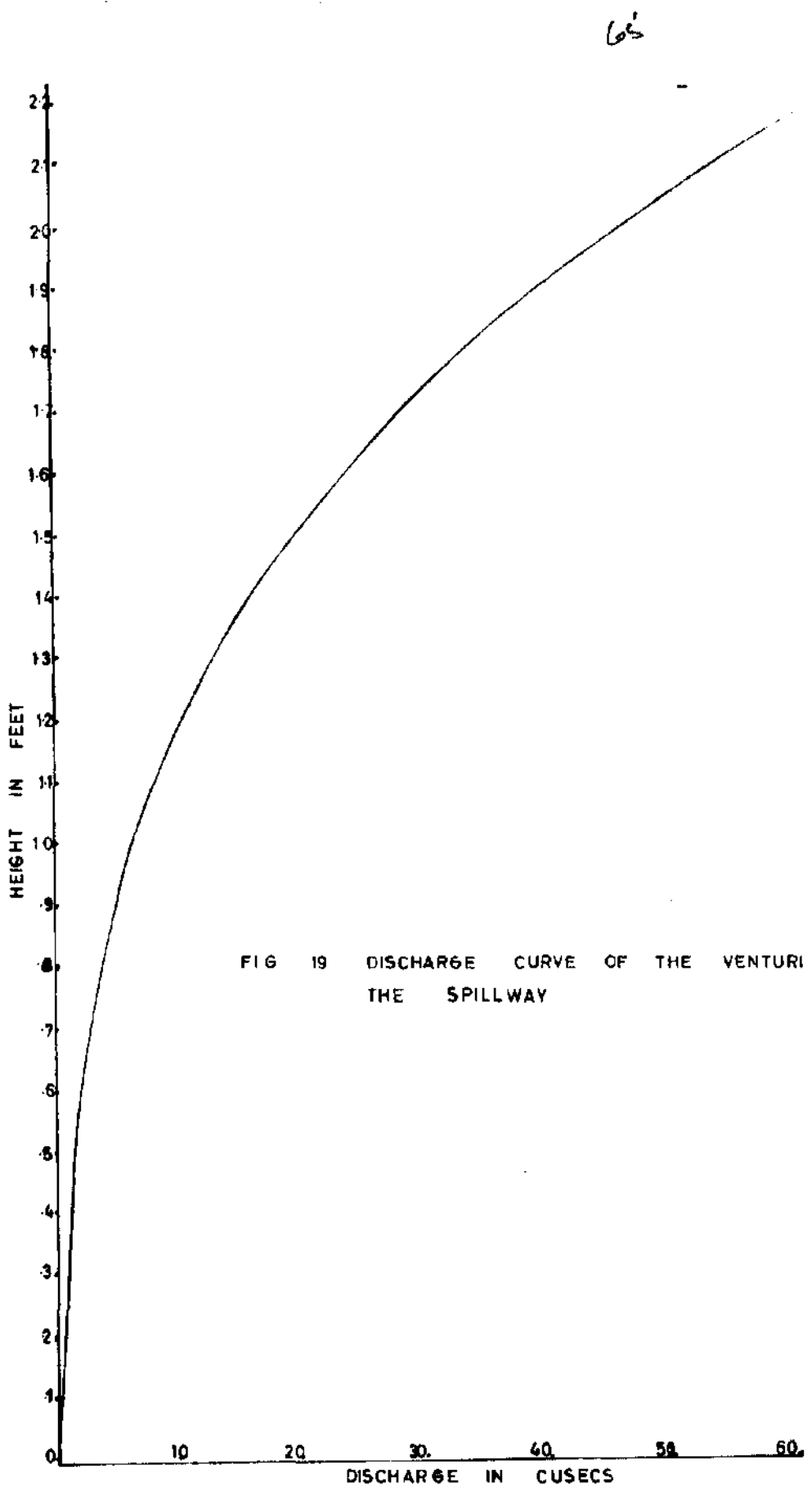



FIG 19 DISCHARGE CURVE OF THE VENTURI FLUME AT THE SPILLWAY

gradients and seepage discharge as measured from the spillway is as shown in Appendix V. In Fig. 20 the regression line is as shown. The correlation coefficient by calculation is + 0.946 indicating high correlation between the two variables. It was also observed that the total discharge from the spillway is mostly due to the effluent seepage of the ground water. The total discharge of 7663 acre-inches is equivalent to 4.87 inches depth over the catchment basin.

$$Q = 4.87 \text{ inches}$$

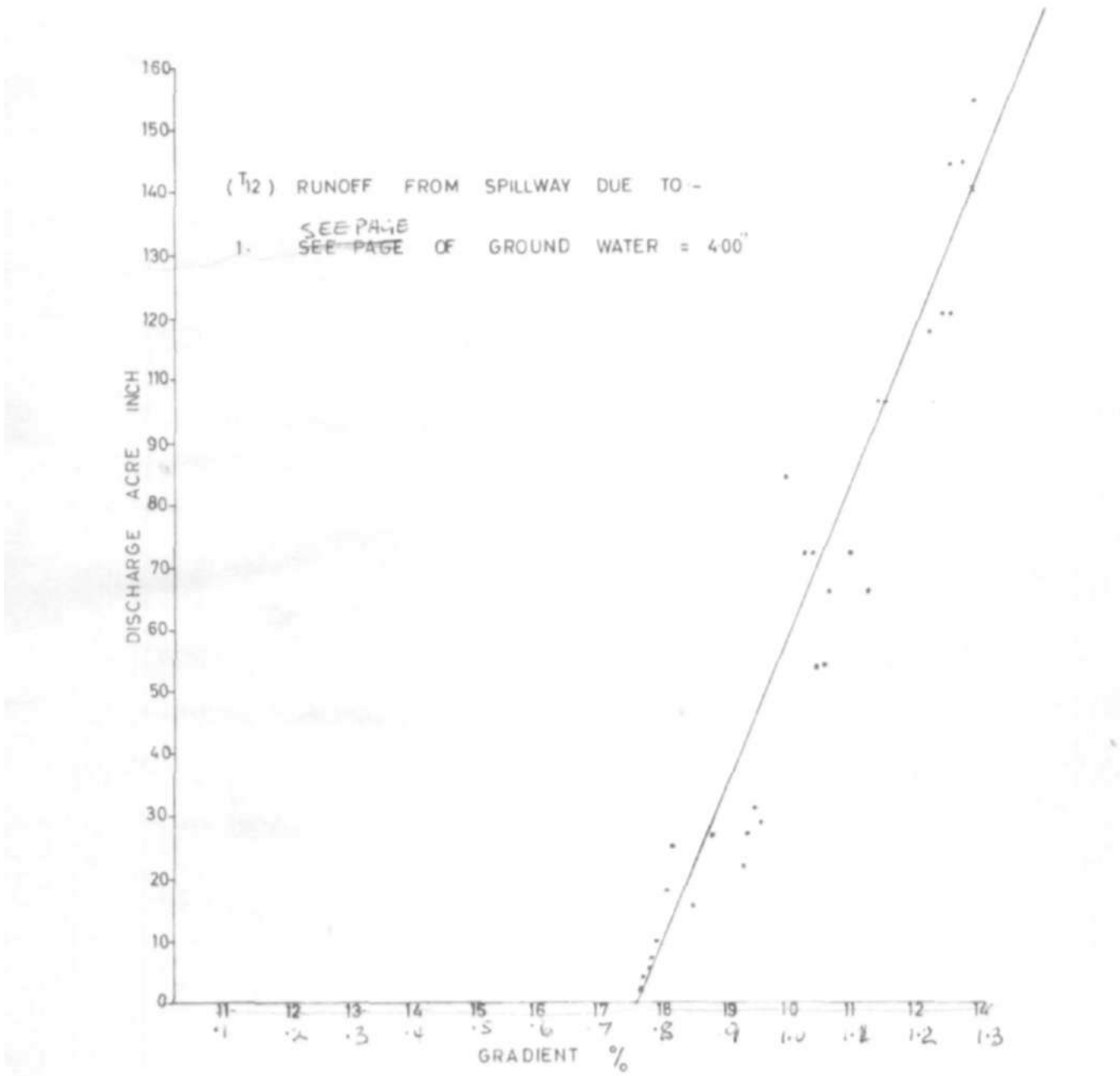
(b) ESTIMATE OF THE CHANGE OF STORAGE IN THE LAKE (WHEN FLOW OVER SPILLWAY CEASED)

$\triangle S$

The minimum lake level recorded during the hydrologic year was 2225.32 feet whilst the crest level of the spillway is 2229.58 feet. The surface areas at these levels represent 28 and 44 acres respectively. The corresponding change in storage $\triangle S$ was 153 acre-feet. The total capacity of the lake between these two levels represents only 1.20 inches depth over the catchment basin.

Therefore the total Runoff - $r_{12}$ during the hydrologic year was 4.87 + 1.20 = 6.07 inches.

FIG 20 SEEPAGE AND WATER TABLE GRADIENT CORRELATION CURVE



## (D) COMPUTATION OF VALUES AND CONCLUSIONS

### (i) PRECIPITATION - $R_{12}$

The total depth of precipitation by Thiessen's method as calculated previously was 39.34 inches, for the hydrological year. November 13, 1967 to October 5, 1968.

### (ii) RUNOFF - $r_{12}$

The total runoff as discussed earlier was 6.06 inches.

### (iii) EVAPOTRANSPIRATION, $E_{12}$

The total evapotranspiration was obtained by difference between total depth of precipitation $R_{12}$ and total runoff ($r_{12}$)

$$\therefore E_{12} = R_{12} - r_{12}$$

Putting the numerical values into the equation,

$$E_{12} = 39.34 - 6.06 = 33.28 \text{ inches}$$

With $E_a$ as 20.27", $E_b$ is therefore 13.01 inches or 0.19 inch per day. Using this value of $E_b$ and working backwards the net radiation from the basin was 70% of the total solar radiation.

One can do very little to prevent evapotranspiration ($E_{12}$) and in fact, it is not lost as generally believed but contributes to the future occurrence of precipitation by maintaining the level of the relative humidity.

The item that needs to be conserved is the $r_{12}$. With that which longer and better distributed precipitation than occurred this year the value of $r_{12}$ is bound to increase. If $r_{12}$, is 6.06

inches as in this year, it is sufficient to supply 20,000 people throughout the year with 20 gallons per day per head. This is more than sufficient for both Bomo and Samaru villages for their domestic water needs.

With a crop delta of 18 - 24 inches such as wheat, the $r_{12}$ is sufficient to cope fully with not less 300 acres (i.e. considering all losses) of farmland, during the dry season. It is evident from this study that inadequate water conservation and management is an important factor affecting the agricultural growth of the areas of the Loess Plain Soils which this basin is believed to be representative.

Table III RAINFALL MARCH 1965

THIESSEN POLYGON METHOD

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| STATION | ELEVATION | AREA IN ACRES | % OF TOTAL AREA | OBSERVED P in ins. | WEIGHTED P (4x5) |
| 1 | 2270.97 | 105.68 | 6.70 | 0.16 | 0.011 |
| 2 | 2271.98 | 79.32 | 5.00 | 0.13 | 0.007 |
| 3 | 2240.68 | 47.04 | 3.00 | 0.11 | 0.003 |
| 4. | | 25.96 | 1.64 | 0.10 | 0.002 |
| 5 | 2263.64 | 95.6 | 6.06 | 0.13 | 0.008 |
| 6 | 2284.65 | 118.00 | 7.50 | 0.11 | 0.003 |
| 7 | 2290.58 | 46.00 | 2.91 | 0.08 | 0.002 |
| 8 | 2270.60 | 122.60 | 7.78 | 0.07 | 0.005 |
| 9 | 2247.48 | 90.72 | 5.75 | 0.18 | 0.010 |
| 10 | 2250.20 | 54.56 | 3.46 | 0.06 | 0.002 |
| 11 | 2240.00 | 77.03 | 4.89 | 0.07 | 0.003 |
| 12 | 2248.44 | 33.73 | 2.13 | 0.07 | 0.001 |
| 13 | 2272.50 | 32.92 | 2.09 | 0.05 | 0.001 |
| 14 | 2296.33 | 25.48 | 1.61 | 0.05 | 0.001 |
| 15 | 2268.30 | 87.64 | 5.56 | 0.01 | 0.001 |
| 16 | 2239.49 | 87.68 | 5.56 | 0.08 | 0.004 |
| 17 | 2249.01 | 70.16 | 4.52 | 0.06 | 0.003 |
| 18 | 2265.00 | 62.60 | 3.91 | 0.06 | 0.002 |
| 19 | 2261.67 | 68.08 | 4.40 | 0.06 | 0.003 |
| 20 | | 63.56 | 4.06 | 0.04 | 0.002 |
| 21 | 2261.37 | 54.24 | 3.50 | 0.06 | 0.001 |
| 22 | 2270.00 | 31.28 | 2.01 | 0.04 | 0.001 |
| 23 | 2287.82 | 61.70 | 3.90 | 0.04 | 0.002 |
| 24 | 2298.51 | 11.24 | 0.71 | 0.03 | 0.001 |
| 25 | 2315.00 | 21.40 | 1.35 | 0.03 | 0.001 |
| | | 1574.27 | 100.00 | | 0.076 |

Table IV



WEIGHTED PRECIPITATION IN INCHES (1965)

| STATION | J | F | M | A | M | J | J | A 1-15 | A 16-31 | S | O |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | 0.011 | .226 | .324 | .289 | .472 | .346 | .411 | .323 | .019 |
| 2 | - | - | 0.007 | .148 | .300 | .257 | .389 | .191 | .322 | .326 | .020 |
| 3 | - | - | 0.003 | .067 | .174 | .131 | .241 | .109 | .196 | .174 | .011 |
| 4 | - | - | 0.002 | .035 | .085 | .074 | .123 | .093 | .099 | .100 | .005 |
| 5 | - | - | .008 | .156 | .344 | .267 | .422 | .251 | .424 | .348 | .016 |
| 6 | - | - | .008 | .269 | .401 | .347 | .603 | .320 | .624 | .461 | .024 |
| 7 | - | - | .002 | .010 | .170 | .141 | .264 | .109 | .236 | .143 | .005 |
| 8 | - | - | .005 | .268 | .451 | .272 | .683 | .174 | .636 | .235 | .009 |
| 9 | - | - | .001 | .189 | .333 | .288 | .447 | .266 | .436 | .342 | .015 |
| 10 | - | - | .002 | .010 | .204 | .161 | .299 | .143 | .277 | .206 | .008 |
| 11 | - | - | .033 | .140 | .288 | .236 | .406 | .201 | .323 | .284 | .016 |
| 12 | - | - | .001 | .055 | .117 | .105 | .199 | .089 | .136 | .128 | .008 |
| 13 | - | - | .001 | .051 | .135 | .098 | .191 | .092 | .139 | .119 | .008 |
| 14 | - | - | .001 | .046 | .108 | .075 | .155 | .065 | .109 | .103 | .008 |
| 15 | - | - | .001 | 0.201 | .325 | .257 | .465 | .236 | .455 | .329 | .012 |

Table IV (contd.)



| STATION | J | F | M | A | M | J | J | A 1-15 | A 16-31 | S | O |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | - | - | .004 | .161 | .304 | .296 | .448 | .225 | .402 | .286 | .013 |
| 17 | - | - | .003 | .144 | .250 | .180 | .336 | .172 | .294 | .226 | .009 |
| 18 | - | - | .002 | .123 | .222 | .177 | .348 | .178 | .325 | .236 | .009 |
| 19 | - | - | .003 | .136 | .252 | .201 | .381 | .190 | .333 | .249 | .010 |
| 20 | - | - | .002 | .119 | .254 | .190 | .335 | .168 | .290 | .244 | .012 |
| 21 | - | - | .001 | .098 | .200 | .165 | .291 | .150 | .237 | .200 | .009 |
| 22 | - | - | .001 | .060 | .115 | .095 | .182 | .093 | .157 | .118 | .006 |
| 23 | - | - | .002 | .108 | .232 | .193 | .365 | .170 | .282 | .233 | .010 |
| 24 | - | - | .001 | .001 | .004 | .003 | .068 | .023 | .048 | .041 | .002 |
| 25 | - | - | .001 | .037 | .079 | .065 | .135 | .061 | .094 | .075 | .005 |
| TOTAL | | | 0.076 | 2.86 | 5.67 | 4.57 | 8.25 | 4.12 | 7.31 | 5.53 | .27 = |

39.34

up to 27.7.68 = 20.27"

up to 15.8.68 when discharge over spillway started = 33.54"

Table V

SPILLWAY DISCHARGE 1968 MEASURED FROM THE HYDROGRAPH RECORD OF THE VENTURI FLUME

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 15/8 | 1.30 – .85 | 15 | 12.5 – 4.5 | 127.5 |
| | 1.15 – 0.80 | 9 | 8.0 – 4.0 | 54.0 |
| 16/8 | .75 – .70 | 9 | 3.0 – 2.5 | 28.9 |
| | 1.10 – 1.45 | 15 | 7.5 – 17.5 | 187.5 |
| 17/8 | 1.45 – 1.05 | 24 | 17.5 – 6.5 | 288.0 |
| 18/8 | 1.10 – 0.95 | 24 | 7.5 – 5.0 | 150 |
| 19/8 | 0.95 – 0.90 | 15 | 5.0 – 4.9 | 75.0 |
| | 0.90 – 1.40 | 9 | 4.9 – 15.0 | 90.0 |
| 20/8 | 1.55 – 1.60 | 3 | 22.0 – 23.0 | 67.5 |
| | 1.60 – 1.10 | 21 | 23.0 – 7.5 | 215.3 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 21/8 | 1.15) | 18 | 8.0) | 126.0 |
| | 1.00) | | 6.0) | |
| | 1.50 | 6 | 19.0 | 114.0 |
| 22/8 | 1.50) | 4 | 19.0) | 88.0 |
| | 1.65) | | 25.0) | |
| | 1.65) | 20 | 25.0) | 360.0 |
| | 1.25) | | 11.0) | |
| 23/8 | 1.25) | 17 | 11.0) | 149.6 |
| | 1.05) | | 6.5) | |
| | 1.05) | 7 | 6.5) | 261.) |
| | 2.07) | | 48.0) | |
| 24/8 | 2.05) | 24 | 48.0) | 727.2 |
| | 1.30) | | 12.5) | |
| 25/8 | 1.25) | 24 | 11.0) | 228.0 |
| | 1.15) | | 8.0) | |
| 26/8 | 1.15) | 24 | 8.0) | 158.4 |
| | 0.95) | | 5.0) | |
| 27/8 | 1.00 | 24 | 6.0 | 144.0 |
| 28/8 | 1.00 | 24 | 6.0 | 144.0 |
| 29/8 | 1.00 | 24 | 6.0 | 144.0 |
| 30/8 | .95 | 24 | 5.0 | 120.0 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 31/8 | .95 | 24 | 5.0 | 120.0 |
| 1/9 | .90 | 24 | 4.9 | 117.6 |
| 2/9 | .90)<br>.75) | 24 | 4.9)<br>3.0) | 96.0 |
| 3/9 | .75)<br>.70) | 24 | 3.0)<br>2.5) | 66 |
| 4/9 | .70)<br>1.05) | 5 | 2.5)<br>6.5) | 22.5 |
| | 1.05)<br>.95) | 19 | 6.5)<br>5.0) | 109.3 |
| 5/9 | .95)<br>.85) | 24 | 5.0)<br>4.5) | 114.0 |
| 6/9 | .85)<br>.80) | 11 | 4.5)<br>4.0) | 46.8 |
| | .80)<br>1.10) | 5 | 4.0)<br>7.5) | 28.8 |
| | 1.10 | 8 | 7.5 | 60.0 |
| 7/9 | 1.10)<br>.95) | 12 | 7.5)<br>5.0) | 75.0 |
| | 1.20 | 12 | 10.0 | 120.0 |
| 8/9 | 1.15)<br>.90) | 24 | 8.0)<br>4.9) | 154.8 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 9/9 | .90) .75) | 24 | 4.9) 3.0) | 96.0 |
| 10/9 | .75) .65 | 24 | 3.0) 2.5) | 66.0 |
| 11/9 | .70 | 24 | 3.0 | 72.0 |
| 12/9 | .70) .65) | 24 | 3.0) 2.5) | 66.0 |
| 13/9 | 0.65) 0.65) | 24 | 2.5) 2.0) | 54 |
| 14/9 | .65) .60) | 24 | 2.5) 2.0) | 54 |
| 15/9 | .60 | 6 | 2.0 | 12.0 |
| | .90 | 18 | 4.9 | 88.2 |
| 16/9 | .90 | 10 | 4.9 | 49.0 |
| | .90) 2.00) | 4 | 4.9) 45.0) | 100 |
| | 2.00) 1.65) | 10 | 45.0) 25.0) | 376 |
| 17/9 | 1.60) 1.10) | 24 | 23.0) 7.5) | 360.0 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 18/9 | 1.10)<br>)<br>.90) | 24 | 7.5)<br>)<br>4.9) | 148.8 |
| 19/9 | .90)<br>)<br>.75) | 24 | 4.9)<br>)<br>3.0) | 96 |
| 20/9 | .75)<br>)<br>.70) | 24 | 3.0)<br>)<br>3.0) | 72 |
| 21/9 | .70 | 24 | 3.0 | 72 |
| 22/9 | 0.70)<br>)<br>0.55) | 12 | 3.0)<br>)<br>2.0) | 30.0 |
| | 0.50)<br>)<br>1.15) | 3 | 1.5)<br>)<br>8.0) | 14.3 |
| | 1.10 | 9 | 7.5 | 67.5 |
| 23/9 | 1.15)<br>)<br>0.75) | 24 | 8.0)<br>)<br>3.0) | 132.0 |
| 24/9 | .75)<br>)<br>.85) | 2 | 3.0)<br>)<br>4.0) | 7.0 |
| .85 | .85)<br>)<br>.75) | 22 | 4.0)<br>)<br>3.0) | 77.0 |

Table V (contd.)

SPILLWAY DISCHARGE 1968

Measured from the Hydrograph Record 90°V. Notch

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 25/9 | 0.75 | 24 | 1.22 | 29.3 |
| 26/9 | .80)<br>)<br>.75) | 24 | 1.43)<br>)1.33<br>1.22) | 31.9 |
| 27/9 | .75)<br>)<br>.70) | 24 | 1.22)<br>)1.13<br>1.03) | 27.1 |
| 28/9 | .70)<br>)<br>.65) | 24 | 1.03)<br>).94<br>.85) | 22.6 |
| 29/9 | .65 | 12 | .85 | 10.2 |
| | .65)<br>)<br>1.00) | 3 | .85)<br>)1.67<br>1.49) | 5.0 |
| | 1.00 | 9 | 2.49 | 22.4 |
| 30/9 | 1.00)<br>)<br>.80) | 24 | 2.49)<br>)1.96<br>1.43) | 47.0 |
| 1/10 | .80)<br>)<br>.65) | 24 | 1.43)<br>)1.15<br>.85) | 27.6 |
| 2/10 | .65)<br>)<br>.50) | 24 | .85)<br>).65<br>.45) | 15.6 |
| 3/10 | .50 | 3 | .45 | 1.4 |
| | .60 | 5 | .70 | 3.5 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| | .80)<br>)<br>.75) | 16 | 1.43)<br>)1.33<br>1.22) | 21.3 |
| 4/10 | .75)<br>)<br>.65) | 24 | 1.22)<br>)1.04<br>.85) | 25.0 |
| 5/10 | .65)<br>)<br>.55) | 24 | .85)<br>).71<br>.56) | 17.6 |
| 6/10 | .55)<br>)<br>.50) | 24 | .56)<br>).51<br>.45) | 12.2 |
| 7/10 | .50)<br>)<br>.45) | 24 | .45)<br>).40<br>.34) | 9.6 |
| 8/10 | .50)<br>)<br>.45) | 24 | .45)<br>).40<br>.34) | 9.6 |
| 9/10 | .45)<br>)<br>.40) | 24 | .34)<br>).30<br>.26) | 7.2 |
| 10/10 | .40)<br>)<br>.35) | 24 | .26)<br>).22<br>.18) | 5.3 |
| 11/10 | .35)<br>)<br>.30) | 24 | .18)<br>).16<br>.13) | 3.8 |
| 12/10 | .30)<br>)<br>.20) | 24 | .13)<br>).09<br>.05) | 2.2 |

Table V (contd.)

| Date | Head in Feet | Time in hrs. | Discharge in cusecs | Discharge in acre-inch |
|---|---|---|---|---|
| 13/10 | .20)<br>)<br>.15) | 24 | .05)<br>).04<br>.02) | 0.7 |
| 14/10 | .15 | 24 | .02 | 0.4 |

Grand Total = 7663 acre in or 4.87" over the whole basin.

Appendix I (contd.)

| Year | (inches) x | Rank of Item in the Series | $x - \bar{x}$ | $(x - \bar{x})^2$ |
|---|---|---|---|---|
| 1946 | 56.12 | 2 | +12.50 | 156.25 |
| 7 | 45.27 | 16 | + 1.65 | 2.72 |
| 8 | 35.31 | 38 | - 8.31 | 69.06 |
| 9 | 38.93 | 27 | - 4.69 | 22.00 |
| 1950 | 35.39 | 37 | - 8.23 | 67.73 |
| 1 | 45.67 | 13 | + 2.05 | 4.20 |
| 2 | 43.51 | 18 | + 0.11 | 0.01 |
| 3 | 45.49 | 14 | + 1.87 | 3.50 |
| 4 | 58.34 | 1 | +14.72 | 216.68 |
| 5 | 52.97 | 4 | + 9.35 | 87.42 |
| [illegible] | 36.63 | 34 | - 6.99 | 48.86 |
| 7 | 54.91 | 3 | +11.29 | 127.46 |
| 8 | 34.99 | 39 | - 8.63 | 74.47 |
| 9 | 41.87 | 32 | - 1.75 | 3.06 |
| 1960 | 42.97 | 19 | - 0.65 | 0.42 |
| 1 | 32.45 | 40 | -11.17 | 124.77 |
| 2 | 51.27 | 7 | + 7.65 | 58.52 |
| 3 | 42.96 | 20 | - 0.66 | 0.44 |
| 4 | 41.54 | 23 | - 2.08 | 4.33 |
| 5 | 38.49 | 31 | - 5.13 | 26.32 |
| 6 | 52.46 | 5 | + 8.84 | 78.15 |
| 7 | 38.10 | 32 | - 5.52 | 30.47 |

Appendix I (contd.)

| Year | (inches) x | Rank of Item in the Series | $x - \bar{x}$ | $(x - \bar{x})^2$ |
|---|---|---|---|---|
| 1966 | 52.46 | 5 | + 8.84 | 78.15 |
| 7 | 38.10 | 32 | - 5.52 | 30.47 |
| | | | TOTAL | 1701.44 |

$$\text{Standard deviation } S = \sqrt{\frac{1701.44}{39}} = 6.64$$

At 95% confidence limits and with one degree of freedom the "Students t" = 2.02 from the relation $95\% = 2\int_{t}^{\infty} f(x)dx$

$\therefore$ 95% confidence limits are $\bar{x} \pm t\frac{s}{\sqrt{n}} = 43.62 \pm 2.02 \times \frac{6.64}{\sqrt{40}}$

$= 43.62 \pm 2.12$

Coefficient of Variation $= \frac{6.64}{43.62} = 0.1515$ or 15%

Appendix II

FREQUENCY AND RETURN PERIOD OF VALUES OF
ANNUAL PRECIPITATION FOR SAMARU 1928 - 1967

| Order No. | Year | Precipitation (inches) | m - 0.5 | Hazen's F | T |
|---|---|---|---|---|---|
| 1 | 1954 | 58.34 | 0.5 | 1.25 | 80.00 |
| 2 | 1946 | 56.12 | 1.5 | 3.75 | 26.67 |
| 3 | 1957 | 54.91 | 2.5 | 6.25 | 16.00 |
| 4 | 1955 | 52.97 | 3.5 | 8.75 | 11.43 |
| 5 | 1966 | 52.46 | 4.5 | 11.25 | 8.89 |
| 6 | 1933 | 52.06 | 5.5 | 13.75 | 7.27 |
| 7 | 1962 | 51.27 | 6.5 | 16.25 | 6.15 |
| 8 | 1929 | 50.94 | 7.5 | 18.75 | 5.34 |
| 9 | 1943 | 50.12 | 8.5 | 21.25 | 4.71 |
| 10 | 1928 | 49.70 | 9.5 | 23.75 | 4.21 |
| 11 | 1932 | 47.17 | 10.5 | 26.25 | 3.81 |
| 12 | 1931 | 47.16 | 11.5 | 28.75 | 3.48 |
| 13 | 1951 | 45.67 | 12.5 | 31.25 | 3.20 |
| 14 | 1953 | 45.49 | 13.5 | 33.75 | 2.96 |
| 15 | 1936 | 45.29 | 14.5 | 36.25 | 2.76 |
| 16 | 1947 | 45.27 | 15.5 | 38.75 | 2.58 |
| 17 | 1939 | 44.46 | 16.5 | 41.25 | 2.42 |
| 18 | 1952 | 43.51 | 17.5 | 43.75 | 2.29 |
| 19 | 1960 | 42.97 | 18.5 | 46.25 | 2.16 |

Appendix II (contd.)

| Order No. | Year | Precipitation (inches) | m - 0.5 | Hazen's F | T |
|---|---|---|---|---|---|
| 20 | 1963 | 42.96 | 19.5 | 48.75 | 2.05 |
| 21 | 1934 | 42.39 | 20.5 | 51.25 | 1.95 |
| 22 | 1959 | 41.87 | 21.5 | 53.75 | 1.86 |
| 23 | 1964 | 41.54 | 22.5 | 56.25 | 1.78 |
| 24 | 1930 | 41.23 | 23.5 | 58.75 | 1.71 |
| 25 | 1941 | 40.71 | 24.5 | 61.25 | 1.63 |
| 26 | 1935 | 39.23 | 25.5 | 63.75 | 1.57 |
| 27 | 1949 | 38.93 | 26.5 | 66.25 | 1.52 |
| 28 | 1938 | 38.86 | 27.5 | 68.75 | 1.45 |
| 29 | 1945 | 38.73 | 28.5 | 71.25 | 1.40 |
| 30 | 1937 | 38.70 | 29.5 | 73.75 | 1.36 |
| 31 | 1965 | 38.49 | 30.5 | 76.25 | 1.31 |
| 32 | 1967 | 38.10 | 31.5 | 78.75 | 1.27 |
| 33 | 1942 | 36.84 | 32.5 | 81.25 | 1.23 |
| 34 | 1956 | 36.63 | 33.5 | 83.75 | 1.19 |
| 35 | 1944 | 36.56 | 34.5 | 86.25 | 1.16 |
| 36 | 1940 | 35.86 | 35.5 | 88.75 | 1.13 |
| 37 | 1950 | 35.39 | 36.5 | 91.25 | 1.10 |
| 38 | 1948 | 35.31 | 37.5 | 93.75 | 1.06 |
| 39 | 1958 | 34.99 | 38.5 | 96.25 | 1.04 |
| 40 | 1961 | 32.45 | 39.5 | 98.75 | 1.01 |
| | TOTAL | 1744.65 | | | |
| | MEAN | 43.62 | | | |

Appendix III

SOIL ANALYSIS (UPPER SLOPE)

| DEPTH IN FEET | Mean % Clay | Mean % Silt | Mean % Fine Sand | Mean % Coarse Sand | REMARKS |
|---|---|---|---|---|---|
| 0 - 6" | 11 | 11 | 48.4 | 29.6 | Horizon consists of plant residue mixed with mineral matter. Gradual and smooth boundary. |
| 6" - 1 | 26 | 11 | 40.86 | 22.14 | |
| 1 - 2 | 38 | 3 | 42.1 | 16.9 | Depth of transported material. Gradual and wavy boundary. |
| 2 - 3 | 36 | 5 | 41.9 | 17.1 | |
| 3 - 4 | 35 | 5 | 38.4 | 21.6 | |
| 4 - 5 | 32 | 4 | 35.6 | 28.4 | |
| 5 - 6 | 30 | 4 | 32.7 | 33.3 | |
| 6 - 7 | 28 | 4 | 32.6 | 35.4 | Transitional soil Weathered soil Gradual and wavy boundary. |
| 7 - 8 | 29 | 5 | 31.0 | 35.0 | |
| 8 - 9 | 32 | 6 | 27.1 | 34.9 | |
| 9 - 10 | 33 | 6 | 25.2 | 35.8 | |
| 10 - 11 | 32 | 8 | 24.7 | 35.3 | |
| 11 - 12 | 27 | 7 | 25.6 | 40.4 | Zone of pronounced weathering of granite gneisses. Clear and wavy boundary. |
| 12 - 13 | 24 | 6 | 24.8 | 45.2 | |
| 13 - 14 | 23 | 11 | 26.2 | 38.8 | |
| 14 - 15 | 19 | 11 | 24.6 | 45.4 | |
| 15 - 16 | 17 | 7 | 20.4 | 55.6 | |
| 16 - 17 | 15 | 7 | 19.0 | 59.0 | |
| 17 - 18 | 12 | 7 | 17.8 | 63.2 | |
| 18 - 19 | 10 | 6 | 22.4 | 61.6 | |
| 19 - 20 | 10 | 7 | 26.5 | 56.5 | |

Appendix IV

ANALYSIS OF THE HYDROLOGICAL YEAR RAINFALL OVER THE CATCHMENT

| Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| April | 3.38 | 2.95 | 2.24 | 2.16 | 2.58 | 3.59 | 3.35 | 3.44 | 3.28 | 3.01 | 2.86 | 2.58 | 2.46 | 2.89 | 3.62 | 2.90 | 3.18 | 3.15 |
| May | 4.84 | 6.01 | 5.81 | 5.21 | 5.67 | 5.35 | 5.86 | 5.79 | 5.80 | 5.90 | 5.88 | 5.50 | 6.46 | 6.73 | 2.84 | 5.46 | 5.54 | 5.68 |
| June | 4.31 | 5.13 | 4.36 | 4.51 | 4.41 | 4.63 | 4.83 | 4.66 | 5.01 | 4.64 | 4.82 | 4.94 | 4.68 | 5.20 | 4.63 | 5.35 | 3.99 | 4.52 |
| July | 7.04 | 7.76 | 8.02 | 7.49 | 6.17 | 8.04 | 9.07 | 8.78 | 7.78 | 8.65 | 8.30 | 9.35 | 9.15 | 9.65 | 8.37 | 5.06 | 7.44 | 8.91 |
| August | 9.29 | 9.22 | 10.12 | 10.05 | 11.13 | 12.57 | 11.90 | 12.39 | 12.16 | 12.06 | 10.78 | 9.27 | 11.00 | 10.73 | 12.47 | 11.26 | 10.12 | 12.82 |
| September | 4.82 | 6.52 | 5.81 | 6.10 | 5.75 | 6.14 | 4.90 | 5.61 | 5.94 | 5.95 | 5.81 | 6.02 | 5.71 | 6.43 | 5.89 | 5.15 | 5.00 | 6.04 |
| October | .28 | .40 | .36 | .32 | .26 | .32 | .16 | .30 | .26 | .24 | .32 | .36 | .38 | .52 | .22 | .24 | .20 | .22 |
| TOTAL | 36.96 | 37.99 | 36.72 | 35.84 | 35.97 | 40.64 | 40.07 | 40.97 | 40.23 | 40.45 | 38.77 | 38.02 | 39.84 | 42.15 | 41.04 | 38.42 | 35.47 | 41.34 |

Appendix IV (contd.)

| Stations | 19 | 20 | 21 | 22 | 23 | 24 | 25 | T |
|---|---|---|---|---|---|---|---|---|
| April | 3.10 | 2.93 | 2.79 | 3.00 | 2.76 | 2.73 | 2.75 | 7 |
| May | 5.72 | 6.26 | 2.71 | 5.72 | 5.94 | 5.71 | 5.83 | 1 |
| June | 4.57 | 4.69 | 4.70 | 4.74 | 4.94 | 4.82 | 4.84 | 11 |
| July | 8.65 | 8.25 | 8.32 | 9.06 | 9.35 | 9.56 | 10.01 | 2 |
| August | 11.88 | 11.30 | 10.51 | 12.44 | 11.57 | 10.39 | 10.19 | 2 |
| September | 5.67 | 6.02 | 5.71 | 5.88 | 5.97 | 5.65 | 5.59 | 1 |
| October | .22 | .30 | .26 | .28 | .26 | .26 | .40 | |
| TOTAL | 39.81 | 39.75 | 38.00 | 41.12 | 40.79 | 39.12 | 39.61 | 9 |

n = 25

TOTAL = 976.09

(C.F.) Correction Factor = 952751.68/25 =

Sum of Squares SS = 38216.52

SS - CF = 38216.52 - 3811

$$S = \sqrt{\frac{106.46}{24}}$$

∴ Average

Appendix V

DISCHARGE AND WATER TABLE GRADIENT
(CORRELATION)

| Item | Gradient % x | Discharge Acre-inch y | Computations |
|---|---|---|---|
| 1 | 1.28 | 158.4 | $\Sigma x = 30.86$ $\bar{x} = 0.995$ $n = 31$ |
| 2 | 1.26 | 144.0 | $\Sigma y = 1924.4$ $\bar{y} = 62.08$ |
| 3 | 1.26 | 144.0 | $\Sigma x^2 = 31.69$ $\Sigma y^2 = 191001.0$ $\Sigma xy = 2169.53$ |
| 4 | 1.24 | 144.0 | $\frac{1}{31}(\Sigma x)^2 = 30.8$ $\frac{1}{31}(\Sigma y)^2 = 119400$ |
| | | | $\frac{1}{31}\Sigma x \Sigma y = 1918.00$ |
| 5 | 1.24 | 120.0 | $C_{xx} = \Sigma x^2 - \frac{1}{n}(\Sigma x)^2$ |
| 6 | 1.23 | 120.0 | $= 31.69 - 30.80 = 0.97$ |
| 7 | 1.21 | 117.6 | $C_{yy} = \Sigma y^2 - \frac{1}{n}(\Sigma y)^2$ |
| | | | $= 191001.0 - 119400 = 71601$ |
| 8 | 1.14 | 96.0 | $C_{xy} = \Sigma xy - \frac{1}{n}(\Sigma x \Sigma y)$ |
| | | | $= 2169.53 - 1918 = 251.83$ |
| 9 | 1.13 | 96.0 | The simple regression line of y on x is |
| 10 | 1.10 | 66.0 | $y - \bar{y} = b(x - \bar{x})$ |
| 11 | 1.08 | 72.0 | i.e. $y = a + bx$ where $a = \bar{y} - b\bar{x}$ |
| 12 | 1.05 | 66.0 | |
| 13 | 1.04 | 54.0 | |
| 14 | 1.03 | 54.0 | |
| 15 | 1.02 | 72.0 | |

Appendix V (contd.)

| Item | Gradient % x | Discharge Acre-inch y | Computations |
|---|---|---|---|
| 16 | 1.01 | 72.0 | |
| 17 | .97 | 84.0 | |
| 18 | .94 | 29.3 | $b = \frac{Cxy}{Cxx} = \frac{251.83}{0.97} = 259.0$ |
| 19 | .93 | 31.9 | |
| 20 | .92 | 27.1 | Then $a = \bar{y} - b\bar{x} = 62.08 - 259 \times .995 = -192.0$ |
| 21 | .91 | 22.6 | $\therefore y = -192 + 259x$ |
| 22 | .86 | 27.6 | ANALYSIS OF VARIANCE OF REGRESSION:- |
| 23 | .83 | 15.6 | Total sum of squares (ss) = Cyy = 71601 |
| 24 | .80 | 25.0 | Due to regression(ss) $= \frac{(Cxy)^2}{Cxx} = 64500$ |
| 25 | .79 | 17.6 | |
| 26 | .78 | 12.2 | Correlation coefficient = |
| 27 | .77 | 9.6 | $r = \sqrt{\frac{\text{Due to Regression ss}}{\text{Total sum of squares ss}}}$ |
| 28 | .77 | 9.6 | |
| 29 | .76 | 7.2 | $= \sqrt{\frac{64500}{71601}}$ |
| 30 | .76 | 5.3 | $= +0.94$ |
| 31 | .75 | 3.8 | |

# B I B L I O G R A P H Y


1. Armstrong, W. (1967b) — The Oxidizing Activity of Roots in Water logged Soils - Physiologia. P1. 20: 920 - 926

2. Butler, S.S. (1957) — Engineering Hydrology - Prentice-Hall Inc. Englewood Cliffs. N.J. pp. 356

3. Chow, V.T. (1964) — Editor - Handbook of Applied Hydrology: a compendium of water resources technology Mc Graw Hill, pp. 1253

4. Davies, J.A. (1965) — A note on the relationship between net radiation and solar radiation Q. J. Re. Met. Soc. 93 pp.395

5. Higgins, G.M. (1963) — Present position in pedological mapping in Northern Nigeria - Paper prepared for U.N. Conference on the Application of Science and Technology in less developed areas - Geneva Feb. 4 - 10 1963

6. Keay, R.W.J. (1960) — An example of Northern Guinea Zone vegetation in Nigeria. Nigerian Forest Information Bulletin New Series, No.1 pp.46

7. Klinkinberg, K. (1968) — Private Communication

8.a Kowal, J.M. (1967) — The assessment of the physical properties Nigerian Soils - Samaru Miscellaneous Paper No.25

b. Kowal, J.M. (1968) — Private Communication.

9. Lawes, D.A. (1963) — The influence of rainfall conservation on the fertility of the Loess Plain Soils of Northern Nigeria. J. Geogr. Assoc. of Nigeria Vol.5 No.I

10. Lutz, J.F. (1952) Mechanical impendance and plant growth. Soil physical conditions and plant growth. Agronomy Monograph - Academic Press New York.

11. Manning, H.L. (1951) Empire Cotton Growing Corporation Confidence limits of expected monthly rainfall. J. Agric. Sci. 1951 40 pp. 169 - 176.

12. Naylor, A.H. (1965) Design of Venturi flume (Samaru Dam) Letter Ref. A.8 of 27.3.65 to Dr. J.M. Kowal Institute for Agric. Research, Ahmadu Bello University, Zaria.

13. Penman, H.L. (1955) The Components of Water Balance Royal Meteo. Society. Q.J. Vol. 81 pp 280 - 284.

14. Sandover, J.A. (1960) Theodolite Practice Cleaver-Hume Press Ltd. London pp 110

15. Thomas W.N. (1961) Surveying - 5th edition Edward Arnold (Publishers) LTD. London.

16. Todd, D.K. (1959) Ground Water Hydrology Toppan Co. LTD. Tokyo, Japan

17. Trewartha, G.T. (1954) An introduction to Climate 3rd ed. McGraw-Hill, New York pp 381 - 383

18. Varder Harst and Stokman.
Soil Moisture Retention Curves
I - Directions for the use of the pressure Membrane apparatus Range pF 3.0 to 4.2
II - Directions for the use of the Sand-box apparatus Range pF 0 to 2.7