3.3 Analysis of Well Water Level

The fluctuation pattern of well water level and river water level are classified as follows. Refer to Fig.-3.2. The water level fluctuation of each well is summarized as shown in Table-3.3. In Fig.-3.3, the typical patterns of water level fluctuation are shown.

<Linked Relationship (Type A)>

Groundwater level fluctuations occur in unison with river water level fluctuations. In cases where the rivers and wells are close, it is thought that they are connected. Observation wells No.9 and No.12 are examples of this case.

<Delayed Relationship (Type B)>

Groundwater level fluctuations occur with a time lag after fluctuations in river water levels. Groundwater levels show gradual increases after increases in river water levels or gradual decreases after decreases in the river water levels. A time lag of 1 month is common for water level highs and lows. Observation wells No.1, 2, 3, 7, 8, 11 and No.18 are examples of this case.

<Preceding Relationship (Type C)>

Groundwater levels decrease, preceding decreases in river water levels. In mountain areas, groundwater levels increase due to the effects of rain, etc., and when decreases in river water levels occur groundwater levels also decrease after a time lag. Observation wells No.5 and No.15 are examples of this case.

<Combined Relationship (Type D)>

Type D1 (A/B combination):

Linkage relationship is indicated when the river water levels are high and a delayed link is indicated when the river water levels are low. When river water levels decrease, there is a delay before the groundwater levels decrease. Observation wells No.4-2 and No.14 are examples of this case.

Type D2 (B/C combination):

Preceding relationship is indicated when the river water levels are high and a delayed linkage relationship is indicated when the river water levels are low. In mountain areas groundwater levels increase quicker than river water levels due to the effects of rain, etc., and compared to the decrease in river water levels, there is a delay in the decrease of groundwater levels. Observation wells No.4-1 and No.6-1 are examples of this case.

<Irregular Relationship (Type E)>

Type E1 (Stable water levels - temporary water level drop):

Groundwater levels are normally stable regardless of river water levels but occasionally show small temporary decreases. Observation well No.6-2 is and example of this case.

Type E2 (Overall decrease trend - temporary increase):

Showing a general decrease in water levels for the period from June, 1990 to September, 1991 but show partial recovery during the rainy season. Observation wells No.16 and No.17 are examples of this case.

Type E3 (Flooded):
Flooded during the rainy season shows a preceding relationship when the river water levels are low. Observation well No.10 is an example of this case.

It is clear that the level of groundwater near the river is closely related with the river water level although there are some types of water level fluctuation according to the topography , geology and permeability of ground. It is clarified that the groundwater recharged with rainfall is flowing into the river because the well water level is higher than the river water level at each observation station. It seems that groundwater development is a promising mean for the development of water resources if the development scale is suitable. More detailed and extensive investigation is required to prepared the development plan of groundwater.

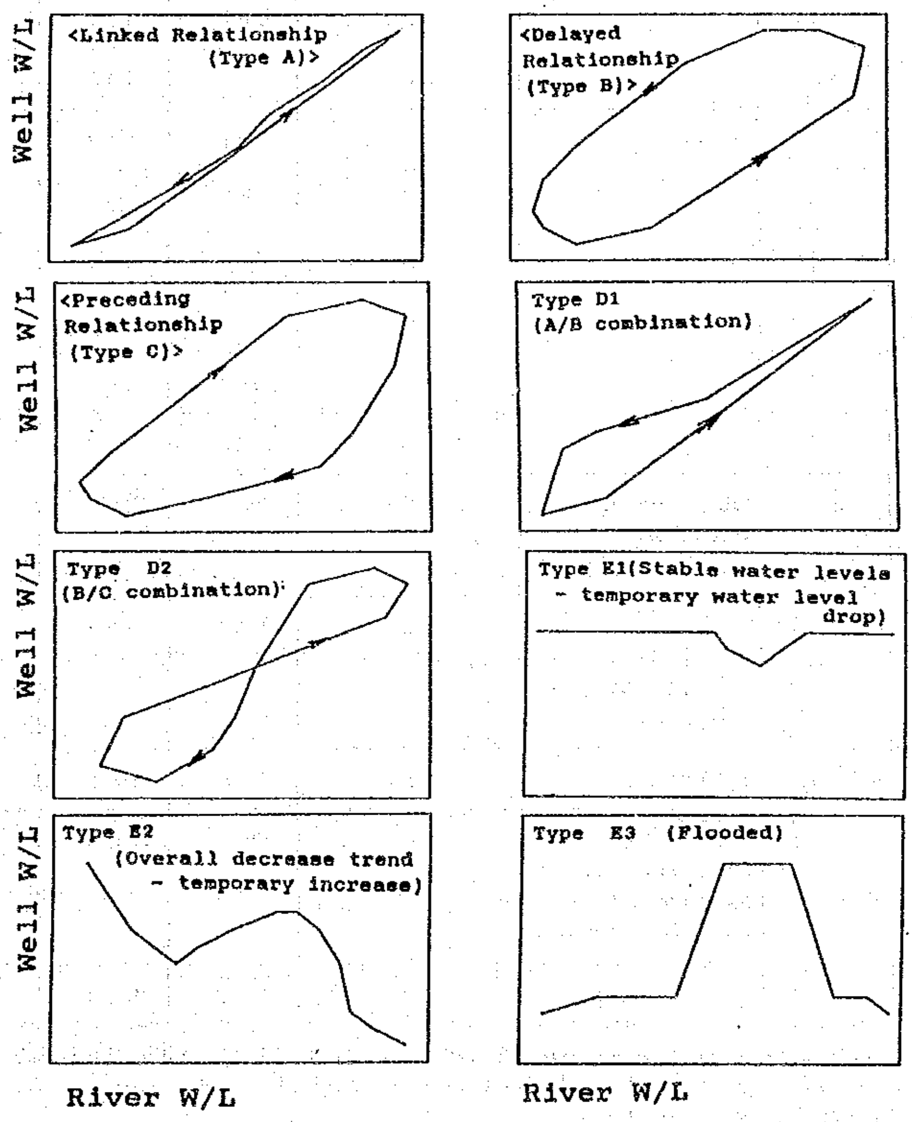
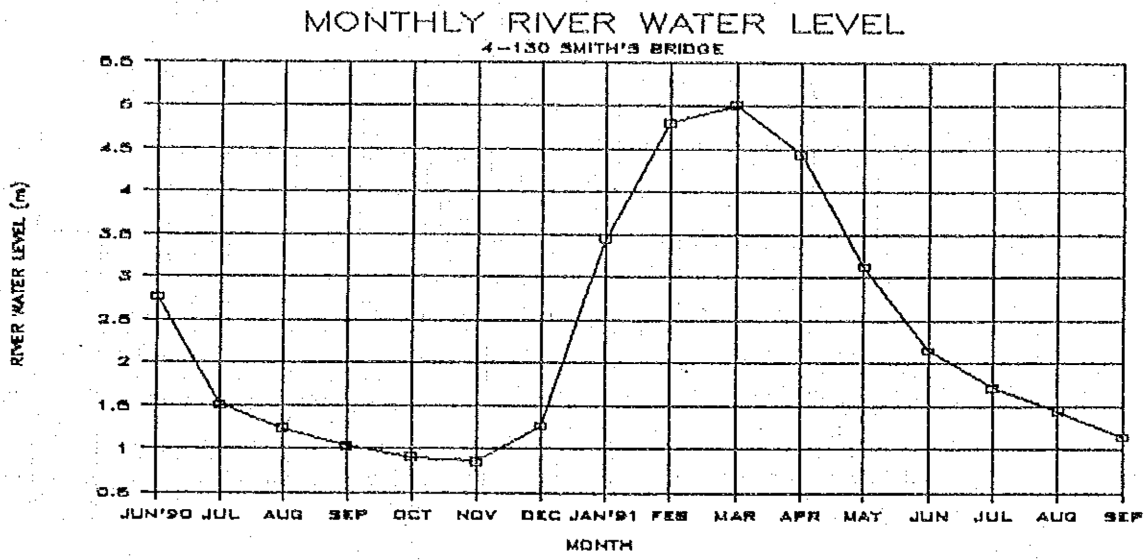


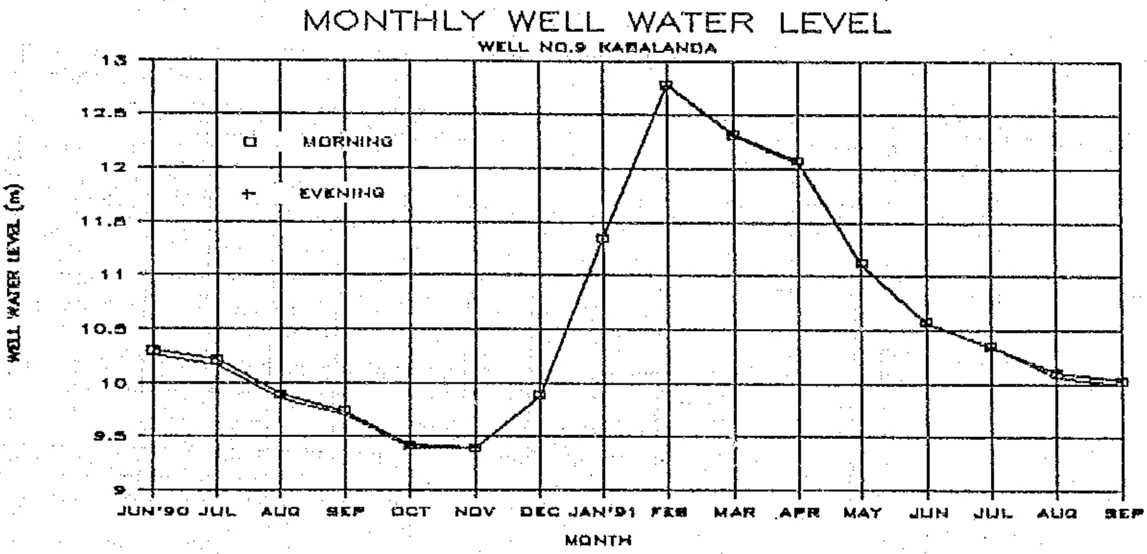
Fig.-3.2 Correlation Pattern between River W/L and Well W/L

Table- 3.3 Well Water Level Fluctuation

Well No.	Dis.*1 (km)	Height (m)*2	Geology	Fluctuation Pattern	Hmax. Month	Hmin. Month	dH *3 (m)
1	8.5	28	Sands of Kalahari Group	B	Mar	Dec	4.5
2	6.0	21		B	Mar	-	-
3	0.8	2	Alluvium	B	Mar	Jan	1.1
4-1	7.0	17	Sands of Kalahari Group	D2	Feb	Nov	1.7
4-2	30	32		D1	Feb	Nov	1.4
5	4.2	11		C	Feb	Nov	0.9
6-1	4.1	14		D2	Feb	Nov	0.65
6-2	20	28		E1	-	Jul	0.4?
7	9.1	41	Alluvium	B	Apr	Nov	2.6
8	0.07	4		B	Feb	Dec	2.7
9	0.54	4		A	Feb	Dec	3.4
10	0.35	1.5		E3	-	Aug	1.1?
11	1.5	4		B	Mar	Dec	3.5
12	30	0		A	Mar	Dec	2.1
14	0.5	32	Weathered Shales of Kandelungu G	D1	Feb	Nov	4.6
15	5.4	2.6	Alluvium and SIlt Stones of Upper Karoo	C	Mar	Nov	1.2
16	6.5	183	Alluvium	E2	Feb	Dec	4 ?
17	1.6	3.5	Wethered Calcsilicate Rocks of Pre-Katenga	E2	Mar	Dec	2 ?
18	0.6	1.9	Alluvials	B	Feb	Dec	0.8

[Note] *1: Distance between well and hydro.St., *2: Height from river bench mark upto well observation point, *3: Max. fluctuation range of well water level





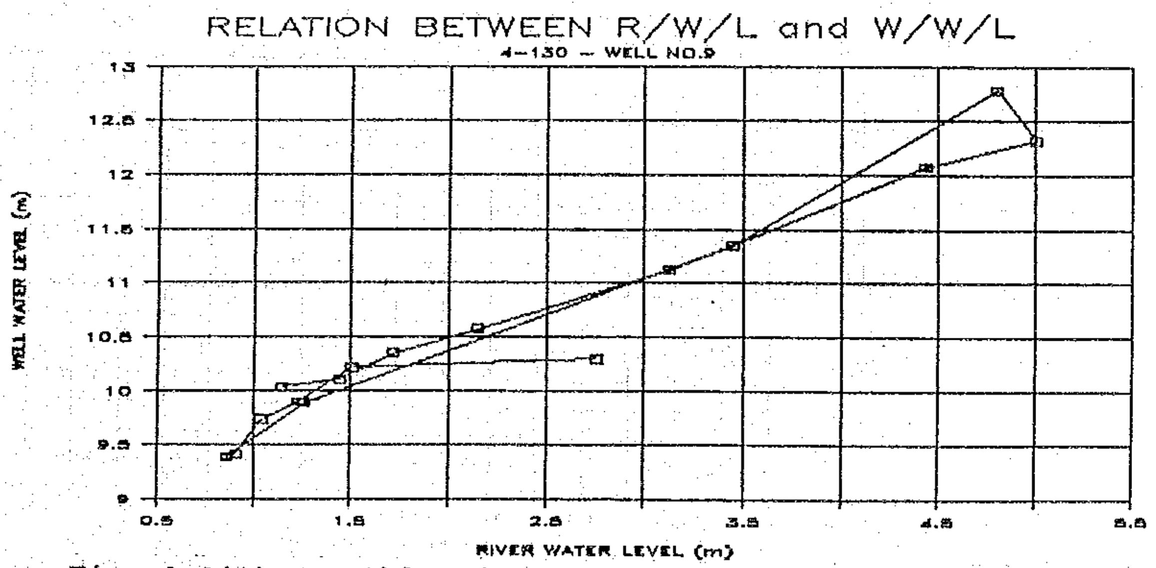


Fig.-3.3(1) Monthly River and Well Water Level Fluctuation (Linked Type A: No.9 Kabalanda)

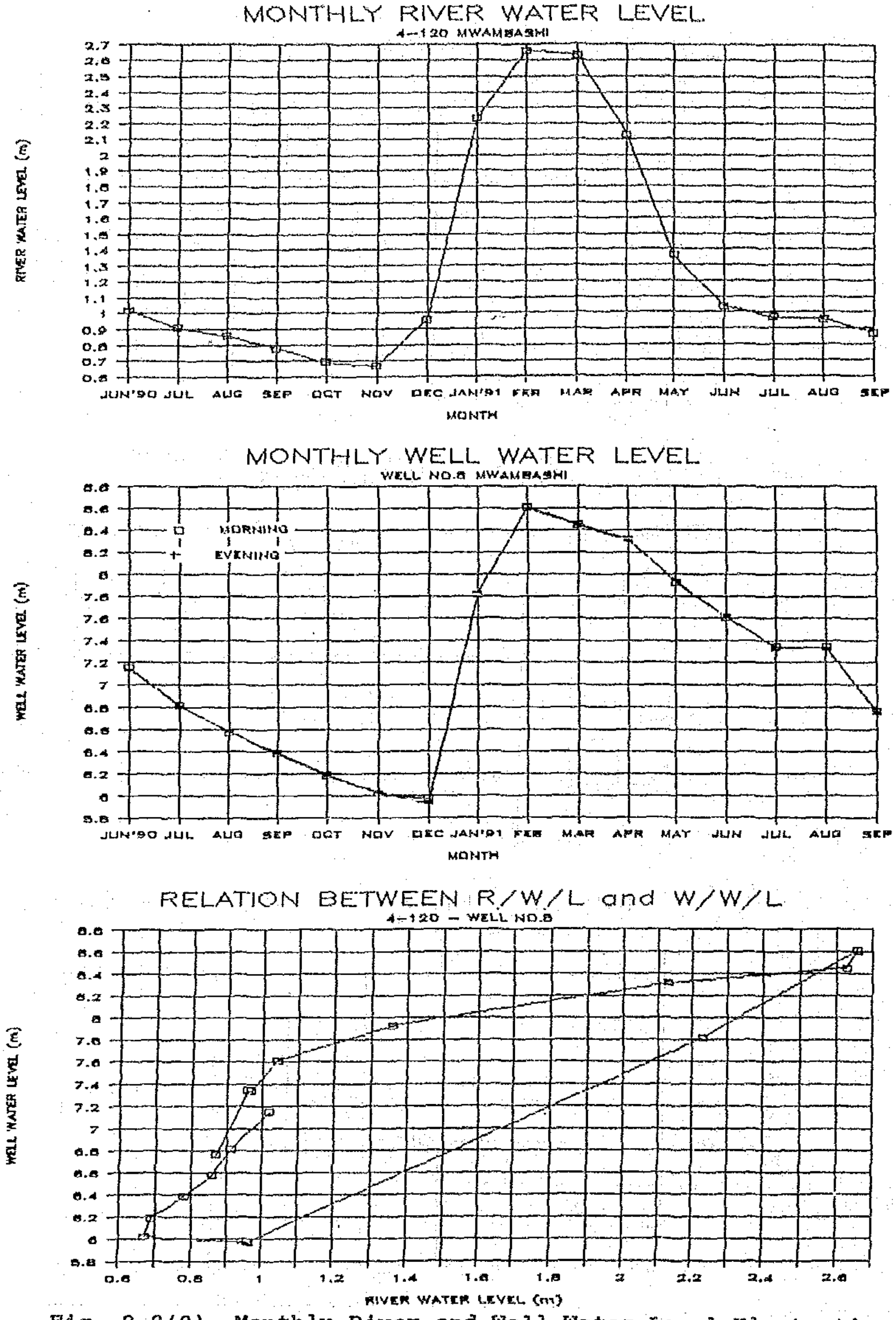
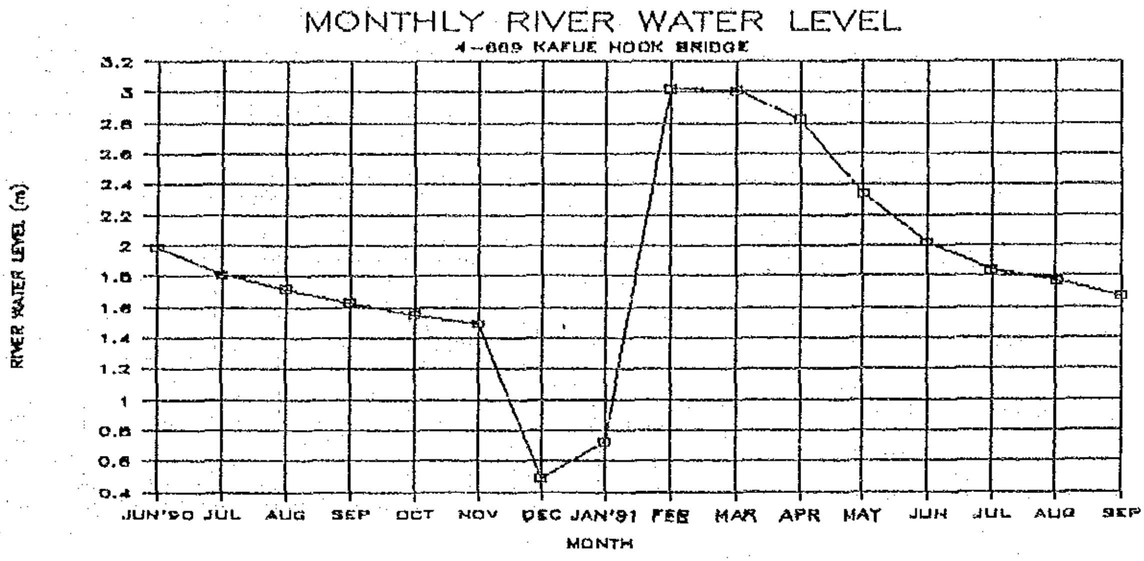
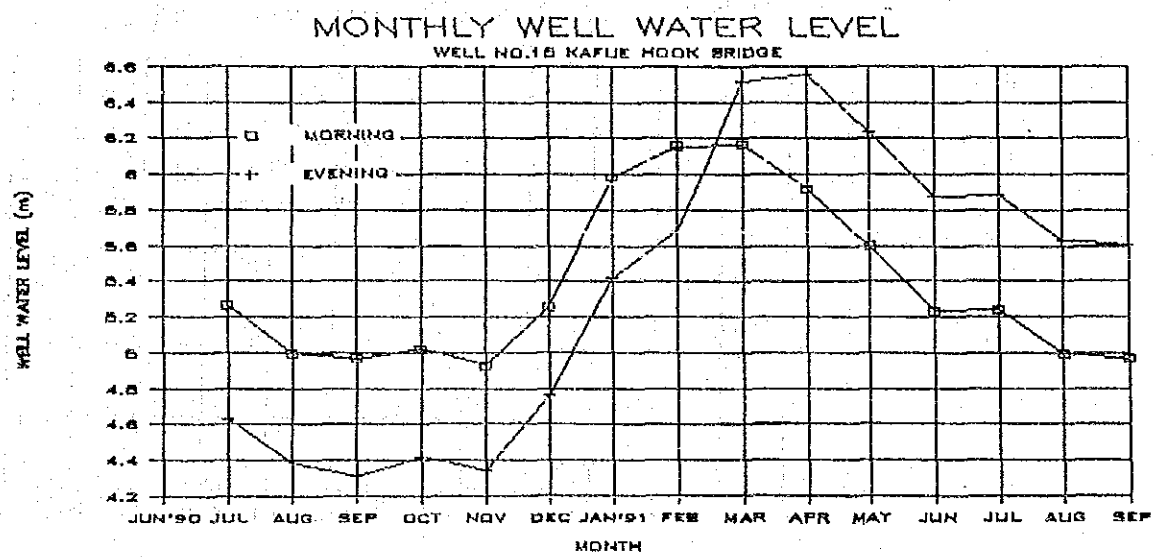


Fig.-3.3(2) Monthly River and Well Water Level Fluctuation (Delayed Type B: No.8 Mwambashi)





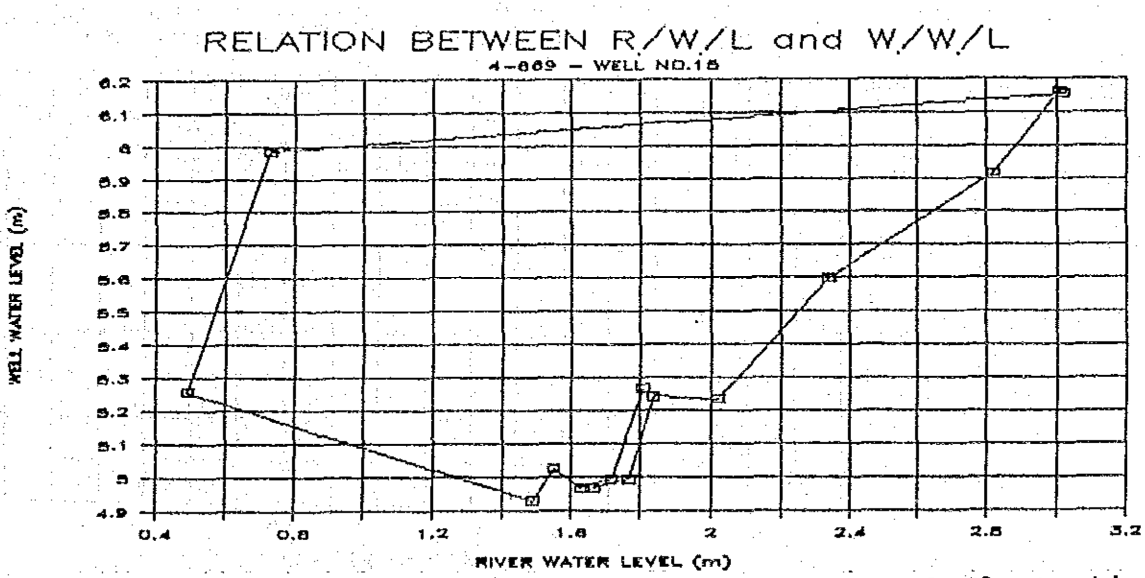


Fig.-3.3(3) Monthly River and Well Water Level Fluctuation
(Preceding Type C: No.15 Kafue Hook Bridge)

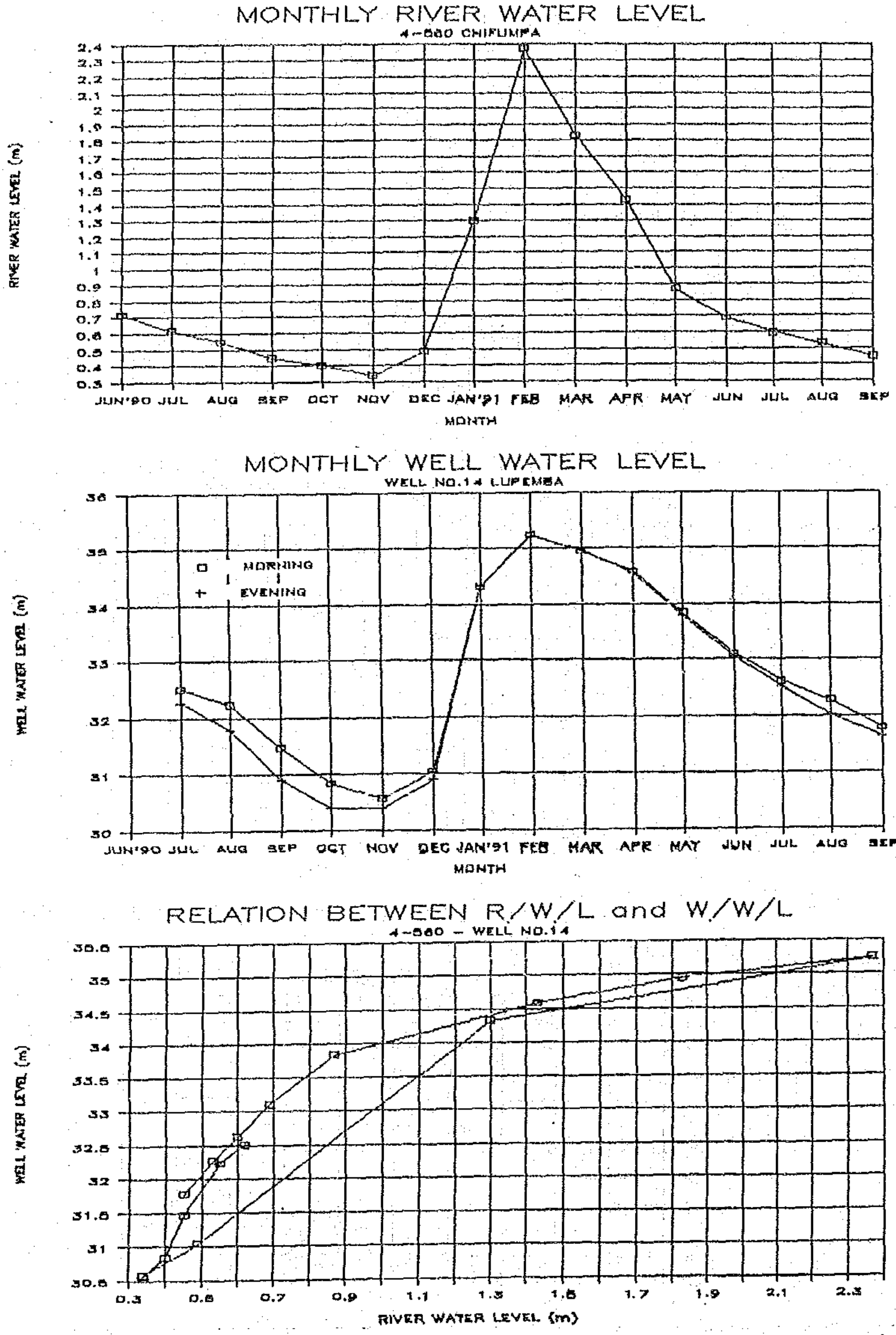
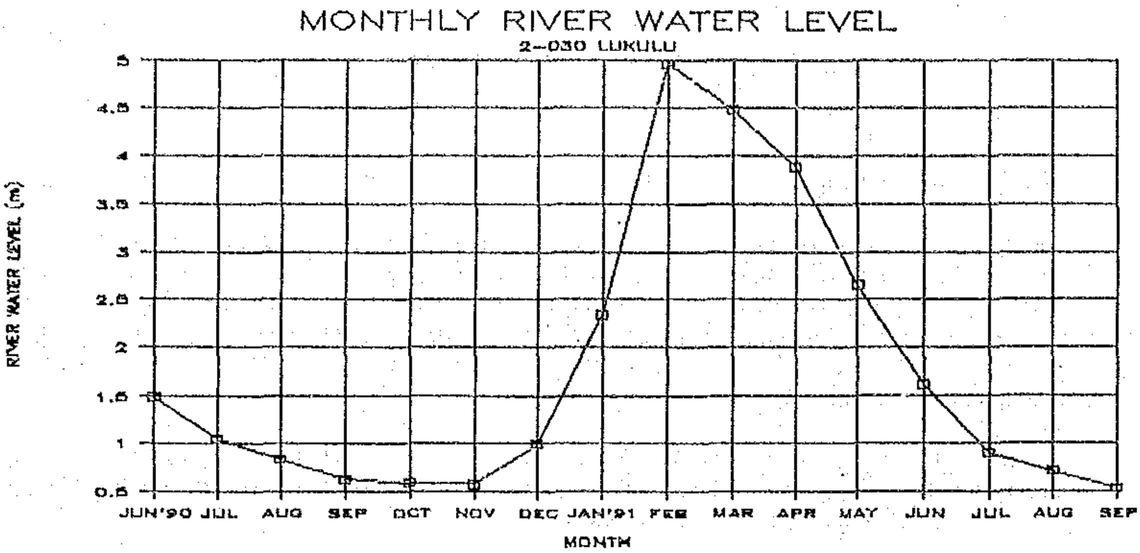
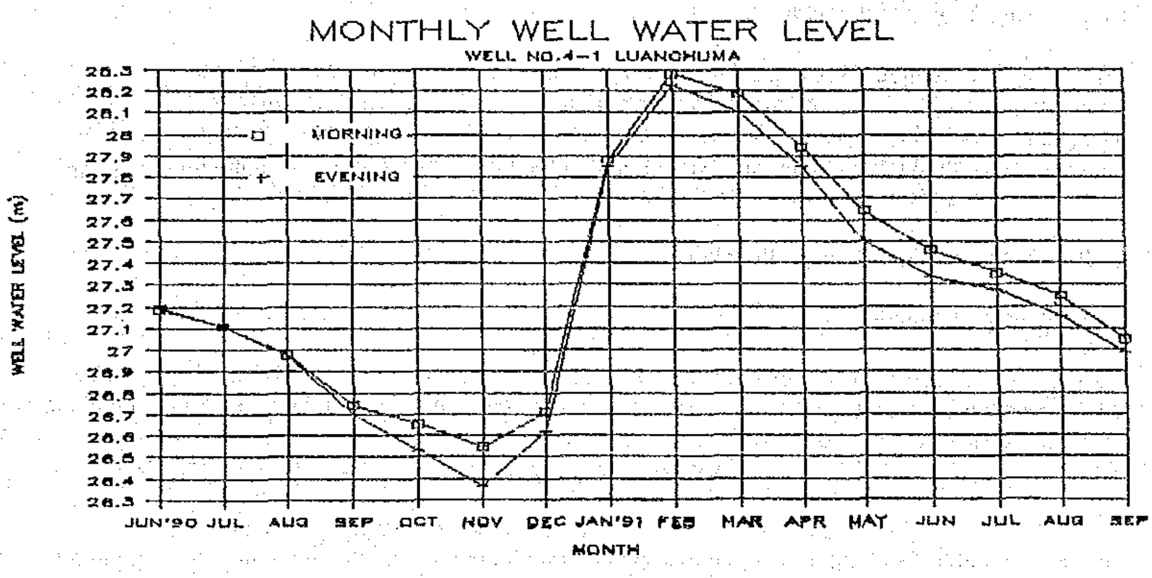


Fig.-3.3(4) Monthly River and Well Water Level Fluctuation
(A/B Combination Type D1: No.14 Lupemba)





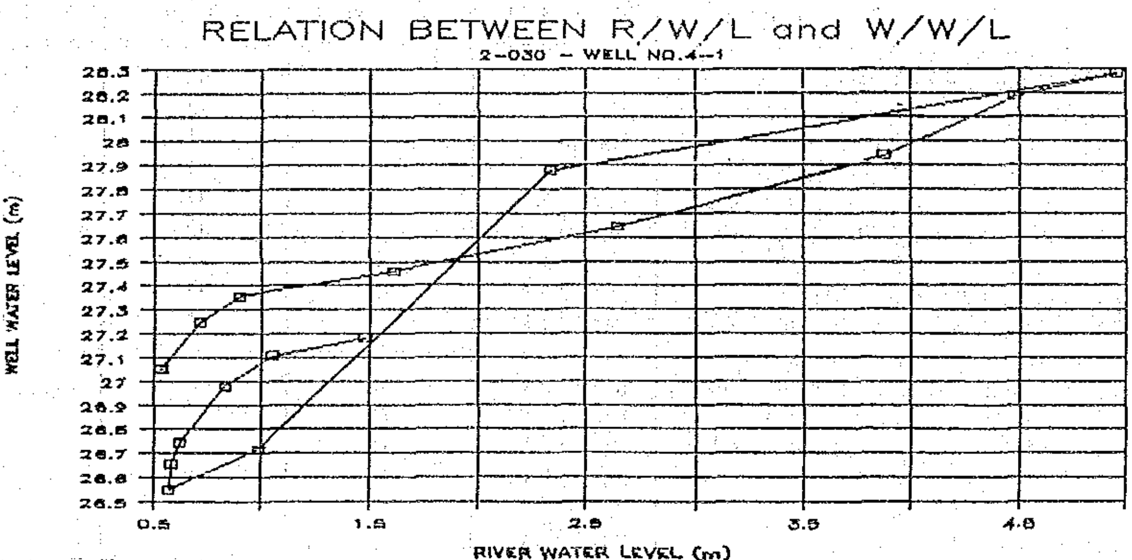


Fig.-3.3(5) Monthly River and Well Water Level Fluctuation
(B/C Combination Type D2: No.4-1 Luanchama)

CHAPTER - 4 WATER QUALITY INVESTIGATION

4.1 Water Sampling

(1) Sampling Time

To generally comprehend the water quality of main streams, the programs for water sampling and testing were executed through the following three seasons. The 1st Program was the original program proposed at the beginning of this Study. However, in response to a request from the Counterpart the 2nd and 3rd Program were additionally formulated.

1) 1st Program: (1990,Jun. and Jul.) in Dry Season
2) 2nd Program: (1990,Dec.,91,Jan & Feb.) in Rainy Season
3) 3rd Program: (1991,Aug. and Sep.) in Dry Season

(2) Sampling Points

The most sampling points are concentrated in Kafue River basin (56 points). The other points are 8 points in Zambezi River main stream basin and 2 points in Luangwa River basin. The total sampling points are 66 points including 13 hydrometric stations. The locations of the points are shown in Fig.-4.1.

4.2 Water Quality Tests

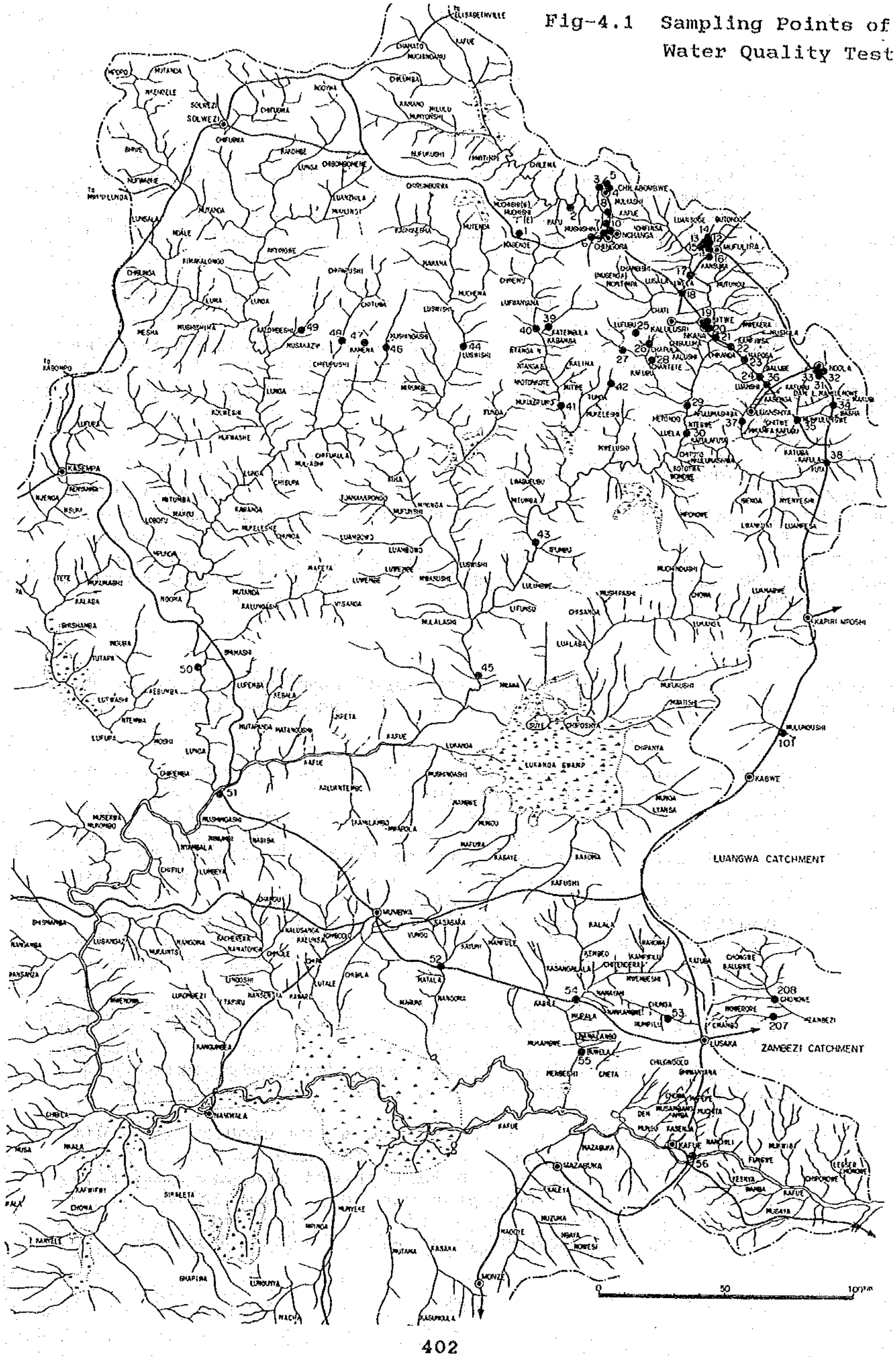
(1) Test Items

General items and special items as shown in Table-4.1 were tested in water quality test programs. Water quality tests for general items were carried out at all the points mentioned above. However, test for special items were made at the selected points.

Table-4.1 Test Items for Water Quality

Test Items	Unit	1st Pgm	2nd Pgm	3rd Pgm
<< General Items >>				
1) Temperature (Temp)	Deg.C	O	O	O
2) Turbidity (Turb)	mg/lit	O	O	O
3) Hydrogen Ion (pH)	-	O	O	O
4) Ele.Conductivity (EC)	mv/cm	O	O	O
5) Dissolved Oxygen (DO)	mg/lit	O	O	O
6) Chloride Ion (Cl-)	mg/lit	O	O	O
7) Copper Ion (Cu2+)	mg/lit	O	O	O
8) Manganese Ion (Mn2+)	mg/lit		O	O
<< Special Items >>				
1) Total Iron (Fe)	mg/lit	O		
2) Total Copper (Cu)	mg/lit	O		
3) Total Manganese (Mn)	mg/lit	O		
4) Arsenic (As)	mg/lit	O		
5) Cadmium (Cd)	mg/lit	O		
6) Lead (Pb)	mg/lit	O		

Fig-4.1 Sampling Points of Water Quality Test



(2) Test Methods

< General Items >

Regarding five (5) items (Temperature, Turbidity, Hydrogen Ion, Electric Conductivity and Dissolved Oxygen), just after sampling, the water samples were measured in the field by the Water Checker (Horiba Co.,Ltd.,Japan). Furthermore, the water samples were measured again in the laboratory to determine changes in the water quality. In the 1st Program, chloride ions and copper ions of the same water sample were analyzed by the Ion Meter (Horiba Co.,Ltd.,Japan). The quantitative limit of the Ion Meter for analyzing both ions is 0.15 mg/lit. In the 2nd and 3rd Program, copper and manganese ions were analyzed by the German-made Photometer (quantitative limit: 0.1 mg/lit). Also in 2nd and 3rd programs, chloride ions were analyzed by the Volumetric Titration Method (quantitative limit: 0.3 mg/lit).

< Special Items >

The water samples were analyzed by a simplified detecting tube ("Yoshitest", Yoshitomi Co., Ltd., Japan). The quantitative limits for total iron, total copper, total manganese and arsenic were 0.5 mg/lit, and for cadmium, 0.1 mg/lit. Because chemical constituents change to insoluble salts, such as hydroxides, after sampling and are suspended in insoluble matter, the water samples were acidified with sulfuric acid before being analyzed.

(3) Test Results

All the test results of water quality are shown in Table-4.2 for general items and 4.3 for special items. The summaries of test results are as follows.

1) A total number of 279 water samples were tested, including 66 tests in the laboratory.
2) The main pollutant source (organic and non-organic) to rivers in the Copperbelt areas is the waste water produced by the mining work and related activities. The contamination caused by this pollutant source was found at some points in these areas.
3) Judging from the test results, the pollution caused at the upper Kafue River does not affect the middle and lower stream due to self purification system of Kafue River.
4) In some tributaries around Lusaka affected by the municipal waste water, there is active overgrowth of plants and algae. The water is contaminated with organic pollution causing the eutrophication at some dead water areas.
5) The water quality of the main streams of Zambezi and Luangwa River is good.
6) The water quality in rainy season shows higher turbidity than that in dry season. On the contrary, chloride ion in rainy season is lower than that in wet season, generally.
7) Ions of copper and manganese etc. are found in the waste water form mining and some points of river water affected by this in the Copperbelt areas. But these ions are not

found in the middle and lower reaches of the Kafue River.

Table-4.2 Test Results of General Items

Test Items	Data Items	1-Pgm	2-Pgm	3-Pgm	Total
Turbidity [Turb] (mg/lit)	Nu.of Sample	109	98	60	267
	Max.	257	399	330	399
	Min.	2	2	1	1
	Average	12	44	24	26
pH value [pH]	Nu.of Sample	120	97	59	276
	Max.	8.6	9.5	8.6	9.5
	Min.	5.9	5.4	6.2	5.4
	Average	7.5	7.9	8.0	7.7
Ele.Conductivity [EC] (mv/cm)	Nu.of Sample	110	97	60	267
	Max.	1.9	2.9	2.0	2.9
	Min.	0.1	0.2	0.2	0.1
	Average	0.9	1.0	0.8	0.9
Dissolved Oxygen [DO] (mg/lit)	Nu.of Sample	111	96	42	249
	Max.	12.3	18.0	10.7	18.0
	Min.	0.7	0.1	0.5	0.1
	Average	7.4	5.2	6.6	6.4
Chloride Ion [Cl-] (mg/lit)	Nu.of Sample	41	93	6	140
	Max.	53.6	18.0	3.0	53.6
	Min.	0.6	0.0	0.6	0.0
	Average	6.4	1.0	2.4	2.7
Copper Ion [Cu2+] (mg/lit)	Nu.of Sample	42	93	60	195
	Max.	6.3	51.0	38.0	28.0
	Min.	0.0	0.0	0.0	0.0
	Average	0.3	0.8	2.4	0.4
Manganese Ion [Mn2+] (mg/lit)	Nu.of Sample	-	93	59	152
	Max.	-	28.0	27.0	28.0
	Min.	-	0.0	0.0	0.0
	Average	-	0.3	0.5	0.4

Table-4.3 Test Results of Special Items (mg/lit)

Basin	No	Points	Date	Fe	Cu	Mn	As	Cd	Pb
Kafue River	2	St. Raglam Farm	90/06/06	-	ND	ND	-	-	ND
	7	Stream	90/06/20	5	45	31	5	ND	2
		(Waste Water)	90/06/20	10	53	32	7	ND	2
	8	Chililabombwe	90/06/20	0.3	1.0	0.4	ND	ND	Tr
		Road Bridge	90/06/20	0.4	1.0	0.6	Tr	ND	Tr
	17	Kafironda	90/06/20	Tr	Tr	ND	ND	ND	ND
	21	Comm.Center Br.	90/06/21	Tr	Tr	ND	ND	ND	ND

[Note] ND : Not Detected, Tr.: Trace

4.3 Consideration on Test Results

(i) Water Quality in Kafue River

< Main Pollutant Source >

There are large-scale stopes and deposit yards of copper ore. plants, business offices and allied offices of the refinery, are widely distributed throughout the Copperbelt Province and the upper reaches of the Kafue River, and they make up towns such as Ndola, Kitwe, Chingola, Chililambwe, Mufulira and Luanshya. These business establishments and towns feed industrial waste water and municipal sewage water into the Kafue River through waterways and small rivers.

The waste water produced by the mining work, the main pollutant source, contains a lot of inorganic matter, The tributary river, feeding the waste water near the Chililambwe Bridge of the Kafue River, is considerably polluted by waste water from Chingola. This is shown in the test results of the water in the dry and rainy seasons sampled at Point-7. Besides a large quantity of copper and manganese, iron and toxic substances such as arsenic and lead can also be detected in the water sample at Point-7. In the water sampled at Point 8, Chililambwe Bridge, the same substances as detected at Point-7 are also detected. Point-8 is located at the downstream of Point-7.

The test results show that river water in rainy season becomes high in turbidity and slightly alkaline. This is because the rain water flushes the suspended solids and mining lime deposits into the rivers.

< Pollution and Self-purification >

Judging from the test results of samples collected at the middle and lower reaches of the Kafue River, the pollution caused at the upper Kafue River never affects the middle and lower stream of Kafue River.

In general, mining waste water contains a large quantity of suspended matter and metallic components, this is because an acidification of waste water will increase the quantity of the dissolved metallic components. The test results show that the water-soluble metallic components are hydrated to hydroxides which become insoluble metal salts and precipitate onto the river bed along with other suspended matter. This occurs because the acidic waste water is artificially neutralized with limestone and the water of Kafue River shows neutral or slightly alkaline. Besides, according to the test results of electric conductivity and chloride concentration, good water from the tributary rivers feeds into the Kafue River resulting in a dilution of the river water which allows the water quality of the Kafue River to improve.

< Organic Pollution >

To examine organic pollution, the dissolved oxygen (DO) and its change were measured instead of measuring such organic water pollution indexes as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). It can be inferred from test results that the extent of the organic pollution in the upper reaches of the Kafue River is not a great problem, although the dissolved oxygen measured at some tributaries (Point-19 and 32) in Kitwe and Ndola municipalities shows low values, and the water of these points is emitting an offensive odor.

The year-round water temperature of the tributary rivers feeding the Kafue River is comparatively high resulting in the increased density of water plants. There are some cases in which the carbon dioxide assimilation of water plants allows the dissolved oxygen concentration and the pH value to increase. Especially at the Ndola Dam, there is active overgrowth of plants and algae in the stagnated water. Judging from these, the eutrophication of the river water is remarkable.

< Countermeasure and Monitoring >

At present , the main stream of the Kafue River can purify itself. However, the metallic components in the waste water will deposit for many years at the bottom of river. Ultimately these deposits might become a source of pollution. If the river water is used for drinking water, it is necessary to take measures to enforce waste water treatment such as neutralization, precipitation and separation. It will also be necessary to monitor the quality of the river water to reduce the pollutant loads before they are fed into the river since the mining waste water contains many kinds of materials restricted by the water quality standard as shown in Table-4.4.

Table-4.4 Water Quality Standard for Materials Contained in Mining Waste Water (Unit: mg/lit)

Standard	Fe	Cu	Mn	As	Cd	Pb
Environmental Quality Standard (Japan; 1970)	-	-	-	0.05	0.01	0.1
Effluent Standard (Japan; 1970)	10	3	10	0.5	0.1	1.0
Water Quality Standard for Drinking Water (Japan; 1970)	0.3	1.0	0.3	0.05	0.01	0.1
Water Quality Guideline for Drinking Water (Zambia; 1986)						
- Permissible Limit -	1.0	1.5	-	0.05	0.1	0.05
- Desirable Limit -	0.3	1.0	-	0.01	0.005	0.01

(2) **Water Quality in Other Rivers**

Some tributaries around Lusaka (point 53 and 54) are affected by the municipal waste water of Lusaka, which contributes to the increase of organic pollution and causes the eutrophication in the dead-water area to become increasingly conspicuous.

The water in the main stream of Luangwa River and Zambezi River, some tributaries of which are only slightly affected by the municipal waste water from Lusaka, seems to be of good quality judging from the results of this investigation.

(3) **Seasonal Variation of Water Quality**

As a general tendency that the tests results revealed , the water quality in rainy season shows higher turbidity and slightly lower electric conductivity than those in dry season. The rain water brings a lot of suspended solids to the rivers. The decrease of electric conductivity is caused by dilution due to rain water. Judging from the higher water temperature and lower dissolved oxygen, it is presumed that the organic materials increase in rainy season. Fig.-4.2 shows the seasonal variation of water quality at the main points along the main stream of the Kafue River. At all points the values of turbidity in rainy season are higher than those in dry season. This tendency is appeared at almost all test points.

The direct pollutant loads from the process waste water of the mining activities are generally constant through the year unless the activities change. However, in rainy season the indirect pollutant loads from mining stopes, deposits, yards etc. are brought to rivers with rain water. The higher turbidity in rainy season is testified by this fact.

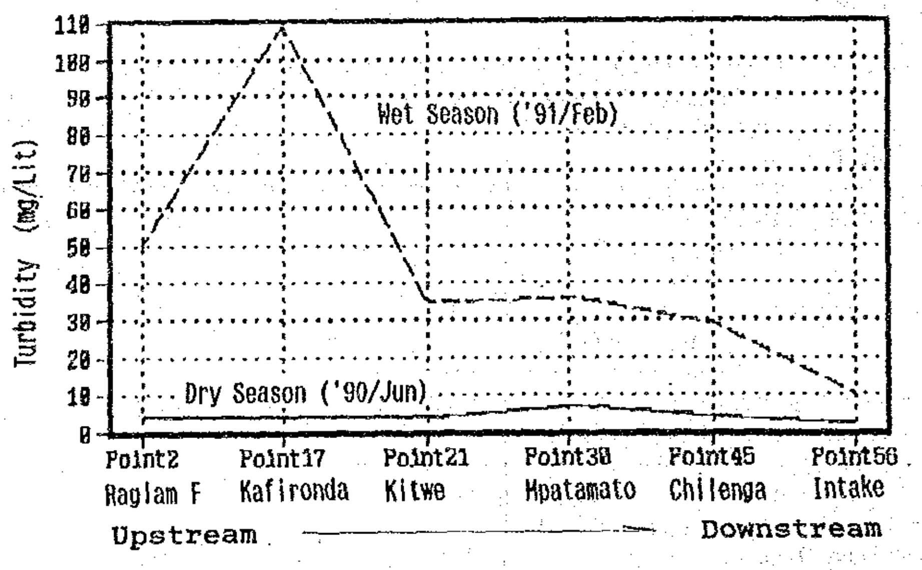


Fig.-4.2 Variation of Turbidity along Kafue River

CHAPTER - 5 HYDROLOGIC ANALYSIS

5.1 Hydrologic Database

All the hydrologic observation data dealt with in the Study was filed and analyzed with use of the computer database systems. In this Study, 12 computer systems were developed as shown in Table-5.1. See Fig.-5.1. These systems run using Lotus 123 software.

Table-5.1 Hydrologic Database System

No.	Application	Input to System	Output from System
DB-01	Compilation of Flow Meas.Data	Measurement Data by Measurement	Discharge Mean Discharge
DB-02	Filing of Flow Meas. Data	Measurement Data by Station	List of Flow Measurement Data
DB-03	Rating Curve (Type-1)	C/Sec., W/S/Slope Manning Roughness	Discharge Rating Curve
DB-04	Rating Curve (Type-2)	Measured Discharge and Water Level	Discharge Rating Curve
DB-05	Daily R/W/L and Discharge	Daily R/W/L and Rating Curve	Table of R/W/Level and Discharge
DB-06	Hourly R/W/L and Discharge	Hourly R/W/Level and Rating Curve	Table of R/W/Level and Discharge
DB-07	Discharge Correlation	Discharge of Two Stations	Correlation Curve
DB-08	Flow Regime of Station	Daily Discharge in One Year	Table of Flow Regime
DB-09	River Flow Analysis	Daily, Monthly or Annual Discharge	Table of River Flow
DB-10	Reservoir Water Balance	W/L, Outflow Evp, H-A-V Curve	Table of Reservoir Water Balance
DB-11	Daily Well Water Level	Daily Well Water Level	Table of Daily Well Water Level
DB-12	Correlation between W/W/L & R/W/L	Well Water Level River Water Level	Correlation btw Well/W/Level and River/W/Level

[Note] W/W/L: Well Water level, R/W/L: River Water Level
C/Sec: Cross Section, W/S/Slope: Water Surface Slope
H-A-V Curve: Water Level - Reservoir Area - Storage Volume curve

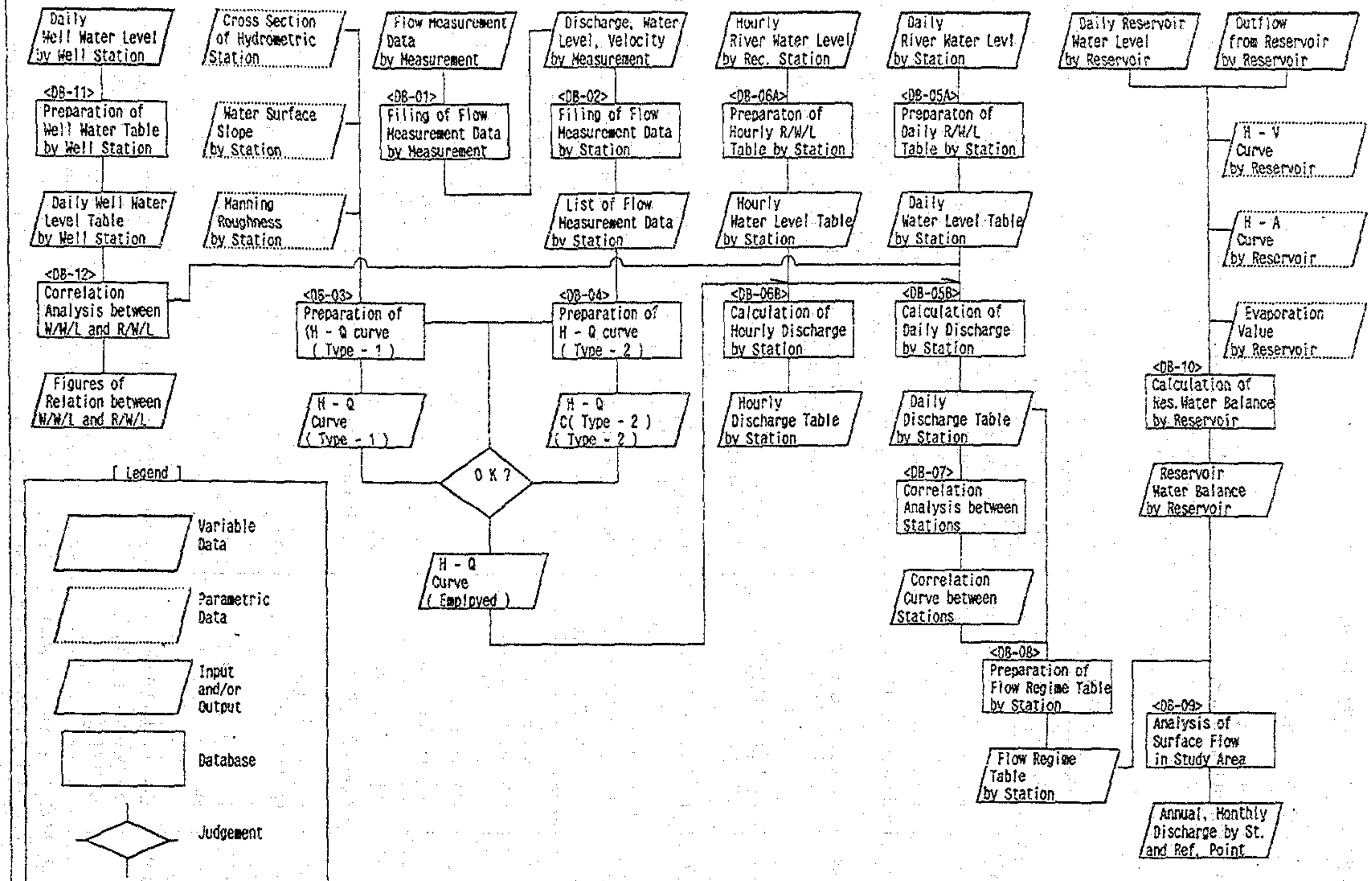


Fig.-5.1 Hydrologic Database System

5.2 Discharge Rating Curve

The discharge rating curves of the selected 19 stations for the Study were prepared as shown in Table-5.2. Refer to Fig.-5.9.

Table-5.2 Discharge Rating Curve

No.	Hydrometric Station	Discharge Rating Curve
1	1-150 Zambezi P/H	Q=25.626*(H+1.085)^2
2	1-650 Kabompo Boma	Q=66.342*(H-0.715)^2
3	1-950 Watopa Pontoon	Q=29.791*(H-0.262)^2
4	2-030 Lukulu	Q=28.448*(H+2.567)^2
5	2-250 Kalabo	Q= 7.404*(H+0.654)^2 H < 3.179m Q=132.763*(H-2.270)^2 H >= 3.179m
6	2-400 Senanga	Q=50.805*(H+1.747)^2
7	4-050 Raglam Farm	Q= 5.677*(H+0.167)^2
8	4-120 Mwambashi	Q= 1.933*(H-0.008)^2 H < 2.732m Q= 5.837*(H-1.222)^2 H >= 2.732m
9	4-130 Smith's Bridge	Q= 6.078*(H+0.184)^2
10	4-200 Mpatamato	Q= 7.269*(H+0.676)^2
11	4-280 Machiya Ferry	Q=10.964*(H-1.012)^2
12	4-350 Chilenga	Q= 8.771*(H+0.439)^2 H < 5.134m Q=40.036*(H-2.525)^2 H >= 5.134m
13	4-450 Lubungu	Q=31.695*(H-0.476)^2
14	4-560 Chifumpa Pont.	Q=25.326*(H+0.562)^2
15	4-669 Kafue Hook B.	Q=110.511*(H-0.937)^2
16	4-941 Kaleya Dam S.	Q= 1.780*(H-0.115)^2 H < 4.663m Q=32.948*(H-3.603)^2 H >= 4.663m
17	4-958 Uruaff Farm	Q= 8.421*(H-0.009)^2
18	5-030 Exchange Farm	Q= 1.684*(H+0.084)^2 H < 0.720m Q= 9.681*(H-0.386)^2 0.72m<=H<1.64m Q=21.059*(H-0.729)^2 H >= 1.640m
19	5-940 Luangwa Bridge	Q=60.157*(H-1.003)^2

5.3 Reservoir Water Balance

To comprehend the factors of reservoir water balance, the simulation of reservoir water balance was done regarding the existing three (3) main dams: 1) Itezhi-tezhi Dam 2) Kafue Gorge Dam 3) Kariba Dam. The simulation results of reservoir water balance for 3 main dams are shown in Table-5.3. Refer to Fig.-5.2.

Table-5.3 Summary of Reservoir Water Balance

Items		Itezhitezhi	Kafue Gorge	Kariba
Simulation Period		12ys(1980-91)	12ys(1980-91)	29ys(1963-91)
<Inflow>	(m3/s)	261.2 (100%)	282.1 (100%)	1,620 (100%)
	(mcm)	8,237	8,896	51,088
<Outflow>	(m3/s)	247.6 (95%)	252.7 (90%)	1,340 (83%)
	(mcm)	7,808	7,969	42,258
+ Water Power	(m3/s)	-	155.7 (55%)	789 (49%)
+ Spillway	(m3/s)	247.6 (95%)	97.0 (35%)	551 (34%)
<Evaporation>	(m3/s)	17.0 (6%)	28.9 (10%)	279 (17%)
	(mm/d)	4.5	5.1	4.7
<Change of Vol>	(m3/s)	-3.4 (-1%)	0.4 (0.2%)	0.7(0.04%)

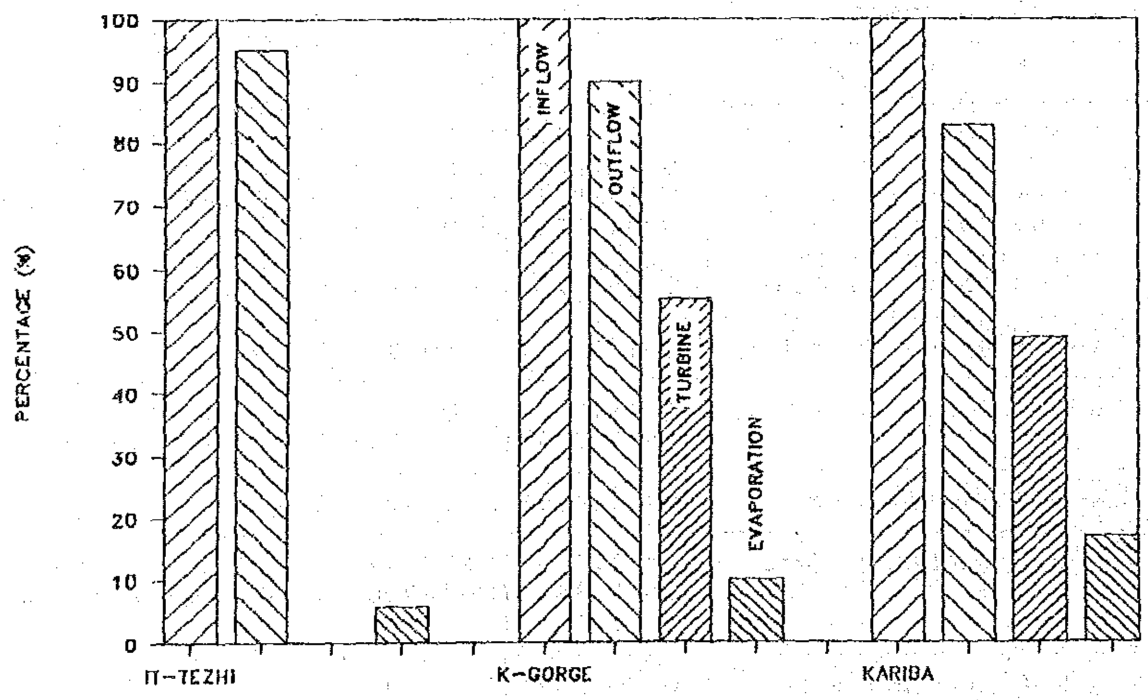
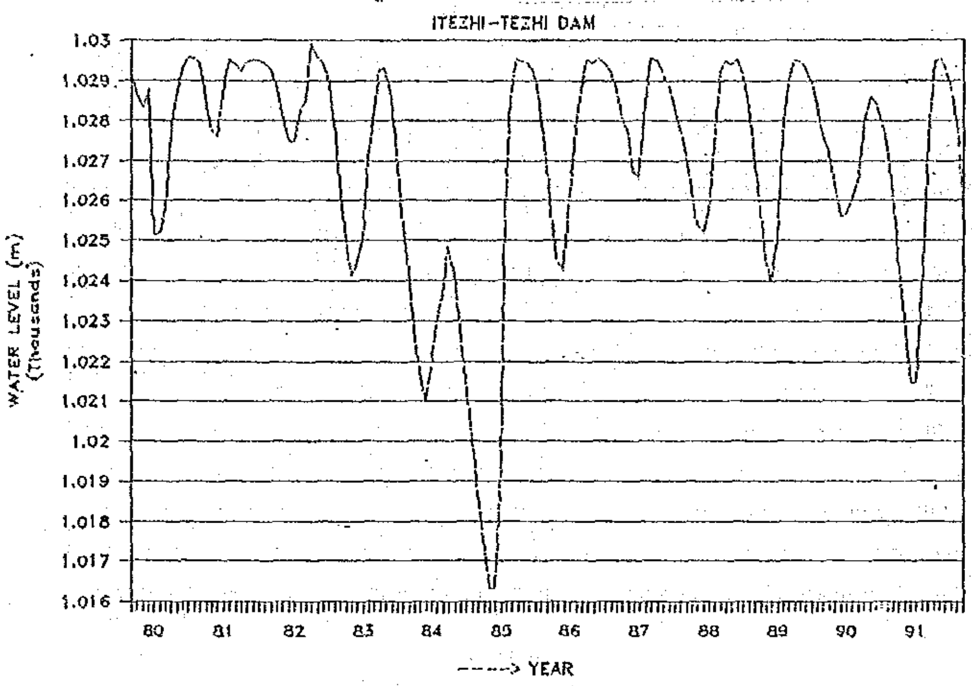


Fig. -5.2 Summary of Reservoir Water Balance

(1) Itezhi-tezhi Dam

The reservoir water balance of Itezhi-tezhi Dam is as shown in Fig.-5.3.

<Monthly Reservoir Water Level>



<Annual Inflow, Outflow and Evaporation>

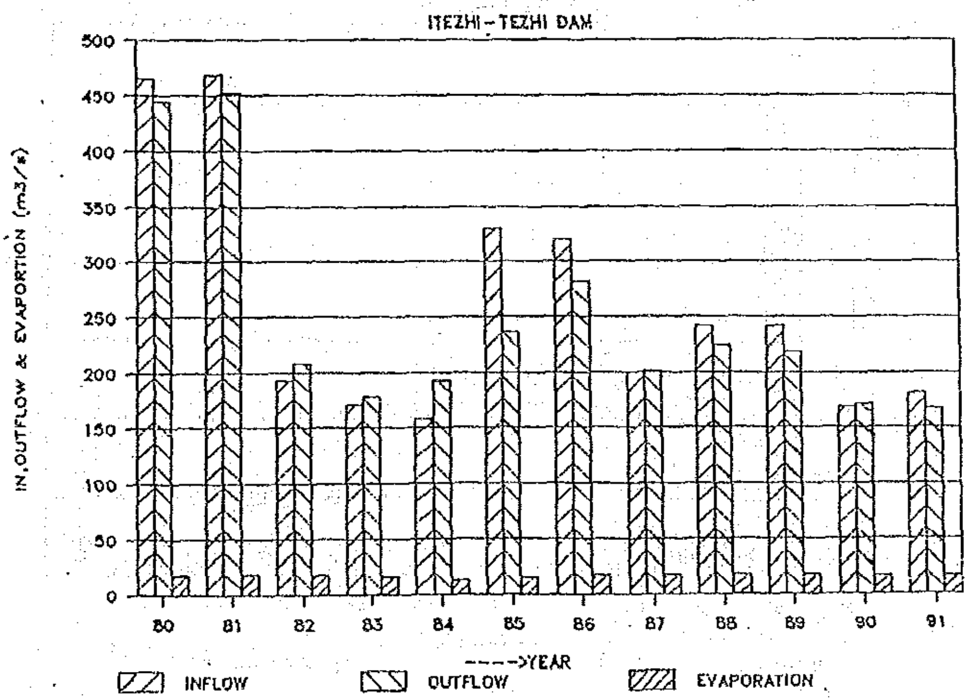
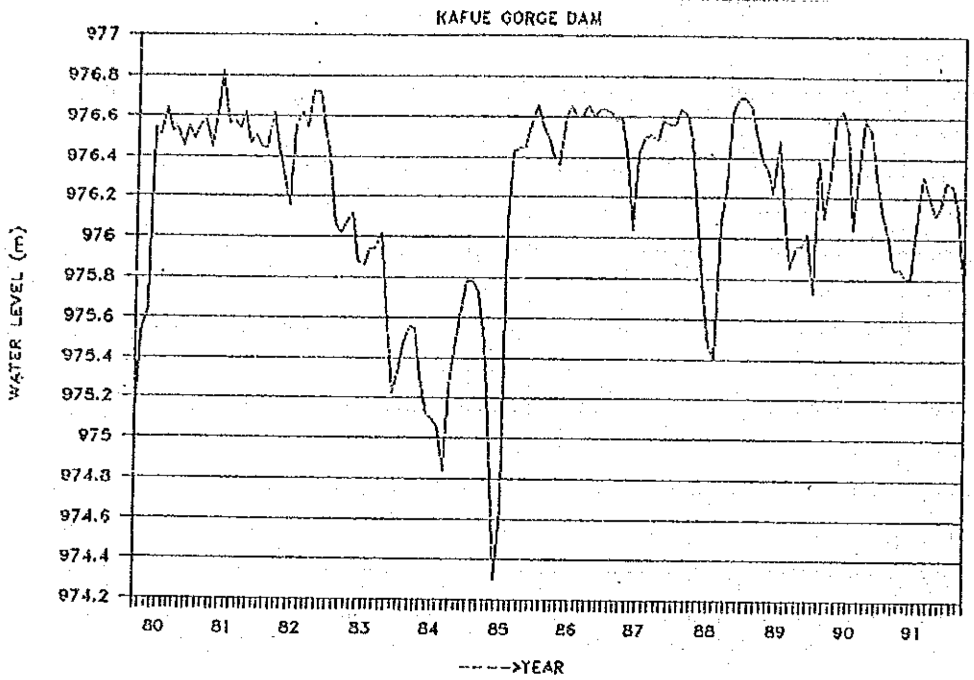


Fig.-5.3 Reservoir Water Balance of Itezhi-tezhi Dam

(2) Kafue Gorge Dam

The reservoir water balance of Kafue Gorge Dam is as shown in Fig.-5.4.

<Monthly Reservoir Water Level>



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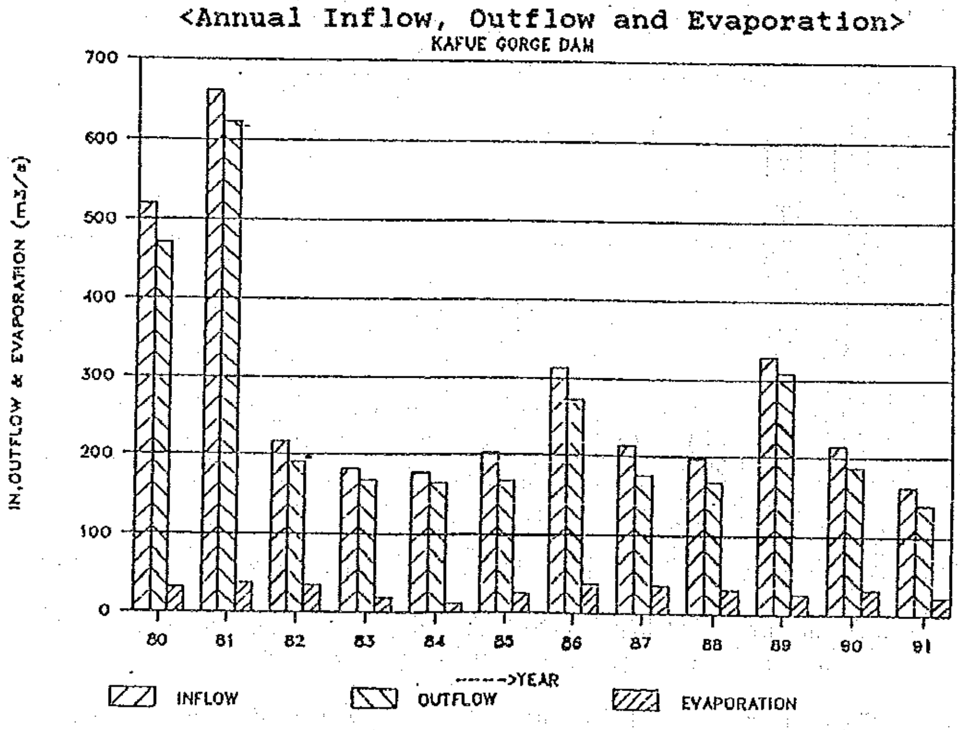
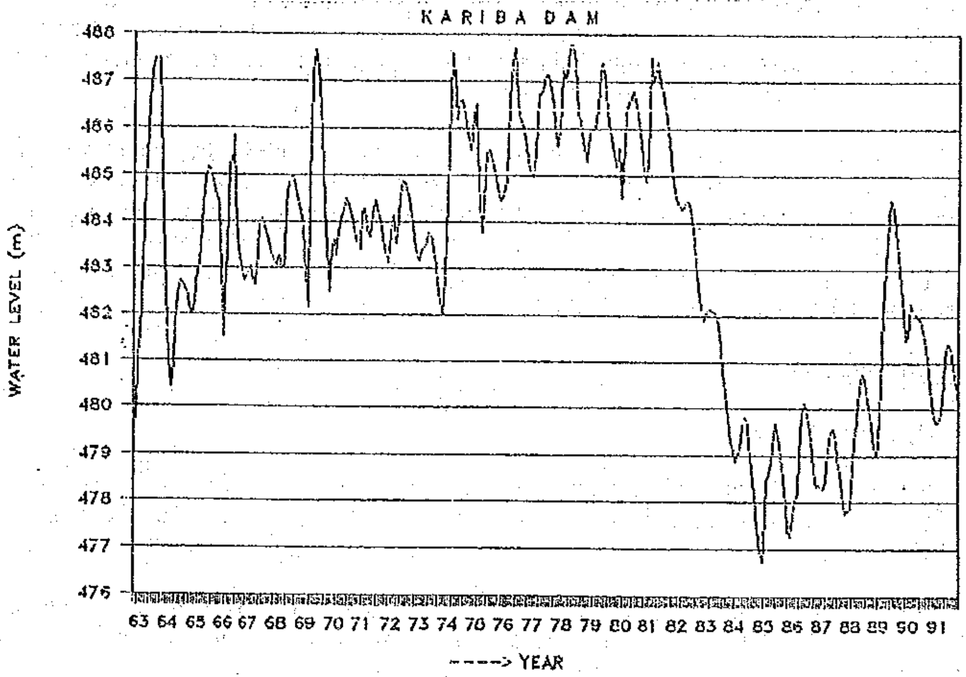


Fig.-5.4 Reservoir Water Balance of Kafue Gorge Dam

(3) Kariba Dam

The reservoir water balance of Kariba Dam is as shown in Fig.-5.5.

<Monthly Reservoir Water Level>



<Annual Inflow, Outflow and Evaporation>

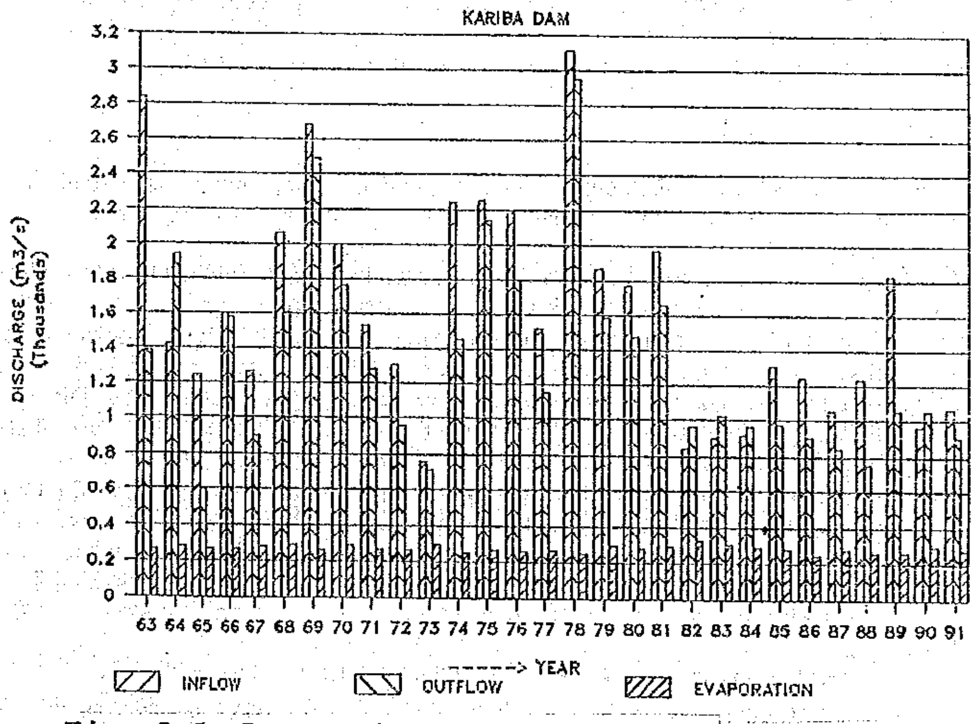


Fig.-5.5 Reservoir Water Balance of Kariba Dam

5.4 River Flow Analysis

(1) Division of Area

The simulation of river flow was done using the Database DB-09 developed in the Study. The area for simulation is divided into 34 units (Zambezi River :17 units, Kafue River: 15 units, Luangwa River 2 units) to analyze the river flow balance. 45 points are set to obtain discharge. Refer to Fig.-5.6.

The whole area is divided into the two areas. This division was made due to the data availability of each area. The Upper Area has some hydrometric stations and long-term data for more than 30 years. While the Lower Area has no working hydrometric station but three (3) operating dams. The common data to each dam's operation is available from 1979.

(2) Simulation Model

< Model for Upper Area >

For Upper Area : (Zambezi River : point 1 -16, Kafue River : point 21 - 35 and Luangwa River : point 43-44), the simulation is done as follows:

1) The discharge at hydrometric station is obtained through Database DB-05 on the basis of the observed water level and the discharge rating curve.
2) The discharge at the other point is calculated in proportion to the catchment area considering the values of discharge at both the hydrometric stations in upper and lower reaches.
3) Simulation period : 32 years (1959/60 - 1990/91)

< Model for Lower Area >

For Lower Area : (Zambezi River : point 17 - 20, 41 - 42 and 45, Kafue River : point 36 - 40), simulation is done as follows:

1) The input discharge to the reservoir and output discharge from the reservoir are obtained from the reservoir simulation results through Database DB-10. The extraction from the reservoir (evaporation etc.) and variation of storage volume are also obtained through Database DB-10.
2) The discharge at Livingstone (point 17) observed by ZRA is employed as the Livingstone discharge Q(17).
3) From the difference between Livingstone discharge Q(17) and Kariba dam inflow Q(18) obtained through the simulation, the specific discharge q(m3/s/km2) of unit area AZ-15 is obtained. This specific discharge is applied to the calculation of discharge from unit area AZ-16, AZ-17 and AK-15.
4) Simulation period : 12 years (1979/80 - 1990/91).
   For this period, a set of reservoir operation data of the main 3 dams is available.

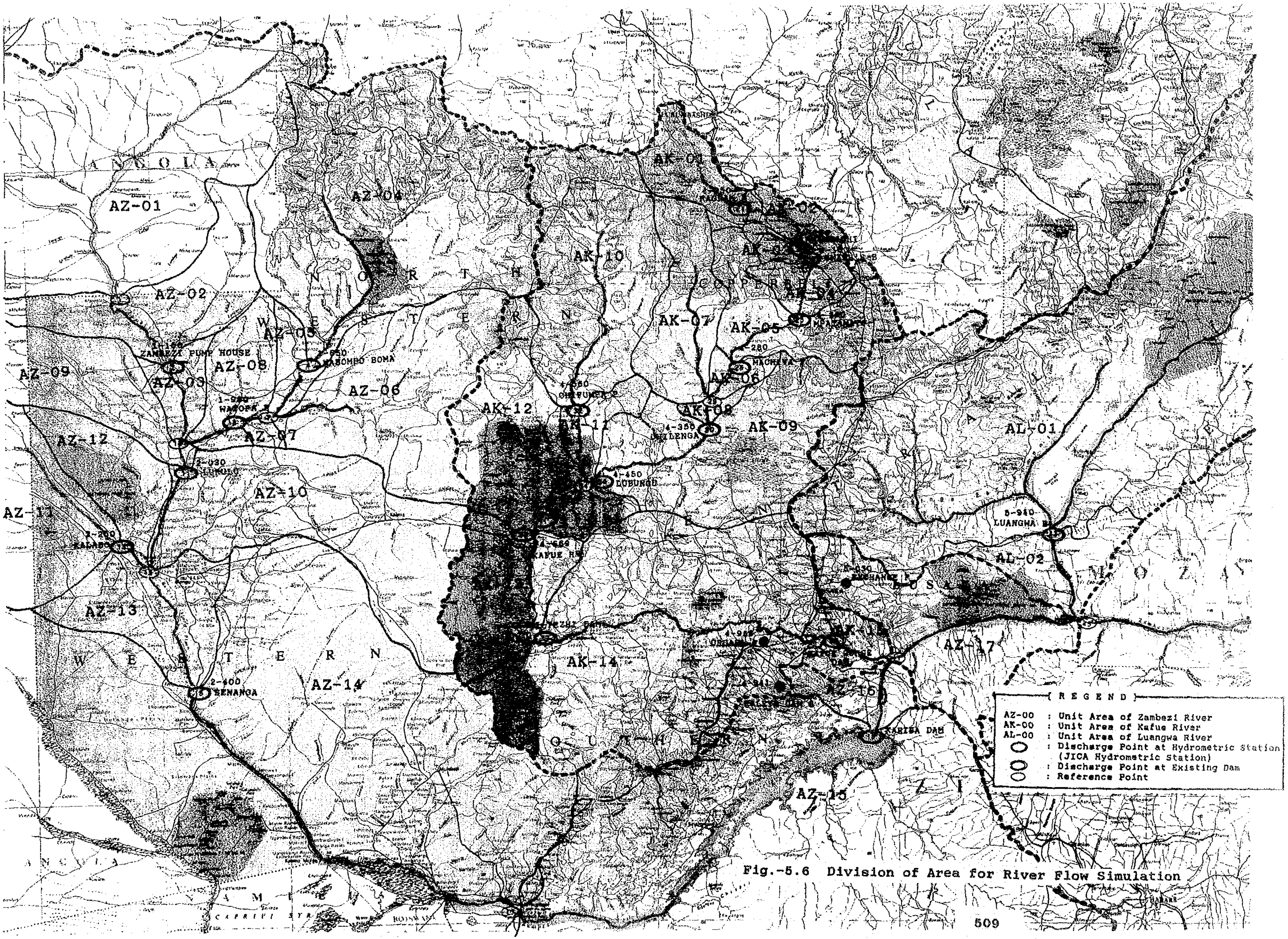


Fig.-5.6 Division of Area for River Flow Simulation

(3) Simulation Results

The river flow of the upper area for 32 years (1959/60 - 1990/91) is as shown in Fig.-5.7. The river flow of the whole area for the last 12 years (1979/80 - 1990/91) is as shown in Fig.-5.8.

5.5 Characteristics of River Flow

(1) Annual Discharge and Monthly Discharge

The characteristics of discharge at each hydrometric stations are as shown in Table-5.4 and Fig.-5.9.

Table-5.4 Characteristics of Discharge

Station	Annual (m3/s)			Daily Discharge (m3/s)					
.	Mean	Max.	Min	Max.	Min.	High	Normal	Low	Drought
1-150	693	1301	278	5106	21	978	258	121	77
1-650	219	451	109	1703	17	290	151	99	61
1-950	264	597	120	2582	36	355	155	105	74
2-030	808	1125	514	2943	197	1102	543	385	315
2-250	74	175	13	881	3	104	34	13	9
2-400	986	1433	637	3500	261	1459	722	444	337
4-050	37	80	10	333	0.2	56	17	7	3
4-120	7.8	15.2	3.4	177	0.6	10.8	4.4	2.5	1.2
4-130	79	142	31	531	3	124	50	23	11
4-200	98	178	35	562	7	149	56	28	15
4-280	145	298	47	889	5	221	76	39	21
4-350	189	396	59	1164	8	297	98	47	25
4-450	199	414	62	1230	5	324	109	54	28
4-560	99	245	26	1642	12	142	70	42	24
4-669	336	832	128	2811	28	480	187	108	67
4-941	0.24	0.43	0.09	15	0.00	0.21	0.18	0.14	0.01
4-958	0.31	0.85	0.00	103	0.00	0.16	0.10	0.08	0.00
5-030	0.22	0.72	0.05	21	0.00	0.15	0.07	0.04	0.02
5-940	626	1505	301	7754	11	863	206	82	37

[Note] Period of Discharge Data: 32 years (1959/60 - 1990/91)
High Discharge : 95th discharge from the greatest
Normal Discharge : 185th discharge from the greatest
Low Discharge : 275th discharge from the greatest
Drought Discharge: 355th discharge from the greatest

Fig.-5.7 River Flow of Upper Area

Period : 32 years (1959/60 - 1990/91)

<<< Annual Mean Discharge >>>

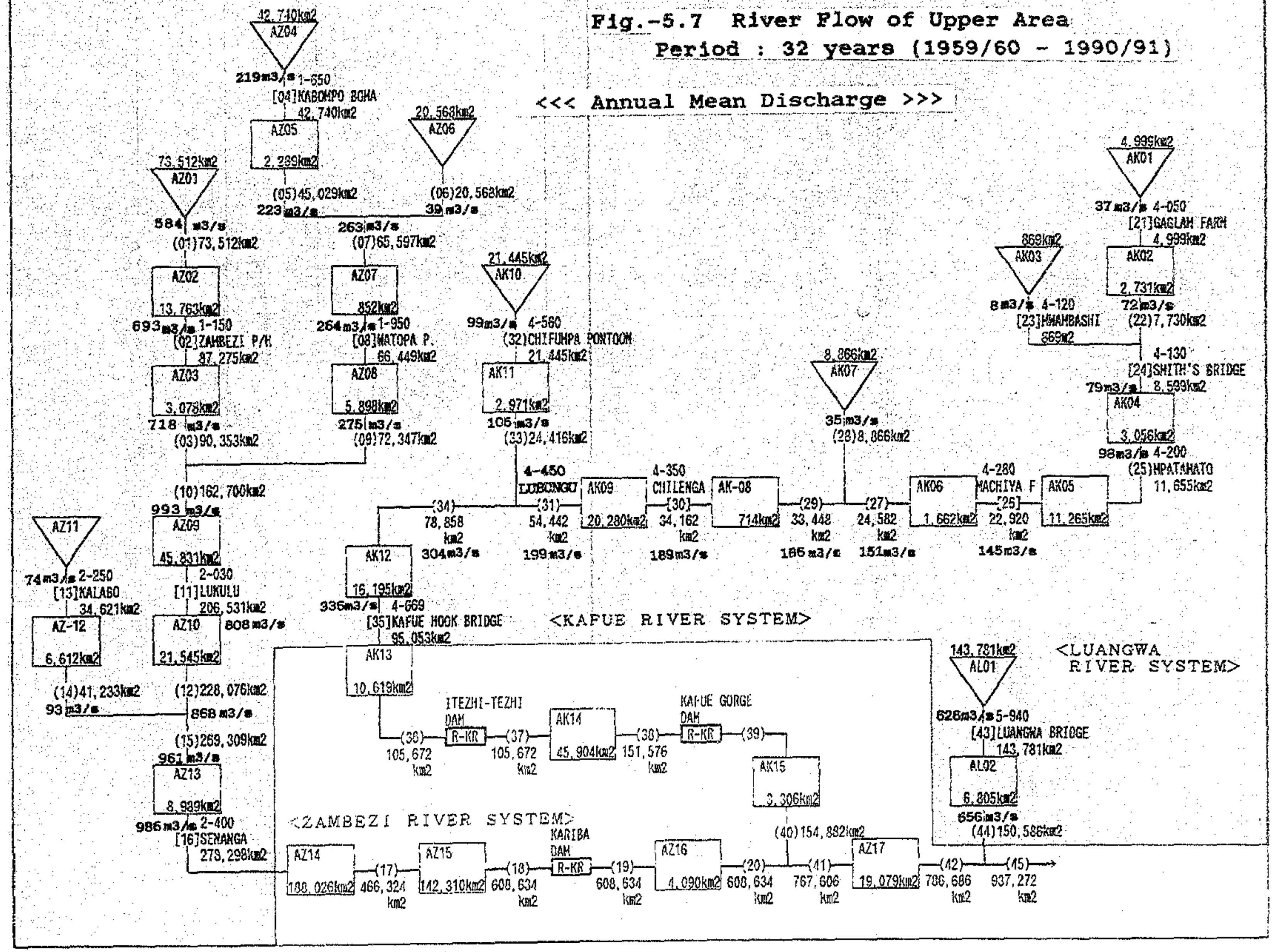
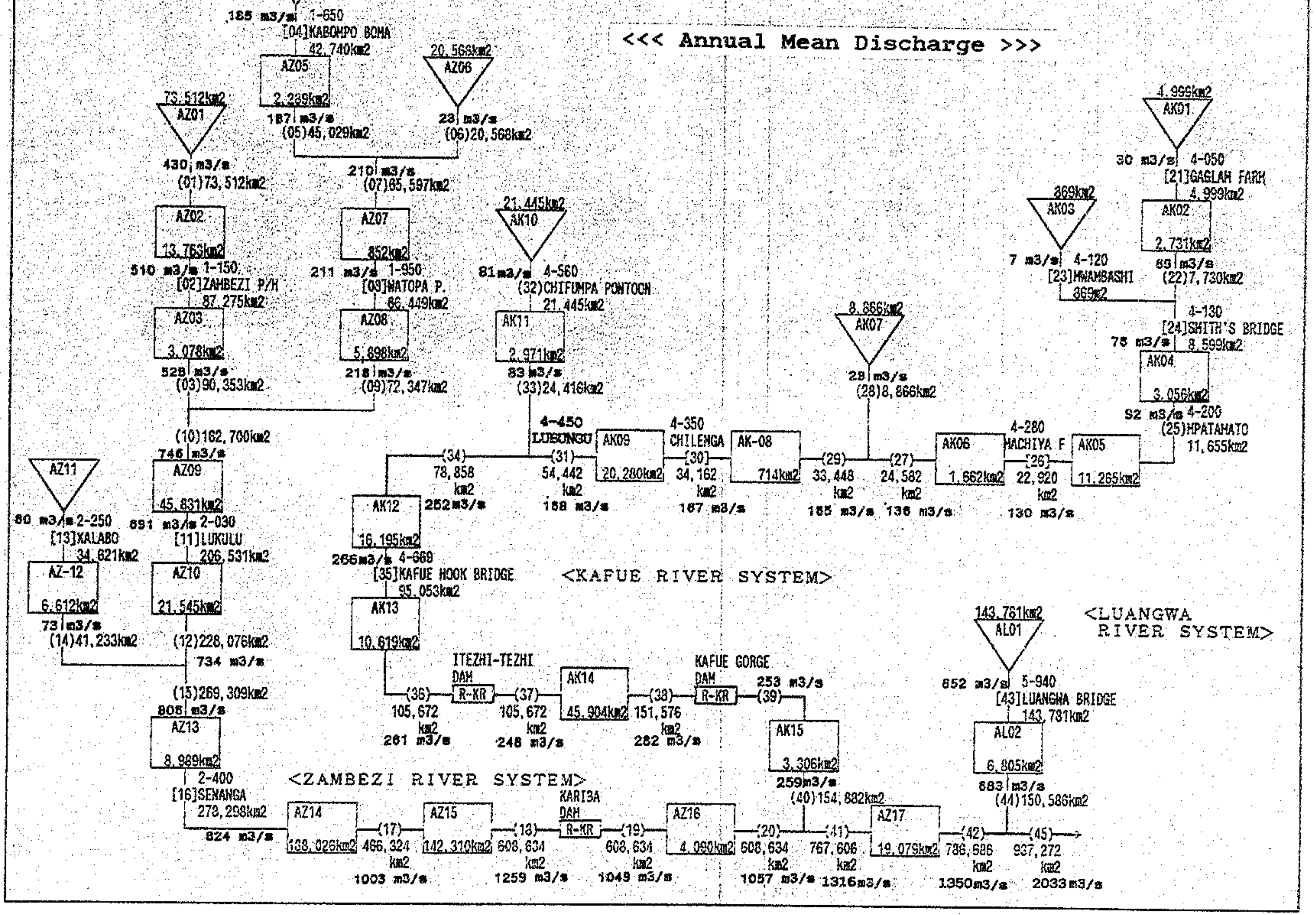


Fig.-5.8 River Flow of Whole Area

Period : 12 years (1979/80 - 1988/89)

<<< Annual Mean Discharge >>>



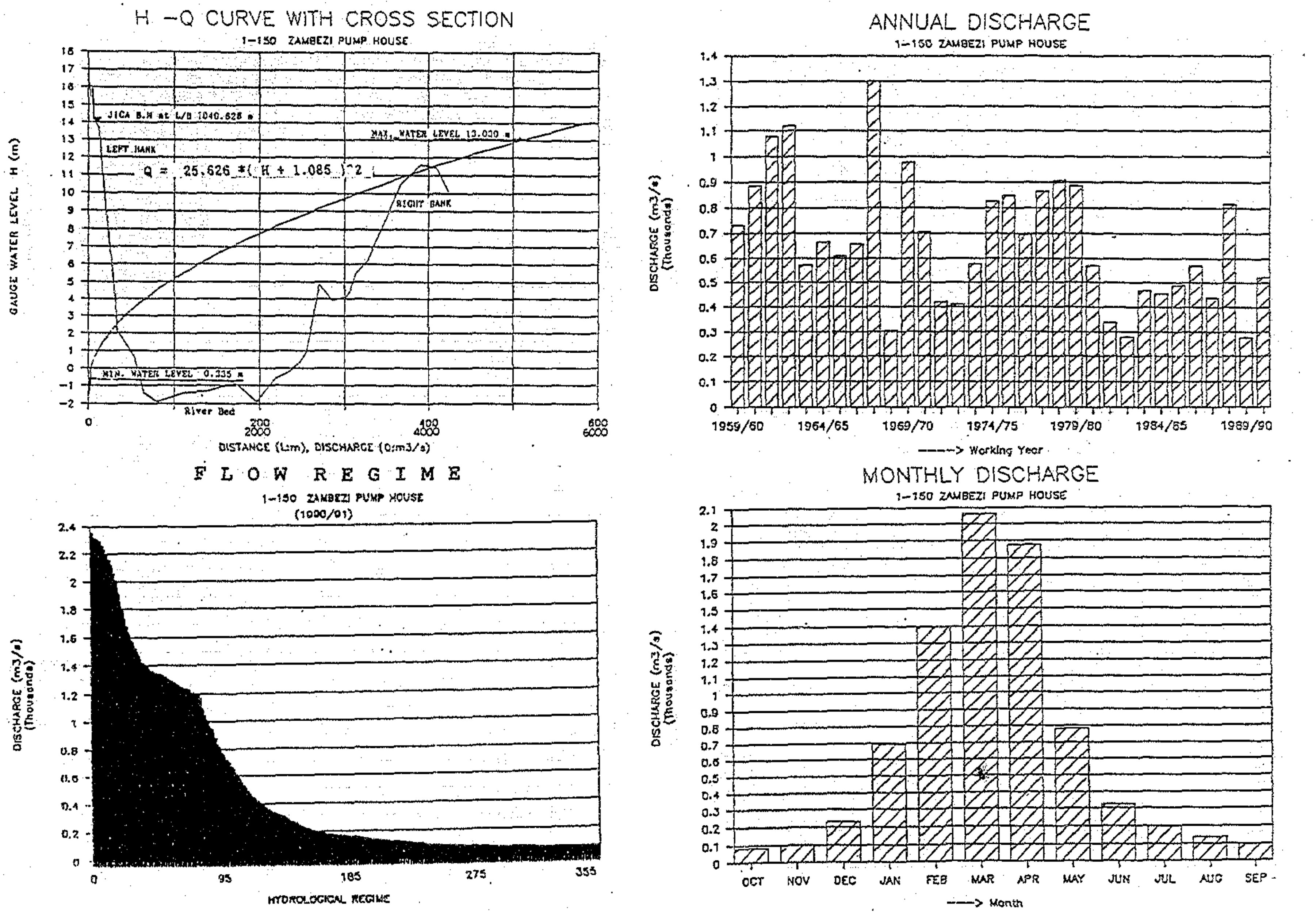


Fig.-5.9(1) Hydrometric St. (1-150 / Zambezi P/H)

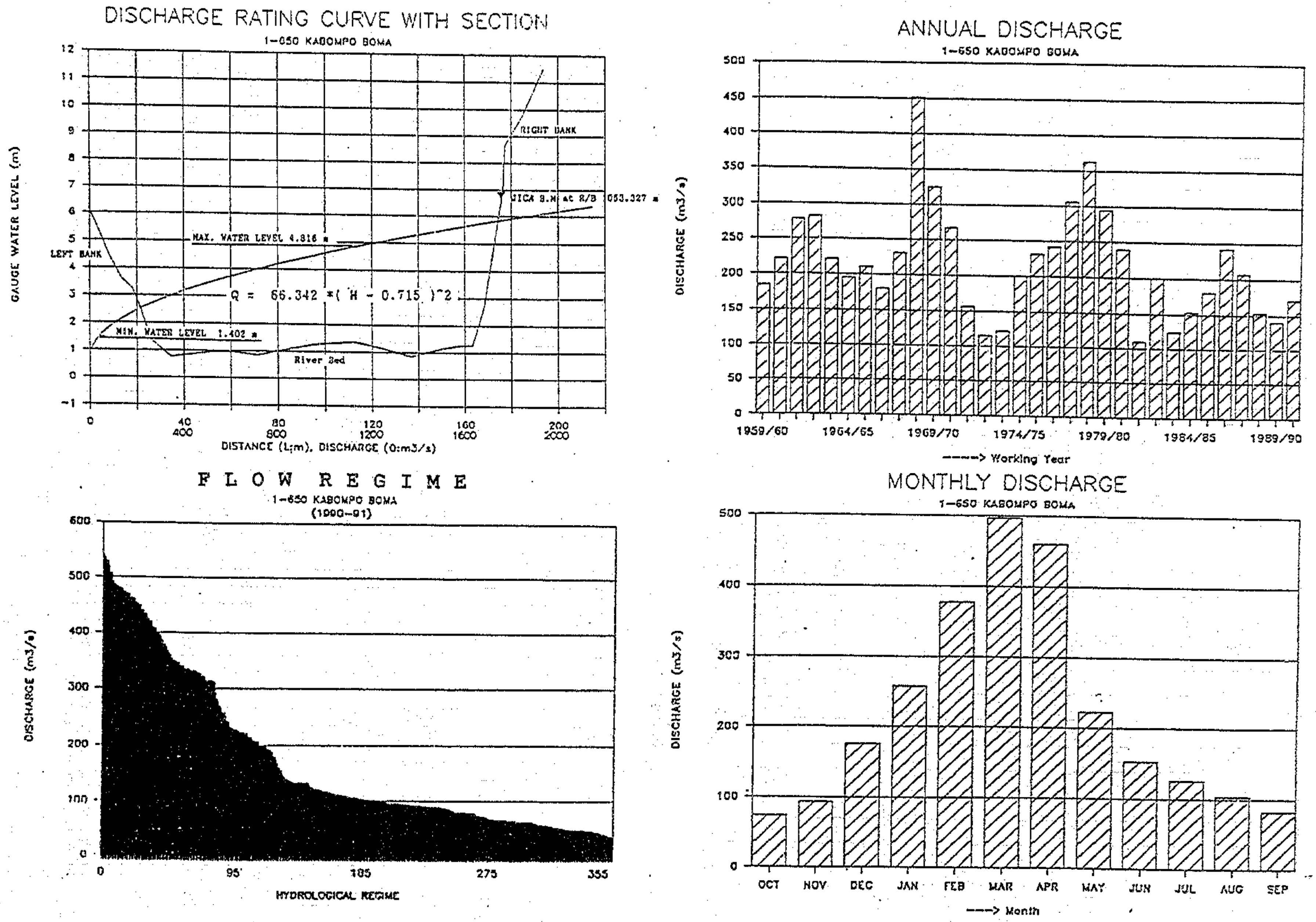


Fig.-5.9(2) Hydrometric St. (1-650 / Kabompo Boma)

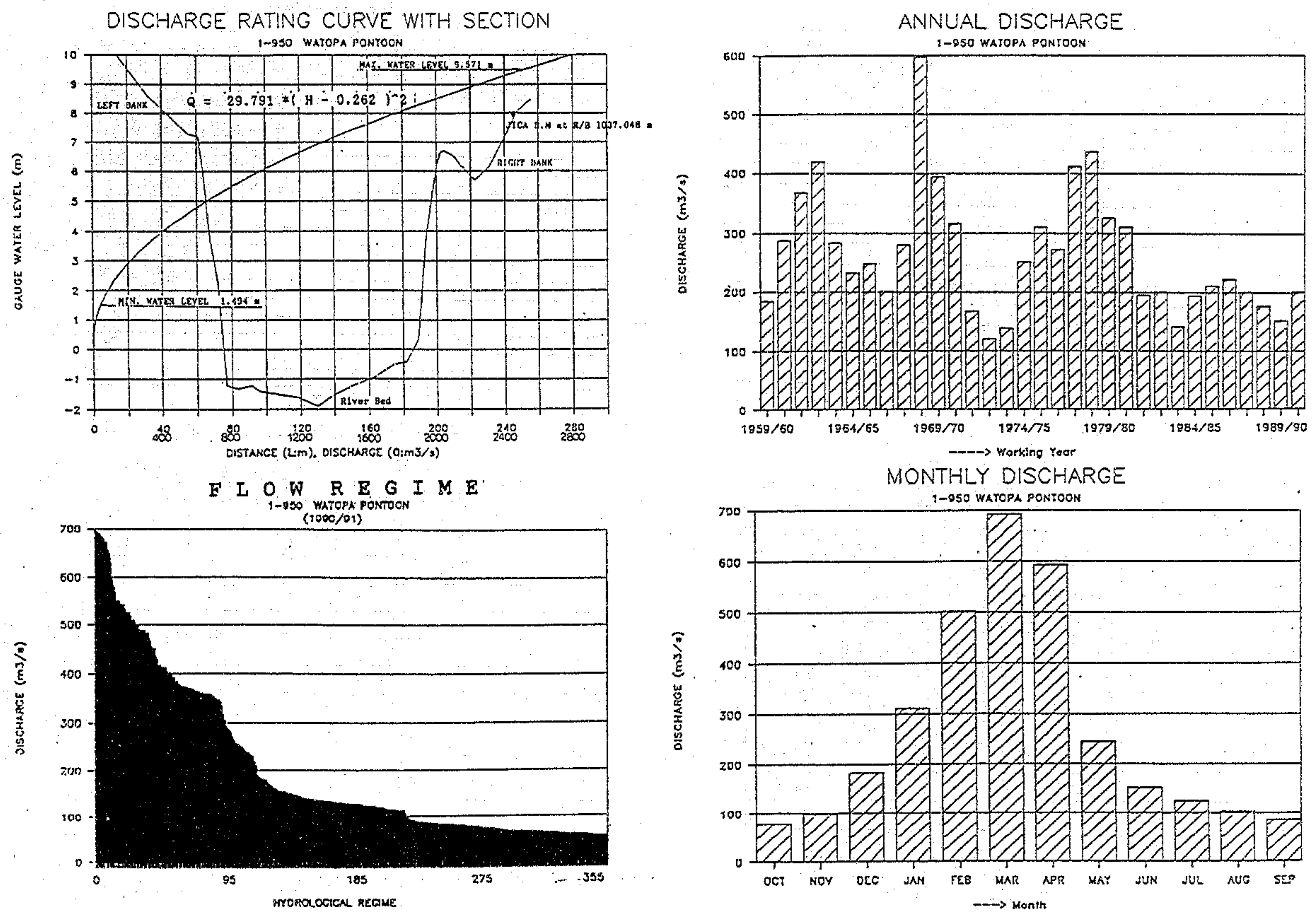


Fig.-5.9(3) Hydrometric St. (1-950 /Watopa Pontoon)

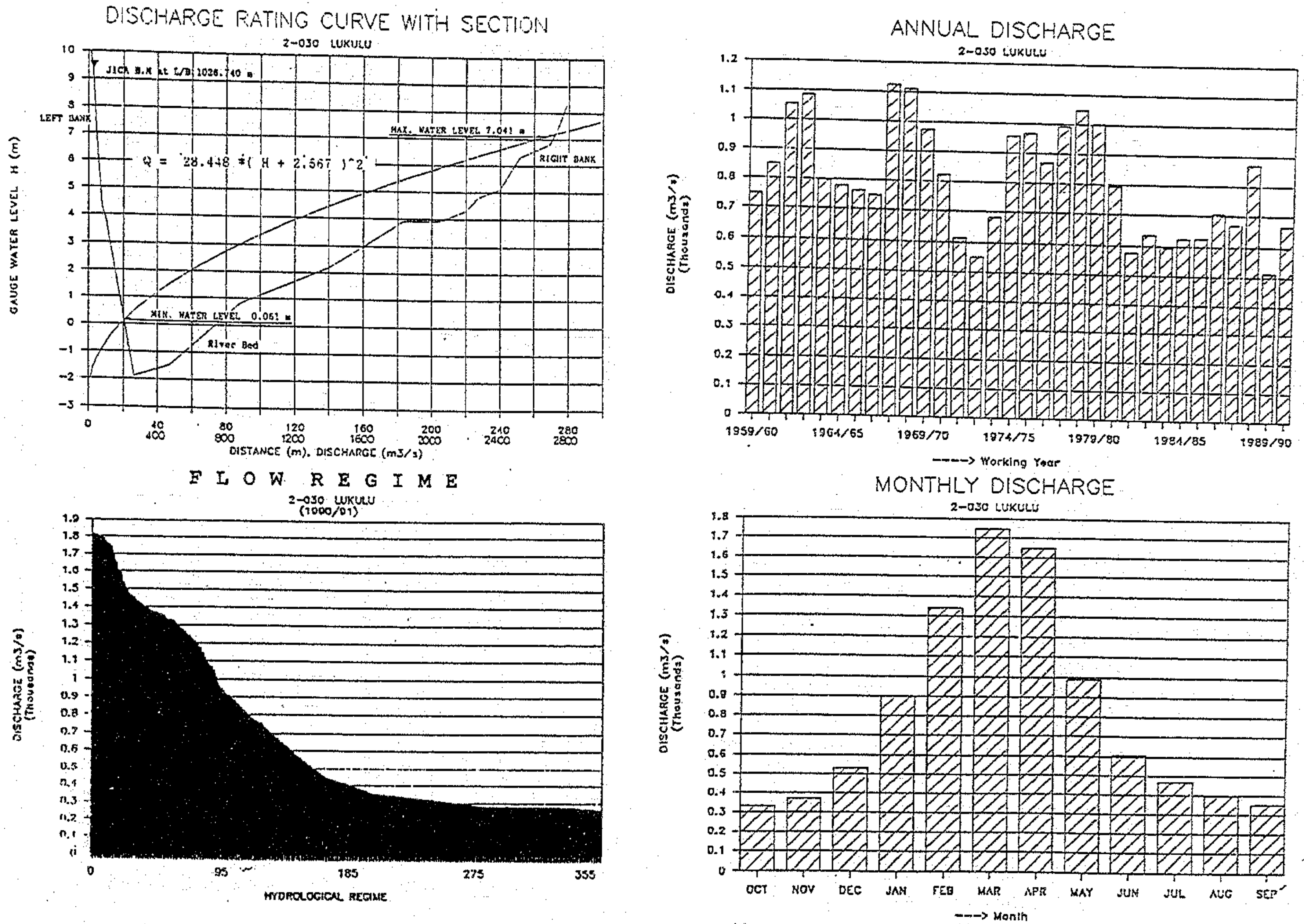
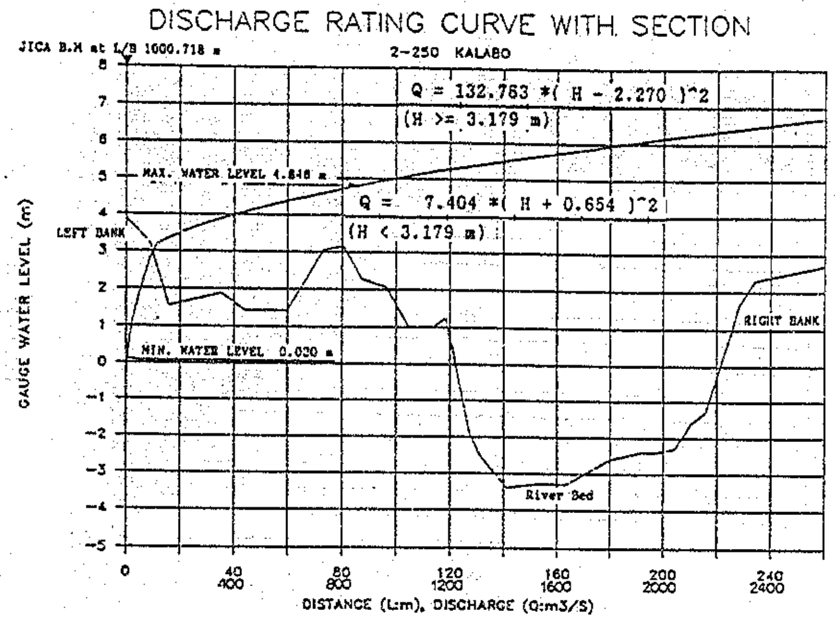
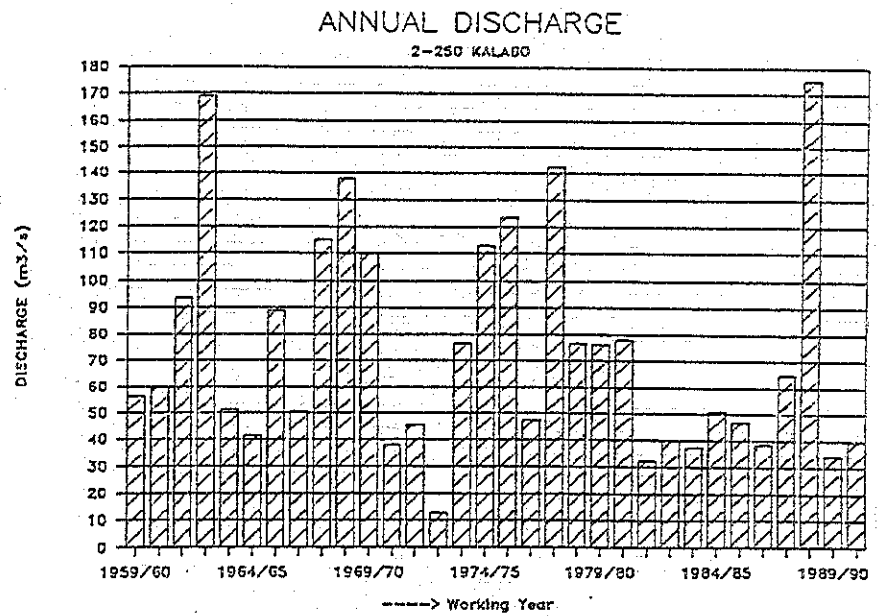
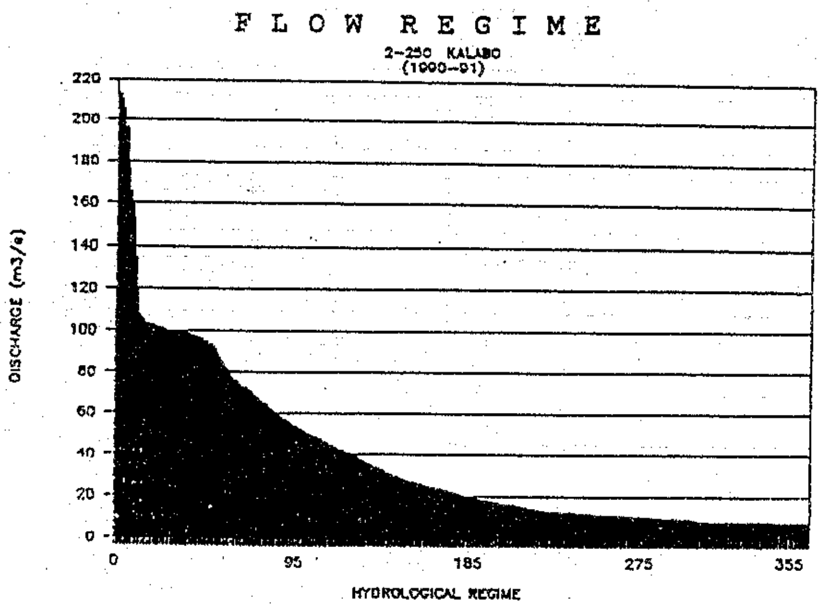


Fig.-5.9(4) Hydrometric St. (2-030 / Lukulu)







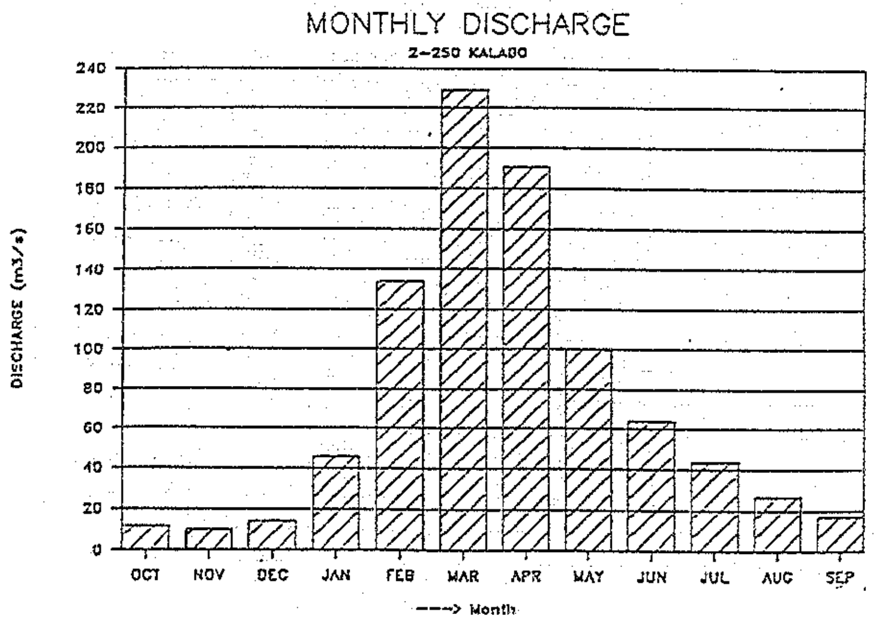


Fig.-5.9(5) Hydrometric St. (2-250 / Kalabo)

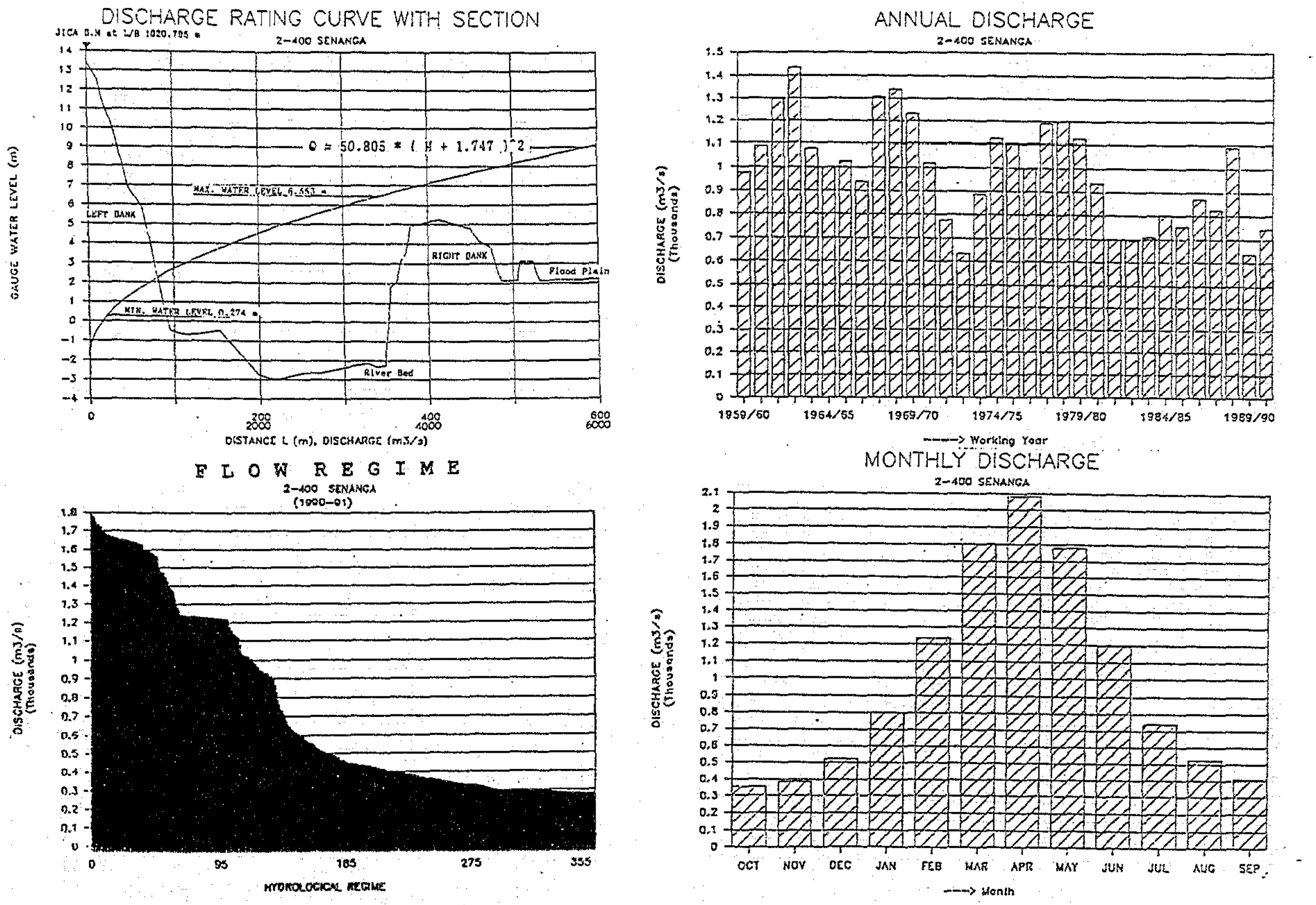
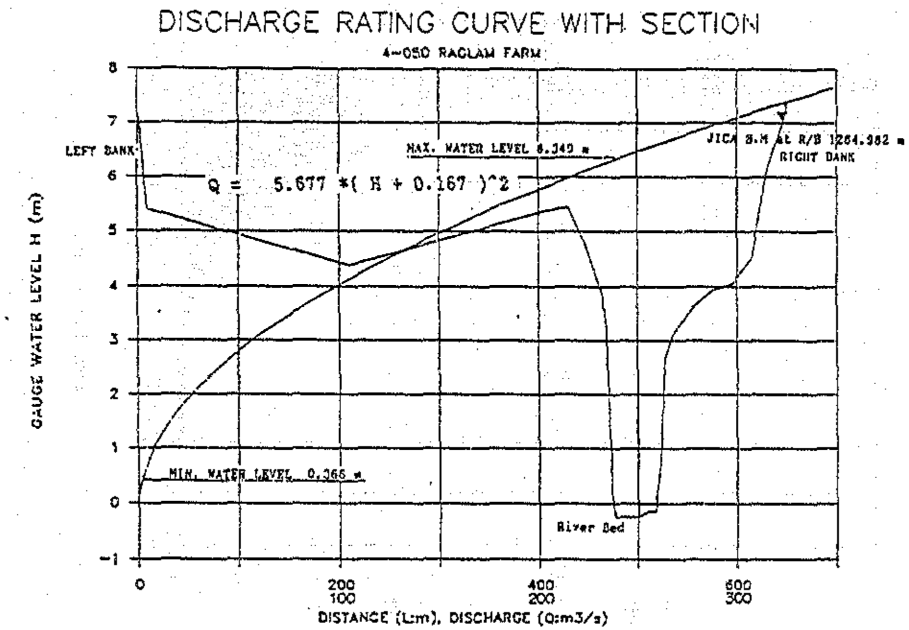
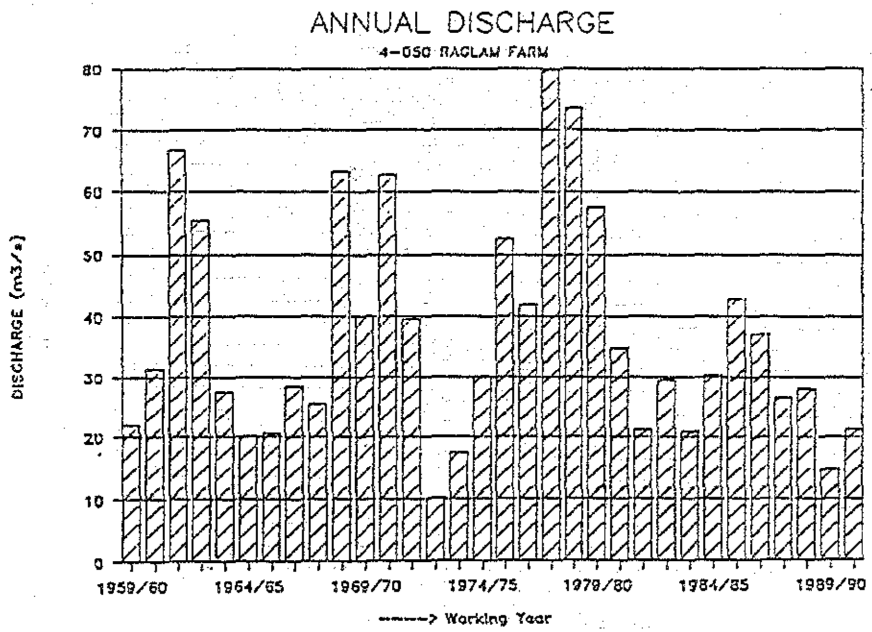
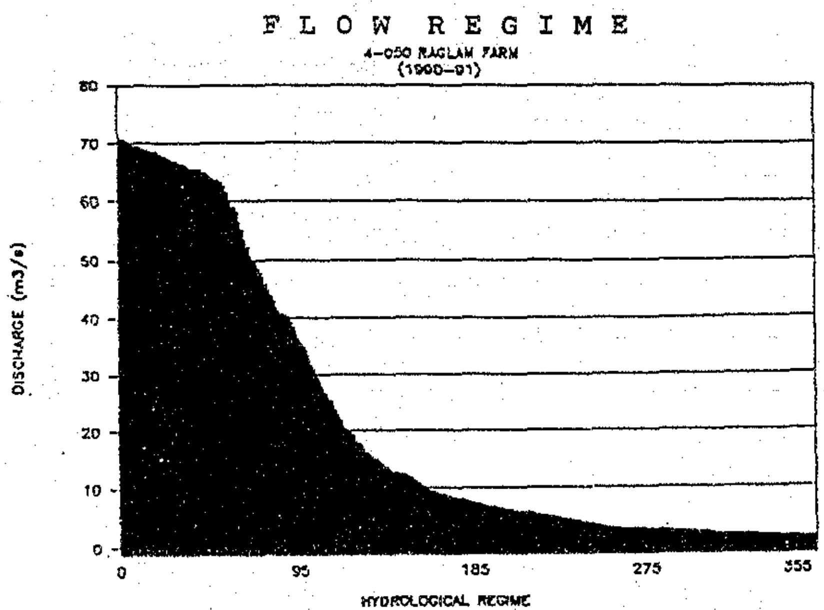


Fig.-5.9(6) Hydrometric St. (2-400 / Senanga)







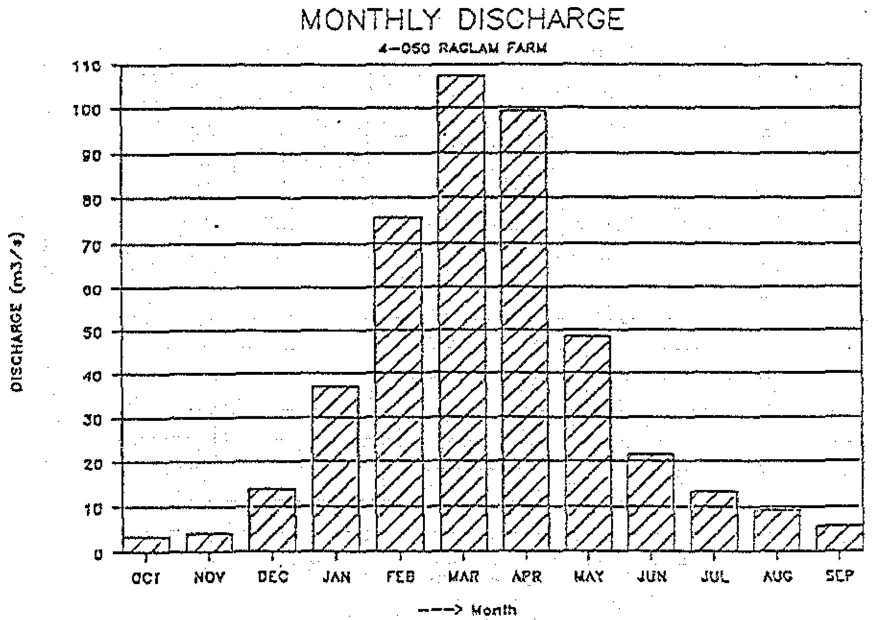


Fig.-5.9(7) Hydrometric St. (4-050 / Raglam Farm)

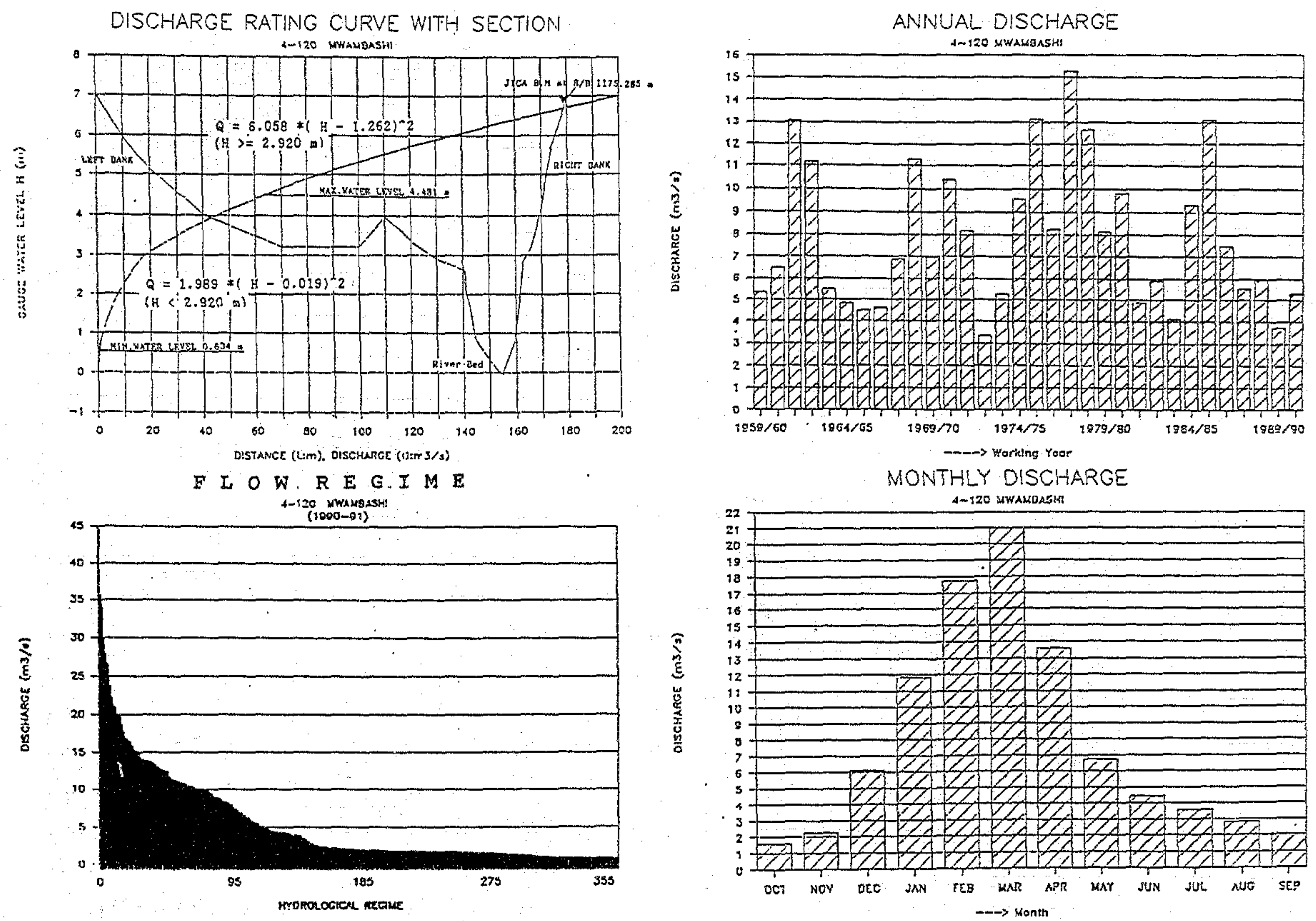


Fig.-5.9(8) Hydrometric St. (4-120 / Mwambashi)

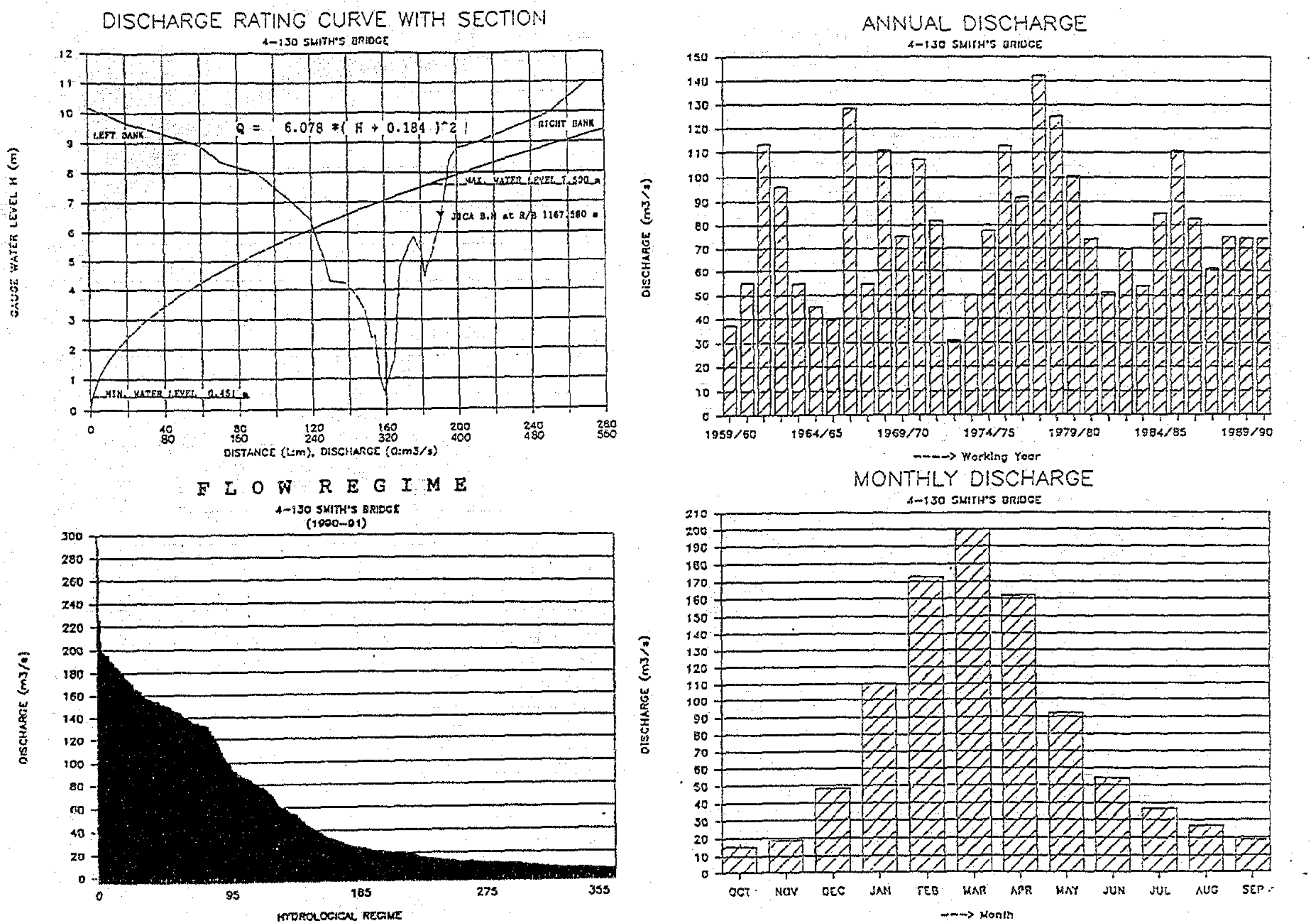


Fig.-5.9(9) Hydrometric St. (4-130 / Smith's Bridge)

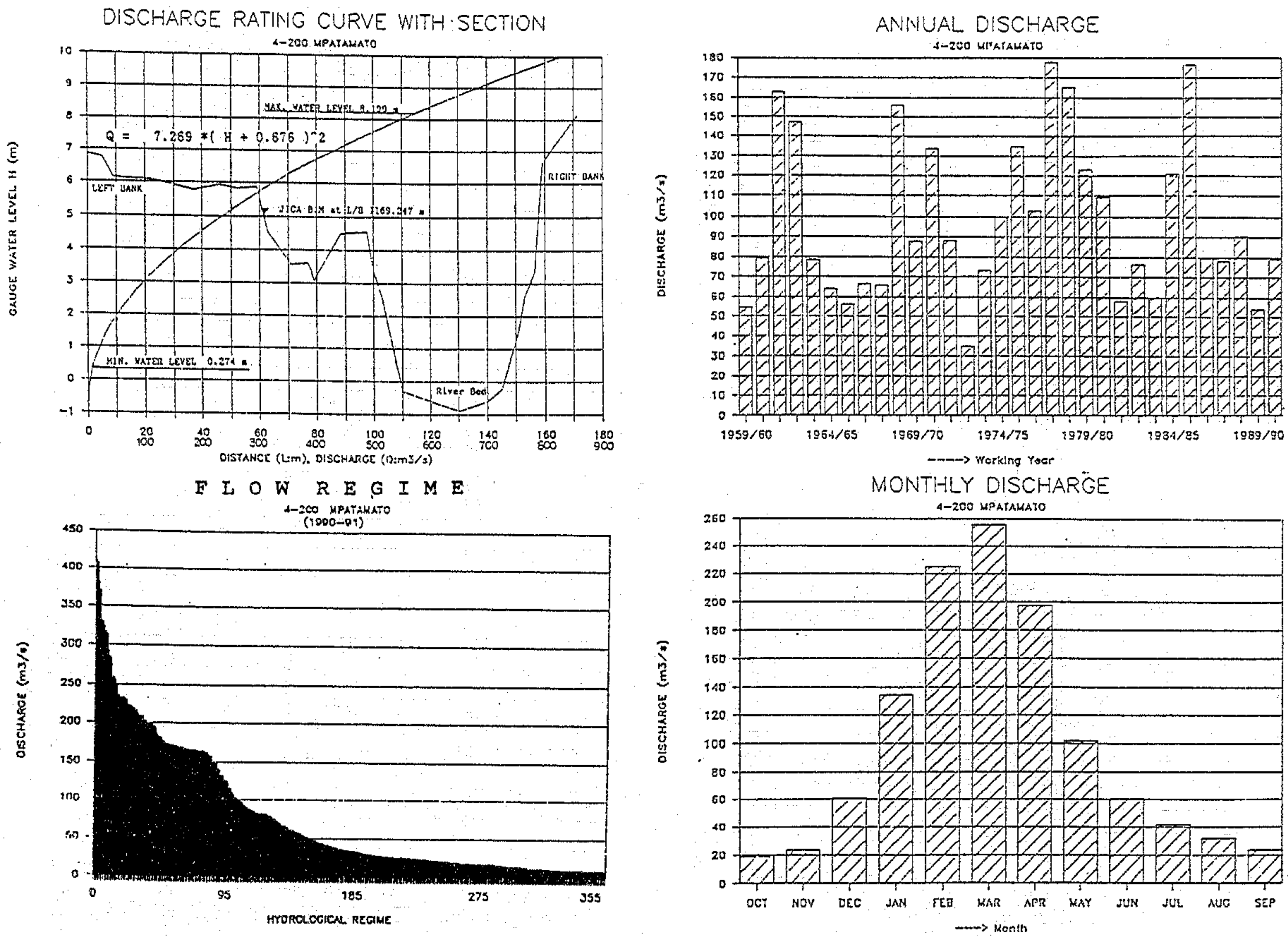


Fig.-5.9(10) Hydrometric St. (4-200 / Mpatamato)

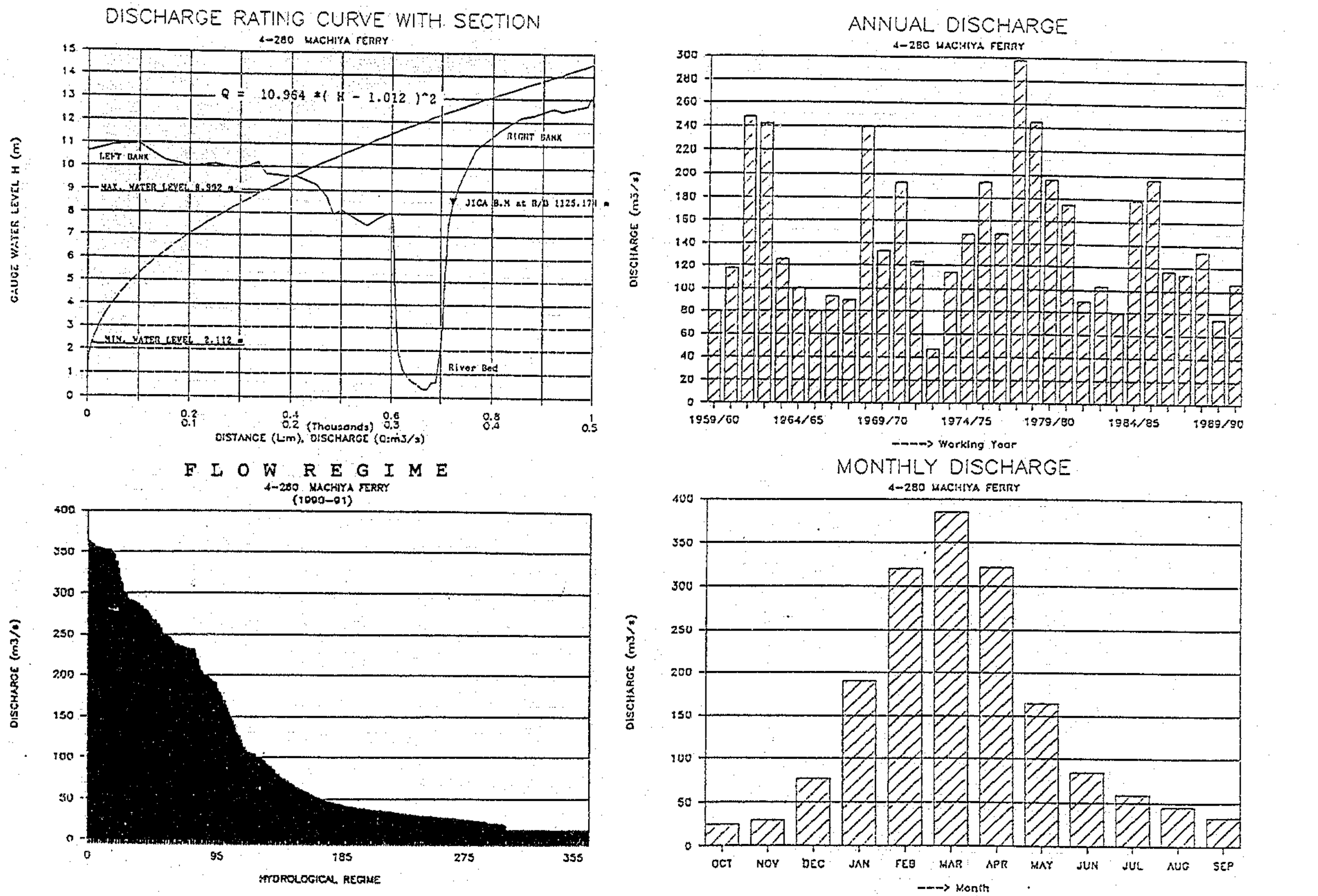


Fig.-5.9(11) Hydrometric St. (4-280 / Machiya Ferry)

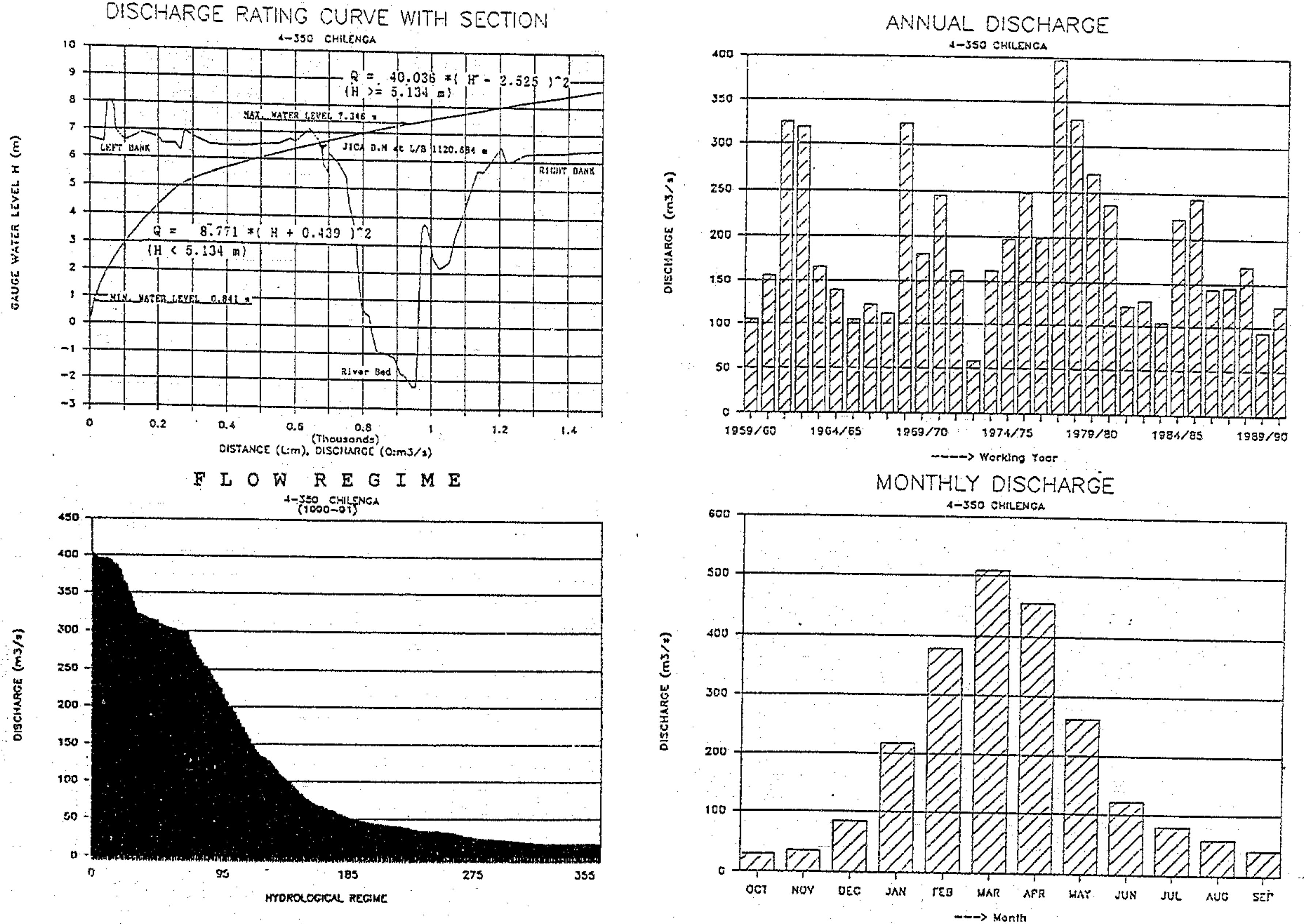


Fig.-5.9(12) Hydrometric St. (4-350 / Chilenga)

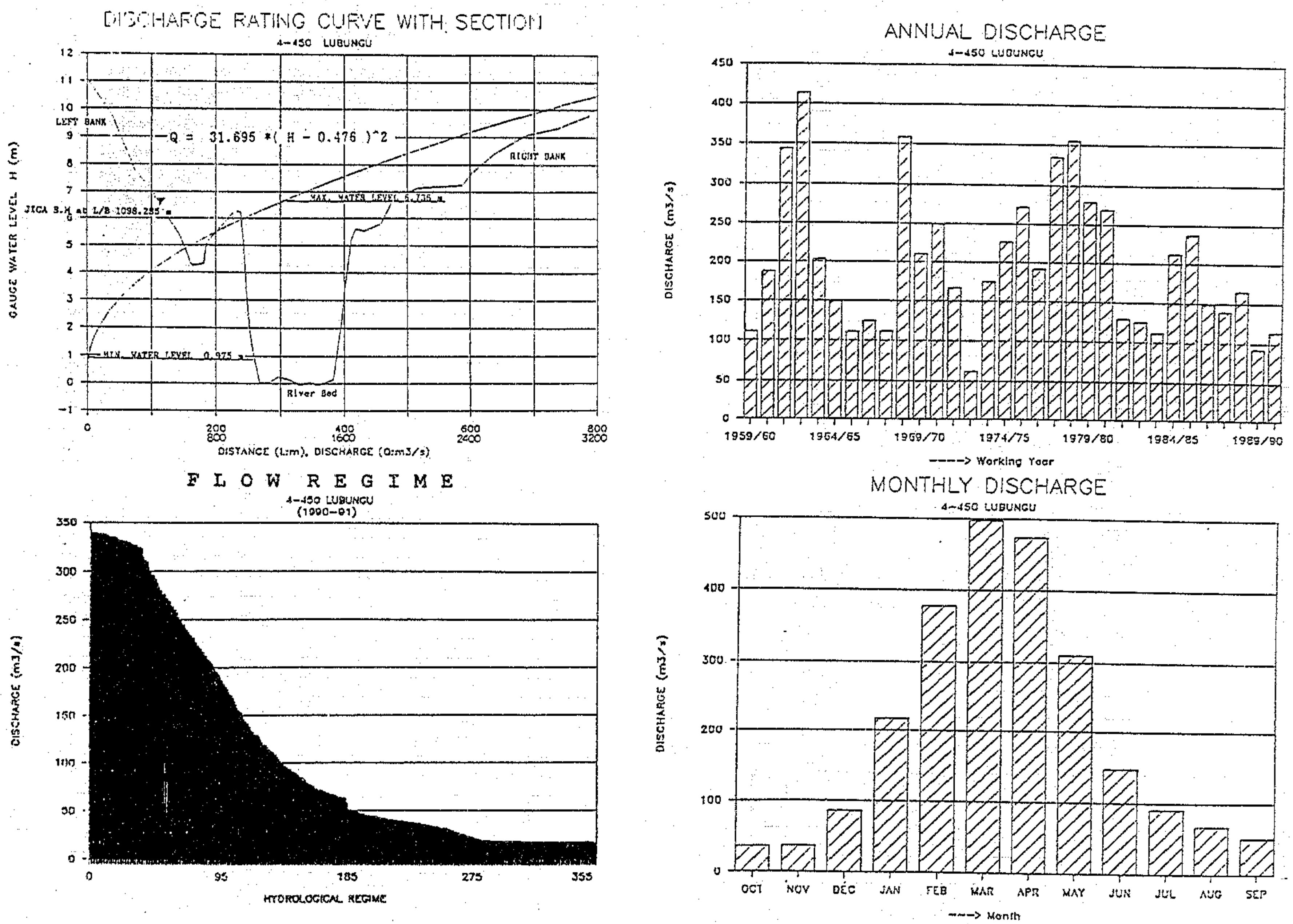


Fig.-5.9(13) Hydrometric St. (4-450 / Lubungu)

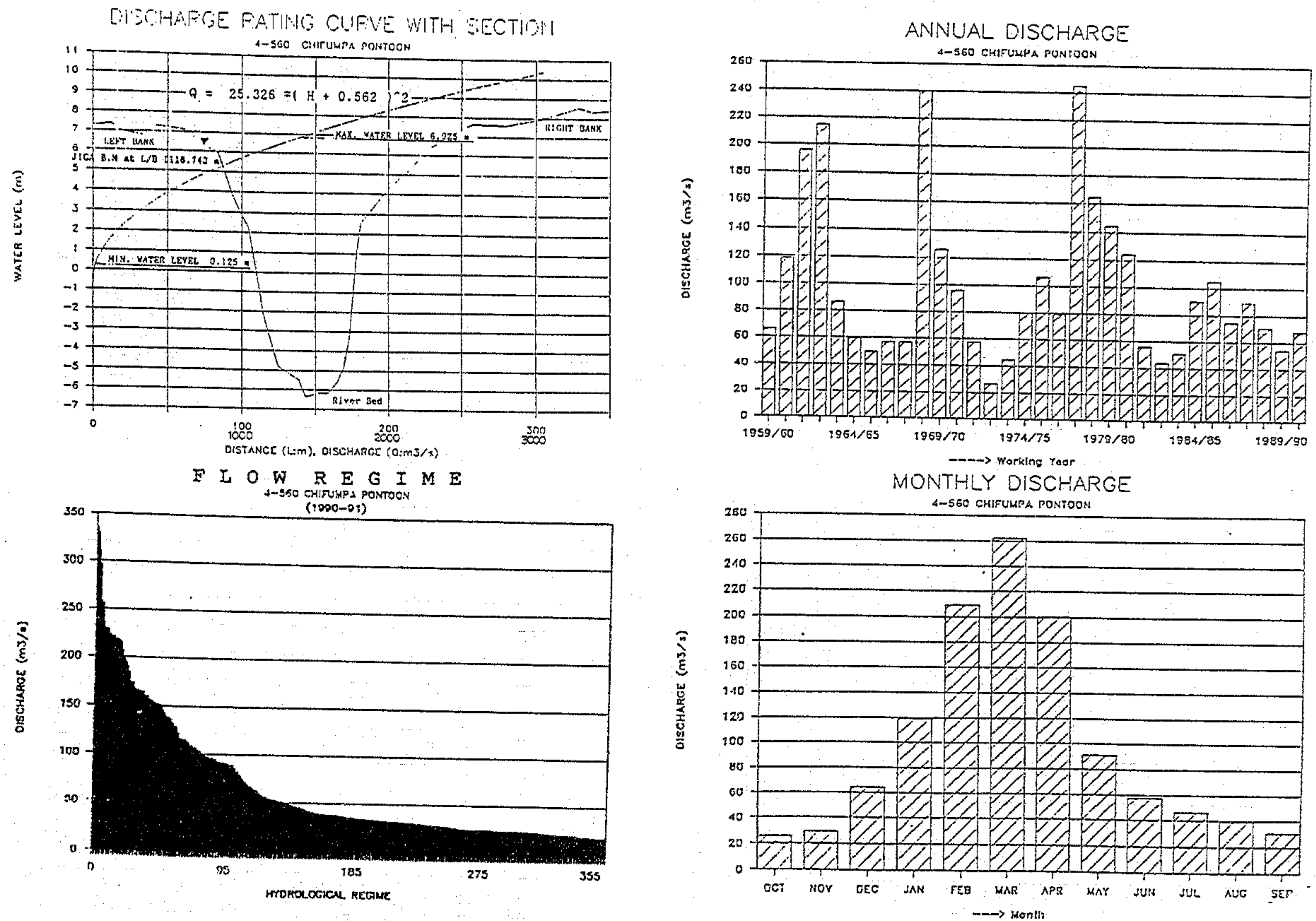


Fig.-5.9(14) Hydrometric St. (4-560 Chifumpa Pontoon)

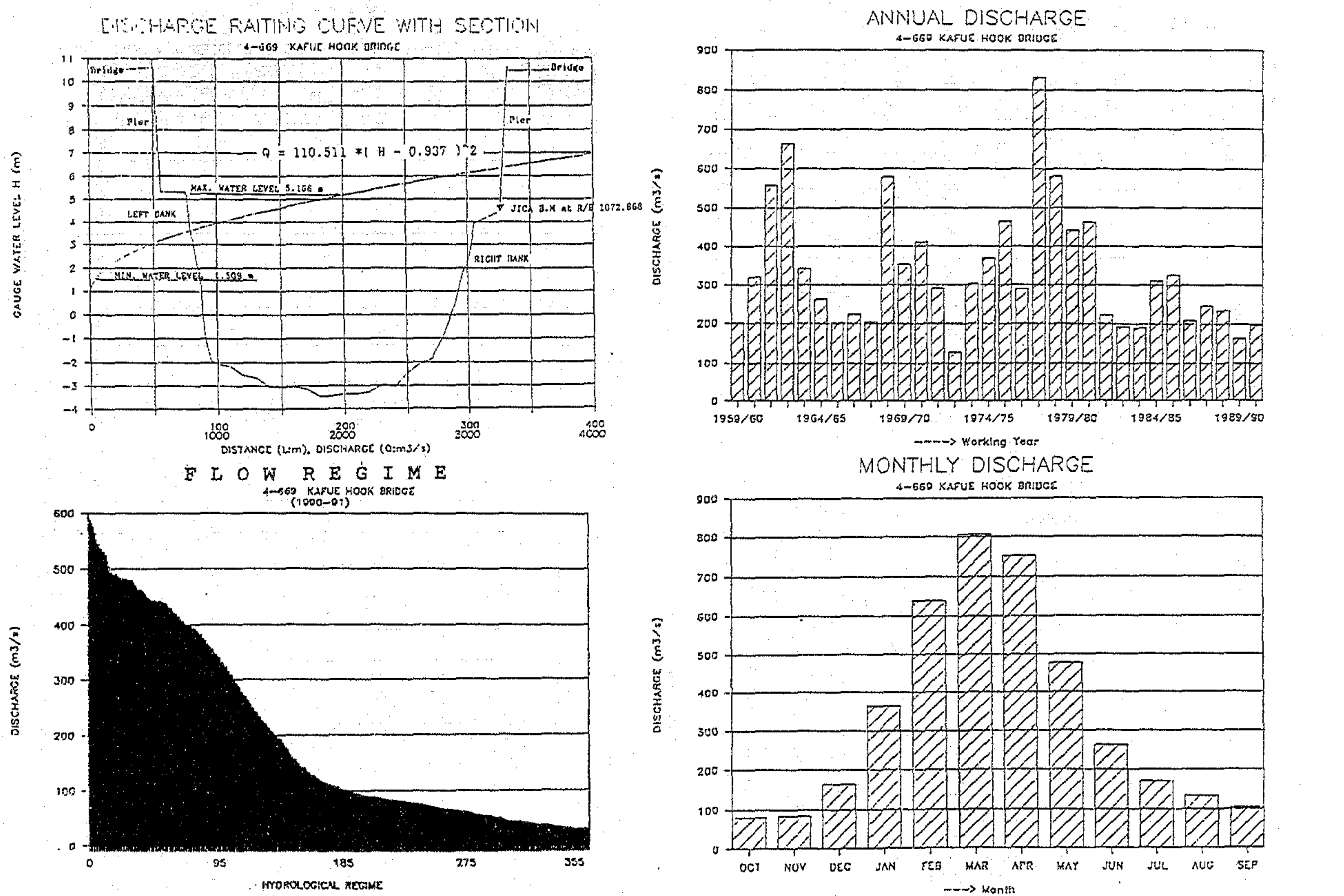


Fig.-5.9(15) Hydrometric St. (4-669 / Kafue H. Bridge)

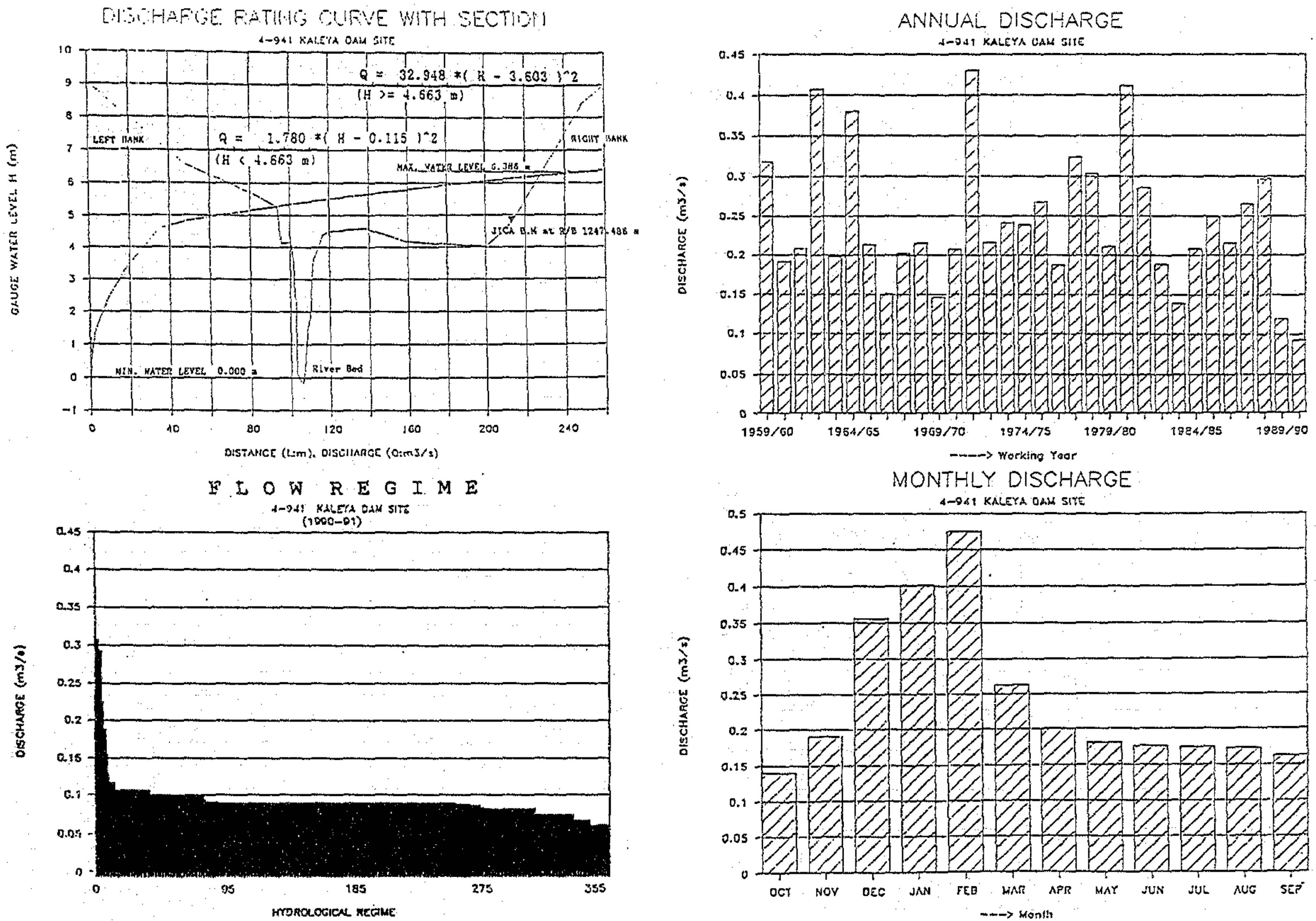


Fig.-5.9(16) Hydrometric St. (4-941 / Kaleya Dam Site)

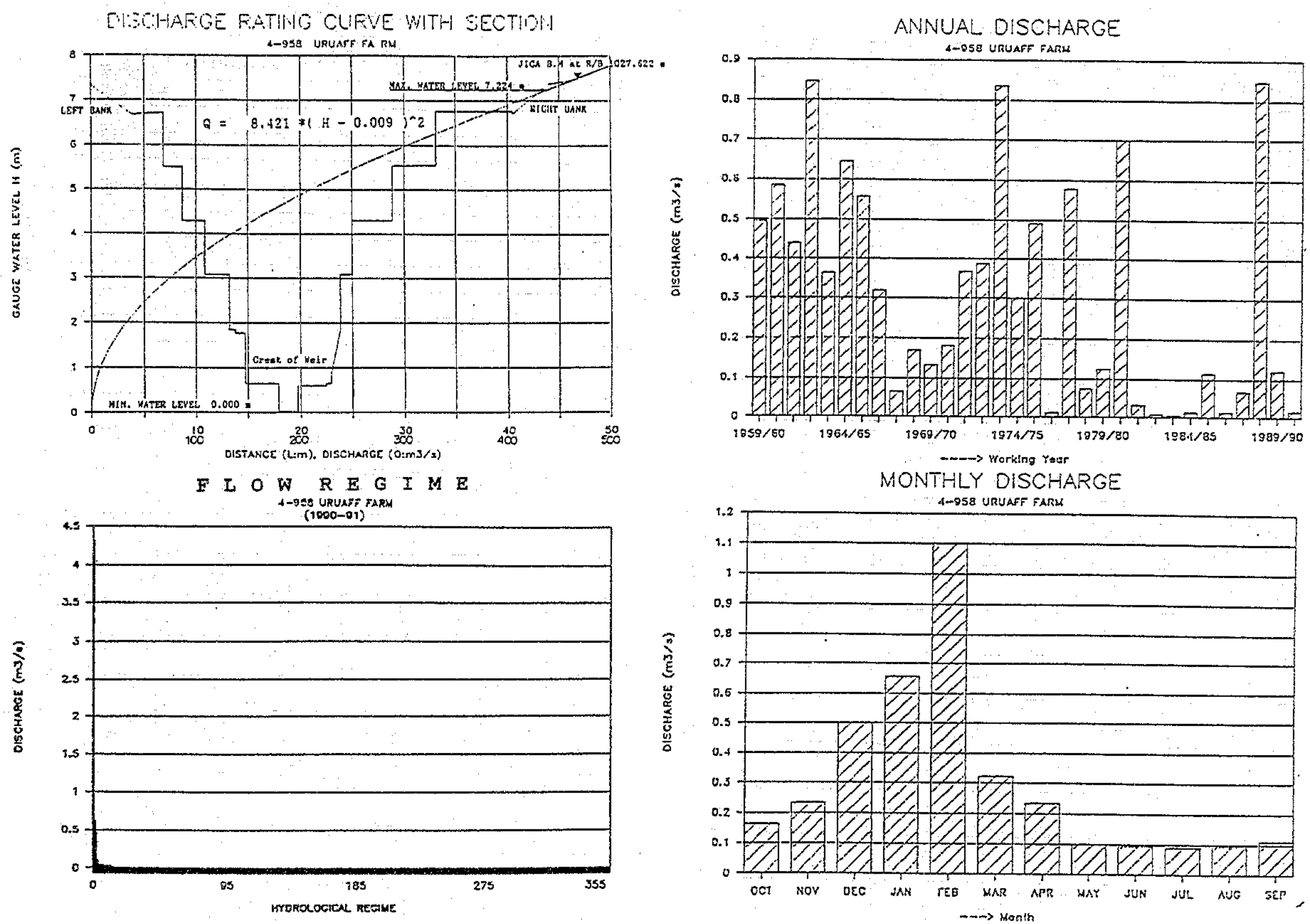


Fig.-5.9(17) Hydrometric St. (4-958 / Uruaff Farm)

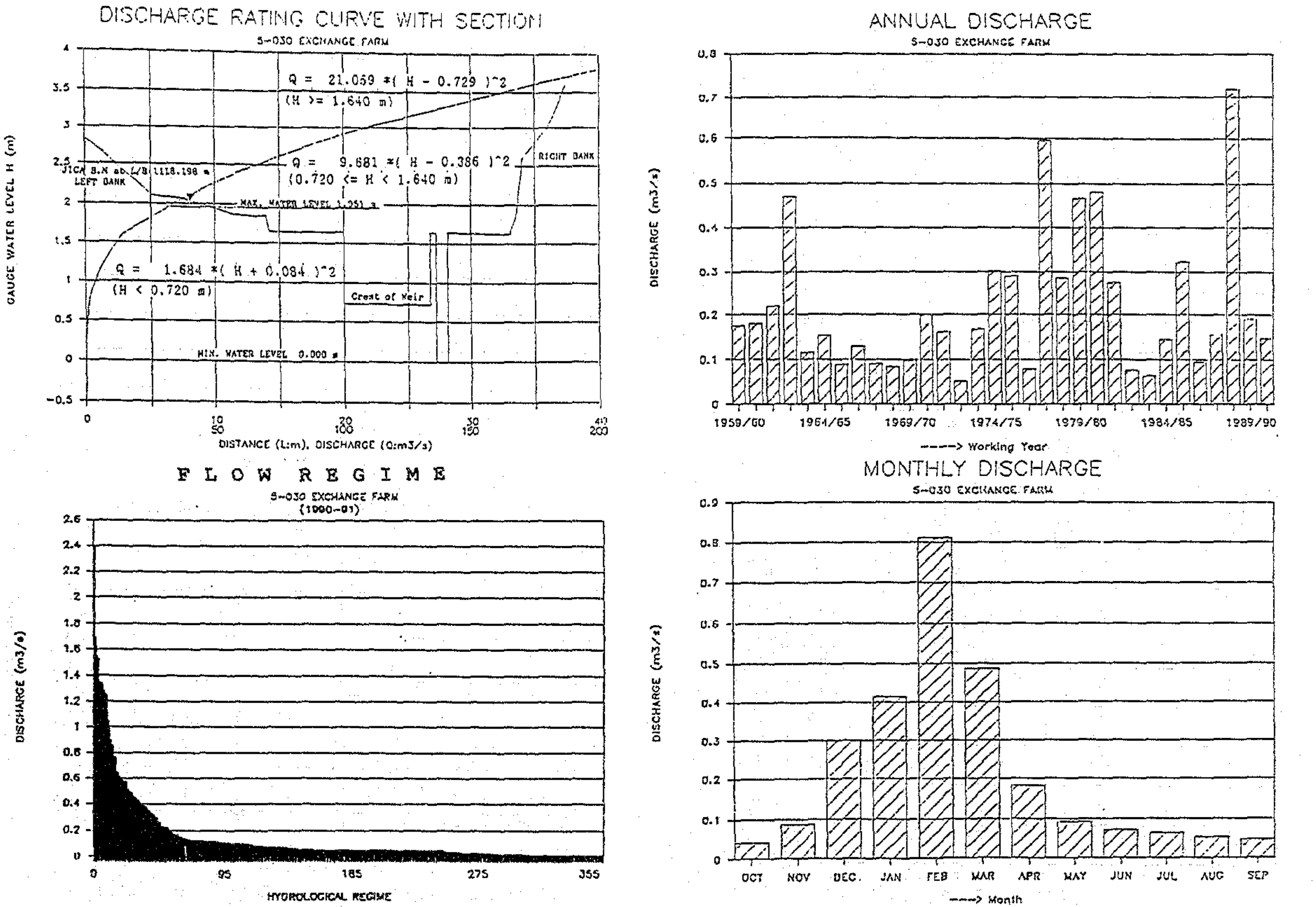
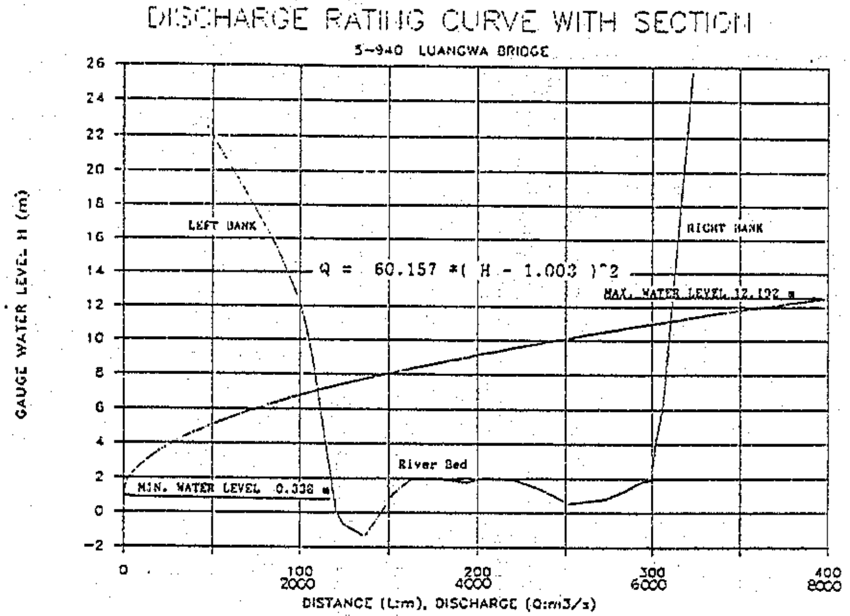
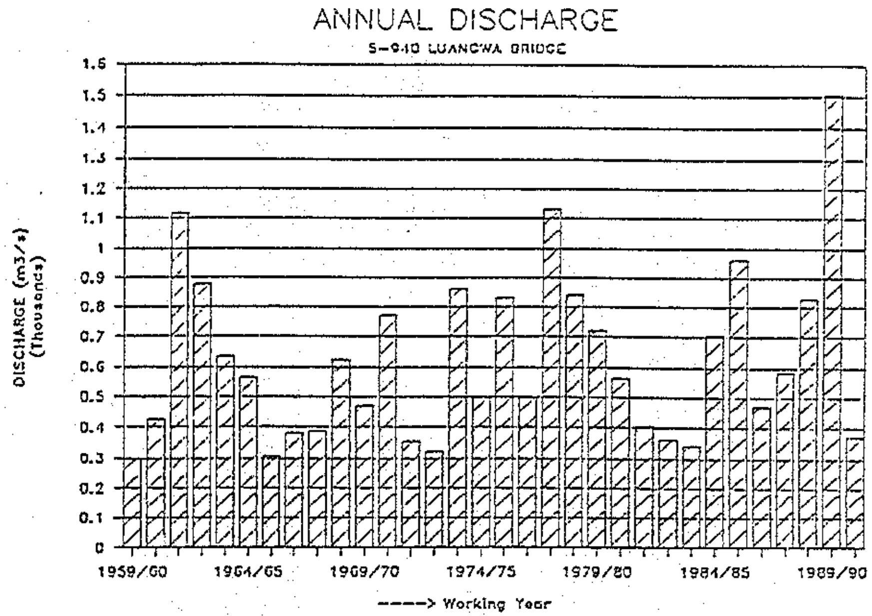
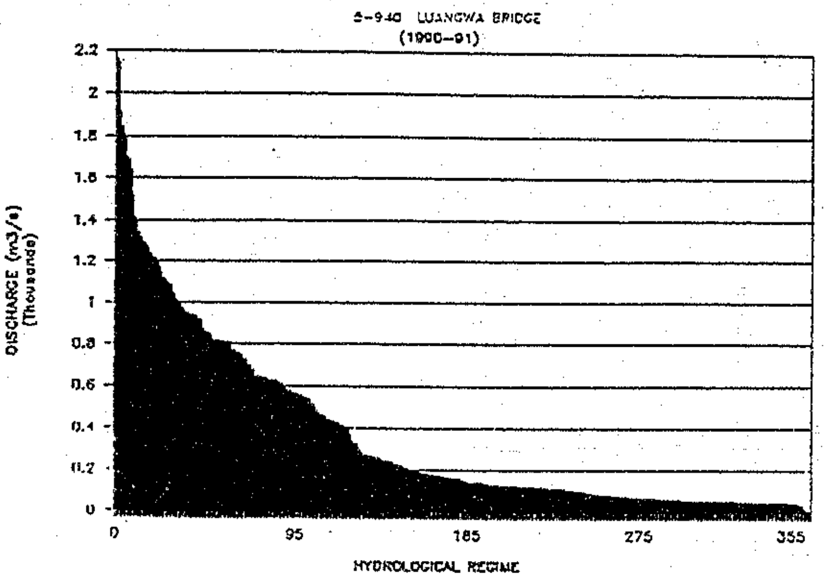


Fig.-5.9(18) Hydrometric St. (5-030 / Exchange Farm)







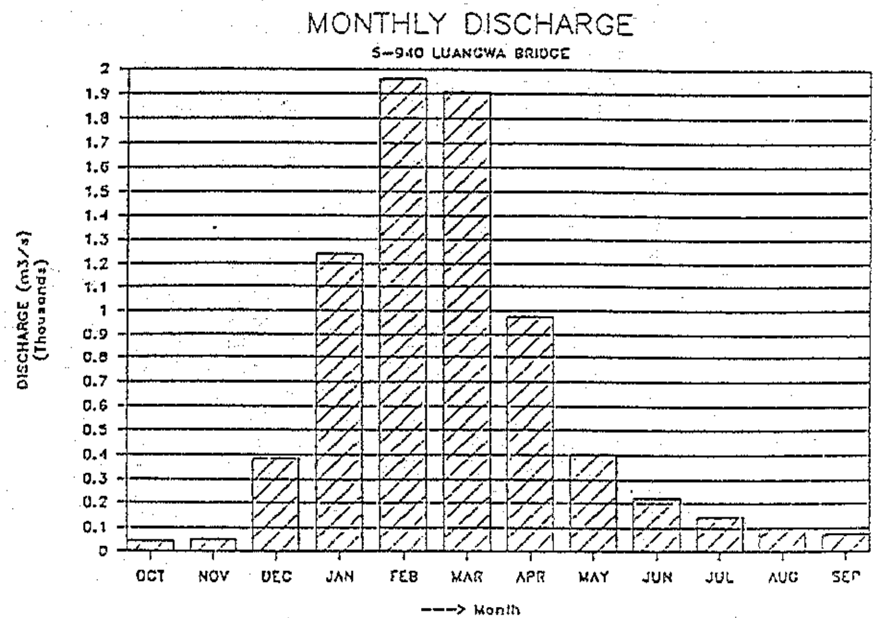


Fig.-5.9(19) Hydrometric St. (5-940 / Luangwa Bridge)

(2) Locality of Discharge

Regarding the locality of discharge in the Study Area, the simulation results (recent 12 years, 1979/80 - 1990/91) are obtained and illustrated in Fig.-5.10. These data reveal the following.

1) The specific discharge of the Zambezi River main stream is 2 - 3 times larger than that of the Kafue River main stream.

2) The specific discharge of the Zambezi River tributary, the Kabompo River, is same as that of the Kafue River main stream. The specific discharge of the Luanginga River is smaller than that of the Kafue River main stream.

3) The specific discharge of the Kafue River in Upper areas such as Mwambashi and Raglam Farm, is smaller than that of the Kafue River Main Stream.

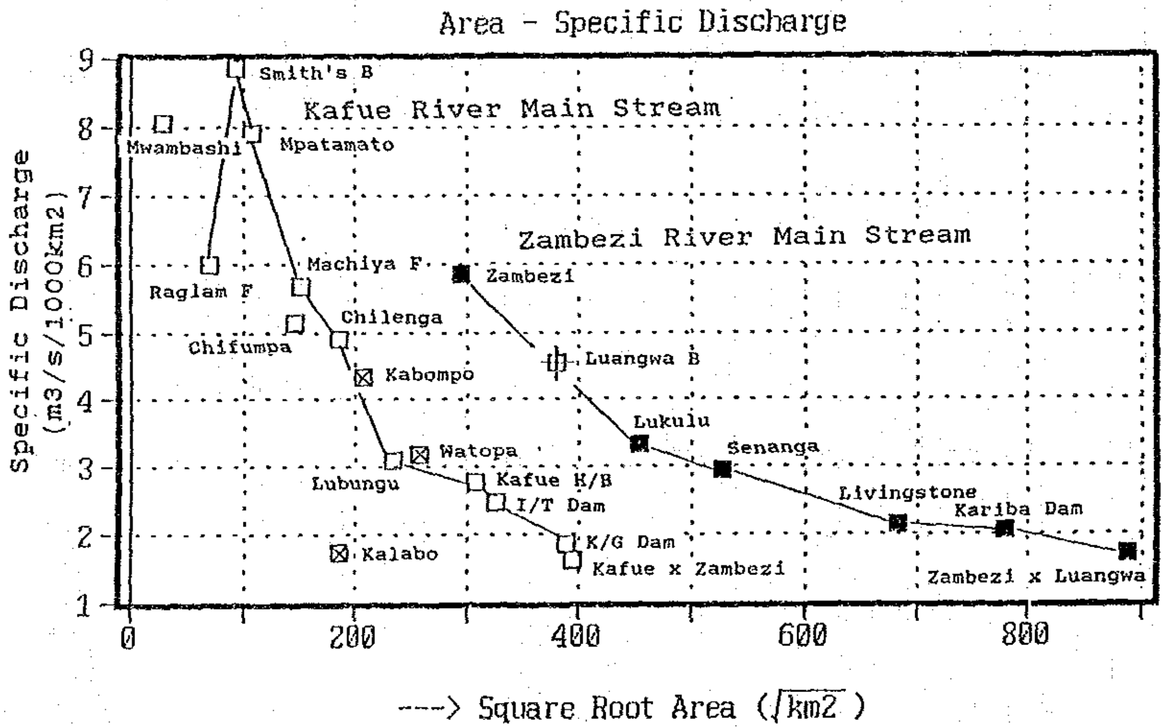


Fig.-5.10 Specific Discharge

(3) Runoff Coefficient of Kafue River Basin

Table-5.5 shows the estimation of the average runoff coefficient of Kafue River basin, of which the whole area is included in the Study Area and annual mean rainfall can be calculated. The conditions of this estimation are as follows.

1) Rainfall data:
   Average rainfall of recent 10 years (1979/80 -1988/89)

2) Calculation method of mean rainfall: Thiessen method using the rainfall stations: Solwezi, Kafilonda, Ndola, Kasempa, Mumba, Kabwe, Kaoma, Lusaka, Magoye and Choma

3) Discharge Data:
   Average discharge of recent 10 years (1979/80 -1988/89)

Table-5.5 Runoff Coefficient of Kafue River Basin

Name of Points	Basin Area (km2)	Annual Mean --Discharge-- (m3/s)	(bcm)	Annual Mean --Rainfall-- (mm)	(bcm)	Runoff Coeff. (%)
(4-050) Raglam Farm	4,999	33	1.04	1,286	6.43	16.2
(4-200) Mpatamato	11,655	97	3.06	1,259	14.67	20.9
(4-450) Lubungu	54,442	181	5.71	1.078	58.69	9.7
Iteshi-tezhi Dam In	105,672	279	8.80	1,069	112.96	7.8
Kafue Gorge Dam In	151,576	301	9.49	992	150.36	6.3
Kafue River Mouth	154,882	268	8.45	989	153.18	5.5