AGRICULTURAL AND WATER SURVEYS

SOMALIA

FINAL REPORT

Volume II

WATER RESOURCES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

The Final Report on Somalia consists of the following volumes:

Volume I - General

An account of the objectives, work and findings of the entire project is given in this volume. The recommendations arising from the findings of the survey are summarized, and the volume concludes with an estimate of the total returns for all the development projects proposed. A summary of the report on the FAO Livestock Development Survey of 1966 in Somalia is included in the volume as an appendix.

The following technical reports were prepared by the Lockwood Survey Corporation, which carried out the corresponding surveys under the supervision of the Food and Agriculture Organization of the United Nations:

Volume II - Water Resources

The volume deals with climate, surface water and groundwater, and investigates the potential groundwater supplies for irrigation, and for the use of livestock, herdsmen and small communities. The text of the volume is abundantly supported with figures, tables and maps and with statistical appendixes.

Volume III - Landforms and Soils

Nineteen landforms are identified, some with subdivisions; in the first part of the volume, and the soils associated with each landform are described and classified. Landforms and soils are then discussed on the basis of the natural regions. The text concludes with a summary and with recommendations. Soil profile descriptions and the methods and results of chemical and physical soil analysis are given in appendixes.

Volume IV - Livestock and Crop Production

The volume describes the surveys carried out on agricultural production and on rangeland in the project area. Details are given of regional farm practices, of present land use from region to region, and of recommendations for crop improvement. There are conclusions and recommendations on the potential of rangeland and on problems in its development. The final chapter deals with the livestock count made during the project. Species and ground cover characteristics of the ecological formations are given in an appendix.

Volume V - Engineering Aspects of Development

The volume discusses in detail the possibilities of irrigation development on the Shebelle river. It also examines briefly the possibilities on the Juba river. Surface water supplies for human and animal consumption and the possibilities of development for small streams are investigated. An account of the topographical survey and mapping work carried out and extracts from the results of reconnaissance soil survey in the Bulo Mererta area are included in the volume.

Volume VI - Social and Economic Aspects of Development

The volume deals with land tenure conditions and agricultural economics in Somalia. A sample of economic returns to agriculture in the project area in 1963 is given, and the typical returns of banana plantations are included in the typical farming returns given for the various regions and sub-regions. The volume concludes with a detailed estimate of the total returns for all the development projects suggested. A revised recommendation for a rural development project for the improvement of traditional agriculture is given in an appendix.

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SOMALIA

Final Report

Volume II

Water Resources

Report prepared for the
Food and Agriculture Organisation of the United Nations

by

Lockwood Survey Corporation Limited

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1968

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CLIMATE OF THE SURVEY AREA

Introduction

1. The climate of the survey area is tropical, semi-arid to arid, with a seasonal rainfall pattern influenced by the monsoon winds.

2. The rains occur during April, May, June and September, October, November. The first rainy period of the year is termed the "Gu" season. The latter rainy period is called the "Der" season.

3. Three broad climatic zones may be recognized. These are characterized by a difference in rainfall pattern. In the coastal zone significant amounts of rain occur during July and August. These are called the "Hagi" rains, and they effectively lengthen the "Gu" season. The semi-arid zone has two strongly defined rainy season; light rains may occur during July and August. The arid zone has a lower annual rainfall than the other two zones with dry periods in July - August.

4. The rainfall tends to be variable, unreliable and failure of the rains, is not uncommon, particularly in the arid areas. The amount of rain can vary considerably from the averages presented in the bar charts at the end of the chapter. This is an important factor to consider in assessing the value of the seasonal rains in terms of agriculture.

5. The temperature is fairly uniform throughout the year averaging from 25° to 30° centigrade. Based on average figures the coolest month is August and the warmest is April, the difference in temperatures averaging 2° to 4° centigrade.

6. Relative humidity varies between 70 and 80 per cent in areas near the coast and between 40 to 60 per cent in the more arid regions of the interior. Deviations from the yearly mean values are negligible.

7. The monsoon winds are the important factor affecting the climate, and the time of the rainy periods. The southwest monsoon winds prevail during June, July and August. The northeast monsoon winds prevail during December, January and February. The seasonal rains are associated with the directional changes of these winds. Although the statistics show a moderate wind velocity, personal observations would indicate that the monsoon winds are remarkably steady with velocities sufficient to cause damage to banana plantations. Wind velocity and direction is an important factor to be considered in agronomic planning.

Rainfall

8. The actual density of rain-gauges cannot support a sound general theory of the rainfall pattern in the southern region of Somalia. (Map 1 showing the observation stations will be found in Chapter 2 of this Volume.) The period for which basic data are available is of short duration (5 - 12 years) except for one station at Johar (27 years). Therefore, no rainfall run-off calculations were made.

9. Tables of monthly rainfall (Appendix 1a) and of the mean monthly and yearly

rainfall (Appendix 1b) is given for every station in Somalia; those in Ethiopia were of too short duration (3 - 5 years) to be of any significance in the computation of standard deviations. The maximum and minimum monthly precipitations and the average number of rainy days, were used to compute the extreme values and intensities that can be encountered. The coefficients of variation increased as the station is farther inland. This seems to agree generally with the law stating that rainfall usually decreases as the distance from the sea increases. No other major factor seems to be superimposed on the distance effect as the land is relatively flat and no important mountains are encountered before the Ethiopian Border. From there to the upper reaches, the relationship is probably a combined effect of distance and altitude, resulting in an exponential relation.

10. Generally speaking, the rains are very erratic, even in the coastal area and many more rain-gauges will be needed before the pattern can be fully understood and meteorologic and topographic factors properly assessed.

11. From rainfall diagrams (figures 1 to 4 at the end of this chapter), two main types of rainfall distribution prevail; the coastal and the continental group. Near to the coast, "Gu" precipitations (April - June) are linked by "Hagi" (July - August), minor rains to the "Der" (September - November), the second important rainy season. Inland, at Lugh Ganana for example, the two rainy seasons are definitely separated by four dry months (June - September). The Baidoa station follows the inland pattern but, due to the sudden rise of the land in the area, the precipitation is, probably, the most reliable in the project area.

12. The monthly rainfall in terms of per cent of the total year, are given in figures 5 to 8. It is interesting to note for example that in Mogadiscio and Johar, the rain falling during the "Gu" season, represents respectively 50 and 42 per cent of the total yearly precipitation.

13. Typical storms were selected at key stations having a rain-recorder in operation during the period 1963 - 1965. Storm intensity curves in figure 9 show the pattern. The highest spot-intensity of 180 milimeters per hour occured at Giamama in the Lower-Juba area. Storms at Mahaddei Uen are of more regular shape with a peak of 80 milimeter per hour. These storms represented the maximum encountered in 2 years. All the other storms were of less intensity and for a longer period.

Meteorologic Factors

Temperatures - Winds - Relative Humidity

14. The following data on temperature, winds and relative humidity were compiled from reports supplied by the Ministry of Agriculture and the Aeronautic Section of the Ministry of Transport. In Appendix 1c, mean and mean maximum temperatures are given for every month of the year. These values are representative if we consider that the variation of temperature is negligible in the southern part of Somalia. The difference between the coldest month (August) and the warmest (April) is 3^{o} on the coastal region and 7^{o} at Lugh Ganana whilst Belet Uen temperature varies by only 3^{o}C.

15. Mean monthly relative humidity and barometric pressure, as shown in table 1 at the end of this chapter, are constant and the deviations from the yearly mean values are negligible. As expected the relative humidity is higher near the coast and decreases as the station is farther away from the sea. The extreme yearly variation is in the order of 3 to 4 per cent.

16. Barometric pressures follow the same trend in daily and monthly periods, and are therefore practically uniform all year long.

17. Wind average velocity and prevailing directions are shown in Table 2. The two main directions N.E. and S.W. are predominant. The wind pattern is irregular and varies substantially for nearby stations. This may partially explain the difficulty of drawing reliable isohyets without a dense network of rain-gauges. Stations listed are representative of the inter-river area.

Evaporation

18. Due to uncontrollable difficulties, no evaporation tanks were installed except for a Piche evaporimeter during the last 6 months; the potential evaporation was computed with the help of meteorlogical data. The data obtained from the evaporimeter enabled us to support the adoption of the coefficient relating computed values to free-surface evaporation over extensive areas.

19. Many attempts were made to correlate the evaporation capacity of the atmosphere to different factors such as: temperature of the air and water, sunshine, relative humidity, wind, barometric pressure and altitude. Almost all of the parameters were interrelated in such a way that the most important and easiest to control can be used in a simplified formula. At this stage, computations giving the mean evaporation over large areas and covering long periods can be accepted. The available meteorlogical data were mean monthly maximum temperature, mean monthly barometric pressure and relative humidity.

20. The LUGEON formula was used as follows:-

$$E = 0.398 \ n \ (Fe-Fa) \ \frac{273 + t}{273} \cdot \frac{760}{B-Fe}$$

in which E is the evaporation in millimeters for a month of "n" days,

Fe = Saturated vapor pressure (Hg mm.) related to the mean monthly maximum temperature,

Fa = Average actual vapor pressure (mm. Hg) for a given temperature,

B = Average monthly barometric pressure in mm. of Hg,

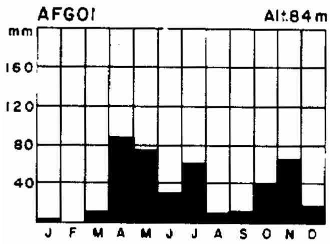
t = Mean monthly maximum temperature in ^{o}C.

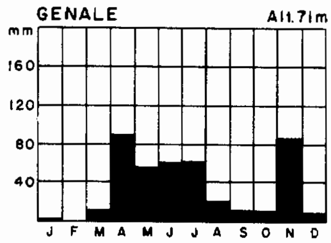
21 Computed and observed evaporations at Johar were compared for a six month period, and it appeared that the computations give values generally higher by about 10 per cent. The fact that sunshine and wind were not taken into consideration and the latter factor being of importance, may explain this constant discrepancy. A coefficient of 0.8 was selected to correlate computed evaporation to possible evaporation over free surface water covering large areas. The computed monthly mean evaporation is shown in Table 3.

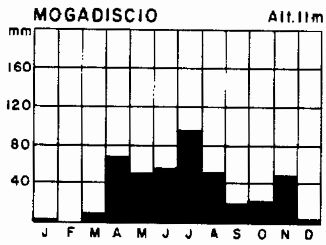
MEAN MONTHLY RAINFALL DIAGRAMS

COASTAL ZONE

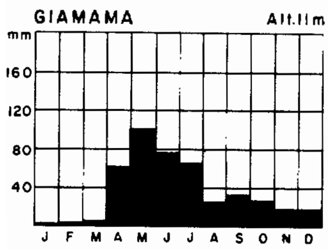
SHEBELLE RIVER

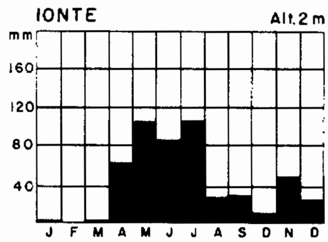


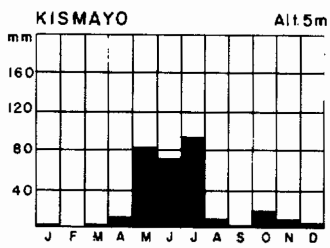




JUBA RIVER



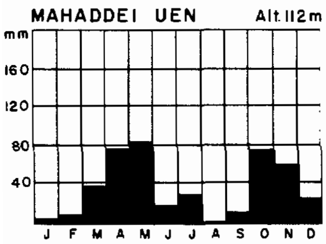


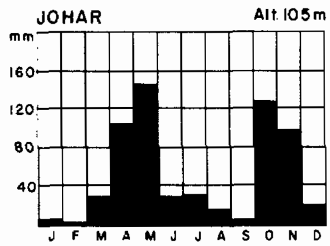


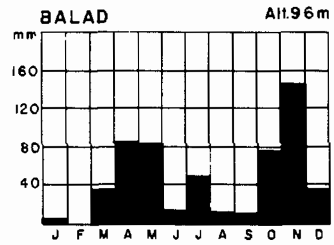
MEAN MONTHLY RAINFALL DIAGRAMS

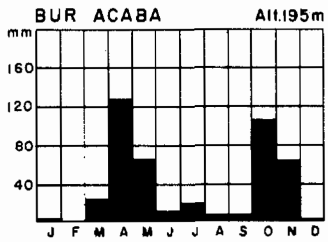
SEMI-ARID ZONE

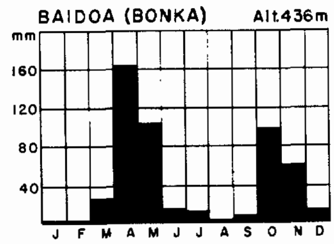
SHEBELLE RIVER











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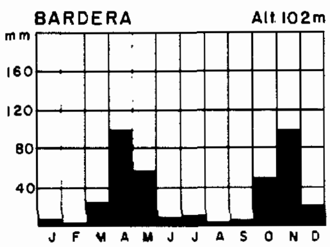
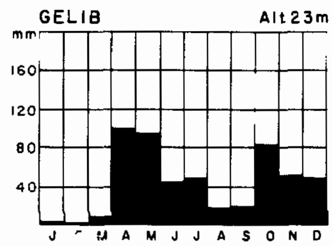
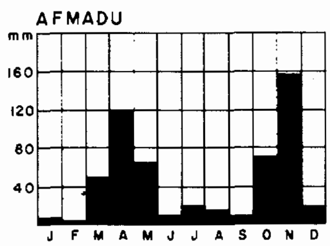




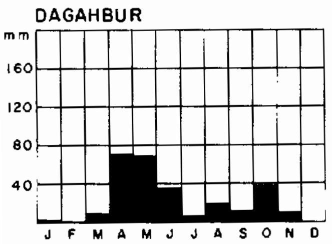


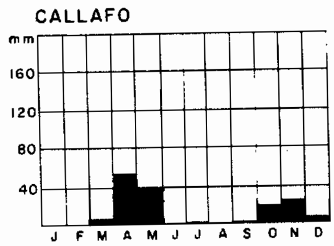
Vol. I Fig. 2 — Vol. II Fig. 2

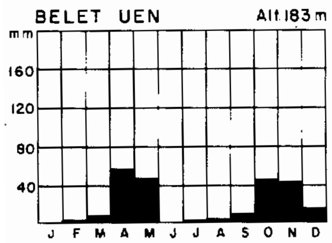
MEAN MONTHLY RAINFALL DIAGRAMS

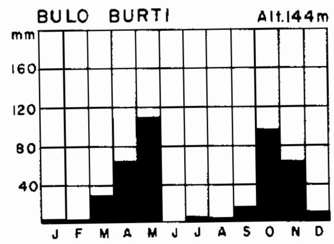
ARID ZONE

SHEBELLE RIVER









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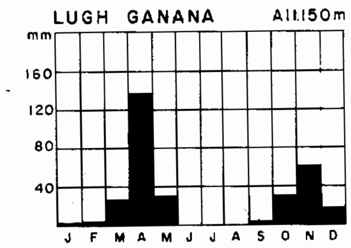
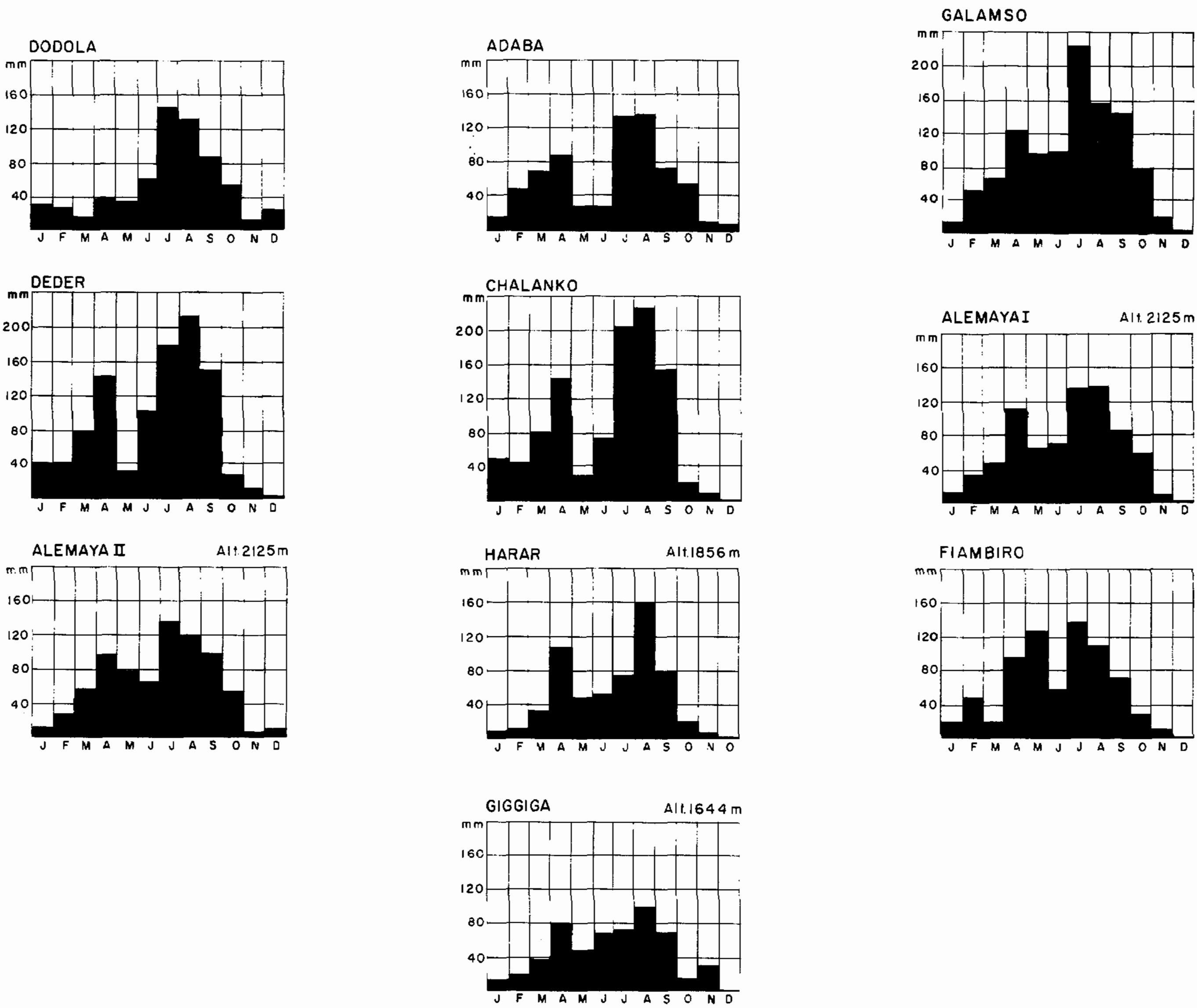


Vol. I Fig. 3 – Vol. II Fig. 3

MEAN MONTHLY RAINFALL DIAGRAMS

MONTANE ZONE

SHEBELLE RIVER



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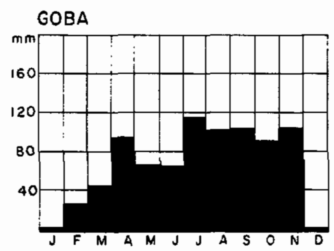


AWASH RIVER

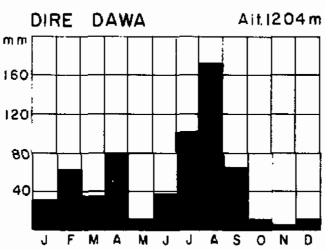
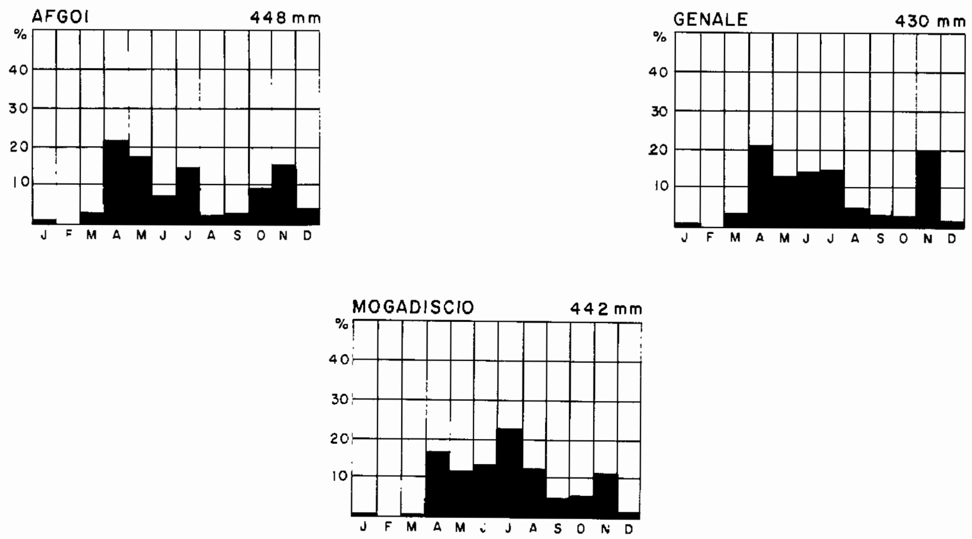


Figure 4

MONTHLY RAINFALL AS A PERCENT OF YEARLY RAINFALL

COASTAL ZONE

SHEBELLE RIVER



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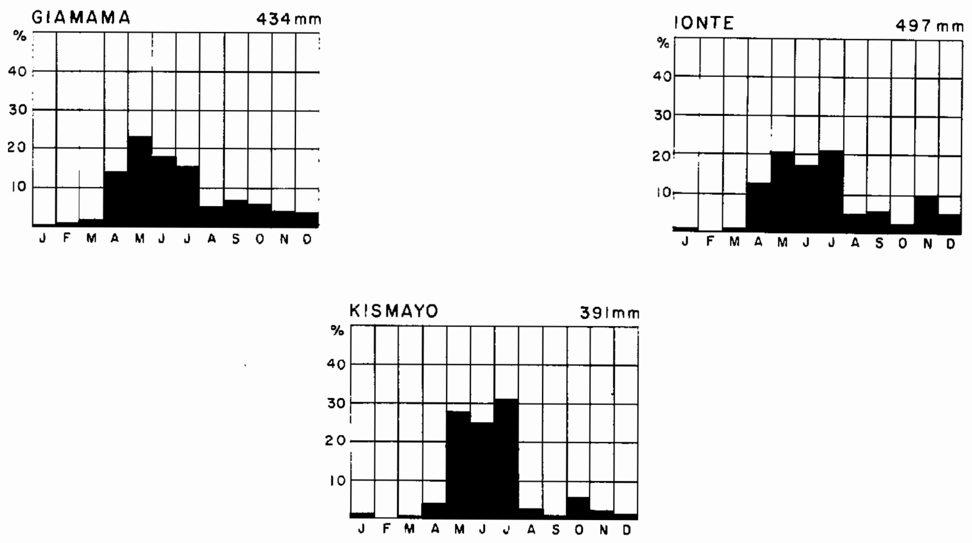


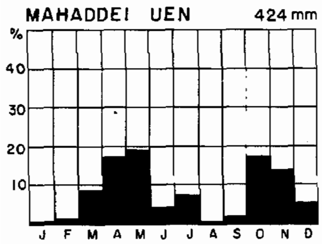
FIGURE REPRESENTS YEARLY AVERAGE RAINFALL IN mm

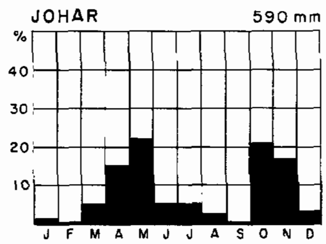
Figure 5

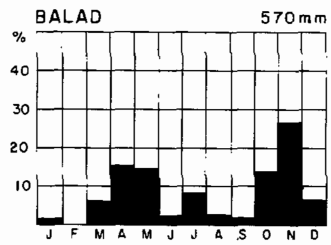
MONTHLY RAINFALL AS A PERCENT OF YEARLY RAINFALL

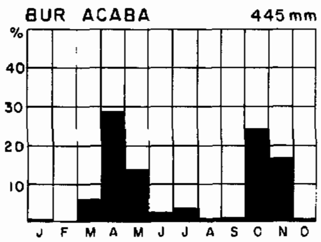
SEMI-ARID ZONE

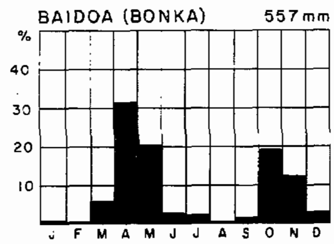
SHEBELLE RIVER



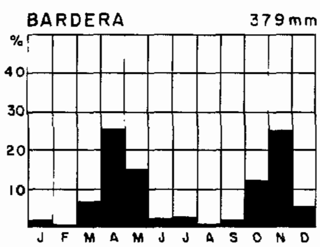


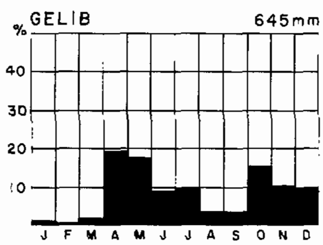






JUBA RIVER





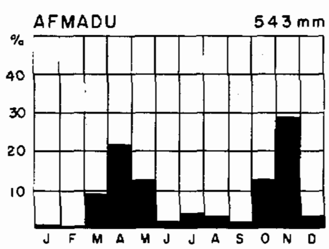


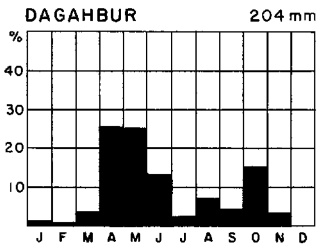
FIGURE REPRESENTS YEARLY AVERAGE RAINFALL IN mm

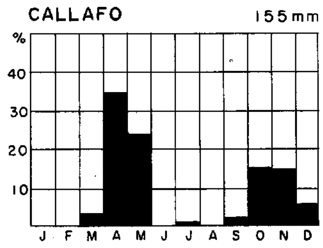
Figure 6

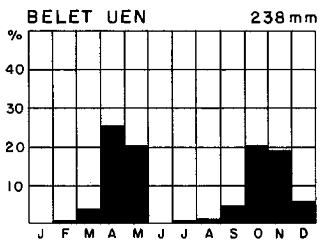
MONTHLY RAINFALL AS A PERCENT OF YEARLY RAINFALL

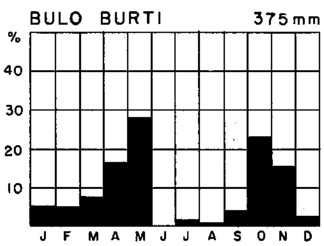
ARID ZONE

SHEBELLE RIVER









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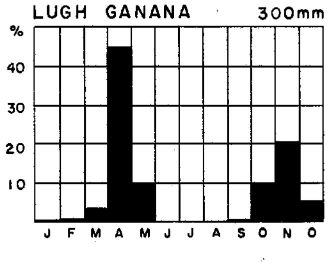


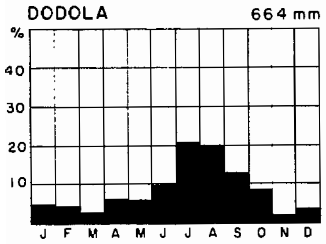
FIGURE REPRESENTS YEARLY AVERAGE RAINFALL IN mm

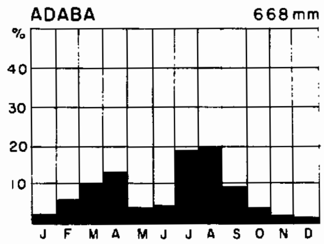
Figure 7

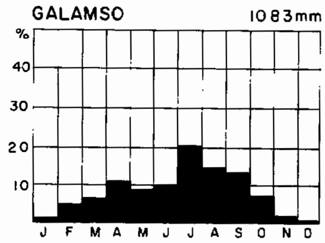
MONTHLY RAINFALL AS A PERCENT OF YEARLY RAINFALL

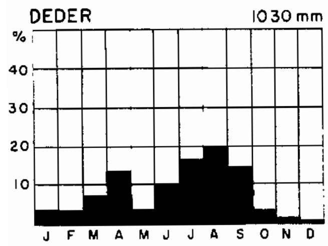
MONTANE ZONE

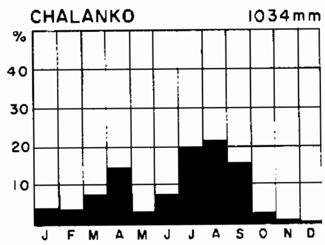
SHEBELLE RIVER

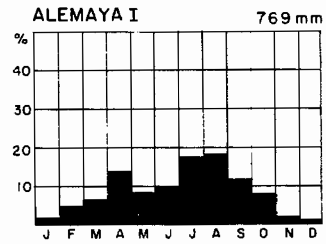


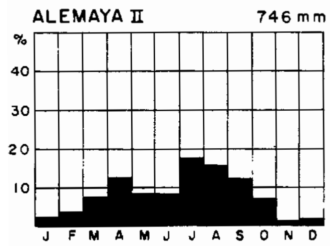


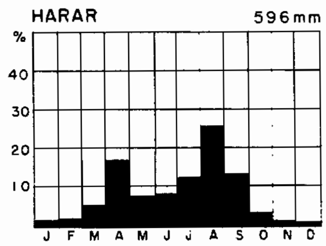


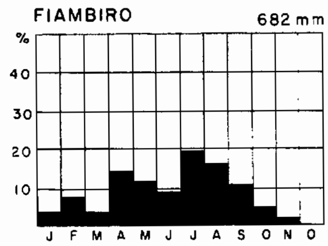


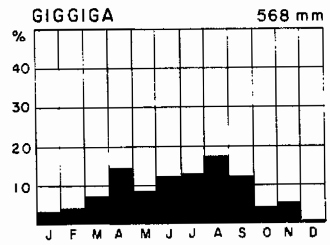




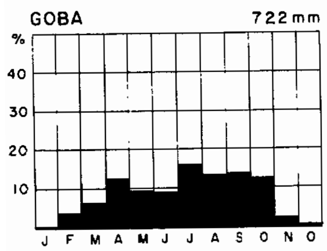








JUBA RIVER



AWASH RIVER

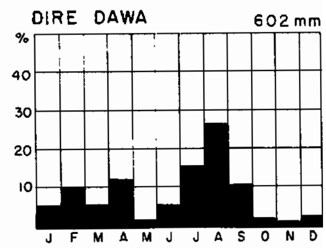


FIGURE REPRESENTS YEARLY AVERAGE RAINFALL IN mm

Figure 8

STORM INTENSITY PATTERNS OF HEAVY STORMS

PERIOD 1963 - 1965

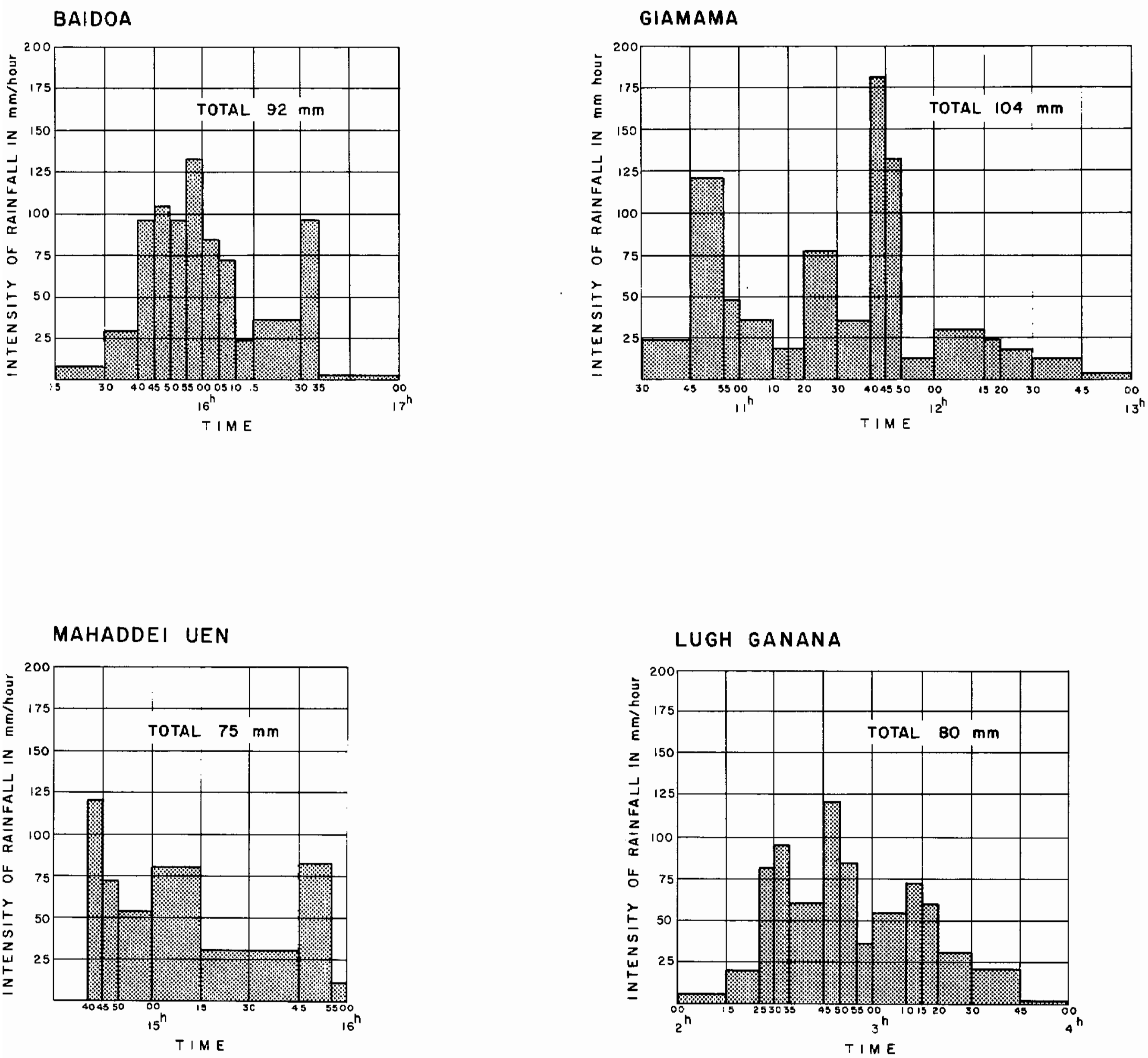


Figure 9

TABLE 1

RELATIVE HUMIDITY

AND BAROMETRIC PRESSURE

YEARS 1953 - 1964

mb = millibars

STATION		MONTHLY MEAN RELATIVE HUMIDITY IN PERCENT AND BAROMETRIC PRESSURE IN MILLIBARS											
		JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Belet Uen	mb	991.1	990.5	989.5	988.8	990.7	990.9	991.4	991.4	989.9	992.8	991.4	992.2
	%	55.7	54.2	51.9	56.5	59.9	56.7	59.5	57.6	55.0	61.0	58.7	56.2
Bulo Burti	mb												
	%	52.3	50.2	49.3	53.9	58.3	57.6	56.0	55.2	50.8	60.1	59.0	47.5
Johar	mb												
	%	67.0	65.7	64.0	68.8	74.8	73.5	76.5	71.6	71.0	73.1	76.6	71.8
Balad	mb												
	%	71.1	68.5	67.5	74.3	77.0	77.1	76.1	74.2	73.0	74.1	78.0	75.1
Afgoi	mb												
	%	66.4	62.5	63.4	66.8	71.8	71.4	74.3	73.6	72.1	70.1	70.5	71.7
Mogadiscio	mb	1012.9	1012.4	1011.7	1011.7	1013.1	1015.0	1015.5	1015.7	1015.1	1014.2	1013.5	1013.1
	%	71.3	71.4	71.6	70.9	73.1	74.4	75.3	74.7	73.9	74.2	73.4	71.9
Genale	mb												
	%	74.2	72.9	71.6	74.6	79.1	78.1	81.6	79.5	80.9	80.2	79.2	76.6
Baidoa	mb	960.3	959.4	959.1	959.4	960.3	964.1	962.6	962.8	968.0	962.4	960.9	961.4
	%	61.5	58.7	60.4	72.2	76.4	73.3	74.0	70.3	65.7	72.8	73.6	67.0
Bur Acaba	mb												
	%	52.6	52.6	56.7	64.2	68.5	63.1	65.6	63.9	60.6	65.2	65.7	59.5
Kismayu	mb	1011.7	1011.3	1011.1	1010.8	1012.2	1014.0	1014.7	1015.4	1014.8	1013.9	1012.9	1012.3
	%	77.2	70.3	75.6	75.9	78.4	79.0	81.3	79.8	79.1	78.0	77.4	76.7
Afmadu	mb												
	%	59.6	62.3	62.6	67.6	70.9	70.0	65.1	68.6	60.1	68.4	68.5	66.8
Oddur	mb												
	%	53.5	49.6	49.4	61.7	64.9	58.1	61.9	59.1	54.0	65.0	63.1	56.2
Ionte	mb												
	%	73.6	73.7	73.0	75.9	79.4	79.4	81.4	78.3	77.8	77.0	75.8	77.3
Gelib	mb												
	%	72.6	70.2	69.5	74.7	77.2	79.2	78.9	76.9	75.1	75.2	77.2	76.4
Bardera	mb	998.3	997.7	997.6	997.8	999.9	999.5	1002.9	1002.8	1001.7	1001.0	1000.3	999.5
	%	55.2	53.7	56.2	62.3	66.7	64.7	67.5	66.0	61.8	60.8	64.3	60.5
Lugh Ganana	mb												
	%	47.4	42.0	46.0	57.0	61.3	55.6	59.1	56.1	53.9	59.1	59.2	52.2

TABLE 2

WIND AVERAGE VELOCITY

AND PREVAILING DIRECTIONS

STATION	AVERAGE MONTHLY VELOCITY - km/hr. J	F	M	A	M	J	J	A	S	O	N	D	PREVAILING DIRECTION - IN % N-E	E	S-E	S	S-W
Belet Uen	3.8	3.5	2.6	1.8	3.3	5.0	5.2	4.8	4.1	2.1	2.9	3.3	36	10	8	24	22
Baidoa	2.4	2.9	2.5	2.0	2.1	3.0	3.0	3.2	3.2	2.0	1.6	2.2	0	33	16	22	29
Johar	1.4	1.5	1.3	0.8	1.1	1.5	1.5	1.7	1.7	1.0	1.3	1.2	10	20	20	42	8
Mogadiscio	4.5	4.4	3.6	2.5	3.5	4.0	4.7	4.3	4.1	3.9	3.0	4.1	20	18	8	20	34
Genale	1.6	1.5	1.6	1.3	1.8	2.0	2.1	2.1	1.9	1.3	0.5	1.0	16	21	17	35	11
Bardera	3.0	2.5	2.1	1.6	2.8	4.5	4.5	4.6	4.0	2.2	2.0	1.7	8	27	13	29	23

TABLE 3

MONTHLY MEAN COMPUTED, EVAPORATION IN MILLIMETERS

FROM A FREE WATER SURFACE

STATION	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR TOTAL
Belet Uen	252	220	264	228	188	204	184	204	228	208	192	200	2572
Bardera	248	276	264	220	160	172	156	160	172	204	168	208	2408
Baidoa	180	200	172	128	92	100	88	108	116	100	96	144	1524
Mogadiscio	100	88	112	120	104	92	88	92	88	100	92	104	1180

INTRODUCTION

Purpose

1. The purpose of this survey was to assemble information on the main water courses to determine the quantity and quality of water, and to train Somali personnel in river gauging and sampling.

2. Economic and feasibility studies regarding the uses of available water were not part of this survey. These considerations are found in Volume 5 "Engineering Aspects of Development".

Previous Surveys

3. There was no established hydrological service in Somalia prior to this survey. Remnants of staff gauges were found on both rivers. Gauging had been carried out at Mahaddei Uen spasmodically since 1918, but records were kept for various stations only since 1951. These were intermittent and did not include meterings.

4. Reports on hydrology included the following.

(a) Dr. Conforti - report on the Uebi Shebelle, 1955.

(b) The results of a survey in 1959 - 1960 by the United States International Co-operation Administration were published in a report "Inter-River Economic Exploration" in 1961.

(c) "Preliminary Study on the Waters of Somalia" prepared for Hunting Survey Corporation Limited by Doxiadis and Ionides Associates Limited of London, England.

Execution

5. The establishment of a series of permanent recording stations was the first phase of the field work.

6. A gauge reader was appointed for each station, and regular meterings were made at the various stations by a team of trained technicians from the central office.

7. The gauge readers collected samples for chemical analysis which was done at the central office utilising a Hach DR-EL portable laboratory. Specific conductance determinations were done by USAID at their laboratory in Afgoi.

8. Sediment sampling was done by technicians from the central office but only in the last few months of the survey.

9. The elevations of the gauging stations were determined by third order level-

ling and carried out by the Agricultural and Water Survey.

10. The data obtained from the field and from existing records were processed by Somali technicians.

11. There was close co-operation with other organizations concerned with hydrological studies. These included USAID and Technopromexport of the Economic Council of the Embassy of the U.S.S.R.

Acknowledgements

12. Acknowledgement of assistance received during the survey is made with sincere appreciation. Special recognition is made to the Ministry of Public Works, who supplied us with all available hydrological data, USAID, who tested our water samples in their laboratory, and Technopromexport who provided information they had collected on the Juba River. Sincere appreciation also is made to Societa Nazionale Agricola Industriale (S.N.A.I.) who provided information on the Shebelle River at Johar.

RIVER BASINS

13. The Shebelle and Juba Rivers occupy the only large drainage basins in Somalia. Other watercourses such as Lak Dera, Lak Giro and Bohol Madagoi, though locally important for water supplies, are comparatively small and generally intermittent. The river courses are shown on Map 1 and the profiles of the Juba and Shebelle Rivers are shown on Figure 10 which will be found at the end of this chapter.

14. Both the Shebelle and Juba Rivers rise along the eastern slopes of the eastern plateau of Ethiopia approximately 1,000 kilometers inland from the Indian Ocean.

15. The areas of the drainage basins are estimated at 300,000 square kilometers for the Shebelle and 275,000 square kilometers for the Juba, but most of the effective drainage takes place in the upper reaches of the basins. In Somalia and the arid border zone of Ethiopia contribution is limited to a relatively narrow zone adjacent to the rivers. The flow in small watercourses is diminished by infiltration and evaporation to such an extent that it ceases before reaching the main rivers.

16. In the highland area of Ethiopia, where most of the flow originates, the drainage areas of the two rivers appear to be similar, with that of the Shebelle perhaps slightly larger than that of the Juba; yet the flow in the Juba is more than twice that in the Shebelle. This can be explained only by differences in precipitation and/or in the run-off coefficients. There is insufficient data on precipitation in the Upper Juba basin of Ethiopia to compare it with the Shebelle basin, but geological maps indicate that the headwater tributaries of the Juba flow on the basement, which presumably is impervious, whereas the headwater tributaries of the Shebelle probably are influent over sedimentary rock.

17. Drainage areas at the river gauging stations along the Shebelle and Juba Rivers are shown in Table 5. Drainage area by length of course is shown in Figure 11 and area elevation curves will be found in Figure 12.

Physical Description

18. The Uebi Shebelle rises in the high plateau of eastern Ethiopia. Its' tributaries drain the eastern slopes of this plateau from Dodola in the southwest to the area east of Harar, a distance of over 500 kilometers.

19. The drainage basin is between 900 and 1,000 kilometers long extending from the Harar Plateau to the Indian Ocean. Its area has been estimated at 300,000 square kilometers, of which 90,000 square kilometers is within Somalia. This has no real significance, particularly in Somalia and the border area of Ethiopia, where tributary streams are short and intermittent, and the river is known to be influent, at least in the reaches downstream from Gialalassi.

20. From the Harar Plateau, the river flows in a southeastern direction for about 700 kilometers before entering Somalia at Fer Fer about 31 kilometers north of Belet Uen.

21. Within Somalia, the river traverses a distance of approximately 630 kilometers before the last significant traces of it disappear about 30 kilometers east of the Juba River and about the same distance from the ocean. The length of the channel within Somalia is approximately 1,100 kilometers.

22. With minor exceptions the river receives no contribution within Somalia; the discharge decreases progressively downstream, the flow being reduced by evaporation, infiltration, use, and by overbank spillage when the stage is high. A natural result of this and the meandering nature of the river is that the cross-section area of the channel decreases progressively.

23. From the border to the area between Bulo Burti and Gialalassi, a distance of about 150 kilometers, the river flows in a wide valley towards the south-southeast over and generally parallel to the strike of Cretaceous limestone, marl and gypsum formations. The channel is 50 meters wide at Belet Uen and 45 meters wide at Bulo Burti.

24. The river flows southwest from the area south of Bulo Burti as far as Balad. The hills that form the upstream valley gradually disappear in the vicinity of Bulo Burti, and at Gialalassi the river enters a broad flood plain underlain by deep alluvial deposits. The flood plain is 50 to 60 kilometers wide downstream from Mahaddei Uen. At this point the river is approximately at the centre, at Balad it is at the extreme eastern limit of the flood plain. Remnants of several old channels fan out westward from the Mahaddei Uen area.

25. At Balad the river is forced to flow towards the southwest, parallel to the coast, by a coastal ridge of littoral deposits. It flows in the southeast part of the flood plain, which is about 50 kilometers wide. The width of the channel continues to decrease and at Audegle is only 35 meters. Old channel remnants parallel the present channel on both sides.

26. At Falcheiro downstream from Coriole, the nature of the river changes entirely. The single well-defined channel is replaced by a network of small channels and ponds that form approximately 61,800 hectares of swamp land. The swamp varies in width from 1 to 10 kilometers and ends about 8 kilometers upstream from Avai, where a single channel is again formed with a width of about 20 meters.

27. Beyond Avai the small channel continues towards the Juba river, but is scarcely

defined in the final reaches. Flow may end anywhere after Avai and only when flows are unusually high, as in 1961, does the Shebelle actually reach the Juba. This takes place near Camsuma.

River Flow

28. The flow of the Shebelle River is torrential ranging from less than 10 to over 270 cumecs at Belet Uen. This is illustrated in Figures 13a - f, which contain hydrographs for the Shebelle River for the years 1951 to 1965. It can be seen that high flows of short duration occur in April to May and of longer duration from August to December. The higher flows generally are experienced in the latter period but this is not always the case, as in 1963, when at Belet Uen, the first peak reached 250 cumecs as compared to a little more than 170 for the second peak. The peaks are not attained at the downstream stations because of overbank spillage.

29. The low flow period, when the flow is less than 10 cumecs, occurs between December and May. It generally occurs over a period of over two months but can be as much as five months, or less than two weeks. These periods are illustrated diagramatically in Figure 14 for the years 1925 to 1963.

30. The flow decreases progressively downstream. This is shown clearly in Figures 13a - f and 15a, b, c, and by the maximum recorded discharges and channel capacities at the various gauging stations. These are as follows:

	Max.Recorded Discharge Cumecs	Approx. Channel Capacity, Cumecs
Belet Uen	281	350
Bulo Burti	276	310
Mahaddei Uen	130	140
Balad	93	105
Afgoi	93	110
Audegle	80	90

31. Exceptions to the decrease in flow downstream are caused by local rainstorms, local exfluent ground water and the return of overbank spillage to the channel.

32. The median monthly total flow passing gauging stations and the changes in this flow between stations are shown in Tables 6 and 7.

33. In the section between Belet Uen and Bulo Burti there are water losses in most months. These are highest when the river stage is high and overbank spillage takes place. The small gains, which more than offset evaporation losses in January, can be attributed only to an inflow of ground water probably from wadi beds and bank storage; whereas the higher but still small gains in March are due to surface runoff.

34. From Bulo Burti to Mahaddei Uen losses occur throughout the year except in June. The increase in flow during June probably is the result of a return to the river of some of the overbank spillage that occurred in the previous month. The channel losses from January to April appear to be offset slightly by subsurface inflow provided no overbank spillage takes places, as is the case occasionally in April.

35. The losses in the stretch from Mahaddei Uen to Balad are high, and occur

every month, with the highest loss occurring in May, and from August to November, when the river stage is high and overbank spillage takes place. The spillage is aggravated by a weir at Johar which was constructed to raise the water level and allow water to flow by gravity to a sugar plantation. Embankments that were constructed upstream from the weir are damaged because of a lack of maintenance and are now totally ineffective.

36. The channel from Balad to Afgoi is unique in that it is capable of carrying, without overbank spillage, all the water that enters at Balad. Consequently the losses are relatively low. There appears to be a slight increase in flow in May and from August to December. There is no evidence of surface run-off to explain this and it cannot be correlated with precipitation, therefore, it must be a result of a contribution from ground water in shallow perched aquifers, the cause of which is overbank spillage upstream and rainfall. These gains more than offset the losses to the permanently saturated zone.

37. From Afgoi to Audegle the flows, as tabulated, show that there is normally a slight increase between these two stations in the period of January to July, except in May when overbank spillage occurs. This is not the result of rainfall and surface run-off, and must be ascribed to subsurface flow. No measurements of water passing the control gates at Falcheiro have been made, hence the natural losses and the water used by controlled and inundation irrigation downstream of Audegle are not known. Water will pass into the swamps below Falcheiro when the stage is high and when irrigation requirements are only a fraction of the flow. In the period of January to early April and in June and July, very little water if any will pass. It has been estimated, based on crop requirements that the reduction in flow in the median year is approximately 40,000 hectare meters, whereas the total flow in the median year is approximately 110,000 hectare meters.

38. Careful examination of the channel at Avai indicates that the outflow from the swamps never reaches the high rates of inflow that are often maintained for many weeks at Falcheiro from September to December. It may be safely assumed that the total annual inflow to the swamps is greater than the outflow. However, outflow is always maintained, although inflow often ceases entirely for a month or two. It is likely that most of the losses from the swamps are due to evapotranspiration. Some infiltration may take place, but it is thought that the floor is relatively impervious and the swamps are perched above the water table.

39. The distance beyond Avai along which flow takes place depends upon the amount of flow upstream. In low years it would not reach far beyond Avai, but when it is unusually high, as in late 1961 and 1962 the flood plain in this area is completely submerged, and water from the Shebelle actually reaches the Juba River.

40. Monthly flow frequencies expressed as the percentage of times that the monthly flow values are equalled or surpassed at the various stations are shown in Figure 16a,b,c,d,e,f.

Water Quality

41. The Shebelle River water carries more dissolved solids than does the Juba. Values of specific conductance, which generally are less than 1,500 micromhos, vary from less than 500 up to 4,000 micromhos. The high values occur after a long dry spell when the first rains wash the soluble materials that have accumulated along the land surface into the river. This can be seen by referring to the Conductivity Dishcharge Hydrographs of Figure 17a,b,c. Chloride concentrations generally vary between 10 and 500 parts per million (ppm.). The high chloride values can be correlated with the high values for specific conductance. (See Appendix 2)

42. Sulphates vary from 100 to 600 ppm. but the high values do not necessarily correlate with high chlorides and specific conductance. The relatively high sulphates probably arise from the dissolved gypsiferous rocks upstream.

43. Sediment samples were taken at various stations along the river during the latter part of the survey. The sediment concentrations measured during 1965 are listed in Table 10.

44. The swamps act as a huge settling basin for the suspended load of the Shebelle River. The river is very turbid down to Falcheiro, but the outflow from the swamps at Avai is virtually clear.

THE JUBA RIVER

Physical Description

45. The Juba River rises in the eastern plateau of Ethiopia immediately south of the Shebelle basin. The three main tributary streams, namely the Uebi Gestro, the Canale Doria, and the Daua Parma, drain the eastern slopes of this plateau for a distance of about 300 kilometers southeast of the Dodola-Goba area. The Uebi Gestro, and the Canala Doria unite to form the Juba River just north of Dolo, and the Daua Parma joins the Juba River at Dolo having formed the Kenya-Ethiopia border and the Somalia-Ethiopia border in the area west of Dolo.

46. The drainage system is about 900 kilometers long from the plateau to the Indian Ocean. Its area has been estimated at 275,000 square kilometers, 98,000 of which are within Somalia; but like the Shebelle River the effective surface drainage basin is limited to the head waters and a narrow zone adjacent to the river. Ground water that apparently discharges into the upper stretches of the river within Somalia may have flowed a considerable distance through the ground, but in the lower reaches the river is influent.

47. The tributary rivers generally flow towards the southeast, after uniting to form the Juba River, this direction is maintained into Somalia as far as Lugh Ganana, from which point it flows generally towards the south. Within Somalia the river traverses a distance of about 580 kilometers with a channel length of about 800 kilometers.

48. From the border to about 30 kilometers south of Lugh Ganana, a channel distance of about 135 kilometers, the river flows in a wide valley that is well defined by hills of fair height. The bed tends to be shallow and islands occur north of Lugh Ganana. The channel has generally stable banks and varies in width usually between 50 and 100 meters; in a few places it is as much as 300 meters wide.

49. Below Lugh Ganana the valley narrows and about 30 kilometers south of the town the river enters more rugged terrain, which continues for about 120 kilometers to the area north of Bardera, a total channel distance of 200 kilometers. In this section the river bed is rugged and rapids occur in several places. The banks, being formed of hard limestones, are stable, with numerous short but deep tributary valleys.

50. Near Bardera the valley widens and the surrounding hills progressively disappear, although the river continues to flow through limestone terrain as far as Saco, about 75 kilometers south of Bardera. The channel is generally from 120 to 150 meters wide in this stretch.

51. Between Saco and the Dugiuma area the river is incised in drift material that apparently covers the basement. From there to the ocean the slope decreases and the river enters its broad flood plain. It traverses a distance of about 180 kilometers across its flood plain from Dugiuma to the ocean. In the Giamama area the channel width varies generally from 80 to 100 meters.

52. Near Beled Amin, about 12 kilometers north of Giamama, the Shebelle River joins the Juba when the flow is exceptionally high.

River Flow

53. Though the flow of the Juba River is twice that of the Shebelle River, it is similar to the Shebelle in the torrential nature of its flow, which ranges from over 800 to less than 10 cumecs. Furthermore the flow patterns are similar, with high flows of short duration occurring in April to May, and for a longer duration from August to December. Peaks are irregular in magnitude and the highest flows may occur in either period. The irregular nature of the flow is well illustrated in Figure 13g,h,i. In the years 1961 and 1962 a distinct peak of short duration occurred in May and was followed by higher peaks in the more prolonged August to December period, whereas in 1963 the earlier peak was higher although of short duration. In 1964 the earlier peak was hardly noticeable and seems to be part of a general increase in flow that culminated in a peak at the end of October.

54. Regular changes in flow along the course of the river are illustrated in Table 9. It is possible to understand the reasons for these changes more clearly when they are compared with total flows shown in Table 8 and Figures 13g,h,i, and 15d,e, and with rainfall data.

55. In the section from Lugh Ganana to Bardera, the losses in May and in the period from August to November coincide with high river flows. They must be a result of overbank spillage, much of which probably infiltrates the ground as bank storage to re-appear in the river at a later time. The gains in June and July and from December to March, in the lower flow periods, represent a contribution from ground water, some of which will be bank storage returning to the river. In each period the gains decrease progressively as the bank storage is depleted and as the ground-water head decreases. The sharp increase in gains in April probably is caused by run-off as a result of the April rains. The effect of run-off caused by rains in October and November is overshadowed by the high flows and the channel losses in that period.

56. From Bardera to Kaitoi the flow pattern is more complicated because of changes in the terrain over which the river flows. From Bardera to Saco, it flows over limestones and gains from groundwater can be expected, whereas from Saco to Dugiuma the river crosses the drift covered basement and expected changes would be due to evaporation losses and gains from local run-off. The remaining reach, from Dugiuma to Kaitoi, is over the flood plain, and losses by infiltration and overbank spillage can be expected. The changes in flow shown in Table 9, indicate substantial gains in the periods May to June and September to December, corresponding to periods of high river flow and high rainfall. They also correspond to the main losses upstream but lag behind by about one month, at least in the latter period. They probably are caused by a re-entry of flood water that infiltrated the higher ground upstream and by local run-off. During periods of low flow the only gains are in January and March. Throughout the rest of the low flow period they are more than offset by infiltration losses.

57. From Kaitoi to Giamama,steady losses due to infiltration, evaporation and use take place throughout the entire year. They increase sharply in October and continue at a high level in November when the river stage is highest and overbank

spillage takes place. This condition probably continues as far as the ocean.

58. Monthly flow frequencies expressed as the percentage of times that the monthly flow values are equalled or surpassed at the various stations are shown in Figures 16g,h,i,j.

Water Quality

59 The water of the Juba River generally contains less dissolved solids than that of the Shebelle, but like the Shebelle the chemical quality varies throughout the year and periods of higher salinity can be correlated with periods of rainfall. Figure 17d. The increase in specific conductivity at Lugh Ganana during December 1964 does not correlate with local precipitation but it may have been due to a rain storm upstream. There is a steady increase in specific conductance during the January to March dry seasons both at Lugh Ganana and Bardera. This probably is caused by an inflow of more saline ground water, which is more significant during the low flow period.

60. Variations in the chloride content correlate with the specific conductance. The highest value was 330 parts per million, recorded at Lugh Ganana in December 1964, but values generally are less than 100 parts per million. (See Appendix 2)

61. Unlike the Shebelle River, the sulphates in the Juba River water are low, being less than 100 parts per million. Analyses were not made for the complete range of flows but a slight increase in sulphates coincides with an increase in specific conductance at Bardera during March 1964.

62. Sediment concentrations were determined during 1965 only. They are listed in Table 10.

HYDROMETRIC DATA

Water Levels

63. The first field work done in the hydrology section was the establishment of permanent staff gauges and stilling wells equipped with water level recorders. The only water level data to be found was for Lugh Ganana and Belet Uen for the periods 1951 to 1962 but with much data missing.

64. Gauge readers were appointed and daily observations started in April 1963. Water level recorders started functioning a few months later and have contrived uninterrupted since. The graphs frequently helped in checking the monthly records and clarified questionable values. When the river stage varied rapidly graphs were used to compute daily mean values.

65. When levelling circuits were balanced and the elevations of reference Bench Marks were determined, the zero of all staff-gauges was tied to the general network. This made it possible to express all water level figures in meters above sea level, which made them directly available for any design work.

66. Synthetic hydrographs were computed for the period 1951 to 1962 by correlation with the stage relations of 1963 and 1964. Comparison between correlated and observed monthly flows in 1963 and 1964 gave an average accuracy of five per cent. It was assumed that no significant inflow entered from side catchment basins and no alteration took place in the river bed or in local agricultural consumption. In the

lower sections of the rivers, particularly the Juba River, inflow arising from local rains can be of importance but this factor is not as important upstream. In addition overbank spillage returns to the river in places.

67. The graphical method of Blanchet was used to determine time lags.

68. The water level frequency curves (Figures 18a,b,c,d, e.) show the percentage of time during the period 1951 to 1964 that water levels were equalled or surpassed on a weekly basis. The percentages shown are 10, 25, 50, 75 and 90 per cent. The accuracy is limited by the short 13 year period of records during which time (1961) an exceptional flood took place. Consequently, values are inadequate for design purposes.

River Flow

69. Table 11 gives the main features at the river gauging stations. Detailed descriptions of the Bench Marks are to be found in the Survey Department files.

70. After more than a year of continuous flow measurements, it was possible to draw the stage-discharge relation curves with acceptable accuracy. (Figures 17a, b,c,d.) Extremely high stages occurred in April 1963 but the metering campaign started effectively a few weeks later. These conditions were not found afterwards, but fairly high flows were measured at the end of 1963 and in 1964. All stations along the two rivers, with the exception of Lugh Ganana and Bardera, have a stable control section for the entire range of water levels; the river bed does not indicate major alterations from year to year. They follow the general rule of rivers flowing in their alluvial bed, carrying heavy sediment concentrations, that is to say, alternatively scouring and filling, by approximately the same amount. The maximum theoretical discharges were computed by extrapolation of mean velocity and area curves; however, a sudden shifting of the control occurred for values higher than normal peaks. As a result the roughness coefficient and water surface slope method was used to extrapolate the theoretical discharge. Unfortunately, no water levels of importance were obtained and results are meaningless. The only solution left was to extrapolate mean velocity curves and assume a flattening of the water surface slope for extremely high stages.

71. Stage-discharge nomograms (Figure 19) and curves (Figures 20a to i) represent all the flow measurements for the period 1963 - 1965.

72. Values were compared with data taken from an old report (1925) where cross-section and velocities were given. It was concluded, after relating the elevations to the project reference datum, that the river bed showed no important modification.

73. Discharge hydrographs (1951 - 1962) (Figures 13 a to i) are derived from the computed water levels using Lugh Ganana and Belet Uen stations as references. During the period 1963 - 1965, direct observations were taken without interruption.

74. Figures 21a,b,c, and d represent the relative discharges at different stations along the two rivers. The highest values on the respective curves indicate the maximum channel capacity of the stretch of river between the two stations considered.

75. Table 4, gives the approximate time-lags along the Shebelle River.

TABLE 4

DISCHARGE TIME-LAG - SHEBELLE

UPSTREAM STATION	DISCHARGE CUMECS	DOWNSTREAM STATION	APPROX. TIME-LAG IN DAYS
Belet Uen	225	Bulo Burti	5
" "	200	" "	4
" "	150	" "	2
" "	125 & below	" "	1
" "	150	Mahaddei Uen	2
" "	100 & below	" "	1

Between Mahaddei Uen and downstream stations, delays are one day or less. Along the Juba River, the time lag is generally 2 days from Lugh Ganana to Bardera and 7 days to Giamama for all median values.

76. Discharge frequencies are given in terms of values equalled or surpassed, as percentages of time, during a given period. Figures 22 a,b,c,d, and e represent monthly flows in 5 day period values, for 10-25-50-75 and 90 per cent occurrences, and Figure 14 show the annual dry season at Johar during a period of 25 years.

77. Figure 23 shows the computed recession curves, the coefficient at the station and the total amount of water that was flowing during this period in hectare-meters.

78. The recession coefficients computed for the two years 1964 - 1965 show no difference; therefore, only one curve is included for the stations concerned. The coefficient "a" is derived by expressing the depletion part of the discharge hydrograph as an exponential function:

$$q = q_o \ e \ - \ a(t-t_o)$$

Where q_o, t_o are discharge and time elapsed at the origin,

$$t_o = 0$$

q and t = values of discharge and time after a given number of days.

79. Along the Shebelle, values for "a" vary from 0.035 to 0.060; along the Juba River, from 0.035 to 0.045. The computed coefficients indicate that the water entering the rivers flows through soils of similar permeability and for similar distances. The period of recession (100 days) is directly tied to the rainfall pattern in the higher reaches.

Suspended Load:

80. In Table 10 sediment concentrations in the two rivers are listed. At the present time values do not cover the entire stage on the Shebelle, except at two stations where only extra values are available (Afgoi and Audegle). Along the Juba, concentrations may vary from a minimum of 30 to a maximum of 5000 grams per cubic meter at Giamama as compared to extremes of 100 and 14,500 grams per cubic meter at Afgoi on the Shebelle.

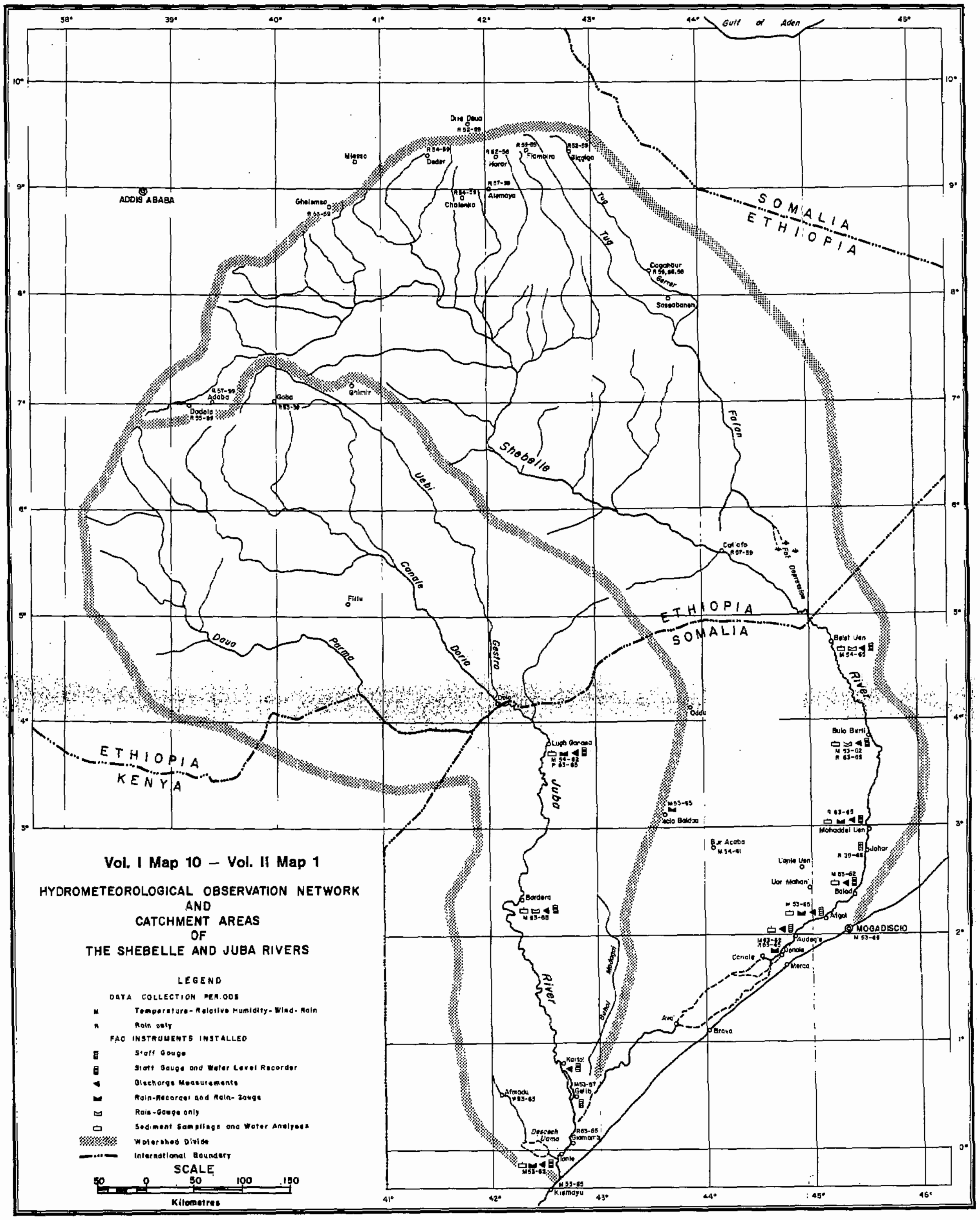
81 The granulometric curves of the sediments do not cover entirely the grain sizes because the only sieves available had openings from 0.074 mm to 0.420 mm. In periods of high flows, when the carrying capacity is increased, up to 80 per cent of the grains would remain on the 0.420 mm sieve. This preliminary information makes it possible to fix the limits of the concentration values to be found. More samples, will be needed to construct a discharge-sediment curves to evaluate the rate of siltation in the lower reaches of the rivers. Curves on the analysis of sediment samples are shown in Figures 24 a,b,c,d,e.

Specific Conductance

82. Chemical analyses of samples taken from both rivers are listed in Appendix 2 at the end of this Volume.

83. In Figures 25 a,b,c,d,e, specific conductance is plotted against discharge. The points are scattered but show a general decrease in specific conductance with an increase in flow.

84. The conductivity-discharge hydrographs, Figures 17 a to d also contain precipitation data. These indicate a more direct relationship between precipitation and conductivity. The highest values generally are found after a prolonged dry period when the first rains flush from the dried surface the river salts accumulated during evaporation.

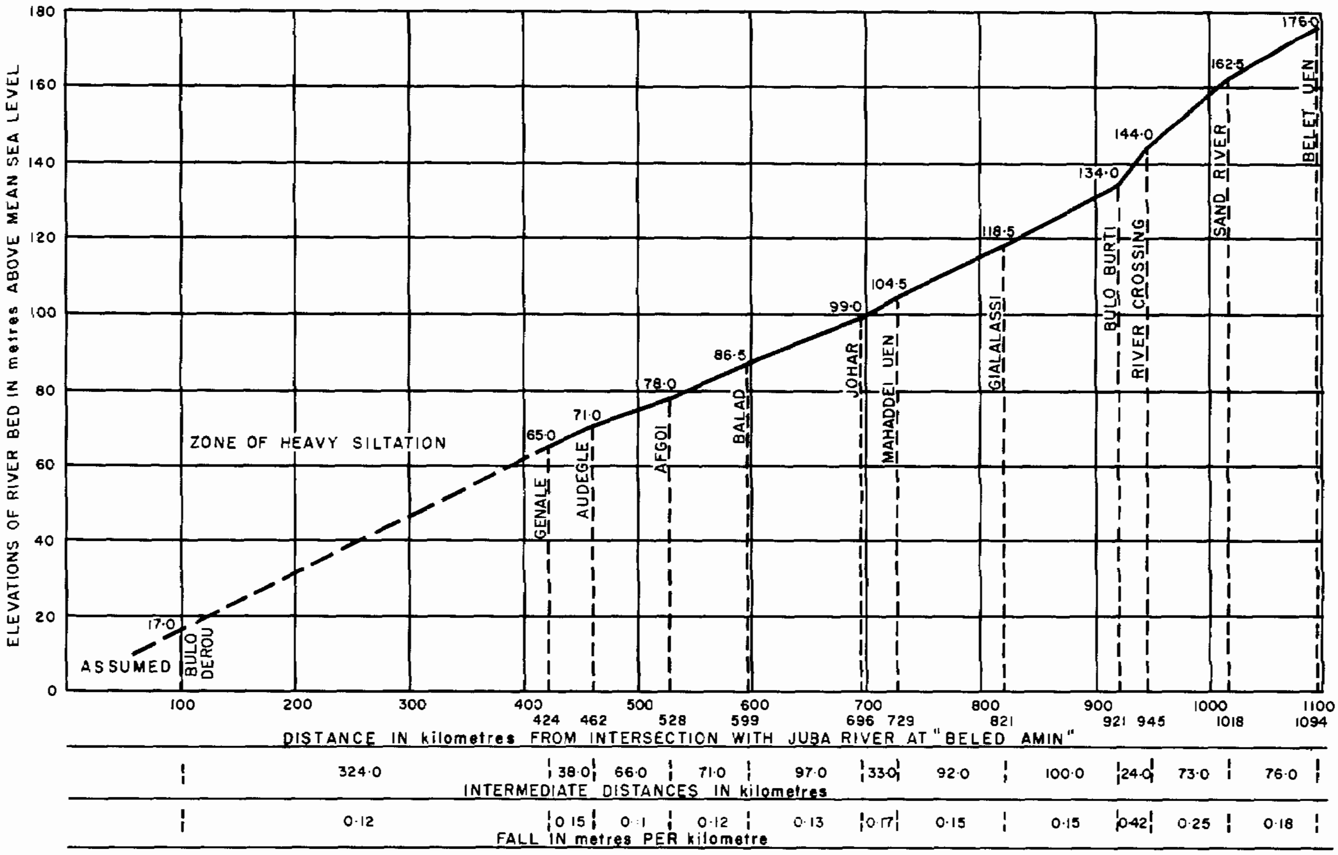


Vol. I Map 10 — Vol. II Map 1

HYDROMETEOROLOGICAL OBSERVATION NETWORK
AND
CATCHMENT AREAS
OF
THE SHEBELLE AND JUBA RIVERS

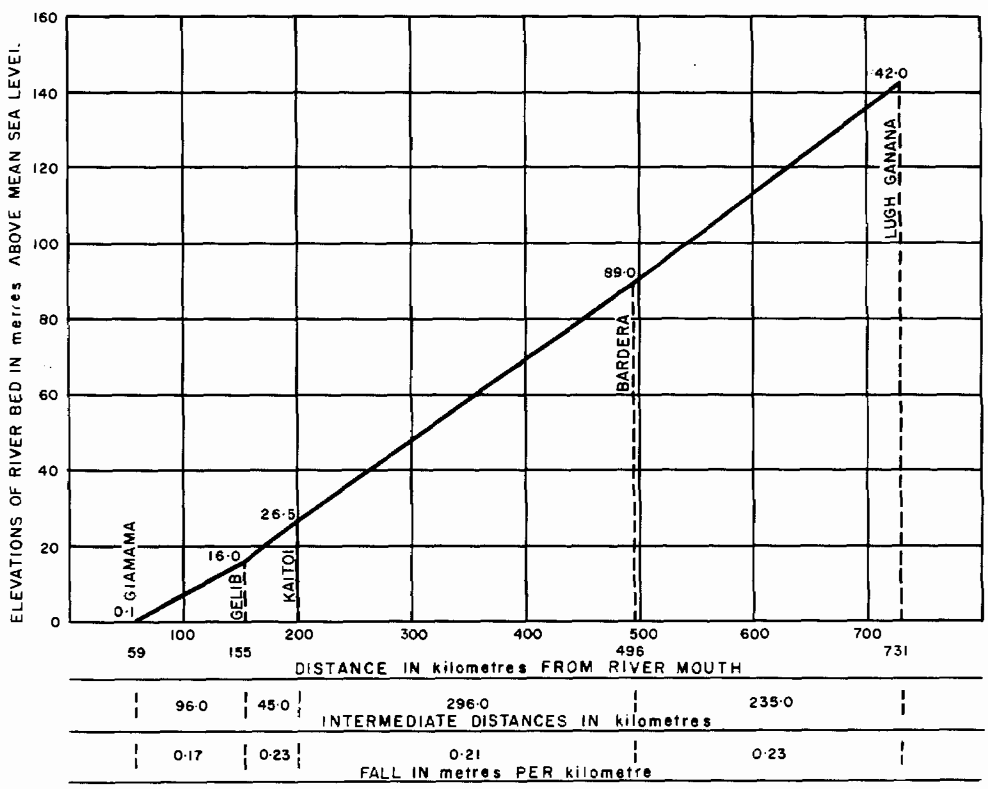
PROFILE OF THE SHEBELLE RIVER COURSE

FROM JUBA INTERSECTION TO BELET UEN



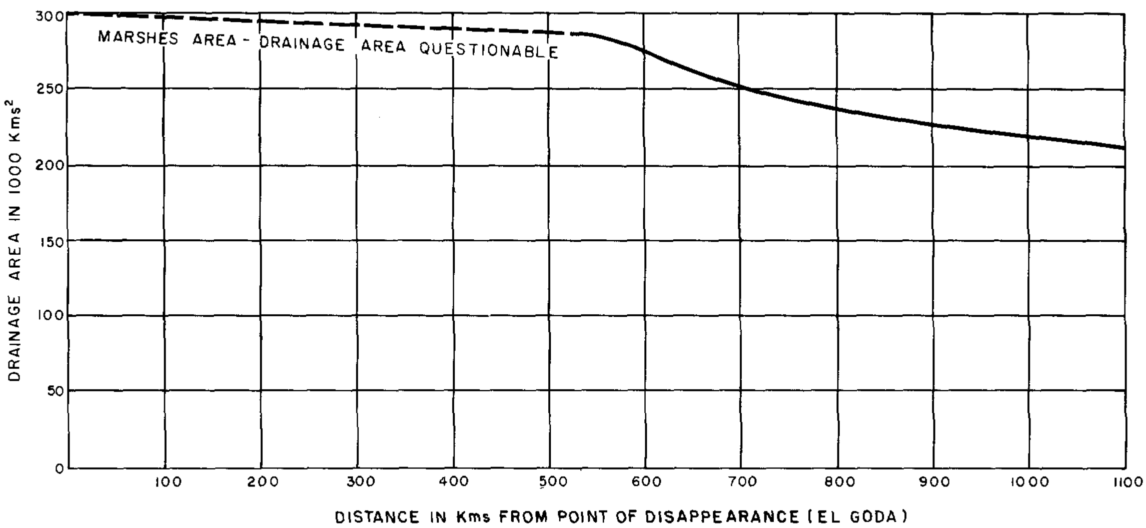
PROFILE OF THE JUBA RIVER COURSE

FROM THE MOUTH TO LUGH GANANA



Vol. I Fig. 5 – Vol. II Fig. 10

DRAINAGE AREA vs LENGTH OF COURSE
SHEBELLE RIVER



DRAINAGE AREA vs LENGTH OF COURSE
JUBA RIVER

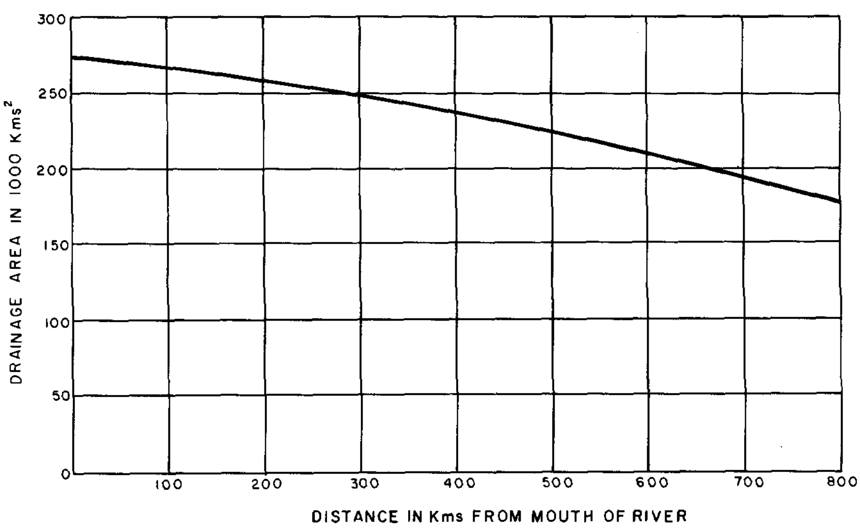
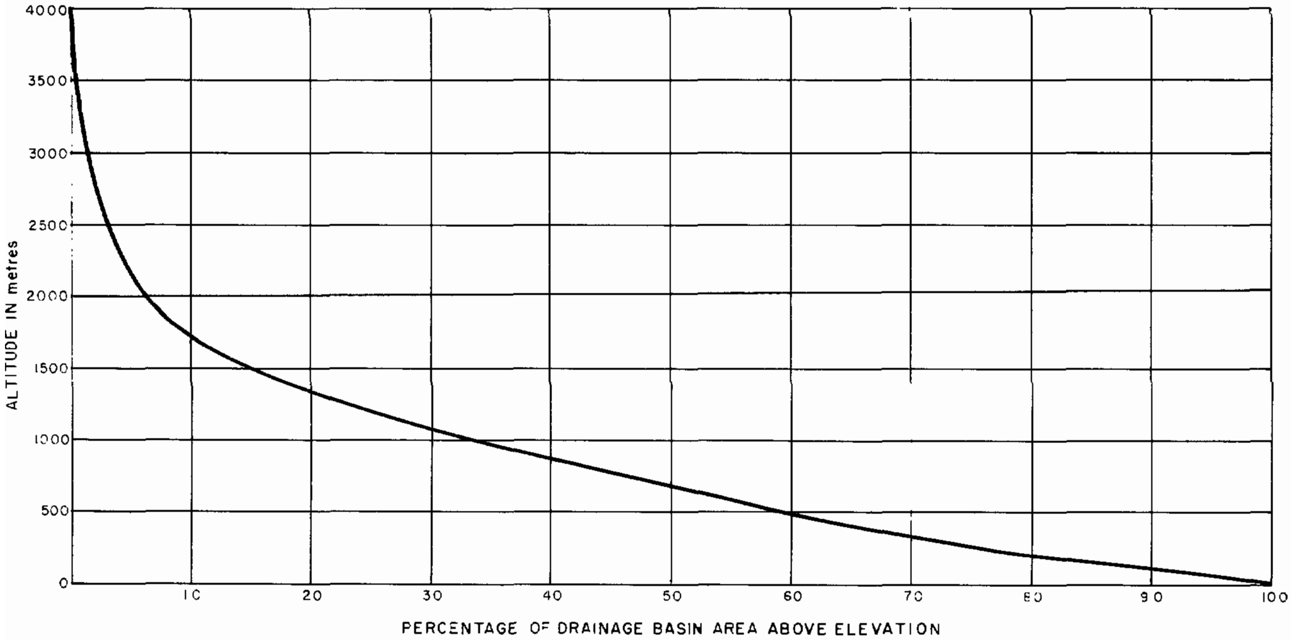


Figure 11

AREA ELEVATION CURVE
SHEBELLE RIVER



AREA ELEVATION CURVE
JUBA RIVER

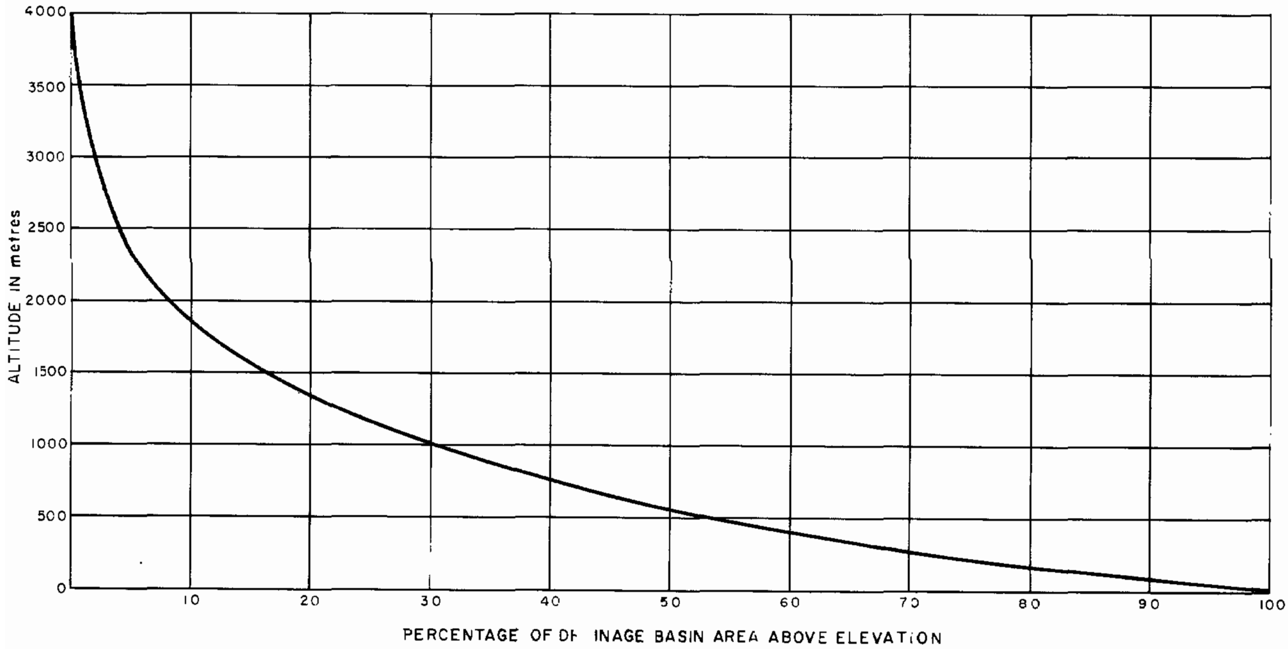
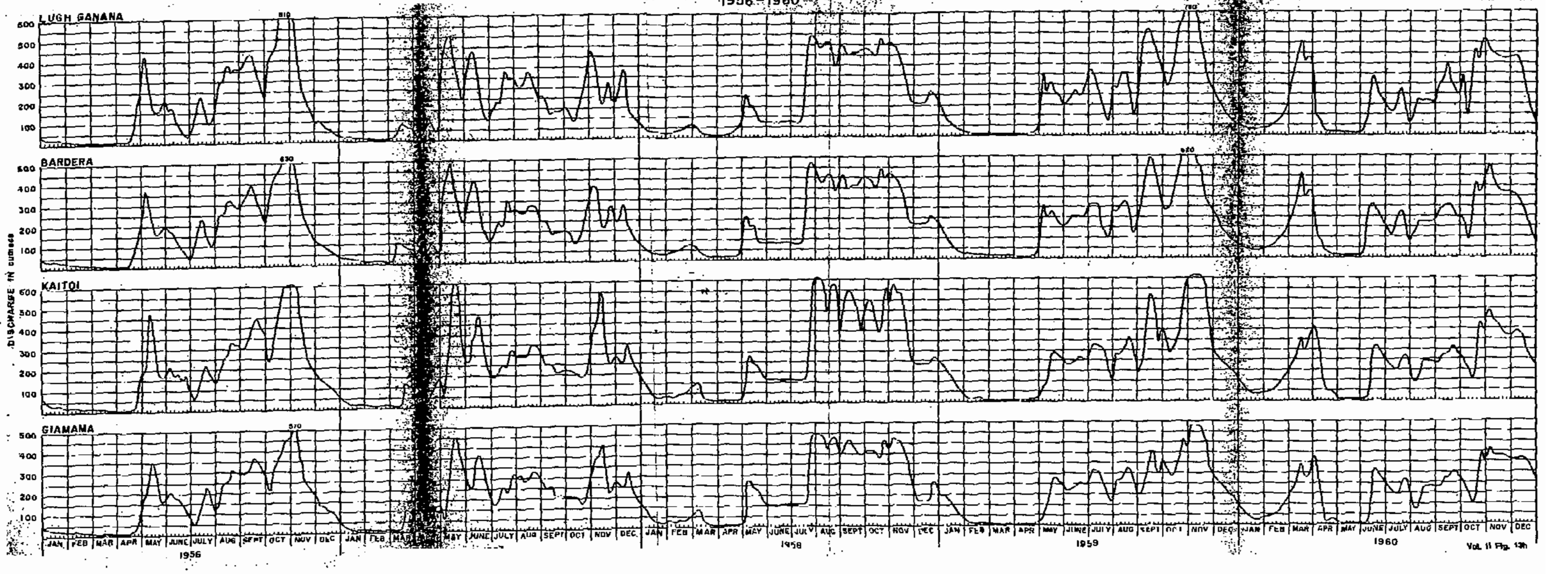
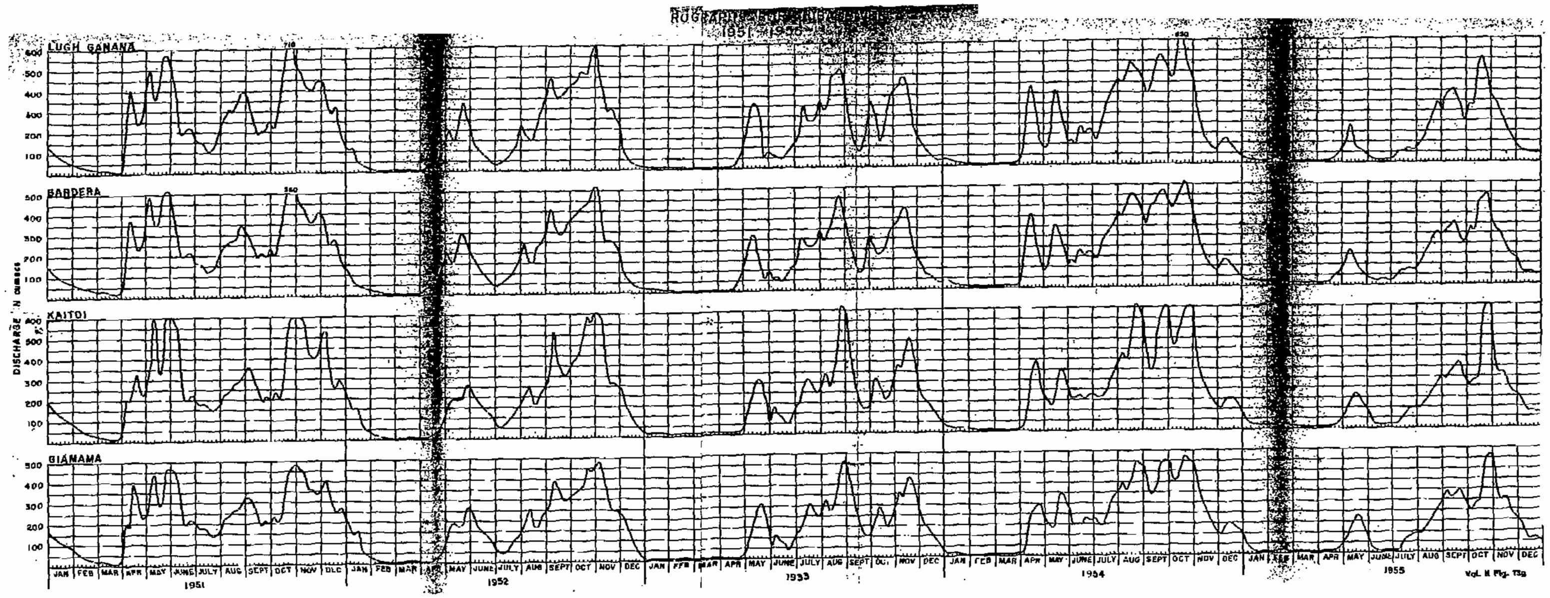


Figure 12

HYDROGRAPHS FOR JUBA RIVER 1956 - 1960

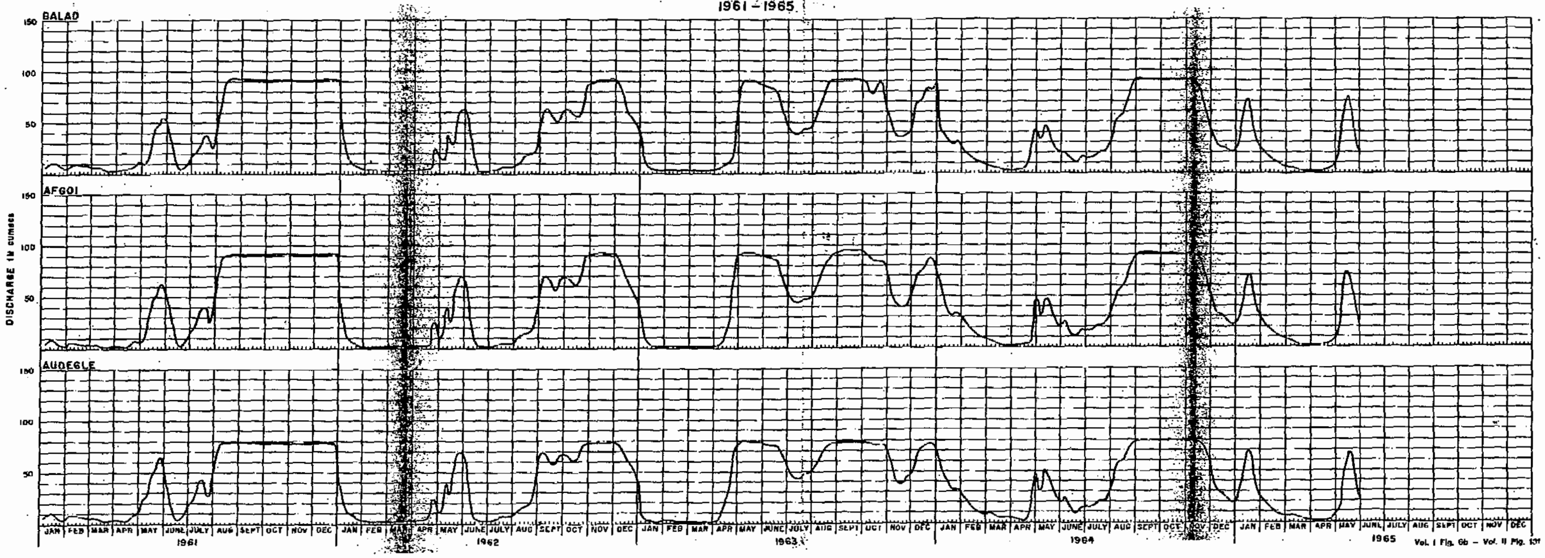


Vol. II Fig. 13h



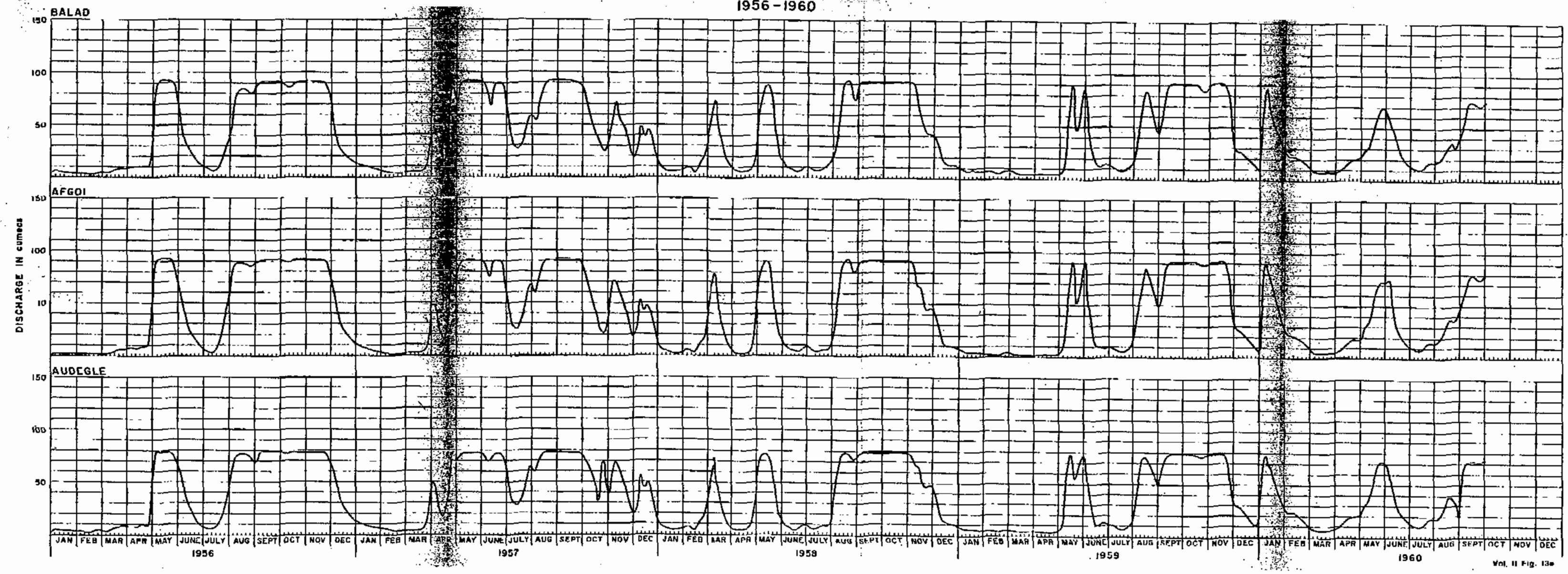
Vol. II Fig. T3a

HYDROGRAPHS FOR SHEBELLE RIVER
1961 – 1965



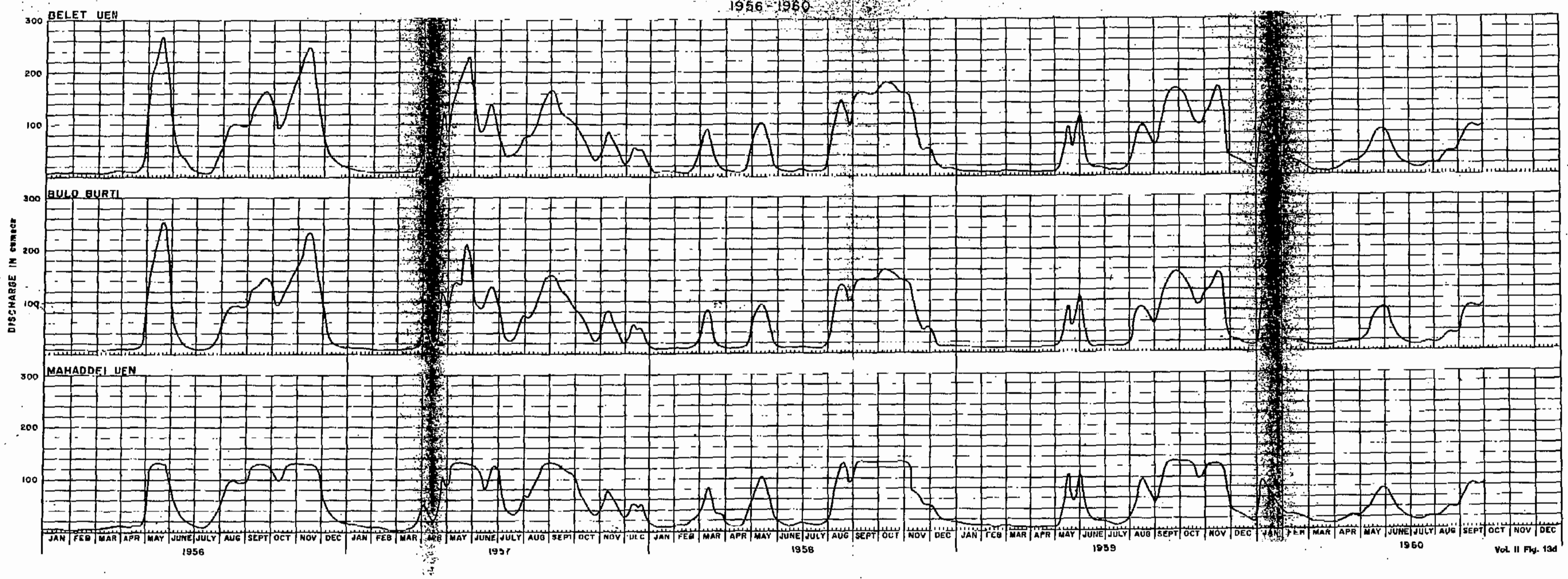
Vol. I Fig. 6b – Vol. II Fig. 5?

HYDROGRAPHS FOR SHEBELLE RIVER
1956-1960



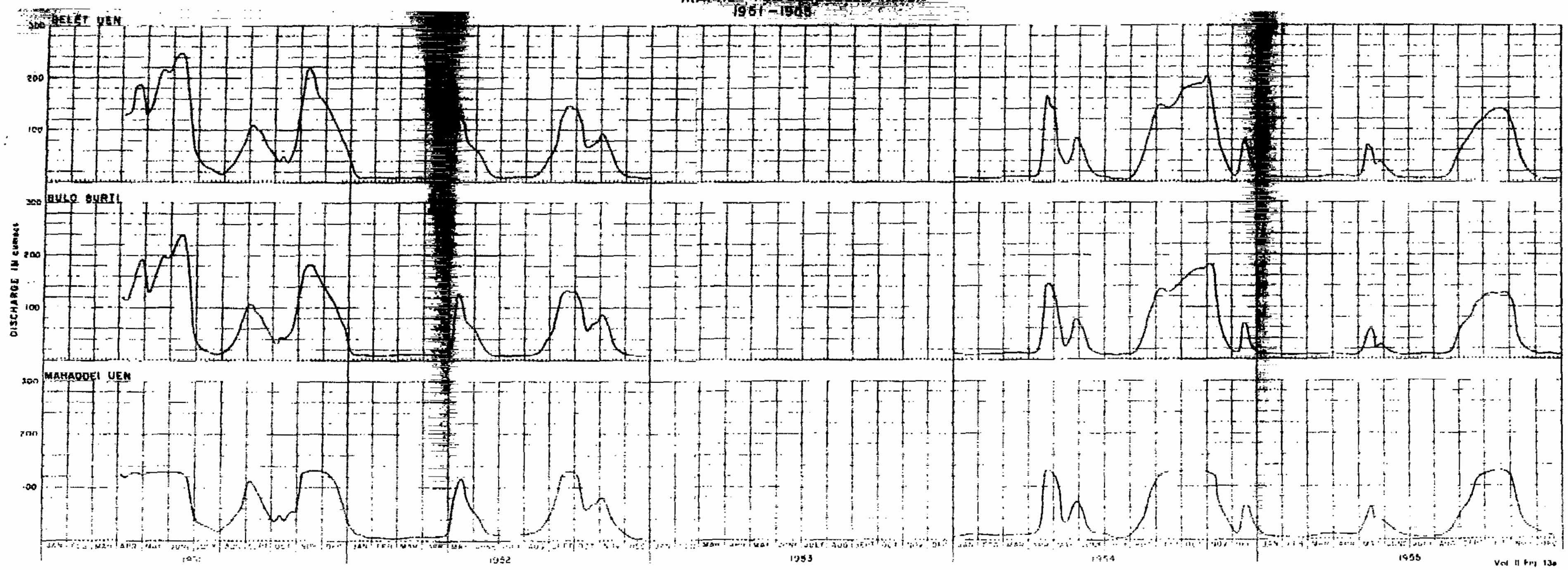
Vol. II Fig. 13e

HYDROGRAPHS FOR SHEBELLI RIVER 1956–1960



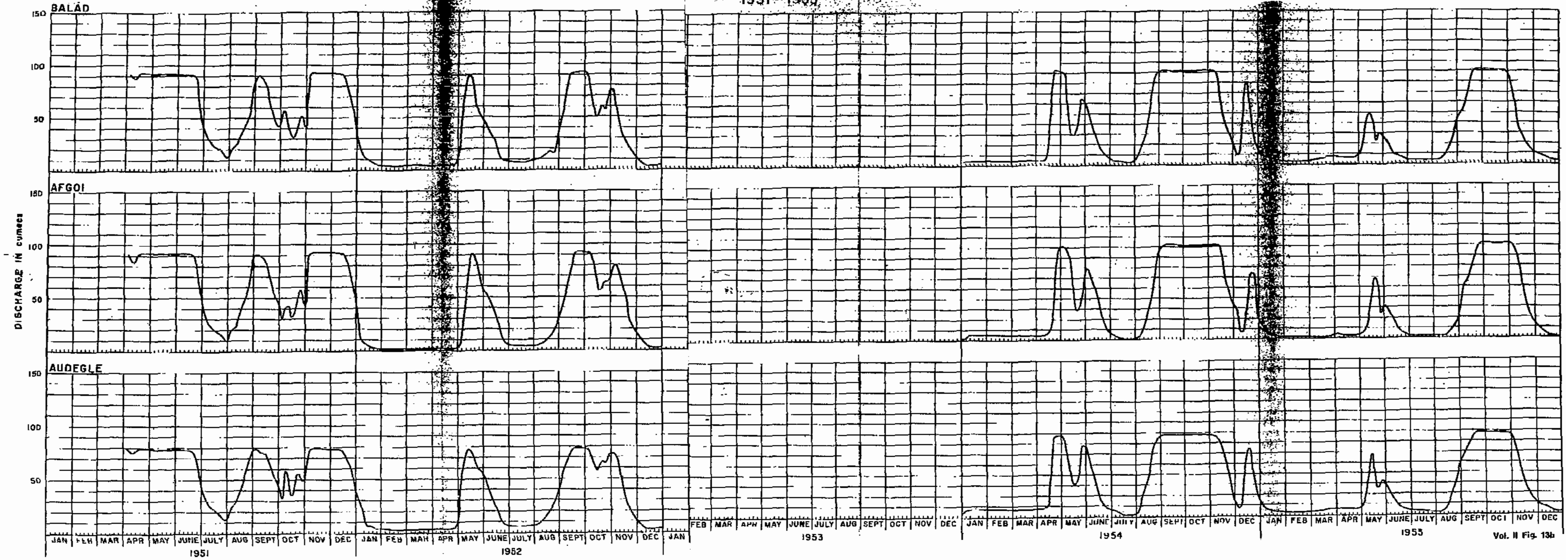
Vol. II Fig. 13d

1951 – 1955



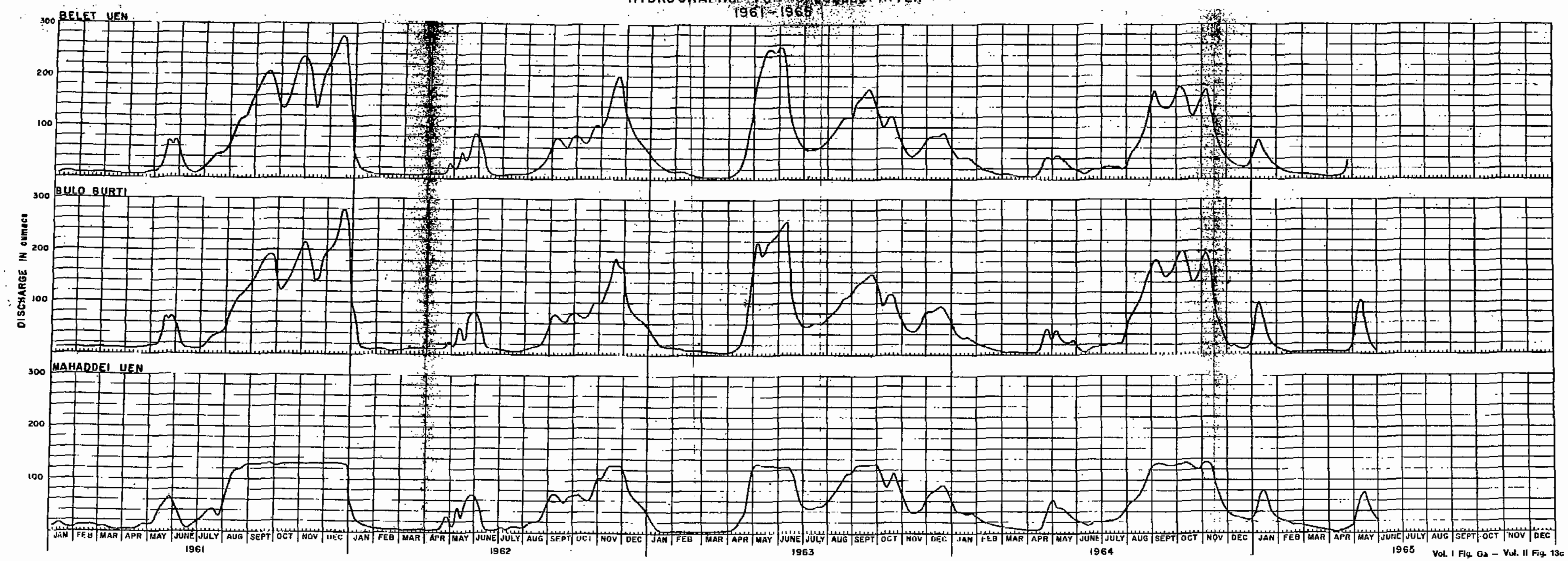
Vol II Fig 13a

HYDROGRAPHS FOR SHEBELLI RIVER
1951 – 1955



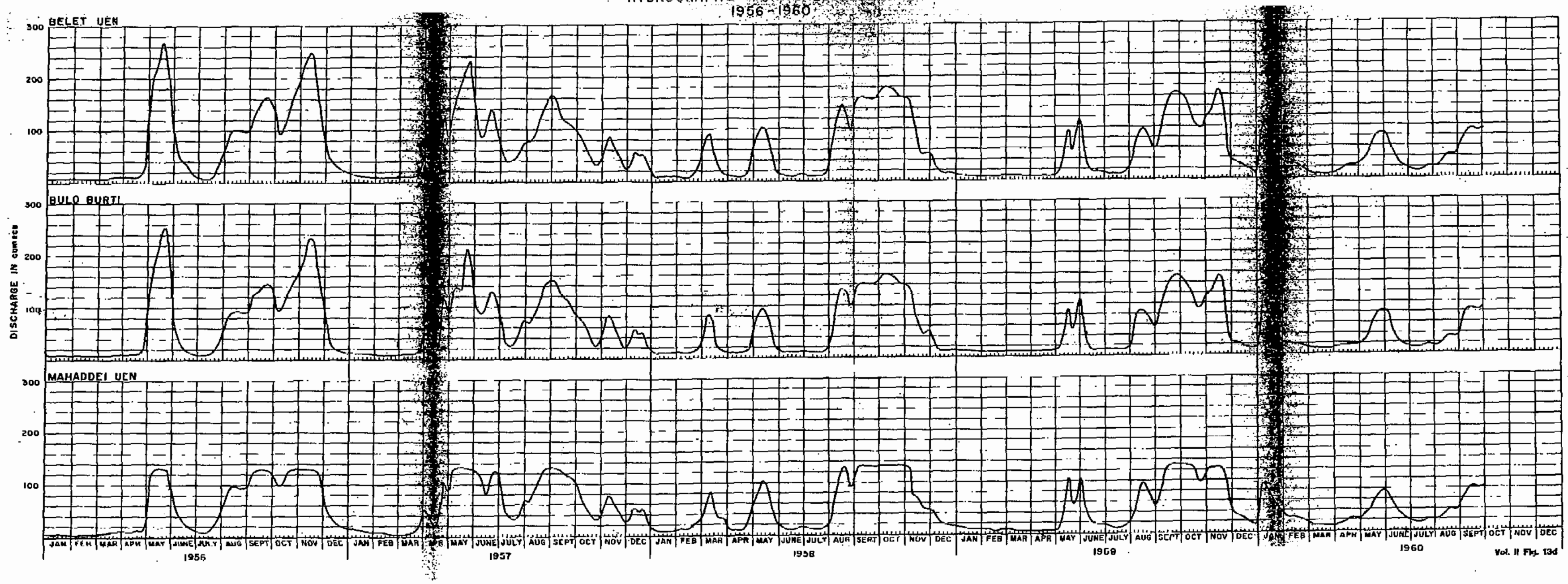
Vol. II Fig. 13b

HYDROGRAPHS FOR SHEBELLE RIVER 1961 – 1965



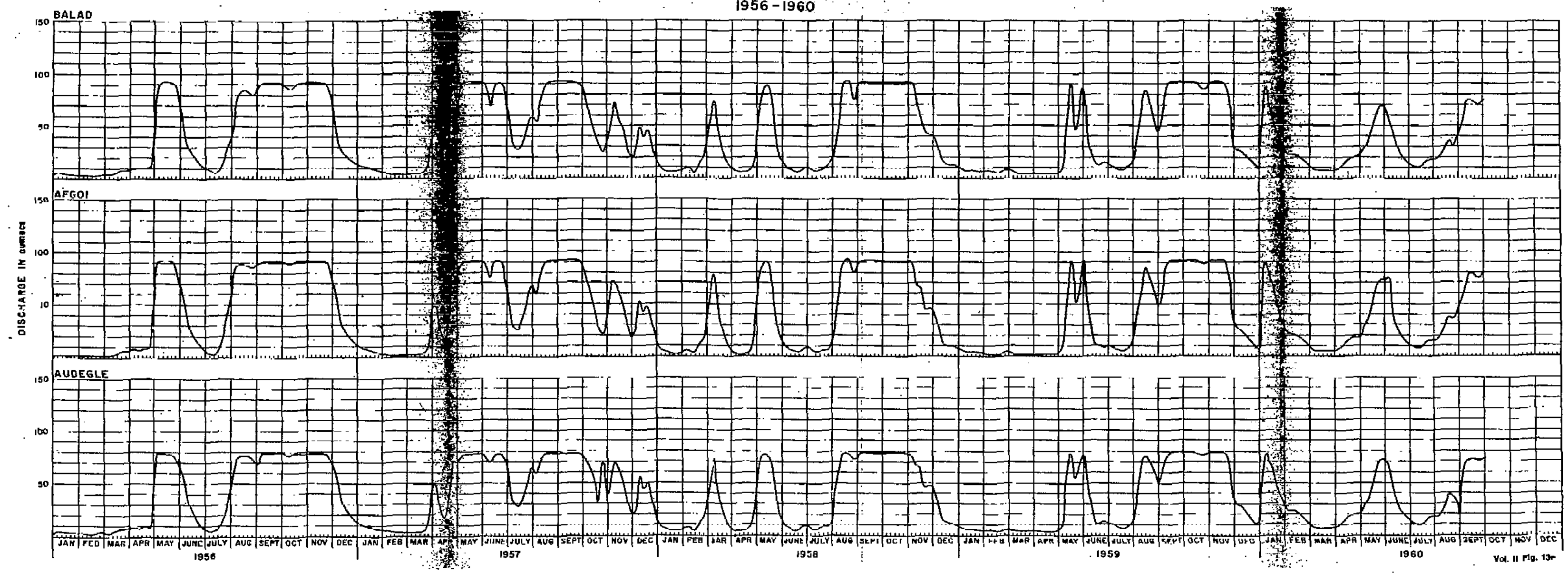
Vol. I Fig. 6a – Vol. II Fig. 13c

HYDROGRAPHS FOR SHEBELI RIVER 1956-1960



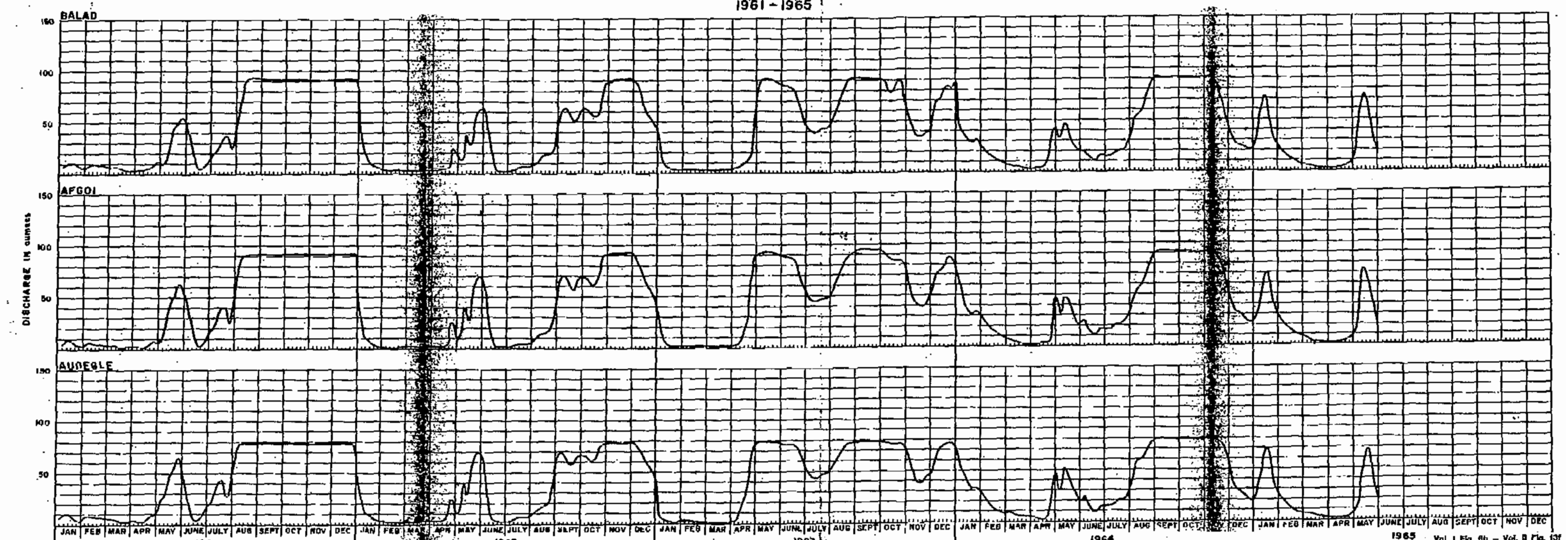
Vol. II Fig. 13d

HYDROGRAPHS FOR SHEBELLE RIVER
1956 - 1960



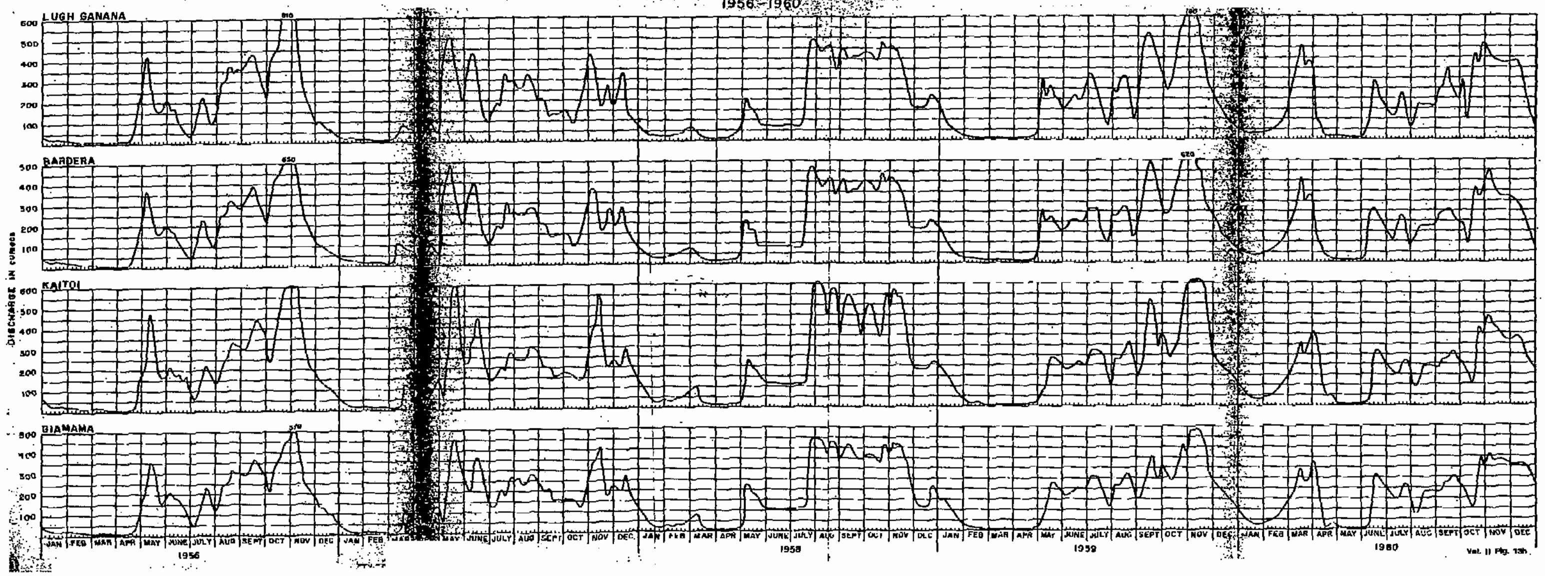
Vol. II Fig. 13e

HYDROGRAPHS FOR SHEBELLE RIVER
1961 - 1965



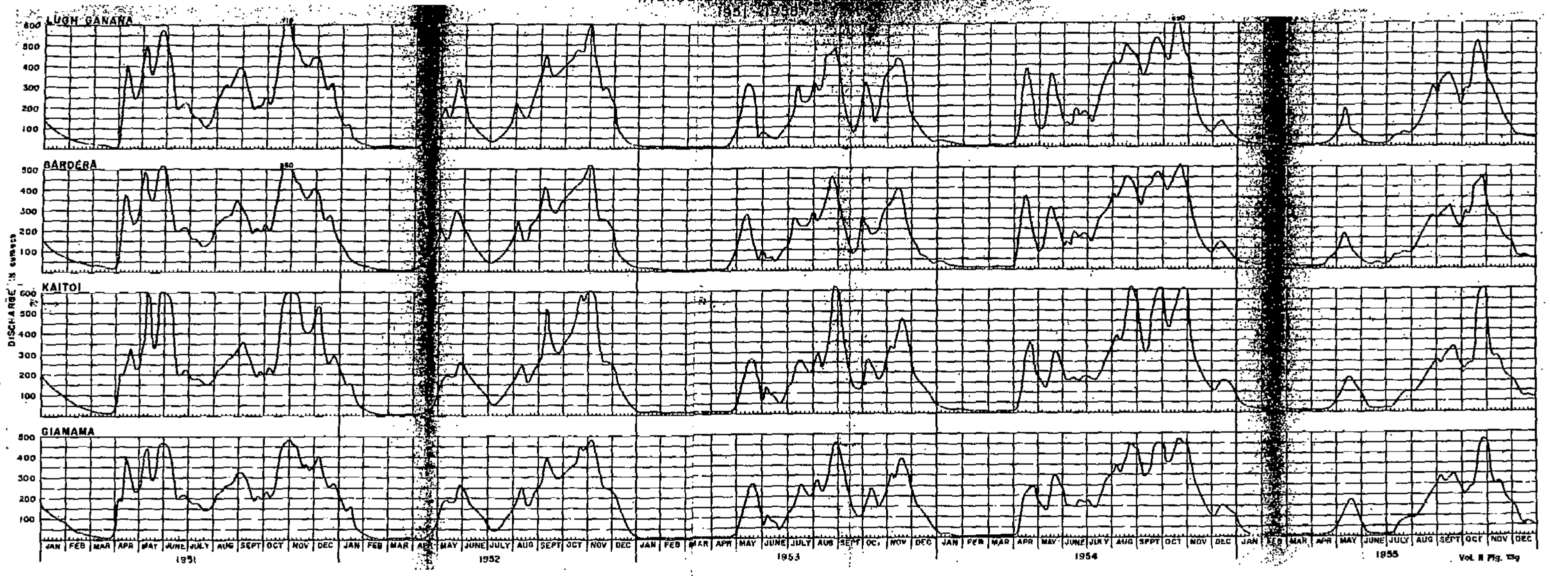
Vol. I Fig. 6b – Vol. II Fig. 13f

HYDROGRAPHS FOR JUBA RIVER 1956–1960



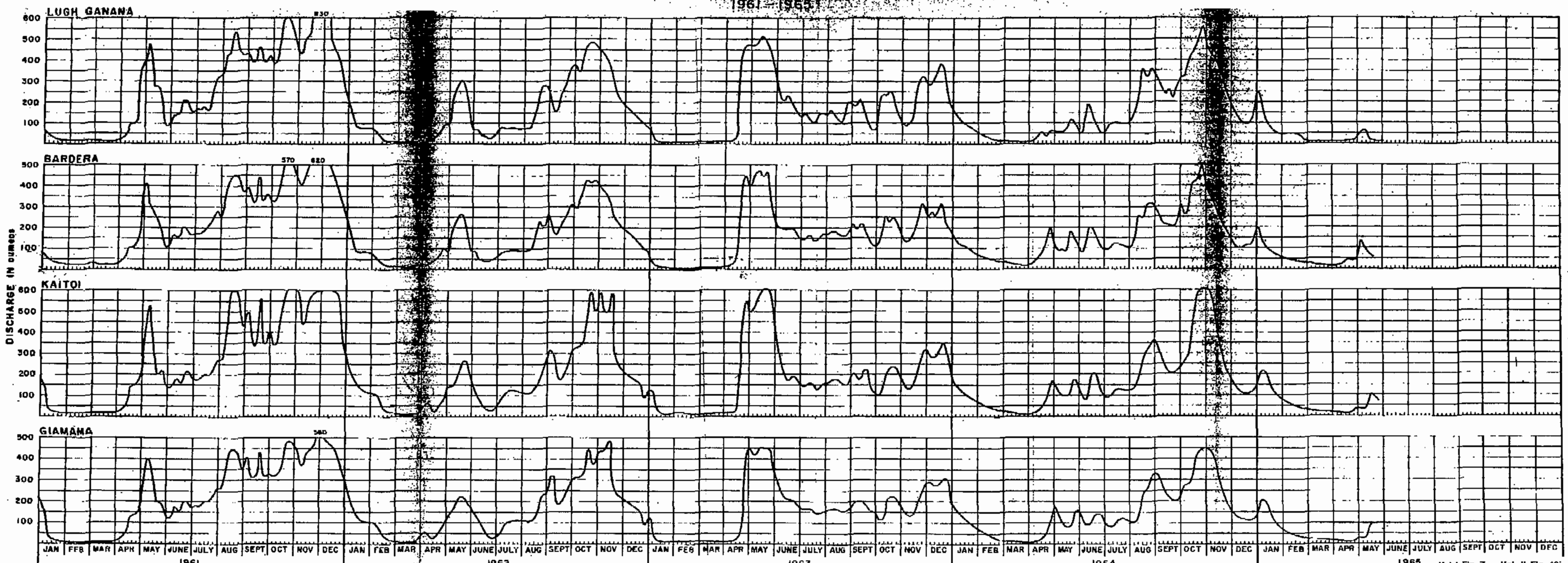
Vol. II Fig. 13h.

HYDROG[illegible]
1951-1955 [illegible]



Vol. II Fig. 13g

HYDROGRAPHS ... 1961 – 1965

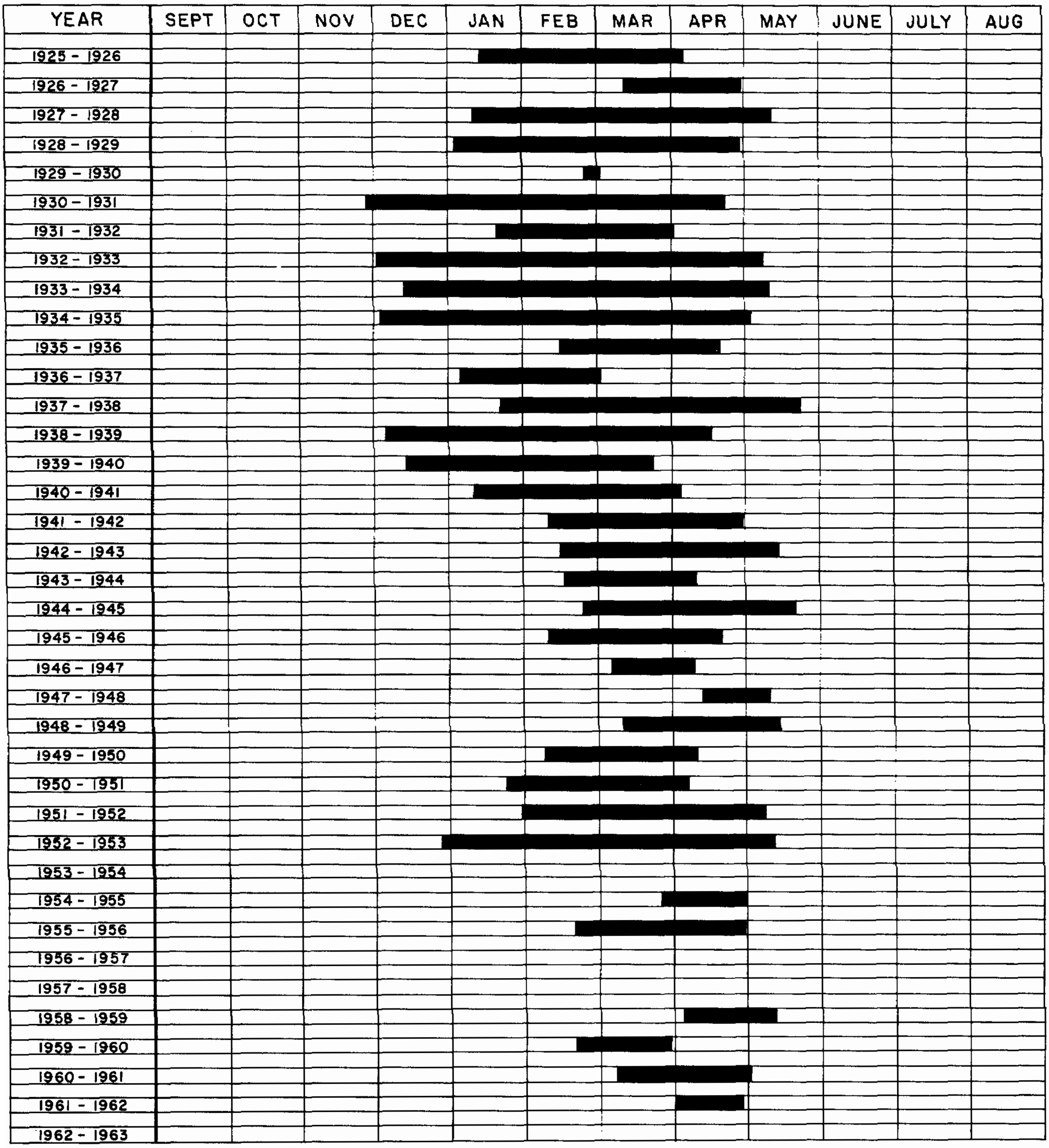


Vol I Fig. 7 – Vol. II Fig. 13i

DIAGRAM SHOWING

LOW-FLOW PERIOD OF THE SHEBELLE RIVER

AT JOHAR



NOTE: LOW-FLOW MEANS BELOW 10 cumecs

Vol. I Fig. 10 — Vol. II Fig. 14

MONTHLY FLOW DIAGRAM (SHEBELLE RIVER)

STATION **MAHADDEI UEN**

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	YEARLY FLOW IN 1000 Ha/m
1965	14.7	4.1	2.0	1.5	12.6	3.8							
1964	9.9	4.4	2.0	6.4	9.5	5.8	8.1	23.9	33.4	34.0	23.0	7.1	167.5
1963	1.7	0.9	0.8	13.1	34.3	24.1	13.8	26.0	33.8	24.9	12.2	21.6	207.2
1962	4.2	0.9	1.0	3.0	13.2	4.0	2.3	7.1	17.6	21.6	32.6	18.6	126.0
1961	3.0	2.9	1.4	2.2	13.4	4.4	11.0	30.5	33.5	34.5	33.6	34.7	205.1
1960	16.6	6.0	3.0	5.4	15.9	9.6	4.9	9.9	20.6				
1959	2.6	1.8	1.5	1.4	19.8	6.1	3.8	18.5	30.0	31.1	26.7	6.2	149.5
1958	2.5	4.0	11.2	5.8	17.0	3.0	3.8	27.0	33.6	34.7	17.9	5.3	165.8
1957	3.6	1.6	4.1	14.0	34.3	26.5	12.5	28.3	31.1	13.1	13.4	10.5	193.0
1956	1.5	0.9	2.6	4.9	31.8	7.4	6.6	24.4	33.0	31.7	31.2	8.1	184.1
1955	1.6	0.7	2.0	2.2	10.3	3.5	0.7	5.4	24.2	33.8	10.3	1.8	96.5
1954	3.0	2.8	3.0	18.8	16.1	6.9	1.1	19.1	33.4	34.7	17.9	9.0	165.8
1952	2.9	1.3	1.4	1.3	20.8	5.8	2.7	6.4	23.0	21.1	10.9	1.2	98.8
1951				31.5	34.6	27.6	5.9	14.7	20.3	12.3	33.6	24.6	

Figures indicate monthly flow in 1000 ha/m. Scale: 1mm = 6000 ha/m. Scale: 1mm = 30,000ha/m

MONTHLY FLOW DIAGRAM (SHEBELLE RIVER)

STATION **BALAD**

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	YEARLY FLOW IN 1000 Ha/m
1965	11.7	2.9	0.8	0.7	11.0	2.3							
1964	8.9	3.3	0.9	4.5	7.0	3.8	6.1	19.0	23.6	24.3	19.0	6.4	126.8
1963	1.5	0.8	0.9	6.3	24.2	18.3	11.5	21.6	23.9	21.7	10.5	20.9	162.1
1962	3.4	0.8	1.0	2.6	11.6	3.6	1.7	6.0	15.3	18.7	23.9	16.0	104.6
1961	2.2	2.1	1.2	1.7	10.5	3.1	9.0	23.6	23.9	24.8	23.9	24.8	150.8
1960	14.5	5.0	2.2	4.3	14.0	8.1	3.9	8.6	18.3				
1959	1.9	1.4	1.2	1.2	15.8	5.0	2.4	16.3	22.4	24.1	20.4	5.0	117.1
1958	1.8	3.2	9.4	3.7	14.7	2.2	2.9	21.7	24.0	24.8	14.6	4.2	127.2
1957	2.6	1.2	3.4	12.0	24.8	21.2	10.7	22.1	23.8	11.3	11.6	8.9	153.6
1956	1.3	1.0	2.0	3.9	23.5	6.8	5.3	22.0	24.0	24.3	22.9	6.6	143.6
1955	1.4	0.8	1.6	1.7	8.8	2.8	0.9	4.6	19.8	24.8	8.8	1.5	77.5
1954	2.2	2.0	2.2	13.7	13.8	5.7	1.0	14.5	24.0	24.8	14.4	8.6	126.9
1952	2.2	1.1	1.2	1.2	17.8	5.4	2.0	5.1	21.6	17.7	9.4	1.1	85.8
1951				23.7	24.8	20.5	5.6	12.6	17.3	11.9	20.0	19.4	

Figures indicate monthly flow in 1000 ha/m. Scale: 1mm = 6000 ha/m. Scale: 1mm = 30,000ha/m

Vol. I Fig. 8b — Vol. II Fig. 15b