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A PRELIMINARY STUDY OF THE RUNOFF CHARACTERISTICS OF THE KADUNA BASIN

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OF THE KADUNA BASIN

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INTRODUCTION

The report

This report on the hydrology of the Kaduna Basin, Nigeria, was commissioned by Parkman Consultants Limited, to form part of a pre-feasibility study of the agricultural potential of the area.

The aims of the hydrological study have been to appraise the hydrological network and records collected, to review the rating curves for river flow gauging stations and thus the discharge records and to collate and analyse the rainfall records. This preliminary analysis is then used in a general study of the runoff of the Kaduna Basin, and in relating the mean annual runoff to catchment characteristics like area, slope, mean annual rainfall and land type so that the mean annual runoff at other sites can in turn be estimated from catchment characteristics. The variability of the annual runoff between years and the seasonal variation of runoff are also studied. Recommendations are made for the hydrometric network required for subsequent investigations.

Chapter 1 describes the sources of data used during the investigation. The rainfall data are assessed and analysed in Chapter 2, while Chapter 3 and Appendix are devoted to a review of the available runoff data. The processed runoff data are then used to produce the required regression relationships in Chapter 4.

Ways of improving the existing hydrological data collection procedures are suggested in Chapter 5. Study of the available hydrological records has highlighted the very real need for more attention to be paid to the collection of the basic hydrological data. Most of the hydrometric authorities visited were carrying out their duties on a minimal budget, with insufficient manpower and equipment. The full realisation of the water resources of the Kaduna Basin relies upon long and accurate hydrological records, which are only possible with an adequately supplied and maintained hydrometric network.

The Kaduna Basin

The area studied comprises the Kaduna Basin above its confluence with the Niger, covering an area of about 66,000 square kilometres. From a hydrological point of view, the catchment is dominated by the Jos plateau at the south-eastern corner of the basin, where higher elevation and slope and heavier rainfall result in runoff which is high both as a depth and as a percentage of rainfall, and where the vegetation is relatively thick. To the west of the Jos plateau, the country is much flatter with occasional inselbergs, though the basin has more relief south and west of Kaduna with a number of massive granite outcrops. The topography becomes flatter again on sandstone at the southern part of the basin, with some flat plateaux standing above the plain. The vegetation varies from thorn scrub with some broader leaved trees north of Zaria, though broad-leaved trees and bush to thick forest in many river valleys and in the south-west of the basin.

Summary of results

The mean annual runoff at sites in the Kaduna Basin (except for the Nupe Sandstone) can be estimated using the relationship:

$$MAR = -1057 + 1.004 \times (RAIN) + 7.065 \times (SLOPE) + 5.170 \times (LAND)$$

where MAR is the mean annual runoff in millimetres

RAIN is the mean annual rainfall in millimetres

SLOPE is a catchment slope parameter given by the difference in height of the upper end of the tributary and the gauging station (in metres), divided by the square root of the catchment area (in square kilometres)

LAND is a weighted land type coefficient that can be calculated from the equation:

$$LAND = 0.35\ S_{1a} + 0.2S_1 + 0.15\ S_2 + 0.1\ S_3$$

where S_{1a} is the percentage of the catchment covered by land type 1a, and so on.

The minimum monthly flow can be estimated using the equation:

Minimum flow (mm/month) = 2.836 + 0.1825 x (SLOPE) - 0.3269 x (LAND)

The decay of the flow throughout the dry season is given by the relationship:

$$Q = \frac{\overline{Q}_m}{K^t}$$

where $\overline{Q}_m$ is minimum monthly flow

K is the recession constant (obtained from Figure 3.3)

t is the time in days before the assumed end of the dry season. For the catchment above Kaduna South gauging station this is taken to be 1 March, below being 15 March

Estimation of the seasonal variation of flow within the Galma sub-catchment must be made by comparison with the available records from the Ribako and the two Zaria gauging stations.

The annual variation of the mean annual runoff can be expressed as a series of growth factors - for estimating either higher-than-average or lower-than-average flows.

Mean Annual Runoff - Growth Factors for Various Return Periods

	Return Period (years)			
	2	5	10	50
Low flow	1.01	0.77	0.68	(0.45)
High flow	0.99	1.20	1.34	(1.7)

where the growth factor = (runoff) ÷ (mean annual runoff) and figures in brackets are to be treated with caution.

The reduction of the minimum monthly flow for various return periods can be similarly expressed:

Return Period (years)	2	5	10
Reduction factor	1.0	0.55	0.4

CHAPTER 1

INFORMATION AVAILABLE AND PREVIOUS STUDIES

The reliability of a hydrological investigation depends on the availability and quality of the basic hydrological data, in this case rainfall and streamflow records. During this study it was necessary to visit a large number of agencies for the river flow records, and the quality of the records varies considerably. Any move to centralise the hydrological data storage facilities and to standardise the quality of the data throughout the country would be of considerable benefit to future water resources studies.

1.1 RAINFALL DATA

Rainfall records for all stations throughout Nigeria are held at the Meteorological Office in Lagos. Because delays were encountered in retrieving these records, most of the rainfall information available for use during the current study had been collected by MRT Consulting Engineers (Nigeria) for their study of the water resources of Kaduna State. This meant that more data were available for analysis in Kaduna State than in Niger State.

It has also been found that the rainfall records held at Lagos are much more intermittent in recent years, with little data available after 1975. As most of the stream gauging has been carried out in the last few years, this made it difficult to compare rainfall and runoff.

1.2 CLIMATE DATA

There are a number of synoptic climatological stations in the catchment; again, the records are held in the Meteorological Office in Lagos. However, the Agroclimatological Atlas produced at the Institute of Agricultural Research (IAR), Samaru, effectively summarises all available data up to the time of publication (1972).

1.3 RUNOFF DATA

Runoff information for the Kaduna basin is held by the Water Boards of Plateau, Kaduna and Niger States, the National Electric Power Authority and the Inland Waterways Division (IWD) of the Federal Ministry of Transport. Additional information for neighbouring catchments was obtained from Water Resources and Engineering Construction Agency (WRECA), Kano State. The information obtained from these different agencies varied in both form and quality. WRECA had carried out comparatively sophisticated analyses on their streamflow data, while Kaduna State Water Board (KSWB) had produced mean daily discharge estimates for most of their gauging stations. The records from Niger State Water Board consisted of gauge readings and discharge measurements. The Plateau State Water Board was not approached for information from its one or two insignificant gauged catchments.

Most of the information used came from Kaduna State Water Board, and their two books of published streamflow records, dated 1972 and 1975. Additional information was also collected directly from the Water Board's offices in Kaduna, which enabled us to make an objective appraisal of the quality of the records.

The Niger State Water Board have only recently been established following re-organisation, and rating curves and daily discharges had not yet been calculated from the gauge readings and discharge measurements. As there were no photocopying facilities to copy basic data for processing elsewhere, only the most significant stations were analysed.

Information collected for the IWD gauging station at Wuya Bridge consisted of mean daily gauge heights and calculated mean daily discharges.

In order to supplement the information obtained within the Kaduna catchment some adjacent catchments were also examined. Mean daily discharges were obtained from WRECA for the Kano and Challawa catchments to the north, and the Gurara and Chanchaga catchments to the south.

1.4 PREVIOUS STUDIES

The River Kaduna and its tributaries have been the subject of a number of reports in the past. These have mostly been concerned with the hydro-power potential of the main river, especially at the Shiroro Gorge site. The studies of particular relevance to this project are outlined below:-

(a) Shiroro Hydro-electric Project - feasibility study by Charles T Main

This report describes the meteorology of the Kaduna Basin, and gives an estimate of the probable maximum flood at Shiroro based on probable maximum precipitation. The consultants have, in addition, produced a series of monthly flow duration curves for the Kaduna at Shiroro. An examination of these produces an estimate of the annual runoff at this site some 25% greater than that given by the data available for this study, which cover the period 1955-1961.

The Main analysis was based on measured flows from 1962 to 1974 extended back to 1939 using a rainfall/runoff correlation model. The flow records used by Main for the analysis were not available for this study.

(b) Plan for Electrical Power System Development - Motor Columbus

The principal interest in this report lies in the flow estimates made for two sites on the Kaduna River (Shiroro Gorge and Zungeru) and maps showing the variation of potential evaporation and annual rainfall throughout Nigeria. The estimated annual runoff at Shiroro is some 11% smaller than that calculated during this study.

The report also contains monthly flows for the Kaduna River at both Kaduna and Wuya Bridge. These data mainly agree closely with information collected from KSWB and IWD, but with some differences. The record at Kaduna completes some gaps in the data available from KSWB, and the Wuya record is occasionally quite different from the IWD calculated flows. It has not been possible to establish the reason for these discrepancies.

(c) Investigation of Low Flows in the River Kaduna at Kaduna, Nigeria - Hydraulics Research Station, UK

This report, and the associated working files, provided a good background to the problems of estimating low flows in the Kaduna Basin, as well as supplementary streamflow data for the Kaduna River at both Kaduna and

Kirmin Gurmana.

(d) A Review of Hydrological Data and Analyses for the Gongola Catchment to Numan - Institute of Hydrology, UK

This report correlates runoff with catchment characteristics in an adjacent catchment and thus provides the basis for the approach used in this study.

(e) The Land Resources of Central Nigeria - Land Resources Division, ODM

Discussions with the staff of LRD involved in the preparation of the report, and the report itself, provided much background information for the preparation of the "land type" map, used to locate areas of differing runoff potential.

(f) Kangimi Irrigation Scheme - Detailed Feasibility Report - Enplan Group

Enplan investigated the feasibility of using water from the Kangimi to irrigate a strip of land along the River Kaduna. The hydrology of the River Kangimi formed part of their study and Enplan produced a revised estimate of the flows for the gauging station located on the Kangimi 3 miles upstream of Rihogi Village.

(g) Water Resources and Engineering Construction Agency, Kano State (WRECA)

WRECA are regarded as the leading hydrological authority in Northern Nigeria, and as such have been asked to undertake studies outside Kano State. Of particular interest to this investigation are their studies into the River Challawa and of the Rivers Gurara and Chanchaga.

(h) Institute of Agricultural Research, Samaru

The Agroclimatological Atlas, produced by IAR, provides a valuable summary of the available climatological data of Northern Nigeria. An interesting study of the runoff from a small catchment at Samaru was also carried out at IAR.

CHAPTER 2

RAINFALL AND EVAPORATION

2.1 METHOD OF RAINFALL ANALYSIS

Although rainfall data were available as daily values, the aim of the rainfall analysis was to produce estimates of the average rainfall over any sub-catchment within the Kaduna Basin. The analysis was therefore based on monthly and annual rainfall values.

Rainfall records are commonly very variable in terms of gauge distribution and periods of record; these problems are particularly acute in the Kaduna Basin. The available rainfall data were therefore reduced to a common, long-term mean for use in an isohyetal map.

Selection of stations

All readily available, relevant rainfall data were collected. Some of the records are very short; some appear to be unreliable and others are very intermittent. These stations were not analysed unless they were in an area sparsely covered by rain-gauges.

The selection of long-term stations for the rainfall analysis depended on completeness of record for the selected 50 year period 1926-1975. By filling a few gaps from adjacent stations complete records were obtained for four long-term stations:

Jos Aerodrome
Kaduna Junction
Maigana Agricultural Station
Kano Government Farm

Each short-term station was allocated by Thiessen polygons to the nearest long-term station for adjustment. The location of the stations, and the polygons, are shown in Figure 2.1.

Extension of data

The rainfall average from a short-term rain-gauge was reduced to the common, long-term period average by direct comparison with an adjacent rain-gauge. The ratio of the rainfall at the short-term station to the rainfall at the long-term station during the common period was multiplied by the average at the long-term station over the whole period of record.

2.2 RESULTS OF ANALYSIS

For each rainfall station, both the straightforward annual average rainfall figure and the value adjusted to the long-term period are given in Table 2.1. The isohyetal map (Figure 2.2) was constructed using the adjusted annual average figures. Extrapolation of the isohyets into areas sparsely covered with rain-gauges was necessarily somewhat subjective; the isohyets over Kaduna State are more reliable than those over the western part of the catchment.

During a study of the Challawa catchment, WRECA detected a significant drop in the annual rainfall in recent years. For the 10 years to 1976 the rainfall at Kano Airport was 81% of the long-term mean, and Zaria water-works experiences for the same period a drop to 87% of the long-term mean. This could imply that the runoff records (taken, for the most part, during the last 10 years) might seriously underestimate the true average runoff from the catchment. For the catchment to the Challawa Gorge gauging station it was estimated by WRECA that the runoff in the recent 10 year period was only 66% of the long-term average runoff.

The data from the four long-term stations, together with data from Katsina Aerodrome, were examined for this trend. The results are summarised in Table 2.2.

The stations significantly affected by this trend (Kano and Katsina) lie to the north of the Kaduna catchment. It appears that the annual runoff assessed by the available runoff records should correspond reasonably with the long-term averages.

TABLE 2.1

RAINFALL STATIONS

Reference Number	Station Name	Lat	Long	Elevation (ft)	Average Annual Rainfall (mm)	Extended Average (mm)
1	Keffi Jun Pry School	8-50	7-52	1500	1390	1403
2	Gudi Min of Works	8-53	8-15	1300	1619	1553
3	Alushi EKAS School	8-53	8-21	1200	1393	1399
4	Akwanga Agric School	8-55	8-23	1200	1475	1484
5	Wamba DO	8-55	8-31	1050	1664	1659
6	Arum NA School	9-08	8-39	2000	2119	2126
7	Diko SIM	9-15	7-12	1775	1500	1528
8	Abuja NA	9-10	7-10	1600	1606	1640
9	Bwari Jun Pry School	9-17	7-23	1900	1505	1466
10	Tayu NA School	9-17	8-36	3000	1627	1633
11	Kwoi ECWA School	9-27	8 00	2400	1722	1739
12	Jagindi Jun Pry School	9 20	8-12	1600	1605	1633
13	Dogon-Kurmi For Res Stn	9-20	8-20	1600	1653	1729
14	Kafin Jun Pry School	9-32	7-05	2000	1554	1485
15	Kurmin-Musa Jn Pry School	9-34	7-59	2200	1467	1476
16	Kafanchan Medical Dept	9-36	8-18	2500	1655	1640
17	Kagoro SIM	9-36	8-23	2700	1633	1658
18	Riyom Agric Dept	9-38	8-46	4050	1350	1371
19	Barakin-Ladi ATMN	9-33	8-50	4300	1211	1206
20	Ropp North ATMN	9-30	8-55	4400	1270	1270
21	Zonkwa Agric Station	9-44	8-23	2750	1466	1488
22	Vom Vet Dept	9-44	8-47	4150	1376	1400
23	Kuta SIM Dispensary	9-52	6-43	1200	1342	1325
24	Shiroro Gorge NEPA	9-58	6-51	1100	1330	1292
25	Kachia Snr Pry School	9-52	7-57	2400	959	980
26	Miango SIM	9-51	8-46	3700	1537	1524
27	Miango Kent Academy SIM	9-51	8-40	3900	1517	1544
28	Jos Aerodrome	9-52	8-54	4215	1410	NA
29	Naraguta School of Forestry	9-57	8-53	3800	1382	1387
30	Rayfield Mines	9-51	8-54	4260	1342	1356

RAINFALL STATIONS (Continued)

Reference Number	Station Name	Lat	Long	Elevation (ft)	Average Annual Rainfall (mm)	Extended Average (mm)
31	Lamingo Hydro Station Dam	9-54	8-56	4200	1368	1383
32	Tegina SIM	10-04	6-12	900	1325	1317
33	Bassa CFC	10-06	6-37	1000	1368	1339
34	Serkin Pawa Railway Station	10-02	7-06	1400	1443	1399
35	Kurmin-Biri Railway Station	10-02	8-01	2300	1438	1418
36	Tugan-Bako Baptist School	10-18	6-14	1250	1237	1237
37	Gwagwada Railway Station	10-15	7-14	1800	1283	1273
38	Jengre SDA Mission	10-15	8-48	3100	1192	1194
39	Shanga Jun Pry School	10-14	8-55	4400	1228	1239
40	Kaduna Junction	10-29	7-25	1920	1291	NA
41	Kakuri Federal Prisons	10-28	7-24	2000	1440	1418
42	Afaka Forest Reserve	10-37	7-17	2000	1233	1211
43	Kaduna Aerodrome	10-36	7-27	2116	1281	1291
44	Kaduna Hydro-Station	10-30	7-26	1940	1334	1326
45	Kauru Jun Pry School	10-35	8-10	1950	1172	1102
46	Kudaru Min of Works	10-35	8-27	2500	1320	1313
47	Birnin Yero Railway Station	10-48	7-31	2200	1187	1203
48	Ririwai Mining Station	10-44	8-44	2890	1365	1341
49	Sabon Birni Jun Pry School	10-50	7-18	1950	1011	1075
50	Dutsin-Wai BCGA	10-50	8-15	2150	1100	1136
51	Dutsin-Wai Jun Pry School	10-50	8-15	2150	1169	1108
52	Takalafia PO	10-57	8-22	2300	1153	1148
53	Kontokora NA	11-01	5-57	1570	1178	1171
54	Zaria Aerodrome	11-08	7-41	2150	1087	1064
55	Zaria Waterworks	11-05	7-46	2141	1100	1078
56	Maigana Agric Station	11-02	7-56	2200	1140	NA
57	Burra Jun Pry School	11-01	8-59	3000	1160	1160

RAINFALL STATION (Continued)

Reference Number	Station Name	Lat	Long	Elevation (ft)	Average Annual Rainfall (mm)	Extended Average (mm)
58	Kaya Jun Pry School	11-15	7-14	2200	1154	1090
59	Shika Agric Research	11-13	7-33	2100	1047	1048
60	Samaru Agric Station	11-11	7-38	2250	1073	1081
61	Ikara Primary School	11-15	8-12	2300	1030	1115
62	Tudan-Wada Jun Pry School	11-15	8-25	2020	838	948
63	Dandume Jun Pry School	11-27	7-08	2300	1071	983
64	Danja Jun Pry School	11-23	7-33	2200	1035	958
65	Daudawa Govt Farm	11-38	7-09	2300	1051	1029
66	Daudawa Jun Pry School	11-38	7-09	2100	1017	937
67	Funtua Jun Pry School	11-32	7-19	2100	1051	1031
68	Funtua CAP Ginnery	11-32	7-19	2100	1179	1129
69	Bakori LA School	11-34	7-26	2100	991	910
70	Kafur Jun Pry School	11-39	7-39	2000	1051	977
71	Dangora Jun Pry School	11-33	8-09	1850	797	818
72	Rano Snr Pry School	11-33	8-35	1590	941	966
73	Faskari Jun Pry School	11-44	7-01	2100	1107	1022
74	Malumfashi Jun Pry School	11-47	7-38	2150	993	932
75	Mahuta Jun Pry School	11-44	7-47	2050	970	922
76	Kankara Elementary School	11-56	7-26	1900	964	904
77	Kabo Girls School	11-51	8-10	1500	886	952
78	Kano Govt Farm	11-59	8-32	1650	833	NA

TABLE 2.2

RECENT RAINFALL TRENDS

Station	Average Annual 1926-75 (a)	Rainfall (mm) 1966-75 (b)	Ratio $^b/_a$
Jos Aerodrome	1409	1410	1.001
Kaduna Junction	1296	1289	0.995
Maigana Agric Stn	1141	1113	0.976
Kano Govt Farm	837	724	0.865
Katsina Aerodrome	706	576	0.816

2.3 EVAPORATION

Detailed climatological records for the basin are given in the Agroclimatological Atlas. Monthly and annual evapotranspiration totals, estimated by the Penman method, are given in Table 2.3 for the stations in the Kaduna basin. There is little variation over the area of the Kaduna catchment. Because a 25% reflection coefficient for vegetation was used to estimate transpiration, and a 5% coefficient would be more appropriate for open water, the open water evaporation will be about 25% higher than these transpiration estimates.

AVERAGE PENMAN EVAPOTRANSPIRATION FOR SELECTED STATIONS IN KADUNA BASIN (mm)

	Bida	Jos	Kaduna	Minna	Samaru
January	117	117	141	133	116
February	121	121	138	140	121
March	139	148	154	155	147
April	122	123	141	142	153
May	107	115	134	134	154
June	86	101	110	106	125
July	79	84	96	87	108
August	72	78	84	86	97
September	77	95	99	93	107
October	96	116	115	113	120
November	111	119	119	117	109
December	110	115	123	112	106
Annual	1237	1332	1454	1418	1463

CHAPTER 3

RUNOFF ANALYSIS

3.1 REVIEW OF GAUGING STATIONS

Most of the gauging stations in the Kaduna Basin, and most of the runoff data available, are the responsibility of the Kaduna State Water Board. As a result, there is a consistent approach to the problem of gauging rivers. Because the hydrometric network in Northern Nigeria was established in the early 1960s by one organisation, a similar approach is maintained by the other principal gauging authority, the Niger State Water Board.

Much of the available hydrometric information is in Water Board publications in the form of daily flows. However, a close scrutiny of the published flows raised some doubts as to their accuracy, especially during periods of low flow. The Water Boards were therefore visited and some of the raw data obtained to enable the calculation of mean daily flows to be repeated.

It was found that before the low flow regime of any river could be examined, the records from each station had to be carefully checked for consistency. Some stations were much more reliable than others, and a two tier system of analysis was adopted. The analysis was based on records from thirteen primary gauging stations, and checked against data from another thirteen stations which were considered of secondary importance. Two stations, gauging runoff wholly from the Nupe Sandstone, had very different flow characteristics and these stations were analysed separately. The locations of all these gauges are shown in Figure 3.1. Effort was concentrated on verifying and adjusting data for the primary stations; this work is described in an appendix.

The approach adopted was to fit a straight line on logarithmic paper through the discharge measurements, with the stage zero adjusted to correspond with zero flow. Once this basic stage-discharge relationship had been derived, shift corrections were adopted to bring the discharge measurements during periods between individual floods back to the basic curve.

3.2 FLOW ESTIMATION PROBLEMS GENERAL TO THE KADUNA BASIN

Calculation of mean daily gauge height

WRECA have found, during their studies of the hydrology of Northern Nigeria, that significant errors can arise from the assumption that the average of the observed gauge heights in any one day equals the mean daily gauge height.

Most of the gauging authorities record the gauge heights 3 times daily (at 0700, 1200 and 1700), and more frequently when the water level is changing rapidly. However, on smaller catchments flood peaks will be missed by this method of measurement. In addition, it has been noted that in parts of Nigeria (most particularly in the north-west) the rainfall occurs predominantly at night, and so a significant proportion of the total runoff could be missed in this way. If the rainfall follows any pattern significantly different from a random distribution through the day, the averaging of 3 gauge height values to obtain a mean daily figure introduces a consistent error. WRECA have overcome this problem by using automatic water level recorders wherever possible, and by computing mean daily values from a plotted hydrograph. For the present study this type of error is unlikely to be important, but in later, more detailed, studies will become more significant.

The estimation of low flows

Most of the gauged rivers in the Kaduna Basin have shifting, sandy beds; this means that a new stage-discharge rating curve should be produced each year. In some cases this becomes difficult as discharge measurements are required during the dry season, when few measurements appear to be made. When no discharge measurements are taken in a dry season, the reliable estimation of the low flows becomes impossible.

The whole pattern of discharge measurements by the Water Boards could be improved. At the moment, the principal interest in the region's water resources is concentrated upon the supply of water for domestic use, irrigated agriculture and hydro-power needs. In all these cases the low flow regime in the dry season is important. To establish accurate estimates of these flows requires regular discharge measurements to be made during the dry season - perhaps once or twice monthly. At the moment, disproportionate effort is being expended in measuring discharges once every two days during the wet season at some stations.

Abstractions

The information available for this study provided the material from which river discharges could be estimated at various points throughout the catchment. It was assumed that all runoff passed these gauging points. However, in any detailed water resources evaluation it would be necessary to estimate the total runoff from the area, which would include all water abstracted from the river for domestic water supply, agriculture, industry (if any), and so on. This is particularly important when the abstractions have increased appreciably during the history of the flow gauges.

There are indications that some of the tributaries of the Kaduna are being significantly affected by abstractions during the dry season. In a more detailed study this would need to be checked, and if necessary allowed for in the calculations.

3.3 ANALYSES

Relationships were required between mean annual runoff, minimum flow, variability of annual runoff and catchment characteristics. The derivation of the flow indices is described in the following section.

Mean annual runoff

The mean annual runoff was based on a year starting in January and ending in December, in preference to the normal hydrological year used in Northern Nigeria (April to March), to simplify the minimum discharge computations. The January to December year ensured that both maximum monthly flows and minimum monthly flows in any one year should be independent of the values of the preceding and following years. In an April to March year consecutive months might be the minimum monthly discharge for consecutive years, and the events would not remain independent.

For each gauging station an annual flow was calculated for all years with a complete record. In many cases, data were missing for only one or two months of the dry season, and an average monthly figure was added to enable the annual flow to be computed with a fair accuracy. The mean annual runoff was calculated from the arithmetic mean of all annual flows so computed. This figure can be expressed either in terms of discharge (m^3/s) or as a depth of water over the catchment area (mm/year).

Minimum monthly flow

For simplicity, the time period selected for use when estimating the low flow parameter was a calendar month. For each discharge station, the smallest monthly flow in each year was extracted whenever the available record included the complete dry season.

It was decided not to compute a direct arithmetic mean of these data for each station, as the data sometimes included one value an order of magnitude greater than the rest, which would unrealistically bias such a mean. The "average" figure selected for the parameter was taken to correspond to the median value of the data.

Recession analysis

In order to describe the month-to-month variation in flow of the rivers of the Kaduna Basin, some form of recession analysis seemed essential. The simplest assumption is that the flow in the dry season can be described by the relationship:

$$Q = Q_o K^t$$

where Q is the flow

Q_o is the flow at time t = 0

K is the recession constant

t is the time (in days, usually)

TABLE 3.1

KADUNA AT KADUNA SOUTH

ANNUAL FLOW - LOW FLOW ANALYSIS (m^3/s)

Distribution:	Return Period (years)			
	2	5	10	50
Normal	166	132	115	
Gumbel	163	129	114	
Log-Gumbel	163	123	103	69
Log-normal	161	131	117	

TABLE 3.2

KADUNA AT KADUNA SOUTH

ANNUAL FLOW - HIGH FLOW ANALYSIS (m^3/s)

Distribution:	Return Period (years)			
	2	5	10	50
Gumbel	164	200	222	271
Log-normal	161	199	222	269

If the recession does follow this pattern, then a plot of the logarithm of the flow against time should give a straight line relationship.

This analysis, when applied to the available discharge records was, in general, very encouraging. A number of stations produced a relationship approximating closely to a straight line (for example, the Karami at Saminaka, Figure 3.2), whilst others did not (for example, the Tubo at Mile 20, Figure 3.3).

The Tubo record was examined for a more complex recession pattern. An attempt was made to fit the relationship

$$Q = Q_o e^{-K't^n}$$

where K',n are constants
e is the base of natural logarithms

However, this proved no more successful than the first method. Considering the purposes of this investigation, it was decided that the single parameter approach to the recession analysis should prove adequate.

The records of all the primary gauging stations were examined, and a value for the recession constant K was deduced for each.

Variation of annual runoff

The variations of the annual runoff was examined to estimate both high and low flow rates corresponding to various return periods. The analysis concentrated on the station with the longest gauging history - the Kaduna at Kaduna South Water works.

For the low-flow analysis a number of different distributions were fitted to the data, and the flows corresponding to various return periods estimated. There are no fully convincing theoretical arguments to justify selecting any one distribution. The results obtained by fitting the various distributions are shown in Table 3.1.

FIGURE 3.2

Recession Curve - Karami at Saminaka

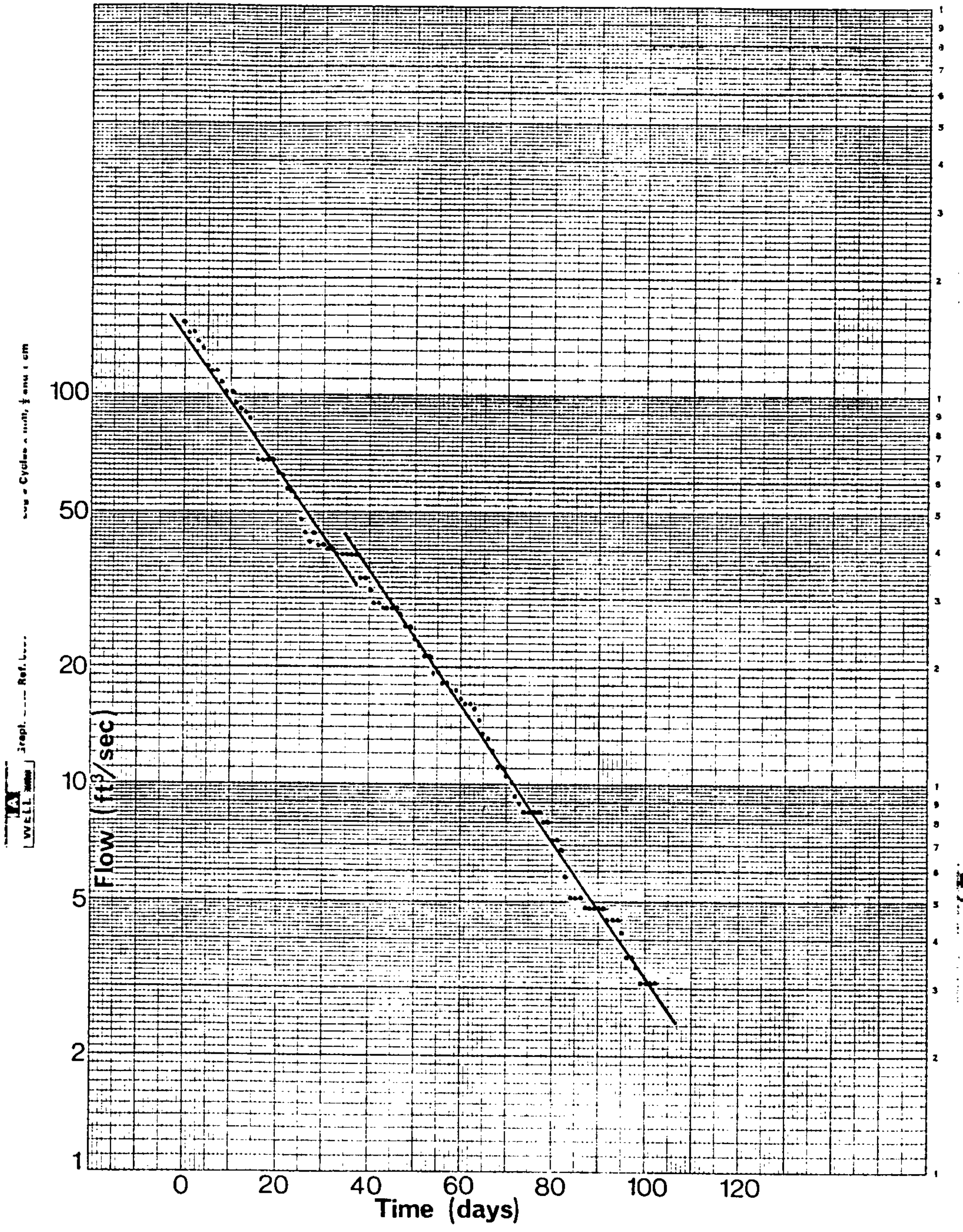
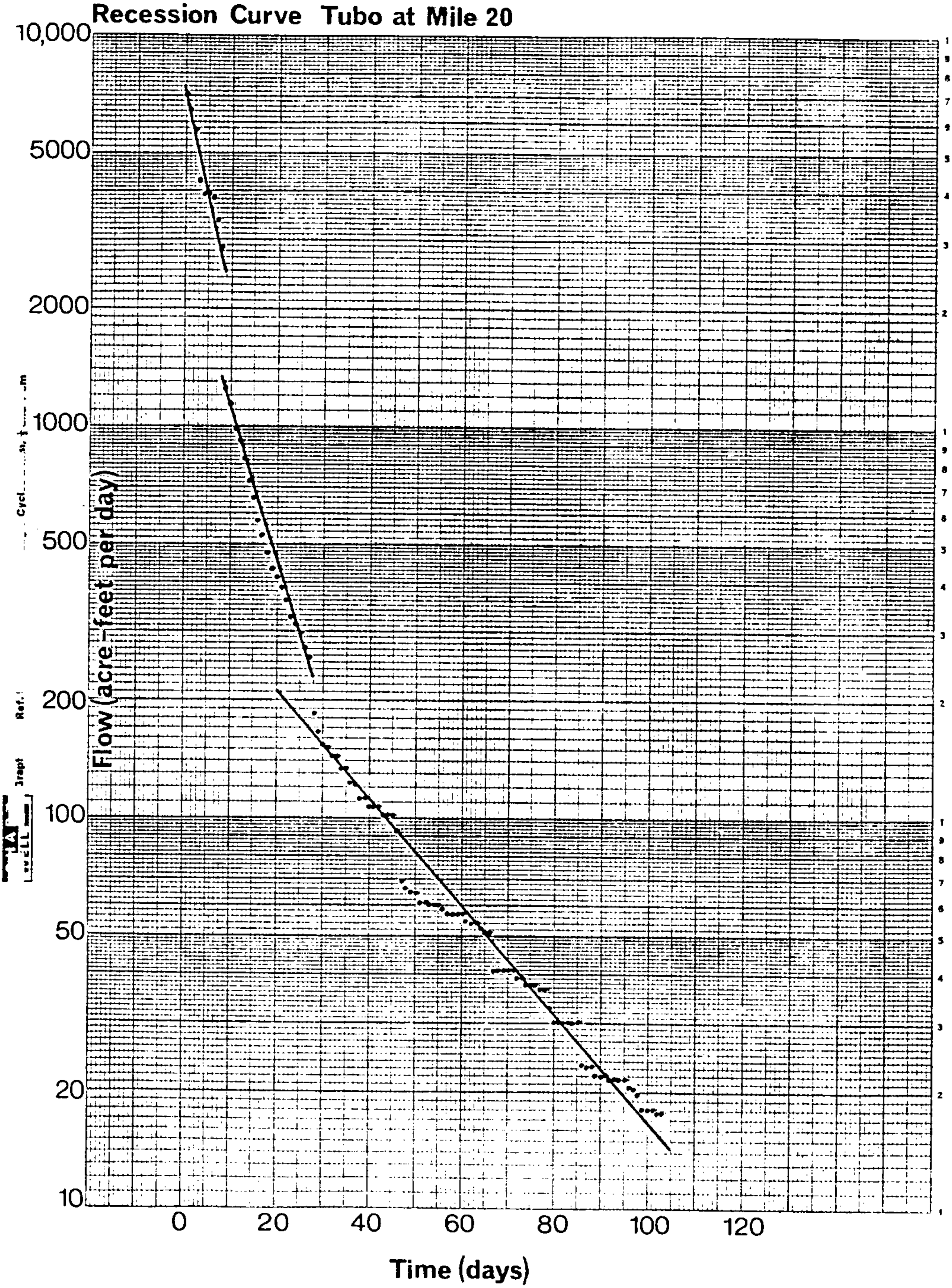


FIGURE 3.3



Recession Curve Tubo at Mile 20
10,000
5000
2000
1000
500
200
100
50
20
10
Flow (acre-feet per day)
0
20
40
60
80
100
120
Time (days)

For our purposes, the discrepancies between the different methods are insignificant. For simplicity, the analysis of data from other stations with a shorter record was based on a log-normal distribution.

It was found that the reduction of the annual runoff for increasing return periods could be expressed in the form of a general catchment "reduction factor" to be applied to the mean annual runoff. The appropriate factors are contained in the summary table, Table 3.3.

The analysis of the annual flow records for the Kaduna at Kaduna South continued by reversing the analysis, and examining the variation in the higher annual flows for various return periods. This time, both a Gumbel and a log-normal distribution were fitted to the data, to produce virtually identical results, Table 3.2.

Once again, log-normal distributions were fitted to the data from other gauging stations, and catchment growth factors deduced, Table 3.3.

Variation of minimum monthly flow

The basic analysis of the variation of the minimum monthly flow rate was again carried out on the Kaduna at Kaduna South record. Again, a number of different distributions were tried, with the log-Gumbel distribution having probably the closest fit. The results are contained in Table 3.4.

The extension of the analysis to cover the other gauging stations did not prove very satisfactory. Once again the log-normal distribution was used for ease of calculation. However, this time the growth factor varied appreciably from station to station, particularly for those stations with a larger variation between wet and dry season flow rates. As a result, any catchment "growth factors" are going to be, at best, approximate. Our best approximation, without more detailed study, is contained in Table 3.5.

Runoff from Nupe Sandstone

Few good stations measure the runoff from Nupe Sandstone areas in and around the Kaduna Basin. Enquiries at the Niger State Water Board's

TABLE 3.3

ANNUAL FLOW-GROWTH FACTORS[1] FOR VARIOUS RETURN PERIODS

	Return Periods (years)			
	2	5	10	50
Low flow:	1.01	0.77	0.68	(0.45)[2]
High flow:	0.99	1.20	1.34	(1.7)[2]

TABLE 3.4

KADUNA AT KADUNA SOUTH
MINIMUM MONTHLY FLOW FREQUENCY ANALYSIS (m^3/s)

Distribution:	Return Period (years)			
	2	5	10	50
Normal	3.85	2.35	1.56	
Log-normal	3.42	2.19	1.73	1.15
Gumbel	3.75	2.40	1.80	
Log-Gumbel	3.71	2.34	1.72	0.86
HRS Report, (1962)			1.10	0.35

[1] Growth factor = flow/mean annual flow

[2] Figures in brackets to be treated with caution

TABLE 3.5

MINIMUM MONTHLY FLOW - REDUCTION FACTORS FOR VARIOUS RETURN PERIODS

Return Period (years)	2	5	1.0
Growth factor	1.0	0.55	0.4

where "growth factor" = (flow) ÷ (average minimum flow) offices in Minna provided two stations gauging runoff from the sandstone, namely the River Bakogi at Agaie and the River Yiko at Guzan.

The stations have a similar history, described in the appendix. However, the records displayed somewhat different characteristics. The Bakogi is a much steeper catchment than the Yiko, and is better defined on contour maps. The dry season recession is steeper, and the mean annual runoff is about double that of the Yiko. Due to this dissimilarity a general analysis of runoff from sandstone areas was not possible, and it was decided merely to record the flow characteristics for these stations.

CHAPTER 4

RUNOFF RELATED TO CATCHMENT CHARACTERISTICS

The objective of this study has been to provide a means whereby the runoff from any catchment in the Kaduna Basin can be estimated. The approach adopted was that employed in the IH Gongola Report, where the principal runoff parameters are correlated with catchment characteristics such as rainfall, land type, slope and area.

4.1 MEAN ANNUAL RUNOFF

Because of the brevity of some of the station records for the mean annual runoff regression analysis, attempts were made to extend the records by direct correlation with one of the stations with a longer history. However, the annual runoff figures were very poorly correlated, and the regression analysis was continued using only recorded data. The catchment characteristics employed in the analysis were as follows.

Land type coefficient

An attempt was made to establish a hierarchy of runoff - producing land types, taking account of such aspects as soil type, rock type and dominant slope. Geological and topographical maps were examined to produce a first estimate of the location of the various land types, and these were then discussed with the Land Resources Division, ODM. The land type map (Figure 4.1) was revised after this discussion. The land types were split broadly along the lines of the Gongola Report being:

Type 1a	Steep, rocky areas
1	Fairly steep, rocky areas
2	Dissected basement complex
3	Undulating basement complex
5	Flood plain
6	Nupe Sandstone

but these groupings were adjusted in the light of local knowledge.

The coefficient calculated from the land type map is given by the relationship:

$$\text{Land type coefficient} = 0.35\, S_{ia} + 0.2S_1 + 0.15S_2 + 0.1S_3$$

where S_{ia} is the percentage of the area covered by type 1a.

This is identical to the coefficient quoted in the Gongola report, and it remained a useful index. However, it is apparent that the assumption of zero runoff from land types 5 and 6 is not valid for the sandstone area in the Kaduna Basin; the decision to treat the sandstone part of the catchment separately makes this discrepancy academic. For all primary gauging stations the estimated sub-division of the catchment area into land types is shown in Table 4.1.

Slope index

The index employed for the Gongola report was maintained in this analysis, mainly for its simplicity. The index is calculated using the relationship:

$$\text{Slope index} = \frac{H_1 - H_2}{\sqrt{A}}$$

where H_1 is the elevation, in metres, of the highest point on a marked stream on the 1:250,000 scale mapping

H_2 is the elevation, in metres, of the gauging station

A is the catchment area to the gauging station in square kilometres

Rainfall

The catchment average annual rainfall was estimated from the isohyetal map described and reproduced in section 2.2.

TABLE 4.1

CALCULATION OF LAND TYPE COEFFICIENT

	Catchment Area (km^2)	Area of Land Type (km^2) 1a	1	2	3	5	6	Land Type Coefficient
Kaduna at Kaduna	18400	1012.5	425	1650	13587.5	1725		11.25
Kaduna at Kurmin Gurmana	34970	1200	425	5768.8	25151.2	2425		10.85
Kaduna at Wuya	65530	1406.3	675	15928.7	37345	2675	7500	10.20
Galma at Zaria	4350	125		125	3625	425		9.80
Galma at Ribako	6886	125		537.5	5323.5	900		9.60
Tubo at Mile 20	5900			750	4750	400		10.05
Mariga at Mariga	12700		43.8	1687.5	10718.7	250		10.41
Karami at Saminaka	736	225		125	386			18.60
Shika at Rail Bridge	855			37.5	780	37.5		9.70
Kangimi at Rihogi	350			12.5	337.5			10.20
Kogum at Kagoro	93	25	12.5	6.2	49.3			18.40
Kogum at Ungwar Rimi	463	25	75	6.2	356.8			12.80
Gurara at Kachia	450			43.8	406.2			10.50

Results

A regression relationship was sought between the values of the calculated mean annual runoff and various catchment parameters for the thirteen "primary" gauging stations. The most successful related mean annual runoff (MAR), in millimetres, to the land type coefficient (LAND), the slope index (SLOPE) and the rainfall (RAIN). The relationship produced was:

$$MAR = -1057 + 1.004 \times (RAIN) + 7.065 \times (SLOPE) + 5.170 \times (LAND)$$

The data used in this analysis are summarised in Table 4.2.

Values of MAR calculated for each station using this relationship are shown plotted against the measured value in Figure 4.2.

A more detailed breakdown of the statistics of the regression relationship is given in Table 4.3. The ratio of the variation of MAR explained by the relationship to the total variation, R^2, indicates the closeness of fit. In this case, almost 99% of the variation is explained.

Attempts were also made to correlate the runoff coefficient (RO) with the catchment parameters. A good fit was also obtained for this regression relationship, but it remained inferior to the adopted relationship. Details of the best runoff coefficient regression are contained in Table 4.4.

4.2 MINIMUM FLOW

Attempts were made to correlate the average minimum monthly flow with the various catchment parameters described previously. The most successful of these produced the relationship:

$$\text{Minimum flow} = 2.836 + 0.1825 \times (SLOPE) - 0.3269 \times (LAND)$$

where "minimum flow" is expressed in millimetres per month over the catchment area. The data used are summarised in Table 4.5.

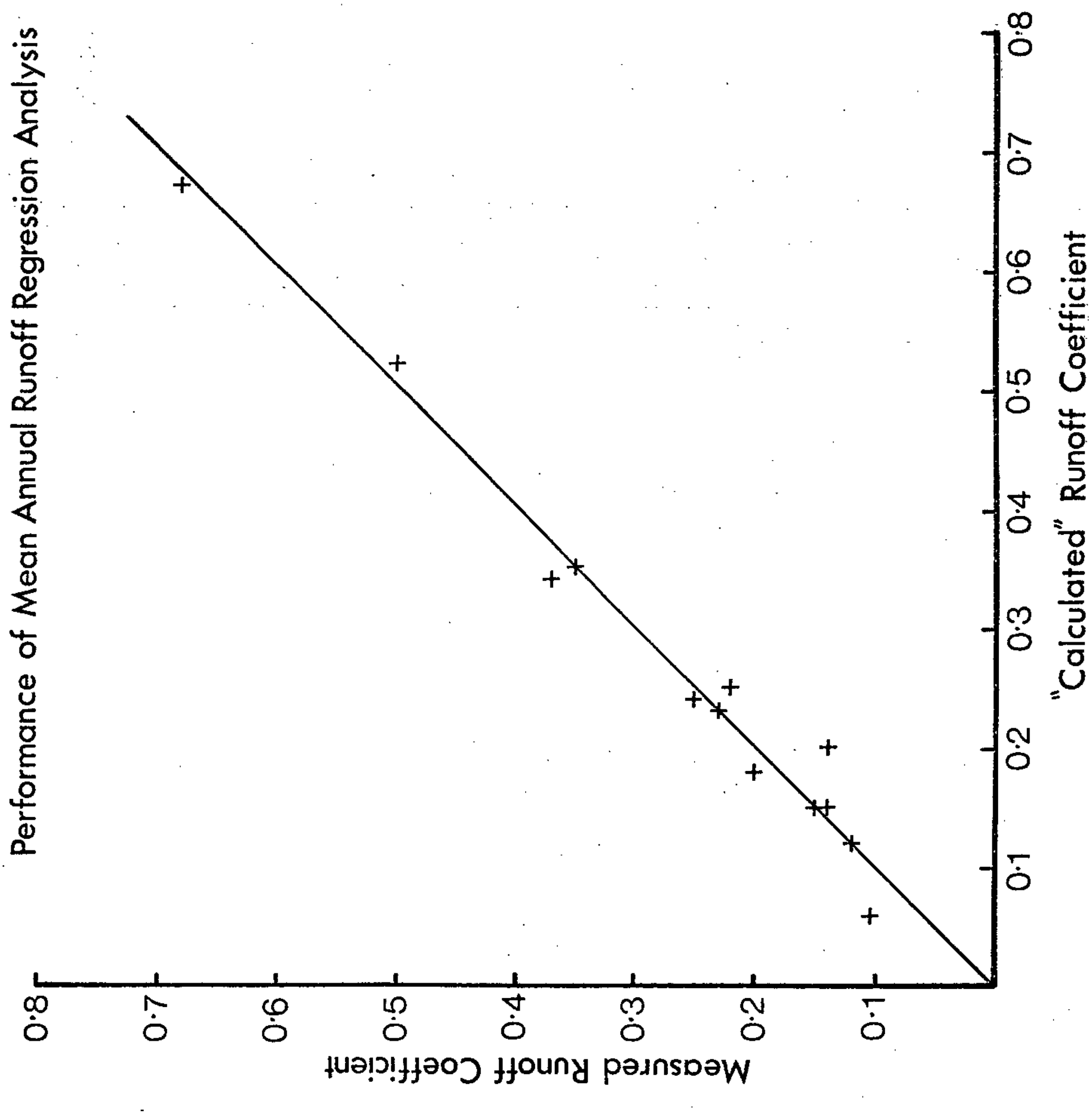
Details of the regression relationship are contained in Table 4.6.

TABLE 4.2

CALCULATION OF MEAN ANNUAL RUNOFF (MAR)

Station	Catchment Rainfall (mm)	SLOPE Measure	LAND Type Coefficient	Measured MAR (mm)	Calculated MAR (mm)
Kaduna at Kaduna South	1270	5.53	11.25	284	315
Kaduna at Kurmin Gurmana	1260	5.75	10.85	309	305
Kaduna at Wuya	1250	4.88	10.20	287	285
Galma at Zaria	1150	3.59	9.80	163	174
Galma at Ribako	1150	3.07	9.60	174	169
Tubo at Mile 20	1125	1.95	10.05	133	138
Mariga at Mariga	1175	4.26	10.41	234	207
Karami at Saminaka	1270	19.2	18.6	443	450
Shika at Rail Bridge	1050	2.74	9.70	110	67
Kangimi at Rihogi	1200	4.81	10.2	167	235
Kogum at Kagoro	1625	59.1	18.4	1107	1087
Kogum at Ungwar Rimi	1550	33.9	12.8	771	805
Gurara at Kachia	1450	5.76	10.5	540	494

FIGURE 4.2



Performance of Mean Annual Runoff Regression Analysis
Measured Runoff Coefficient
"Calculated" Runoff Coefficient
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8

TABLE 4.3

REGRESSION OF MAR ON RAIN, SLOPE, LAND

Name	Coefficient	Standard Error	"t"	R	R^2
Constant	-1057	158.7	-6.658	0.9941	0.9882
RAIN	1.004	0.116	8.652		
SLOPE	7.065	1.585	4.458		
LAND	5.170	5.854	0.883		

TABLE 4.4

REGRESSION OF RO ON RAIN, SLOPE, LAND

	Coefficient	Standard Error	"t"	R	R^2
Constant	-0.6791	0.106	-6.401	0.9921	0.9843
RAIN	0.0006306	0.000078	8.136		
SLOPE	0.002565	0.00106	2.422		
LAND	0.009652	0.00391	2.467		

TABLE 4.5

CALCULATION OF AVERAGE MINIMUM MONTHLY FLOW

Station	Slope Measure	Land Type Coefficient	Average minimum monthly flow Measured (mm)	Calculated (mm)
Kaduna at Kaduna South	5.53	11.25	0.49	0.17
Kaduna at Kurmin Gurmana	5.75	10.85	0.29	0.34
Kaduna at Wuya	4.88	10.20	0.24	0.39
Galma at Zaria	3.59	9.80	0.053	0.29
Galma at Ribako	3.07	9.60	0.18	0.26
Tubo at Mile 20	1.95	10.05	0.13	-0.09
Mariga at Mariga	4.26	10.41	0.005	0.21
Karami at Saminaka	19.2	18.6	0.32	0.26
Shika at Rail Bridge	2.74	9.70	0.13	0.17
Kangimi at Rihogi	4.81	10.2	0	0.38
Kogum at Kagoro	59.1	18.4	7.35	7.61
Kogum at Ungwar Rimi	33.9	12.8	5.28	4.84
Gurara at Kachia	5.76	10.5	0.81	0.45

TABLE 4.6

REGRESSION OF MINQ ON SLOPE, LAND

	Coefficient	Standard Error	"t"	R	R^2
Constant	2.836	0.4454	6.229	0.9937	0.9874
SLOPE	0.1825	0.00834	21.889		
LAND	-0.3269	0.04476	-7.304		

4.3 RECESSION ANALYSIS

The recession constant deduced for each of the primary gauging stations was very poorly correlated with each of the catchment parameters outlined above. The most satisfactory relationship is a geographical one, and this is shown in Figure 4.3.

The recession constant can be used in conjunction with the average minimum monthly flow to obtain an indication of dry season flows. The runoff records of the Kaduna Basin show that, in general, the discharges decrease from early December until the end of March on average in a manner that can be represented by the relationship:

$$Q = Q_o K^t$$

where Q is the flow at time t

Q_o is the flow at time t = 0

K is a recession constant

Any rainfall during this period will upset the pattern temporarily. March is, in the majority of cases (70% of the time) the month with the lowest discharge. Therefore, assume March discharge is the average minimum monthly flow, say $\overline{Q}_m$. A February figure can then be deduced as:

$$\overline{Q}_f = \frac{\overline{Q}_m}{K^{30}}$$

The January ($\overline{Q}_J$) and December ($\overline{Q}_D$) figures can then be calculated from:

$$\overline{Q}_J = \frac{\overline{Q}_m}{K^{60}} \; ; \; \overline{Q}_D = \frac{\overline{Q}_m}{K^{90}}$$

The application of this method to the data from the gauging stations revealed some inconsistencies. The average monthly flow comes from several years, with the recessions beginning and ending at different times. Thus, the average March flow is, in general, larger than the minimum monthly flow. The accuracy of this method can be improved by adopting a different "ending date" for the recession. By splitting the catchment at the Kaduna South gauging station, the catchment above the station can be assumed to have a recession ending on 1 March, the lower catchment a recession ending on 15 March. In other words:

(a) For the lower catchment:

$\overline{Q}_m$ = minimum monthly flow figure

$$\overline{Q}_F = \frac{\overline{Q}_m}{K^{30}} \; ; \; \overline{Q}_J = \frac{\overline{Q}_m}{K^{60}} \; ; \; \overline{Q}_D = \frac{\overline{Q}_m}{K^{90}}$$

(b) For the upper catchment (excluding Galma)

$\overline{Q}_m$ = minimum monthly flow figure

$$\overline{Q}_F = \frac{\overline{Q}_m}{K^{15}} \; ; \; \overline{Q}_J = \frac{\overline{Q}_m}{K^{45}} \; ; \; \overline{Q}_D = \frac{\overline{Q}_m}{K^{75}}$$

For the gauged catchments this method, with three exceptions, produced estimates within 50% of the measured flow figures, and so it remains a very approximate guide to the flow variation. The noticeable exceptions came from interference with the natural flow regime by farmers, which has caused the estimation of the smallest monthly flows themselves to be very approximate.

As the Galma catchment is gauged at three primary stations, the best indication of the seasonal variation in runoff is likely to be obtained by comparison with one or more of the primary stations records.

4.4 RUNOFF FROM NUPE SANDSTONE

Records were obtained from two gauging stations on streams flowing off the Nupe Sandstone - the Yiko at Guzan and the Bakogi at Agaie. Analysis of the available records is summarised in Table 4.7.

Because of the different runoff characteristics of the sandstone and the rest of the Kaduna Basin, this area was not included in the general

TABLE 4.7

RUNOFF FROM NUPE SANDSTONE

	Yiko at Guzan	Bakogi at Agaie
Catchment Area (km^2)	530	519
Average Annual Discharge (m^3/s)	0.92	1.76
Mean Annual Runoff (mm)	55	107
Average minimum monthly discharge (m^3/s)	0.5	0.1
Average minimum monthly runoff (mm)	2.5	0.5
Recession constant	0.997	0.994
Catchment slope index (m/km)	0.4	6.15
Catchment rainfall (mm)	1250	1200

catchment analysis. Because the data from the two stations are dissimilar, no attempt was made to estimate general "sandstone" runoff characteristics. If flow estimates have to be made for catchments within the Nupe Sandstone, personal judgement must be used to estimate which of the gauged catchments is the more similar from a hydrological point of view, and approximate flow estimates made accordingly.

4.5 CHECK ON MEAN ANNUAL RUNOFF REGRESSION

Data from the "secondary" gauging stations provided a independent check on the principal regression analysis - to calculate mean annual runoff.

However, the data from the secondary stations were rejected in preparing the regression relationship - and so disparities between "recorded" and "calculated" values are to be expected. The results of this exercise are contained in Table 4.8.

These results are fairly encouraging. The Resa runoff was expected to be grossly over-estimated as no allowance was made for planted forest, and the Koriga runoff data are limited to one year only. The estimates to the north of the area are disappointing, with the Kano, Challawa and Shika all being under-estimated, but these stations are outside the rainfall range used in the regression. When estimating mean annual runoff using the regression equation in areas of low rainfall (say < 1050 mm), the tendency to under-estimate the runoff should be borne in mind. With these exceptions, the measured and calculated mean annual runoff agree quite closely.

However, caution should be exercised when applying these equations to sites with catchment characteristics outside the range used in the regression analysis. In other words, these estimates should be checked by runoff measurements, especially for small, steep or particularly wet or dry catchments.

TABLE 4.8

CHECK ON MEAN ANNUAL RUNOFF REGRESSION ANALYSIS

	"RAIN"	"SLOPE"	"LAND"	Mean Annual Runoff (mm) Calculated	Measured
Kusheriki to Birnin Gwari	1175	20.8	10	321	383
Resa to Afaka Forest	1225	8.0	10	281	85
Koriga to Mile 56	1175	6.82	11.5	230	366
Chalwe to Zangon Katab	1500		10		850
Challawa to Challawa Gorge	975	3.81	10	0.5	162
Kano to Chiromawa	1050	4.28	(10)	(79)	175
Kaura to Mile 7	1215	7.70	10	269	245
Kubani to Zaria	1075	9.30	15	166	209
Shika to Hankuyi	1000	2.99	10	20	74
Jamna to Soba	1100		10		
Gurara to Kitikwa	1460	5.85	10	502	550
Gurara to Izom	1470	7.56	10	524	490
Chanchaga to Chanchaga	1425	8.52	15	511	520

CHAPTER 5

RECOMMENDATIONS FOR FURTHER MEASUREMENTS AND INVESTIGATIONS

5.1 RAINFALL MEASUREMENT

In recent years there seems to have been a rapid decline in the number and completeness of the available rainfall records. At present all records are collected centrally in Lagos, which is inconvenient for regional studies. Much time would be saved if all records were collected together at the State Water Board Headquarters, copied, and then passed on to Lagos.

The raingauge network in the Kaduna Basin is far from uniform, with the gauges concentrated within the more densely populated regions of the Jos plateau and the Kaduna-Zaria area. A minimum desirable raingauge density for the region is about one gauge per 2000 square kilometres. To achieve this everywhere within the basin would require a further 21 stations, located for the most part to the west of the 7°00'E meridian. The gauges must also be sited where there are good, reliable observers.

Future development of the water resources of the area will be aided by the establishment of autographic stations to measure rainfall intensity as well as daily totals. A minimum, representative coverage would be to locate autographic gauges at Jos, Kaduna and Minna.

The existing network of gauges should be inspected. All sites should be visited to make sure that the raingauges are correctly positioned, and the reliability of the observers should be confirmed.

5.2 DISCHARGE MEASUREMENT

The existing network of flow gauging stations is centred around the road and rail systems within the basin. As a result, coverage is far from uniform. Any extension to the network must take into consideration the need for all gauging stations to be accessible throughout the year.

The development of the network should therefore be based on the planned road system.

Study of the 1975-1980 road plan for the area has identified a number of promising sites for gauging stations. Establishment of stations at the following locations is considered essential to complete a basic network within the Kaduna Basin (see Figure 5.1).

On the River Kodoko, where crossed by the existing Zungeru-Bida road (site a). At present, there are no gauged left bank tributaries of the Kaduna, and the Kodoko seems representative of the lower ones.

On the River Beiri, where crossed by the existing Tegina-Kontagora road (site b). This station would measure runoff from the Kontagora area.

On the River Eba, where crossed by the proposed north-south road from Bari to the Bida-Mokwa road (site c). This provides an opportunity to gauge a river flowing from Nupe Sandstone.

The establishment of these 3 stations, together with the existing station on the Mariga at Mariga should provide an adequate network for the lower part of the basin.

Two large tributaries of the Kaduna that require gauging are the Dinya and Sarkin Pawa. At the moment, the only means of access to possible gauging sites is by railway, and so it is recommended that some arrangement is entered into with the railway authority to facilitate regular access to the two sites (d and e). It is possible that a new road from Kaduna to the new Federal capital will be constructed across the area, which might provide alternative locations for the gauges.

A third area poorly served by gauging stations is the upper reaches of the Kaduna itself. Possible locations for further gauges are a Gyashari on the Kogin Kuri site (f), which would be a cableway installation, and where the proposed Rahama-Zangon-Katab road crosses the Mariri site (g) and the Kaduna site (h). These stations provide the only means of gauging runoff in the upper Kaduna basin.

The locations for new gauging stations outlined above can be no more than suggestions. Field visits will be required to locate the optimum sites. It is recommended that stations at sites a, b, d and e, which are accessible at present, should be established as rapidly as possible. The other stations should be established as soon as access is possible.

The present hydrometric network can be improved in other ways. The problem of human fallibility in measuring water levels can be overcome by using mechanical water level recorders, which provide a continuous hydrograph which records all peaks. Local observers would need to be retained to provide a check on the automatic recorders.

More care is also required in the collection and processing of streamflow data. Some of the data obtained from the water boards were obviously inaccurate, and so more care is required over the quality control checks and procedures to ensure that gauge readers present reliable information. Discharge measurements should be made at each gauging station at least twice a month to ensure a reliable rating curve. The zero levels of all gauge boards should be checked against a fixed bench mark at least once a year. Finally, all current meters must be sent regularly for maintenance and re-calibration as recommended by the manufacturers to ensure accurate discharge measurements.

5.3 SEDIMENT MEASUREMENT

Full utilisation of water resources will involve river regulation with associated problems of sediment deposition. Because theoretical knowledge alone is inadequate to produce estimates of sediment load, the only means of ensuring adequate, economical design is to institute a network of stations at which regular measurements of sediment load are made.

In the Kaduna Basin the requisite measurements would be made most conveniently at the same time and place as discharge measurements. A depth integrating sampler, using either wading rod or cable suspension, should be used in accordance with the US Geological Survey publication "Field Methods of Fluvial Sediment Measurement" (1970).

Until an adequate and economical means of measuring bed load has been devised, calculation of the total sediment load of rivers should be based on the measured suspended sediment and empirical formulae.

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APPENDIX

Primary gauging stations - review of data

The depth to which the review could be taken for any station was dependent upon the information available; the files and archives of the Kaduna State Water Board headquarters in Kaduna were made freely available. However, it was found that due to limited storage space, much of the older information had not been kept.

Ten of the thirteen primary stations are the responsibility of Kaduna State Water Board (KSWB). One belongs to Niger State Water Board and no records have been published; the review attempts to convert all available gauge levels to mean daily flows. The two remaining gauges belong to the National Electric Power Authority (NEPA) and the Inland Waterways Division (IWD); their data could not be checked.

Karami at Saminaka (KSWB)

This station underwent the most detailed examination, because the station had been visited, seemed to suffer badly from inconsistencies in the published flows and also because much additional information was available. It was therefore treated as a test case and illustrates the problems of flow measurement in the sandy rivers of the Kaduna basin.

The actual discharges measurements were first used to construct a rating curve for the site. Due to the sandy nature of the river section at Saminaka (which is typical of the vast majority of gauging sites visited and documented) the variations of the discharge measurements were allowed for by applying shift corrections. This approach assumes that all deviations from the basic stage-discharge relationship can be explained by movements of the stream bed.

It was assumed that bed movements occur during high flows. Thus, the basic stage-discharge relationship could be obtained from all discharge measurements made between one period of high flows and the next. Enough information was available for this site for this to be repeated a number of times.

A further assumption was made about the nature of the rating curve. Whereas KSWB plot the data on arithmetic scales and fit a parabolic curve through the discharge measurements, it was assumed in this study that the relationship could be represented by a straight line on double logarithmic paper with the level of zero flow corresponding to zero stage.

A consistent set of curves was produced for each year of analysis. An average line (Figure A.1) was constructed and found to represent the relationship

$$Q = 50\ H^2$$

The 'shifts' or apparent movements of the river bed were then computed from the discharge measurements, on a monthly basis. These are shown in Table A.1 .

The mean daily flows were computed using these shifts. The mean monthly flows were then deduced, and compared with those published by the KSWB; this comparison is summarised in Table A.2.

The two estimates of the mean annual runoff are similar. The major differences between the two estimates are in the dry season flows. Comparison of the daily flow estimates and the actual discharge measurements suggests that the KSWB approach is less reliable than the current approach.

The study of this station showed that the shifting nature of the river beds in the area could be allowed for simply in constructing rating curves with reasonable results. The problems of estimating flows during the dry season were brought out and the review of the other gauging stations concentrated on this aspect of the flow regime.

Kaduna at Kaduna South (KSWB)

This station is the most important flow gauging station in the catchment, having a relatively long gauging history, a reasonably stable cross section and easy access for the gauging authority in Kaduna. The

Kaduna flow record has been studied by a number of consulting engineers and others.

It was the subject of an investigation in 1962 by the Hydrological Research Unit, then part of the Hydraulics Research Station. This study was commissioned by Messrs Scott Wilson Kirkpatrick and Partners in connection with a scheme to supply water to the town of Kaduna. The object of the study was to investigate the low flows in the River Kaduna. There is close agreement between the flows deduced for this report and those published by the KSWB.

There are some anomalies in the published data after 1972. A rating curve for the Kaduna was established (Figure A.2) and 'shifts' computed for the period 1972-77, as for the Karami at Saminaka. The dry season flow estimates were then reviewed, and in many cases altered, to produce the revised monthly flows given in Table A.3.

Kaduna at Kirmin Gurmana (NEPA)

A gauge was installed at Kurmin Gurmana on the River Kaduna when Shiroro Gorge was being studied for its hydro-power potential. The flow information for this site is difficult to obtain. Motor Columbus, during their study, were unable to find any data. We have obtained, by courtesy of Sir Alexander Gibb and Partners, mean daily discharge estimates for the period 1955 to 1961. This information could not be cross-checked rigorously but seems to be consistent and is compatible with the data from stations both upstream and downstream. The monthly flow estimates produced are in Table A.4.

Kaduna at Wuya Bridge (IWD)

The River Kaduna is gauged at Wuya Bridge by the Inland Waterways Division of the Federal Ministry of Transport. The Motor Columbus Report contains a monthly flow summary for this station, which differs, in places, from the flows estimated by IWD. It appears that the present rating curve employed by IWD was constructed in 1952, which probably explains the variation in dry-season flows. Motor Columbus have altered or omitted these flows in their analysis.

As the basic discharge measurements are not available, the summary table of Motor Columbus was accepted for this gauging station and is reproduced as Table A.5.

Tubo at Mile 20, Kaduna to Lagos road (KSWB)

This station has suffered more than most from the lack of storage space in Kaduna, and very few of the basic discharge measurements survive. This gauging station, visited during our field visits, is said to be one of the better ones operated by the KSWB, and an examination of the computed discharges seems to confirm this. Where comparison between discharge measurements and computed flows was possible (1975 to 1977) the flows were somewhat overestimated and this was allowed for when constructing the monthly flow summary table (Table A.6).

Mariga at Mariga (NSWB)

All the information obtained for this station came from working files held at the Water Board's offices in Minna, in the form of discharge measurements and gauge levels.

The rating curve (Figure A.3) was established and the 'shifts' were then deduced from the discharge measurements. Comparison of these with the gauge height records revealed a number of anomalies in the data after 1974 and the variations and sudden changes in gauge heights suggested that these data should not be used in the analysis. For periods during the gauge levels appear reliable, mean daily flows were computed using estimated shifts and the rating curve. From these mean monthly flows were deduced, and these are summarised in Table A.7.

Galma at Ribako (KSWB)

This site is a typical sandy-bedded river of the Kaduna Basin, located at a road bridge. However, the method of constructing a rating curve used for the other gauging stations failed in this case to produce very satisfactory results. The discharge measurements were more scattered than usual, and, although a line was drawn through the data (see Figure A.4), the calculated shifts from that line remained dependent on discharge. As a result, the calculated rating curve remained a compromise solution.

The 'shift' calculations indicated a lot of bed movement, and from one year to the next the net change was appreciable. As a result, it was difficult to estimate dry season flows for seasons during which no discharge measurements were made. However, when comparisons were possible, it was found that there were no appreciable differences between the flow estimates of the KSWB and ours, so the flows quoted in Table A.8 are essentially those of the water board.

Galma at Zaria (KSWB)

This station was considered by the water board to be less reliable than the station at Ribako, and appears to have recently been abandoned - the station being transferred to the new dam on the Galma near Zaria.

Discharge measurements were obtained for the period 1971 to 1974, and these agree with the daily flows computed by the water board. The differences, however, are greater during periods of low flow. Because, in general, it was found that the earlier records are more reliable than the recent ones, the discharges computed by the water board for this station were accepted as correct, and are reproduced in Table A.9.

Comments appearing on the gauge height records indicate that the water levels in the Galma are influenced during the dry season by the damming of the river by farmers, presumably for irrigation or livestock watering. It is also noticeable that the estimated dry season flows have decreased in recent years. This could indicate increasing dry-season abstractions from the river, which could invalidate our calculations. If more detailed studies are required later, efforts should be made to assess these past and present abstractions.

Shika at Kano - Zaria Rail Bridge (KSWB)

This station has been well documented since its opening in 1965 but discharge measurements during the dry season have been infrequent. This station appears to suffer from raising of water levels due to local damming by farmers during periods of low flow and to backwater effects from the Galma during periods of high flow.

The flow records computed by the water board were found to be consistent and adequate for most of the year but there remained uncertainties over the dry season flows. However, the available records do not enable us to improve on the low flow estimates produced by the water board. The flow estimates are contained in Table A.10.

Kangimi at Rihogi (KSWB)

The Kangimi is a small tributary of the Kaduna that has grown in importance recently due to the construction of a large dam across the river. This station was investigated and used by consulting engineers during studies associated with the dam, and the records produced by Enplan in their report on the irrigation potential of the Kangimi water resources are contained in Table A.11.

Kogum at Kagoro (KSWB)

Although this station is outside the Kaduna basin, it is useful because the catchment is hydrologically similar to the Upper Kaduna catchment, and the station appears to be reliable. The additional information collected at the water board headquarters supported the flows calculated by the board, reproduced in Table A.12.

Kogum at Ungwar Rimi (KSWB)

This station is also outside the Kaduna catchment and possesses a stable section, with the rating curve being consistent up to 1974. Thereafter, significant deviations occur and the water board's calculations over-estimate the dry season flows. These have been amended and are shown in Table A.13.

Gurara at Kachia (KSWB)

This station, outside the Kaduna catchment, is visited frequently by the hydrometric staff of the water board and there are a large number of discharge measurements recorded on the headquarters file. These were used to construct a rating curve, reproduced in Figure A.5. The early discharge measurements appeared to be adequately reliable but it was found that the discharge estimates in recent years required occasional modification. The low flow estimates appear to be consistently somewhat higher than the discharge measurements during the corresponding periods. The revised discharge estimates are contained in Table A.14.

Yiko at Guzan (NSWB)

This station, gauging a small stream to the west of the Kaduna catchment, was selected for examination because its catchment area is entirely on the Nupe Sandstone and is likely to have different runoff characteristics from the other gauged streams.

The information obtained from the water board headquarters in Minna consisted of all available dischargement measurements and calculated mean daily gauge heights. Examination of the discharge measurement data showed the river cross-section at the gauge to be fairly stable, although the data are very scattered. An average line was drawn to produce an approximate rating curve (Figure A.6) which should be adequate for this study. The computed mean monthly discharges are given in Table A.15.

Bakogi at Agaie (NSWB)

A second station with a catchment area within the Nupe Sandstone was on the Bakogi. Discharge measurements and mean daily gauge heights were obtained, a stable rating curve was constructed (Figure A.7) and mean monthly discharges, computed from the available gauge heights, are reproduced in Table A.16.

Secondary gauging stations

In addition to the primary streamflow stations, there are a number of stations for which data are also available, but which are not considered suitable for the primary network. A brief description of these stations follows, with the reason for exclusion.

Kusheriki at Birnin Gwari (KSWB): only one year's data available. Gauge located downstream of Bagoma dam. Visited during field visit.

Resa at Afaka Forest (KSWB): a gauge with a fairly complete gauging history but the forested catchment produces abnormally low runoff, which is at least partly attributable to faults in the structure.

Koriga at Mile 56 (KSWB): data were found for only one year. Station visited during field visit.

Chalwe at Zangon Katab (KSWB): another station with a very short history. A small catchment in the upper Kaduna Basin similar to other catchments with a longer gauging history.

Kaura at Mile 7 (KSWB): a station gauging a very small catchment area in a part of the Kaduna Basin well represented by other gauges. A station with a record of moderate length (4 years).

Kubani at Zaria (KSWB): a reasonably long record available, but station adversely affected by backwater effects from the River Galma. Record intermittent and unreliable.

Shika at Hankuyi (KSWB): a very incomplete record available. River adequately gauged downstream.

Jamma at Soba (KSWB): a small sub-catchment contained within the Galma catchment. Record short and very poor.

Kano at Chiromawa (WRECA): a well-documented station to the north-east of the Kaduna Basin, with a relatively long gauging history. However, the flow regime of this river appears to be significantly different from that of the Galma (the nearest gauged catchment inside the Kaduna Basin), with the river regularly drying completely.

Challawa at Challawa Gorge (WRECA): a station that has been closely examined by WRECA, and whose records have been extended back to 1960. However, the seasonal distribution appears to be significantly different from gauged Kaduna tributaries, with the river drying up for about 5 months of the year.

Gurara at Kitikwa (WRECA): a recently established station to the south of the Kaduna Basin, with only one year's data available.

Gurara at Izom (NSWB/WRECA): interest in this station has recently revived due to the location of the new Federal capital. WRECA have estimated the mean daily discharges for 1976 only, the rest of the data are in fairly crude form. Located to the south of the Kaduna Basin.

Chanchaga at Chanchaga (NSWB/WRECA): a station in a very similar state to Guarar at Izom, to the south of the Kaduna Basin.

FIGURE A.1

Rating Curve for Karami at Saminaka

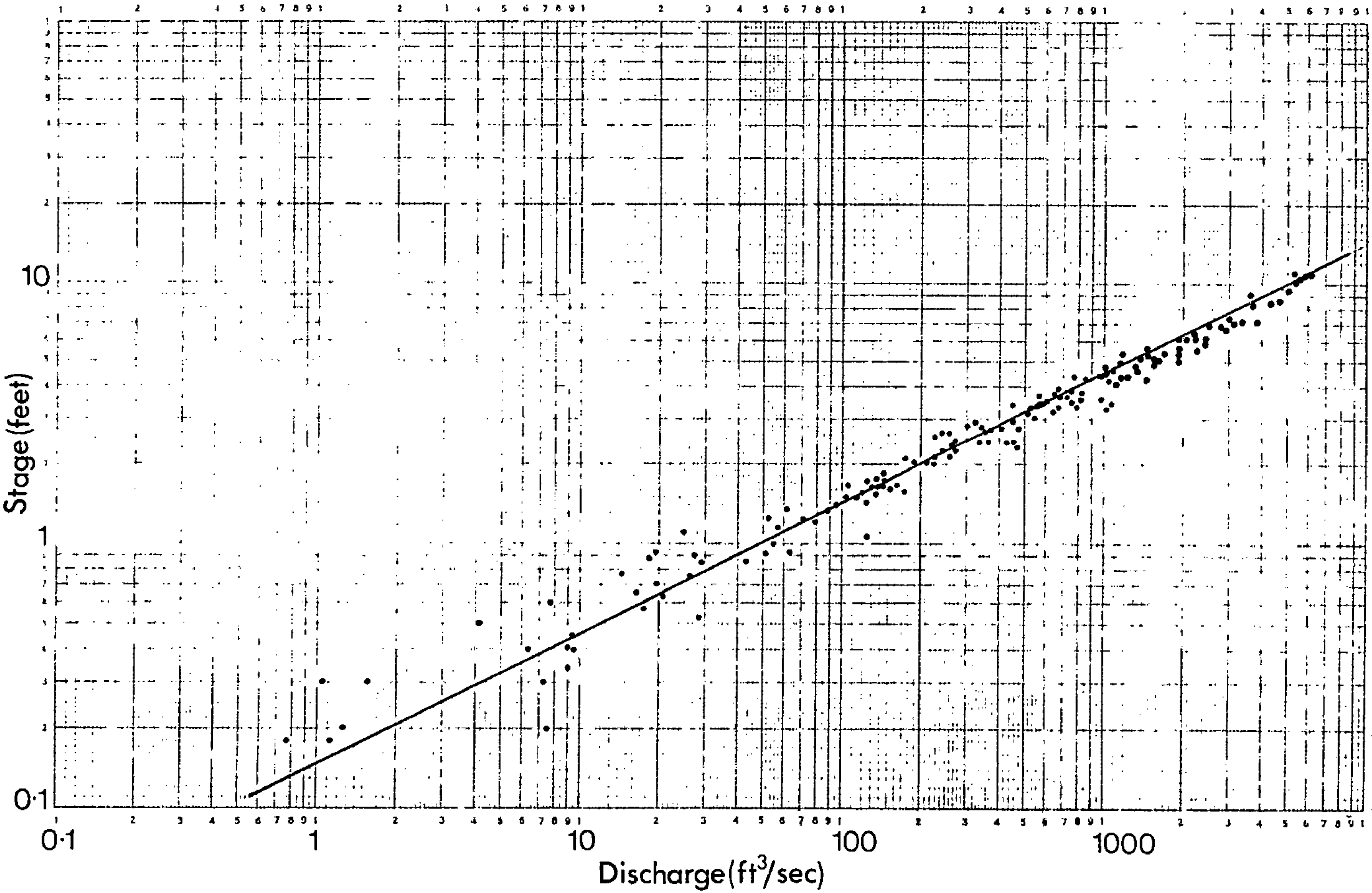
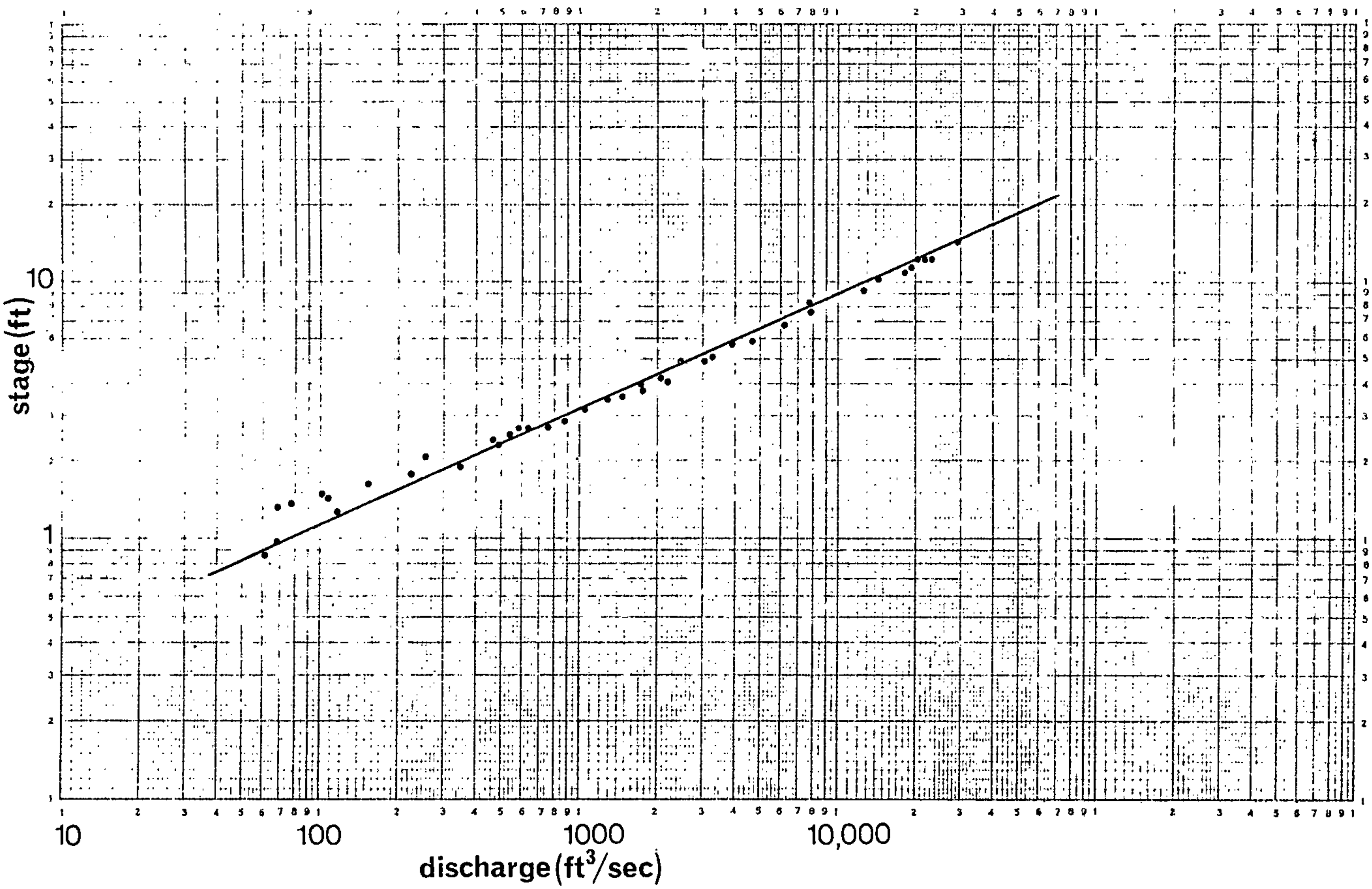


FIGURE A.2

Rating Curve for Kaduna at Kaduna



Rating Curve for Mariga at Mariga

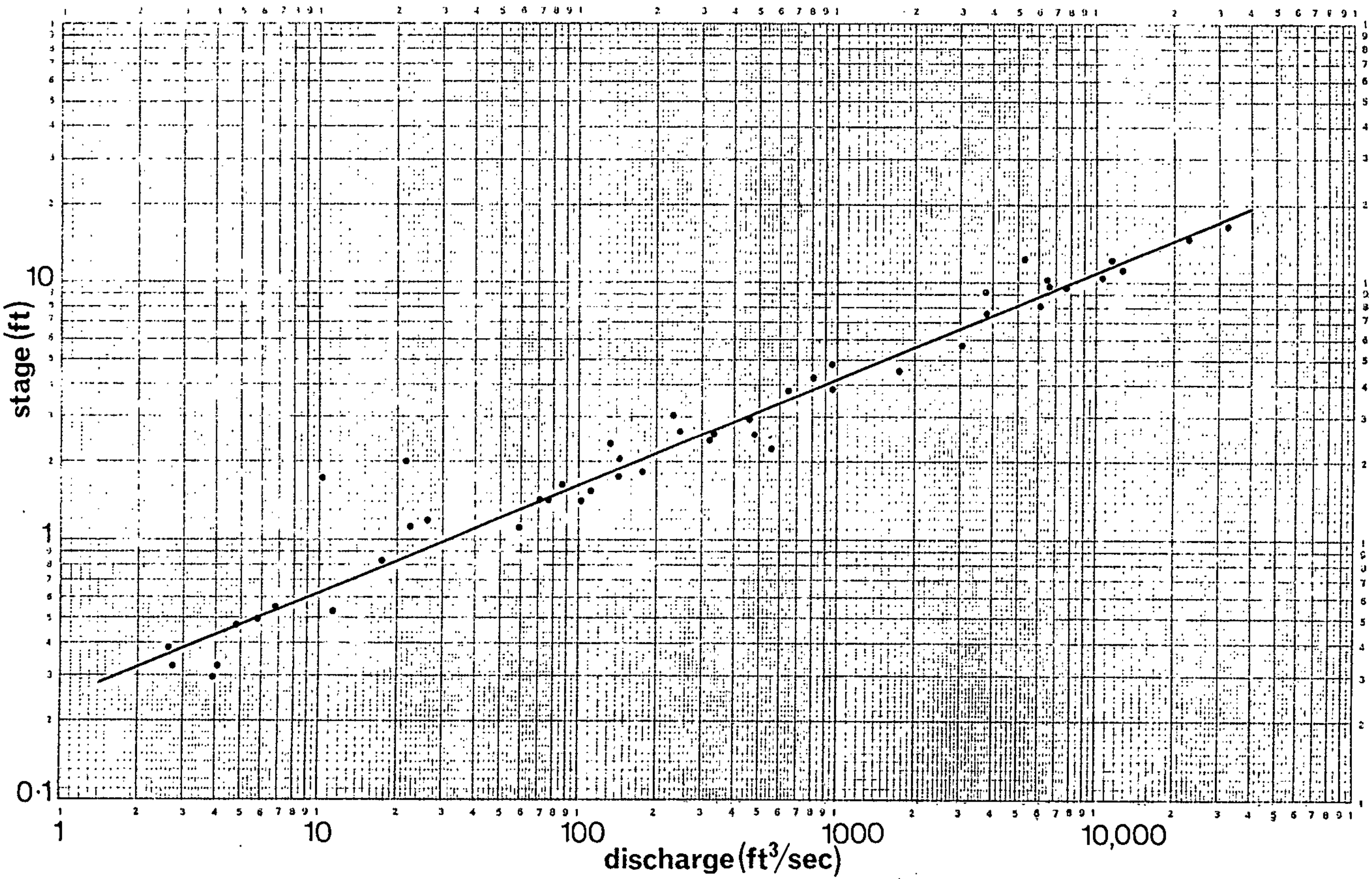


FIGURE A.3

FIGURE A.4

Rating Curve for Galma at Ribako

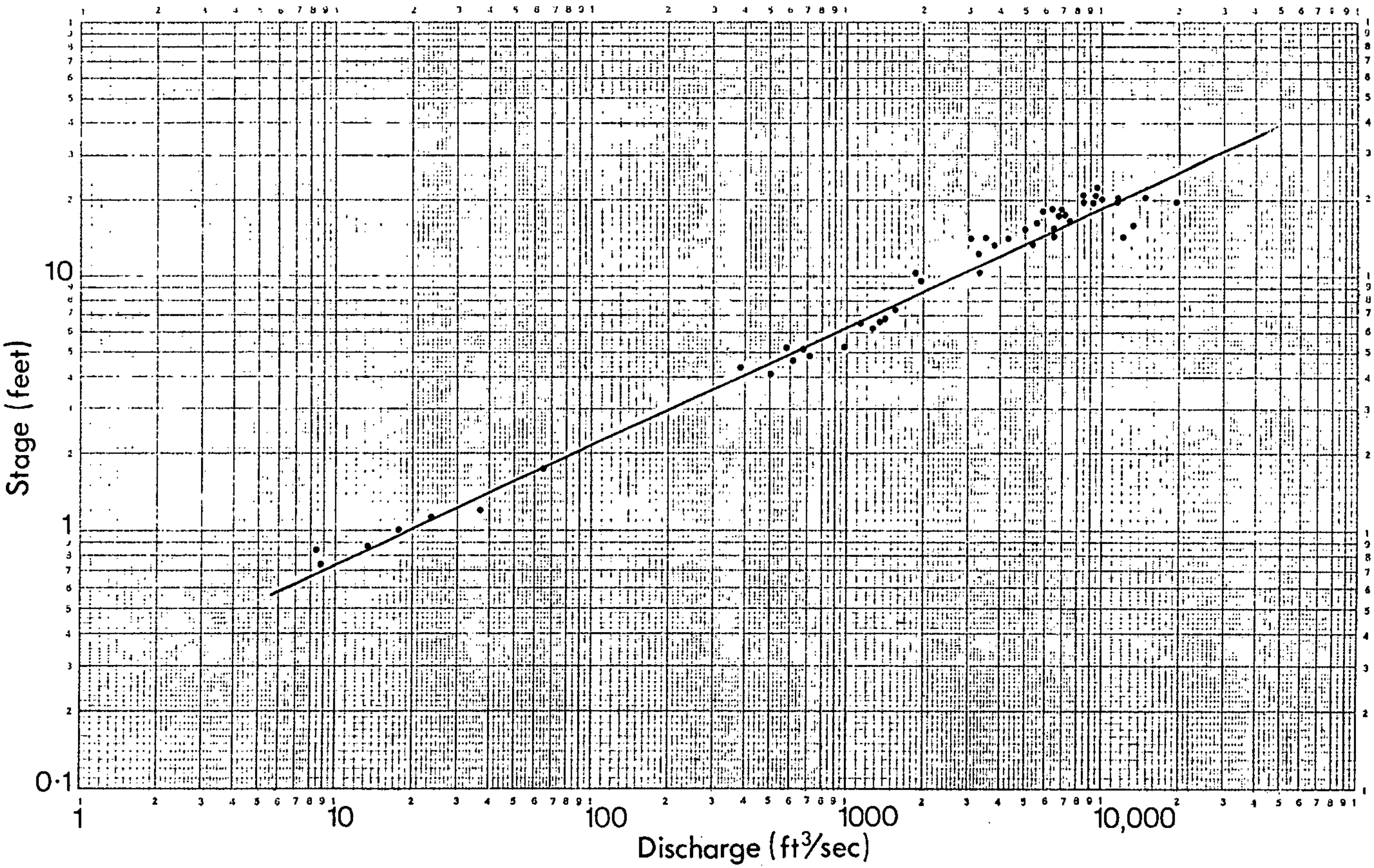


FIGURE A.5

Rating Curve for Gurara at Kachia

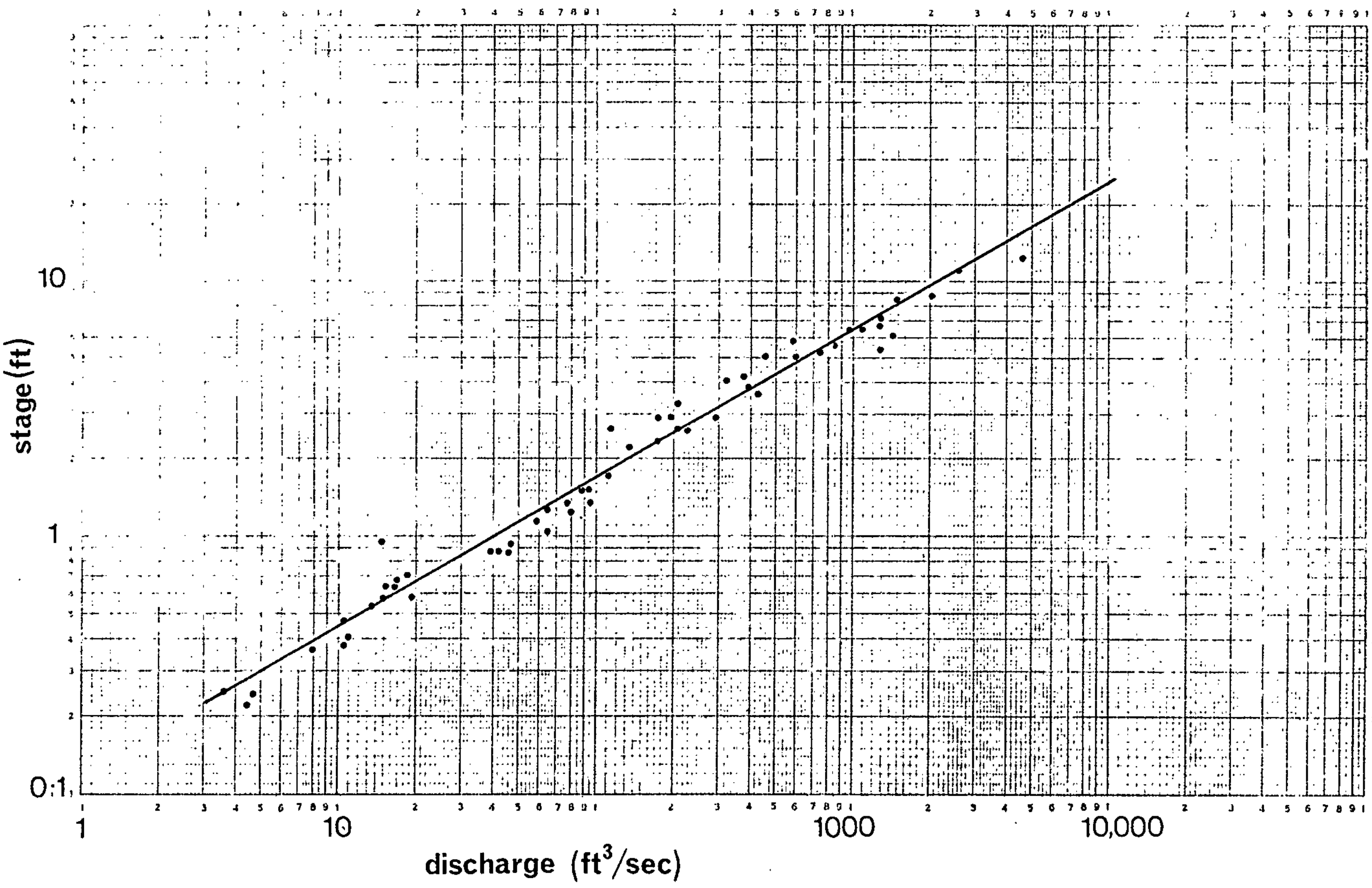


FIGURE A.6

Rating Curve for Yiko at Guzan

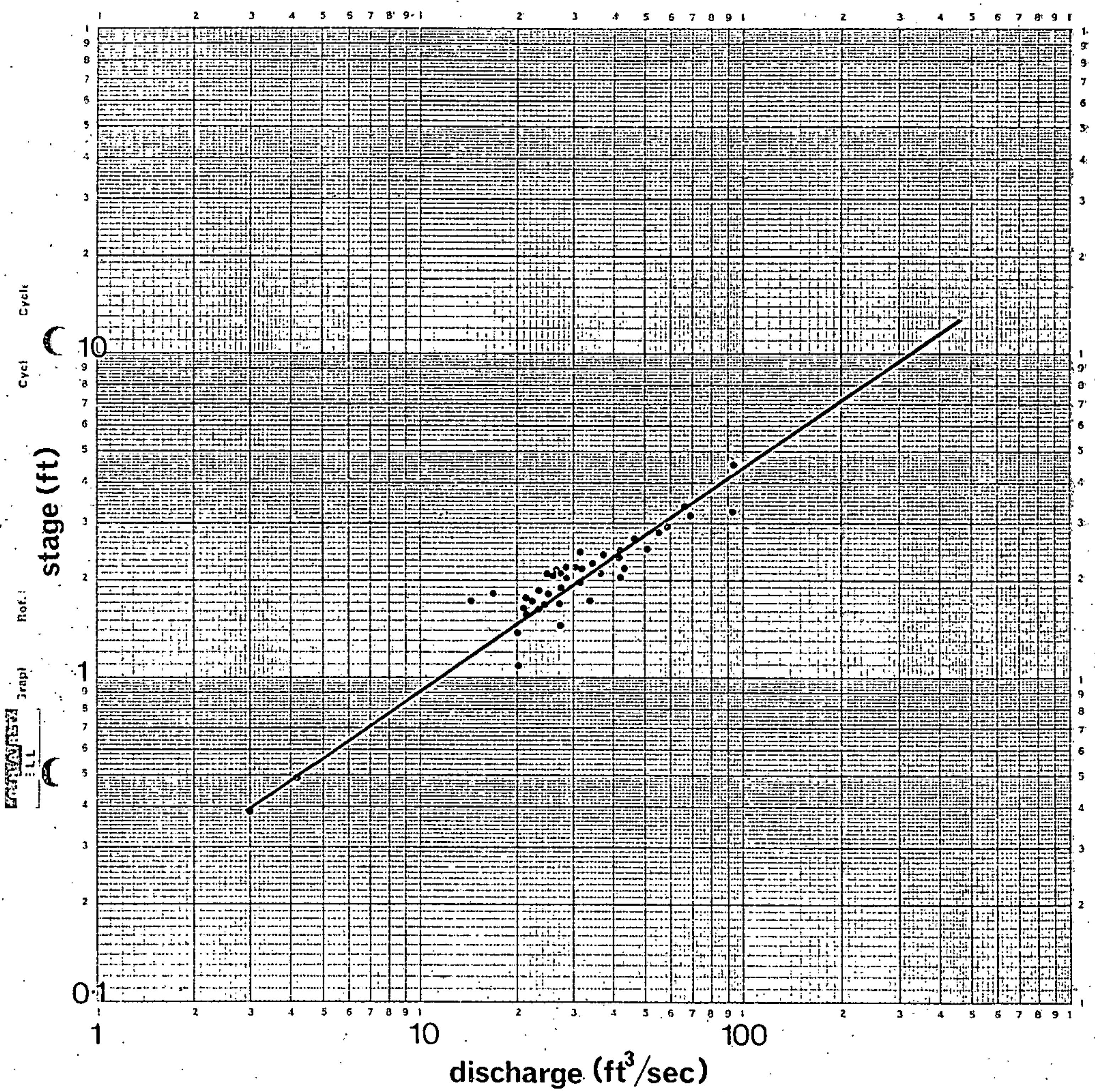


FIGURE A.7

Rating Curve for Bakogi at Agaie

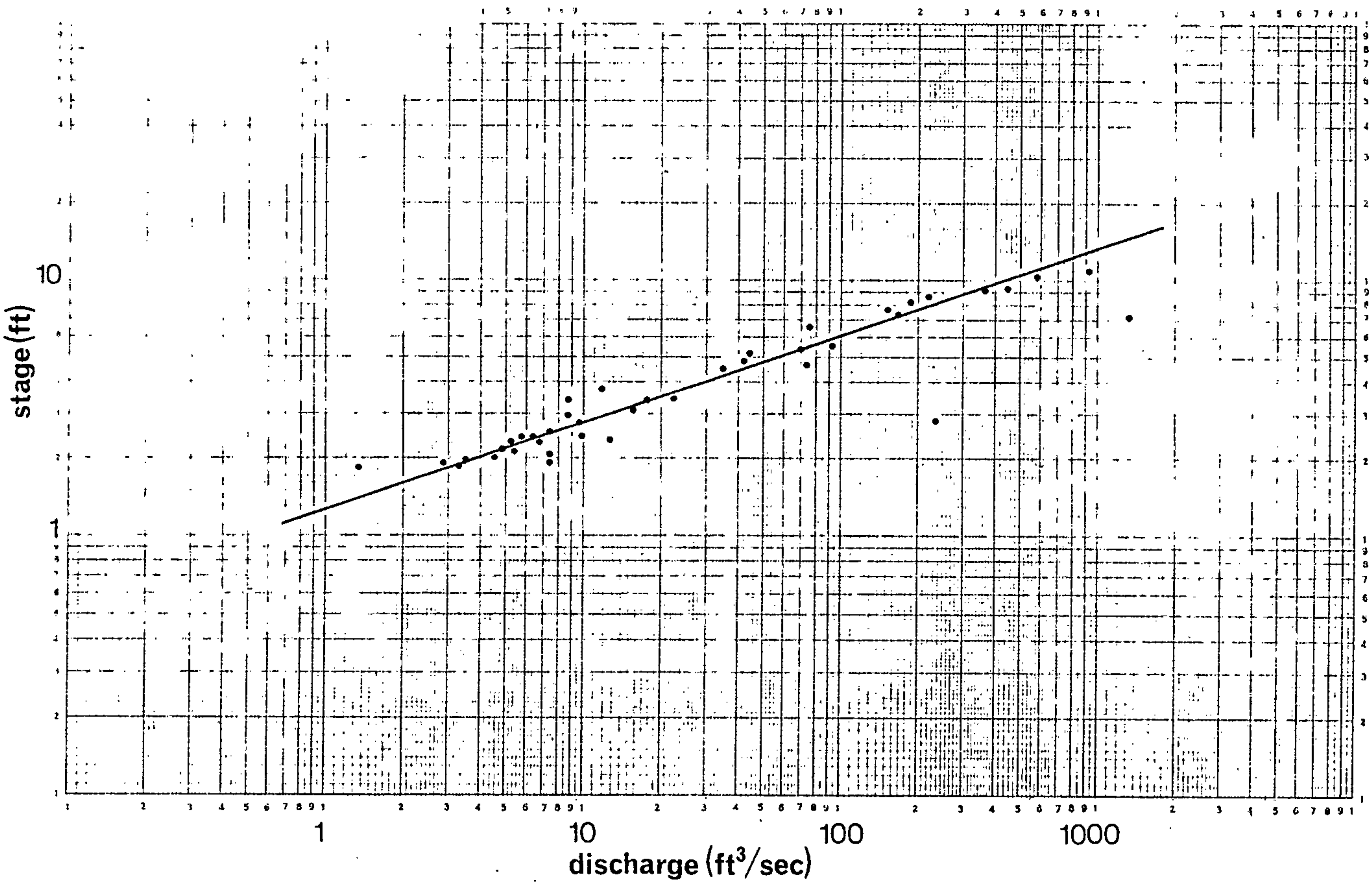


TABLE A.1

KARAMI AT SAMINAKA - APPLIED SHIFTS (FEET)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1972	0	0	0	0	0	+0.2	+0.4	+0.6	+0.2	0	0	0
1973	0	0	0	0	0/-1.1	-1.0	-0.5	-0.7	-0.7	-0.8	-0.8	-0.8
1974	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.75	-1.0	-1.0	-1.5	-1.5	-1.5
1975	-1.5	-1.5	-1.5	-1.5	-1.5	-1.75	-2.0	-2.3	-2.7	-2.3	-2.6	-2.7
1976	-2.8	-2.85	-2.8	-2.5	-2.3	-2.3	-2.4	-2.1	-2.0	-1.95	-2.9	-2.9
1977	-2.9	-2.9	-2.9									

TABLE A.2

COMPARISON OF MEAN MONTHLY FLOW ESTIMATES - KARAMI AT SAMINAKA (m^3/s)

YEAR	METHOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1972	KSWB				0.45	6.23	4.64	23.4	51.5	19.8	3.77	0.51	0.01	
	IH				0.23	6.34	7.7	20.4	54.1	27.4	8.2	1.22	0.37	
1973	KSWB	0	0	0	0.91	2.29	6.51	15.0	39.1	18.4	4.59	0.71	0.44	7.3
	IH	0.08	0.07	0.19	0.94	0.57	10.2	13.1	41.3	17.2	2.57	0.44	0.16	7.2
1974	KSWB	0.40	0.38	0.32	0.44	7.22	8.55	15.4	36.9	41.9	17.3	6.20	3.65	11.6
	IH	0.13	0.11	0.05	0.14	6.77	7.33	14.8	51.1	51.1	10.2	2.29	1.03	12.1
1975	KSWB	2.46	2.05	1.82	0.99	3.96	2.55	18.4	35.0	43.5	5.79	3.13	2.44	10.2
	IH	0.44	0.28	0.18	1.07	6.77	3.45	30.6	41.7	44.9	5.89	1.42	0.54	11.4
1976	KSWB	2.20	1.90	1.90	2.18	3.60	4.81	22.0	26.3	37.1	10.1	4.13	3.07	9.9
	IH	0.23	0.10	0.10	0.76	2.97	5.30	23.7	32.1	49.2	15.1	1.90	0.72	11.0
1977	KSWB	2.63	2.25	2.06										
	IH	0.35	0.16	0.08										

IH annual average 10.3 m^3/s or 443 mm

TABLE A.3

STATION : KADUNA AT KADUNA SOUTH

Latitude : 10^{0}-30' Longitude : 07^{0}-26' Catchment Area : 18410 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1947	10	7.2	2.8	6.6	5.5	95	210	600	862	25	6.3	1.6	155
1948	7.4	5.6	4.2	35	40	138	183	490	727	163	37	14	154
1949	8.5	6.0	5.0	8.5	39			420	328	68	19	8.9	
1950	7.7	6.2	4.9	9.8	60	93	186	286	356	135	26	11	98
1951	7.6	5.4	3.6	6.2	49	67	170	557	589	364	111	27	163
1952	13	7.9	6.4	4.4	44	51	192	279	465	244	38	14	113
1953	8.5	6.3	7.5	5.7	85	141	243	493	781	200	46	15	169
1954	8.9	6.8	6.1	31	59	109	255	472	795	258	65	23	174
1955	11	7.0	4.5	4.2	37	98	296	515	870	390	83	25	195
1956	13	8.7	9.0	11	14	44	145	344	479	138	23	12	103
1957	4.7	3.1	2.2	5.1	77	158	370	556	1010	631	109	35	247
1958	17	6.8	5.2	16	31	94	165	340	590	211	35	10	127
1959	6.2	3.4	0.8	4.1	39	76	145	336	669	185	30	11	125
1960	5.7	3.0	1.5	30	29	89	231	553	595	214	43	16	151
1961	9.3	6.0	3.5	4.0	8.8	74	256	396	459	109	22	9.6	113
1962	5.1	3.5	4.2	13	27	93	215	530	1302	421	92	32	228
1963	18	8.8	5.2	22	46	102	211	589	421	499	96	35	171
1964	16	6.7	2.5	8.9	33	104	256	760	1186	188	46	10.6	217

TABLE A.3

STATION : KADUNA AT KADUNA SOUTH (Continued)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1965						174	205	407	491	90	9.1		
1966												13.7	
1967	10.3	5.1	2.4	12.0	36	85	366	616	825	280	49	16	191
1968	8.7	6.1	5.2	21	71	284	439	646	761	145	33	12	203
1969	8.6	5.0	2.0			49	213	501	695	255	75	17	160
1970						51	161	510	721	75	27		
1971						63	177	542	726	133	29	13	
1972				6.15	60	114	222	870	655	186	35	10	181
1973	6.3	2.6	2.2	5.2	8.8	62	149	728	672	125	26	7.8	149
1974	5.4	2.9	6.1	10.4	70	70	244	531	941	299	40	12	185
1975	8.2	4.4	1.9	14.7	92	92	342	695	1015	323	54	13	220
1976	10.4	3.8		9.3	39	107	296	441	475	372	114	24	157
1977	15.7	9.0	2.4										

Annual average 166 m^3/s or 284 mm

TABLE A.4

STATION : KADUNA AT KURMIN GURMANA

Latitude : 09°-58'   Longitude : 06°-51'   Catchment Area : 34970 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1955			3.52	6.21	44	130	550	960	1770	1080	160	59	399
1956	16.3	6.5	14.2	7.3	8.4	98	460	1150	1690	1225	102	22.9	400
1957	9.6	5.1	3.01	7.7	149	304	715	990	2280	1280	246	76	505
1958	31.2	12.1	7.0	17.2	50	178	247	439	1227	578	126	61	248
1959	30.4	11.6	6.75	11.6	74.7	154	360	686	1262	411	63.7	24.9	258
1960	12.3	4.3	1.46	46.4	50.4	186	537	1124	1388	519	126	39.0	336
1961	14.2	8.1	2.21	2.94	8.9	151	660	804	984	264	50	14.1	247

Annual average 332 m^3/s or 300 mm

TABLE A.5

STATION : KADUNA AT WUYA BRIDGE

Latitude : 09^0-10'   Longitude : 05^0-50'   Catchment Area : 65,530 sq km

Mean Monthly Flows (m^3/s)
(after Motor Columbus)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1947	17.5	10	10	45	41	312	657	1937	2953	1604	451	111	679
1948	19	10	10	82.4	144.2	445	536	1591	2339	1237	153.5	46	551
1949	18.7	7.6			46.4	117.8	342	1426	1606	709	149.5	50.6	392
1950	19.2	12.9	8.2	5.6	100.5	190.4	423	822	1784	1209	157.6	50	399
1951	19.3	13		40	147.4	156.3	402	1868	2948	2475	1040	195	776
1952					220.8	303.7	683	1193	2084	1966	252	96	573
1953					289.7	571	1185	1729	2892	1486	324	141.4	727
1954	18.5	10	10	94.1	184.9	327.1	940	1565	3641	1622	476	165	754
1955				41.6	105.0	245.9	977	2062	3374	2435	653	273.3	850
1956				143.7	105.3	211.3	335.2	740	2180	979	200.3	87.5	418
1957				22.1	191.0	534.0	1229	2129	3542	2393	663	201.1	912
1958				33.8	78.2	268.7	322.2	592	1915	1232	156.9	41.6	389
1959		4.8	4	30	44.1	144.1	422.8	1221	2591	1163	104.7	26.0	481
1960		4.1	4.0	26.6	28.0	134.4	772	1932	2776	1346	197.6	38.0	606
1961	13.4	6.1	4.0	4.1	4.5	117.0	829	1305	1949	571	17.4	5.6	402
1962		4.0	4.0	10.1	31.8	125.5	319.5	1642	3470				
1963	73.3		31.8	27.3	93.4	193.6	604.5	1918	2008	1934	554.6	118.3	633
1964	62.7	30.7	13.3		47.0	180.6	435.2						

TABLE A.5

STATION : KADUNA AT WUYA BRIDGE (Continued)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1965													
1966													
1967													
1968							667	1908					
1969						94	655	2014	2891	1599	582	115	
1970						103	362	2107	3110	767	136		
1971						162	454		3149	1034	150	76	
1972						271		1736	1813	583			

Annual average 596 m^3/s or 287 mm

TABLE A.6

STATION : TUBO AT MILE 20

Latitude : 10^0-35'   Longitude : 07^0-13'   Catchment Area : 5903 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1960				0.60	0.87	8.4	45	112	150	41	6.0	2.5	30.7
1961	1.3	0.72	0.46	0.51	0.49	7.1	40	53	66	8.5	1.7	0.56	15.0
1962	0.41	0.41	0.41	0.26	0.60	9.2	30	104	23	11	1.5	0.44	15.1
1963	0.61	0.83	0.37	2.7	5.0	12	21	89	60	105	16	4.1	26.4
1964	1.8	0.79	0.47	0.43	2.4	10	37	89	182	36	7.7	3.9	31.0
1965	1.9	1.2	0.85	0.74	4.8	48	59	100	103	8.4	3.7	4.2	28.0
1966	0.28	0.28	0.51	0.71	3.6	27	46	105	209	55	13	7.4	39.0
1967	3.3	5.1	0.93	0.42	4.3	14	40	62	108	35	4.4	1.4	23.2
1968	0.59	0.34											
1969				0.08	0.54	8.6	48	123	120	31	9.3	1.9	28.6
1970	0.51	0.17	0.08	0.25	5.0	5.7	15	138	113	13	3.1	1.5	24.6
1971	1.0	0.74	0.57	0.1	0.2	6.0	18	120	160	15	4	2	27.3
1972	1	0.5	0.5	0.85	6.0	13	6.1	89	65	17	4.8	1.8	17.2
1973	1.1	0.15	0.09	0.76	1.4	3.4	8.9	48	63	44	2.1	1.5	14.5
1974	2.2	2.2	1.6	0.59	2.3	2.9	18	102	179	4.8	3.0	1.1	26.6
1975	0.96	0.72	0.52	1.2	8.7	6.0	33	81	185	29	4.8	2.0	29.4
1976	1.2	1.5	0.3	1.6	5-7	16	50	68	36	58	16	3.1	21.5
1977	1.0	0.6	0.3										

Annual average : 24.9 m^3/s or 133 mm

TABLE A.7

STATION : MARIGA AT MARIGA

Latitude : 10^0-08'   Longitude : 06^0-02'   Catchment Area : 12,700 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1966								300	1022	195	20		
1967			0.65	0.54	3.55	23.3	50	279	694	251			109.3
1968	0.65	0.20	0.08	3.26	5.04	21.3	73	226	371	82	6.23	1.10	65.8
1969	0.31	0.07			4.37	10.5	76	541	811	181			136.2
1970	0.79	0.31	0.10	0.099		5.01	18.0	371	479	73	10.3	2.42	75.4
1971	2.04	1.68	0.49	0.04		19.5	65	428	599	169			108.1
1972						37.6	25.9	379	293	104	4.23	0.34	70.8
1973	0.04	0.012	0.003	0.04	0.49		24.9				3.16	0.34	

Annual average 94 m^3/s or 233 mm

TABLE A.8

STATION : GALMA AT RIBAKO

Latitude : 10^0-25'   Longitude : 07^0-45'   Catchment Area : 6886 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1960							37	84	166	109	13	1.8	
1961		0.08				16	58	86	163	51			
1962				0.31	0.85	12	32	159	278	123	24	8.1	53.5
1963	3.7	2.1	1.3	2.5	4.6	11	32	104	186	122	23	7.3	41.7
1964	3.5	1.9	1.2	0.96	2.7	9.9	41	204	286	56	16	7.6	52.6
1965	4.6	3.1	2.0	1.6	2.6	77	51	101	173	42	9.7	5.0	39.4
1966	3.2	2.1	1.1	1.3	14	33	29	123	194	112	21	9.9	45.3
1967	5.9	5.9	1.3				50	114	151			4.8	
1968	2.3	1.6	1.1	3.8	13	14	88	91	99	22	6.1	3.2	28.8
1969	2.1	1.1	0.91	1.8	2.5	7.2	47	101	127	38	24		30.1
1970													
1971													
1972				0.50	9.4	23	32	56	105	28			22.3
1973		0.27	0.21	0.15	0.63	8.7	35	138	162	76	2.8	0.19	35.3
1974	0.03	0.19	0.23	0.34	6.0	3.5	50	106	164	60	7.3	7.4	33.7
1975	0.65	0.39	0.31	2.2	15	11	57	127	228	60	10	3.0	42.9
1976	0.94	0.58	0.38	1.5	4.3	19	50	93	75	84	32	5.8	30.5
1977	1.2	0.58	0.4										

Annual average 36.6 m^3/s or 168 mm

TABLE A.9

STATION : GALMA AT ZARIA

Latitude : 11°-05' Longitude : 07°-43' Catchment Area : 4350 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1966				0.79	11	22	17	112	114	65	14	6.9	30.6
1967	4.0	2.4	1.1	1.4	2.3	8.7	31	81	95	38	6.1	2.7	22.8
1968	1.4	0.82	0.42	2.3	8.4	6.4	48	79			2.2	0.85	
1969	0.40	0.20	0.03	0.93	1.1	6.5	47	84	83	35	9.5	6.4	22.8
1970	4.6	2.1	1.3	3.8	5.5	5.8	18	82	127	29	6.2	3.1	24.0
1971	2.0	1.9	0.42	0.01	0.03	4.2	22	103	112	29	5.0	0.76	23.5
1972	0.23	0.1	0.1	0.13	17	13	16	90	70	18	1.9	0.58	18.9
1973	0.11	0.02	0.01	0	0	7.9	17	73	68	8.1	1.1	0.15	14.6
1974	0.08	0.03	0.02										

Annual average 22.5 m^3/s or 163 mm

TABLE A.10

STATION : SHIKA AT KANO/ZARIA RAIL BRIDGE

Latitude : 11^{0}-09'   Longitude : 07^{0}-45'   Catchment Area : 855 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965								8.6	11.6	1.25	0.23	-	
1966							1.98	15.7	21.3	7.5	1.13	0.34	
1967	0.20	0.17	0.11	0.57	0.57	2.89	4.7	12.9	16.3	4.9	0.54	0.22	3.67
1968	0.15	0.11	0.08	0.34	1.81	0.84	9.6	16.0	8.3	1.47	0.34	0.23	3.27
1969	0.14					1.30	7.7	13.7	12.4	3.77	0.96	0.25	
1970					1.19	1.15	2.8	14.8	18.0	2.41	0.54		
1971													
1972				0.18	1.12	0.94	1.14	19.6	10.6	5.6	0.05	0.05	3.29
1973	0.05	0.06	0.05	0.06	0.04	1.48	3.2	11.5	12.5	0.32	0.06	0.06	2.45
1974	0.08	0.05	0.04	0.02	0.05	1.55	11.5	3.54	21.7	6.7	0.18	0.08	3.79
1975	0.06	0.05	0	0.12	0.86	1.86		10.1	22.0	2.78	0.19	0.08	
1976	0.11	0.08	0.04	0.04	0.30	3.48	13.9	14.1	10.6	6.4	0.91	0.10	4.17
1977	0.07	0.08	0.04										

Annual average 3.44 m^3/s or 110 mm

TABLE A.11

STATION : KANGIMI 3 MILES UPSTREAM RIHOGI

Latitude : 10^0-38'   Longitude : 07^0-36'   Catchment Area : 350 sq km

Mean Monthly Flows (m^3/s)
(after Enplan)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1969	0			0	0.023	0.50	3.42	7.5	9.3	1.65	0.38	0.033	1.90
1970	0	0	0	0	0.18	0.06	1.01	7.3	10.9	0.75	0.13	0.015	1.69
1971	0	0	0	0	0.13	0.16	2.20	9.8	12.4	1.56	0.06	0.012	2.19
1972	0	0	0	0	0.35	1.37	2.11	13.3	6.3	0.84	0.06	0.023	2.03
1973	0.003	0	0	0	0	0.012	1.44	7.1	7.5	0.73	0.07	0.014	1.40

Annual average 1.85 m^3/s or 167 mm

TABLE A.12

STATION : KOGUN AT KAGORO

Latitude : 09°-37' Longitude : 08°-24' Catchment Area : 93 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1965							5.0	8.8	6.2	1.67	0.52	0.35	
1966	0.22	0.18	0.24	0.37	1.27	4.4	3.26	6.6	8.1	4.05	0.97	0.61	2.52
1967	0.42	0.26	0.25	1.06	0.90	4.5	6.8	10.3	9.6	2.12	0.94	0.52	3.14
1968	0.34	0.22	0.24	0.85	1.77	2.91	12.4	9.6	9.1	1.24	0.20	0.16	3.25
1969			0.74	0.32	2.09	1.57	13.5	14.4	8.9	5.9	3.21	0.53	4.30
1970	0.27	0.20	0.17	0.19	0.30	1.39	1.60	10.1	9.3	2.24	0.54	0.26	2.21
1971	0.18	0.16	0.17										
1972				0.26	3.34	3.82	6.82	10.4	6.2	2.97	1.08	0.52	2.99
1973	0.38	0.21	0.18		0.34	1.25		21.9	18.0	6.9	1.06	0.23	4.83
1974	0.20	0.17	0.15	0.46	1.40	1.03	4.05	7.6	10.0	4.6	1.45	0.78	2.66
1975	0.40	0.58	0.61	2.07	1.15	2.69	4.90	8.0	11.2	4.3	1.40	1.65	3.25
1976	1.36	1.48	1.26	1.47	2.14	4.4	10.3	5.5	5.1	6.2	2.10	0.60	3.49
1977	0.32		0.40										

Annual average 3.26 m^3/s or 1107 mm

TABLE A.13

STATION : KOGUM AT UNGWAR RIMI

Latitude : 09^{0}-34'   Longitude : 08^{0}-14'   Catchment Area : 463 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1965							20	36	30	11	4.2	3.4	
1966	2.1	1.2	1.3	2.4	7.1	13	20	23	29	12	4.2	2.9	9.9
1967	1.6	1.1	0.9	3.2	5.8	12	17	27	33	15	4.3	2.5	10.3
1968	2.1	1.8	1.7	1.6	5.2	9.5	30	24	21	9.1	4.2	2.9	9.4
1969	2.1	1.6	1.2	1.6	4.4	6.2	23	32	35	20	15	4.7	12.2
1970	3.1	2.0	1.7	1.5	3.3	6.2	11	34	63	9.6	4.2	2.5	11.8
1971	1.6	1.0	0.6										
1972				1.7	6.4	8.5	12	33	19	10	4.9	2.8	8.5
1973	2.0	1.5	1.9	5.0	6.9	7.3	15	42	30	11	6.8	4.0	11.1
1974	3.0	1.4	2	6.4	4.1	5.1	17	40	47	19	5.9	4.3	12.9
1975	2.5	1.7	1.3	3.9	7.1	8.7	34	37	44	19	7.2	2	14.3
1976	0.5	0.2	0.1	0.1	7.1	14	27	34	24	25	9.6	5.0	12.8
1977	3.5	2.1	1.3										

Annual average 11.3 m^3/s or 770 mm

TABLE A.14

STATION : GURARA AT KACHIA

Latitude : 09^0-52' Longitude : 07^0-58' Catchment Area : 450 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970				0.36	3.1	8.9	12.9	34	11.3	6.0	1.74	0.62	6.64
1971	0.25	0.09	0.09	1.39	3.5	2.8	7.6	22.8	21.4	7.7	1.60	1.10	5.86
1972	0.20	0.15	0.05	0.05	4.8	8.9	21.4	39.0	23.9	7.7	2.05	1.13	9.11
1973	0.41	0.24	0.25	1.0	1.4	4.8	9.0	28.8	31.2	10.1	1.71	1.00	7.49
1974	0.40	0.22	0.14	1.1	6.2	4.3	17.9	24.5	36.5	7.3	2.22	1.17	8.50
1975	0.77	0.59	0.56	1.4	4.7	5.5	24.9	33.4	36.9	8.1	2.12	1.24	10.0
1976	0.57	0.26	0.13	0.4	3.8	7.1	12.7	16.2	16.0	13.0	3.9	1.70	6.31
1977	0.6	0.3	0.1										

Annual average 7.70 m^3/s or 540 mm

TABLE A.15

STATION : YIKO AT GUZAN

Latitude : 09^0-01' Longitude : 05^0-29' Catchment Area : 530 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970						1.09	1.08	1.79	2.66	1.51	1.01	0.81	
1971		0.68	0.67	0.57	0.84	0.76	1.45	1.25	1.43	1.01	0.75	0.70	
1972				0.46		0.61	0.68	0.84	1.19		0.59		
1973	0.57	0.52	0.46	0.48	0.74	0.82	0.91	1.28	1.54	1.35	0.99		
1974	0.84	0.76	0.71										
mean	0.71	0.65	0.61	0.50	0.79	0.82	1,03	1.29	1.71	1.29	0.84	0.76	0.92

Annual average 0.92 m^3/s or 55 mm

TABLE A.16

STATION : BAKOGI AT AGAIE

Latitude : 09^{0}-01'   Longitude : 06^{0}-17'   Catchment Area : 519 sq km

Mean Monthly Flows (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970				0.12	0.18	0.89	0.74	3.74	11.3	7.0			
1971	0.19	0.12	0.11	0.10	0.13	0.17	1.08						
1972						0.38	1.04		5.7	3.26	0.46	0.24	
1973	0.24	0.25		0.15	0.17	0.48	1.00	4.6	6.9	6.3	1.12		
1974		0.21	0.18										
mean	0.22	0.19	0.15	0.12	0.16	0.48	0.97	4.2	8.0	5.5	0.8	0.24	1.76

Annual average 1.76 m^3/s or 107 mm