ESTIMATION OF STREAMFLOW IN THE UPPER BENUE RIVER BASIN USING CLIMATIC WATER BUDGET METHOD

BY

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D E C L A R A T I O N

The work reported in this Thesis was carried out by me under the supervision of Dr. S. Mustafa.

The work has not been previously published or accepted elesewhere for the award of any degree.

All works, opinions and ideas, other than mine have been fully acknowledged.

Sulaiman Naibi Musa

December, 1985 .

C E R T I F I C A T I O N

This thesis entitled "Estimation of Streamflow in the Upper Benue River Basin Using Climatic Water Budget Method", by Sulaiman N. Musa meets the regulations governing the award of the degree of Master of Science (Water Resources and Environmental Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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To
The Giver
Of Natural
Resources
And Knowledge.

ABSTRACT

Water is a fundamental element in the economic and social development of any country.

A survey of surface water development in the Upper Benue Basin is made here in and availability of necessary data for water resources development discussed.

A set of average monthly Temperature and Rainfall data have been used to estimate monthly streamflow values at three gauging stations by the Book keeping technique of the Climatic VJater Budget analysis. After a few trials, each time using a set of values for VJater Holding Capacity of soils and other factors of the Budget analysis, monthly streamflow values were arrived at which compare favourably with corresponding observed (measured) strcamflows at the gauging stations.

Another set of Temperature and rainfall data is then used in conjuction with the final set of values of VJater Holding capacity and other factors like overland runoff (Direct Runoff) and channel conveyance coefficients to estimate monthly Runoff for three consecutive years at one of the gauging stations.

The result of this exercise shows that the Climatic VJater Budget method can be reliably applied to the various sub-basins of the Benue River to estimate streamflows from rainfall data.

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C H A P T E R I

THE UPPER BENUE RIVER BASIN AND THE RIVER BASIN DEVELOPMENT AUTHORITY

1.1 I N T R O D U C T I O N :

Water second only to air is a very essential requirement for the existence of any living thing on earth whether plant or animal, micro or macro in nature. In fact the further the advancement in technology the more is the necessity for water as a component of development realised in all aspects of national development. It can be said that water is one of the important fundamental natural resources largely determining the economic potential of any nation.

The need to harness efficiently the water resources of a country therefore, cannot be over-emphasised. However, Nigeria like any other developing country lacks grossly, the technology to manage its water resources. To identify such potentials water data have to be available adequately. Stream flow data if adequate would have saved the situation, unfortunately even rainfall data is far from being adequate both in terms of coverage and continuity and or reliability.

Moreover, even where some rainfall data is available it often proves difficult if not impossible to utilise it for computation of stream flows mostly due to non-availability of other data on

relevant variables in the formulae necessary for the computations.

The aim of this project includes demonstrating the applicability of a simple method of stream flow computation from rainfall data. This method known as "climatic water budget" requires the following parameters to compute a stream flow from a water shed using rainfall data:-

i) Mean monthly or daily air temperature

ii) Mean monthly or daily rainfall

iii) Water holding capacity of the soils in the area under consideration.

To estimate runoff from rainfall the Penman Method would require wind Speed, Wet and dry bulb temperatures and sunshine duration/cloudiness data in addition to the information on temperature, rainfall and water holding capacity enumerated above.

While the first two parameters can easily be measured, the third can be estimated reasonably using existing rainfall data and corresponding stream flow data relevant to the water shed being considered as illustrated in Chapter IV.

Average monthly temperature for five stations and average monthly rainfall for 26 stations all relevant to the Gongola basin

have been provided by Knabe and Kowal (1972). Long term values were not available for this thesis. Average monthly stream flows for 4 stations spread evenly over the basin are also available. Using the three sets of data above, soil holding capacities of the areas covered by each of the 26 rain gauge stations have been estimated.

Using the final estimated soil holding capacities and another set of temperature and rainfall records, monthly stream flow at one of the stations have been computed for 3 years and the computed stream flow values compared with the corresponding measured discharge values.

1.2 CREATION OF RIVER BASIN AUTHORITIES:

In consideration of the importance of water Resources, the then Military Government of Nigeria established eleven River Basin Development Authorities in 1976. The Authorities' various areas of jurisdictions were formulated on the concept of River Basins as development units which was conceived as early as 1970 as a result of studies financed by the Federal Ministry of Water Resources.

Each Basin Authority is to carry out a number of functions spelt out in section 2 sub-section (I) of decree No. 25 of 1976 and modified in section 4 of decree No. 87 of 28th September, 1979 and Act No. 7 of 1st October, 1981 as enumerated below:-

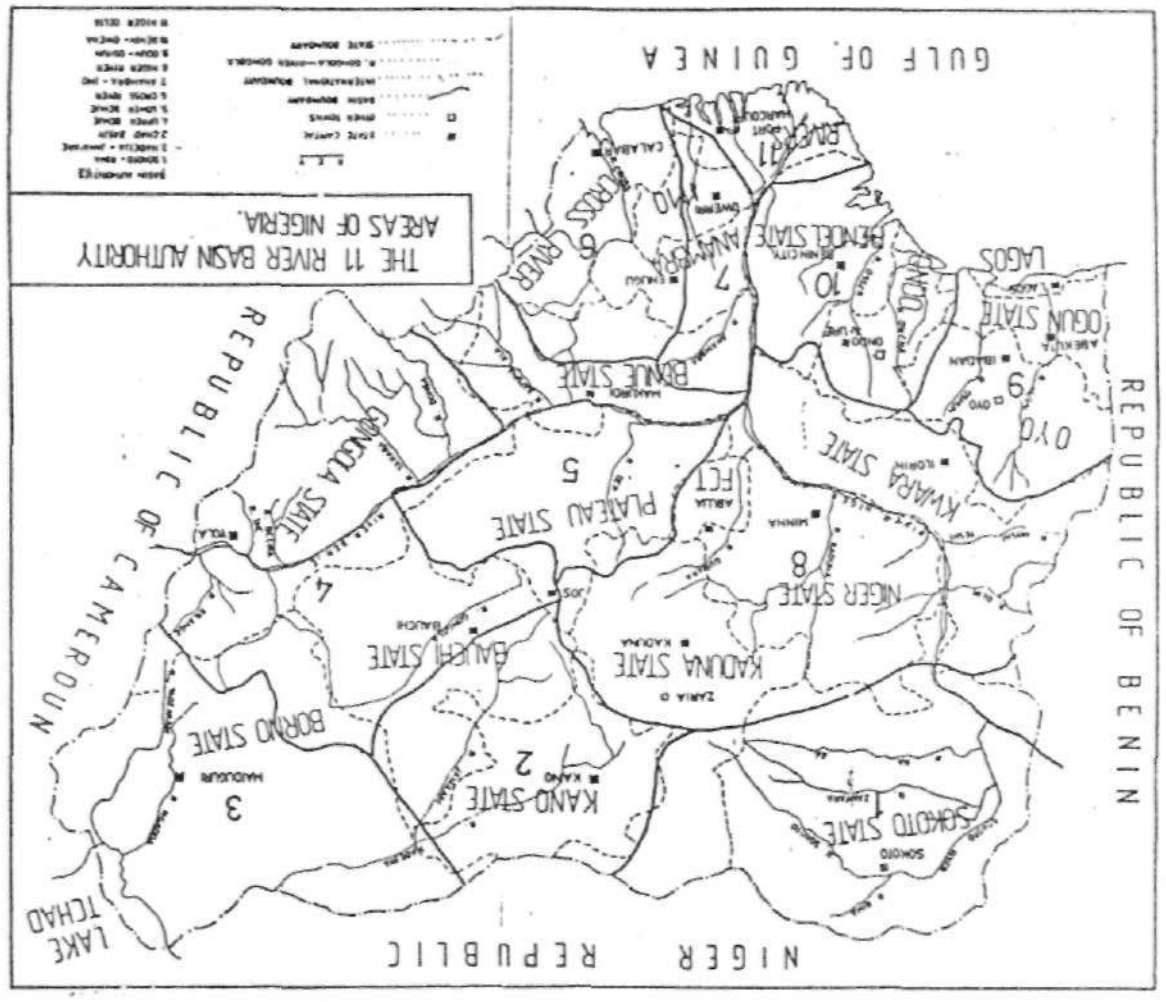

THE 11 RIVER BASIN AUTHORITY
AREAS OF NIGERIA.
GULF OF GUINEA
REPUBLIC OF BENIN
NIGER REPUBLIC
LAKE TCHAD
REPUBLIC OF CAMEROUN
BENUE STATE
PLATEAU STATE
NIGER STATE
KADUNA STATE
KANO STATE
BAUCHI STATE
BORNO STATE
GOMBE STATE
ADAMAWA STATE
TARABA STATE
KWARA STATE
OGUN STATE
LAGOS
ONDO STATE
EDO STATE
ANAMBRA STATE
ENUGU STATE
CROSS RIVER
FCT
1
2
3
4
5
6
7
8
9
10
11

FIG. 1.2

(a) To undertake comprehensive development of both surface and underground water resources for multi-purpose use .

(b) To undertake Schemes for the control of floods and erosion, and for water shed management including afforestation.

(c) To construct and maintain dams, dikes, polders, wells, borcholes, irrigation and drainage systems and other works necessary for the achievement of the Authority's function under this section.

(d) To provide water from resources and lakes under the control of the Authority for Irrigation purposes to farmers and recognised associations as well as for urban water supply schemes for a fee to be determined by the Authority concerned, with the approval of the Minister.

(e) The control of pollution in rivers, lakes, lagoons in the Authority's areas in accordance with nationally laid down standards.

(f) To resettle persons affected by the works and schemes specified in this section or under special resettlement schemes.

(g) To develop fisheries and improve navigation on the rivers, lakes, reservoirs, lagoons and creeks in the Authority's area.

(h) To undertake the mechanised clearing and cultivation of land for the production of crops and livestock and for forestry in areas both inside and outside Irrigation Projects for a fee to be determined by the Authority concerned with the approval of the Minister.

(i) To undertake the large-scale multiplication of improved seeds, livestock and tree seedlings for distribution to farmers and for afforestation schemes.

(j) To process crops, livestock products and fish produced by farmers in the Authority's area in partnership with State Agencies and any other person.

(k) To assist the State and Local Governments in the implementation of the following rural development work in the Authority's area:-

i) The construction of small dams, wells and boreholes for rural water supply schemes and of feeder-roads for the evacuation of farm produce.

ii) The provision of power for rural electrification schemes from suitable Irrigation dams and other types of power stations under the control of the Authority concerned.

iii) The establishment of agro-service centres.

iv) The establishment of grazing reserves and

v) The training of staff for the running and maintenance of rural development schemes and for general extension of work at the village level.

1.2.2 Summary:

The functions of the Basin Development Authorities is an over-all development and optimization of the land and water resources potentials of the whole country. The Machinery for the over-all development of water resources has therefore, been set with the creation of the Basin Authorities. What remains is to monitor and control it so that the development will be realised effectively and efficiently.

One of the eleven Basin Authorities is the Upper Benue River Basin Development Authority, the area of jurisdiction of which is the area drained by the River Benue and all its tributaries lying within Bauchi and Gongola States.

1.3 AREA UNDER STUDY:

1.3.1 Location:

The Upper Benue Basin is the area drained by the upper reaches of the Benue River and its tributaries lying in Bauchi and Gongola States bounded by Latitude 6^{o} 03'N, to the south and Longitude 9^{o} 30'E, to the West and the International Boundary with

Cameroun Republic to the east (see Fig. 1.3.1).

The description of the area of jurisdiction of the Upper Benue River Basin Development Authority is "the area drained by the Benue River and its tributaries from the International Boundary with Republic of Cameroun down to and including the Pai River Basin on the Northern Bank and Donga River Basin on the Southern Bank". This tallies with the description of the area under study.

1.3.2 Drainage:

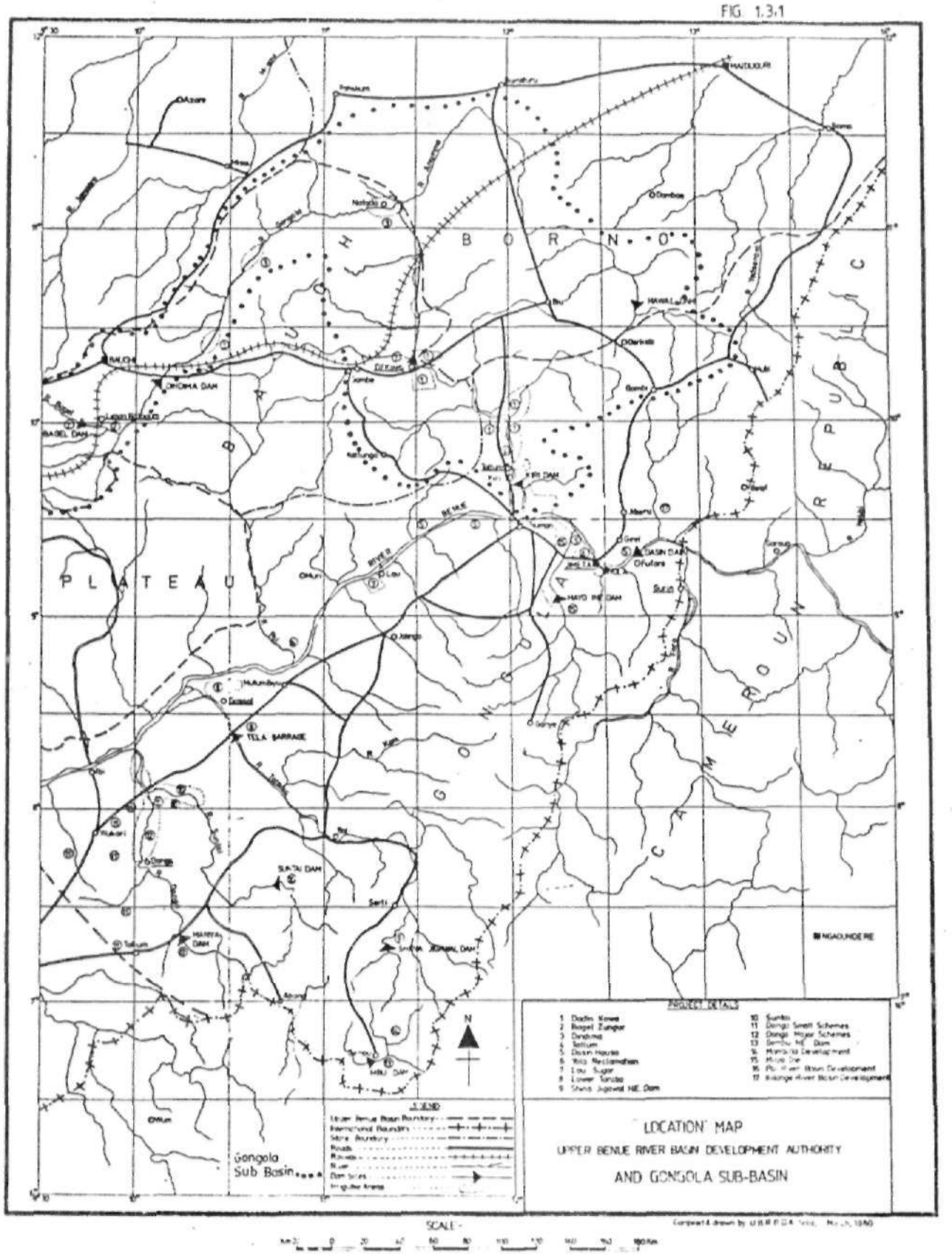
The area under study is traversed by the Benue River from which the Basin derives its name. It is the main river draining the area and it has four major tributaries, three on the southern bank and one on the northern bank. Three of the four tributaries lie within the study area i.e. Rivers Donga and Taraba on the sourthern bank and River Gongola on the northern bank.

The Benue River has numberous smaller tributaries which include Rivers Pai and Kilange on the northern bank and Rivers Mayo Belwa, Mayo Ine and Lamurde on the southern bank to name some of those lying in the study area.

Most of the Rivers mentioned which also lie in the study area have some literature mostly written by Consultants commissioned to undertake Agricultural and other water Resources pre-feasibility and or feasibility studies.

Schemetic representation of mean annual discharge of the Benue Basin is given at Fig. 1.3.2. A brief description

FIG 1.3.1


PLATEAU
BORNO
GONGOLA
CAMEROUN
YOLA
BAUCHI
GOMBE
ADAMAWA
TARABA
BENUE
NGAOUNDERE
YELA BARRAGE
DADIN KOWA DAM
GASHUA DAM
KIRI DAM
HAYO RE DAM
SUNTAI DAM
SHIRA JOGWAL DAM
MBU DAM
Gongola Sub Basin
PROJECT DETAILS
1 Dadin Kowa
2 Bagel Zungur
3 Dindima
4 Ibbitum
5 Dasin Hausa
6 Yola Reclamation
7 Lau Sugar
8 Lower Taraba
9 Shira Jogwal HE Dam
10 Suntai
11 Dongo Sweet Schemes
12 Dongo Maize Schemes
13 Serti-Ku HE Dam
14 Mambilla Development
15 Muri Dam
16 Pai River Basin Development
17 Ibbianga River Basin Development
LEGEND
Upper Benue Basin Boundary
International Boundary
State Boundary
Roads
Rivers
River
Dam Sites
Irrigation Areas
N
LOCATION MAP
UPPER BENUE RIVER BASIN DEVELOPMENT AUTHORITY
AND GONGOLA SUB-BASIN
SCALE -

of some of the major and smaller tributaries is reviewed here under which will reflect their development potentials when their hydrology is considered later.

1.3.3 The Benue Basin:

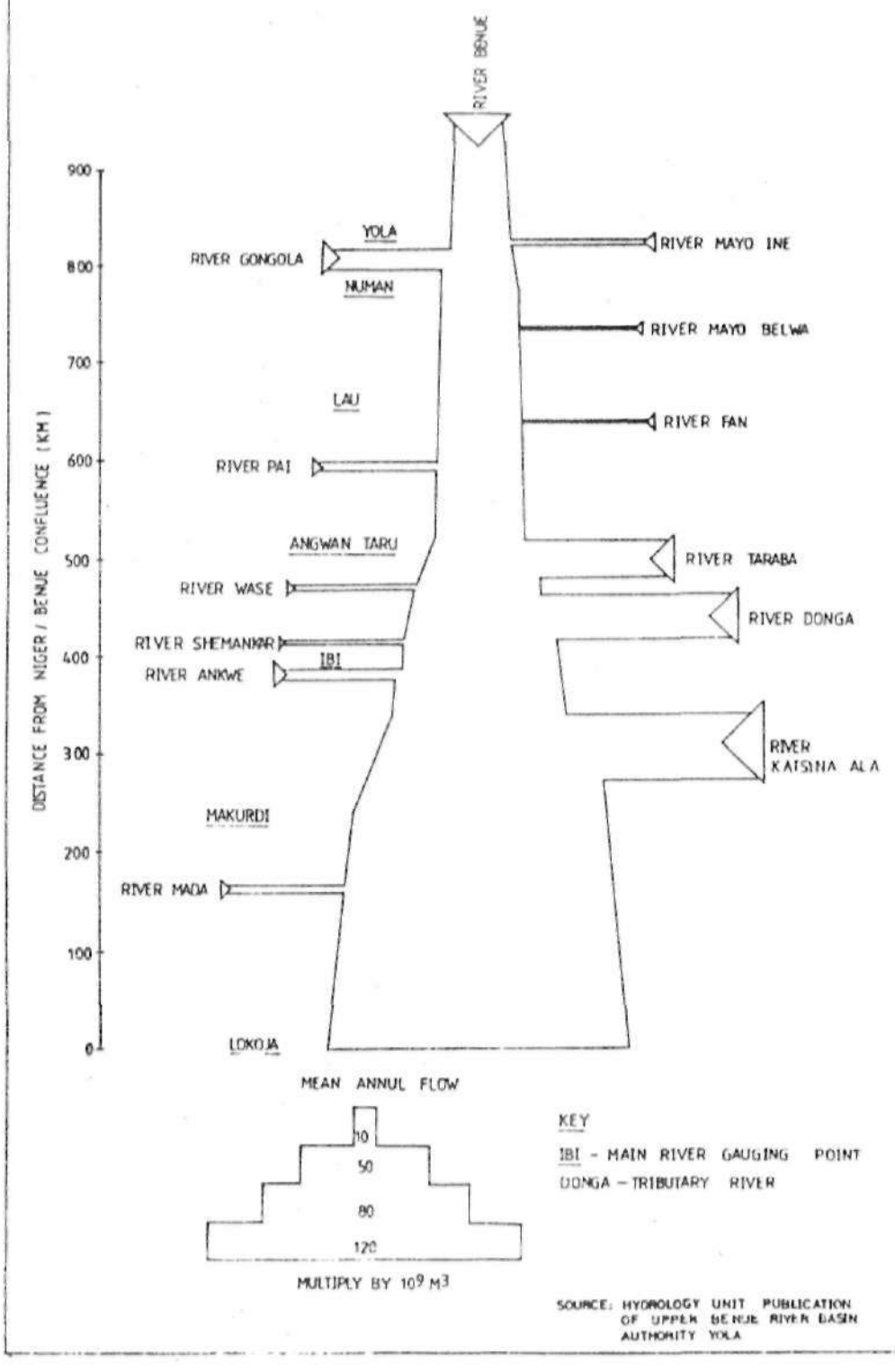
River Benue originates on the Cameroun Highlands flowing in the westerly direction, in the Cameroun republic, for about 140 kilometers and intersects the Nigeria-Cameroun boundary upstream of Dasin Hausa. It then flows in the south-westerly direction for about three-quarters of its total length to join the River Niger at Lokoja. The Niger inturn flows southwards to drain into the Atlantic Ocean in deltaic form. The total catchment area of the Benue River within the Nigerian territory is about 200,000 square-kilometers, three-quarters of which lies within area of study estimated at 150,000 square kilometers. Roughly two-thirds of the study area lies in Gongola State.

At the high point in the Benue Basin on the Cameroun Highland, the elevation is about 600 meters. The elevation at the confluences with Gongola River at Numan and with the Niger River at Lokoja are roughly 145 m and 120 meters respectively above mean sea level (a.m.s.l.).

River Benue traverses Turunian Cretaceous terrain mainly formed by arkosic sandstone of the Bima - Yola formation from the Cameroun border downstream to Yola. Alluvium of Sandy composition lines both margines of the river forming almost a continuous strip. Below the sandstones lies the Pre-Cambrian undifferentiated basement complex. Cretaceous sandstone seems

FIG. 1.3.2

SCHEMATIC REPRESENTATION OF MEAN ANNUAL DISCHARGE – BENUE BASIN



SOURCE: HYDROLOGY UNIT PUBLICATION OF UPPER BENUE RIVER BASIN AUTHORITY YOLA

Table 1.3.2 Mean Annual Runoff from The Upper Benue Basin

S/No.	Gauging Station/Catchment	Mean Annual Runoff ($\times 10^6 m^3$)
1	(a) Benue at Cameroun/Nigeria boarder	22,000
	(b) Benue at Lau	31,500
	(c) Benue at Ibbi	61,500
2.	Kilange	500
3.	Gongola	6,156
4.	Mayo-Ine	1,520
5.	Mayo-Belwa	500
6.	Donga	18,400
7.	Taraba	14,800

to fill a great area and is extensively covered by recent river sands forming the Upper Benue Plane that extends to the east in the direction of the Cameroun border. Small rhyolitic and basaltic volcanoes of post-Cretaceous age occur near the Ribadu and Wuro-Bokki areas (HIDROSERVICE, 1982).

Downstream of Yola the Benue has the characteristics of a low-land River with many sand banks crossing through alluvial beds most of its remaining length.

1.3.4 The Gongola Basin:

The Gongola River originates on the Jos Plateau. It is the largest Benue Tributary on the Northern Bank and it is roughly 500 kilometers long. It flows in a North-Easterly direction from its source for about 330 kilometers and then bends to the south to joint the River Benue at Numan. The total catchment area of Gongola River is approximately 54,000 square kilometers (SHAWMONT 1972) which forms about 26% of total catchment area of the Benue Basin.

At the high point in the Gongola Basin on the Jos Plateau, the elevation is 1,300 meters and the elevation at the confluence with the Benue is about 145 meters. The Gongola River, after leaving the foot hills of the Jos Plateau, runs over a lower Plateau (TAUCHI PLATEAU).

Downstream of Ashaka, which is roughly located at the elbow where the River turns, it has the character of a low-land

River with many sand banks and few rock outcrops in the river bed itself. In the stretch from Ashaka to Dadin Kowa, the reservoir area of Dadin Kowa Dam, which is now under construction, the River has cut into an older flood plain of a considerable size. The River valley cross-section in this area consists of a series of terraces and is far less hilly than the area downstream of Dadin Kowa.

The Bima Hills dominate the area around Dadin Kowa with the peak of the Hills rising about 600 meters above the Gongola River plane, 5 kilometers upstream of Dadin Kowa (SHAMMONT, 1974).

1.3.5 The Kilange Basin:

The Kilange River is one of the smaller Northern bank tributaries of the Benue River. It originates around the Madura Mountains near Hubi and flows southwards to join the Benue River at Wuro Boldi.

The Kilange is about 140 kilometers long and has a total catchment area of about 5,480 km^2, comparatively very small. The Kilange River Basin lies within the basement complex of Pre-Cambrian granites and migmatites.

1.3.6 The Donga Basin:

The Donga River, one of the three major southern bank tributaries of the Benue originates on the Mambilla Plateau and flows fairly steeply for about 40km after which the slope decreases to about 0.1% for another 15 kilometers. The River

then, plunges down the escarpment falling 950 meters over a distance of 90km i.e. at an average slope of 1.0 percent.

Further downstream the slope reduces and gradually flattens and the River meanders in an alluvial bed at a slope of 0.03% from Donga town to join the Benue River near the village of Jibu. Donga River is about 400 kilometers long and has a catchment area of about 17,000 square kilometers. At the source of the Donga River on the Mambilla Plateau, the elevation is about 1,750 meters and the elevation at Abong, 139 kilometers from the source, is 240 meters. The elevation at the confluence with the Benue is about 130 meters.

1.3.7 The Taraba Basin:

The Taraba River, like the Donga River originates on the Mambilla Plateau. It flows from the Plateau down the escarpment in the north-westerly direction. The slope of the River bed reduces and flattens as the Taraba River approaches River Benue. River Taraba joins the Benue at Garin Dali. The Taraba has similar features to that of Donga River.

The elevation at the source of the Taraba is about 658 meters above mean sea level and the elevation at the confluence with the Benue is about 135m. The Taraba is 230 kilometers long and has a catchment area of about 34,000 square kilometers.

1.3.8 The Mayo Ine Basin:

Mayo Ine River is one of the minor southern bank tributaries of the Benue. It originates from around the foot hills of Shebshi Mountains and flows in northerly direction in a deeply incised channel. North of Dulumi the topography becomes undulating and the character of the River changes as it passes through an area of relatively wide and complex flood plain which extends to its confluence with the Benue 40 kilometers long and has a catchment area of about 5,500 square kilometers bounded by mountains and hills to the south and east. The lower portion of the Mayo Ine Basin lies on the Bima sandstone; a Cretaceous rock deposited over the basement complex.

1.3.9 Summary:

All the major southern bank tributaries of the Benue River arise from the Mambilla high lands and the Benue itself arises from hills in the Cameroun Republic. The Gongola River which is the only major northern bank tributary and the longest tributary of the Benue originates from the Jos Plateau. All the tributaries originate from highlands and flow steeply over escarpments and then assume characteristics of low-land Rivers as they flow downstream to their respective confluences.

1.4 METEOROLOGY:

1.4.1 Climate:

The area to the northern bank of the Benue River is characterised by a tropical sub-humid and thorn wood land

vegetation according to Holdridges classification of world's life zones as reported by HIDROSERVICE (1982). The vegetation of the area to the southern bank is mainly of the savanna type lying between Sudan savanna to the North and the Tropical rainforests of the south.

The overall climatic characteristics of the Benue Basin, like the rest of the country, is determined by the Equatorial maritime and Tropical Continental air masses. The boundary between these two known as the Intertropical Discontinuity (ITD) moves across the country with the change of seasons generally on the North/South direction.

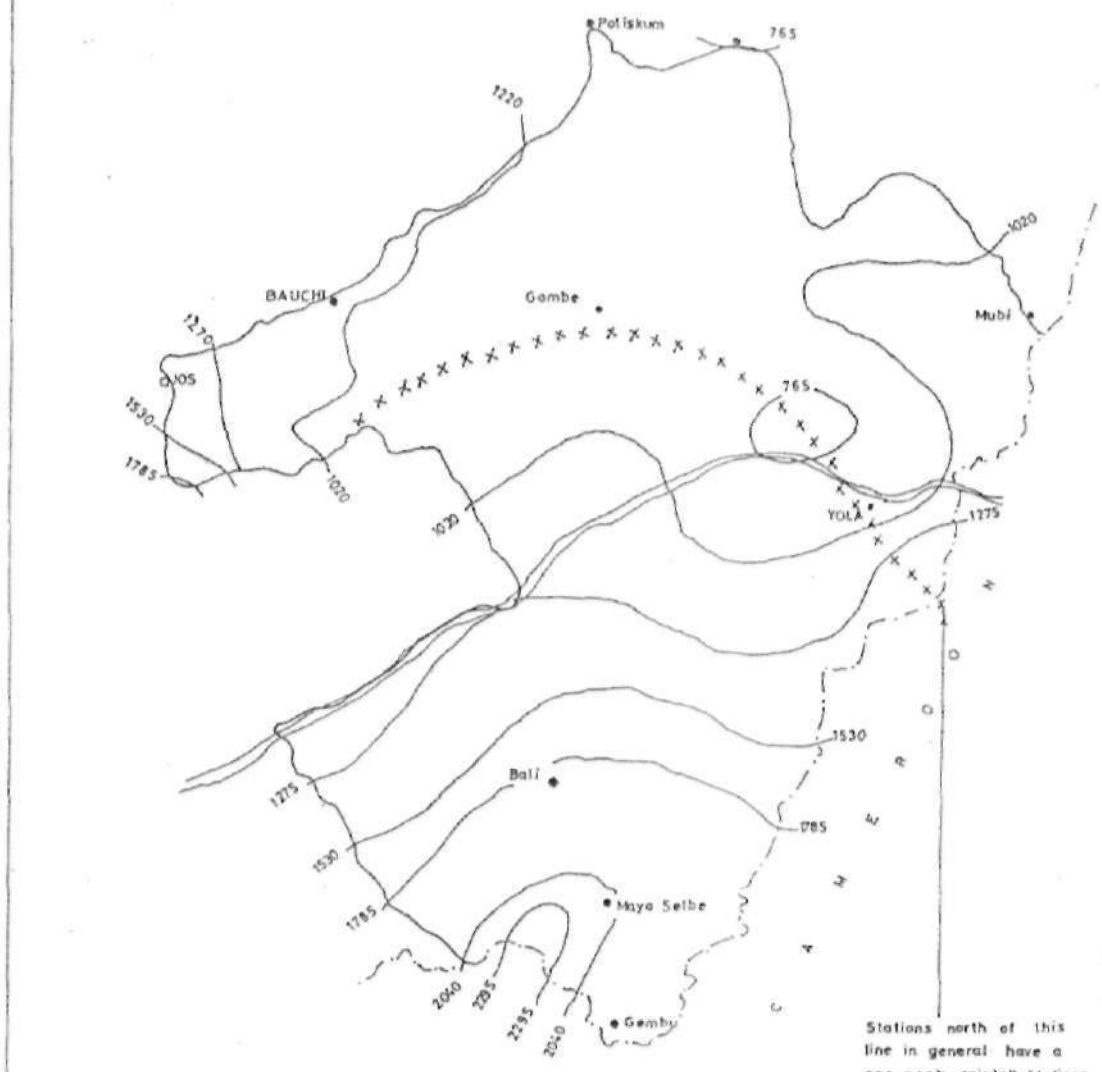
During the period from December to February the ITD is situated over the Southern parts of the country and North-Easterly dry winds occur throughout the Northern parts of the country often carrying very fine dust giving rise to the Harmattan Weather. The Harmattan is characterised by great temperature fluctuations. During the night imes temperatures fall as low as $10^{o}C$ and at day times, temperatures rise up to $40^{o}C$. The Harmattan is dry and hazy.

The ITD, on receding Northward the Equatorial Maritime air masses move in and bring about the rains generally under south-westerly winds.

1.4.2 Rainfall:

The mean annual rainfall ranges from 765mm in the North of study area with a distinct isolated area of higher rainfall around the Madura Mountains near Mubi to rainfalls of over 2,000mm

FIG. 1.4.2



MEAN ANNUAL RAINFALL (mm)

based on maps prepared by

M W Walter,

Institute for Agricultural Research Samaru (Unpublished)

and

Federal Surveys of Nigeria Lagos.

annually near Gembu on the Mambilla Plateau (See Fig. 1.4.2).

The rainy season generally starts in March, peaks in August and ends in October. Drought spells occur quite often in the study area North of the Benue River either due to delayed rains at the beginning of the season or lack of enough rains in the months of July and August. When such incidences occur crop yields are very small, and in the far North, sometimes zero, a very rare situation south of the Benue River. The Donga Basin for instance, has considerable potential for rainfed Agriculutral Development (MRT, 1978).

1.4.3. Rain Gauge Network:

Rain gauge is perhaps the most common of all the Hydro-meteorological measuring Instruments, second only to Thermometer, in the country. Though so, the distribution of rain gauges is very sparse. Moreover, the maintenance of the gauges is very poor and the records they yield un-reliable. PFP. (1982) report that there were no meteorological stations or rain gauges sited within the Kilange Basin. The Consultants had to use records from stations as far apart as Yola and Mubi which they believe were indicative of rainfall patterns in the low irrigable and the high hilly areas respectively. In the Donga Basin, MRT, (1978) have also reported that there were only nine rain gauge stations relevant to the Donga catchment and only four of these were functional. Out of the nine stations also, only four were right in the catchment area. The distribution of rain gauges in the

catchment (all relevant gauges) was one gauge in every 2,200 square kilometers. Compared to the minimum acceptable distribution by the World Meteorological Organization (1974) of 100-25km^2 to one gauge or 250-1,000km^2 to one gauge for difficult areas, the percentage distribution is 11 to 45% only.

By 1974, only 11 functioning rain-gauge stations existed in the whole of Gongola catchment area of 54,000km^2 giving a distribution of about 5,000km^2 to a gauging station. This distribution is also very poor in fact worse than that of Donga catchment area mentioned above. Mean monthly records summarised by SHAWMONT (1972) exist for Bauchi, 1906 - 1972 and for Biu, 1940 - 1972 also are available. Shorter records exist for Gombe and Tafawa-Balewa also. All the stations exhibit missing records during the period 1966 - 1972 perhaps due to the unrest in the country during the period.

Other records, Damatura, 1952 - 1965, Fika, 1952 - 1966, Darazo 1953 - 1970, did not only show missing records during the period, but no records exist for the period after 1972. The poor availability of data in the Gongola, Kilange and Donga Catchments is applicable to the whole study area and to the whole country at large.

1.4.4 Evaporation:

Evaporation data is very essential for the estimation of storage volumes of a reservoir. It is moreso if a proposed reservoir is to be sited within a region of long dry seasons like

in the area North of Benue River and other parts of Northern Nigeria.

Scarcity of evaporation records is worse than that of rainfall in the study area. For the Gongola Basin, monthly evaporation records for Bauchi, Maiduguri and Yola were the only reliable available by 1974. Piche evaporimeters were available at each of the three stations and in addition class 'A' Pan were available at Yola and Maiduguri. All sets of data have numerous gaps in them (SPARMONT, 1973).

In the Donga Catchment evaporimeters were available at Donga and Ibi only. The Pan at Ibi was installed in 1977 and therefore, has a short record.

1.4.5 Summary:

Rainfall varies from scarce in the North, making rainfed Agriculture difficult and very risky to abundant and steady in the south of the area of study. Rains sometimes delay in the North such that grasses do not grow early enough. When the rains finally begin to fall, it is often torrential causing a lot of erosion due to high runoffs, since there is no grass cover to break the speed of flow into the streams.

The sparse distribution and poor up-keep of rain gauges result in too few, short and unreliable data essential for water resources development planning and designs. This situation arises from the fact that most of the gauges have been left in

the care of persons who are unenlightened on the importance of the gauges. It is perhaps common knowledge that most of the Primary Schools use to have rain gauges in their premises. Some pupils were assigned to maintain and record the measurements. When the schools close for holidays the gauges were abandoned and corresponding data missed. Perhaps these measurements were considered, by the Authorities vis-avis pupils, of academic importance only. Other causes of the deplorable situation include inaccessibility in the hilly and mountainous areas which form high rainfall belts and lack of appropriate manpower at all levels.

1.5 HYDROLOGY:

1.5.1 Runoff:

The design of any major water Resources scheme cannot be satistactory without adequate hydrologic information.

For the design of dams and other flood control structures flow volumes and patterns in rivers at the proposed sites for the structures have to be determined to some level of accuracy. To achieve this, runoff records over a long period for a proposed site have to be available.

Like rainfall data, runoff records are very scarce and less reliable in many cases. The few records available are too short and or discontinuous for their purposes.

Water level measurements have been made on the Gongola River at Dadin Kowa by Inland Waterways Division (I.W.D.) of the Federal Ministry of Transport and Aviation since 1942. The record is quite discontinuous to May, 1965. From then to 1973 the record is fair with only missing figures here and there featuring mostly during the dry seasons. A similar record exists, compiled by the Irrigation Division of the defunct North Eastern State of Nigeria for the period 1968 to 1973, at the same station at Dadin Kowa. The two records when compared for the over-lapping period from April, 1968 to February, 1973 no consistent relationship have been found between them (SHAWMONT, 1974). The differences between the daily gauge heights as measured on the two sets of gauges varied considerably over the period.

One might depend on observed gauge heights and estimated rating curve at a section along a river channel in estimating reservoir volumes. Problems associated with this are so numerous that such a rating curve is often rendered unreliable. Relation between stage and discharge might be distorted in any one rainy season due to bed shifts. This is not unexpected where river channel runs through alluvial plains like most of the length of the Benue River downstream of Yola and lower sections of its tributaries. In the alluvial plains the channel gradient is so low and therefore, the flow velocity reduces considerably forcing the bed load to settle down resulting in lift of the river bed. The bed shift factor is more pronounced when sediment and bed load are considerable.

It has been reported that the most frequent causes of unreliability seem to be the following:

i) The staffs are not firmly fixed, they are often torn-off by the river current. The torn-off staffs are often the lowest ones which account for the scarcity of data on low flow (ALTS, 1981).

ii) The observer is often not well trained - it has been observed that some observers do correct the readings on the staff, but it has been impossible to understand what criteria they use in making the corrections (ALTS, 1981).

iii) Discharge measurements made are often too few for the purpose of producing a rating curve (ALTS, '81).

iv) Stage measurements at low flows could be rather unreliable in meandering rivers as it is possible for the river channel to move to opposite banks in different years, hence the gauge staff could be isolated in some years and the gauge readings may indicate much lower flow values than that actually flowing (MRT, 1978).

1.5.2 Sediment Transport:

The amount of material moving as bed load and sediment, and silt carried by a stream affects considerably, the life-span of a reservoir created across such a stream. In the design of a reservoir, therefore, a provision has to be made to take care of

the volume being lost over the life time of the reservoir.

The volume of settleable material flowing into the reservoir is estimated for the design life-span of reservoir and added to the live storage volume of the reservoir. The volume so estimated is known as 'dead storage'.

The major agent of siltation is erosion. Erosion is higher when the soil surface is bare and moreso when it is loose. Therefore, it is not unexpected to encounter serious siltation problems in the reservoirs in this country especially in the far North. Apart from the fact that the vegetation is scanty in the far North, annual burning of the bushes is a strong tradition in Nigeria, a phenomenon aggravating the problem of siltation in this region. Brown (1972) investigated the hydrologic effect of a bushfire in a catchment in south-eastern New South Wales and reported that runoff and sediment loads were greater than before the fire. Improper land use and overgrazing are other erosion aids and therefore, siltation helpers.

In 1955 and 1956 NEDECO (1958) conducted measurement of silt, sediment and bed load at Nyankawola on the Donga River. Their report shows that the waters of Donga River were much cleaner than that of the Benue and a strip of black water (i.e. clear water) was evident for some distance along the Benue beyond the Donga - Benue confluence. However, the reverse is the case in recent times, indicating higher silt content in Donga than the Benue. This may be due to increased human activities within the catchment of the Donga River.

The total suspended sediment load in River Donga seemed slightly less than comparable suspended sediment loads from other rivers world wide. NEDECO (1958) estimated sediment load at 1.1 million tonnes annually; at Manya and MRT (1978) gave a figure of 5.41 million tonnes at the same station. The sediment load has increased to five folds in two decades which can only be explained by unsatisfactory land management.

SHAMMONT (1973) has estimated reservoir sedimentation at Dadin Kowa: 4.91×10^6 m^3 annually corresponding to 7.37 million tonnes.

Data is not available to facilitate comparison of sediment transport over the years in the Gongola River unlike in the Donga River.

Generally, sediment transport has not been given enough attention though very important in determination of reservoir capacities.

C H A P T E R II

PHYSICAL ACHIEVEMENTS

2.1 AGRICULTURAL DEVELOPMENT

Emphasis have been laid on Agricultural development by successive Governments beginning 1975. The 'Operation Feed the Nation', 'Green Revolution' and the 'Go Back to Land' campaigns by recent regimes are clear evidences of efforts being made by Nigerian Governments to boost agriculture to a status of economic saviour.

Though Ministries of Agriculture have been in existence for about two decades their agricultural activities have never expanded beyond pilot projects, hardly making any impact on the community. The pilot projects range from about 4ha to about 70ha. scattered here and there most of which were taken over by the Basin Authority in Gongola and Bauchi States in 1977 and 1978.

2.1.1 Agriculture

With the creation of River Basin Authorities, in 1977 Agriculture assumed a new dimension in Nigeria. Investigations have been undertaken to explore fully the land and water Resources of the country.

Feasibility studies have been commissioned through indigenous and expatriate consultants. Many reports have been completed and quite a number of them have been accepted and the recommendations therefrom are being implemented. The reports have revealed

tremendous Agricultural and Hydroelectric power potentials of the country. While investigations continued, the pilot farm schemes taken over from the ministries were expanded and irrigation methods introduced in all the schemes. There was only one irrigation scheme among the farms taken over on an area of 69ha in 1977. The total area put under irrigation by the end of 1983 was 1,600 ha while the total area cultivated including rainfed rose to 13,000 ha in the same period. In addition the Authority has been managing the operation and maintenance of Kiri Dam which supplies irrigation water to Savannah Sugar Estate. The area put under irrigation by the end of 1983 by the sugar company was 2,000 ha about 17% of the ultimate development of 12,000 ha.

The total grain yield from the 13,000 ha in 1983 was 11,000 tonnes against forecast yield of 21,000 tonnes, a 50% loss due to the drought recorded that year.

In the Upper Benue a gross total area of about half a million ha. has so far been identified to be suitable for irrigated agriculture. The estimated yield from this area is about two million tonnes of grains and vegetables annually (table 2.1.1).

TABLE 2.1.1 DEVELOPMENT POSSIBILITIES AND DERIVABLE BENEFITS FROM THE UPPER BENUE RIVER BASIN.

S/N	Sub-Basin or Project Area	Ultimate Development Possibility *(Ha)	Ultimate annual yield *(Tonnes of grains or vegetable)
1.	Dasin Hausa	150,000	653,250
2.	Yola Reclamation	1,200	20,000
3.	Mayo Ine	30,000	350,000
4.	Kilange	17,000	74,000
5.	Gongola	50,085	428,644
6.	Donga	26,696	305,244
7.	Taraba	43,000	227,800
8.	Shina Jigawal	155,000	97,000
	TOTAL	472,981	2,155,938

*Hectarage (UPPER BENUE BASIN AUTHORITY 1982), Tonnage (estimated by Author).

This alone will yield about 0.8 billion Naira revenue annually assuming a conservative average cost of ₦400/ton.of produce. This figure is about four times the Authority's capital expenditure; since its inception, of 215 million Naira.

2.1.2 Liverstock

For maximum profit the benefits of farming must be utilized to the last bit. To achieve this, fodder from the farm land must be utilised. Livestock is therefore integrated into

Agriculture. The Basin Authority has incorporated livestock farming in its programmes. Apart from aiding participating farmers to manage their livestocks, the Authority establishes its own livestock farms. The major ranch, called Yelwa ranch, is situated on the Mambilla Plateau and had a total of about 1,300 heads of cattle at the end of 1983.

2.1.3 Poultry

Similarly, poultry farming is being undertaken by the Authority. The intention is to make maximum use of the agricultural produce and the accrueing bye-products to maximise benefits. To run a poultry business on large scale, feeds have to be produced in large quantities on regular basis at reasonable costs. This can only be possible if the raw materials are produced and preferably processed by the poultry owners. The Authority started the poltry farm at its headquarters in Yola with a laying flock of 1,500 in 1981 and is being expanded to about 10,000 layers.

2.1.4 Fisheries

It is obvious to create large water bodies during the course of harnessing flood water for the purpose of irrigation. To maximise benefits, the Authority has embarked on fish farming in which both natural and artificial lakes under the jurisdiction of the Authority will find additional use. Ponds and hatcheries have been constructed on total of about 43ha in its various projects. It has

been estimated that participating farmers numbering 500 made a total catch of about 500 tonnes in 1983. Dadin Kowa Dam one of the Dams being constructed by the Authority is expected to yield about 20,000 tonnes of fish annually when completed. Fish yield for other dams which are under construction or at proposal stage are not available.

2.1.5 Forestry

The sub-saharan region of Africa has been experiencing desert encroachment phenomenon. Erosion has also been threatening the land resources and stability of natural and artificial earth reservoirs and channel banks.

Agricultural development involves large scale clearing of bushes and forests likewise earth movement. These activities encourage both desert encroachment as well as land erosion. To eliminate the unwanted side effects of these developmental activities and minimise the desert encroachment and erosion phenomena the Basin Authority places emphasis on aforestation. In 1983 about 400,000 seedlings of forest and fruit species were raised and distributed to organisations and individuals. Among proposed aforestation programmes are water-shed management programmed over an area of 5,600 KM^2 in the Dadin Kowa Dam catchment area and a citrus plantation covering 2,000 ha in Baissa.

2.2 Water Resources Development

For agriculture to thrive in a region of scarce rainfall and erratic rainy season like in Nigeria, particularly the northern part of the country, water resources must be fully harnessed for maximum exploitation. It is moreso if the agricultural development is to be harmonised with the growth of the industries knowing that power is the livewire of industrial development.

2.2.1 Reservoir Construction

The Upper Benue River Basin has 16 dams under its area of operation most of which are at proposed stages (table 2.2.1). Kiri Dam is completed while Dadin Kowa and Gubi Dams are nearing completion. Cham and Balanga dams are at low level of completion (5% - 10% completion). There are also 2 small dams of below half a million cubic metre storages and seven ponds which provide drinking water for livestock. 17 medium and small dams have been proposed for construction during the fifth National Development Plan period (1986 - 1990).

By the year 1990 about 16 billion cubic metres of water is expected to be stored in reservoirs of the dams for irrigation, industrial and domestic water supplies. This represents 26% of the total (61.5 billion M^3) annual runoff from the Upper Benue Basin measured at Ibbi (see table 1.3.2). Advantage of the irrigation water reservoirs is taken to produce electricity wherever

Table 2.2.1 LIST OF DAMS IN THE UPPER BENUE BASIN

S/N	Name of Dam	State Located	Capacity Million m^3	Height above lowest foundation	Type/Purpose	Status - 1983
1	Cham	Bauchi	4.5	12.3m	Multipurpose	Under construction
2	Bagel	- do -	63	24.0m	*Irrigation	Under Design
3	Dadin Kowa	- do -	2,855	42.0m	Multipurpose	Nearing completion (over 90%)
4	Dindima	- do -	2,885	50.0m	*Irrigation	Under study
5	Hawal	Gongola	350	22.0m	*Irrigation	Proposed
6	Dasin Hausa	- do -	8,000	48.0m	Multipurpose	Proposed
7	Shina Jigawal	- do -	80	50.0m	- do -	- do -
8	Tela Barage	- do -	2,200	21.0m	*Irrigation	Designed
9	Suntai Bakundi	- do -	62	15.0m	Multipurpose	Proposed
10	Manya	- do -	1,843	40.0m	Multipurpose	Proposed
11	Gembu	- do -	300	83.0m	Multipurpose	Proposed
12	Dulumi	- do -	250	18.5m	- do -	Proposed
13	Kiri	- do -	600	-	- do -	Completed (1981)
14	Gubi	Bauchi	45	2.2	*Water Supply	Nearing completion (over 80%)
15	Balanga	- do -	-	-	*Irrigation/ Water Supply	Under construction
16	Kura Dam	Gongola	9	16.2m	*Irrigation	Proposed.

*Dams are actually multipurpose in that they would also provide fisheries and recreaction facilities.

high heads can be economically created during the construction of such reservoirs. Dam Projects are often economically more feasible when they are designed to serve multi-purpose use where excess water over irrigation requirements is utilised for power generation and the reservoir itself is utilised for fish farming. A living example is the Dadin Kowa Dam Project which was first conceived for power generation solely, but later found infeasible. However, it was found feasible when irrigation and fisheries were made the major components of development and electric power generation a third product.

2.2.2 Hydro-electric Power:

Investigation reports (UBR 1982) have shown the possibility of generating upto a total of 1,661 MW from seven dams one of which is Dadin Kowa Dam already under construction. This represents about 20% of the Projected total grid available electric power (8116 MW)* for the country by the year 1990. Proposed dams of major power potential are Gembu (1,170 MW), Suntai (200 MW) and Dasin-Hausa (150 MW). Construction of these dams are expected to be undertaken during the next national plan period (1986 - 1990). Further investigations may reveal more of suitable sites for hydro-electric power potentials. The Upper Benue River Basin therefore, represents a substantial percentage of the power potentials of the country.

* NEPA (SEPTEMBER, 1982).

C H A P T E R III

ESTIMATION OF STREAM FLOW BY THE CLIMATIC WATER BUDGET METHOD.

3.1 THE WATER BUDGET AND DETERMINATION OF UNMEASURED FACTORS

The water budget hereunder is used to determine factors necessary for the computation of stream flows in the Gongola River Basin. Records of average monthly temperature from five synoptic stations and average monthly rainfall records from 22 rainfall stations, in addition, has been reproduced from a publication of the Ahmadu Bello University Press "An Agroclimatological Atlas of the Northern States of Nigeria 1972" by Kowal and Knabe (Annex I). Stream flows have been reported by Shawmont (1972) and Diyam (1977). These records in conjuction with flow records are used to estimate one of the principal requirements, water holding capacity of soils, for the computation of stream flows by water budget method. In addition runoff co-efficients for stream flows are also estimated. The estimated values of water holding capacity and runoff coefficients are used in computation of stream flow values for three consecutive years, 1980 - 1982, at Dadin Kowa in Chapter V.

3.1.1 Definition of the water budget

The water budget has been defined as the daily, weekly or monthly accounting of moisture in-flows, out-flows and storages at a particular place or over a geographic area (Mather 1978).

3.1.2 Factors Influencing the Water Budget

Most of the factors affecting the budget are principally climatic such as precipitation, evaportranspiration, moisture storage in the soil, surface run-off and the movement of water through the root zone in the soil.

3.1.3 Application of the water budget

The budget has a wide range of application ranging from the study of climate, soils, vegetation and ocean levels to the study of hydrology, agriculture, irrigation schedulling, land use, forestry and environmental factors such as ground water recharge/ urbanisation relations. The water budget is herein utilised to demonstrate its applicability in determining stream flows from rainfall and temperature data. One of the major sub-basins/Gongla basin, being typical of the Upper Benue sub-basins is chosen for the purpose of the project study. This sub-basin seems to have more hydro-meteorological data necessary for application of the budget than any other in the Upper Benue basin a phenomenon which can easily be explained. The Gongola river as seen in Chapter I Traverses three States viz:

(a) Plateau State where it originates;

(b) Bauchi State in which most of its length lie, and

(c) Gongola State in which it joins the Benue River.

Meteorological records, for quite long periods, have been recorded at Jos and Yola airports and at potiskum and Bauchi

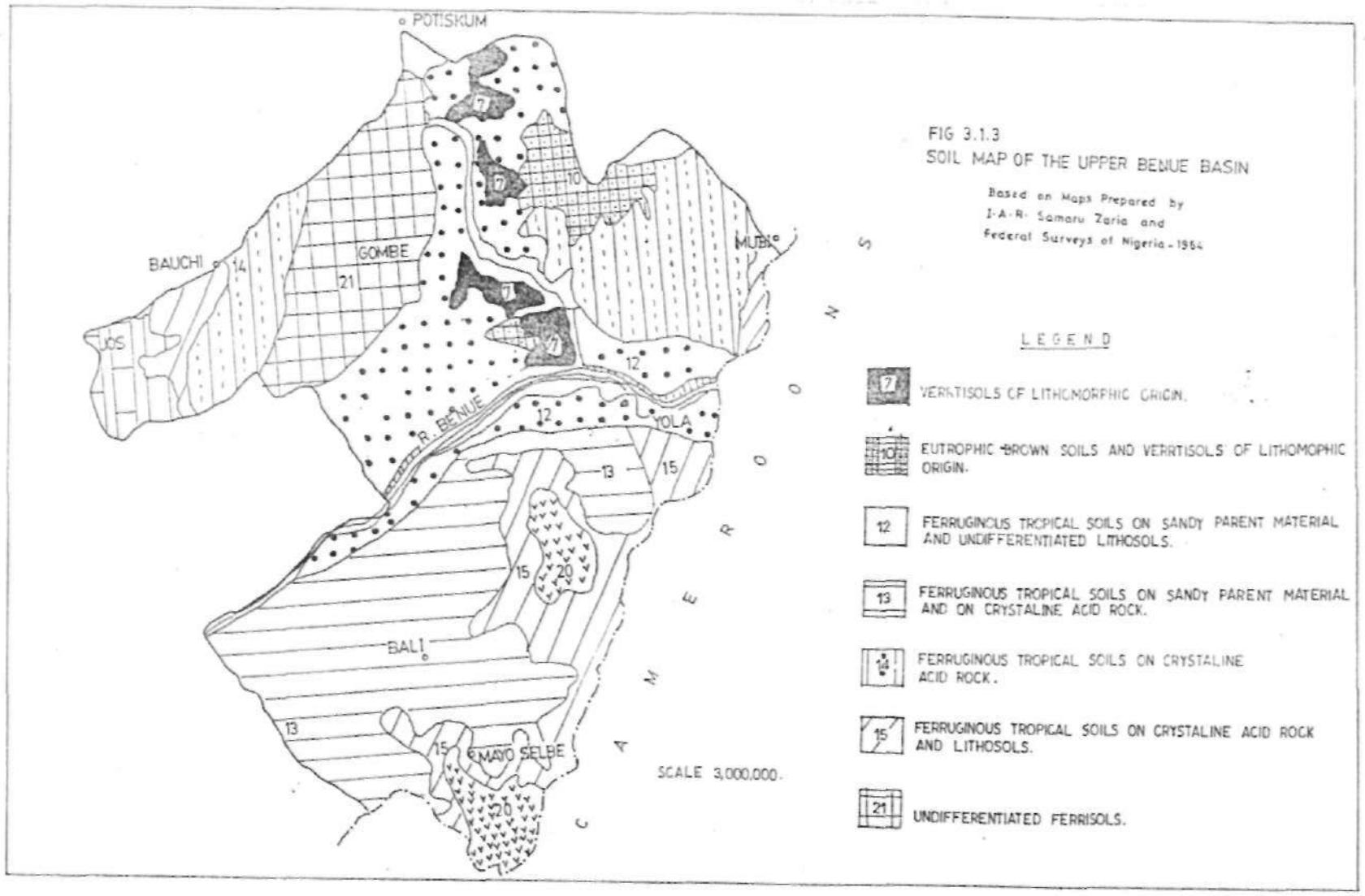


FIG 3.1.3
SOIL MAP OF THE UPPER BENUE BASIN

Based on Maps Prepared by
I.A.R. Samaru Zaria and
Federal Surveys of Nigeria - 1964

aerodromes all of which are quite relevant to the sub-basin under study. Other places where fairly adequate meteorological data relevant to the Gongola sub-basin, are to be found included Pankshin and Gindin Akwati in Plateau State and Dadin Kowa in Bauchi State. Useful stream discharge records are available for stations at Dindima, Dadin Kowa, Garkida and Bare for sometime before the 1970^{s} while only those at Dindima and Dadin Kowa have been the only ones properly maintained in recent times.

3.1.4 Elements of the water budget and their determination:

Of the three parameters of the water budget, Rainfall (P), Actual evapotranspiration (AE), and soil storage (ST), only rainfall is often directly measured while Evapotranspiration and soil storage are derived or estimated from temperature and soil types respectively.

From the equation:

$$P = DR + ST + AE + RO$$

Direct Runoff (DR) plus Runoff (RO) from moisture surplus give rise to stream flow. Conveyance coefficient has been introduced to account for losses to ground water storage and open water evaporation when the stream flows from a gauging station to the next one. Evapotranspiration can be tetermined using serveral techniques such as: Mass transport, aerodynamic or profile techniques, eddy correlation techniques, energy budget techniques and empirical (book keeping) techniques. Of the six methods of determining evapotranspiration the book keeping technique as developed by

Table 3.1.3 Water Holding Capacities of Soils and Wilting point for crops for available water in mm per meter depth (After Kowal and Knabe 1972)

TEXTURAL CLASS	WATER HOLDING CAPACITY		WILTING POINT		AVAILABLE WATER	
	Range	Average	Range	Average	Range	Average
1 Coarse Sand less 10% clay and silt	56 - 90	70	22 - 34	28	28 - 56	42
2 Fine Sand less 10% clay and silt	78 - 112	95	28 - 45	39	50 - 67	56
3 Fin Loamy Sand 10-29% clay and sand	112 - 168	140	34 - 67	50	78 - 101	90
4 Sand clay 30-50% clay and sand	157 - 179	168	56 - 78	67	101	101
5 Clay loan 45-60% clay and silt	202 - 224	213	78 - 90	84	123 - 134	129
6 Sandy clay 60-70% clay and silt	235 - 274	252	146 - 157	151	90 - 118	101
7 Vertisols 50% clay.	336 - 504	420	224 - 336	280	112 - 168	140

Thornthwaite is employed herein. Water holding capacities of the soils in the study area are estimated by assigning assumed values to the soils and using these and a set of rainfall and temperature records, flows are determined at stations where discharge record exist for the time corresponding to the set of rainfall and temperature records. The so computed discharge values are compared to the measured values. The assigned water holding capacities are then adjusted and the same process repeated until a fair comparison is obtained by regression analysis between the determined and measured values of stream flows.

The first assigned values of water holding capacities (WHC) are assumed by looking at table 3.1.3, which gives ranges and average values of WHC for different soil types and Fig 3.1.3. which gives broad classification of the soils in the basin. WHC is defined as the quantity of water in millimeters that can be retained per meter depth of soil above which excess is released for deep percolation.

3.1.5 Definition and determination of evapotranspiration.

Actual Evapotranspiration (AE) is the water loss from a place, an area or a geographical zone which actually takes place. It depends among other things, on the water available in root zone of the soils, the vegetation cover of the area and the percentage of in-coming solar radiation reflected from the surface of the area. It is not easy if not impossible to measure or calculate the actual evapotranspiration directly.

To calculate AE, potential evaporanspiration (PE) is determined first. PE is defined as the water loss from a large

homogeneous vegetation covered area that never suffers from a lack of water (ideal situation). Potential evapotranspiration is primarily a function of climatic condition (energy from the sun) and is not a function of type of vegetation, type of soil, soil moisture content or land management practices while Actual evapotranspiration depends on all these other factors in addition to the climatic factors.

3.1.6 Potential Evapotranspiration (PE)

Thornthwaite, fitting data of evaporation from water sheds and irrigation plots to air temperatures, obtained the following expression for unadjusted potential evapotranspiration (unadj.PE).

$$\text{Unadj PE (cm/month)} = 1.6 \left\{ \frac{10t}{I} \right\}^a$$

Where t - mean monthly temperature (^oC)

I - annual heat index determined from the sum of the 12 month heat Index values (I)= $\sum i$

where

i - Monthly heat Index

a - a none linear function of the heat index equal to

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49.$$

These expressions are complicated and mathematically inelegant. They can only be evaluated readilly with the use of tables and nomograms (Mather 1978). Unadjusted PE is the water loss for a 30-day month with each day 12 day light hours long.

This value is adjusted by a factor which takes into consideration the differences in length of the actual day and month which are either longer or shorter than 12 hours and 30 days respectively.

3.1.7 Procedure for calculating Unadj. PE and adjustments.

The procdure has been illustrated using data from Jos, Plateau State and another data from Numan, Gongola State. The former station is one of those relevant to the source of Gongola river and the latter relevant to the end of the river where it flows into the Benue. Five synoptic stations were the only reliable ones relevant to the basin for the period considered for this purpose. They are:-

1. Jos
2. Bauchi
3. Maiduguri
4. Potiskum
5. Yola.

Therefore the whole of the basin is zoned into five by method of Thiessen polygon weighting method and each zone covered by one of these stations (FIG. 5. 1A).

At Jos average monthly temperature varies from 20.2^{oC}-24.2^{oC}. Temperature is high in March to May and low in January, July and August.

Undajusted 30-day potential evapotranspiration has been closely related to air temperature by Thornthwaite through the expression PE = 1.6 $\left\{ \frac{10t}{I} \right\}^{a}$, parameters as explained above (section 3.1.6).

It is necessary to adjust the value of PE by taking into consideration the actual number of day-light hours per day as well as the variation in number of days in the month from 28 to 31 as mentioned above. Table 3.1.7c Provides values of the monthly heat index (i) for different monthly temperatures (row 3 of table 3.1.7A). Summation of these 12 monthly values provides the annual heat index (I) for the stations (row 3 column 13 of the same table) i.e. 113.

Table 3.1.7D provides values of undajusted daily potential evapotranspiration from informations on the annual heat index (I) and mean monthly temperature ($T^{o}C$). Different I values are given along the top of the table. The nearest I value on the table is 115.0. The values of unadjusted PE corresponding to the monthly temperatures under I value equals to 115.0 are in row 4 of table 3.1.7A.

Table 3.1.7E provides latitudinal values of the product of the number of days in the month multiplied by the mean daily duration of sunlight expressed in units of 12 hours. These are the correction factors (row 5 of 3.1.7A) by which the unadjusted daily PE is

Table 3.1.7A (continued at page 52 as table 3.1.8A)

Computation of PE at Jos.

1	MONTH	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
2.	Temperature (°C)	20.8	22.7	24.2	24.0	23.1	21.8	20.5	20.2	21.2	22.2	21.7	21.2	
3.	Heat Index (i)	8.66	9.88	10.89	10.75	10.15	9.29	8.47	8.28	8.91	9.55	9.23	8.91	113.0
4.	Unadj PE	2.6	3.2	3.6	3.5	3.3	2.8	2.5	2.4	2.7	3.0	2.8	2.7	
5.	Adj. Factor (F)	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7	
6.	Adj. PE	78	87	111	108	107	89	81	77	83	92	82	80	1075

Table 3.1.7B (continued at page 59 as table 3.1.8C)

Computation of PE at Numan.

1	MONTH	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
2.	T°C	25.5	28.1	31.6	30.3	27.4	26.8	26.3	26.5	27.6	26.7	25.0	27.8	
3.	Heat Index (i)	11.78	13.65	16.30	16.30	15.30	13.14	12.78	12.35	12.49	13.28	12.63	11.44	161
4.	Unadj PE	3.9	5.0	5.7	5.7	4.5	4.8	4.6	4.3	4.4	4.8	4.6	3.7	
5.	Adj. Factor (F)	30.3	27.6	30.9	30.9	32.1	31.5	32.1	31.8	30.6	30.6	29.4	30.0	1748.8
6.	Adj. PE	117.0	136.5	176.1	176.1	178.1	152.6	147.7	138.0	134.6	146.9	135.2	109.9	

Table 3.1.7C.
Monthly values of heat Index (i) Corresponding to Monthly mean temperatures ($T^{o}C$)
(After J.R. Mather, 1978).

T°C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0			.01	.01	.02	.03	.04	.05	.06	.07
1	.09	.10	.12	.13	.15	.16	.18	.20	.21	.23
2	.25	.27	.29	.31	.33	.35	.37	.39	.42	.44
3	.46	.48	.51	.53	.56	.58	.61	.63	.66	.69
4	.71	.74	.77	.80	.82	.85	.88	.91	.94	.97
5	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.22	1.25	1.29
6	1.32	1.35	1.39	1.42	1.45	1.49	1.52	1.56	1.59	1.63
7	1.66	1.70	1.74	1.77	1.81	1.85	1.89	1.92	1.96	2.00
8	2.04	2.08	2.12	2.15	2.19	2.23	2.27	2.31	2.35	2.39
9	2.44	2.48	2.52	2.56	2.60	2.64	2.69	2.73	2.77	2.81
10	2.86	2.90	2.94	2.99	3.03	3.08	3.12	3.16	3.21	3.25
11	3.30	3.34	3.39	3.44	3.48	3.53	3.58	3.62	3.67	3.72
12	3.76	3.81	3.86	3.91	3.96	4.00	4.05	4.10	4.15	4.20
13	4.25	4.30	4.35	4.40	4.45	4.50	4.55	4.60	4.65	4.70
14	4.75	4.81	4.86	4.91	4.96	5.01	5.07	5.12	5.17	5.22
15	5.28	5.33	5.38	5.44	5.49	5.55	5.60	5.65	5.71	5.76
16	5.82	5.87	5.93	5.98	6.04	6.10	6.15	6.21	6.26	6.32
17	6.38	6.44	6.49	6.55	6.61	6.66	6.72	6.78	6.84	6.90
18	6.95	7.01	7.07	7.13	7.19	7.25	7.31	7.37	7.43	7.49
19	7.55	7.61	7.67	7.73	7.79	7.85	7.91	7.97	8.03	8.10
20	8.16	8.22	8.28	8.34	8.41	8.47	8.53	8.59	8.66	8.72
21	8.78	8.85	8.91	8.97	9.04	9.10	9.17	9.23	9.29	9.36
22	9.42	9.49	9.55	9.62	9.68	9.75	9.82	9.88	9.95	10.01
23	10.08	10.15	10.21	10.28	10.35	10.41	10.48	10.55	10.62	10.68
24	10.75	10.82	10.89	10.95	11.02	11.09	11.16	11.23	11.30	11.37
25	11.44	11.50	11.57	11.64	11.71	11.78	11.85	11.92	11.99	12.06
26	12.13	12.21	12.28	12.35	12.42	12.49	12.56	12.63	12.70	12.78
27	12.85	12.92	12.99	13.07	13.14	13.21	13.28	13.36	13.43	13.50
28	13.58	13.65	13.72	13.80	13.87	13.94	14.02	14.09	14.17	14.24
29	14.32	14.39	14.47	14.54	14.62	14.69	14.77	14.84	14.92	14.99
30	15.07	15.15	15.22	15.30	15.38	15.45	15.53	15.61	15.68	15.76
31	15.84	15.92	15.99	16.07	16.15	16.23	16.30	16.38	16.46	16.54
32	16.62	16.70	16.78	16.85	16.93	17.01	17.09	17.17	17.25	17.33
33	17.41	17.49	17.57	17.65	17.73	17.81	17.89	17.97	18.05	18.13
34	18.22	18.30	18.38	18.46	18.54	18.62	18.70	18.79	18.87	18.95
35	19.03	19.11	19.20	19.28	19.36	19.45	19.53	19.61	19.69	19.78
36	19.86	19.95	20.03	20.11	20.20	20.28	20.36	20.45	20.53	20.62
37	20.70	20.79	20.87	20.96	21.04	21.13	21.21	21.30	21.38	21.47
38	21.56	21.64	21.73	21.81	21.90	21.99	22.07	22.16	22.25	22.33
39	22.42	22.51	22.59	22.68	22.77	22.86	22.95	23.03	23.12	23.21
40	23.30									

multiplied to produce the adjusted monthly PE (row 6 of table 3.1.7A). The closet latitude to Jos is 10^{o}N, therefore the values of correction factor against 10^{o}N in table 3.1.7E are written at row 5 of table 3.1.7A.

The same procedure is applied to produce adjusted PE for Numan using temperature records at Yola and the result is in Table 3.1.7B.

At Numan (Yola temperature records) the average monthly temperature varies from 25^{o}C to 31.6^{o}C. If average monthly temperature exceeds 26.5^{o}C the relationship between evapotranspiration and air temperature is independant of I (Mather 1978) hence table 3.1.7D provides values of unadjusted daily PE for temperatures higher than 26.5^{o}C irrespective of the I value. The highest I value in the table is 140 while the I value for Numan (row 3 column 13 of table 3.1.7D) is 161. Therefore when I value is greater than or equal to 140 and temperatures less than or equal to 26.5^{o}C values of unadjusted daily PE corresponding to I equal to 140 are satisfactory.

3.1.8 Procedure for computing actual evapotranspiration.

Actual evapotranspiration (AE) is calculated from PE by considering two things. Whether the potential evapotranspiration is satisfied, a situation occuring only when the water holding capacity (WHC) is satisfied and there is still a surplus of precipitation to satisfy PE or the surplus precipitation is not enough to satisfy (WHC) let alone PE. Therefore to compute Actual

Table 3.1.7D.
Values of Unadjusted Daily Potential Evapotranspiration (UnAdj.PE) In Millimeters For Different Mean Monthly Temperatures (T°C). And Annual Heat Index (I) values.
(After J.R. Mather, 1978).

I	115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
T°C											
13.50	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
13.75	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5
14.00	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.5	0.5
14.25	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.5	0.5
14.50	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6
14.75	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6
15.00	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7
15.25	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7
15.50	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8
15.75	1.2	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
16.00	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9
16.25	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9
16.50	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	0.9	0.9
16.75	1.4	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.0	1.0	1.0
17.00	1.5	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.0	1.0
17.25	1.6	1.5	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1
17.50	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2	12
17.75	1.7	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.2	1.2
18.00	1.8	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.3
18.25	1.8	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.4
18.50	1.9	1.8	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.4	1.4
18.75	1.9	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.5	1.5	1.5
19.00	1.9	1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.6	1.5	1.5
19.25	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.6	1.6
19.50	2.1	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.7	1.7	1.6
19.75	2.2	2.0	2.0	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.7
20.00	2.2	2.1	2.1	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.8
20.25	2.3	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.0	2.0	1.9
20.50	2.4	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.0
20.75	2.5	2.4	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.1	2.1
21.00	2.6	2.5	2.4	2.4	2.3	2.3	2.3	2.3	2.2	2.2	2.2
21.25	2.7	2.6	2.5	2.4	2.4	2.4	2.4	2.3	2.3	2.3	2.3
21.50	2.7	2.6	2.5	2.5	2.4	2.4	2.4	2.4	2.3	2.3	2.3
21.75	2.8	2.7	2.6	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4
22.00	2.9	2.8	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.5
22.25	3.0	2.9	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.6
22.50	3.1	3.0	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.7	2.7
22.75	3.2	3.1	3.0	2.9	2.9	2.9	2.9	2.9	2.9	2.8	2.8
23.00	3.3	3.2	3.1	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
23.25	3.3	3.3	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.0
23.50	3.4	3.4	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.1	3.1
23.75	3.5	3.5	3.4	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.1

Table 3.1.7D. (continued)

T°C \ I	115.0	117.5	120.0	22.5	125.0	127.5	130.0	132.5	135.0	137.5	140.0
24.00	3.5	3.5	3.4	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.2
24.25	3.6	3.6	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3
24.50	3.7	3.7	3.6	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.4
24.75	3.8	3.8	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.5
25.00	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.7
25.25	4.0	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8
25.50	4.1	4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9
25.75	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.1
26.00	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.2
26.25	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.3
26.50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.4

Values of Unadjusted Daily Potential Evapotranspiration for Mean Temperatures Above 26.5°C

(Unadjusted Potential Evapotranspiration in mm)

T°C	0.0	0.1	6.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
26						4.5	4.5	4.6	4 6	4.6
27	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.9	4.9
28	4.9	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.2
29	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.4	5.4
30	5.4	5.4	5.4	5.5	5.5	5.5	5.5	5.5	5.6	5.6
31	5.6	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.7	5.8
32	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9	5.9
33	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.0	6.0	6.0
34	6.0	6.0	6.0	6.0	6.1	6.1	6.1	6.1	6.1	6.1
35	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
36	6.1	6.1	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
37	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
38	6.2									

Note:-
Only the portion of table relevant to computation of UnAdj.PE for Gongola Basin($T^{o}C$ greater than $20^{o}C$) is reproduced above.

Table 3.1.7E.
Mean Possible Monthly Duration of Sunlight In The Northern Hemisphere Adjusting Factor (F) For UnAdj. PE (Expressed in Units of 12 Hours) (After J.R. Mather, 1978).

	J	F	M	A	M	J	J	A	S	O	N	D
Northern Latitudes												
0°	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
1	31.2	28.2	31.2	30.3	31.2	30.3	31.2	31.2	30.3	31.2	30.3	31.2
2	31.2	28.2	31.2	30.3	31.5	30.6	31.2	31.2	30.3	31.2	30.0	30.9
3	30.9	28.2	30.9	30.3	31.5	30.6	31.5	31.2	30.3	31.2	30.0	30.9
4	30.9	27.9	30.9	30.6	31.8	30.9	31.5	31.5	30.3	30.9	30.0	30.6
5	30.6	27.9	30.9	30.6	31.8	30.9	31.8	31.5	30.3	30.9	29.7	30.6
6	30.6	27.9	30.9	30.6	31.8	31.2	31.8	31.5	30.3	30.9	29.7	30.3
7	30.3	27.6	30.9	30.6	32.1	31.2	32.1	31.8	30.3	30.9	29.7	30.3
8	30.3	27.6	30.9	30.9	32.1	31.5	32.1	31.8	30.6	30.6	29.4	30.0
9	30.0	27.6	30.9	30.9	32.4	31.5	32.4	31.8	30.6	30.6	29.4	30.0
10	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7
11	29.7	27.3	30.9	30.9	32.7	31.8	32.7	32.1	30.6	30.6	29.1	29.7
12	29.4	27.3	30.9	31.2	32.7	32.1	33.0	32.1	30.6	30.3	29.1	29.4
13	29.4	27.3	30.9	31.2	33.0	32.1	33.0	32.4	30.6	30.3	28.8	29.4
14	29.4	27.3	30.9	31.2	33.0	32.4	33.3	32.4	30.6	30.3	28.8	29.1
15	29.1	27.3	30.9	31.2	33.3	32.4	33.6	32.4	30.6	30.3	28.5	29.1
16	29.1	27.3	30.9	31.2	33.3	32.7	33.6	32.7	30.6	30.3	28.5	28.8
17	28.8	27.3	30.9	31.5	33.6	32.7	33.9	32.7	30.6	30.0	28.2	28.8
18	28.8	27.0	30.9	31.5	33.6	33.0	33.9	33.0	30.6	30.0	28.2	28.5
19	28.5	27.0	30.9	31.5	33.9	33.0	34.2	33.0	30.6	30.0	27.9	28.5
20	28.5	27.0	30.9	31.5	33.9	33.3	34.2	33.3	30.6	30.0	27.9	28.2
21	28.2	27.0	30.9	31.5	33.9	33.3	34.5	33.3	30.6	30.0	27.6	28.2
22	28.2	26.7	30.9	31.8	34.2	33.6	34.5	33.3	30.6	29.7	27.6	27.9
23	27.9	26.7	30.9	31.8	34.2	33.9	34.8	33.6	30.6	29.7	27.6	27.6
24	27.9	26.7	30.9	31.8	34.5	34.2	34.8	33.6	30.6	29.7	27.3	27.6
25	27.9	26.7	30.9	31.8	34.5	34.2	35.1	33.6	30.6	29.7	27.3	27.3
26	27.6	26.4	30.9	32.1	34.8	34.5	35.1	33.6	30.6	29.7	27.3	27.3
27	27.6	26.4	30.9	32.1	34.8	34.5	35.4	33.9	30.6	29.7	27.0	27.0
28	27.3	26.4	30.9	32.1	35.1	34.8	35.4	33.9	30.9	29.4	27.0	27.0
29	27.3	26.1	30.9	32.1	35.1	34.8	35.7	33.9	30.9	29.4	26.7	26.7
30	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.7	26.4
31	27.0	26.1	30.9	32.4	35.4	35.1	36.0	34.2	30.9	29.4	26.4	26.4
32	26.7	25.8	30.9	32.4	35.7	35.4	36.3	34.5	30.9	29.4	26.4	26.1
33	26.4	25.8	30.9	32.7	35.7	35.7	36.3	34.5	30.9	29.1	26.1	25.8
34	26.4	25.8	30.9	32.7	36.0	36.0	36.6	34.8	30.9	29.1	26.1	25.8
35	26.1	25.5	30.9	32.7	36.3	36.3	36.9	34.8	30.9	29.1	25.8	25.5
36	26.1	25.5	30.9	33.0	36.3	36.6	37.2	34.8	30.9	29.1	25.8	25.2
37	25.8	25.5	30.9	33.0	36.6	36.9	37.5	35.1	30.9	29.1	25.5	24.9
38	25.5	25.2	30.9	33.0	36.9	37.2	37.5	35.1	31.2	28.8	25.2	24.9
39	25.5	25.2	30.9	33.3	36.9	37.2	37.8	35.4	31.2	28.8	25.2	24.6

evaptranspiration, monthly precipitation, in this case monthly rainfall (P) has to be compared with PE. Evapotranspiration is assumed to take place only after the portion of rainfall that immediately drains overland refered to as direct runoff (DR) reaches the stream (Mather 1981), therefore DR is deducted from P before the comparison is made.

Again Jos and Numan stations are used to demonstrate the computation of actual evapotranspiration.

Monthly rainfall at Jos varies from 2mm in the driest months of December and January to 320mm in the wet month of July. Annual average rainfall equals 1391mm. Climatic water supply (rainfall) and climatic water demand (evapotranspiration) at Jos are out of phase in seven months, Jan. to April and October to December respectively.

The first step in the computation of Actual evapotranspiration (AE) from computed potential evapotranspiration (PE) is to seperate the portion of the rainfall that will runoff overland (DR) and the remaining portion from which the rest of computations will continue is refered to as effective rainfall (Peff).

The U.S. soil conservations service (SCS) has prepared a series of tables and nomograms by which the amount of daily overland runoff from inhouse precipitation can be estimated from information on slope, ground cover, soil type and antecedent precipitation (Mather, 1982). Unfortunately, such an information

is not available for the purpose of this project. Evaluation of overland runoff (DR) from intense rainfall by SCS method is a four-step process (Mather 1981). The first step involves determining the hydrologic soil group in the area from a master list prepared by the SCS. The soils are classified from A through D on the basis of runoff potential. The second step is to determine the five day antecedent soil moisture condition on the basis of the precipitation record for the five preceding days. The third step is to determine the actual runoff from precipitation. This decision is made on the basis of the land cover, the cultivation treatment, the hydrologic condition of the soil, and the hydrologic soil group of the particular soil. The fourth step is to determine for each daily rainfall episode in the period under consideration, the actual amount of overland flow (DR) that occurs from the information on antecedent five day moisture condition, hydrologic soil group, and the run-off curve number. Daily values of the so computed overland runoff are then summed up for the month.

Since the information necessary for computing DR similar to the SCS method is not available, DR for each station is assumed on the basis of slope, vegetation cover and value of the monthly rainfall. For Jos DR is assumed to be 10% for the months of May and June and 5% for July, August and September. The 10% value for May and June is chosen because in these months the grounds would not have been covered by grass after bush fires

Table 3.1.8A (continuation of Table 3.7.8A at page 44)

Computation of Actual Evapotranspiration at Jos.

S/N	MONTH	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
6.	Adj (PE)	78	87	111	108	107	89	81	77	83	92	82	80	1075
7.	Rainfall (P)	2	3	24	95	187	223	320	278	213	41	3	2	1391
8.	(DR)	0	0	0	5	18.7	22.7	16	14	11	0	0	0	82
9.	(Peff)	2	3	24	90	168	200	304	264	202	41	3	2	1369
10.	(Peff-PE)	-76	-84	-87	-18	61	111	223	187	119	-51	-79	-78	234
11.	ST	115	87	65	61	122	233	300	300	300	253	194	149	
12.	ΔST	-34	-28	-22	-4	+61	+111	+67	0	0	-47	-59	-45	
13.	AE	36	31	46	94	107	89	81	77	83	88	62	47	
14.	D	42	56	45	14	0	0	0	0	0	4	20	33	
15.	S	0	0	0	0	0	0	156	187	119	0	0	0	
16.	RC	0	0	0	0	0	0	78	132	126	63	31	16	
17.	TRO	8	4	2	5	19	23	94	176	137	63	31	16	

might have burnt the grasses in the preceding dry season. Since Jos is on the plateau where River Gongola originates the slope is quite steep in the area. These two factors combine to leave no room for surface detention of the runoff and therefore infiltration is inhibited and overland runoff is high in the early months of the wet season. The value of 5% for the months of July through September assumes that during this period the grass cover increases to maximum. These results for DR are written in row 8 of the budget (Table 3.1.8A). Actually the shape of discharge curve could be adjusted by altering the chosen percentages for DR especially in period of Deficits (low ST).

The DR is then subtracted from (P) monthly rainfall values and the result (Peff) is the portion that will enter into the rest of the stages for computing AE.

The next step in the computation is to compare the effective rainfall (Peff) and PE by subtracting the latter from the former. The result gives a series of positive and negative figures, the former indicating soil water recharge period by Peff or period of soil water retention equals the holding capacity of the soil, while the latter indicates removal of water (loss) from soil retention through evapotranspiration. The results are entered in row 10.

Soil water retention values (ST) are then computed from the values of Peff - PE. It is at this juncture that the holding capacity (WHC) of the soil must be known. After three

Table 3.1.8B.
Soil Moisture Retention (ST) For Water Holding Capacity (WHC) - 300 millimeters.
(After J.R. Mather, 1978).

(Soil Moisture Retained after Different Amounts of Potential Evapotranspiration Have Occurred. Water-Holding Capacity of Soil Is 300 mm)

Accum. P-PE eff	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
	Water Retained in Soil									
0	300	299	298	297	296	295	294	293	292	291
10	290	289	288	287	286	285	284	283	282	281
20	280	279	278	278	277	276	275	274	273	272
30	271	270	269	268	268	267	266	265	264	263
40	262	261	260	260	259	258	257	256	255	254
50	254	253	252	251	250	249	248	248	247	246
60	245	244	244	243	242	241	240	240	239	238
70	237	236	236	235	234	233	232	232	231	230
80	229	228	228	227	226	225	225	224	223	222
90	222	221	220	219	219	218	217	216	215	215
100	214	214	213	212	212	211	210	209	209	208
110	207	207	206	205	204	204	203	202	202	201
120	200	200	199	198	198	197	196	196	195	194
130	194	193	192	192	191	191	190	189	189	188
140	187	187	186	186	185	184	184	183	182	182
150	181	181	180	179	179	178	178	177	176	176
160	175	175	174	173	173	172	172	171	171	170
170	170	169	168	168	167	167	166	166	165	164
180	164	163	163	162	162	161	160	160	159	159
190	158	158	157	157	156	156	155	155	154	154
200	153	153	152	152	151	151	150	150	149	149
210	148	148	147	147	146	146	145	145	144	144
220	143	143	142	142	141	141	140	140	139	139
230	138	138	138	137	137	136	136	135	135	134
240	134	133	133	132	132	132	131	131	130	130
250	130	129	128	128	128	127	127	126	126	126
260	125	125	124	124	124	123	123	122	122	121
270	121	121	120	120	119	119	119	118	118	117
280	117	117	116	116	115	115	115	114	114	114
290	113	113	112	112	112	111	111	110	110	110
300	109	109	109	108	108	108	107	107	106	106
310	106	105	105	105	104	104	104	103	103	103
320	102	102	102	101	101	101	100	100	100	99
330	99	98	98	98	98	97	97	97	96	96
340	96	95	95	95	94	94	94	93	93	93
350	92	92	92	92	91	91	91	90	90	90
360	89	89	89	88	88	88	88	87	87	87
370	86	86	86	86	85	85	85	84	84	84
380	84	83	83	83	82	82	82	82	81	81
390	81	80	80	80	80	80	79	79	79	78

Table 3.1.8B (continued).

Accum. P–PE eff	0	1	2	3	4	5	6	7	8	9
	Water Retained in Soil									
400	78	78	78	77	77	77	77	76	76	76
410	76	75	75	75	74	74	74	74	74	73
420	73	73	72	72	72	72	72	71	71	71
430	71	70	70	70	70	70	69	69	69	68
440	68	68	68	68	67	67	67	67	66	66
450	66	66	66	65	65	65	65	64	64	64
460	64	64	63	63	63	63	63	62	62	62
470	62	62	61	61	61	61	61	60	60	60
480	60	60	59	59	59	59	59	58	58	58
490	58	58	57	57	57	57	57	56	56	56
500	56	56	55	55	55	55	55	54	54	54
510	54	54	54	53	53	53	53	53	52	52
520	52	52	52	52	51	51	51	51	51	50
530	50	50	50	50	50	50	49	49	49	49
540	49	49	48	48	48	48	48	48	47	47
550	47	47	47	47	46	46	46	46	46	46
560	46	45	45	45	45	45	45	44	44	44
570	44	44	44	44	44	43	43	43	43	43
580	43	42	42	42	42	42	42	42	42	41
590	41	41	41	41	41	41	40	40	40	40
600	40	40	40	39	39	39	39	39	39	39
610	38	38	38	38	38	38	38	38	38	37
620	37	37	37	37	37	37	36	36	36	36
630	36	36	36	36	36	36	35	35	35	35
640	35	35	35	34	34	34	34	34	34	34
650	34	34	33	33	33	33	33	33	33	33
660	32	32	32	32	32	32	32	32	32	32
670	32	31	31	31	31	31	31	31	31	31
680	30	30	30	30	30	30	30	30	30	30
690	30	29	29	29	29	29	29	29	29	29
700	28	28	28	28	28	28	28	28	28	28
710	28	27	27	27	27	27	27	27	27	27
720	27	26	26	26	26	26	26	26	26	26
730	26	26	26	26	25	25	25	25	25	25
740	25	25	25	25	25	24	24	24	24	24
750	24	24	24	24	24	24	24	24	23	23
760	23	23	23	23	23	23	23	23	23	23
770	22	22	22	22	22	22	22	22	22	22
780	22	22	22	22	22	21	21	21	21	21
790	21	21	21	21	21	21	21	21	20	20

Table 3.1.8B (continued).

Accum. P-PE Eff.	0	1	2	3	4	5	6	7	8	9
					Water Retained in Soil					
800	20	20	20	20	20	20	20	20	20	20
810	20	20	20	20	20	19	19	19	19	19
820	19	19	19	19	19	19	19	19	19	18
830	18	18	18	18	18	18	18	18	18	18
840	18	18	18	18	18	18	18	17	17	17
850	17	17	17	17	17	17	17	17	17	17
860	17	17	17	17	16	16	16	16	16	16
870	16	16	16	16	16	16	16	16	16	16
880	16	16	16	16	15	15	15	15	15	15
890	15	15	15	15	15	15	15	15	15	15
900	15	15	14	14	14	14	14	14	14	14
910	14	14	14	14	14	14	14	14	14	14
920	14	14	14	14	13	13	13	13	13	13
930	13	13	13	13	13	13	13	13	13	13
940	13	13	13	13	12	12	12	12	12	12
950	12	12	12	12	12	12	12	12	12	12
960	12	12	12	12	12	12	12	12	12	12
970	12	12	11	11	11	11	11	11	11	11
980	11	11	11	11	11	11	11	11	11	11
990	11	11	11	11	11	11	11	10	10	10
1000	10	10	10	10	10	10	10	10	10	10
1010	10	10	10	10	10	10	10	10	10	10
1020	10	10	10	10	10	10	10	10	10	10
1030	9	9	9	9	9	9	9	9	9	9
1040	9	9	9	9	9	9	9	9	9	9
1050	9	9	9	9	9	9	9	9	9	9
1060	8	8	8	8	8	8	8	8	8	8
1070	8	8	8	8	8	8	8	8	8	8
1080	8	8	8	8	8	8	8	8	8	8
1090	8	8	8	8	8	8	8	8	8	8
1100	7	7	7	7	7	7	7	7	7	7
1110	7	7	7	7	7	7	7	7	7	7
1120	7	7	7	7	7	7	7	7	7	7
1130	7	7	7	7	7	7	7	7	7	7
1140	6	6	6	6	6	6	6	6	6	6
1150	6	6	6	6	6	6	6	6	6	6
1160	6	6	6	6	6	6	6	6	6	6
1170	6	6	6	6	6	6	6	6	6	6
1180	6	6	6	6	6	6	6	6	6	6
1190	6	6	6	6	6	5	5	5	5	5
1200	5	5	1300	4	4	1400	3	3		
1210	5	5	1310	4	4	1410	3	3		
1220	5	5	1320	4	4	1420	2	2		
1230	5	5	1330	3	3	1430	2	2		
1240	5	5	1340	3	3	1440	2	2		
1250	4	4	1350	3	3	1450	2	2		
1260	4	4	1360	3	3	1460	2	2		
1270	4	4	1370	3	3	1470	2	2		
1280	4	4	1380	3	3	1480	2	2		
1290	4	4	1390	3	3	1490	2	2		

successive assumptions of WHC and computing total runoff (direct runoff plus runoff from surplus) each time comparing the results with the corresponding measured runoff values, the value of WHC = 300mm for Jos is arrived at.

It is then assumed that the holding capacity of the soil is satisfied towards the end of the rainy season say in September. Then the first nagative Peff-PE value (-51mm) which occurs in October is located in table 3.1.8B and the figure corresponding to this in the first column of the table represents the amount of water remaining in the soil storage (253mm). The negative value (-51) is then added to the next value in November, ignoring the signs, to give (51 + 79) 130. This value is again located in body of the table and the corresponding figure in the first column read (191) which represents the amount of water still in storage at the end of November. This exercise is continued until the last negative (-ve) value of Peff-PE is treated similarly for the month of April after which the value of Peff-PE is positive (+ve). The value of ST for April is 61 and, coincidently, the value for Peff-PE in May is also 61. This means that not only does the precipitation in May satisy PE but also increase the amount of moisture in soil storage by 61mm. The storage therefore becomes (61 + 61), 122mm. The next value of Peff-PE, which is also +ve is added to the storage (122 + 111), 233mm. This process is continued until the full soil storage capacity, 300mm, is attained. In this case the situation occurs in July.

The value of Peff-PE for July is 223 and the value of ST in the preceding month is 233mm. Therefore only 67mm out of 223mm of the Peff-PE value is used to bring the soil storage to capacity (233 + 67), 300mm. The remaining, 156mm, goes into the rest of runoff computation. The subsequent +ve values of Peff-PE go as a whole into the rest of the budget computation as can be seen later.

The next step in the determination of AE is to compute the values of month to month soil storage change (ΔST). The value is -ve when there is a decrease from one month to next and +ve when there is an increase. The value is zero when there is no change, a situation which occurs when ST remains at capacity value or very low (row 12). Finally, AE is computed by adding Peff toΔST (ingnoring the sign) for months in which ΔST is -ve. In months in which ST values are +ve or zero AE equals PE because during this period the climatic water demand is fully satisfied.

Similarly, AE is determined for Numan station except that a different situation occurs in the process of computing ST values.

For Jos the sum of all the Peff-PE values condiering the signs is positive, the values of accumulated potential water loss with which to start accumulating the -ve values of Peff-PE is therefore, 0. For Numan the case is different. The sum of the Peff-PE values is negative so that it is necessary to use the successive approximation method of obtaining the value (-1084) to start the accumulation of Peff-PE values.

Table 3.1.8C (continuation of table 3.1.7B at p 44)

Computation of AE at Numan.

MONTH	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
6. Adj PE	117	137	176	176	178	153	148	138	135	147	135	110	1749
7. P	0	5	10	33	118	121	116	141	158	52	1	1	754
8. DR	0	0	0	0	6	6	6	7	8	0	0	0	35
9. Peff	0	5	10	33	112	115	110	134	150	52	1	1	719
10. Peff-PE	-117	-132	-116	-142	-66	-38	-38	-4	+15	-95x	-134	-109	
10B Cum Peff-PE	(-1537)	(-1669)	(-1785)	(-1928)	(-1994)	(-2032)	(-2070)	(-2074)	(-1082)	(-1177)	(-1311)	(-1420)	
11. ST	4	3	2	2	1	1	1	1	16	12	8	5	
12. ΔST	-1	-1	-1	0	-1	0	0	0	+15	-4	-4	-3	
13. AE	1	6	10	31	113	115	110	134	135	56	5	4	
14. D	116	131	166	145	65	38	38	4	0	91	130	106	
15. S	0	0	0	0	0	0	0	0	0	0	0	0	
16. RO	0	0	0	0	0	0	0	0	0	0	0	0	
17. TRO	0	0	0	0	6	6	6	7	8	0	0	0	35

The water retention capacity of the soil in Numan is assumed to be 350mm. Using table 3.1.8D the value of ST equal to the total Peff-PEs (-992) is found in the body of the table. It is found to be 20. This would be the storage in the soil if the ST at the beginning of the dry period (-ve P-PE) had been at capacity (350mm). Actually it will be some value less than this since the ST was some value less than 350mm at beginning of the dry period because ST was never satisfied to capacity at Numan. To the value of 20 is then added the sum of the +ve Peff-PE values (15) to obtain a new estimated value of ST of 35 at the end of the moist period. This value is found in body of table 3.1.8D to give the amount of potential water loss necessary to result in this value of ST. This value is found to be 805. Now the total -ve Peff-PEs (992) is added to this value (1797) and the new value of ST, at the end of dry period, in the body of the table opposite 1795 is found. The value is 2. Again the total +ve Peff-PE (15) is added to this ST (17) and the value corresponding to this on boarder of the table is found (1064).

The sum of -ve (Peff-PE) is added to this figure to get 2054 and the ST corresponding read in the body of the table.

This value is again added to the sum of positive Peff-PE (16). This is again located in the body of the table and the corresponding sum of Peff-PE read in the first column (1082). This again is added to the sum of -ve Peff-PE (2074) and the value of ST corresponding to this figure is located in body of table (1). This is added to the sum of +ve Peff-PE to give 16.

Table 3.1.8D.
Soil Moisture Retention (ST) For Water Holding Capacity -350 millimeters.
(After C.N. Thornthwaite and J.R. Mather, 1957).

PE	0	1	2	3	4	5	6	7	8	9
	WATER RETAINED IN SOIL									
450	96	96	95	95	95	94	94	94	94	93
460	93	93	93	92	92	92	92	91	91	91
470	90	90	90	90	89	89	89	89	88	88
480	88	88	88	87	87	87	87	86	86	86
490	85	85	85	85	84	84	84	84	84	83
500	83	83	83	83	82	82	82	82	81	81
510	81	81	81	80	80	80	80	79	79	79
520	78	78	78	78	77	77	77	77	76	76
530	76	76	76	75	75	75	75	75	74	74
540	74	74	74	73	73	73	73	73	72	72
550	72	72	72	71	71	71	71	71	70	70
560	70	70	70	69	69	69	69	69	68	68
570	68	68	68	67	67	67	67	67	66	66
580	66	66	65	65	65	65	65	65	65	64
590	64	64	64	64	63	63	63	63	63	63
600	62	62	62	62	62	61	61	61	61	61
610	60	60	60	60	60	60	60	59	59	59
620	59	59	59	58	58	58	58	58	58	57
630	57	57	57	57	56	56	56	56	56	56
640	56	56	55	55	55	55	55	55	54	54
650	54	54	54	53	53	53	53	53	52	52
660	52	52	52	52	52	52	52	51	51	51
670	51	51	51	51	50	50	50	50	50	50
680	50	50	50	49	49	49	49	49	48	48
690	48	48	48	48	47	47	47	47	47	47
700	47	47	47	46	46	46	46	46	46	46
710	45	45	45	45	45	45	45	45	44	44
720	44	44	44	43	43	43	43	43	43	43
730	43	43	43	42	42	42	42	42	42	42
740	42	42	41	41	41	41	41	41	41	41
750	40	40	40	40	40	40	40	40	40	40
760	39	39	39	39	39	39	39	39	39	38
770	38	38	38	38	38	38	38	38	38	37
780	37	37	37	37	37	37	37	37	37	36
790	36	36	36	36	36	36	36	36	35	35
800	35	35	35	35	35	34	34	34	34	34
810	34	34	34	34	34	34	34	33	33	33
820	33	33	33	33	33	33	33	33	32	32
830	32	32	32	32	32	32	32	32	32	31
840	31	31	31	31	31	31	31	31	31	30
850	30	30	30	30	30	30	30	30	30	30
860	30	30	30	29	29	29	29	29	29	29
870	29	29	29	28	28	28	28	28	28	28
880	28	28	28	28	27	27	27	27	27	27
890	27	27	27	27	27	27	27	26	26	26

Table 3.1.8D (continued)

PE	0	1	2	3	4	5	6	7	8	9
					WATER RETAINED IN SOIL					
900	26	26	26	26	26	26	26	26	26	26
910	26	26	26	25	25	25	25	25	25	25
920	25	25	25	25	24	24	24	24	24	24
930	24	24	24	24	24	24	24	24	24	23
940	23	23	23	23	23	23	23	23	23	23
950	23	23	23	23	22	22	22	22	22	22
960	22	22	22	22	22	22	22	22	22	22
970	22	22	22	21	21	21	21	21	21	21
980	21	21	21	21	21	21	21	21	20	20
990	20	20	20	20	20	20	20	20	20	20
1000	20	20	20	20	19	19	19	19	19	19
1010	19	19	19	19	19	19	19	19	19	19
1020	19	19	19	18	18	18	18	18	18	18
1030	18	18	18	18	18	18	18	18	18	18
1040	18	18	18	18	17	17	17	17	17	17
1050	17	17	17	17	17	17	17	17	17	17
1060	17	17	17	16	16	16	16	16	16	16
1070	16	16	16	16	16	16	16	16	16	16
1080	16	16	16	15	15	15	15	15	15	15
1090	15	15	15	15	15	15	15	15	15	15
1100	15	15	15	15	15	15	15	15	14	14
1110	14	14	14	14	14	14	14	14	14	14
1120	14	14	14	14	14	14	14	14	14	14
1130	14	14	14	13	13	13	13	13	13	13
1140	13	13	13	13	13	13	13	13	13	13

	0	5		0	5		0	5
1150	13	13	1300	8	8	1450	5	5
1160	12	12	1310	8	8	1500	5	5
1170	12	12	1320	8	8	1550	4	4
1180	12	12	1330	8	8	1600	4	4
1190	11	11	1340	8	8	1650	3	3
1200	11	11	1350	7	7	1700	3	3
1210	11	11	1360	7	7	1750	2	2
1220	10	10	1370	7	7	1800	2	2
1230	10	10	1380	7	7	1850	2	2
1240	10	10	1390	6	6	1900	2	2
1250	10	10	1400	6	6	1950	1	1
1260	9	9	1410	6	6	2000	1	1
1270	9	9	1420	6	6	2100	1	1
1280	9	9	1430	6	6	2200	1	1
1290	8	8	1440	6	6			

Note:-

Portion relevant to computation of ST values at Numan is reproduced above.

Since the final estimated ST of 16 remains unchanged at this point then it has been determined that the value of potential water loss with which to start accumulation of Peff-PEs is -1082. This procedure is presented schematically in table 3.1.8E. The first -ve Peff-PE value is then added to this to find the ST for the month next to the last wet month (Peff-PE +ve). Then the rest of computation is done similar to that for Jos.

3.1.9 Determination of Runoff and total runoff

The first step in deriving runoff continuing from AE as arrived at in 3.1.8 is to compute soil moisture deficit (D). Here again computation of deficit (D) is demonstrated for the two stations - Jos and Numan. Though not essential if the purpose of the water budget is to compute runoff, D gives prior idea of the months in which surplus moisture (S) will occur in the budget (when D = 0, S is probable).

Soil moisture deficit can be defined as the amount by which PE exceeds AE. When PE equals AE we have a zero deficit. D is computed by subtracting AE from the corresponding PE. The results are entered in row 14 of the budget table 3.1.8A.

Soil moisture surplus (S) is the amount of water in the soil remaining after the soil moisture holding capacity (ST) has been satisfied. From the computed D in row 14, S is expected to occur in the period from May to September for Jos and in September for Numan. S is computed by subtracting ΔST from

corresponding value of Peff-PE in the months of zero deficit. The results have been written in row 15.

The surplus so computed will then runoff into streams in a style depending on the topography and soil texture of the catchment area of the streams. The steeper the topography the faster the surplus reaches the stream. Similarly the less clayey and the more coarse the soil particles the quicker it drains and therefore the sooner the surplus reaches the stream.

Since a surplus soil moisture occuring far away from a gauging station will reach there and pass the station gradually over a long period S has to be aportioned to compute flows at the station. For Jos it is assumed that 50% of S occuring in a particular month will reach the gauging station the same month and the rrmaining half will reach the station the following month. Therefore the runoff in any month consist of 50% of surplus occuring in the preceding month plus 50% of surplus occuring in that month. Computed values of runoff are entered in row 16.

Total runoff (TRO) is the sum of Direct runoff and the runoff in that month (TRO=DR+RO). This is written in row 17 of the budget and completes the computation for the station.

At Numan surplus does not occur through out the year, therfore whatever runoff that occurs is due to Direct Runoff only. The final water budget for the 26 rainfall sations is given at Annex II.

Table 3.1.8E Determination of the value of cummulative -ve Peff-PE values for computation of ST values at Numan.

$\sum$ -ve	$\sum$ +ve
(Peff-PE) = 992	(Peff - PE) = 15
992 →	20
	+ 15
805 ←	35
+ 992	2
1797 →	+ 15
	17
1062 ←	
+ 992	1
2054 →	+ 15
1062 ←	16
+ 992	1
2074 →	+ 15
1062 ←	16

C H A P T E R IV

COMPARISON OF COMPUTED AND MEASURED STREAM FLOW ON THE GONGOLA BASIN

4.1 DERIVED USEFUL FACTORS

With the ability of the climatic water budget to provide reliable values of runoff or stream flow (especially in areas without appreciable snow or ice), it should be possible to use the water budget results in conjuction with measured values of stream flow to provide valuable hydrologic information on a basin (Mather, 1982.

In the process of computing stream flows, average water holding capacities for the soils in the areas represented by each of the rainfall stations has been estimated. Other factors estimated are factors for direct runoff and surplus moisture runoff.

4.1.1 Location of gauging stations and catchment areas.

Figure 4.1.1A and 4.1.1B locate the 5 hydrometeorological and 26 rainfall stations, respectively, covering Gongola basin. Data from these stations are used to compute runoff values at 3 gauging stations (figure 4.1.1C). The hydrometeorological and rainfall stations have been weighted by Thiessen Polygon method to determine the representative area covered by each station (figure 4.1.1A and 4.1.1B).

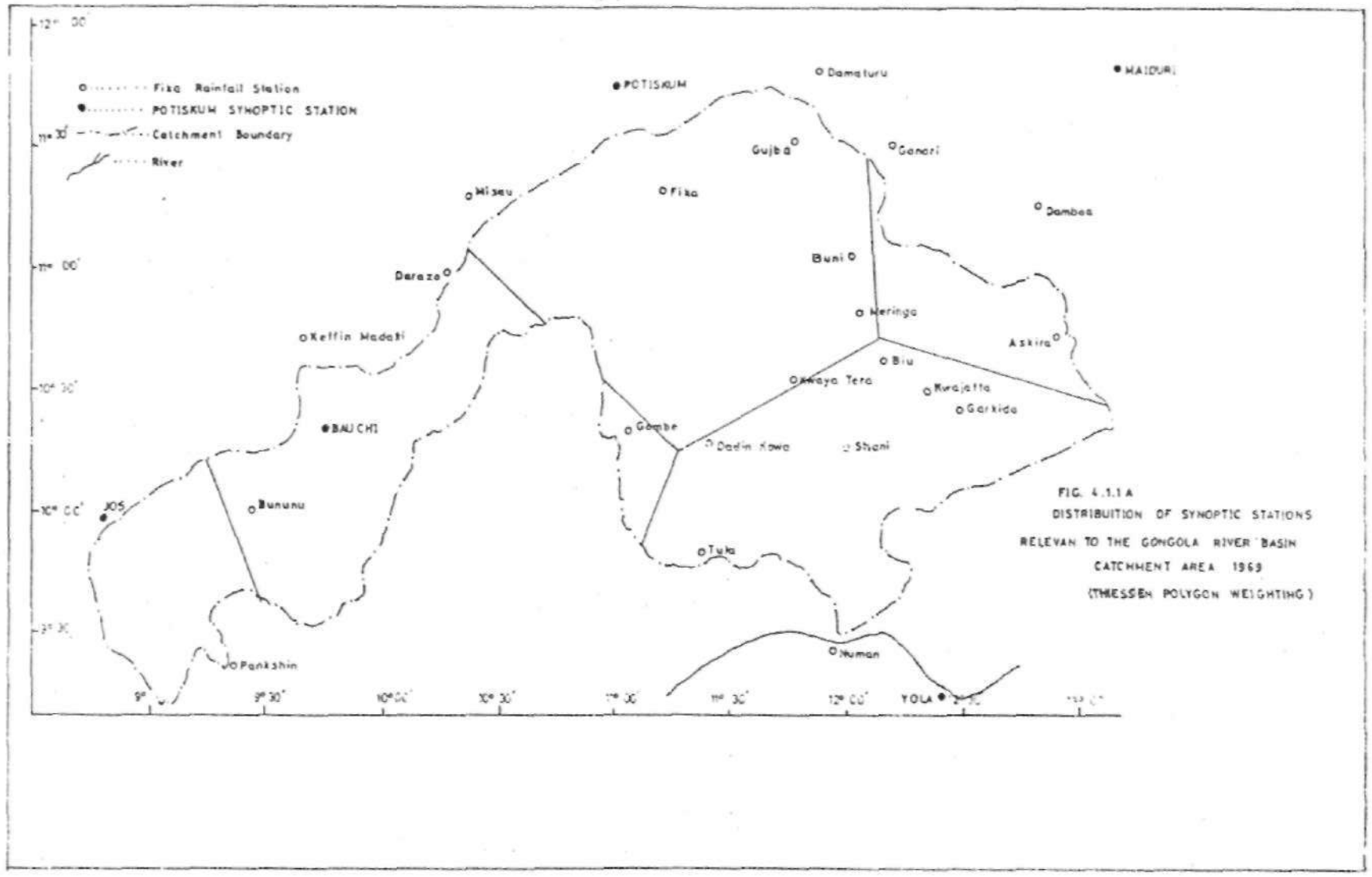


FIG. 4.1.1 A
DISTRIBUITION OF SYNOPTIC STATIONS
RELEVAN TO THE GONGOLA RIVER BASIN
CATCHMENT AREA 1969
(THIESSEN POLYGON WEIGHTING)

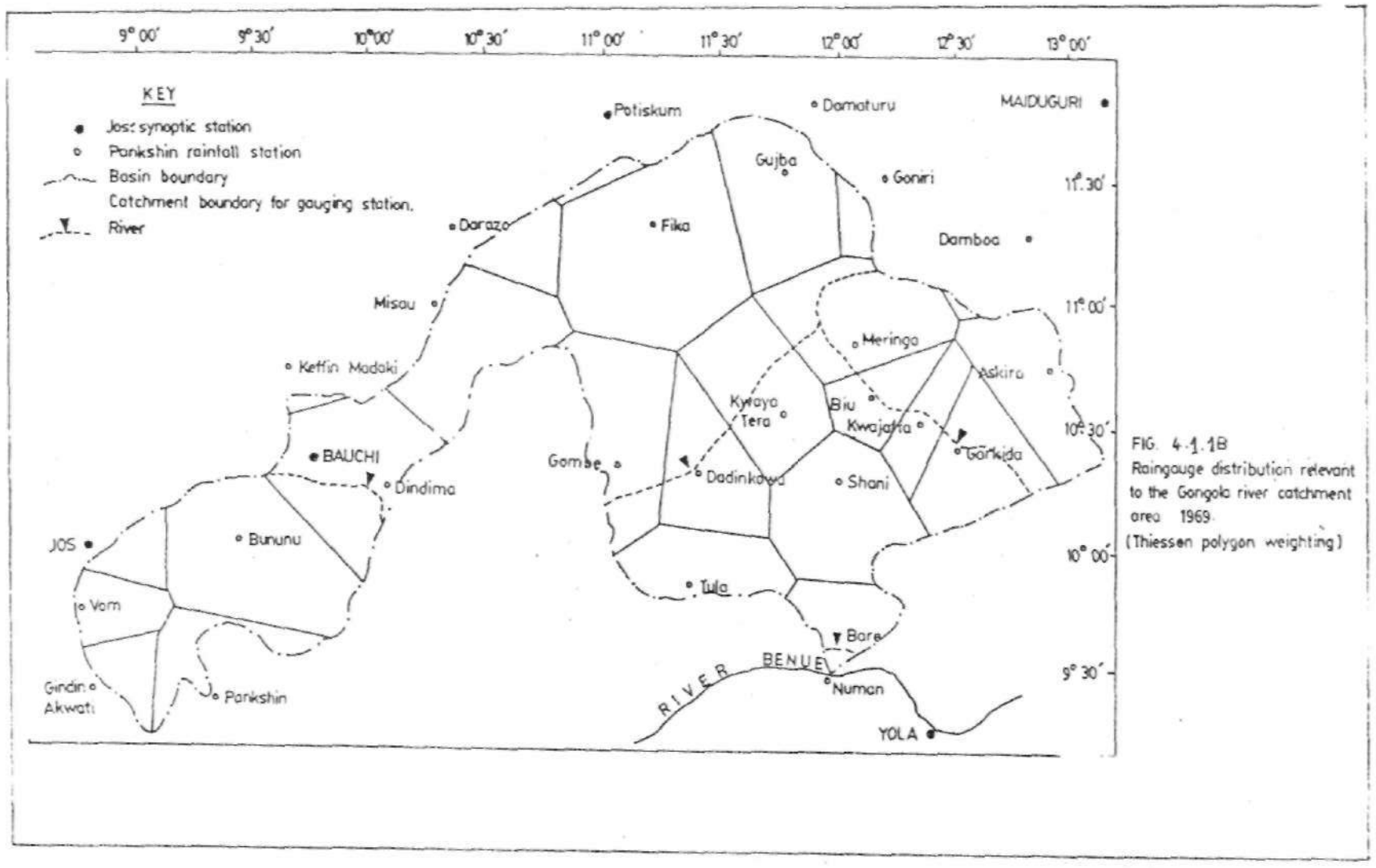


FIG. 4.1.1B
Raingauge distribution relevant to the Gongola river catchment area 1969.
(Thiessen polygon weighting)

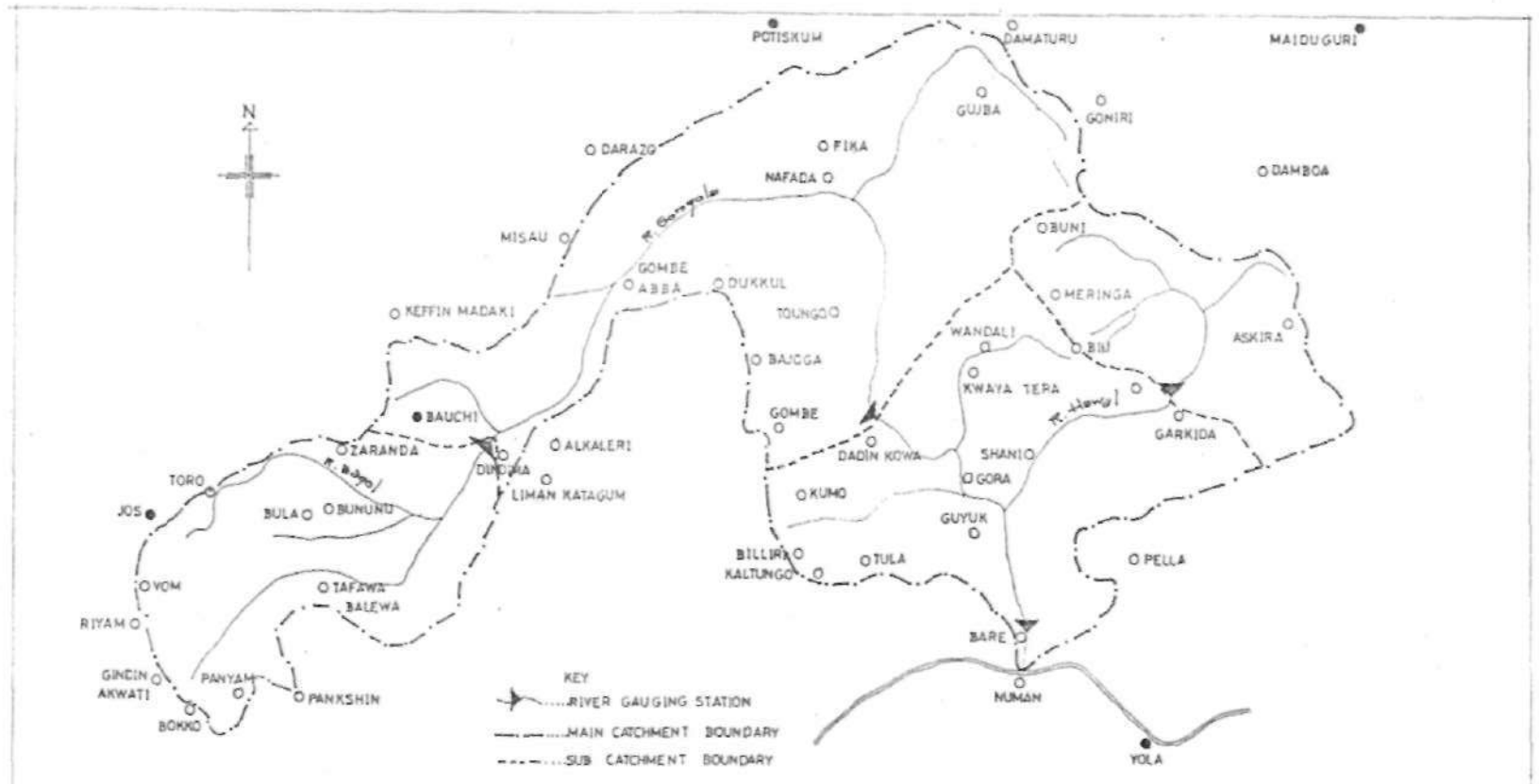


FIG. 4.1.1C The Gongola River Basin
Drainage and Gauging Stations

SCALE 1 : 2,000,000

4.1.2 Comparison of computed and Measured flows.

Average monthly runoff from 26 stations, whose average monthly rainfall records are available as provided by Knabe and Kowal (1972), were determined using a set of assumed water holding capacities for the soils, % monthly runoff from soil water surplus and % of rainfall values for direct runoff. The values of average monthly runoff so determined are compared with measured stream discharge records. This process was repeated by adjusting the set of assumed values until the determined runoff values compare favourably with the corresponding measured stream flow values.

The final computed average monthly values of runoff are compared with the corresponding measured values as reported by Diyam at Dindima, both Shawmont and Diyam at Dadin Kowa and by Diyam at Bare respectively. Table 4.1.2A shows the results of a simple correlation - regression study of measured and computed runoff at the 3 river gauging stations along the Gongola River. Table 4.1.1A gives the values of computed runoff for each of the 3 sets of factors for each gauging station. Figures 4.1.2 (A-I) show the relations between computed average monthly flows and average measured flows for different set of assumed values of WHC of the soils, introduction of overland flow (DR) and conveyance factors (CF).

4.1.3 Channel Conveyance

The runoff from catchment area upstream of a gauging station would flow past the gauging station and proceed down stream to the next gauging station. During the flow from one station to the next station further losses through evaporation and to ground water

are expected. Conveyance factors are chosen to account for these losses depending on the length of channel between which the flow is routed .

The computed flows at Dindima have been routed by an assumed conveyance factor before adding the result to computed runoff from the area between Dindima and Dadin Kowa to give computed runoff at Dadin Kowa. Similarly, the computed runoff at Dadin Kowa is routed by some conveyance factor and added to computed runoff from the area downstream of Dadin Kowa to Bare gauging station. Details of this are given in table 4.1.3C.

Figures 4.1.2 (J-S) shows the successive approximations of computed monthly flow to the corresponding measured values as water holding capacity values and runoff factors are adjusted for each rainfall station.

From table 4.1.2A it can be seen that the final values of correlation coefficient arrived at, for Dindima, Dadin Kowa and Bare indicate close agreement between computed and measured values of streamflow at these gauging stations. Regression equations for Dindima and Dadin Kowa stations indicate over-estimation of the stream flows at these stations while for Bare the regression equation indicates almost perfect fit on Y = X line.

With these results the final assumed values of factors used for computation of runoff have been adopted for application in the computation of stream flow from rainfall records. This time, 14 rainfall stations covering the catchment area of the gauging station at Dadin Kowa have been selected and runoff at Dadin Kowa estimated by the budget method.

Table 4.1.1A

Results of selected 3 successive trials in simulation of Runoffs at Dindima, Dadin Kowa and Bare.

	COMPUTED VALUES OF RUNOFF									MEASURED VALUES OF RUNOFF			
STATIONS	DINDIMA			DADIN KOWA			BARE			DINDIMA	DADIN KOWA		BARE
TRIALS/SE	FIRST	SECOND	THIRD	FIRST	SECOND	THIRD	FIRST	SECOND	THIRD	DIYAM	DIYAM	SHAMDOTT	DIYAM
- Jan.	28	28	20	90	29	35	116	37	43	0	0	10	0
- Feb.	14	11	8	44	14	15	58	17	18	0	0	6	0
- Mar.	7	9	7	23	6	11	29	14	14	0	0	5	0
- Apr.	2	13	14	10	11	12	14	10	11	19	0	9	0
- May	2	58	55	5	67	84	7	152	172	96	65	49	162
- June	2	153	153	4	174	214	4	324	342	182	13	123	324
- July	366	354	354	366	356	442	337	560	649	374	360	366	756
- Aug.	971	788	747	1996	1432	1121	2116	2109	1982	739	1145	1177	1674
- Sept.	965	872	784	1956	1440	1170	2459	2292	2176	394	1046	1093	2322
- Oct.	347	102	181	843	399	332	1074	591	556	154	229	229	540
- Nov.	139	26	76	335	172	140	494	238	209	24	33	36	216
- Dec.	61	0	38	185	74	69	238	98	96	0	0	16	162
TOTAL	2904	2366	2437	5857	4174	3714	6947	6442	6268	1987	3008	3119	6156

Table 4.1.2A

Correlation coefficients and regression equations between computed and measured average monthly runoff at three gauging stations in the Congola Basin.

Station	Catchment Area	Correlation Coefficient (r)	Regression Equation
Dindima	Up-stream of Dindima	Computed/Diyam	
		r1 = 0.89	$Y_1 = 10.2+1.4x_1$
		$r_2 = 0.91$	$Y_2 = -8.2+1.2x_2$
		$r_3 = 0.92$	$Y_3 = 16.0+1.1x_3$
Dadin Kowa	Up-stream of Dadin Kowa	Computed/Diyam	
		r1 = 0.97	$Y1 = 51.9+1.74x_1$
		r2 = 1.00	$Y2 = 50.4+1.23x_2$
		r3 = 1.00	$Y3 = 73.1+0.98x_3$
" "	" "	Computed/Shawmont	
		r1 = 0.97	$Y1 = 52.6+1.68x_1$
		r2 = 0.99	$Y2 = 19.9+1.23x_2$
		r3 = 1.00	$Y3 = 57.4+0.97x_3$
Bare	Up-stream of Bare	Computed/Diyam	
		r1 = 0.95	$Y1 = 13.6+1.1x_1$
		r2 = 0.99	$Y2 = 13.0+1.1x_2$
		r3 = 0.99	$Y3 = 1.5+1.0x_3$

Table 4.1.3c

Computed Monthly Runoff From Average Rainfall Record At 26 Stations - Final Adjustments.

Srl No.	Station	Area ($\times 10^8 m^2$)	WHC (mm)	Computed Runoff (mm).												% Area US DS	Conveyance coeff. to		
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec		Dindima	D/Kowa	Bare
1	Jos	8.38	300	0	0	0	4	16	19	101	165	144	11	1	0		0.93	0.65	0.62
2	Vom	9.50	300	0	0	0	6	18	19	95	165	124	11	1	0		"	"	"
3	Pankshin	12.88	300	3	1	1	0	11	17	13	76	148	22	12	6		"	"	"
4	Gindi Akwati	8.92	300	0	0	0	4	14	20	61	199	123	12	1	0		"	"	"
5	Bununu	45.76	300	14	5	5	0	0	69	64	133	256	105	50	27		"	"	"
				4	2	1	0	0	20	17	65	78	34	17	8	35	"	"	"
6	Bauchi	37.20	300	7	5	3	0	0	36	31	121	145	63	31	14	65		0.70	0.66
7	Keffin Madaki	1.70	250	1	0	0	0	1	1	2	10	10	4	2	1			"	"
8	Darazo	30.40	250	9	6	3	3	12	21	36	207	152	64	30	15			"	"
9	Misau	11.20	200	0	0	0	0	2	6	12	16	8	0	0	0			"	"
10	Fika	63.10	200	6	0	0	0	19	32	69	158	133	36	19	13			"	"
11	Gujba	32.00	150	0	0	0	0	6	16	32	38	45	10	3	3			"	"
12	Damaturu	0.40	125	0	0	0	0	0	0	1	1	1	0	0	0			"	"
13	Potiskum	2.20	150	0	0	0	0	0	1	2	6	3	1	0	0			"	"
14	Goniri	5.40	75	0	0	0	0	1	3	5	5	3	0	0	0			"	"
15	Gombe	28.70	150	7	2	2	0	12	17	24	68	128	53	27	14	64		0.95	0.90
				2	1	1	0	2	3	5	13	24	10	5	3	16		"	"

Table 4.1.3C Cont.

				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	US/DS	Dindima	D/Kowa	Bare
16	Meringa	34.90	75	0	0	0	0	3	6	8	25	62	11	3	1	25		0.95	0.90
				0	0	0	0	11	18	24	76	158	34	8	2	75		"	"
17	Kwâya Têra	31.50	50	0	0	0	0	7	7	44	98	86	18	4	1	47		"	"
				0	0	0	0	9	9	50	110	197	20	5	2	53		"	"
18	Dadin Kowa	27.30	75	0	0	0	0	2	7	11	110	127	32	8	2	38		"	"
				0	0	0	0	3	12	19	179	206	52	14	3	62		"	0.95
19	Damboa	0.60	75	0	0	0	0	0	0	1	3	2	1	0	0				"
20	Askira	27.10	75	8	3	3	0	14	22	24	73	138	54	27	14				"
21	Biu	11.80	50	0	0	0	0	7	8	11	74	84	18	5	1				"
22	Kwajaffa	13.20	50	0	0	0	0	5	9	15	63	74	15	4	1				"
23	Garkida	26.30	75	0	0	0	0	13	18	29	160	110	21	5	3				"
24	Shani	34.90	75	0	0	0	0	17	24	38	213	147	28	7	3				"
25	Tula	21.10	75	0	0	0	0	8	15	17	21	87	8	0	0				"
26	Numan	13.10	350	0	0	0	0	8	8	8	9	10	0	0	0				"

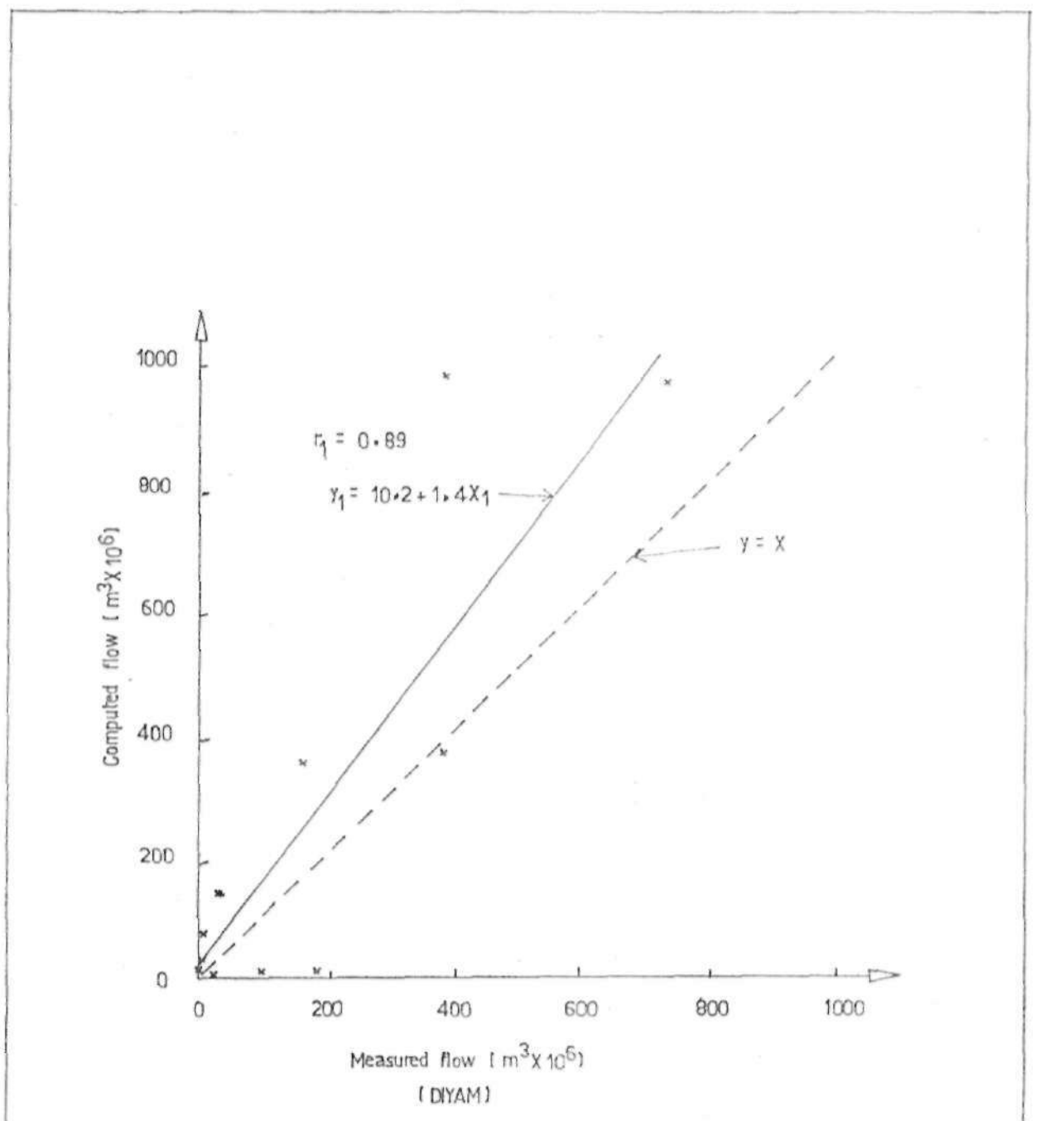


FIG. 4.1.2A Relation between average monthly computed and measured flows at Dindima
(Direct runoff not accounted for)

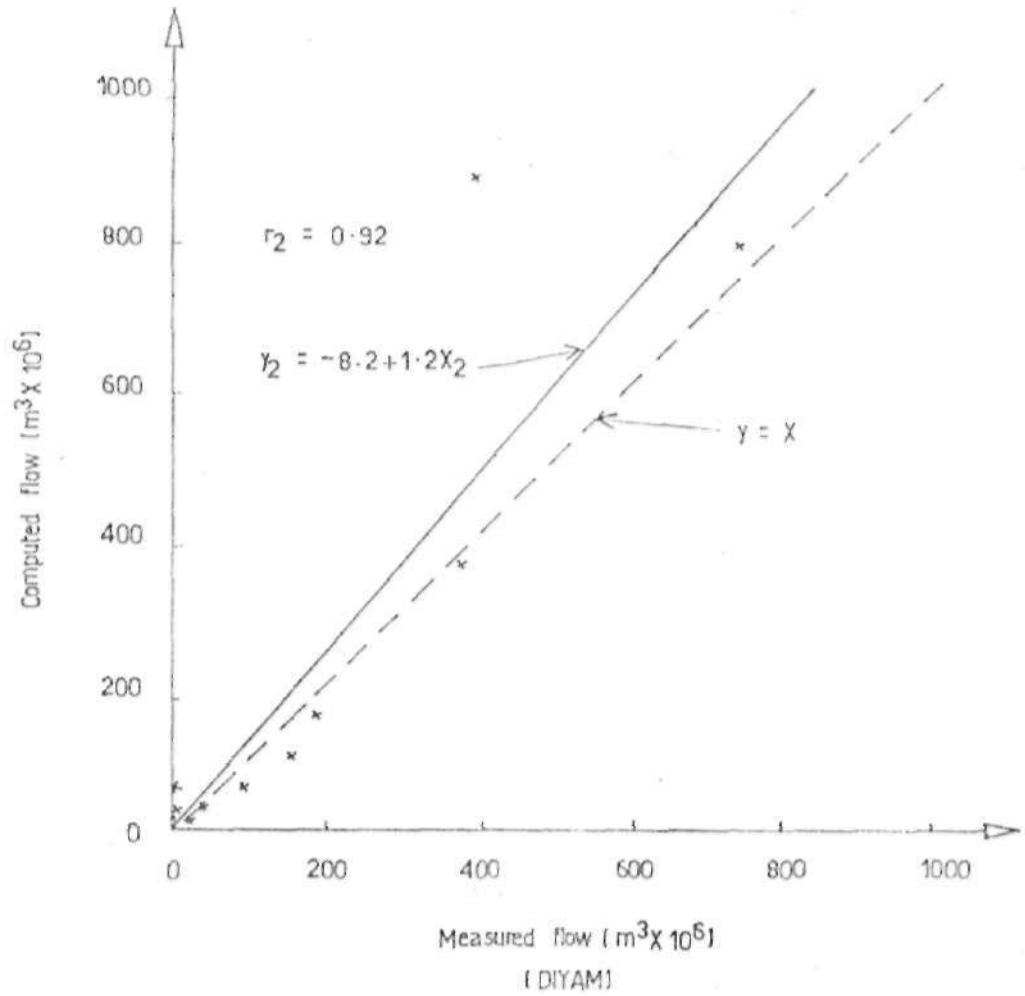


FIG. 4.1.2 B Relation between average monthly computed and measured flows at Dindima.
(Direct runoff accounted for)

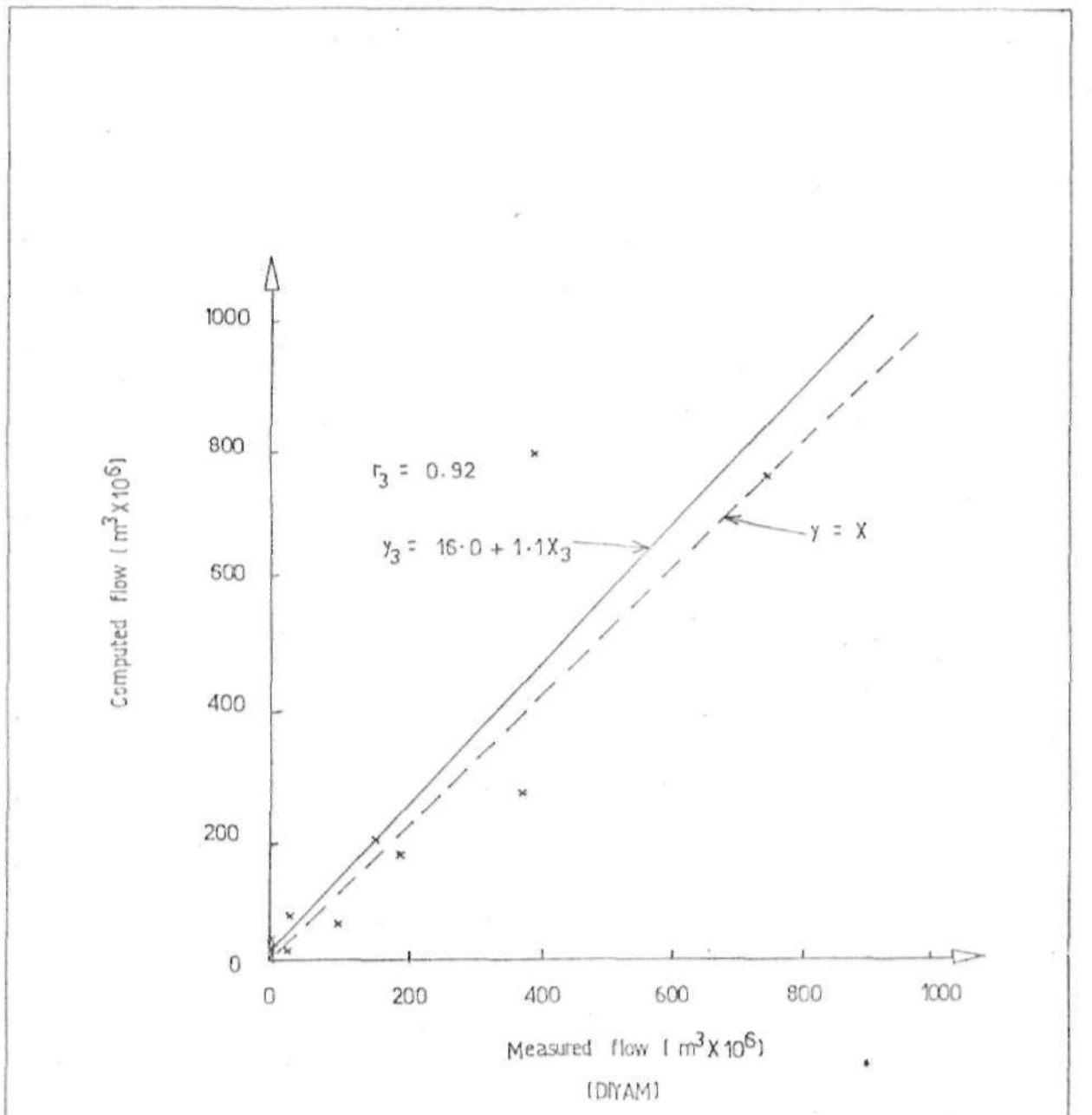


FIG. 4.1·2C Relation between average monthly computed and measured flows at Dindima .
(Final adjustments)

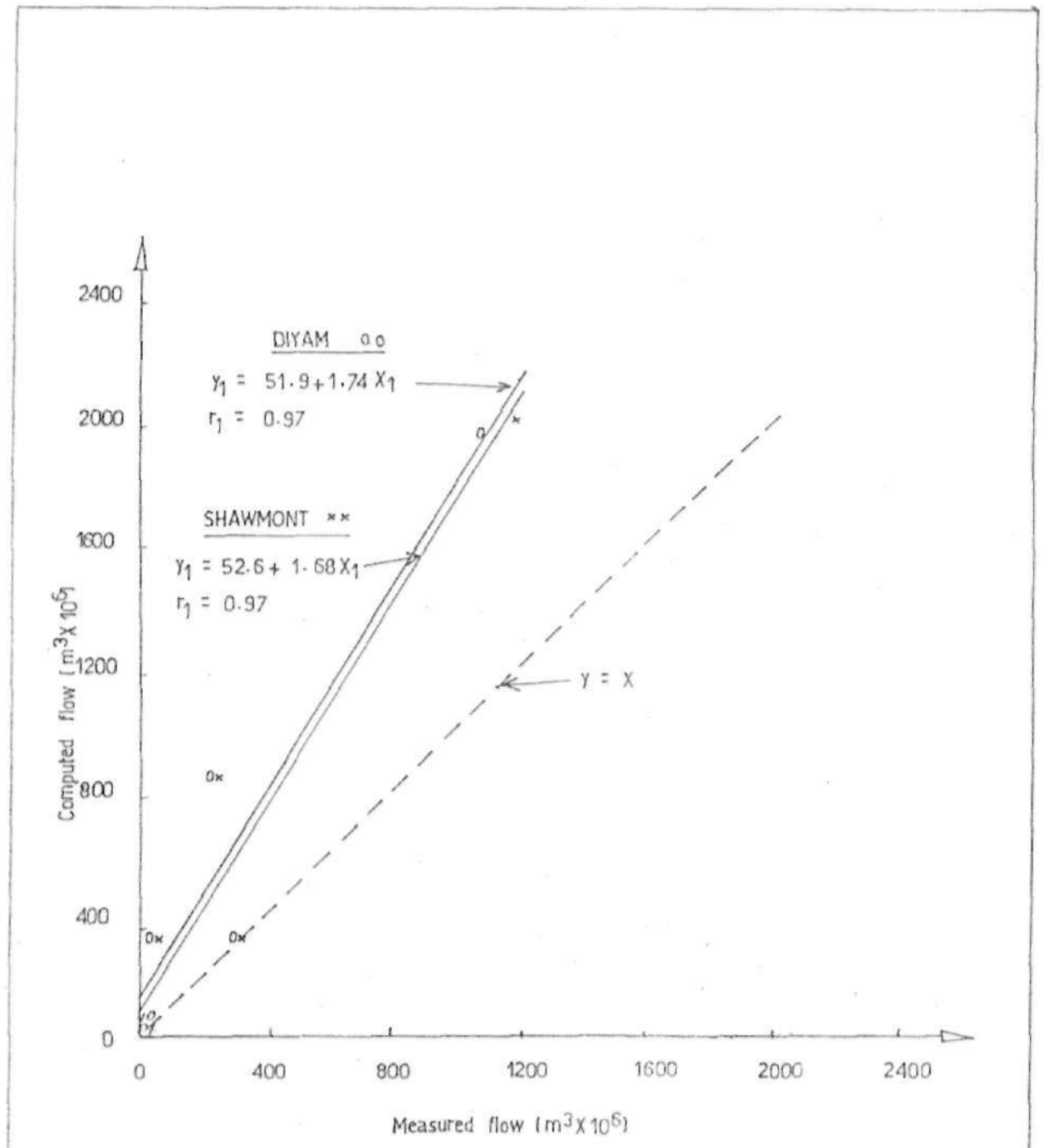


FIG. 4.1.2D Relation between average monthly computed and measured flows at Dadin kowa.
(Direct runoff not accounted for)

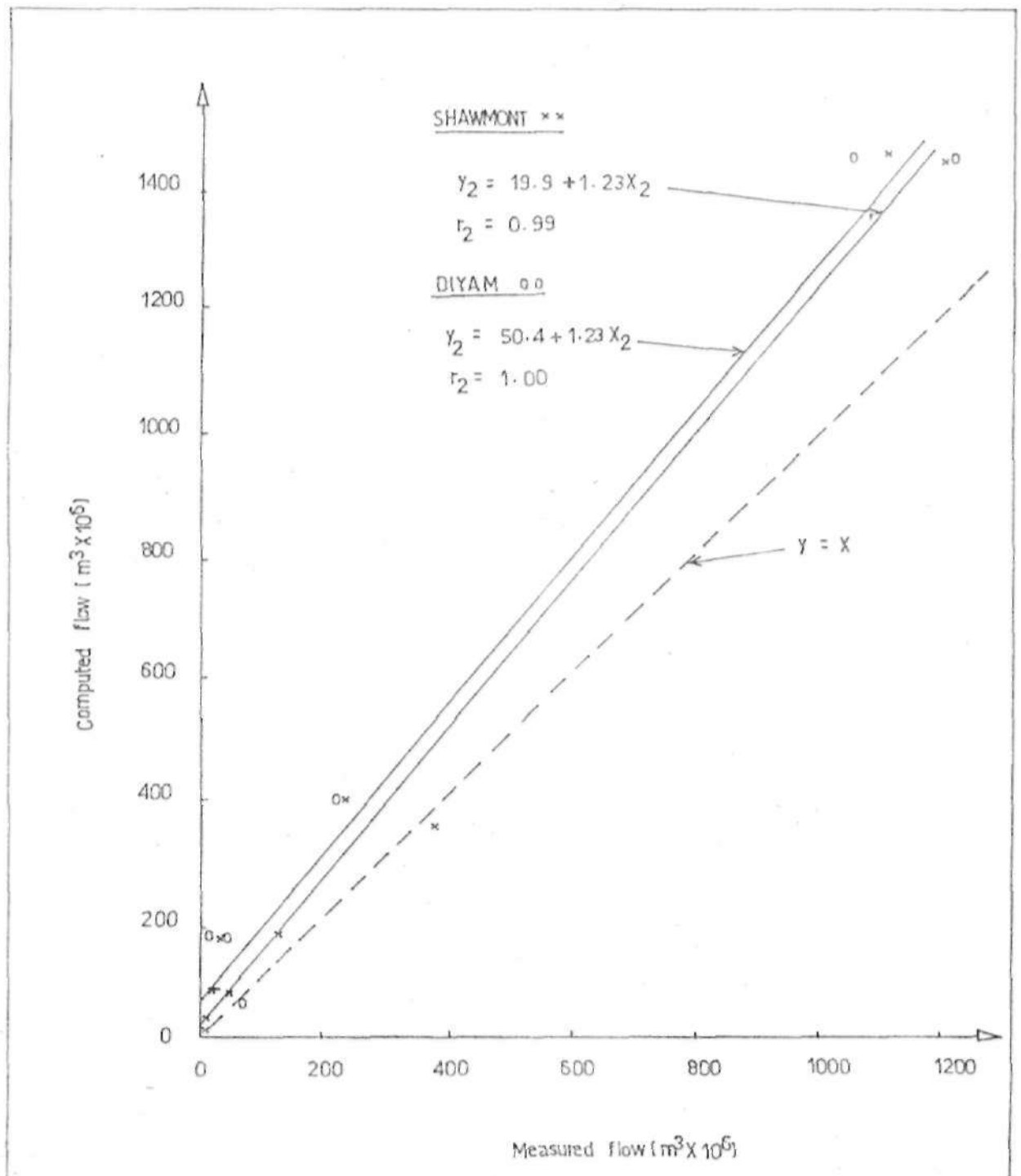


FIG. 4.1.2E Relation between average monthly computed and measured flows at Dadinkowa. (Direct runoff accounted for)

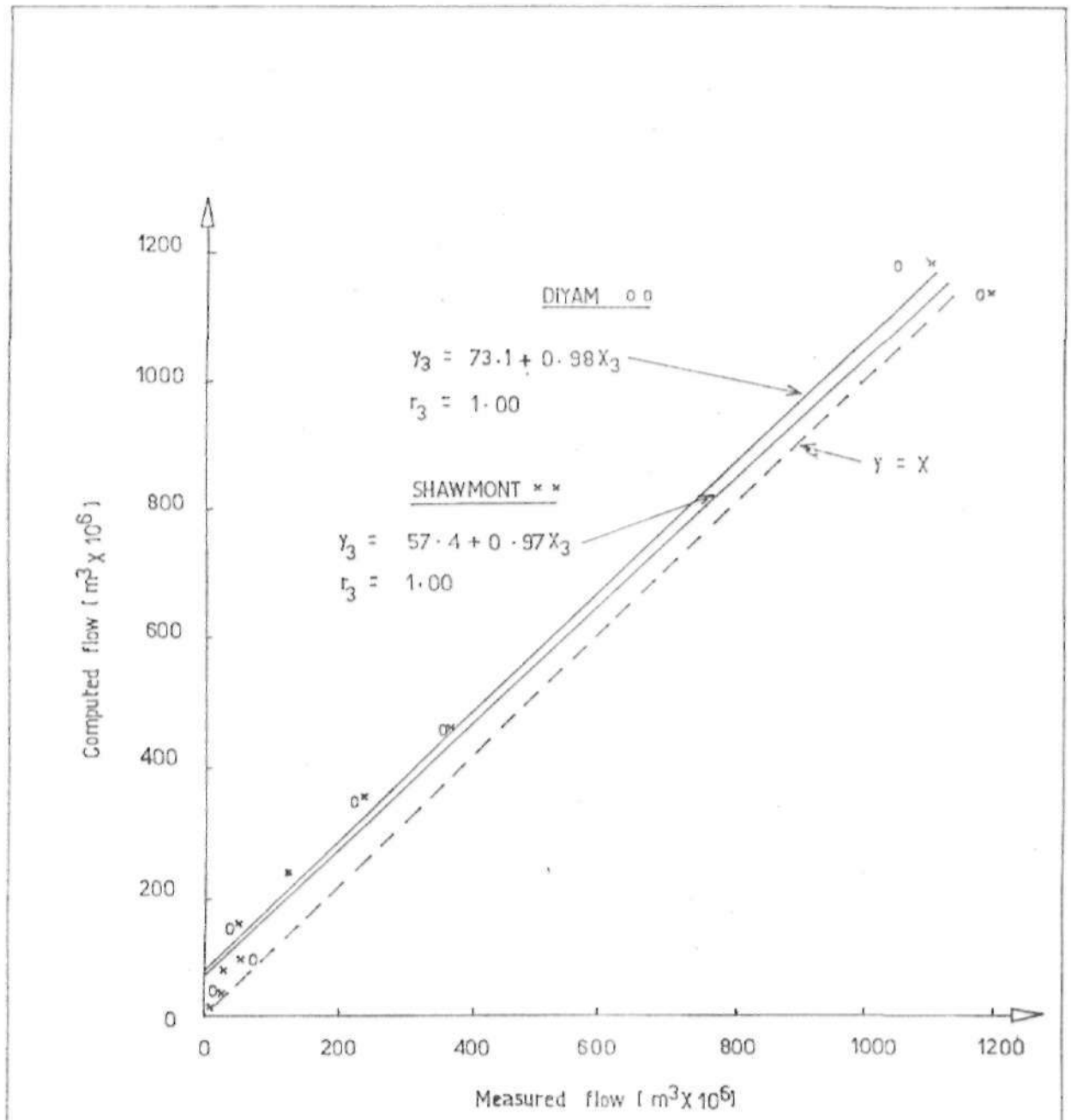


FIG. 4.1·2F Relation between average monthly computed and measured flows at Dadin kowa. (Final adjustments.)

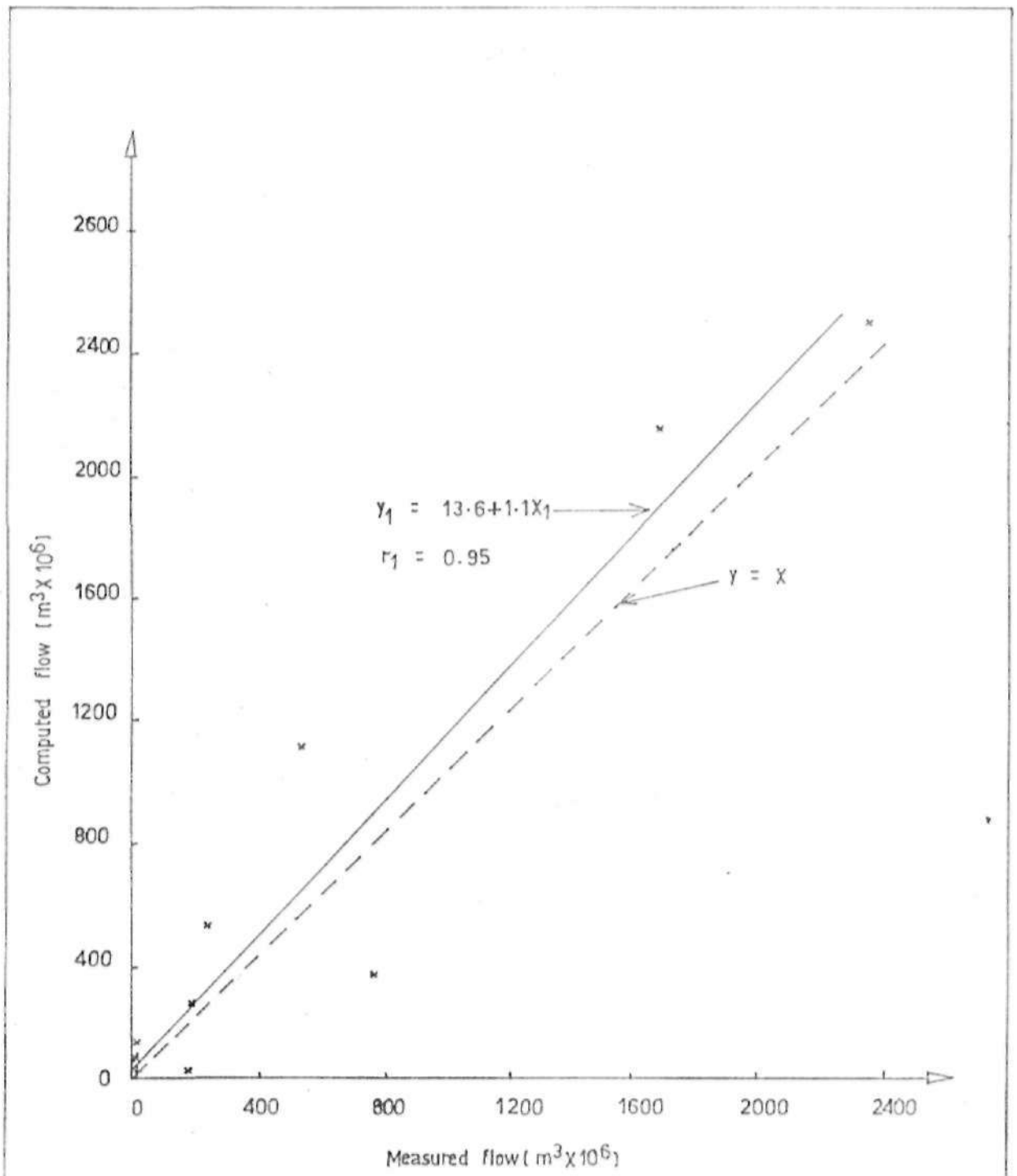


FIG. 4.1·26 Relation between average monthly computed and measured flows at Bare.

(Direct runoff not accounted for)

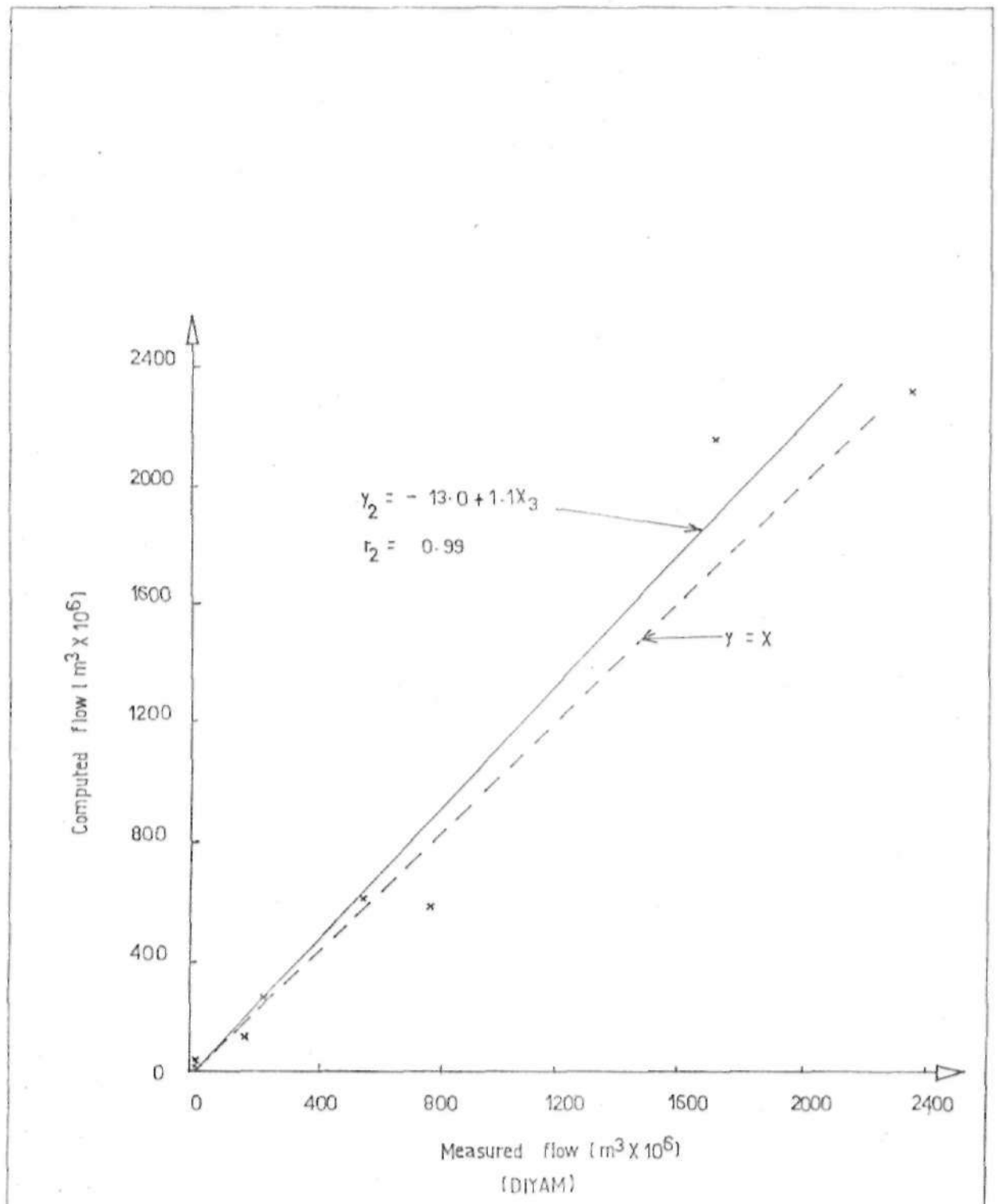


FIG. 4.1.2H Relation between average monthly computed and measured flows at Bare (Direct runoff accounted for)

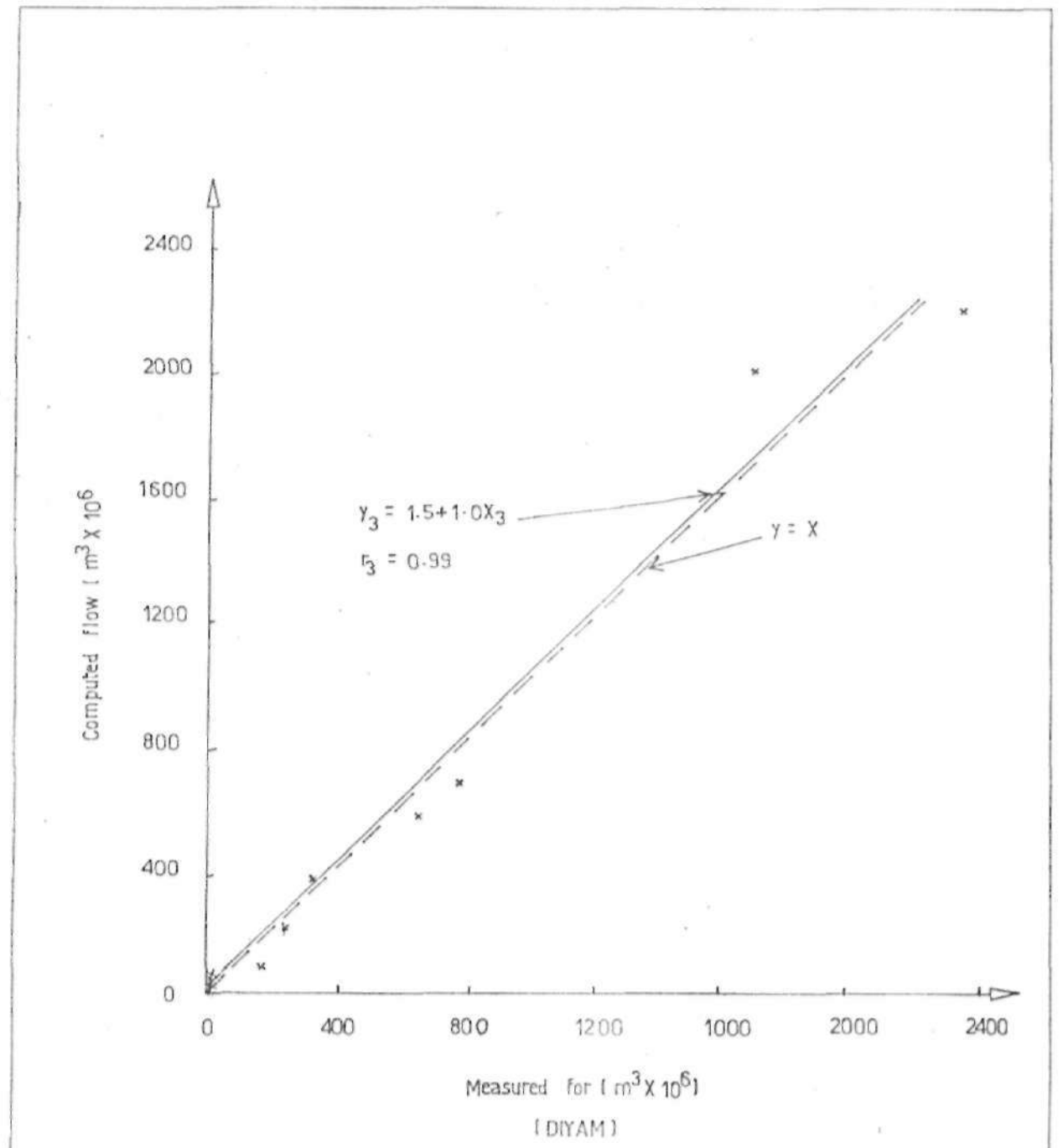


FIG. 4.1·2 I Relation between average monthly computed&measured flows at Bare
(Final adjustments)

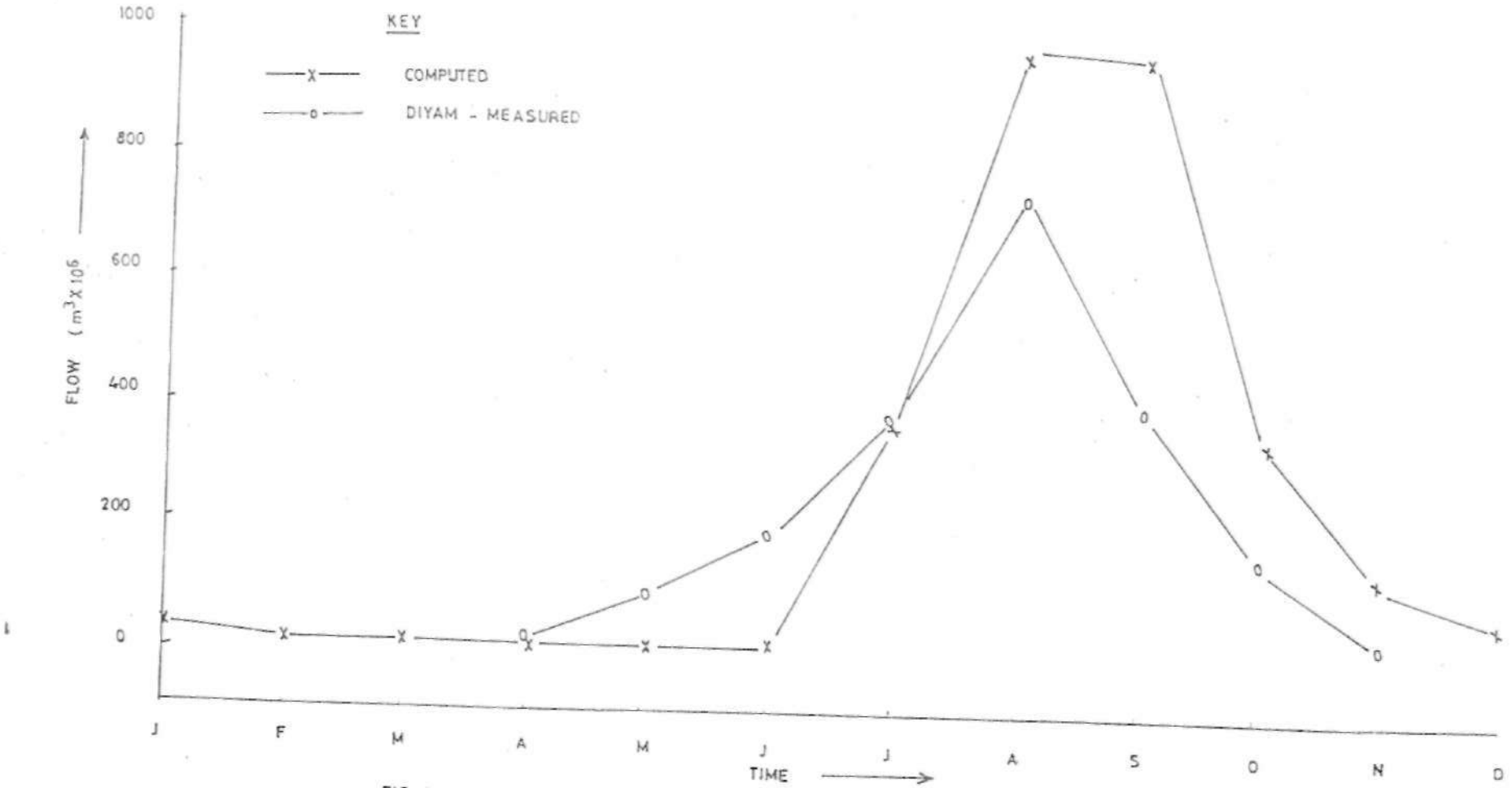


FIG 4.1.2J AVERAGE MONTHLY FLOW AT DINDIMA. (DIRECT RUNOFF NOT ACCOUNTED FOR)

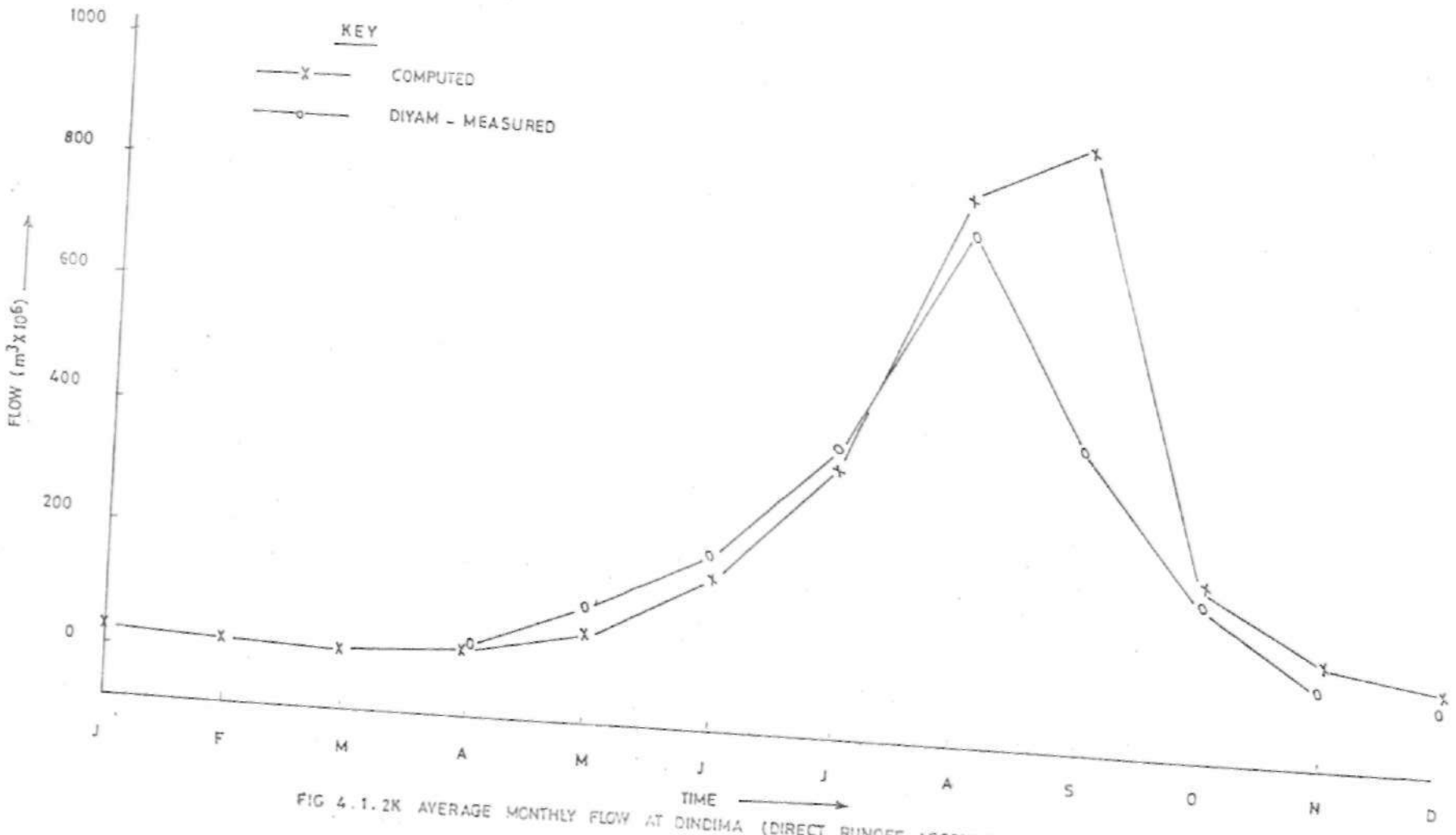


FIG 4.1.2K AVERAGE MONTHLY FLOW AT DINDIMA (DIRECT RUNOFF ACCOUNTED FOR)

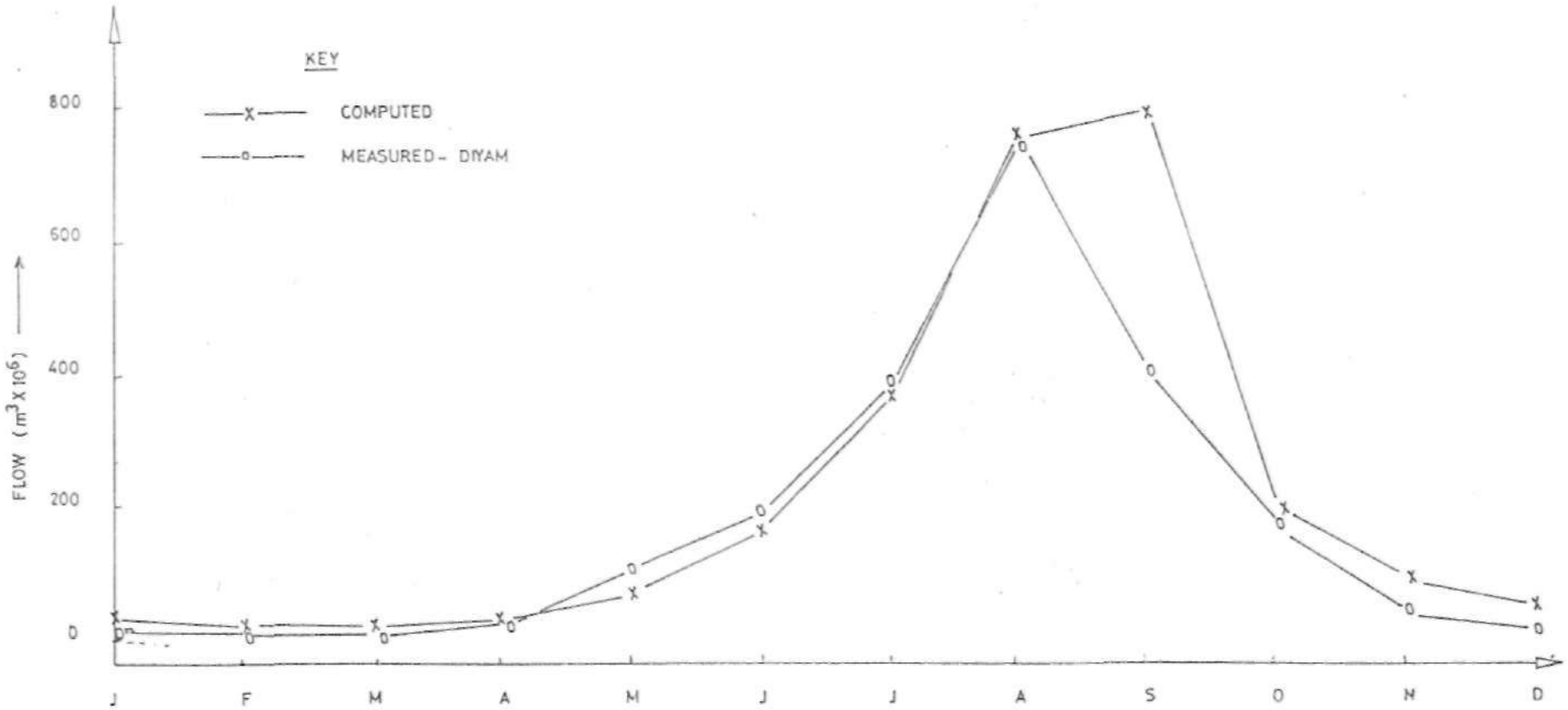


FIG. 4.1.2L AVERAGE MONTHLY FLOW AT DINDIMA (FINAL ADJUSTMENTS)

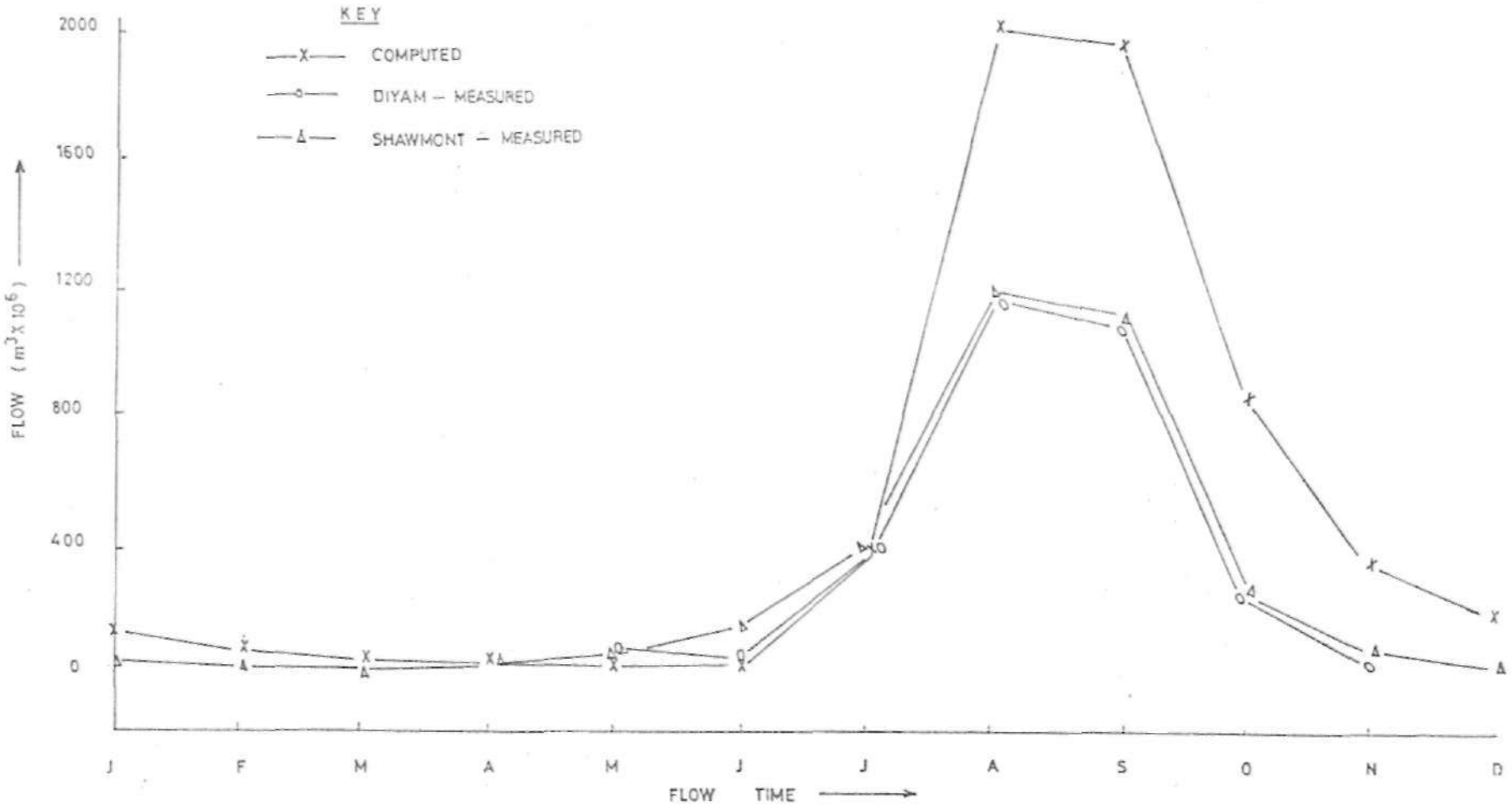


FIG 4.1.2M AVERAGE MONTHLY FLOW AT DADINKOWA (DIRECT RUNOFF NOT ACCOUNTED FOR)

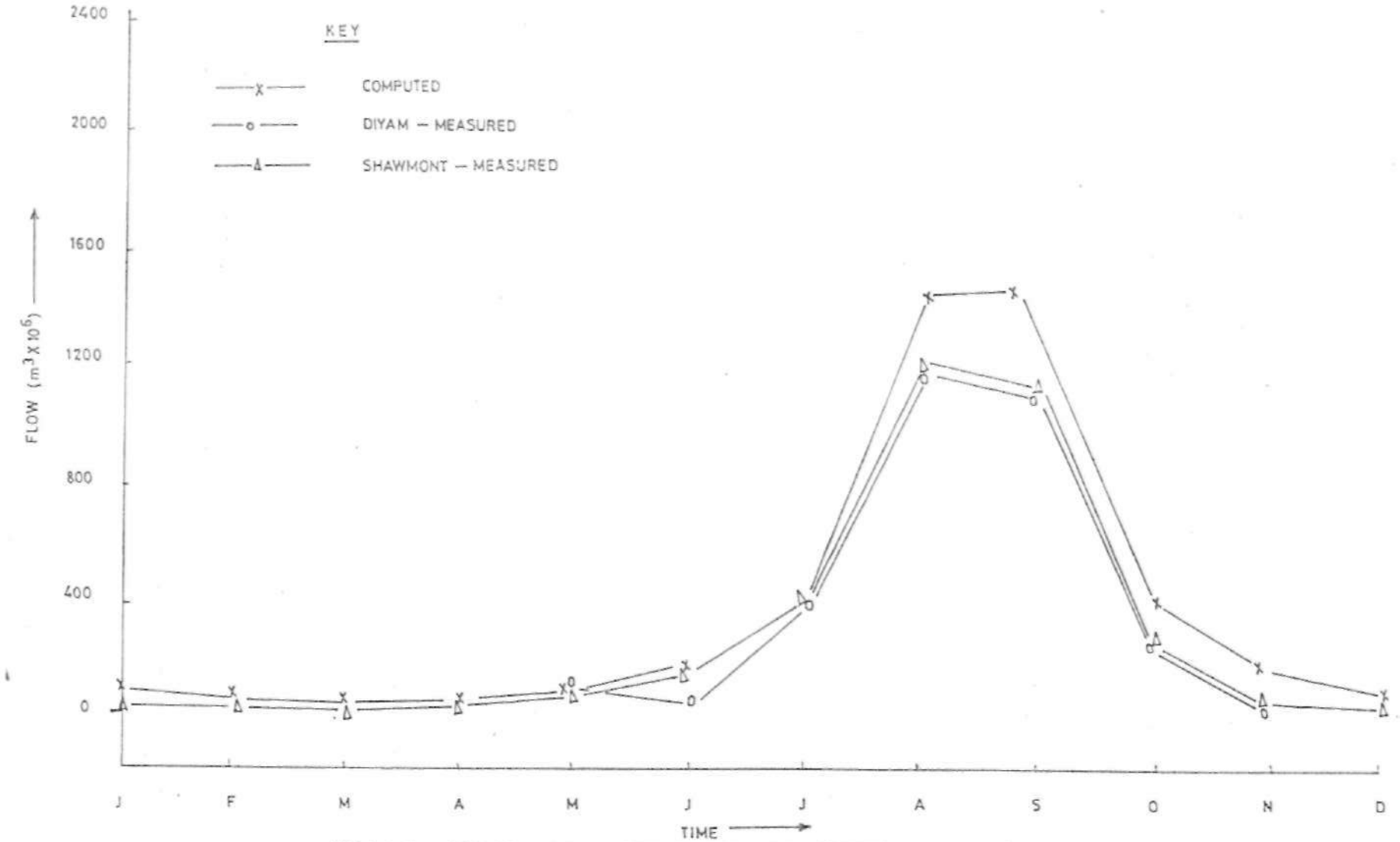


FIG. 4.1. 2N AVERAGE MONTHLY FLOW AT DADIN KOWA (DIRECT RUNOFF ACCOUNTED FOR.)

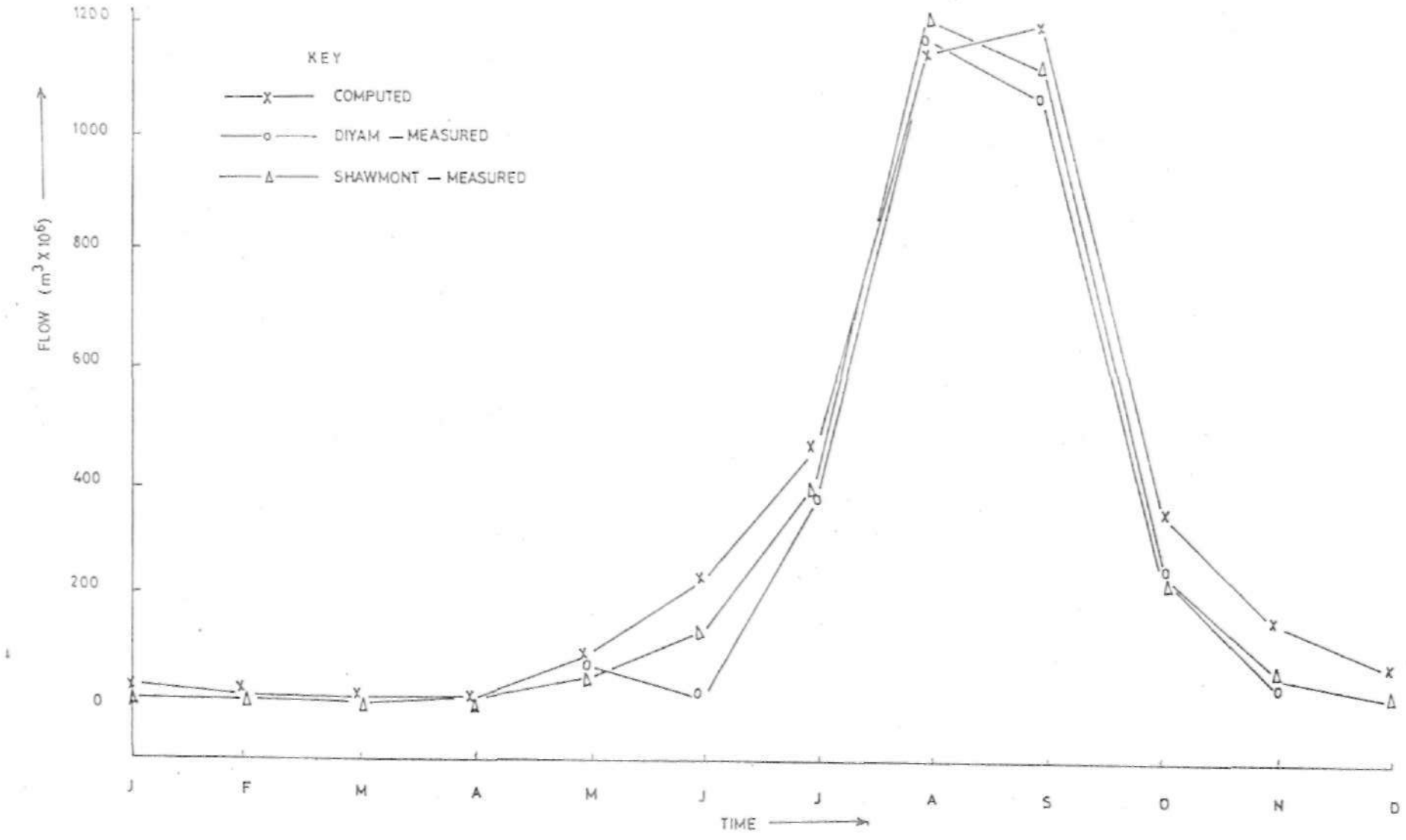


FIG 4.1.2P AVERAGE MONTHLY FLOW AT DADIN KOWA (FINAL ADJUSTMENTS)

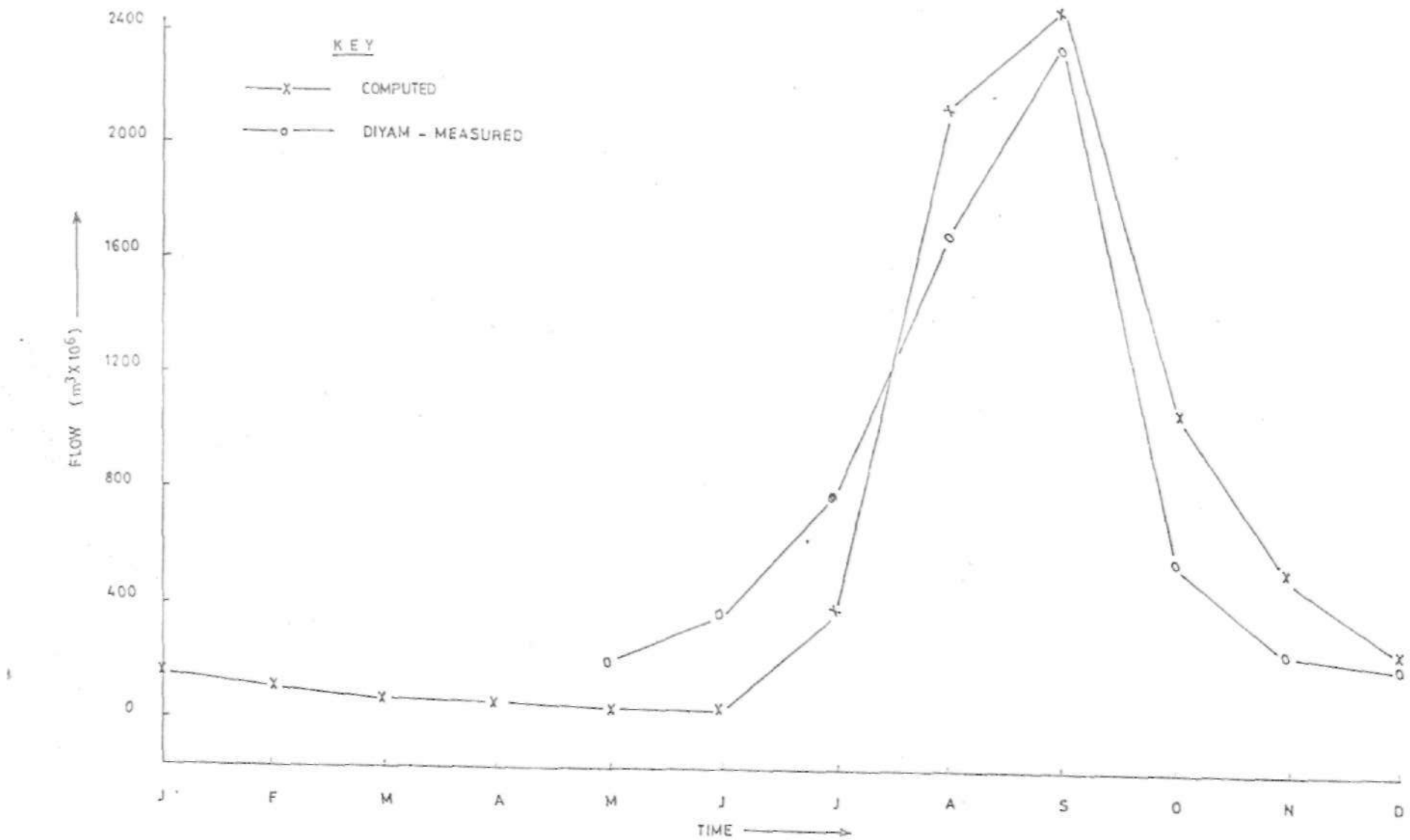


FIG. 4.1.2Q AVERAGE MONTHLY FLOW AT BARE (DIRECT RUNOFF NOT ACCOUNTED FOR)

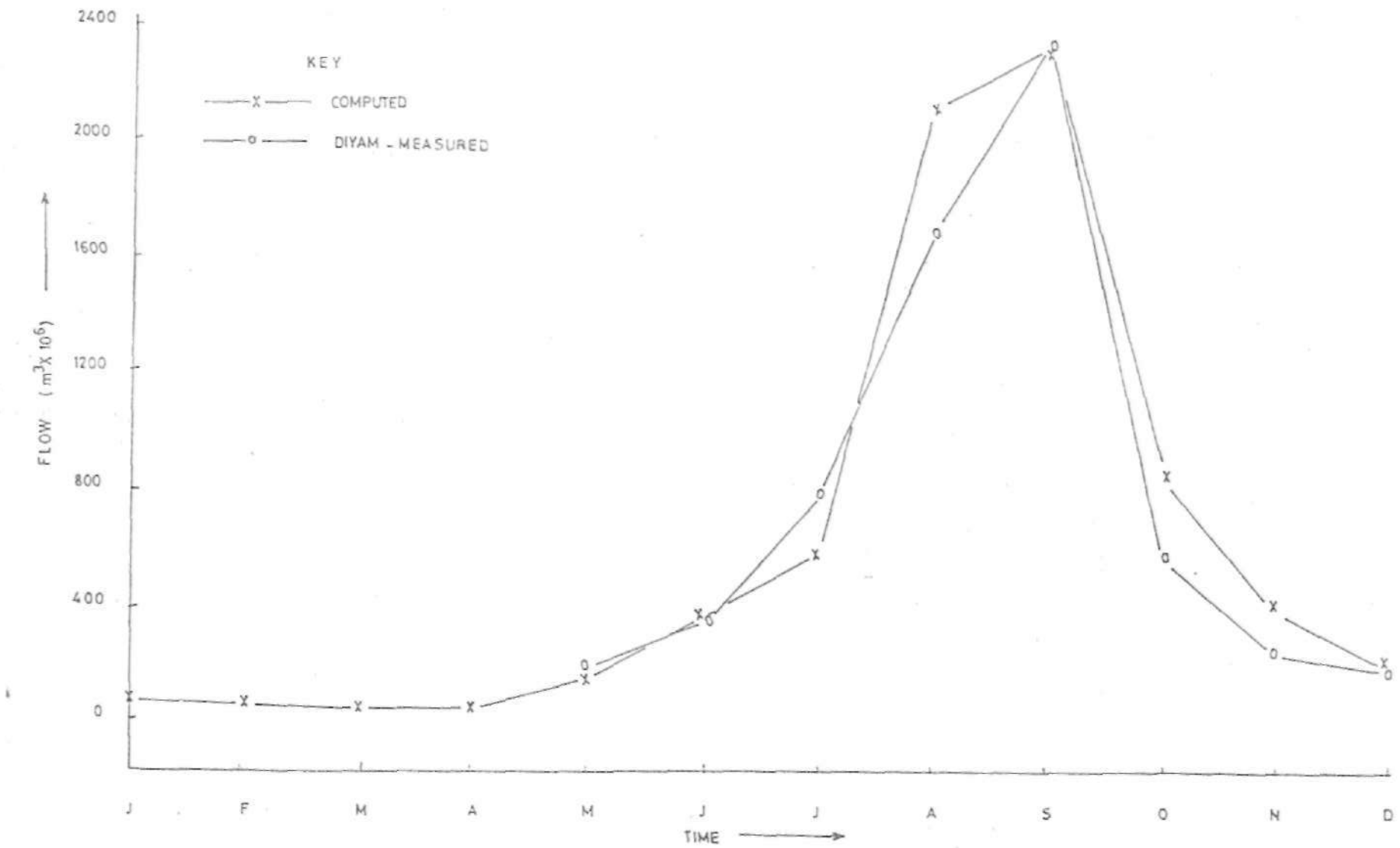


FIG. 4.1.2R AVERAGE MONTHLY FLOW AT BARE (DIRECT RUNOFF ACCOUNTED FOR)

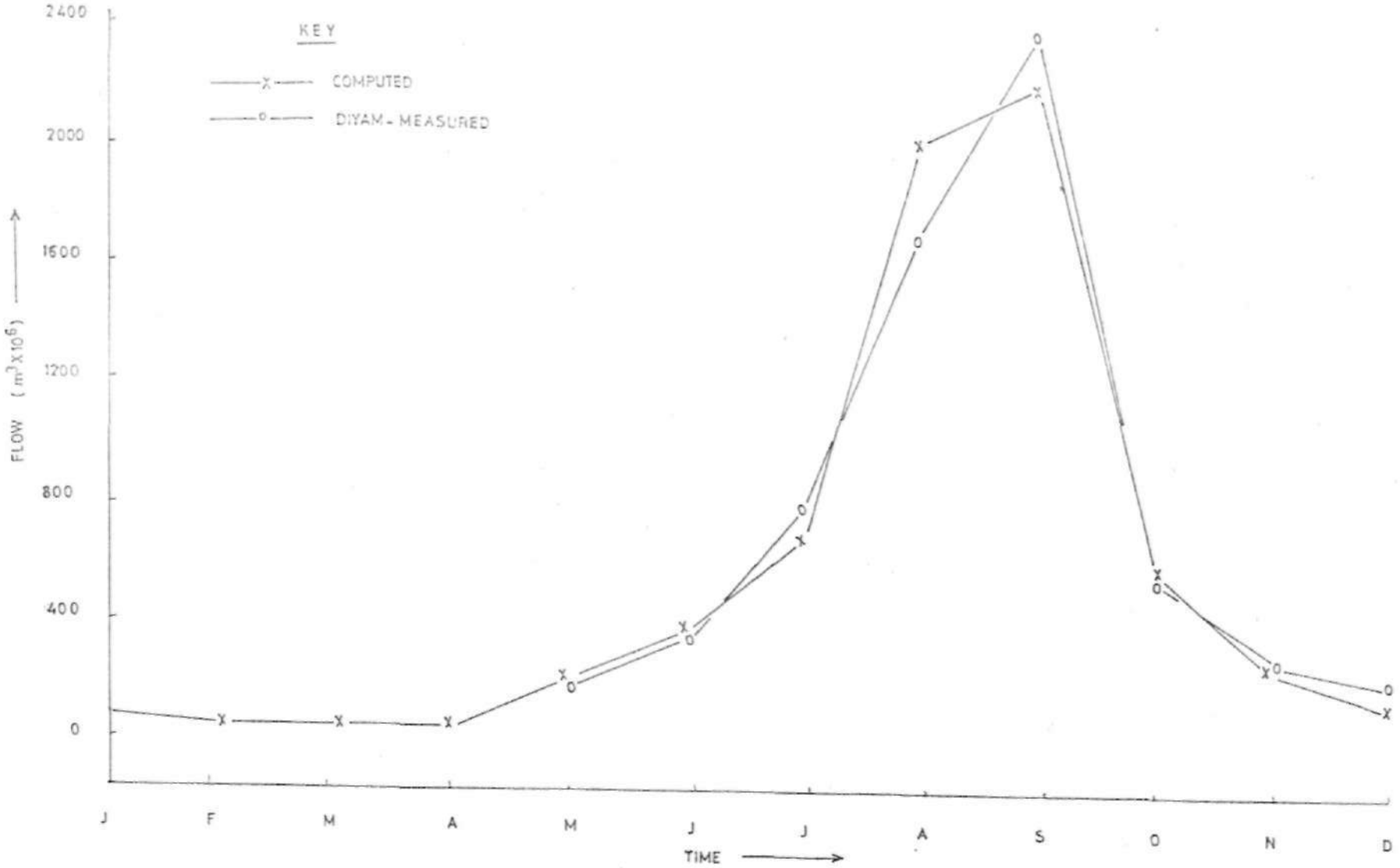


FIG 4.1·25 AVERAGE MONTHLY FLOW AT BARE (FINAL ADJUSTMENTS)

C H A P T E R V

COMPUTATION OF STREAM FLOWS AT DADIN KOWA FOR THE PERIOD 1980 - '82

5.1 Data Collection:

A tour of four out of the 6 synoptic stations and 18 out of the 22 additional rainfall stations (see chapter III) was undertaken between December 1983 and April 1984. A short temperature record in addition to rainfall exists at Dadin Kowa. The tour of one and five synoptic and rainfall stations respectively were not attempted because the former is no more relevant to the area of study while a forehand knowledge of the latter being non-functional was obtained at their respective Zonal Headquarters Offices but Vom rainfall station was skipped because it was considered too close to Jos. While long records are available at the synoptic stations toured, only short and sometimes discontinous records are available for 1980 - 1982 at 10 rainfall stations and missing records for Bula and Dukku had to be estimated by interpolation. It has been found out that only the catchment area upstream of Dadin Kowa has better station coverage (section 1.4.3), coverage being about 1400 km^2 to a rainfall station as against earlier coverage of 2,000 km^2 to a station. Moreover a relatively good flow record is available for the gauging station at Dadin Kowa a situation arising from construction of a Dam 5km upstream of the gauging station which has been in progress during this period. Therefore runoff at Dadin Kowa has been computed and comparison between the computed and measured flows at this station made.

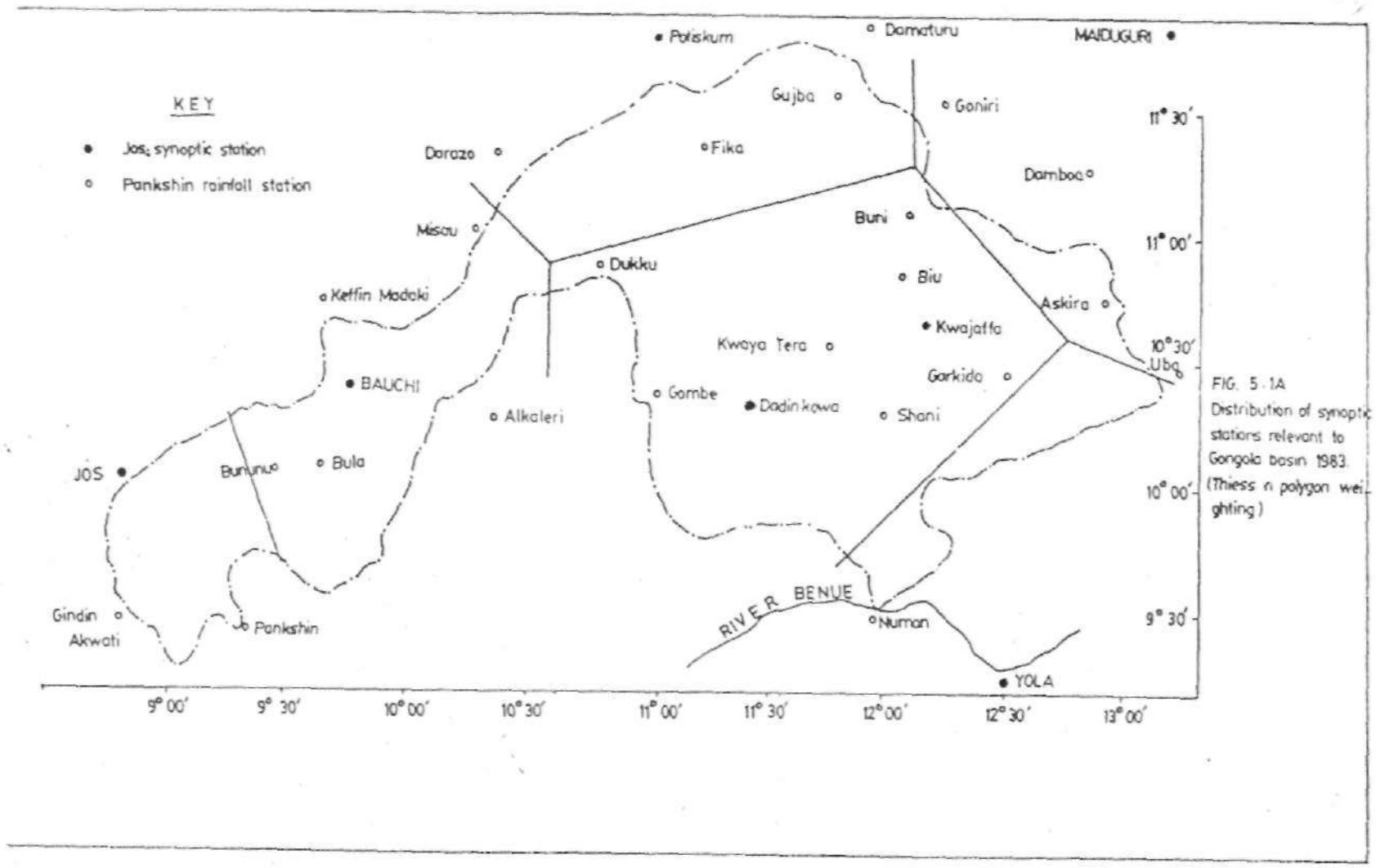


FIG. 5.1A
Distribution of synoptic stations relevant to Gongola basin 1983. (Thiess n polygon weighting)

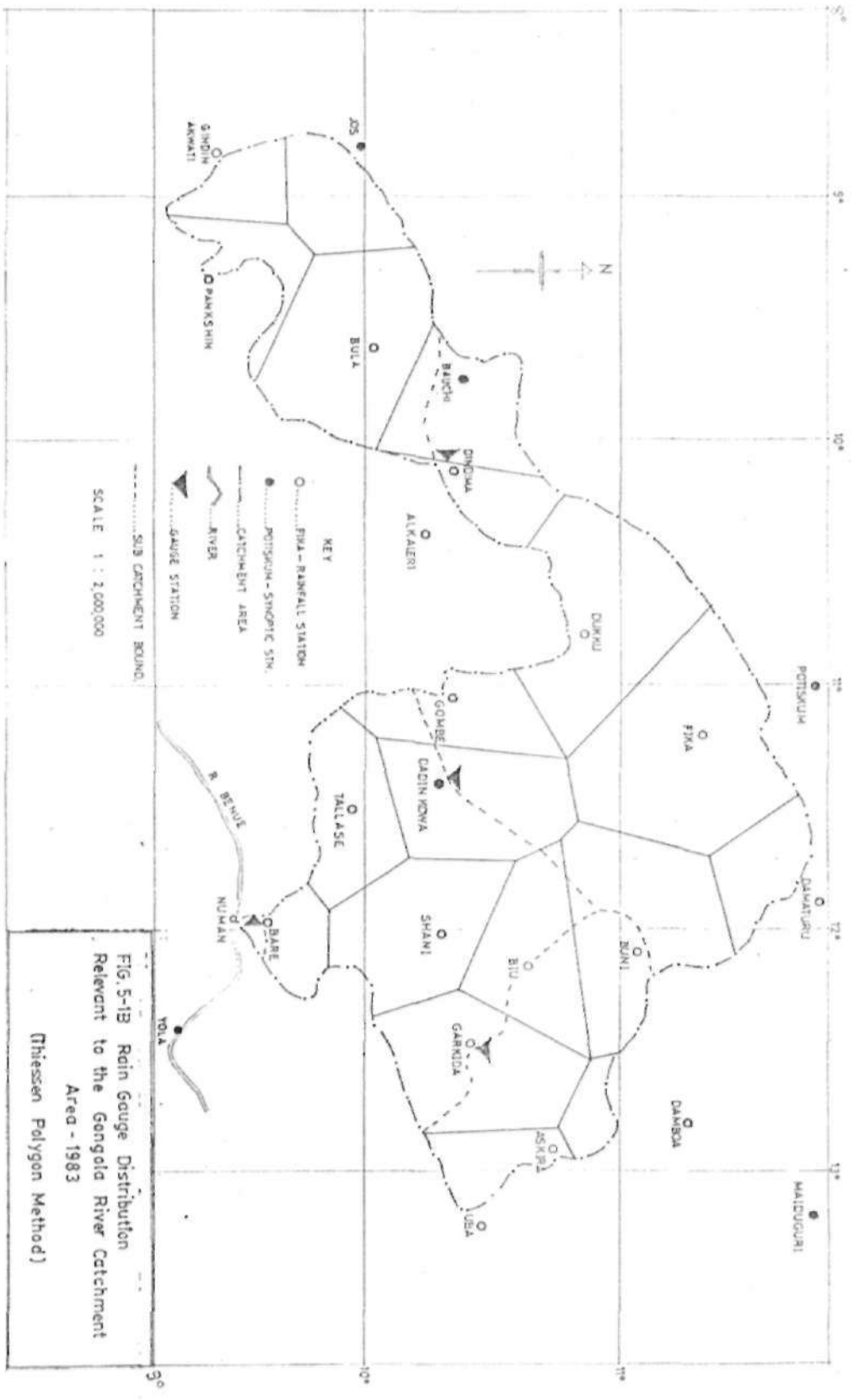


FIG. 5-1B Rain Gauge Distribution Relevant to the Gongola River Catchment Area - 1983
(Thiessen Polygon Method)

Rainfall records at the 14 stations and corresponding temperature records relevant to the stations for the period 1980 - 1982 is presented in Annex III (A-C).

Using the temperature records and tables 3-1.7 (A & D), adjusted potential evapotranspiration values were determined as described in Chapter III. After deducting direct runoff (DR) from rainfall (P) actual evapotranspiration (AE), deficit (D), surplus rainfall (S) and runoff (RO) are determined from Peff,PE and water holding capacity values as determined and described in Chapter III for each month in the period (1980 - 1982). Total monthly runoff (TRO) is finally determined for each station (see table 5.1.1A). Monthly runoff at Dadin Kowa are then determined by applying runoff coefficients as determined in Chapter III and summing up the results.

Computed monthly runoff at Dadin Kowa for 3 years are tabulated in table 5.1.1B, side by side with corresponding measured values. Figure 5-1A and 5-1B show distribution of synoptic and rainfall stations, respectively weighted by Thiessen method.

5.1.1 Interpolation of missing records.

Rainfall at Dukku for the whole of 1980 was not recorded therefore had to be estimated by interpolation. Likewise for Bula, 1981 and 1982, simple interpolation method was employed in this exercise.

Dukku and Bula stations were not existing before 1976 but some records for recent years, 1977-1982, do exist. Bula is very close to Bununu and it is assumed that the average annual rainfall at Bununu will be the same as that at Bula.

ie $\bar{P}_{Bununu} = \bar{P}_{Bula} = 1044$ mm

Also $\bar{P}_{Jos}$ is known = 1391 mm

but $\bar{P}_B \sim \bar{P}_J$ .... (1)

$\therefore \bar{P}_B = K\bar{P}_J$ .... (2)

and $K = \bar{P}_B/\bar{P}_J$ .... (3)

Similarly $P_B \sim P_J$ .... (4)

$\therefore P_B = KP_J$ .... (5)

$\therefore K = \frac{P_B}{P_J}$ .... (6)

hence $\frac{P_B}{P_J} = \frac{\bar{P}_B}{\bar{P}_J}$ ... (7)

$\therefore P_B = \frac{\bar{P}_B}{\bar{P}_J} \times P_J$ .... (8)

where $\bar{P}_J$ - Average annual rainfall at Jos

$\bar{P}_B$ - Average annual rainfall at Bula.

P_J - Monthly rainfall at Jos

P_B - Monthly rainfall at Bula.

Similarly monthly rainfall at Bula for 1982 was computed using

$\bar{P}_J$, $\bar{P}_B$ and P_J for 1982.

$$P_{B82} = \frac{\bar{P}_B}{\bar{P}_J} \times P_{J82}$$

Since Dukku has no station of similar availability of Data close to it, the monthly rainfall for 1980 at Dukku was interpolated by taking the average value of rainfall at four stations surrounding it,i.e Fika, Combe, Alkaleri, and Bauchi. Interpolated figures are put in brackets.

5.1.2 Comparison of computed and measured flow at Dadin Kowa 1980 - 1982.

Annex IV gives the water budget of each of the 14 stations upstream of Dadin Kowa. Table 5.1.1A shows monthly contribution of each of the 14 stations to flow at Dadin Kowa while Table 5.1.1B gives the computed monthly flow at Dadin Kowa side-by side with corresponding measured flows. Figure 5.1.1A gives graphical comparison of computed and measured flow at the station.

5.1.3 Regression lines by the method of least squares.

Further comparison of computed and measured runoff at Dadin Kowa is made by calculating the equation of line of best fit and drawing

the regression lines for each year from table 5.1.1B. Computed and measured flows at Dadin Kowa for the year 1980 is given in column 1 and 2. The line of Best fit is derived as follows:- If computed and measured flow are equal for each month then the equation of the regression line between computed and measured flow would be Y = X. This of course would be possible only if all the factors affecting the runoff phenomenon can be accurately measured. Since the computed values of runoff either over-estimated or otherwise the equation of the line that best fits plot of computed flow against measured flow is determined. How closely computed runoff compares with measured runoff is indicated by the degree by which the regression line (equation of the line of best fit) approximated to the line Y = X. Let this line be described by the straight line equation Y = ax + b. where a and b are constants. Y and X are computed and measured values of runoff respectively.

The constants a and b are evaluted from the following equations.

$$\sum Yr = a\sum x_r + nb \quad \text{..... (1)}$$

$$\sum XrYr = a\sum x^2r + b\sum xr \quad \text{..... (2)}$$

where $\sum Yr$ and $\sum Xr$ are the sums of computed and measured monthly runoff at the gauging station for the year and $\sum Yr^2$ and $\sum x^2r$ are sums of the squares of computed and measured runoff respectively. n is the number of statistics; in this case

Table 5.1.1.A Computed monthly runoff from monthly rainfall for 14 stations - 1980.

	Station	Area ($x10^8 m^2$)	WHC (mm)	Computed Run Off (mm)												Annual Total	Conveyance to Dadin Kowa
				Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	
1	Jos	19.8	300	4.0	2.0	1.0	0.0	24.0	17.0	48.0	91.0	63.0	28.0	14.0	7.0	299	0.65
2.	Gindi Akwati	10.8	300	3.0	2.0	1.0	0.0	19.0	48.0	75.0	80.0	55.0	24.0	12.0	6.0	325	"
3.	Pankshin	15.4	300	0.0	0.0	0.0	0.0	29.0	138.0	188.0	231.0	54.0	13.0	3.0	1.0	657	"
4.	Bule	49.0	300	0.0	0.0	0.0	0.0	0.0	6.0	8.0	11.0	6.0	0.0	0.0	0.0	31	"
5.	Bauchi	28.4	300	0.0	0.0	0.0	0.0	11.0	12.0	16.0	75.0	15.0	4.0	1.0	0.0	134	"
6.	Alkaleri	14.8	250	0.0	0.0	0.0	0.0	0.0	11.0	12.0	13.5	5.5	0.0	0.0	0.0	42	0.75
7	Dukku	47.5	200	0.0	0.0	0.0	0.0	0.0	5.1	12.0	11.7	3.9	0.0	0.0	0.0	33	"
8	Potiskum	1.4	150	0.0	0.0	0.0	0.0	4.6	8.0	9.6	10.8	0.0	0.0	0.0	0.0	33	"
9	Damaturu	15.1	125	0.0	0.0	0.0	0.0	0.0	4.4	0.0	8.4	0.0	0.0	0.0	0.0	13	"
10	Fika	65.3	200	0.0	0.0	0.0	0.0	0.0	4.2	8.2	5.6	0.0	0.0	0.0	0.0	18	"
11	Buni	31.4	150	0.0	0.0	0.0	0.0	0.0	5.2	7.0	12.0	0.0	0.0	0.0	0.0	24	"
12	Biu	0.70	50	0.0	0.0	0.0	0.0	4.8	0.0	0.0	4.4	3.8	0.0	0.0	0.0	13	0.85
13	Gombe	11.2	150	1.0	0.0	0.0	0.0	0.0	5.0	12.2	36.3	17.7	6.0	3.0	2.0	82	"
14	Dadin Kowa	16.8	75	0.0	0.0	0.0	0.0	9.8	4.7	50.0	86.0	18.6	4.7	1.5	0.0	175	0.95

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Table 5.1.1A Cont. for 1982

				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	
1	Jos	19.8	300	5.6	2.8	1.4	21.9	14.4	8.5	128.2	147.1	97.1	45.2	22.6	11.3	506	0.65
2	Gindi Akwati	10.8	300	7.7	3.9	1.9	5.2	1.7	9.7	49.4	167.2	124.2	67.0	30.9	15.5	484	"
3	Pankshin	15.4	300	0.0	0.0	0.0	0.0	0.0	7.2	9.5	63.1	88.2	9.7	4.9	1.2	184	"
4	Bula	49.0	300	0.0	0.0	0.0	15.4	10.8	12.6	28.6	28.4	10.1	0.0	0.0	0.0	106	"
5	Bauchi	28.4	300	0.0	0.0	0.0	0.0	0.0	16.5	23.3	22.9	14.6	0.0	0.0	0.0	77	"
6	Alkaleri	14.8	250	0.0	0.0	0.0	0.0	0.0	5.9	9.4	44.0	23.3	0.0	0.0	0.0	83	0.75
7	Dukku	47.5	200	0.0	0.0	0.0	0.0	6.2	9.4	20.6	27.2	19.9	0.0	0.0	0.0	83	"
8	Potiskum	1.4	150	0.0	0.0	0.0	0.0	0.0	0.0	12.8	35.2	7.6	5.1	0.0	0.0	61	"
9	Daraturu	15.1	125	0.0	0.0	0.0	0.0	0.0	8.6	15.9	18.0	5.0	5.0	0.0	0.0	53	"
10	Fika	65.3	200	0.0	0,0	0.0	0.0	0.0	6.8	10.1	22.4	0.0	0.0	0.0	0.0	39	"
11	Buni	31.4	150	0.0	0.0	0.0	0.0	0.0	12.0	13.1	20.0	11.6	5.6	0.0	0.0	62	"
12	Biu	0.70	50	0.0	0.0	0.0	0.0	0.0	11.4	16.2	24.0	11.1	9.1	0.0	0.0	72	0.85
13	Gombe	11.2	150	0.0	0.0	0.0	0.0	0.0	14.8	14.7	38.3	26.7	7.7	0.0	0.0	102	"
14	DAdin Kowa	16.2	75	0.0	0.0	0.0	0.0	0.0	12.1	15.7	24.2	15.0	14.0	0.0	0.0	81	0.95

Table 5.1.1A Cont. for 1981

				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	
1	Jos	19.8	300	7.4	51.0	1.8	10.9	9.2	21.3	99.2	156.3	127.9	59.2	29.6	14.8	587	0.65
2	Gindi Akwati	10.8	300	5.7	2.8	1.4	4.4	23.7	12.4	28.8	94.9	142.4	45.4	22.7	11.3	396	"
3	Pankshin	15.4	300	0.0	0.0	0.0	3.7	10.4	14.3	10.4	18.5	47.2	4.0	1.0	0.0	110	"
4	Bula	49.0	300	0.0	0.0	0.0	0.0	13.8	15.5	18.7	32.2	14.3	0.0	0.0	0.0	95	"
5	Bauchi	28.4	300	0.0	0.0	0.0	0.0	12.0	24.6	66.5	127.0	68.0	105.0	2.6	0.7	406	"
6	Alkaleri	14.8	250	0.0	0.0	0.0	0.0	0.0	22.7	21.3	37.5	4.4	0.0	0.0	0.0	86	0.75
7	Dukku	47.5	200	0.0	0.0	0.0	0.0	0.0	14.0	21.3	27.0	61.1	0.0	0.0	0.0	123	"
8	Potiskum	1.4	150	0.0	0.0	0.0	0.0	7.2	15.4	20.1	27.8	8.3	0.0	0.0	0.0	79	"
9	Damaturu	15.1	125	0.0	0.0	0.0	0.0	8.7	12.5	10.6	25.5	10.2	0.0	0.0	0.0	60	"
10	Fika	65.3	200	0.0	0.0	0.0	0.0	0.0	18.4	19.7	24.1	0.0	0.0	0.0	0.0	62	"
11	Buni	31.4	150	0.0	0.0	0.0	0.0	0.0	12.4	25.4	16.4	6.8	0.0	0.0	0.0	61	"
12	Biu	0.70	50	0.0	0.0	0.0	0.0	9.1	16.6	83.8	35.1	8.5	7.0	0.0	0.0	160	0.85
13	Gombe	11.2	150	0.0	0.0	0.0	0.0	8.2	15.8	24.4	23.1	10.5	0.0	0.0	0.0	82	"
14	Dadin Kowa	16.8	75	0.0	0.0	0.0	0.0	3.8	7.1	23.3	6.9	0.0	0.0	0.0	0.0	41	0.95

No. of months in the year (12). From table 5.1.2A:

$$\sum Yr = 2355.1 \qquad \sum Yr^2 = 1356705.6$$

$$\sum Xr = 2313.6 \qquad \sum Xr^2 = 1152331.0$$

$$n = 12 \qquad \sum YrXr = 1216277.8$$

Substituting these values into (1) and (2) we have

$$2355.1 = 2313.69a + 126 \quad \ldots (3)$$

$$1216277.8 = 1152331.0a + 2313.6b \quad \ldots (4)$$

Multiplying (3) by 2313.6 and (4) by 12 we have

$$5448759.4 = 5352745a + 27763.2b \quad \ldots\ldots (5)$$

$$14595334.0 = 13827972a + 27763.2b \quad \ldots\ldots (6)$$

Subtracting (5) from (6) we have

$$9146574.6 = 8475227a$$

$$a = 1.08.$$

Subtracting this value of a in (3)

$$b = -11.82.$$

$\therefore$ The regression eqution is:

$$Y = 1.08x - 11.82 \quad \ldots\ldots\ldots (7)$$

5.1.4 Correlation Coefficients

To further examine how closely computed and measured runoff values relate, coefficient of correlation (r) between the two values are calculated from the equation:

$$r = \frac{Sxy}{SxSy} \quad \ldots\ldots (8)$$

where $Sxy = \frac{\Sigma XrYr}{n} - \frac{\Sigma Xr}{n} \times \frac{\Sigma Yr}{n}$ ... (9)

$$Sx = \sqrt{Sx^2} \quad \ldots (10)$$

$$Sx^2 = \frac{\Sigma Xr^2}{n} - \left(\frac{\Sigma Xr}{n}\right)^2 \quad \ldots (11)$$

$$Sy = \sqrt{Sy^2} \quad \ldots\ldots\ldots\ldots (12)$$

$$Sy^2 = \frac{\Sigma Yr^2}{n} - \left(\frac{\Sigma Yr}{n}\right)^2 \quad \ldots\ldots (13)$$

Substituting values of $\Sigma YrXr$, ΣXr, ΣYr, and n as in 5.1.2 in to (9) we have

$$Sxy = \frac{1216277.8}{12} - \frac{2313.6}{12} \times \frac{2355.1}{12}$$

$$= 101356.5 - 37838.6$$

$$= 63517.9.$$

Similarly, substituting the value of ΣXr^2, ΣXr and n into (11) we have::

$$Sx^2 = \frac{1152331}{12} - \left(\frac{2313.6}{12}\right)^2$$

$$= 96027.6 - 58855.8$$

$$= 3717.8$$

Similarly:

$$Sy^2 = 113058.8 - 38517 \text{ from (13)}$$

$$= 74541.5$$

$$Sx = \sqrt{Sx^2} = 242.6 \ldots \text{from (10)}$$

and $Sy = \sqrt{Sy^2} = 273.0 \ldots$ from (12)

Subtituting values of Sxy, Sx and Sy into (8) we have:

$$r = \frac{63517.9}{242.6 \times 273.0} = 0.96$$

Table 5.1.1B Measured and computed flows at Dadin Kowa 1980 - 1982.

Year	1980		1981		1982	
Month	Com-puted	Mea-sured	Com-puted	Mea-sured	Com-puted	Mea-sured
Jan	15.2	2.7	13.5	5.4	12.6	5.4
Feb	7.6	2.5	67.6	4.8	6.3	4.8
Mar	2.0	2.7	3.3	2.7	3.2	2.6
Apr	0.0	0.0	17.1	2.6	80.9	2.6
May	110.6	80.4	124.6	58.9	123.3	58.9
June	316.2	220.3	314.9	259.2	246.8	98.5
July	562.3	535.7	563.8	669.2	624.1	448.0
Aug	914.3	750.0	992.9	910.6	935.1	1098.0
Sept	287.3	466.6	560.7	959.0	526.6	518.4
Oct	86.5	160.7	132.6	166.1	230.2	182.1
Nov	36.6	51.8	60.8	57.0	55.6	57.0
Dec	16.1	26.8	28.3	40.2	26.6	53.6
Total	2355.1	2313.6	2879.7	3135.7	2871.3	2530.0

Table 5.1.2A Derivation of Regression equation between computed and measured monthly runoff at Dadin Kowa for the year 1980.

Month	X	Y	YX	X^2	Y^2
Jan	2.7	15.2	41.0	7.3	231.0
Feb	2.5	7.6	19.0	6.3	57.8
Mar	2.7	2.0	5.4	7.3	4.0
Apr	0.0	0.0	0.0	0.0	0.0
May	80.4	110.6	8892.2	6464.2	12232.4
June	220.3	316.2	69658.9	48532.1	99982.4
July	535.7	562.7	301438.4	286974.5	316631.3
Aug	750.0	914.3	685725.0	562500.0	835944.5
Sept	466.6	287.3	134054.2	217715.6	82451.3
Oct	160.7	86.5	13900.6	25824.5	7482.3
Nov	51.8	36.6	1895.9	2683.2	1339.6
Dec	40.2	16.1	647.2	1616.0	259.2
	2313.6	2355.1	1216277.8	1152331	1356705.6

Similarly regression equations and correlation coefficients between computed and measured average monthly flows for 1981 and '82 have been determined and the results tabulated in table 5.1.2A and graphical representation of same given at Figures 5.1.3 (B - D).

Table 5.1.3A.

Correlation Coefficients and regression equations between computed and measured average monthly flows at Dadin Kowa 1980 - 1982.

Year	Correlation Coefficient (r)	Regression Equation
1980	0.96	Y = 1.08x-11.82
1981	0.94	Y = 0.84x+20.94
1982	0.96	Y = 0.88x+54.63.

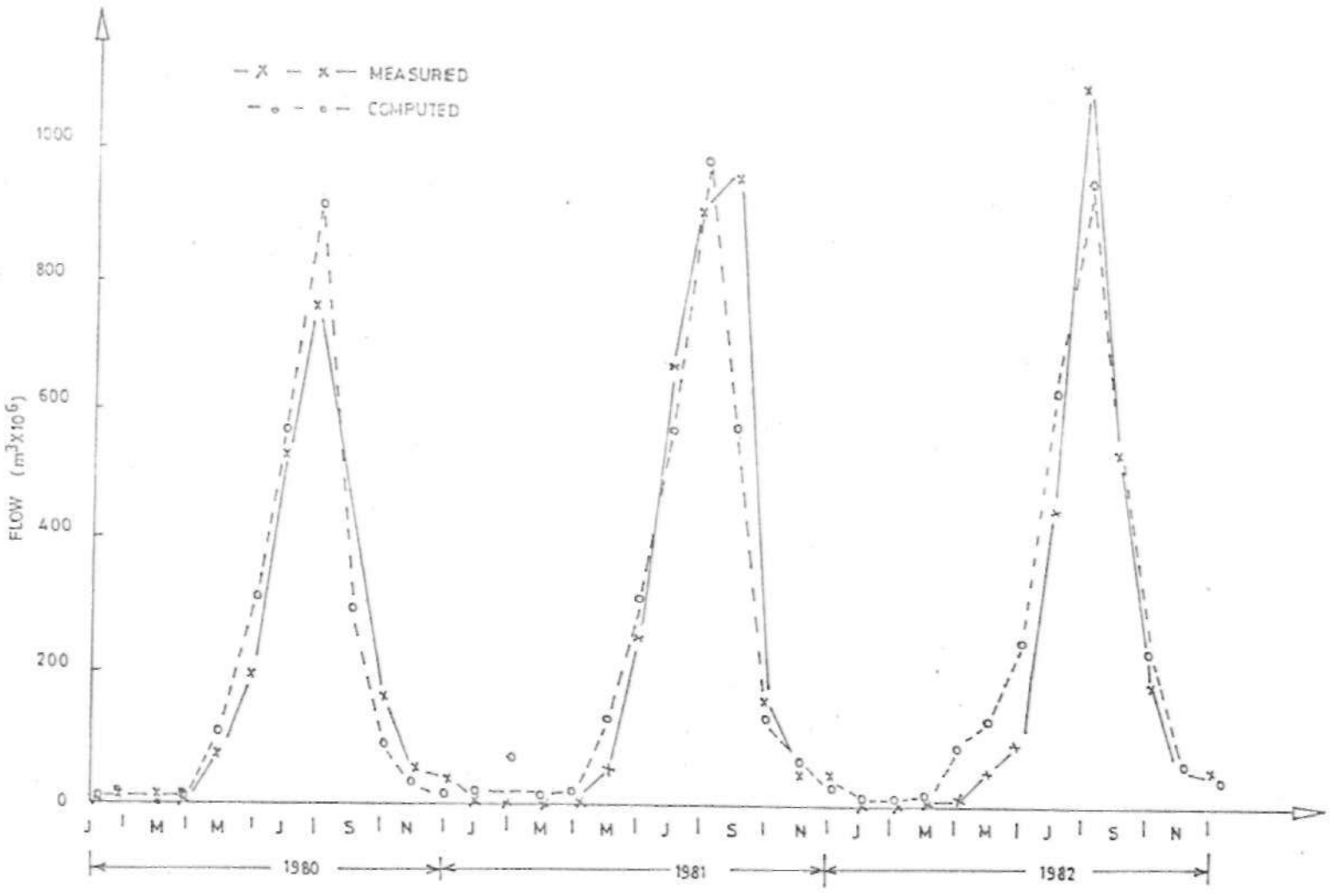


FIG. 5.1-1A RESULT OF SIMULATION OF MEAN MONTHLY STREAM FLOW ON GONGOLA BASIN UP/ STREAM OF DADINKOWA.

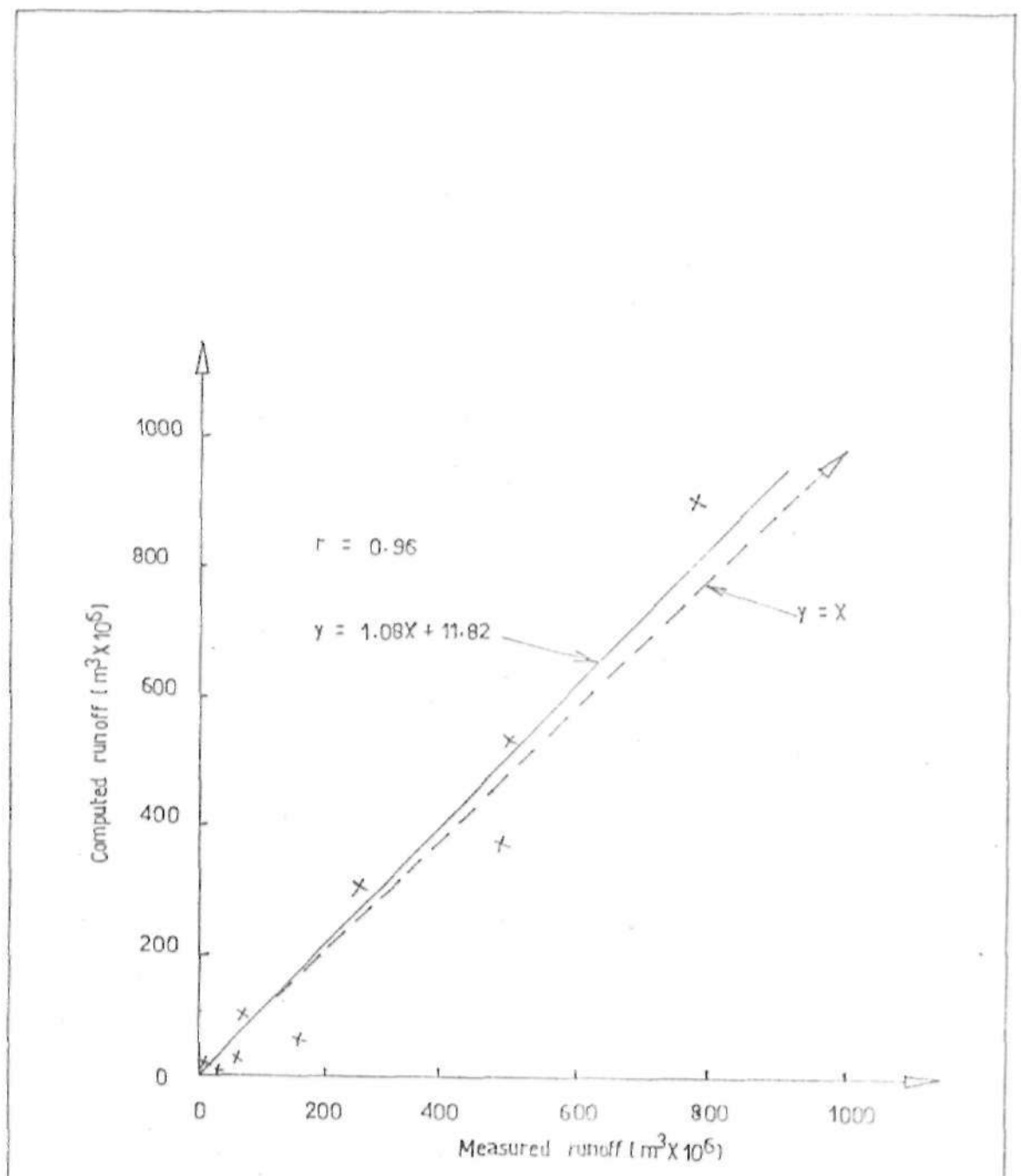


FIG. 5.1.3B Relation between mean monthly computed and measured flows at Dadinkowa. For the year 1980

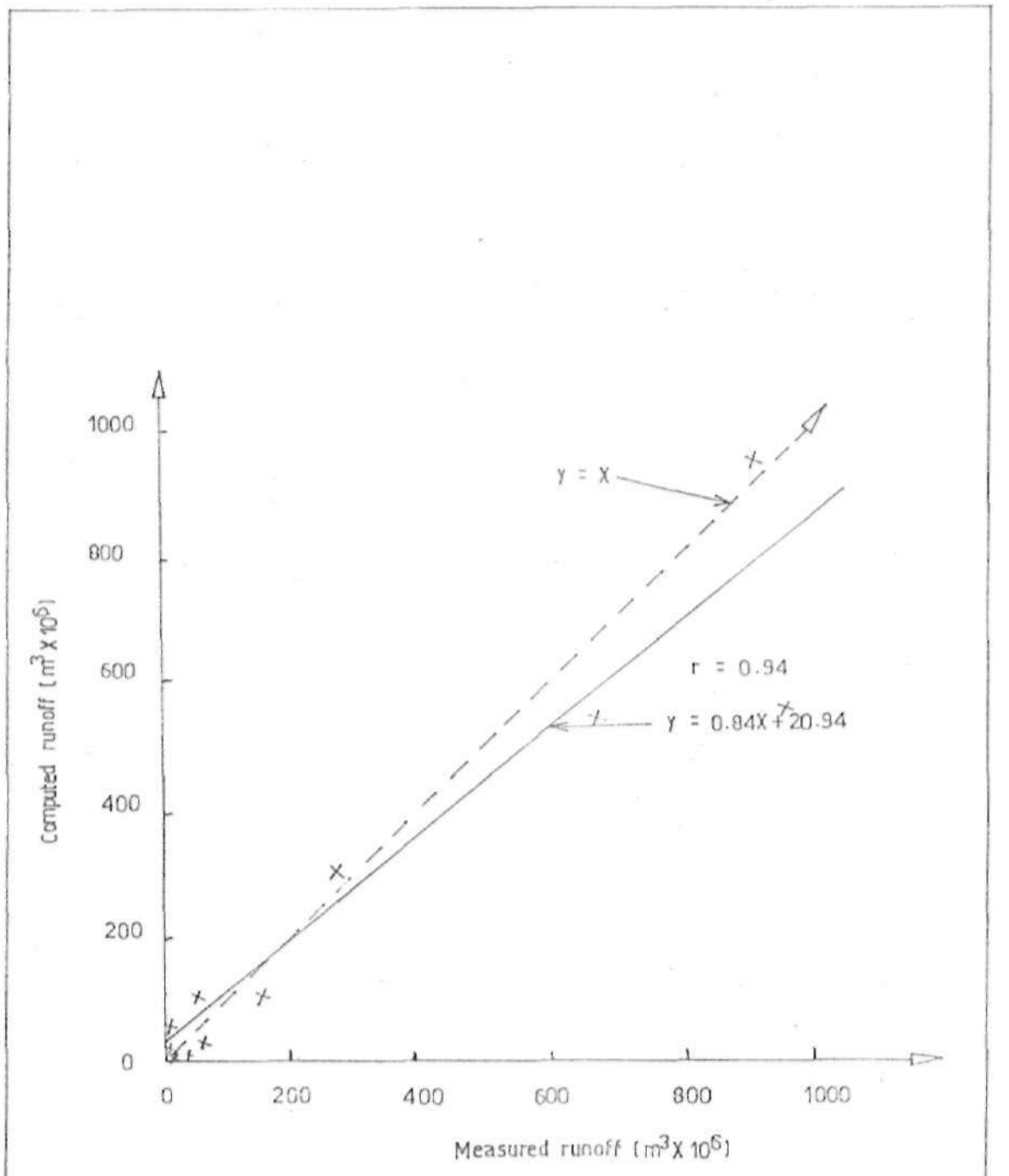


FIG. 5.1.3C Relation between mean monthly computed and measured flows, Gongola Basin, at Dadin kowa. For the year 1981

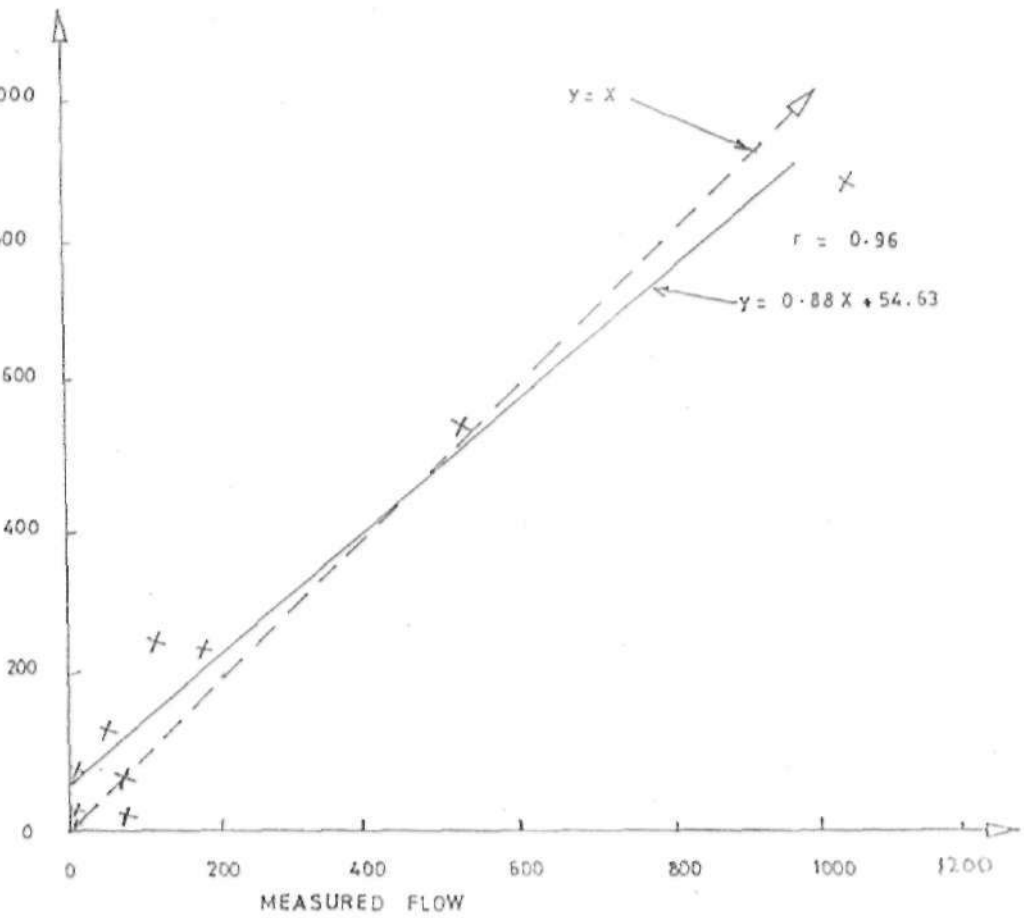


FIG 5.1.3 D

RELATION BETWEEN MEAN MONTHLY COMPUTED AND MEASURED FLOW AT DADIN KOWA - 1982

CHAPTER VI

DISCUSSION OF RESULTS AND CONCLUSIONS

6.1 General Discussion.

Chapter I observes that appreciable effort is being made toward planning and developing the water resources of Nigeria. Eleven River Basin Development Authorities spread to cover the whole country (fig. 1.2) are the agents of this development.

Same chapter also explains the inadequacy of water data necessary for planning and design of water resources projects. A peculiar phenomenon featuring prominently in hydrometeorological activities is some kind of stagnation and or deterioration between the mids of 1960s and 1970s and even beyond. However, a glance at records collected during a tour of some Hydro-met stations indicate a reverse of this trend in some areas of the Congola basin.

This development may not be unconnected with recent efforts being made by Nigerian Government towards boosting agriculture. Chapter II high-lights potentials identified to be available for exploitation. Chapters III and IV explain a method of estimating runoff from rainfall data a strong tool in estimation of parameters necessary for planning, design and management of water resources and Agricultural projects. This method known as Book Keeping technique of computing water Budget of an area has diverse applications.

6.1.1 AVAILABILITY OF DATA:

Though distribution of rainfall stations has been described as sparse before 1970 in Kilange, Donga and Dadin Kowa basins as reported by PFP (1982), MRT (1978) and Shawmont (1973) respectively the situation was worse in the Gongola Basin in recent times. A look at Fig. 6.1.1 (A & B) in conjunction with figures 4.1.1A and 5.3B would reveal that raingauge distribution was better during the period before 1969 and poor thereafter.

Stream gauging and synoptic stations basically remained the same during these periods but did not yield good records

In recent times, 1980 - 1982 the number of stream gauging stations increased to four folds (from 5 - 20) in the Gongola basin. Unfortunately only 10 of these have on record zero level of gauge (table 6.1.1B). Moreover, 9 out of these 10 are not useful for computing discharge as relevant rating curves do not exist. However, a better situation obtains in Donga and Taraba Basins. 8 and 4 gauging stations respectively have adequate informations necessary for reading discharge off stage observations.

Table 6.1.1B Distribution of stream gauging stations in Upper Benue River Basin (1980 - 1982)

River/Basin	No. of Stage Stations	No. of Stations with zero of gauge	Reference BM MSL/Local	No with rating curves
1. Benue river	8	8	7/1	2
2. Gongola Basin	20	10	7/3	2
3. Taraba Basin	8	7	5/1	4
4. Donga Basin	16	13	2/13	8
5. Kilange Basin	3	2	-/2	-
6. Mayo-Ine Basin	3	3	-/2	1
7. Mayo-Balwa Basin	1	1	-/1	-

6.1.2 DEVELOPMENT

Success in water resources planning, development and management in the Upper Benue Basin and in Nigeria at large will ensure economic stability and healthy citizenry of the nation because the potentials are abundantly available. When Agricultural potentials of the Upper Benue so far identified (1983) is fully developed it will yield about 0.8 billion naira revenue annually. Similar revenues could be expected from other subsectors such as fisheries, livestock, forestry and hydropower. With good planning and management, therefore, the Agricultural sector would supplement oil in the economy of Nigeria. Moreover, all necessary foods for healthy growth of the nation's citizens would be available locally and therefore, at affordable costs.

6.1.3 WATER RESOURCES PLANNING AND MANAGEMENT BY THE BOOK-KEEPING METHOD

The Book Keeping technique of the water budget method of computing runoff from rainfall data is equally applicable in the determination of water requirements of crops.

Temperature, rainfall and water holding capacity data are the basic requirement for application of the Book Keeping Technique. While the first two can easily be measured the third parameter can be estimated.

Computed runoff values from Rainfall data are compared with measured stream flow values at 3 gauging stations (Figs 4.1.2(A-S).

Figures 4.1.2.(A-C) and 4.1.2. (J-L) present successive approximations of computed to measured runoff at Dindima when (i) value of water holding capacities of soils in the catchment area of the gauging station at Dindima are assumed but over land runoff (DR) is ignored (fig 4.1.2 (A&S), (ii) Fig. 4.1.2. (B&K) show the comparison when DR is introduced while Fig.4.1.2 (C&L) show the comparison when water Holding Capacity of the soils is increased.

Figures 4.1.2 (D E & F) and 4.1.2. (M N&P) show similar comparisons between computed and measured runoff at Dadin Kowa while figures 4.1.2.(G,H & I) and 4.1.2. (Q,R & S) show the comparison between the two sets of values of flow at Bare.

The comparison of flows at Dindima show that introduction of DR does not affect the relation between computed and measured flows significantly while it affects the relation between these

sets of values of flow for Dadin Kowa and Bare stations.

This can be explained as follows: All the stations in the catchment area for the Dindima gauge are wet stations (average monthly rainfall) i.e water Holding Capacities are satisfied, therefore whether D.R. is introduced or not surplus moisture above WHC will eventually get to the stream. But for some stations in the catchment area for Dadin Kowa and Bare stream Gauging Stations some are dry stations e.g. Numan and Goniri (Annex II). At these stations WHC is never satisfied hence the only moisture that will reach the gauging station from the dry station is the overland runoff (DR). Due to unsatisfactory rainfall and stream gauging distribution in Gongola basin in recent times only stream flow at Dadin Kowa is considered for application of the Book Keeping Method of computing stream flow.

Similar analysis is carried out and final computed runoff at Dadin Kowa is compared with corresponding measured flow values for 1980-1982. Samples of Budget Sheets is presented at Annex IV. During the analysis it was discovered that computed runoff values seem to under-estimate measured flow values as amount of rainfall received decreases annually from 1980 - 1982. To make up for these so that a fair comparison is obtained between computed and measured stream flow values, DR value is increased up to 15% in some months (see Annex IV). Moreover, the number of dry Stations in Gongola basin increased. Even Bauchi was dry in 1982 (see Annex IV and Table 6.1.3B).

Table 6.1.3B STATION RECORDED DRY IN THE GONGOLA BASIN

Year Catchment Area	Average	1980	1981	1982
Dindima Stream Gauge	NONE	NONE	1	2
Dadin Kowa Stream gauge	NONE	6	8	9
Bare Stream Gauge	2	8*	10*	11*

*Expected since Dindima and Dadin Kowa are part of the catchment area for Bare stream gauge.

The less the amount of rainfall received at a dry station the drier it becomes. While there are no dry stations in the catchment area of the Dindima stream gauging station when rainfall is average and in 1980, there were one and two dry stations in 1981 and 1982 respectively. A station is said to be dry in a year if the amount of rainfall received that year is not enough to satisfy the Water Holding Capacity for that station.

There is no dry station in Dadin Kowa catchment area when rainfall is average while there were 6, 8 and 9 dry stations in 1980, 1981 and 1982 respectively. For Bare there are 2 dry stations for average rainfall while 8, 10 and 11 dry stations are probable for 1980, 1981 and 1982 respectively.

The above analysis shows that as the amount of rainfall received goes below average, computed runoff values underestimate measured values. The only way one can reconcile the two values is by increasing the DR percentage. Physical explanation of this is that the lesser the amount of rainfall received in an area the less the amount of water available for vegetation growth. Therefore, the less is the vegetation cover and the more the % of rainfall that would runoff overland. Even if the soil storage is far below capacity most of the rain will find its way to the streams by overland runoff since vegetation cover is less to give enough detention for infiltration to take place. This is a similar effect to that reported by Brown (1972) on Bush fire incidence in a catchment in New South Wales.

6.1.4 RELATION BETWEEN COMPUTED & MEASURED STREAM FLOW:

Table 4.1.2A gives relations between computed and measured values of stream flow at Dindima, Dadin Kowa and Bare when average rainfall data is used for the computation. Table 5.1.3A gives a similar information for stream flow at Dadin Kowa when rainfall records for 1980, 1981 and 1982 are used for computing stream flow. While coefficient of correlation between computed and measured flow at Dindima indicates very good agreement ($r_3 = 0.92$) the regression equation shows that computed value over estimates measured values, ($Y_3 = 15.97 + 1.1X_3$). The values of r_3 for Dadin Kowa and Bare stream gauging stations (1.00 for Diyam and 1.00 for Shawmont at Dadin Kowa and 0.99 for Bare) indicate

close agreement between computed and measured values of stream flows at those stations. Similarly regression equations between the two values at Dadin Kowa show very good fits (Y_3 = 73.1 +0.98X_3 for Diyam and Y_3 = 57.4 + 0.97X_3, for ShawMont) while for Bare it shows an excellent fit (Y_3 = 1.5 + 1.00X_3).

The correlation coefficients 0.96 for 1980 and 1982 and 0.94 for 1981) between computed and measured flows at Dadin Kowa show close agreement likewise the regression equations. The r value of 1 is not obtainable in practice. The values obtained could be due to the use of monthly values of rainfall. Use of long term annual data may yield more realistic results.

6.2 CONCLUSIONS:

6.2.1 WATER RESOURCES POTENTIALS:

Investigation reports have revealed tremendous potentials for water resources and agricultural development in Nigeria as indicated in the Upper Benue Basin. Effective planning and management of the Resources will ease the dependance on single commodity namely oil for the nations economic stability.

6.2.2 HYDRO-METEOROLOGICAL DATA:

There is a serious inadequacy in availablity of data necessary for planning and design of water resources projects. To facilitate efficient exploitation of the potentials great attention has to be paid to Data measurement and collection in the Hydro-meteorological activities of the River Basin Authorites.

6.2.3 BOOK KEEPING METHOD OF COMPUTING WATER BUDGET:

The Book Keeping technique of computing water Budget as developed by Thornthwaite and Mather (1955) and subsequently improvement by Mather (1981) is a useful tool for water shed management.

It can be employed to simulate runoff from a water shed accurately if rainfall and Temperature records are available in conjunction with soil and Topographic maps of the area, as demonstrated for the Gongola Basin.

6.2.4 RECOMMENDATIONS:

(i) Data collection for the purpose of water resources planning should be intensified to enable the nation develop its water resources and Agricultural potentials efficiently.

(ii) The Department of Water Resources and Environmental Engineering of Ahmadu Bello University Zaria and similar Institutions eleswhere in Nigeria should embark on research work to improve on this preliminary study by taking into account water holding capacity of soil in detail and other factors like topography land use and so on.

(iii) The Book Keeping method of water Budget analysis should be adopted for application in the water resources planning, development and management in basins where enough runoff records do not exist.

FIG 6.1.1A Distribution of rainfall stations and available records in Gongola basin 1916 - 1969

SRL No.	YEAR / STATION	LENTH OF RAINFALL RECORDS 1916 - 1969 (32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70)
1	JOS	1922
2	VOM *	
3	PANSHIN	
4	GINDIN – AKWATI *	
5	BUNUNU *	
6	BAUCHI	1915
7	KAFFIN MADAKI	
8	DARAZO	
9	MISAU	
10	FIKA	
11	GUJBA *	
12	DAMATURU	

* Complete records, other stations have missing records

FIG 6·1·1A (Continued)

SRL No.	YEAR / STATION	32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
13	POTISKUM	
14	GONIRI	
15	GOMBE *	
16	MERINGA	
17	KWAYA–TERA	
18	DADIN–KOWA	
19	DAMBOA	
20	AŞKIRA	
21	BIU	
22	KWAJAFA *	
23	GARKIDA *	
24	SHAM	
25	TULA	
26	NUMAN *	

Derived from average monthly rainfall data presented by kowal and knabe (1972) * Complete records, other stations have missing records

FIG 6·1·1B Distrubution of rainfall stations and available record in Gongola basin 1970 – 1983

SRL No.	YEAR / STATION	70 72 74 76 78 80 82 84
1	JOS	———
2	VOM	XVXVXVX
3	PANKSHIN	———
4	GINDIN – AKWATI	———
5	BUNUNU	XRXRXR
6	BAUCHI	———
7	KEFFIN – MADAKI	XRXRXR
8	DARAZO	XRXRXR
9	MISAU	XRXRXR
10	FIKA	———
11	GUJBA	record at Yadin Buni ———
12	DAMATURU	———
13	POTISKUM	———
14	GONIRI	XVXVXVX
15	GOMBE	———
16	MERINGA	XRXRXR
17	KWAYA TERA	XRXRX
10	DADIN – KOWA	———

XRXRXR – no record XVXVXV – not visited

FIG. 6·1·1B (Continued)

SRL No	YEAR / STATION	70 72 74 76 78 80 82 84
19	DAMATURU	some records said to be available
20	ASKIRA	XRXRXR
21	BIU	
22	KWAJAFFA	some records said to be available
23	GARKIDA	
24	SHANI	XRXRXR
25	TULA	XVXVXV
26	NUMAN	
27	WANDALI	
28	KUMO	
29	DEBA	
30	BILLIRI	
31	TALASSE	
32	TUMU	
33	ZAMBUK	
34	KALSHINGI	
35	KEMBU	
36	KASHERE	

XRXRXR — no record XVXVXV — not visited

FIG. 6·1·1B (Continued)

SRL No.	YEAR / STATION	70 72 74 76 78 80 82 84
37	WADACI	
30	BULA	
39	LAWANTI	
40	ALKALERI	
41	GARIN TAFITA	
42	DUGURI	
43	DUKKU	
44	DADIYA	
45	NAFADA	
46	UBA	
47	MAIDUGURI	temperature records for the years 1951–1965 used in computation of average monthly runoff.
48	YOLA	

XRXR – No record
XVXV – Not visited

STATION No. 27-46 ARE CONCENTRATED IN A FEW ZONES OF THE BASIN HENCE DOES NOT GIVE ADEQUATE DISTRIBUTION.

Table 6.1.3A

Selected 3 sets of parameters assumed for successive trials in sumulation of runoff from 26 runoff potentials.

	STATION	FIRST			SECOND			THIRD		
		WHC (mm)	DR %P	CF %	WHC (mm)	DR %P	CF %	WHC (mm)	DR %P	CF %
1	Jos	250	-	-	250	5	-	300	5-10	62
2	Vom	250	-	-	250	5	-	300	"	"
3	Pankshin	250	-	-	250	5	-	300	"	"
4	Gindi Akwati	250	-	-	250	5	-	300	"	"
5	Bununu	250	-	-	250	5	-	300	"	"
6	Bauchi	250	-	-	250	5	-	300	"	"
7	Keffin Madaki	200	-	-	200	5	-	250	"	66
8	Darazo	150	-	-	150	5	-	250	"	"
9	Misau	150	-	-	150	5	-	200	"	"
10	Fika	150	-	-	150	5	-	200	"	"
11	Gujba	150	-	-	150	5	-	150	"	"
12	Damaturu	125	-	-	125	5	-	125	"	"
13	Potiskum	125	-	-	125	5	-	150	"	"
14	Goniri	75	-	-	75	5	-	75	"	"
15	Gombe	150	-	-	150	5	-	150	"	"
16	Meringa	150	-	-	150	5	-	75	"	90
17	Kwaya Tera	150	-	-	150	5	-	50	"	"
18	Dadin Kowa	150	-	-	150	5	-	75	"	95
19	Damboa	150	-	-	150	5	-	75	"	"
20	Askira	150	-	-	150	5	-	75	"	"
21	Biu	150	-	-	150	5	-	50	"	"
22	Kwajaffa	150	-	-	150	5	-	50	"	"
23	Garkida	150	-	-	150	5	-	75	"	"
24	Shani	150	-	-	150	5	-	75	"	"
25	Tula	100	-	-	100	5	-	75	"	"
26	Numan	300	-	-	300	5	-	350	"	"

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ANNEX I

AVERAGE MONTHLY RAINFALL AND TEMPERATURE RECORDS FOR 26 STATIONS RELEVANT TO THE GONGOLA BASIN.

Annex – 1

Average monthly Rainfall and Temperature records for 26 stations

A – Rainfall

	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	No of Years	Period
1	Jos	2	3	24	95	187	223	320	278	213	41	3	2	1391	45	1922 – 1965
2	Vom	3	4	30	114	188	197	271	260	209	49	6	1	1332	20*	1946 – 1965
3	Pankshin	2	1	15	54	105	129	195	266	218	67	7	1	1060	34	1932 – 1965
4	Gindi Akwati	6	7	41	106	159	221	238	319	212	45	6	1	1361	15*	1951 – 1965
5	Bununu	0	0	14	42	68	148	280	274	191	24	3	0	1044	10*	1955 – 1964
6	Bauchi	0	0	5	33	89	148	250	341	182	36	1	0	1085	48	1916 – 1965
7	Keffin Madaki	0	0	6	17	83	150	265	310	171	36	0	0	1038	14	1952 – 1960
8	Darazo	0	0	3	20	77	134	233	386	161	35	0	0	1049	13	1953 – 1965
9	Misau	0	0	0	11	39	97	213	271	136	22	0	0	789	12	1953 – 1965
10	Fika	0	0	0	19	54	109	217	296	159	24	0	0	878	14	1952 – 1965
11	Gujba	0	0	0	13	47	103	197	240	157	22	0	0	726	10*	1952 – 1961
12	Damaturu	0	0	2	8	23	89	204	255	122	15	0	0	718	12	1952 – 1965
13	Potiskum	0	0	0	11	39	97	213	271	136	22	0	0	789	30	1936 – 1965
14	Goniri	0	0	2	12	39	90	189	199	121	26	0	0	678	12	1952 – 1963
15	Gombe	0	0	8	47	104	147	197	220	184	48	3	0	958	16*	1954 – 1969
16	Merinça	0	0	2	46	88	138	182	205	189	57	0	0	907	9	1952 – 1960
17	Kwaya Tera	0	0	4	23	101	109	228	232	190	82	5	0	944	11	1952 – 1962
18	Dadin Kowa	0	0	10	36	49	140	220	279	261	89	9	3	1096	6	1960 – 1965

Annex – 1 Cont.

	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	No of Years	Period
19	Damboa	0	0	5	14	70	136	231	258	169	21	0	0	904	12	1952 – 1965
20	Askira	0	0	3	11	90	157	189	240	220	65	7	0	982	10	1952 – 1965
21	Biu	0	0	3	23	111	147	188	229	206	60	2	0	979	26	1940 – 1965
22	Kwajaffa	0	0	6	25	79	141	212	195	193	65	0	0	916	9*	1953 – 1961
23	Garkida	0	0	2	28	52	124	168	195	199	72	0	0	840	6*	1960 – 1965
24	Shani	0	0	12	13	107	134	210	242	170	88	3	0	989	10	1951 – 1962
25	Tula	0	0	9	39	85	133	163	192	209	86	10	0	926	15	1952 – 1960
26	Numan	0	5	10	33	118	121	116	141	158	52	1	1	756	14*	1950 – 1963
		B – Temperature														
1	Jos	20.8	22.7	24.2	24.0	23.1	21.8	20.5	20.2	21.2	22.2	21.7	21.2		45	1922 – 1965
2	Bauchi	22.6	25.1	26.3	29.7	28.7	26.2	24.0	23.1	24.6	25.8	23.4	22.6		48	1916 – 1965
3	Potiskum	21.3	23.9	27.8	31.3	31.5	28.6	26.4	25.6	26.4	27.0	24.4	21.8		30	1936 – 1965
4	Maiduguri	22.7	24.4	28.1	31.9	32.2	30,0	27.5	26.7	27.4	28.2	25.1	23.0		15	1951 – 1965
5	Yola	25.5	28.1	31.6	31.6	30.3	27.4	26.8	26.3	26.5	27.6	26.7	25.0		15*	1951 – 1965

ANNEX II

SAMPLES OF WATER BUDGET SHEETS FOR 26 REPRESENTATIVE STATIONS IN THE GONGOLA BASIN.

GONGOLA BASIN WATER BUDGET

Year: 20• Year (AVG) Station: Vom
Rainfell Station: Vom Temperature Station: Jos
DR = 5%P for April - June Water Holding Capacity = 250mm
DR = 5%P for July - Sept.

Row No.1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T℃	20.8	22.7	24.2	24.0	23.1	21.8	20.5	20.2	21.2	22.2	21.7	21.2	-	
3	i	8.66	9.88	10.89	10.75	10.15	9.29	8.47	8.28	8.91	9.55	9.23	8.91	113.0	
4	UnadjPE	2.6	3.2	3.6	3.5	3.3	2.8	2.5	2.4	2.7	3.0	2.8	2.7	-	RO = 0.75S
5	AdjF	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7	-	
6	AdjPE	78	87	111	108	107	87	81	77	83	92	82	90	1075	REVISED COMPUTATION
7	P	3	4	30	114	188	197	271	260	209	49	6	1	1332	
8	DR	0	0	0	6	9	10	14	13	10	0	0	0	62	
9	Peff	3	4	30	108	179	187	257	247	199	49	6	1	1270	
10	Peff-PE	-75	-83	-81	0	72	98	176	170	116	-43	-76	-79	195	
11	ST	83	59	42	42	114	212	250	250	250	210	155	112	-	
12	ΔST	29	24	17	0	+72	+98	+38	0	0	40	45	43	-	
13	AE	32	28	47	108	107	89	89	77	83	89	61	44	-	
14	B	46	59	64	0	0	0	0	0	0	3	21	36	-	
15	S	0	0	0	0	0	0	138	170	116	0	0	0	-	
16	RO	0	0	0	0	0	0	104	153	125	31	8	2	-	20• Years record
17	TRO	0	0	0	6	9	10	118	166	135	31	8	2	486	complete.

GONGOLA BASIN WATER BUDGET

Year: 45 year (AVG) Station: Jos

Rainfall station: Jos Temperature station: Jos

DR NIL %P for: April - June Water Holding Capacity 200mm

DR NIL %P for July - Sept.

Row No. 1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	TC														
3	i														
4	UnadjPE					AS FOR VOM									
5.	AdjF														
6	AdjPE	73	87	111	108	107	89	81	77	83	92	82	80	1075	
7	P	2	3	24	95	187	223	320	278	213	41	3	2	1391	
8	DR														
9	Peff. P	-76	- 84	-87	-13	+80	+134	+239	+ 201	+130	-51	-79	-78	-316	
10	Peff-PE														
11	ST	47	31	20	19	99	200	200	200	200	154	104	70	-	45 years record not complete.
12	ΔST	-23	-16	-11	- 1	+80	+101	0	0	0	- 46	- 50	-34	-	
13	AE	25	19	35	96	107	89	81	77	83	87	53	36	-	
14	D	53	68	66	12	0	0	0	0	0	5	29	44	-	
15	S	0	0	0	0	0	33	239	201	213	0	0	0	-	
16	RO	0.80	0.20	0.10	0	0	25	185	197	209	52	13	3	-	RO = 0.75S
17	TRO														

GONGOLA BASIN WATER BUDGET

Year: 45 Year (AVG)
Rainfall station: Jos
DR = %P for April - June
DR = %P for July - Sept.

Station: Jos
Temperature station: Jos
Water Holding Capacity 250mm

Row No.	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	TC														
3	i														
4	UnadjPE														
5	AdjF					AS FOR JOS above									
6	AdjPE														
7	P														RC = 0.75
8	DR														
9	Peff														
10	Peff-PE														
11	ST	79	56	40	38	118	250	250	250	250	204	146	108	-	REVISED COMPUTATIONS ASSUMED
12	ΔST	29	23	16	2	80	132	0	0	0	46	56	40	-	
13	AE	31	26	40	97	107	89	81	77	83	87	59	36	-	Water holding Capacity = 250mm
14	D	47	61	61	11	0	0	0	0	0	5	23	44	-	
15	S	0	0	0	0	0	2	239	201	130	0	0	0	572	
16	RO	0.6	0.1	0	0	0	1.50	180	196	146	37	9.0	2.30	-	
17	TRO														

GONGOLA BASIN WATER BUDGET

Year: 45 year (AVG) Station: Jos
Rainfall Station: Jos Temperature Station: Jos
DR = 5%P for April - June Water Holding Capacity 250mm
DR = 5%P for July - Sept.

Row No.	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T°														
3	i														
4	UnadjPE						AS FOR JOS ABOVE								
5	AdjF														
6	AdjPE	78	87	111	108	107	89	81	77	83	92	82	80	1075	REVISED COMPUTATION DR ASSUMED
7	P	2	3	24	95	187	223	320	278	213	41	3	2	1391	
8	DR	0	0	0	5	9	11	16	14	11	0	0	0	66	
9	Peff	2	3	24	90	178	212	304	264	202	41	3	2	-	
10	Peff-PE	−76	−84	−87	−18	71	123	223	187	117	−51	−79	−78	-	
11	ST	79	56	40	37	108	231	250	250	250	204	140	108	-	
12	ΔST	−29	−23	−16	−3	71	123	19	0	0	−46	−56	−40	-	
13	AE	31	26	40	93	107	89	81	77	83	87	59	43	-	
14	D	47	61	71	15	0	0	0	0	0	5	23	37	-	
15	S	0	0	0	0	0	0	204	187	117	0	0	0	-	RO = 0.755
16	RO	1.0	0	0	0	0	0	153	179	132	33	0	2	-	
17	TRO	1	0	0	5	9	11	169	193	113	33	0	2	[illegible]	

GONGOLA BASIN WATER BUDGET

Year: 45 Year (AV3) Station: Jos

Rainfall Station: Jos Temperature Station: Jos

DR = 10%P for May - June Water Holding Capacity 300mm

DR = 50%P fro April & July - Sept.

Row No.1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T°														
3	i														
4	UnadjPE														
5	AdjF														
6	AdjPE	78	87	111	108	107	89	81	77	83	92	82	80	1075	
7	P	2	3	24	95	187	223	320	278	213	41	3	2	1391	REVISED COMPUTATION
8	DR	0	0	0	5	18.70	22.70	16	14	11	0	0	0	82	
9	Peff	2	3	24	90	168	200	304	264	202	41	3	2	1309	
10	Peff-PE	−76	−84	−87	−18	+61	111	223	187	119	−51	−79	−78	234	
11	ST	115	87	65	61	122	233	300	300	300	253	194	149	-	
12	ΔST	−34	−28	−22	−4	61	111	67	0	0	−47	−59	−45	-	
13	AE	36	31	66	94	107	89	81	77	83	88	62	47	-	
14	D	42	56	45	14	0	0	0	0	0	4	20	23	-	
15	S	0	0	0	0	0	0	156	187	119	0	0	0	-	
16	RO	0	0	0	0	0	0	140	168	125	13	1	0	-	RO = 0.90S
17	TRO	0	0	0	5	19	23	156	197	136	13	1	0	-	

GONGOLA BASIN **WATER** BUDGET

Year: 48 Year AVG — Station: Bauchi

Rainfall Station: Bauchi — Temperature Station: **Bauchi**

DR = %F for April - June — Water Holding Capacity = 100mm

DR = %F for July - Sept.

Row No.1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	TĈ	22.6	25.1	28.3	29.7	28.7	26.2	24.8	24.1	21.6	25.8	23.4	22.6	-	
3	i	9.82	11.50	11.80	14.84	11.09	12.28	11.23	10.22	11.16	11.99	10.35	9.82	143	
4	UnAdjPE	2.7	3.7	5.0	5.3	5.1	4.3	3.5	3.2	3.4	4.1	3.1	2.7	-	
5	AdjF	30.0	27.3	30.9	30.9	22.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7	-	
6	AdjPE	81	101	155	165	165	137	113	109	104	126	91	80	1420	
7	P	0	0	5	33	89	148	250	317	102	36	1	0	1085	
8	DR														
9	Peff=P	- 81	-101	-150	-131	- 76	11	137	238	78	- 90	- 90	-80	335	
10	Peff-PE														
11	ST	3	1	1	1	1	12	100	100	100	40	60	7	-	
12	ΔST	4	2	0	0	0	11	88	0	0	16	24	9	-	
13	AE	4	2	5	33	89	137	113	103	104	96	25	9	-	
14	D	77	99	150	131	76	0	0	0	0	30	66	71	-	
15	S	0	0	0	0	0	0	49	238	76	0	0	0	-	
16	RO	6.6	3.3	1.5	0.8	0.4	0.2	25	131	105	52	26	13	-	
17	TRO														

GONGOLA BASIN WATER BDUGET

Year: 40 Year AVG
Rainfall Station: Bauchi
DR = 10%F for June
DR = 5%F for July - Sept.

Station: Bauchi
Temperature Station: Bauchi
Water Holding Capacity 300mm.

Row No.	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T^{C}														
3	i														
4	UnadjPE														
5	AdjF														
6	AdjPE	81	101	155	164	165	137	113	103	104	126	91	80	1420	
7	F	0	0	5	33	89	149	250	341	102	36	1	0	1085	AS ABOVE BUT 50% RUN OFF
8	DR	0	0	0	0	0	15	13	17	9	0	0	0	54	
9	P_{eff}	0	0	5	33	89	133	237	324	173	86	1	0	1031	
10	P_{eff-PE}	-81	-101	-150	-131	-76	-4	124	221	69	-40	-90	-80	389	
11	ST	95	68	11	26	20	20	144	300	300	220	164	125	-	
12	ΔST	-	-	-	-	-	-	-	156	-	-	-	-	-	
13	AE														
14	D														
15	S								65	69					
16	RO	3	2	1	0	0	0	0	33	51	26	13	6	-	
17	TRO	3	2	1	0	0	15	13	50	60	26	13	6	-	

GONGOLA BASIN WATER BUDGET

Year: 12 Year AVG — Station: Misau
Rainfall Station: Misau — Temperature Station: Potiskum
DR = 5%P for April - June — Water Holding Capacity = 200mm
DR = 5%P for July - Sept,

Row No. 1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T°C	21.3	23.9	27.8	31.3	31.5	28.6	26.4	25.6	26.4	27.0	24.4	21.8	–	
3	i	6.07	10.68	13.43	16.07	16.25	14.02	12.42	11.85	12.42	12.85	11.02	9.29	119	
4	UnadjPE	2.3	3.1	4.9	5.6	5.7	5.1	4.4	3.9	4.4	4.6	3.4	2.4	–	
5	AdjP	29.7	27.3	30.9	30.9	32.7	31.8	32.7	32.1	30.6	30.6	29.1	29.7	–	
6	AdjPE	68	85	151	173	186	162	144	125	135	141	99	71	1540	12 years record incomplete.
7	P	0	0	0	11	39	97	213	271	136	22	0	0	789	
8	D.N	0	0	0	0	2	5	11	14	7	0	0	0	40	
9	P_{eff}	0	0	0	11	37	92	202	257	129	22	0	0	749	
10	P_{eff-PE}	-68	-85	-151	-162	-149	-70	-58	132	-6	-119	-99	-71	791	
11	ST	13	7	3	1	1	1	59	150	144	64	33	20	–	
12	ΔST	-7	-6	-4	-2	0	0	58	91	-6	-80	-31	-13	–	
13	AE	7	6	4	12	37	92	144	125	135	102	31	13	–	
14	D	61	79	147	161	149	70	0	0	0	39	68	58	–	
15	S	0	0	0	0	0	0	0	41	0	0	0	0	–	
16	RO	1	0	0	0	0	0	0	0	0	0	0	0	–	RO = 0.5QS
17	TRO	1	0	0	0	2	5	11	14	7	0	0	0	40	

GONGOLA BASIN WATER BUDGET

Year: 12 Year AVG — Station: Goniri
Rainfaff Station: Goniri — Temperature Station: Maiduguri
DR = 5%I for April - June — Water Holding Capacity = 75mm
DR = 5%I for July - Sept.

Row No. 1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T°C	22.7	24.4	28.1	31.9	32.2	30.0	27.5	26.7	27.4	28.2	25.2	23.0	-	
3	i	9.88	11.02	13.65	16.54	16.78	15.07	13.21	12.63	13.14	12.72	11.50	10.08	157	
4	UnadjE	2.8	3.4	5.0	5.8	5.8	5.4	4.8	4.6	4.8	5.0	3.9	3.3	-	
5	AdjP	29.7	27.3	30.0	30.9	32.7	31.8	32.7	32.1	30.6	30.6	29.1	29.2	-	
6	AdjE	83	93	155	179	190	172	157	140	147	153	113	96	1684	
7	I	0	0	2	12	39	90	109	199	121	26	0	0	671	
8	DR	0	0	0	0	2	5	9	10	6	0	0	0	33	
9	P_{eff}	0	0	0	12	37	85	100	189	115	26	0	0	645	12 years record not complete.
10	P_{eff-PE}	-83	-93	-155	-167	-153	-87	23	41	-32	-127	-113	-90	1043	
11	ST	1	1	1	1	1	1	24	65	42	7	2	1	-	
12	ΔST	0	0	0	0	0	0	+23	+41	-13	-35	-5	-1	-	
13	AE	0	0	0	11	37	85	157	148	120	61	5	1	-	S = 0
14	D	83	93	155	168	153	87	0	0	19	92	108	97	-	
15	S	0	0	0	0	0	0	0	0	0	0	0	0	-	∴ RO = 0
16	RO	0	0	0	0	0	0	0	0	0	0	0	0	-	
17	TRO	0	0	0	0	2	5	9	10	6	0	0	0	33	TRO = DR

GONGOLA BASIN WATER BUDGET

Year: 14• Year AVG — Station: Numan
Rainfall Station: Numan — Temperature: Yola
DR = 5%F for May - June — Water Holding Capacity = 350mm
DR = 5%F for July - Sept.

Row No. 1	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	TC														
3	1														
4	UnadjE														
5	AdjF														
6	AdjE	117	137	176	176	170	153	140	130	135	147	135	110	1715	Sum of -ve P_{eff}-PE at the end of -ve Peff for starting computation of ST = (-1065)
7	P	0	5	10	33	118	121	116	141	150	52	1	1	754	
8	DR	0	0	0	0	6	6	6	7	8	0	0	0	35	
9	P_{eff}	0	5	10	33	112	115	110	134	150	52	1	1	719	
10	P_{eff}-AE	-117	-132	-166	-143	-66	-38	-38	-4	-15	-95	-134	-109	1030	
11	ST	4	3	2	2	1	1	1	1	16	12	8	6	-	14 years record complete.
12	ΔST	-1	-1	-1	0	-1	0	0	0	15	-4	-4	-3	-	
13	AE	1	6	10	31	113	115	110	134	135	56	5	1	-	
14	D	116	131	166	145	65	38	38	4	0	91	136	106	-	
15	S	0	0	0	0	0	0	0	0	0	0	0	0	-	
16	RC	0	0	0	0	0	0	0	0	0	0	0	0	-	RC = 0
17	TRC	0	0	0	0	6	6	6	7	8	0	0	0	35	

ANNEX III

RAINFALL AND TEMPERATURE RECORDS FOR 14 STATIONS RELEVANT TO THE STREAM GAUGING STATION AT DADIN-KO'IA.

GONGOLA BASIN JOS-DADIN KOWA

RAINFALL DATA - 1980

ANNEX-IIIA

S/NO.	Month / Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	Jos	0.0	18.1	14.2	11.3	238.4	166.3	239.5	237.3	113.6	69.7	0.0	0.0
2	G/Akwati	0.0	15.2	26.2	11.7	192.8	363.2	191.5	168.6	115.3	69.3	0.0	0.0
3	Pankshin	0.0	0.0	2.7	3.8	287.0	359.9	294.6	328.2	4.3	4.3	0.0	0.0
4	Bula	0.0	0.0	0.0	0.0	99.3	124.0	163.8	223.0	111.4	63.0	0.0	0.0
5	Bauchi	0.0	0.0	0.0	0.5	111.6	121.3	314.1	317.2	82.5	40.3	0.0	0.0
6	Alkaleri	0.0	0.0	0.0	5.9	70.3	114.8	240.9	262.0	102.3	52.2	0.0	0.0
7	Dukku	(0.0)	(0.0)	(4.5)	(1.3)	(61.0)	(102.3)	(240.8)	(234.8)	(77.7)	(42.8)	(0.0)	(0.0)
8	Fika	0.0	0.0	0.0	0.0	43.2	83.8	165.1	111.8	12.7	25.4	0.0	0.0
9	Gombe	0.0	0.0	7.8	0.0	19.04	99.1	244.9	245.9	113.1	53.4	0.0	0.0
10	Potiskum	0.0	0.0	0.0	0.0	91.9	159.7	191.8	215.2	18.6	5.6	0.0	0.0
11	Damaturu	0.0	0.0	0.0	0.0	23.2	88.5	8.6	167.2	14.5	11.0	0.0	0.0
12	Buni	0.0	0.0	0.0	0.0	32.6	104.6	139.8	239.5	12.8	8.8	0.0	0.0
13	Biu	0.0	0.0	5.6	11.3	96.0	32.2	65.4	87.2	76.8	10.0	1.1	0.0
14	D/Kowa	0.0	0.0	0.0		195.1	94.5	263.9	229.9	0.0	30.7	0.0	0.0

MEAN MONTHLY TEMPERATURE 1980

D/Kowa	25.5	27.4	31.4	33.2	28.6	27.3	25.9	25.8	26.9	28.3	28.8	26.4
Bauchi	23.3	25.2	28.8	30.9	29.0	26.9	25.1	24.7	25.6	26.3	24.4	21.9
Potiskum	22.2	25.0	28.0	31.7	31.2	28.0	26.8	26.1	28.0	29.0	25.9	21.5
Jos	20.7	22.0	24.0	25.2	23.2	21.5	20.9	20.8	21.5	22.3	21.3	19.2

(Interpolated records are put in brackets)

ANNEX IIIB

GONGOLA BASIN JOS-DADIN KOWA
RAINFALL DATA - 1981

S/No.	Month/ Station	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.	Jos	0.0	233.0	(.0	99.5	183.8	206.3	249.4	294.6	190.7	48.2	0.0	0.0
2.	G/Akwati	0.0	0.0	(.0	73.7	236.7	123.2	230.9	232.2	258.6	16.8	0.0	0.0
3.	Pankshin	0.0	0.0	(.0	74.2	104.2	142.8	104.6	185.3	209.5	61.4	0.0	0.0
4.	Bula	(0.0)	(152.4)	(0.0)	(74.6)	(137.9)	(154.7)	(187.1)	(221.0)	(143.0)	(36.2)	(0.0)	(0.0)
5.	Bauchi	0.0	0.0	0.0	28.2	120.2	246.3	396.3	268.9	172.5	18.4	0.0	0.0
6.	Alkaleri	0.0	0.0	0.0	0.0	0.0	227.3	213.4	250.0	88.0	44.2	0.0	0.0
7.	Dukku	0.0	0.0	0.0	0.0	0.0	139.5	212.6	180.1	61.2	18.8	0.0	0.0
8.	Pika	0,0	0.0	0.0	0.0	6.6	183.9	197.1	160.5	41.9	48.8	0.0	0.0
9.	Gombe	0.0	0.0	0.0	21.0	82.0	158.0	204.0	154.0	105.0	26.0	0.0	0.0
10.	Potirkum	0.0	0.0	0.0	9.8	72.4	154	201.1	185.0	83.2	27.4	0.0	0.0
11.	Damaturu	0.0	0.0	0.0	0.0	87.3	125	105.9	169.7	102.0	0.0	0.0	0.0
12.	Buni	0.0	0.0	0.0	0.0	56.4	124	254.0	164.2	67.6	40.2	0.0	0.0
13.	Biu	0.0	0.0	2.8	32.7	91.2	116.3	301.7	119.0	84.1	111.8	0.0	0.0
14.	D/Kowa	0.0	0.0	0.0	41.1	75.2	141.0	233.0	130.0	55.2	57.0	0.0	0.0

MEAN MONTHLY TEMPERATURE 1981

D/Kowa	25.9	29.0	32.6	34.0	31.3	29.2	26.6	26.4	27.4	33.2	27.0	28.0
Bauchi	21.2	25.0	28.8	30.5	28.7	26.7	24.8	25.6	25.6	26.9	23.4	22.2
Potiskum	19.6	24.5	28.1	31.3	31.3	29.3	26.1	26.8	27.3	28.1	24.3	22.3
Jos	19.4	21.9	24.3	24.8	22.7	21.6	20.0	20.7	21.4	22.6	19.9	20.5

(Interpolated records are put in brackets)

ANNEX IIIC

GONGOLA BASIN JOS -DADIN KOWA

RAINFALL DATA - 1982

S/No.	Month/ Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.	STC
1.	Jos	0.0	0.0	8.4	204.7	144.2	169.2	381.5	252.8	135.5	34.1	0.0	0.0	300
2.	G/Akwati	3.4	3.5	43.7	84.8	139.1	194.3	259.0	359.5	171.5	102.8	0.0	0.0	300
3.	Pankshin	0.0	0.0	39.1	39.1	50.3	144.5	189.5	262.8	200.8	44.3	0.0	0.0	300
4.	Bula	(0.0)	(0.0)	(6.3)	(153.5)	(108.2)	(126.9)	(286.1)	(189.6	(101.6)	(25.6)	(0.0)	(0.0	300
5.	Bauchi	0.0	0.0	0.0	43.8	38.4	164.9	233.2	239.1	146.0	31.6	0.0	0.0	300
6.	Alkaleri	0.0	0.0	0.0	38.0	1.0	118.0	188.0	293.0	155.0	62.0	0.0	0.0	250
7.	Dukku	0.0	0.0	0.0	33.0	62.0	94.0	206.0	272.0	199.0	30.0	0.0	0.0	200
8.	Pika	0.0	0.0	0.0	9.3	54.9	68.0	100.1	149.4	0.0	0.0	0.0	0.0	200
9.	Gombe	0.0	0.0	0.0	51.0	28.0	148.0	147.0	255.0	178.0	77.0	0.0	0.0	150
10.	Potiskum	0.0	0.0	0.0	19.2	40.2	38.3	127.7	235.2	76.0	51.3	0.0	0.0	150
11.	Dameturu	0.0	0.0	0.0	6.0	33.0	86.5	158.5	120.0	49.5	54.5	0.0	0.0	125
12.	Buni	0.0	0.0	0.0	0.0	14.2	120.0	130.9	139.7	116.0	56.2	0.0	0.0	150
13.	Biu	0.0	0.0	2.3	62.8	39.4	113.0	161.8	160.1	110.7	90.8	0.0	0.0	50
14.	D/Kowa	0.0	0.0	0.0	86.5	37.7	120.5	157.0	161.3	149.7	139.4	0.0	0.0	75

MEAN MONTHLY TEMPERATURE 1982

D/Kowa	27.3	29.1	31.8	34.6	32.7	29.6	28.1	27.6	29.3	29.4	24.7	25.6
Bauchi	22.8	23.9	29.0	30.6	28.6	27.0	25.0	24.9	25.2	26.5	23.0	22.7
Potiskum	22.2	24.6	28.9	31.6	31.4	30.1	27.7	26.5	27.5	28.0	23.6	22.1
Jos	20.7	21.7	23.9	23.8	22.7	22.1	20.8	20.4	21.2	22.0	20.3	20.2

(Interpolated records are put in brackets)

ANNEX IV

WATER BUDGET SHEETS FOR CATCHMENT AREA OF THE STREAM GAUGING STATION AT DADIN KOWA FOR THE YEAR 1982

GONGOLA BASIN WATER BUDGET

Year: 14 Station: Numan

Rainfall Station: Numan Temperature Station: Yola

DR = %F for April - June Water Holding Capacity = 350mm

DR = %F for July - Sept.

ROW NO.	Month/ Elem	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	T℃	25.5	28.1	31.6	31.6	30.3	27.4	26.8	26.3	26.5	27.6	26.7	25.0		Starting cumulative
3	i	11.8	13.7	16.3	16.3	15.3	13.1	12.7	12.4	12.5	13.3	12.6	11.4	161	- ve F- PE at the
4	Unadj PE	3.9	5.0	5.7	5.7	5.5	4.8	4.6	4.3	4.4	4.8	4.6	3.7		end of - ve F- PE
5	Adj F	30.3	27.6	30.9	30.9	32.1	31.5	32.1	31.0	30.6	30.6	29.4	30.0		period = 1500
6	Adj PE	117	137	176	176	178	153	148	130	135	147	135	110	1749	
7	i	0	5	10	33	110	121	116	141	150	52	1	1	754	
8	DR	-	-	-	-	-	-	-	-	-	-	-	-	-	
9	F_{eff}	-	-	-	-	-	-	-	-	-	-	-	-	-	
10	F_{eff}-PE	-117	-131	-166	-143	-60	-32	-32	3	23	-95	-131	-109	-995	14 year record complete.
11	ST	1	1	1	1	1	1	1	4	4	2	2	1		
12	ΔST	0	0	0	0	0	0	0	+3	0	-2	0	1		
13	AE	0	5	10	33	110	121	116	130	135	54	1	1		
14	D	116	132	166	143	60	32	32	0	0	91	134	109		
15	S	0	0	0	0	0	0	0	0	0	0	0	0		S = 0
16	RO	0	0	0	0	0	0	0	0	0	0	0	0		RO = 0
17	TRO	0	0	0	0	0	0	0	0	0	0	0	0		

GONGOLA BASIN WATER BUDGET

Year: 1982 Station: Jos.

DR =10 %P for April Temperation station: Jos

DR =5 %P for June-Sept. Water Holding Capacity 300mm

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct	Nov	Dec.	Year	Remarks
2	T_C^o	20.7	21.7	22.7	23.8	22.7	22.1	20.8	20.4	21.2	22.0	20.3	20.2	(I)	
3	i	8.59	9.23	10.62	9.88	9.49	8.66	8.41	8.41	8.91	9.42	8.34	8.28	iii	
4	UnadjPE	2.6	2.8	3.5	3.4	3.2	2.9	2.6	2.5	2.7	2.9	2.4	2.4		
5	AdjF	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7		
6	AdjpE	78.0	76.4	108.2	105.1	103.7	92.2	84.2	80.3	82.6	88.7	70.6	71.3	1041.0	
7	P	0.0	0.0	8.4	204.7	144.2	169.2	381.5	252.8	135.5	34.1	0.0	0.0	1330.0	
8	DR	0.0)	0.0	0.0	20.5	14.4	8.5	19.1	12.6	6.8	0.0	0.0	0.0	82.0	
9	P_{eff}	0.0	0.0	8.4	184.2	129.8	160.7	362.4	240.2	128.7	34.1	0.0	0.0	1248.0	
10.	P_{eff-PE}	-78.0	-76.4	-99.8	+79.1	26.1	68.5	278.2	159.9	46.1	-54.6	-70.6	-71.3	4207.0	
11	ST	119	92	66	145	171	240	240	300	300	249	197	155	-	
12	Δ ST	-36	-27	-26	+79	+26	+69	+69	+60	0	-51	-52	-42	-	
13	AE	36	27	34	105.1	103.7	92.2	84.2	80.3	82.6	85.1	52	42	-	
14	D	42.0	49.4	74.4	0.0	0.0	0.0	0.0	0.0	0.0	3.6	18.6	29.3	-	RO = 0.50S
15	S	0.0	0.0	0.0	0.0	0.0	0.0	218.2	159.9	46.1	0.0	0.0	0.0	-	
16.	RO	5.6	2.8	1.4	1.4	0.0	0.0	109.1	134.5	90.3	45.2	22.6	11.3	-	
17	TRO	5.6	2.8	1.4	21.9	14.4	8.5	120.2	147.1	147.1	97.1	45.2	11.3	-	

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Gindin Akwati
Rainfall Station: Gindin Akwati — Temperature Station: Jos
DR =5 %P for April-June — Water Holding Capacity 300mm
DR =5 %P for July-September.

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct	Nov	Dec.	Year	Remarks
2	°C														
3	i				AS FOR JOS										
4	UnadPE	2.6	2.8	3.5	3.4	3.2	2.9	2.6	2.5	2.7	2.9	2.4	2.4	-	
5	AdjPE	30.0	27.6	30.9	30.9	32.4	31.5	32.4	31.8	20.6	30.6	29.4	30.0	-	
6	AdjPE	78.0	77.3	180.2	105.1	103.7	91.4	84.2	79.5	82.6	88.7	70.6	72.0	-	
7	P	3.6	3.6	43.7	84.8	139.1	194.3	259.0	359.5	171.5	102.8	0.0	0.0	-	
8	DR	0.0	0.0	0.0	4.2	7.0	9.7	13.0	18.0	8.6	5.1	0.0	0.0	-	
9	Peff	3.8	3.6	43.7	80.6	132.1	184.6	246.0	341.5	162.9	97.7	0.0	0.0	-	
10	Peff-PE	-74.2	-73.7	-64.5	- 24.5	+28.4	93.2	161.8	262.0	80.3	9.0	-70.6	-72.0	-	
11.	ST	-	-	-	84	112	211	300	300	300	300	236	-	-	
12	ØST	-	-	-	-	-	-	+89	0	0	0	-64	-	-	
13	AE	-	-	-	-	-	-	-	-	-	-	-	-	-	
14.	D	-	-	-	-	-	-	-	-	-	-	-	-	-	
15	S	0.0	0.0	0.0	0.0	0·0	0.0	72.8	262.0	80.3	9·0	0.0	0.0	-	
16	RO	7.7	3.9	1.9	1.0	1.0	0.0	36.4	149.2	114.8	61.9	30.9	15.5	-	RO = 0.5PS
17.	TRO	7.7	3.9	1.9	5.2	1.7	9.7	49.4	167.2	124.2	67.0	30.9	15.5	-	

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station Pankshin

Rainfall station: Pankshin — Temperature station: Jos

DR = 5 %P for June & July — Water Holding Capacity 300mm

DR = 10%P for August & Sept.

Row No. 1	Month/ Elem.	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	°TC														
3	i														
4	UnadPE	AS FOR GINDI AKWATI													
5	AdjF														
6	AdjPE														
7	P	0.0	0.0	39.1	39.1	50.3	144.5	189.5	262.8	200.8	44.3	0.0	0.0	-	
8	DR	0.0	0.0	0.0	0.0	0.0	7.2	9.5	26.3	20.1	0.0	0.0	0.0	-	
9	Peff	0.0	0.0	39.1	39.1	50.3	137.3	180.0	236.5	180.7	44.3	0.0	0.0	-	
10.	Peff-PE	-78.0	-77.3	-69.2	-66.0	-53.4	+45.9	95.8	152.3	101.2	-4[illegible].1	-70.6	72.0	-	
11	ST	123	95	73	60	50	96	192	300	300	259	204	160	-	
12	ΔST	-ve	-ve	-ve	-ve	-ve	+ve	+96.0	+108	0.0	-ve	-ve	-ve	-	
13	AE	-	-	-	-	-	-	-	-	-	-	-	-	-	
14	D	-	-	-	-	-	-	-	-	-	-	-	-	-	
15	S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.3	101.2	0.0	0.0	0.0	-	
16	RO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.2	84.2	21.1	5.3	1.3	-	RO = 0.75S
17	TRO	0.0	0.0	0.0	0.0	0.0	7.2	9.5	59.5	104.3	21.1	5.3	1.3	-	

GONGOLA BASIN WATER BUDGET

Year: 1982
Rainfall Station: Bula
DR=10 %P for April-July
DR=15 %P for August
1 10 % for September

Station: Bula
Temperature Station: Bauchi
Water Holding Capacity 300mm

Raw No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	°TC	22.8	24.9	29.0	30.6	28.6	27.0	25.0	24.9	25.2	26.5	23.0	22.7	-	
3	i	9.95	11.37	14.32	15.53	14.02	12.85	11.44	11.37	11.57	12.49	10.08	9.88	145	
4	UnadjPE	2.8	3.7	5.2	5.5	5.1	1.6	3.7	3.7	3.8	4.4	2.9	2.8	-	
5	AdjF	30	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7	-	
6	AdjPE	84.0	101.0	160.7	170.0	165.2	148.3	119.9	118.8	116.3	134.6	85.3	83.2	-	
7	P	0.0	0.0	6.3	153.5	108.2	126.9	286.1	189.6	101.6	25.6	0.0	0.0	997.8	
8	DR	0.0	0.0	0.0	15.4	10.8	12.6	28.6	28.4	10.1	0.0	0.0	0.0	997.4	
9	P_{eff}	0.0	0.0	6.3	138.1	97.4	114.3	271.8	161.2	96.5	25.6	0.0	0.0		SUM OF +VE
10	P_{eff-PE}	-84.0	101.0	-154.4	-31.9	-67.8	-32.0	+157.9	+42.4	-19.8	-109	-85.3	-83.2		P_{eff-PE} is less
11	ST	-	-	-	-	-	-	-	-	-	-	-	-	-	than water holding capacity
12	ΔST														
13	AE														
14	D						NO SURPLUS TRO =DRO								
15	S														
16	RO														
17	TRO	0.0	0.0	0.0	15.4	10.8	12.6	28.6	28.4	10.1	0.0	0.0	0.0	-	S= 0

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station Bauchi
Rainfall Station: Bauchi — Temperature Station: Bauhci
DR=10%P for June — Water Holding Capacity 300mm
DR=10%P for July & Sept.
15%p for August

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	T														
3	i														
4	UnadjPE														
5	AdjP						AS FOR BULA								
6	AdjPE														
7	P	0.0	0.0	0.0	43.8	38.4	164.9	233.2	239.1	146.0	31.6	0.0	0.0		
8	DR	0.0	0.0	0.0	0.0	0.0	16.5	23.3	35.9	11.6	0.0	0.0	0.0		
9	P_{eff}	0.0	0.0	0.0	43.8	38.4	156.7	227.1	203.2	231.4	0.0	0.0	0.0		
10	P_{eff-PE}	-84.0	-101.0	-160.7	-126.2	-126.8	+10.4	101.6	84.4	15.1	-103.0	-85.3	83.2		
11	ST	70	56	32	21	14	24	126	210.4	225.5	182	137	103		
12	ΔST														
13	AE						NO SURPLUS BECAUSE W.H.C W.S NEVER								
14	D						SATISFIED THROUGHOUT THE YEAR								
15	S														
16	RO														
17	TRO						TRO = DR								

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Alkaleri

Rainfall station: Alkaleri — Temperature station: Bauchi

DR= 5%P for June & July — Water Holding Capacity 250mm

DR=15%P for Aug.& Sept.

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	$\overline{T}$C														
3	i														
4	UnadjPE														
5	AdjF	AS FOR BULA													
6	AdjPE														
7	P	0.0	0.0	0.0	38.0	1.0	118.0	188.0	293.0	155.0	62.0	0.0	0.0		
8	DR	0.0	0.0	0.0	0.0	0.0	5.9	9.4	44.0	23.3	0.0	0.0	0.0		
9	P_{eff}	0.0	0.0	0.0	38.0	1.0	112.1	178.6	249.0	131.7	62.0	0.0	0.0		
10	P_{eff}-PE	-84.0	-101.0	-130.7	-132.0	164.2	34.2	+ 58.7	130.0	15.7	-72.6	-85.3	83.2		
11	ST	67	45	23	14	7	6	65	195	211	186	132	95		
12	ΔST								1 +130	+15.7					
13	AS														
14	D														
15	S	-	-	-	-	-	-	-	-	0.0	-	-	-		
16.	RO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
17	TRO	0.0	0.0	0.0	0.0	0.0	5.9	9.4	44.0	23.3	0.0	0.0	0.0		K= 0.505

GONDOLA BASIN WATER BUDGET

Year: 1982
Rainfall Station: Dukku
DR= 10 %P for May-July
DR= 15 %P for Aug.& Sept.

Station: Dukku
Temperature Station: D/Kowa
Water Holding Capacity - 200mm

ROW / No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Remarks
2	Rc	27.3	26.1	31.8	34.6	29.6	28.1	27.5	29.3	29.4	24.7	-5.6	172	-	
3	4	13.07	12.21	15.45	18.70	17.17	11.77	13.65	13.28	14.54	11.23	11.85	3.9	-	
4	Unadjpe	1.7	4.2	5.7	6.1	5.9	5.3	5.0	4.8	5.2	14.62	5.3	3.5	29.7	
5	Adjp	29.7	27.3	30.9	32.7	32.7	31.0	32.1	30.6	30.5	29.1	101.9	115.8	-	
6	Adjpe	139.6	114.7	100.5	192.9	160.5	163.5	154.1	159.1	162.2	30.0	0.0	0.0	-	
7	E	0.0	0.0	33.0	62.0	206.0	272.0	199.0	23.9	30.0	0.0	0.0	0.0	-	
8	D2	0.0	0.0	0.0	62.0	94.0	20.6	40.8	231.2	175.1	16.0	-132.2	-115.8	-	
9	Peff	0.0	0.0	0.0	6.2	9.4	195.7	77.1	110	126	07	51	29	-	
10	Effe	0.0	0.0	33.0	62.0	94.0	206.0	231.2	175.1	16.0	-132.2	-101.9	-115.8	-	
11	ST	0.0	0.0	0.0	0.0	0.0	0.0	40.8	23.9	30.0	0.0	0.0	0.0	-	
12	DST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
13	AE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	
14	D	-139.6	-144.7	-176.1	-155.5	-130.9	-79.2	32.7	195.7	231.2	175.1	16.0	-132.2	-101.9	-115.8
15	S	14	0	0	2	1	1	33	77.1	110	126	07	51	29	-
16	NO														
17	TNO	NO SURPLUS THEREFORE TNO = DR													

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Potiskum

Rainfall Station: Potiskum — Temperature: Potiskum

DR = 10%P for July & Sept. — Water Holding CaPacity = 150mm

DR = 15%P for August.

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May.	June.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	TC														
3	1	AS FOR FIKA													
4	UnadjPE	2.6	3.4	6.1	5.7	5.7	5.4	4.8	4.4	4.8	4.9	3.1	2.5	-	
5	AdjF	29.9	27.3	30.9	31.2	32.7	32.1	33.0	32.1	30.6	30.3	29.1	29.4	-	
6	AdjPE	77.7	92.0	188.5	177.9	186.4	173.3	158.4	141.2	146.9	148.5	90.2	73.5	-	
7	P	0.0	0.0	0.0	19.2	40.2	38.3	122.7	235.2	76.0	51.3	0.0	0.0	-	
8	DR	0.0	0.0	0.0	0.0	0.0	0.0	12.8	35.2	7.6	5.1	0.0	0.0	-	
9	P_{eff}	0.0	0.0	0.0	19.2	40.2	38.3	121.1	200.0	76.0	51.3	0.0	0.0	-	
10	$P_{eff_{mPE}}$	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+58.2	-ve	-ve	-ve	-ve	-	
11	ST														
12	DST														
13	AE														
14	D														
15	S														
16	RO														
17	TRO	TRO = DR													

GONGOLA BASIN WATER BUDGET

Year: 1982
Rainfall Station: Damaturu
DR = 10%P for June & July & Sept.
DR = 15%P for August.

Station: Damaturu
Temperature Station: Potiskum
Water Holding Capacity = 125mm

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	°C														
3	i						AS FOR FIKA								
4	UnadjPE														
5	AdjF														
6	AdjPE														
7	P	0.0	0.0	0.0	6.0	33.0	86.6	158.5	120	49.5	54.5	0.0	0.0	-	
8	DR	0.0	0.0	0.0	0.0	0.0	8.6	15.9	18.0	5.0	5.0	0.0	0.0	-	
9	P_{eff}	0.0	0.0	0.0	6.0	33.0	82.2	150.6	102.0	49.5	54.5	0.0	0.0	-	
10	P_{eff-PE}	-	-	-ve	THROUGHOUT										
11	ST														
12	DST														
13	AE														
14	D														
15	S														
16	RO							TRO = DR							
17	TRO														

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Fika

Rainfall Station: Fika — Temperature Station:

DR = 10%P for June & July — Water Holding Capacity = 200mm

DR = 15%P for August.

Raw No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
1															
2	TC	22.2	24.6	28.6	31.6	31.4	30.1	27.7	26.5	27.5	28.0	23.6	22.1	-	
3	i	9.55	11.16	14.02	16.15	31.36	12.49	13.21	13.58	13.58	10.48	9.49	155	-	
4	UnadjPE	2.6	3.4	5.1	5.7	5.7	5.4	4.8	4.4	4.8	4.9	3.1	2.5	-	
5	AdjF	29.9	27.3	30.9	31.2	32.7	32.1	32.7	33.1	30.6	30.3	29.1	29.4	-	sum of +ve P_{eff}-PE
6	AdjPE	77.7	92.6	157.6	177.8	186.4	173.2	156.9	141.2	146.9	148.5	90.2	73.5	-	is less then water
7	P	0.0	0.0	0.0	3.3	54.9	68.0	101.1	149.4	0.0	0.0	0.0	0.0	-	Holding Capacity.
8	DR	0.0	0.0	0.0	0.0	0.0	6.8	10.1	22.4	0.0	0.0	0.0	0.0	-	
9	P_{eff}	0.0	0.0	0.0	3.3	54.9	68.0	96.0	127.0	0.0	0.0	0.0	0.0	-	
10	P_{eff}-	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve		
11	ST														
12	DST														
13	AE														I = C
14	D														TRO = DR
15	S														
16	RO						TRO =DR								
17	TRO														

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Buni

Rainfall Station: Buni — Temperature Station:

DR = 10%P for June, July & Sept. — Water Holding Capacity=150mm

DR = 15%P for August

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	$\frac{\delta}{TC}$														
3	i														
4	UnadjPE					AS FOR DUKKU									
5	AdjF														
6	AdjPE														
7	P	0.0	0.0	0.0	0.0	14.2	120.0	130.9	139.7	116.0	56.2	0.0	0.0	-	
8	DR	0.0	0.0	0.0	0.0	0.0	12.0	13.1	21.0	11.6	5.6	0.0	0.0	-	
9	P_{eff}	0.0	0.0	0.0	0.0	14.2	108.0	117.8	118.7	110.2	56.2	0.0	0.0	-	
10	P_{eff-PE}	-139.6	111.7	-176.1	-188.5	-178.0	-60.5	-45.7	-22.4	-48.9	-106.0	-161.9	-161.9	-115.8	Sum of +ve P_{eff-PE} is less than water Holding Capacity
11	ST														
12	DST							NO SURPLUS							S = O
13	AE														TRO = DR
14	D														
15	S														
16	RO														
17	TRO							TRO = DR							

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Biu

Rainfall Station: Biu — Temperature Station: D/Kowa

DR = 10%P for June, July & Sept. — Water Holding Capacity = 50mm

DR = 15%P for August.

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	T°C						AS FOR DUKKU								
3	i														
4	UnadjPE														
5	AdjP														
6	AdjPE	139.6	111.7	176.1	188.5	192.2	168.5	163.5	154.1	159.1	162.1	101.9	115.8	-	
7	P	0.0	0.0	2.3	62.8	39.4	113.8	161.8	160.1	110.7	90.8	0.0	0.0	-	Sum of +ve P_{ef-PE} is less than Water holding capacity
8	DR	0.0	0.0	0.0	0.0	0.0	11.4	16.2	24.0	11.1	9.1	0.0	0.0	-	
9	P_{eff}	0.0	0.0	2.3	62.8	39.4	108.1	153.7	136.1	105.2	86.3	0.0	0.0	-	
10	P_{eff-PE}	-139.6	-111.7	-173.8	-125.7	-152.8	-60.1	-9.8	- 18.0	-53.9	-75.9	-101.9	115.8	-	
11	ST														S = 0
12	DST														TRO = DR
13	AE														
14	D														
15	S														
16	RO														
17	TRO														

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Gombe

Rainfall station: Gombe — Temperature Station: D/Kowa.

DR = 10%P for June & July — Water Holding Capacity = 150mm

DR = 15%P for Aug. & September.

Raw No. 1	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec	Year	Remarks
2	TC	AS FOR DUKKU													
3	i														
4	UnadjPE	4.7	4.9	5.7	6.1	6.9	6.3	5.0	4.8	5.2	5.3	3.5	3.9		
5	AdjF	30.0	27.3	30.9	30.9	32.4	31.8	32.4	32.1	30.6	30.6	29.4	29.7		
6	AdjPE	141.0	114.7	176.1	188.5	191.2	168.5	162.0	154.1	159.1	162.2	102.9	115.8		
7	P	0.0	0.0	0.0	57.0	28.0	148.0	147.0	255.0	178.0	77.0	0.0	0.0		
8	DR	0.0	0.0	0.0	0.0	0.0	14.8	14.7	38.3	26.7	7.7	0.0	0.0		Sum of the P_{eff-PE} is less than water Holding Capacity.
9	P_{eff}	0.0	0.0	0.0	57.0	28.0	140.6	139.7	216.7	151.3	77.0	0.0	0.0		
10	P_{eff-PE}	-141.0	-114.7	-176.1	-137.5	-163.2	-27.9	-22.3	+62.6	-7.8	85.2	-102.9	-115.8		
11	ST														
12	DST														
13	AE														
14	D														
15	S														S = C
16	RO														
17	TRO														TRO = DR

GONGOLA BASIN WATER BUDGET

Year: 1982 — Station: Dadin Kowa

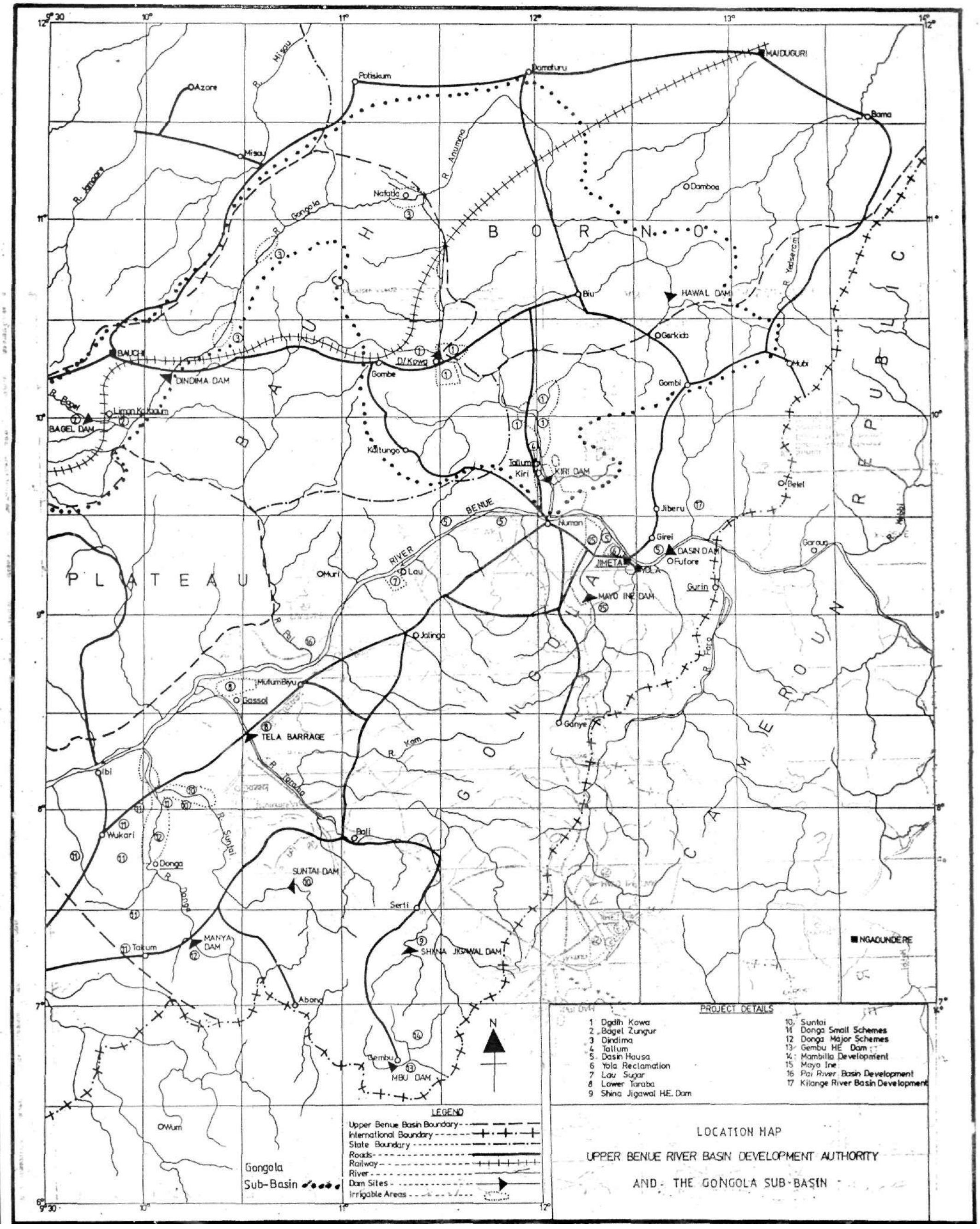
Rainfall Station: Dadin Kowa — Temperature Station: D/Kowa

DR = 10%P for June & July & Sept. — Water Holding Capacity = 75mm

DR = 15%P for August.

Row No.	Month/ Elem.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Remarks
2	~~TC~~														
3	i														
4	$Un_{adj}PE$						AS FOR GOMBE								
5	AdjP														
6	AdjPE														
7	P	0.0	0.0	0.0	26.5	37.7	120.5	157.0	161.3	149.4	139.4	0.0	0.0		
8	DR	0.0	0.0	0.0	0.0	0.0	12.1	15.7	24.2	15.0	14.0	0.0	0.0		
9	P_{eff}	0.0	0.0	0.0	26.5	37.7	114.5	149.2	137.1	142.2	132.4	40.0	0.0		Sum of -ve P_{eff-PE} is less than water Holding Capacity
10	P_{eff-PE}	-141.0	-111.7	-176.1	-162.0	-152.5	-54.0	-12.8	-16.6	-16.9	-29.8	102.9	-115.8		
11	ST														
12	DST														
13	AE														
14	D														
15	S														S = 0
16	RO														TRO= DR
17	TRO						TRO = DR								

FIG. 1.3.1


MAIDUGURI
Potiskum
Damaturu
Azare
Misau
Bama
Damboa
Nafatia
Biu
HAWAL DAM
Gerkida
Mubi
Gombi
BAUCHI
DINDIMA DAM
Gombe
D/Kowa
Limon Kuboam
BAGEL DAM
Kaltungo
Tallum
Kiri
KIRI DAM
Belel
Jiberu
Numan
BENUE
RIVER
Girei
DASIN DAM
Fufore
YOLA
JIMETA
Gurin
Garoua
MAYO INE DAM
Muri
Lau
Jalingo
Mutum Biyu
Gassol
TELA BARRAGE
Ganye
Ibi
Wukari
Donga
SUNTAI DAM
Bali
Serti
Takum
MANYA DAM
SHINA JIGAWAL DAM
Abong
Gembu
MBU DAM
Ntem
NGAOUNDERE
Mbere
Mambila
Faro
Yedseram
Gongola
Sub-Basin
PLATEAU
BORNO
GONGOLA
CAMEROUN
REPUBLIC
N
PROJECT DETAILS
1 Dgdih Kowa
2 Bagel Zungur
3 Dindima
4 Tallum
5 Dasin Hausa
6 Yola Reclamation
7 Lau Sugar
8 Lower Taraba
9 Shina Jigawal H.E. Dam
10 Suntai
11 Donga Small Schemes
12 Donga Major Schemes
13 Gembu HE Dam
14 Mambilla Development
15 Maya Ine
16 Pai River Basin Development
17 Kilange River Basin Development
LEGEND
Upper Benue Basin Boundary
International Boundary
State Boundary
Roads
Railway
River
Dam Sites
Irrigable Areas
LOCATION MAP
UPPER BENUE RIVER BASIN DEVELOPMENT AUTHORITY
AND THE GONGOLA SUB-BASIN