SPECIAL FUND—WORLD HEALTH ORGANIZATION

DRAFT

DESIGN PHASE

OF THE

WATER SUPPLY AND SEWERAGE WORKS

FOR THE

ACCRA-TEMA METROPOLITAN AREA, GHANA

WEIJA NEW DAM

FOR MUNICIPAL WATER SUPPLY AND IRRIGATION

CONSULTING ENGINEERS:
TAHAL CONSULTING ENGINEERS LTD.
in Association with
ENGINEERING SCIENCE, INC.

TEL AVIV
MARCH 1968
P. N. 828

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A. INTRODUCTION

In 1967 a report on irrigation feasibility in the Densu Basin from the proposed reservoir at Weija was prepared by the Irrigation, Reclamation and Drainage Division of the Ministry of Agriculture, Ghana (hereinafter referred to as the "Irrigation Report").

In the Irrigation Report, it is proposed to irrigate, from the Weija Reservoir, two blocks of land together comprising 4,200 acres. The water demand from Weija Reservoir for irrigation is defined on a monthly basis (see Table 11) and amounts to 30,000 acre ft (8,100 mg) per annum. The benefit/cost ratio for the irrigation project calculated in the Irrigation Report is 1.8 if an additional amount of about $700,000 is spent on raising Weija Dam to increase its storage capacity and thus supply the irrigation requirements of the two blocks of land.

At the end of December 1967 an agreement was signed between the World Health Organization, Geneva, and Tahal Consulting Engineers Ltd., Tel Aviv, which provided for Tahal, in association with Engineering-Science Inc. to carry out the final engineering design of Accra-Tema Water Supply, Second Stage, and Sewerage Works, Phase One.

In this agreement Tahal was requested to prepare a report on the capacity of Weija New Dam to provide storage to meet both municipal and irrigation demands.

The purpose of the report is defined in Clause 2.3.1 of the agreement as follows: "A report with recommendations on the capacity of the new Weija dam with due consideration for the findings of the Feasibility Study for water supply and sewerage of the Accra-Tema Area and proposals which have been made for the utilization of the Densu River water source for irrigation. The Consulting Engineer will utilize the data contained in the said proposal as to the quantity of water and time schedule of water use."

In the following chapters the required capacity of Weija Reservoir for the purposes of municipal supply and irrigation is discussed, and recommendations are made.

B. SUMMARY

In the following report a study of the Densu River and the Weija Dam and impounding Reservoir is presented. The report is not self-contained and should be read in conjunction with the Feasibility Study* and the Irrigation Report**.

The results of recent hydrological investigations have been analyzed together with the results of previous studies and the revised conclusions are summarized in Chapter C. It was found that the flow at Weija was on the average about 20 percent greater than the flow at Nsawam. The synthesized hydrograph at Weija indicates a critical period of low flow during the years 1946-47.

On the basis of the critical dry period as indicated in the hydrological study and of the water requirements as defined in the Feasibility Study and in the Irrigation Report, the storage capacity required at Weija will be about 25,000 mg. This storage will ensure municipal and irrigation requirements even in the event of a dry period which, it has been calculated, is only likely to occur on an average once in a hundred years.

The corresponding normal water level (NWL) at Weija Dam for a storage capacity of 25,000 mg is 47 ft O.D. with the level of the dam crest at 53 ft O.D. For municipal water supply only, the required storage capacity would be 14,700 mg with a corresponding NWL at the dam of 41 ft O.D. and crest level of 47 ft O.D. Storage for irrigation will require the dam to be raised by an additional 6 ft to crest level of 53 ft O.D. The construction cost of raising the dam by 6 ft will be $819,000. (orig. Vp. $700.000.-)

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* Feasibility Study for Water and Sewerage Works in the Accra-Tema Metropolitan Area, Tahal, 1966

** Report on Irrigation Feasibility in the Densu Basin from the Proposed Reservoir at Weija, prepared by Irrigation, Reclamation and Drainage Division, Ministry of Agriculture, Ghana

It is recommended that hydrological flow measurements be continued during the coming years, until the water demand reaches the design figures, in order to establish the optimum amount of water which can be exploited from the Densu River along its entire course and in particular the amount to be exploited from the Weija Reservoir.

In the event of the irrigation project being cancelled, the capacity earmarked for it could be utilized for increasing the Accra-Tema municipal supply. During the design of the works for Accra-Tema water supply, the possibility of such extension will be taken into consideration.

C. DENSU RIVER HYDROLOGICAL STUDIES

1. General

The findings of an additional hydrological study of the Densu River are detailed in this chapter. The hydrological data which were available during the feasibility study were not sufficient for finally determining the storage capacity needed at Weija. An additional study based on the old and new data has therefore proved necessary. During the past three years, observations on the Densu River were conducted by the local Hydrological Department, by the firm of Nippon Koei, and by Tahal Consulting Engineers. The Tahal hydrologist, Mr. M. Moneta, carried out jointly with a team of the Hydrological Department a series of flow measurements,and established new gauging stations on the Densu. These observations have provided additional hydrological data of great importance, including a new rating curve for the river at the Nsawam Bridge gauging station. With these data in hand, newly observed as well as synthesized hydrographs have been prepared for the Nsawam Bridge gauging station.

The data recorded at the new gauging station at Manhia, just upstream of Weija, have made it possible to prepare a synthesized hydrograph for Weija and thus to determine the contribution of the lower basin downstream of Nsawam.

A topographical map of the reservoir site,recently prepared with the aid of an air survey,has permitted a new and more accurate area/capacity curve to be plotted.

As a result of the revised findings, the normal water level in the Weija impounding reservoir, if it is to provide water for the Accra-Tema municipal supply only, has been determined as 41 ft (corresponding to 38 ft in the Feasibility Report). The required normal water level in the impounding reservoir, if it is also to provide for irrigation,will be 47 ft.

2. Hydrological Data

a. Densu River Streamflow

The streamflow observation stations on the Densu River referred to in the present study are located at Nsawam, Manhia and Weija.

b. Available Records at Nsawam

Observations in Nsawam have been conducted at the Water Works as well as at the Nsawam Bridge, located a short distance downstream of the Water Works.

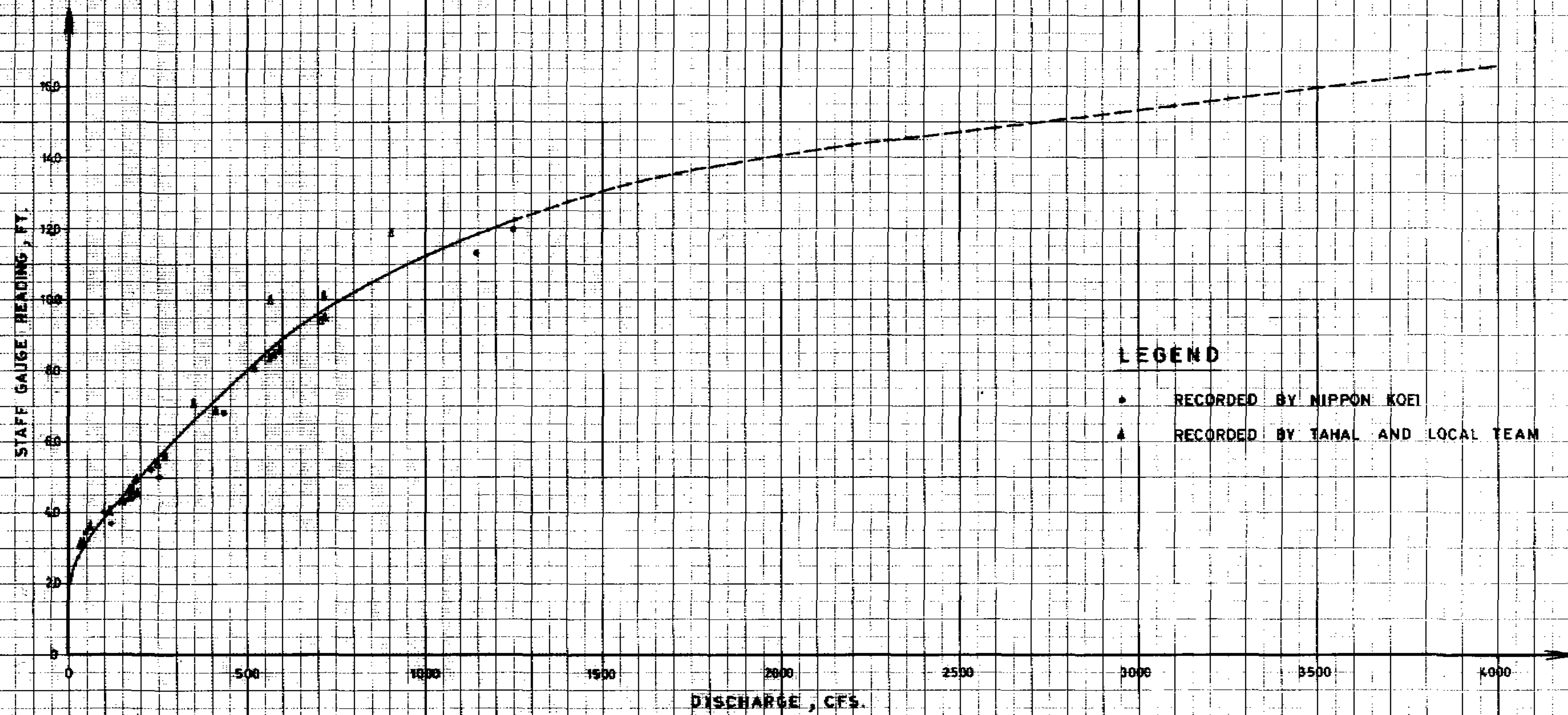
c. Nsawam Water Works Records

Flow records made at the Water Works are available for the period April 1945 through April 1965. The records for the period April 1945 to July 1949, only recently supplied to Tahal, are doubtful, since they are given in monthly totals, without a daily breakdown, and the method by which the entries were determined is unknown. The records for the period August 1949 to December 1954 were derived from daily measurements of river stages, a stage versus flow cross-section graph, and daily velocity measurements by floats. It is apparent from the data that the stage-discharge relations at the station are inconsistent and are probably affected by varying conditions downstream. The records for the period January 1955 to December 1959 are based on daily measurements of the depth of water directly over the boards of the outflow weirs ("surcharge" measurements). The spill level of the weirs varied as boards could be added or removed to control the water levels upstream. In computing the discharge over the weirs, free fall conditions were assumed at all times. The records for the period January 1960 to April 1965 are based on daily records of the crest levels of the boards and the corresponding water levels near the intake tower. The flows were computed by means of a weir formula - the head being the difference between the previous and the later levels. A constant weir coefficient and free fall conditions were assumed at all times. A summary of the monthly flow on record is given in Table 1.

d. The Nsawam Bridge Records

The Nsawam Bridge is equipped with a staff gauge attached to the upper face of one of the main piers. Daily readings of the gauge (one per day) are available for the periods October 1947 to October 1949 and March 1955 to December 1967. There is reason to believe that during the earlier period of observation, this staff gauge was installed 1.1 ft higher than during the later period. Not until recently were there sufficient data to calibrate the bridge station. Attempts to correlate the stage with the computed discharges at the Water Works yielded poor results. Late in 1965 and through 1966 the firm of Nippon Koei undertook the calibration of the station. The calibration work was resumed in September 1967 by a local team headed by Mr. Moneta of Tahal. The data gathered were used to plot an average rating curve for the Nsawam Bridge station (see Table 2 and Fig. 1).

Judging by the scatter of the points in the rating curve diagram, the station appears to be in a poor location and the discharges computed with the rating curve somewhat uncertain. Moreover, due to lack of discharge data at high stages, the corresponding flows as read from the extrapolated portion of the curve may be erroneous. An additional source of error is that of stage fluctuations during one and the same day. A summary of the computed monthly flows at Nsawam Bridge is given in Table 3.



RIVER DENSU — RATING CURVE AT NSAWAM BRIDGE

FIGURE 1

TABLE 1: RECORDED MONTHLY FLOWS AT NSAWAM WATER WORKS

(in thousand mg)

Year \ Month	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Annual
1945-1946	0.2	0.3	0.5	0.7	0.6	0.6	0.4	9.3	2.4	1.2	0.2	0.1	16.5
1946-1947	0.3	0.1	0.5	2.4	1.3	0.0	0.0	1.0	0.9	0.2	0.0	0.1	6.8
1947-1948	0.7	1.3	0.7	4.6	3.4	2.4	3.6	7.2	4.4	2.4	0.2	0.5	31.4
1948-1949	4.6	1.6	3.0	15.0	3.3	0.7	0.3	1.6	3.3	0.4	0.2	0.0	34.0
1949-1950	0.5	0.3	0.6	1.6	21.7*	6.4	22.6	2.4*	2.5*	1.0*	6.9*	0.2	66.7*
1950-1951	1.2	1.0	4.1	5.2	2.6	0.3	0.2	1.6	1.4	0.3	0.1	0.0	18.0
1951 1952	0.7	0.6	0.9	7.7	8.2	0.8	2.4	17.5	17.3	1.7	0.2	0.1	58.1
1952-1953	4.7	0.4	3.4	19.5	10.3	3.1	4.4	21.9	11.5	2.1	0.6	0.4	82.3
1953-1954	0.9	1.1	4.0	15.1	7.9	1.5	2.5	15.3	3.2	0.6	0.2	0.6	52.9
1954-1955	0.6	1.5	2.0	8.2	9.6	0.5	1.4	10.5	8.2	1.6	0.2	0.3	44.6
1955-1956	3.0	1.6	1.4	15.1	24.4	1.2	3.1	16.4	11.6	3.9	0.8	0.6	83.1
1956-1957	1.3	2.7	2.8	14.0	4.0	1.2	1.5	3.1	3.2	2.7	1.1	0.5	38.1
1957-1958	0.2	1.0	1.9	13.9	25.1	4.7	3.1	15.5	4.7	2.2	0.4	0.2	72.9
1958-1959	0.8	1.0	8.8	18.6	1.7	0.2	0.3	1.3	6.1	0.6	0.1	0.0	39.5
1959-1960	1.4	1.6	24.0	15.4*	0.5*	3.3	1.2*	13.5*	12.0*	2.1*	0.3*	1.0	76.5*
1960-1961	2.2	8.3	3.3	16.0	8.9	4.3	4.7	9.1	3.0	1.4	0.1*	0.1*	61.4*
1961-1962	0.1*	0.5*	0.2*	9.8*	18.4	2.6	2.2*	4.7	5.0	0.5	0.3	0.0*	44.3*
1962-1963	0.3	0.4	0.8	8.1	12.9	6.4	2.1	3.8	4.8	2.9	0.8	0.4	43.6
1963-1964	0.4	1.0	6.1	11.8	37.0	28.2	43.1	56.5	13.2	6.4	4.9	3.7	212.3
1964-1965	0.8	2.2	5.3	9.8	3.6	1.0	1.4	1.4	0.7	1.0	0.2	0.9	28.1
Mean	1.2*	1.4*	3.7*	10.6*	10.2*	3.5	5.0*	10.6*	6.0*	1.8*	0.9*	0.5*	55.6*

* Incomplete data. Flows are at least as great as indicated.

TABLE 1

TABLE 2: DISCHARGE MEASUREMENTS AT NSAWAM BRIDGE

a. Measurements by Nippon Koei

Date	Water level ft	Discharge cfs	Date	Water level ft	Discharge cfs
10 Nov. 1965	5.31	233	14 May 1966	3.45	49
23 Nov. 1965	4.70	173	6 June 1966	4.03	106
30 Nov. 1965	5.00	254	15 June 1966	12.00	1,253
22 Dec. 1965	3.70	124	1 July 1966	11.33	1,148
24 Jan. 1966	4.00	117	30 July 1966	6.85	434
11 Mar. 1966	3.09	36			

b. Measurements by Local Team and Tahal

Date	Water level ft	Discharge cfs	Date	Water level ft	Discharge cfs
30 Sept. 1966	11.90	907	19 Sept. 1967	8.46	576
19 Oct. 1966	6.80	408	21 Sept. 1967	10.08	721
29 Oct. 1966	8.60	591	22 Sept. 1967	9.95	569
24 Nov. 1966	5.56	265	23 Sept. 1967	7.05	343
5 Sept. 1967	3.13	41	23 Sept. 1967	6.15	270
11 Sept. 1967	3.20	39	24 Sept. 1967	5.35	242
12 Sept. 1967	3.60	64	25 Sept. 1967	4.66	177
13 Sept. 1967	4.00	116	25 Sept. 1967	4.40	170
14 Sept. 1967	4.93	188	6 Oct. 1967	8.35	565
14 Sept. 1967	4.64	168	8 Oct. 1967	9.40	707
15 Sept. 1967	4.33	154	9 Oct. 1967	9.50	718
15 Sept. 1967	4.30	150	17 Oct. 1967	4.50	192
18 Sept. 1967	8.07	515			

TABLE 3: COMPUTED MONTHLY FLOWS AT NSAWAM BRIDGE

(in thousand mg)

Year \ Month	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Annual
1948-1949	6.9	2.1	3.4	24.4	4.3	0.4	0.4	4.4	6.8	0.5	0.2	0.1	53.9
1955-1956	(1.0)	2.2	2.5	13.5	22.5	2.8	1.5	10.3	8.9	2.4	0.5	0.4	68.5
1956-1957	1.3	2.7	2.6	11.9	3.0	0.6	0.8	1.7	1.8	1.4	0.4	0.2	28.4
1957-1958	0.4	0.8	1.9	14.4	21.6	4.6	2.6	13.7	4.5	2.1	0.5	0.3	67.4
1958-1959	0.6	0.7	8.7	19.8	1.2	0.0	0.3	1.5	1.0	0.7	0.2	0.1	34.8
1959-1960	1.4	1.3	16.8	13.5	21.4	3.2	(4.0)	(14.3)	12.2	4.1	1.1	0.8	(94.1)
1960-1961	1.1	6.2	1.6	12.2	6.0	2.4	2.2	9.2	3.7	1.2	0.8	0.3	46.9
1961-1962	0.3	0.7	0.4	9.7	17.4	3.4	2.5	8.2	6.4	1.9	0.4	0.3	51.6
1962-1963	0.4	0.6	1.7	15.8	19.5	10.6	1.8	2.4	3.3	4.0	1.2	1.0	62.3
1963-1964	0.8	2.0	1.9	5.5	23.9	18.4	25.2	27.5	9.3	3.2	1.3	1.1	120.1
1964-1965	2.0	2.6	5.7	12.6	5.3	1.9	2.2	2.3	1.6	2.0	0.7	(1.4)	(40.3)
1965-1966	1.9	5.9	3.7	13.0	31.5	10.6	13.3	(24.0)	3.4	(2.4)	1.2	1.5	(112.5)
1966-1967	1.4	1.7	4.7	9.4	13.2	4.2	8.0	10.6	7.3	2.1	0.3	0.7	63.6
Mean	1.5	2.3	4.3	13.5	14.7	4.9	(5.0)	(10.0)	5.4	(2.2)	0.7	(0.6)	(65.1)

( ) **Estimated values**

e. Available Records at Manhia

In order to determine how much water is contributed by the part of the catchment area between Nsawam and Weija, a gauging station was established, late in 1967, near the village of Manhia, a short distance upstream of the Weija Reservoir. A local team headed by Mr. Moneta of Tahal conducted numerous discharge measurements to establish a rating curve for the station (see Table 4 and Fig. 2). The computed hydrograph for Manhia for the period September 1967 to December 1967 is shown in Fig. 3. The corresponding hydrograph at Nsawam Bridge and the monthly totals at both stations are included for comparison. It appears from this diagram that very little water,if any,was contributed below Nsawam during the last 4 months of 1967 (during the month of December the flow at Manhia was even less than that at Nsawam).

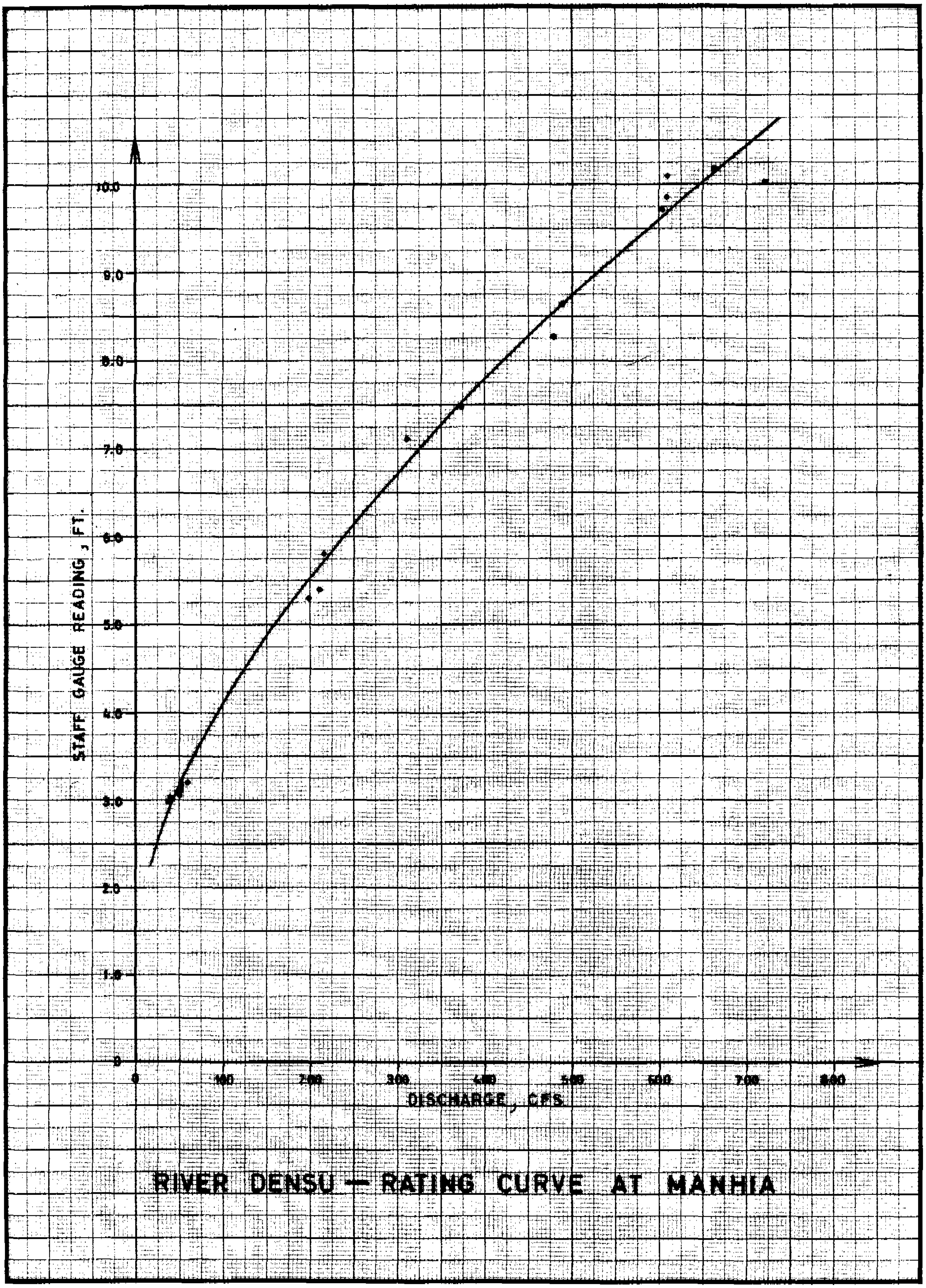
f. Available Records at Weija Reservoir

Water levels in the reservoir have been recorded since 1959. However, no records of the position of the gates have been kept to permit reliable estimates to be made of the outflow from the reservoir and hence of the inflow*. A study of the water level records indicates that a maximum level of +30.10 ft was reached on 24th July, 1961. On the assumption that all the gates were completely open, the outflow from the reservoir is estimated at 8,400 cfs. Since the corresponding maximum flow at Nsawam Bridge is computed at about 2,500 cfs, it can be deduced that a large amount of water was contributed between Nsawam and Weija during this event.

* Outflow data derived from available records of the position of the gates since August 1966 appear insufficient for computation.

TABLE 4: DISCHARGE MEASUREMENTS AT MANHIA

Date	Water level ft	Discharge cfs
5 Sept. 1967	3.02	43
6 Sept. 1967	3.00	43
7 Sept. 1967	3.09	50
7 Sept. 1967	3.15	53
8 Sept. 1967	3.12	54
8 Sept. 1967	3.07	51
9 Sept. 1967	3.21	62
5 Oct. 1967	8.28	479
6 Oct. 1967	8.79	554
7 Oct. 1967	9.40	576
8 Oct. 1967	9.72	605
9 Oct. 1967	10.05	721
10 Oct. 1967	10.20	663
11 Oct. 1967	10.11	609
12 Oct. 1967	9.87	609
13 Oct. 1967	8.65	490
14 Oct. 1967	7.12	313
15 Oct. 1967	7.49	375
17 Oct. 1967	5.80	218
18 Oct. 1967	5.39	214
19 Oct. 1967	5.30	200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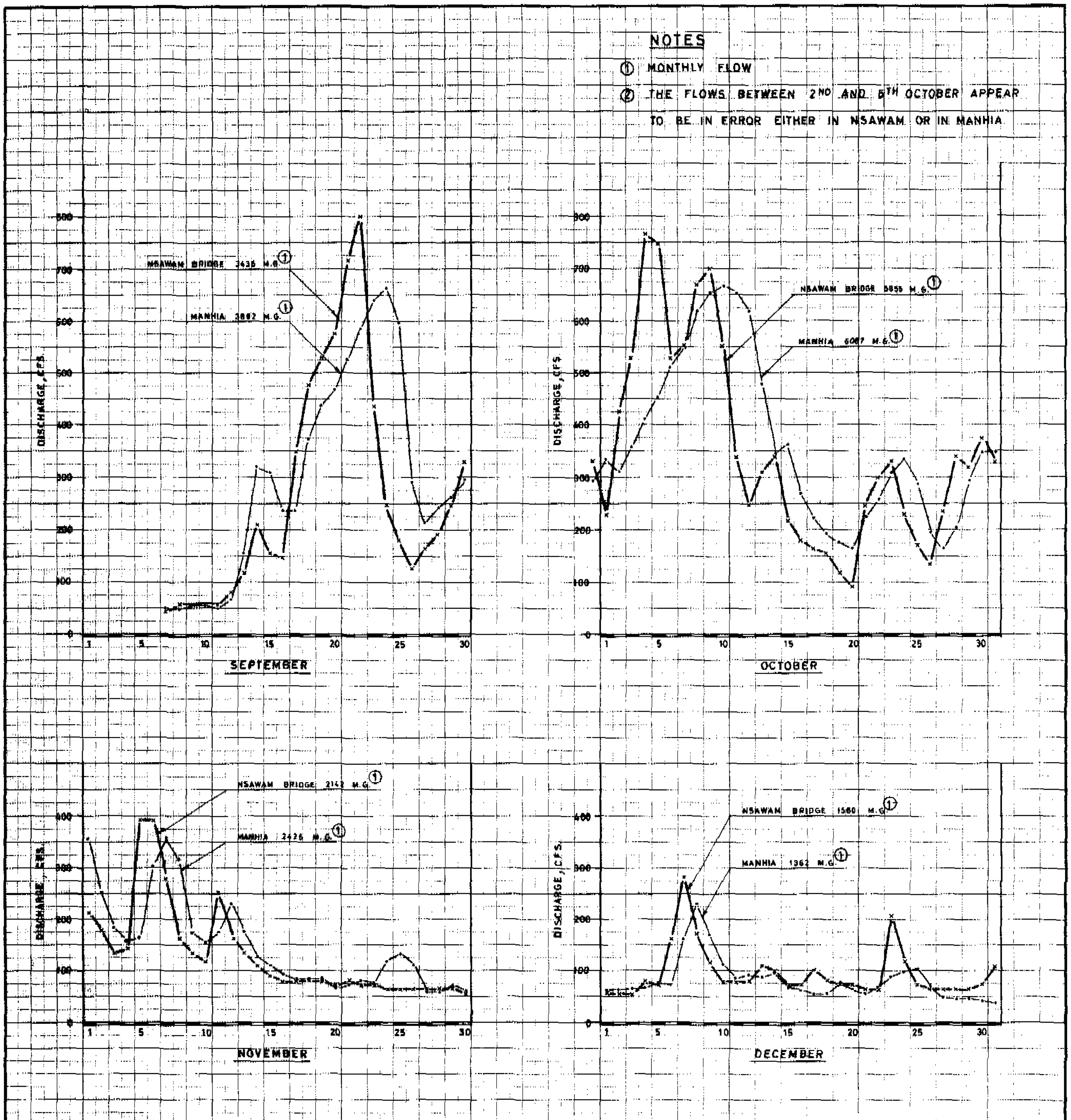
DISCHARGE, CFS.
RIVER DENSU — RATING CURVE AT MANHIA



RIVER DENSU — HYDROGRAPHS AT NSAWAM BRIDGE AND MANHIA FOR SEPTEMBER TO DECEMBER 1967

g. Rainfall

In Table 5 are listed the rainfall stations, located in or near the catchment area of the Densu River, whose records are available, their annual totals (March to February) and their means (see Fig. 4 for location). The station with the longest record is Nsawam (records kept since 1928 with a few interruptions). Based on the means of each station, the mean annual rainfall over the catchment area above Nsawam (583 sq.m) was computed to be about 56 inches, and that over the area between Nsawam and Weija (367 sq.m) about 38 inches.

The rainfall data of Nsawam indicate a minimum of 33.19 inches in 1946-47, followed by 35.35 inches in 1929-30. The records in Aburi indicate a value as low as 28.72 inches in 1958-59.

h. Evaporation

The nearest evaporation station is in Accra. The Nippon Koei Ltd. Preliminary Report on Comprehensive Development Project of Water Resources reports evaporation in Accra as 57.55 inches per year as derived from pan measurements. The monthly breakdown of evaporation in Accra is given in Table 6. Figures for evaporation in Accra are available also in the report for the Volta River Project (prepared in 1956 by Sir W. Halcrow & Partners). In this report the measured evaporation was 64.9 inches and the computed evaporation was 62.2 inches.

TABLE 5: ANNUAL* RAINFALL OVER THE DENSU RIVER CATCHMENT AREA

(inches)

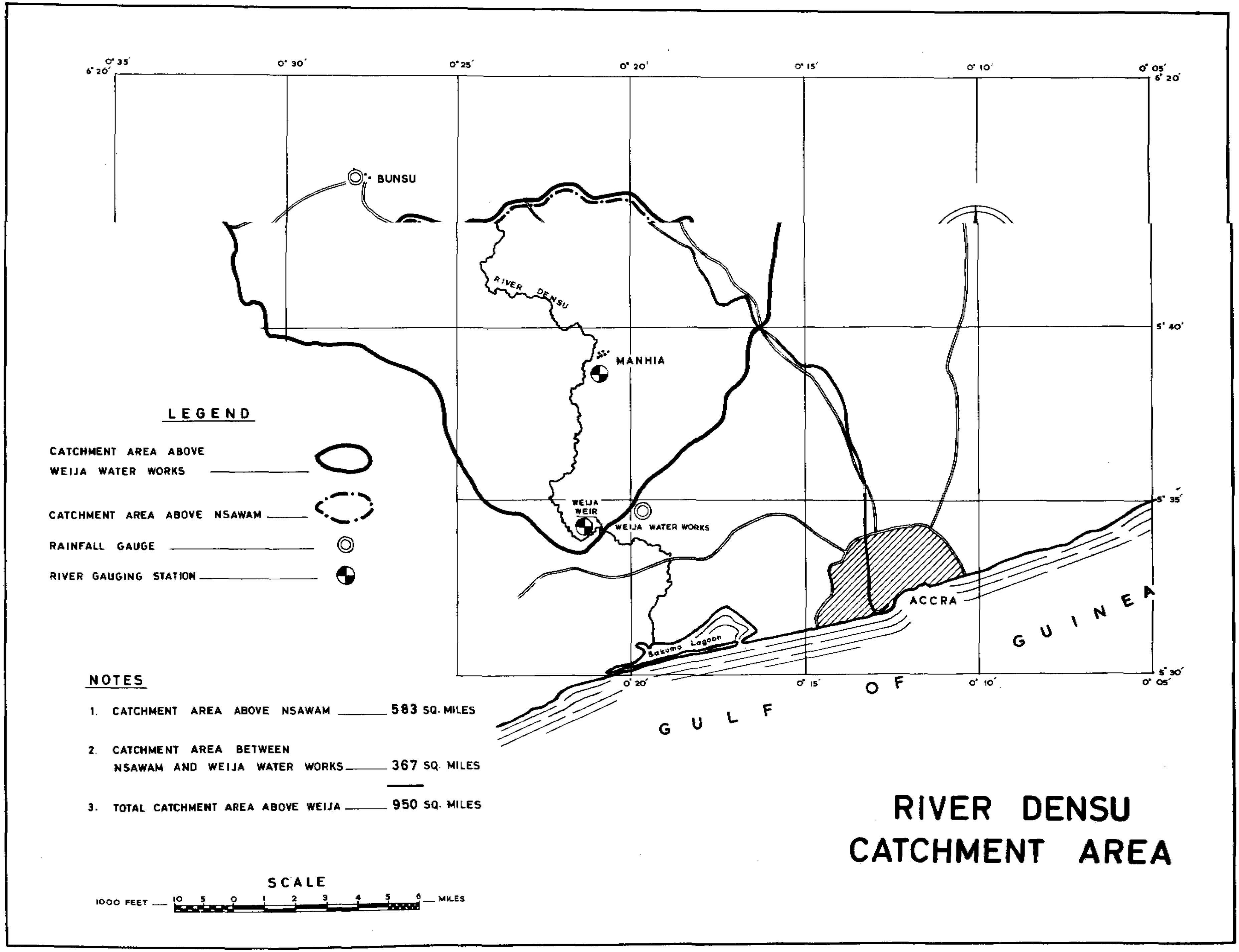
Year	Weija	Adeiso	Nsawam	Aburi	Asuboi	Sohum	Akropong Akwapim	Koforidua	Oyoko	Apedwa	Kibi	Tafo	Bunsu
1928-1929			45.88**										55.11
1929-1930			35.35**				39.20						73.99
1930-1931			50.55**				55.15**						58.12**
1931-1932			(62.34)**				54.15**						65.27**
1932-1933							40.04**						60.28**
1933-1934			56.57**				60.24**						66.74**
1934-1935			51.30**				59.31**						61.00**
1935-1936			51.54**				59.53**				59.30		71.40**
1936-1937			43.12**	43.31			54.00**				74.70		67.82**
1937-1938			45.53**	37.51			43.24**				68.02**		64.56**
1938-1939			44.26**	50.14							62.23**		
1939-1940		52.08	49.81**	52.71			55.08				77.53		70.79
1940-1941		(60.96)	56.45	51.60		55.26					70.16	57.00	
1941-1942			47.57	47.47		(74.18)					79.86	60.13	
1942-1943		(42.59)	47.98	55.17		(64.26)					75.45	56.98	
1943-1944		50.29	46.20	52.10		55.47	44.95				58.01	68.96	68.04
1944-1945			50.88	54.93		42.76	44.43				61.02	53.09	54.66
1945-1946			(39.88)	43.71		55.44						65.86	72.86
1946-1947			33.19	35.29		47.81	38.34**				55.20	50.57	52.30
1947-1948			47.86	52.25		(55.55)	55.56**					71.34	70.49
1948-1949			41.77	36.23		(39.72)	41.96**					65.91	54.57
1949-1950			46.06	47.19		(62.23)			55.03		60.36	74.20	71.94
1950-1951			40.26	41.60		46.35	34.97		46.28		53.74	58.80	57.10
1951-1952			61.71	47.45		(57.82)			73.11		70.57	66.48	76.44
1952-1953			52.43	48.63		61.00			60.16		79.28	67.84	77.00
1953-1954		47.61	52.94	41.95		43.60	38.21	59.54	59.36		71.32	57.43	56.01
1954-1955		50.65	43.05	38.95		49.49	39.14	49.24	47.64		76.46	54.08	76.64
1955-1956		45.14	49.72	52.78	52.22	61.89	52.69	65.68	56.61	65.97	64.82	69.41	67.91
1956-1957		49.75	37.15	38.29		52.90	41.70	46.85	52.53	59.62	61.49	53.78	65.55
1957-1958		50.86	56.95	43.62	67.30	56.17		53.72	65.31	75.92	70.02	74.46	79.51
1958-1959		41.93	36.13	(28.72)		47.18		52.02	52.00		62.01	59.22	63.10
1959-1960		52.79	46.49	49.25		(72.04)	56.17	75.45	75.84	75.34	81.38	71.97	76.35
1960-1961		52.74	46.56	36.15	36.20	53.77		50.88	58.57	66.17	65.21	73.09	70.57
1961-1962		57.91	55.02	48.50		55.74		50.36	48.63			53.93	62.49
1962-1963	33.65	52.68	59.70	47.47	45.03	78.06		53.97	54.34	60.53	56.45	63.98	72.89
1963-1964		63.47	69.58	55.60		81.99		75.46		87.75	70.18	79.35	88.05
1964-1965		46.14	40.63	38.16	51.46	42.80		46.34		63.05	56.02	62.05	73.47
1965-1966	28.36	53.79	63.84	61.64	46.54	67.19		70.43	67.47	70.73		74.10	89.39
1966-1967	(18.15)	(48.33)	(39.54)	(47.04)	(63.03)	(56.46)		(59.45)	56.06			(61.47)	69.72
Mean		50.98	48.57	45.58		56.94	48.00	57.82	58.06		66.95	63.95	68.06

Notes:

* March through February

** Only monthly sums available

( ) The missing daily data were filled in with rainfall data from neighbouring stations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BUNSU
RIVER DENSU
MANHIA
WEIJA WEIR
WEIJA WATER WORKS
Sakumo Lagoon
ACCRA
GULF OF GUINEA
LEGEND
CATCHMENT AREA ABOVE WEIJA WATER WORKS
CATCHMENT AREA ABOVE NSAWAM
RAINFALL GAUGE
RIVER GAUGING STATION
NOTES
1. CATCHMENT AREA ABOVE NSAWAM 583 SQ. MILES
2. CATCHMENT AREA BETWEEN NSAWAM AND WEIJA WATER WORKS 367 SQ. MILES
3. TOTAL CATCHMENT AREA ABOVE WEIJA 950 SQ. MILES
SCALE
1000 FEET 10 5 0 1 2 3 4 5 6 MILES
RIVER DENSU CATCHMENT AREA

FIGURE 4

TABLE 6: MONTHLY EVAPORATION AT ACCRA

Month	Inches
March	6.17
April	4.92
May	5.01
June	4.13
July	3.54
August	4.02
September	4.58
October	5.35
November	5.05
December	4.82
January	4.77
February	5.19
Annual	57.55

3. Flow Analysis

a. General Considerations

In Table 7, a summary is presented of all the annual flows on record. A review of the available flow data in para. 2 reveals that the flow records of Nsawam Water Works lack homogeneity and that the records, at least for the earlier period, may be unreliable. Furthermore, very few flow data are available for Weija. Thus, the flow data from Nsawam Bridge are the only consistent set of records which can be used for planning the Weija Project. However, these records also have obvious shortcomings, the most important of which is the relatively short period for which they are available. Another difficulty is that the records overlook the

TABLE 7: RECORDED AND SYNTHESIZED ANNUAL FLOWS AT NSAWAM AND WEIJA

(thousand mg)

Year Mar. - Feb.	Recorded		Synthesized	
	Nsawam Water Works	Nsawam Bridge	Nsawam	Weija
1940 - 1941			25	64
1941 - 1942			49	59
1942 - 1943			68	88
1943 - 1944			53	58
1944 - 1945			25	40
1945 - 1946	16		39	39
1946 - 1947	7		11	12
1947 - 1948	31		46	50
1948 - 1949	34	54	51	63
1949 - 1950	67*		66	71
1950 - 1951	18		27	27
1951 - 1952	58		69	83
1952 - 1953	82		78	95
1953 - 1954	53		41	58
1954 - 1955	45		31	38
1955 - 1956	83	69	63	69
1956 - 1957	38	28	27	30
1957 - 1958	73	67	79	115
1958 - 1959	40	35	57	65
1959 - 1960	76*	(94)	68	70
1960 - 1961	61*	47	55	58
1961 - 1962	44*	52	45	70
1962 - 1963	44	62	90	111
1963 - 1964	212	120	193	240
1964 - 1965	28	(40)	40	45
1965 - 1966		(112)	109	140
1966 - 1967		63	60	64
Mean				
1940/41-1966/67			58	71
1955/56-1966/67		(65)	74	
1949/50-1964/65	64*		64	
1945/46-1948/49	22		37	

( ) Estimated

* Incomplete

fact that water may be contributed downstream from Nsawam, as happened in July 1961. A study of the Water Works data in Table 7 shows that overlooking a year like 1946-47 may result in a gross underestimate of the required capacity of the reservoir. The study of Nsawam rainfall leads to similar conclusions.

In order to overcome the difficulties mentioned above, it was decided to attempt to synthesize the known flows of the bridge using rainfall data. A successful synthesis would permit the flow records to be extended into the past for as long as rainfall data are available. Similarly, rainfall data could be used to compute the additional flows downstream of Nsawam - the "guidelines" here would be the flow during the later part of 1967 and the flood of July 1961.

b. The Method of Synthesis

The method of synthesis that has been adopted is a daily, two zones, soil moisture accounting procedure in which rainfall, evapotranspiration and runoff are the main components.

The upper layers of the soil (upper zone) are continuously subjected to potential evapotranspiration, a process which upsets the moistening of the soil by rains. Whenever the upper zone is sufficiently moist the additional rain that arrives may flow as surface runoff and/or enter the lower layers of the soil (lower zone), and eventually continue as subsurface flow into the river system. When the moisture in the upper zone has been completely evaporated, evapotranspiration continues from the lower zone, but at a reduced rate. The magnitude of both the surface and the subsurface flow components are functions of the rain, the prevailing lower zone moisture and the character of the soil and vegetative cover. Upon arrival at the river channels the flow is routed downstream through the river system. The entire simulation procedure has been programmed on an I.B.M. 1800 digital computer. The input to the programme consists of daily rainfall at various locations in the watershed, monthly evaporation values, and a group of constants representing the soil type and cover and the watershed geometry. The output consists of daily flows at selected points in the watershed. A flow chart of the simulation programme is depicted in Fig. 5.

c. Flow Synthesis at Nsawam

The synthesis was conducted with the rainfall in Nsawam, Suhum and Tafo, and the evaporation in Accra as inputs. The choice of the rainfall stations was dictated by the extent of the available daily records (1940-41 to 1966-67 with few interruptions) and by the fact that the average of the mean annual rainfall at the three stations resembles the mean over the watershed. There was no better alternative than the evaporation in Accra but it is not anticipated that a sizable error was introduced here.

As the rainfall that prevails in the region is reported to be of the shower type, it was not expected that each of the flood events could be accurately reproduced with only 3 rainfall stations. On the other hand, discrepancies should balance out in the long run, suggesting that for a meaningful synthesis it would be required that, at least, the averages of groups of years are successfully reproduced.

In Table 7 the synthesized and the observed flows at Nsawam are compared. With respect to the Nsawam Bridge data it can be seen that, with the exception of the year 1963-64*, the synthetic data follow the recorded observations quite closely with more or less equal deviations to either side. This is not the case when the first 4 years of the Water Works records are compared with the synthesized data - a fact which reinforces our previous reluctance

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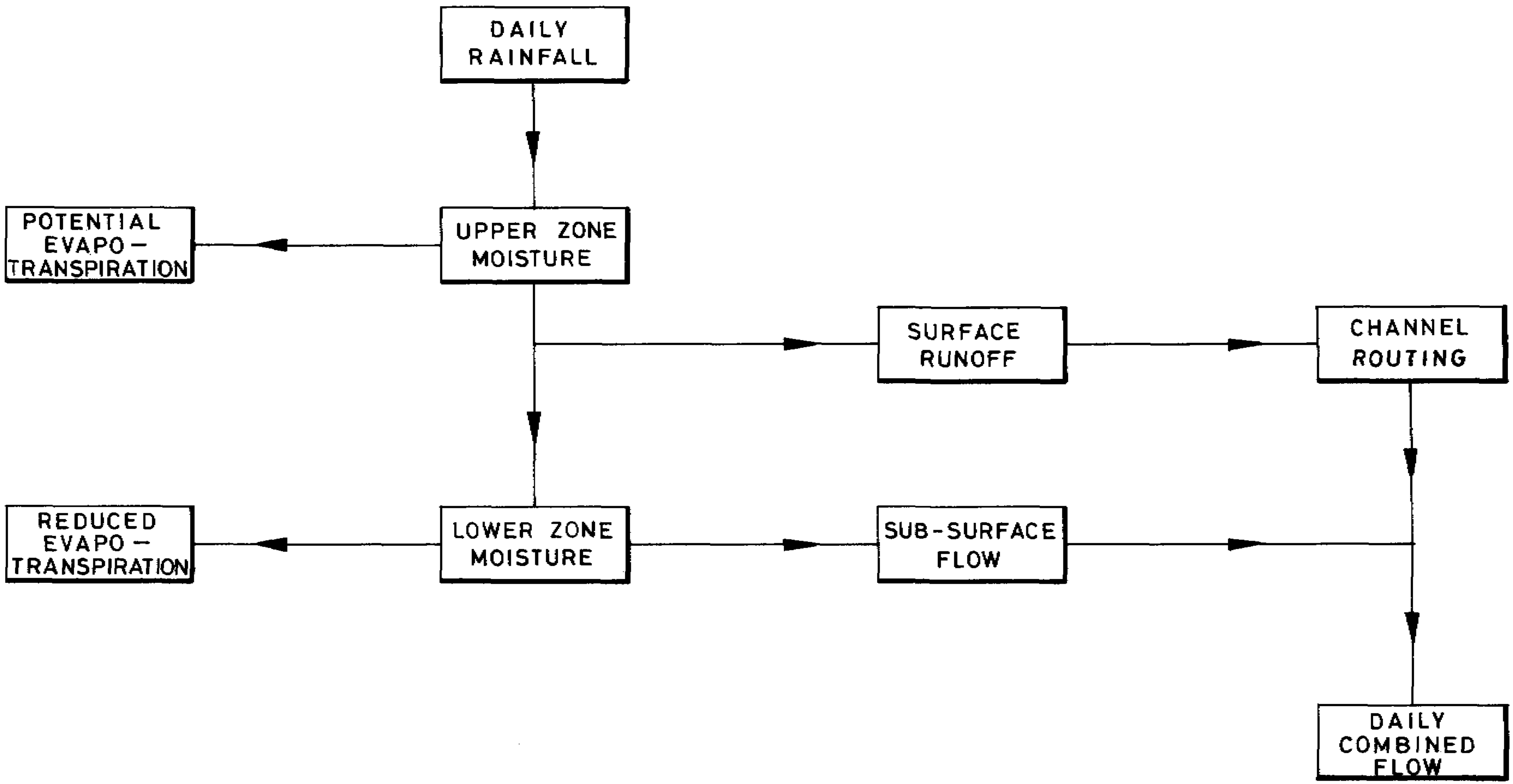
* The discrepancy may be partly the result of underestimating the flows at Nsawam Bridge during high stages.



COMPUTER FLOW CHART FOR HYDROGRAPH SIMULATION PROGRAMME

(SIMPLIFIED)

FIGURE 5

TABLE 8: SYNTHESIZED MONTHLY FLOWS AT NSAWAM

(in thousand mg)

Year \ Month	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Annual
1940-1941	0.2	0.1	0.3	7.8	4.4	0.9	1.3	5.5	3.5	1.1	0.2	0.0	25.3
1941-1942	0.0	1.3	4.2	4.0	12.0	5.9	4.3	11.1	4.3	0.9	0.2	0.7	48.9
1942-1943	0.7	1.4	11.9	24.3	8.2	1.7	0.5	12.4	5.7	1.3	0.3	0.1	68.5
1943-1944	0.0	0.1	10.5	13.6	8.3	1.7	0.3	5.3	8.1	3.8	0.7	0.1	52.5
1944-1945	0.0	0.2	3.1	2.5	7.4	1.4	4.2	4.5	1.3	0.3	0.1	0.0	25.0
1945-1946	0.6	1.3	1.2	1.2	7.8	4.2	1.6	12.8	4.7	3.1	0.5	0.1	39.1
1946-1947	0.9	0.8	0.6	2.5	1.8	0.3	0.1	2.5	1.5	0.3	0.1	0.0	11.4
1947-1948	1.1	2.8	1.5	4.2	5.5	4.5	10.1	10.7	2.8	1.8	0.3	0.4	45.7
1948-1949	4.1	2.3	4.5	22.4	10.7	1.8	0.4	0.1	2.9	1.1	0.4	0.1	50.8
1949-1950	0.9	0.2	0.4	4.3	25.0	9.5	9.5	7.9	1.5	2.2	4.0	0.8	66.2
1950-1951	1.3	4.9	5.7	3.4	2.9	0.6	0.1	1.6	5.4	1.0	0.2	0.0	27.1
1951-1952	0.8	1.5	1.6	7.6	11.4	2.8	0.6	19.7	17.6	4.3	0.8	0.2	68.9
1952-1953	4.1	3.8	4.0	14.6	10.5	3.2	3.8	21.5	10.3	2.0	0.4	0.1	78.3
1953-1954	0.2	0.1	1.4	11.7	10.4	3.1	0.6	8.6	2.8	0.6	0.1	1.2	40.8
1954-1955	0.8	2.4	3.0	5.0	6.6	1.2	1.8	6.7	2.6	0.5	0.1	0.0	30.7
1955-1956	1.7	1.6	0.3	6.0	14.7	3.9	0.8	11.0	19.5	3.0	0.6	0.1	63.2
1956-1957	0.0	4.6	7.1	10.4	3.9	0.8	0.2	0.1	0.3	0.3	0.1	0.0	27.8
1957-1958	0.0	2.3	4.2	17.5	41.1	8.5	1.7	2.6	0.6	0.1	0.0	0.0	78.6
1958-1959	0.8	1.0	14.4	30.2	7.1	1.4	0.3	0.9	0.4	0.1	0.0	0.0	56.6
1959-1960	2.0	2.2	11.5	9.8	21.3	5.7	1.2	5.8	7.0	1.5	0.3	0.1	68.4
1960-1961	0.4	6.5	1.7	13.5	14.5	2.3	2.3	10.4	2.1	0.7	0.3	0.1	54.8
1961-1962	0.0	0.2	0.4	9.6	22.4	7.8	1.6	2.3	1.0	0.2	0.0	0.0	45.5
1962-1963	0.4	0.5	1.4	20.8	29.0	9.7	1.9	3.3	9.6	11.3	1.7	0.3	89.9
1963-1964	0.8	3.7	1.9	8.0	32.6	22.0	41.5	69.7	10.1	2.1	0.4	0.1	192.9
1964-1965	1.2	5.5	11.0	14.0	6.4	1.2	0.3	0.2	0.1	0.0	0.0	0.5	40.4
1965-1966	0.5	3.3	4.1	18.4	33.4	9.5	5.7	28.8	4.0	0.8	0.2	0.2	108.9
1966-1967	2.3	0.4	2.1	7.0	15.8	6.6	6.0	9.1	9.0	1.5	0.3	0.1	60.2
Mean	1.0	2.0	4.2	10.9	13.9	4.5	3.8	10.2	5.1	1.7	0.5	0.2	58.0

to accept these records. The Water Works records for the period 1949-50 to 1964-65, including the year 1963-64, are more or less in agreement with the synthesized set.

Table 8 shows the synthesized monthly flows at Nsawam since 1940-41. To what extent the synthesized flows during dry periods resemble the observed ones can be seen in Table 9, which compares the accumulated observed and accumulated synthesized monthly flows during the five driest periods on record (since 1950-51). Here again, the apparent deviations to either side tend to be cancelled out when the totals are compared.

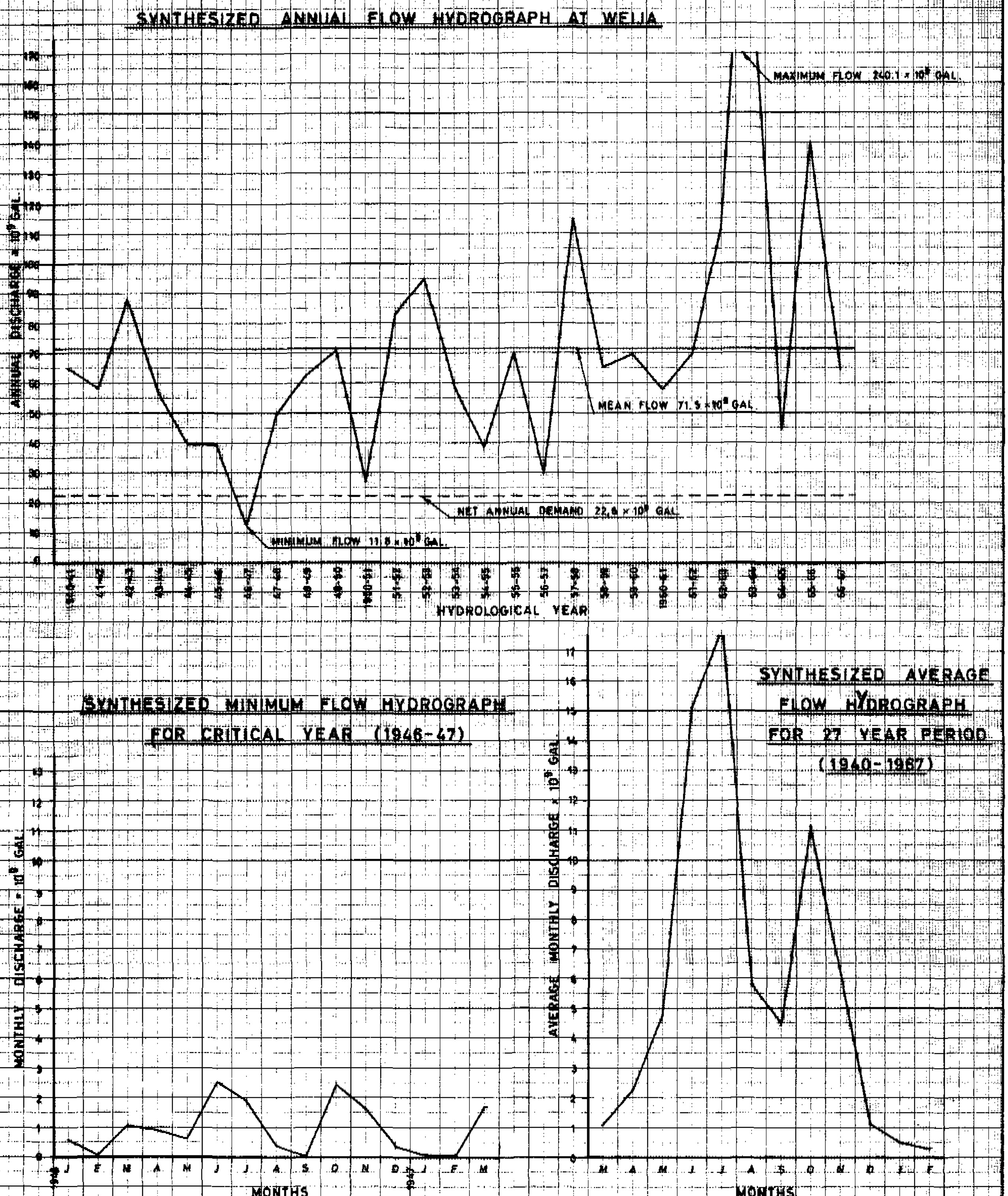
TABLE 9: A COMPARISON BETWEEN RECORDED AND SYNTHESIZED FLOWS DURING THE FIVE DRIEST PERIODS ON RECORD

Period of Dry Flow	No. of Months	Place	Observed Flow (1,000 mg)	Synthesized Flow (1,000 mg)
10/49 - 5/51	20	Nsawam Water Works	33.2	47.4
11/53 - 5/55	19	Nsawam Water Works	55.2	39.0
12/55 - 5/57	18	Nsawam Bridge	34.8	38.0
11/57 - 4/59	18	Nsawam Bridge	44.9	61.5
12/63 - 5/65	18	Nsawam Bridge	57.4	50.9
Total			225.5	236.8

d. Flow Synthesis at Weija (see Fig. 9)

The synthesized flows at Weija were obtained by routing the synthesized flows in Nsawam down the Densu River and adding to them the computed contributions from the area below Nsawam. As there is no representative rainfall station with long records below Nsawam, the additional flows were synthesized with the rainfall of Nsawam multiplied by 0.8. It was thus guaranteed

FIGURE 9



RIVER DENSU — SEASONAL AND CYCLIC FLOW VARIATIONS AT WEIJA that the accumulated rainfall input to the programme would check, on the average, with the actual accumulated rainfall over the area (as judged from the mean annual rainfall at Nsawam and over the area below Nsawam). Since the actual daily rainfall between Nsawam and Weija may not always be in the above relation, the synthesized flows at Weija must be considered to some extent as hypothetical rather than a true reproduction of the past. In Table 7 the synthesized annual flows at Nsawam and at Weija are compared. The table shows that while in some years the contribution downstream of Nsawam is nil, it is by no means negligible in other years. It should be noted that the flood of July 1961 was computed at about 9,400 cfs (against 8,400 cfs - the estimated outflow from the reservoir) and that hardly any additional flow was computed from September to December 1967 - a fact which checks with the available records of Nsawam Bridge and Manhia. The synthesized monthly flows at Weija are given in Table 10.

TABLE 10: SYNTHESIZED MONTHLY FLOWS AT WEIJA

(in thousand mg)

Year \ Month	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Annual
1940-1941	0.2	0.3	1.6	28.5	13.3	2.5	1.6	8.5	5.7	1.8	0.4	0.1	64.5
1941-1942	0.0	3.2	6.0	4.6	14.1	6.6	5.3	12.8	4.7	1.0	0.2	1.3	58.8
1942-1943	0.8	1.5	13.4	34.9	11.4	2.2	0.6	13.5	7.2	1.6	0.3	0.1	87.5
1943-1944	0.0	0.1	11.4	15.7	9.6	1.9	0.4	5.5	8.0	4.2	0.7	0.1	57.6
1944-1945	0.0	0.3	3.8	4.3	14.4	2.6	7.1	5.4	1.5	0.3	0.1	0.0	39.8
1945-1946	0.7	1.2	1.2	1.2	7.7	4.3	1.5	12.4	5.2	3.1	0.6	0.1	39.2
1946-1947	1.1	0.9	0.6	2.6	1.9	0.3	0.1	2.4	1.5	0.3	0.1	0.0	11.8
1947-1948	1.6	4.2	1.9	5.6	5.9	4.5	9.7	11.1	2.6	2.1	0.3	0.4	49.9
1948-1949	5.5	4.5	6.1	27.0	12.4	2.0	0.4	0.1	2.8	1.1	0.4	0.1	62.4
1949-1950	0.9	0.2	0.6	3.9	25.4	10.6	10.1	10.0	1.8	2.1	4.2	0.8	70.6
1950-1951	1.2	4.8	5.7	3.7	2.9	0.6	0.1	1.5	5.5	1.0	0.2	0.0	27.2
1951-1952	1.1	1.6	3.0	8.0	12.8	3.4	0.7	20.8	24.8	5.7	1.1	0.2	83.2
1952-1953	3.5	4.5	3.9	21.6	14.9	3.8	5.9	23.0	11.3	2.1	0.4	0.1	95.0
1953-1954	0.2	0.1	2.4	18.6	14.3	4.1	0.8	11.3	3.5	0.7	0.1	2.1	58.2
1954-1955	1.4	2.9	3.4	5.4	10.9	1.7	1.8	7.2	2.8	0.6	0.1	0.0	38.2
1955-1956	1.8	1.8	0.4	7.1	17.0	4.8	1.0	7.4	23.9	3.4	0.7	0.1	69.4
1956-1957	0.0	4.5	7.0	11.5	4.6	0.9	0.2	0.1	0.3	0.3	0.1	0.0	29.5
1957-1958	0.0	2.2	5.6	31.7	57.8	12.0	2.3	2.7	0.6	0.1	0.0	0.0	115.0
1958-1959	0.8	0.9	13.8	37.3	9.1	1.7	0.3	0.8	0.5	0.1	0.0	0.0	65.2
1959-1960	1.9	2.3	11.9	10.3	21.1	6.2	1.2	5.8	7.1	1.5	0.3	0.1	69.7
1960-1961	0.4	6.7	1.9	13.5	17.0	2.5	1.3	11.4	2.3	0.7	0.3	0.1	58.1
1961-1962	0.0	0.3	0.4	13.9	37.6	11.8	2.3	2.4	1.1	0.2	0.1	0.0	70.1
1962-1963	0.6	0.5	1.9	28.9	37.9	11.4	2.2	4.0	10.1	11.8	1.8	0.3	111.4
1963-1964	1.0	3.6	2.1	8.3	41.2	32.6	52.0	81.5	14.6	2.6	0.5	0.1	240.1
1964-1965	1.4	7.5	12.4	13.6	7.2	1.2	0.3	0.2	0.1	0.0	0.0	0.6	44.5
1965-1966	0.5	3.1	4.4	27.4	48.4	13.7	6.2	30.2	4.7	0.9	0.2	0.1	139.6
1966-1967	3.6	0.5	2.7	7.7	16.2	6.9	5.4	9.4	9.5	1.5	0.3	0.1	63.8
Mean	1.1	2.3	4.8	15.1	18.0	5.8	4.5	11.1	6.1	1.9	0.5	0.3	71.5

D. WEIJA IMPOUNDING RESERVOIR - STORAGE STUDIES

1. Water Demand

The water demand is based on the requirements for Accra-Tema second stage project of 40 mgd*, as defined in the Feasibility Study (see Volume One, Chapter IV), and on the irrigation needs of 30,000 acre ft per annum, as defined in the "Report on Irrigation Feasibility in the Densu Basin from the Proposed Reservoir at Weija", prepared by the Irrigation, Reclamation and Drainage Division of the Ministry of Agriculture (see Fig. 10).

2. Impounding Reservoir

An air-photo survey of the reservoir area has recently been carried out and the topography of the impounding reservoir has been studied. Area/capacity curves have been calculated and drawn (see Fig. 6) based on the topography (see Fig. 11).

3. The Critical Year

Table 7 shows that the minimum annual flow as synthesized at Nsawam is 11 mg (12 mg at Weija) during 1946-47, while the minimum annual flow on record, if the first 4 years of records at Nsawam Water Works are ignored, is 18 mg during 1950-51. Thus, the flow during 1946-47 was 2/3 of the minimum flow recorded. This will undoubtedly have a decisive influence on the computations of the required capacity of the reservoir. To what extent the synthesized flows should be accepted at their face value, it is hard to say. Both the nature of the rainfall input into the simulation programme, and the extreme sensitivity of the flow output, at the low range of flows, to the watershed constants, suggest that the chances for

* The 40 mgd has been taken as uniform supply throughout the year. This will permit continuous full use of the proposed 40 mgd works from Weija to Accra if found desirable.

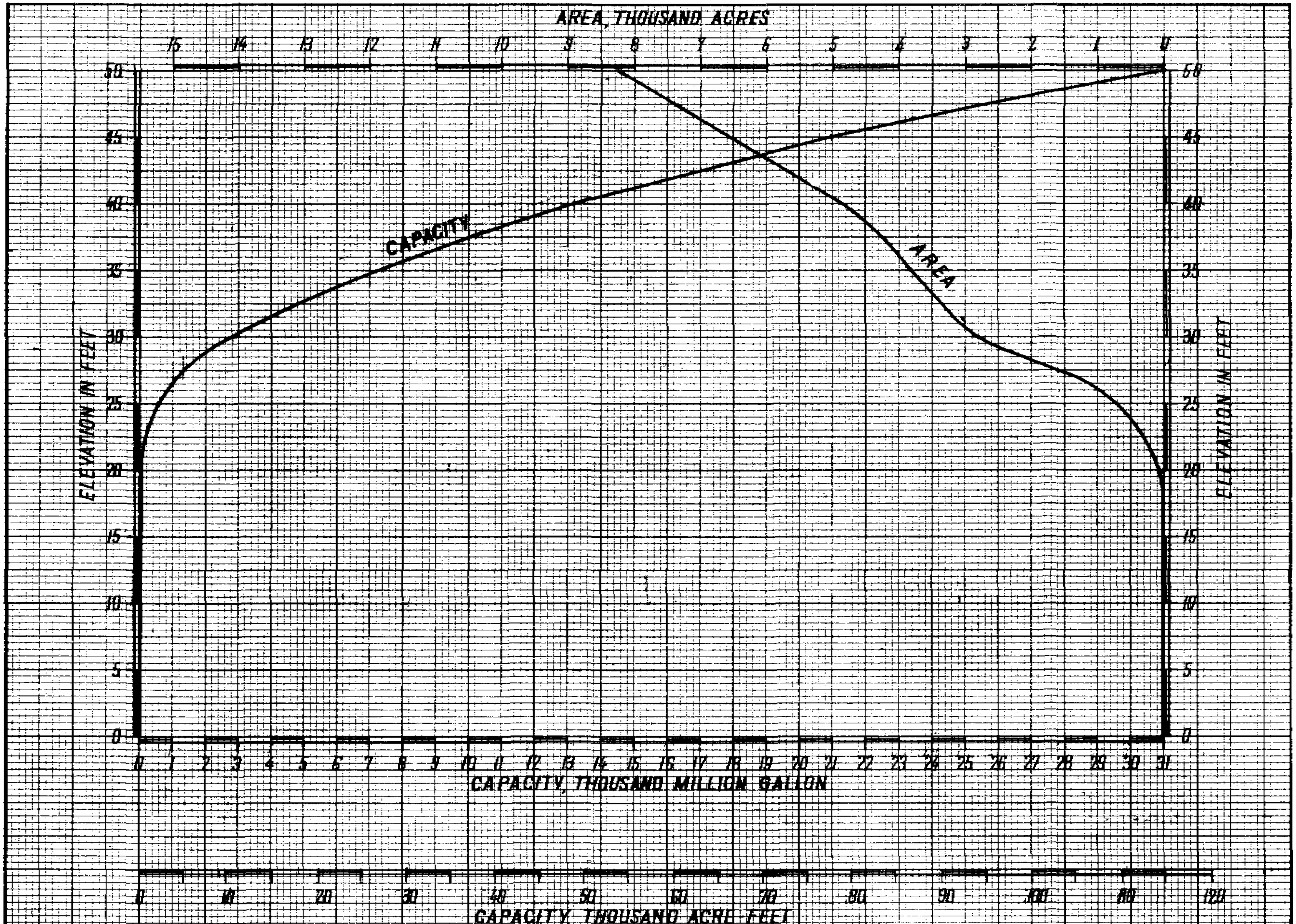
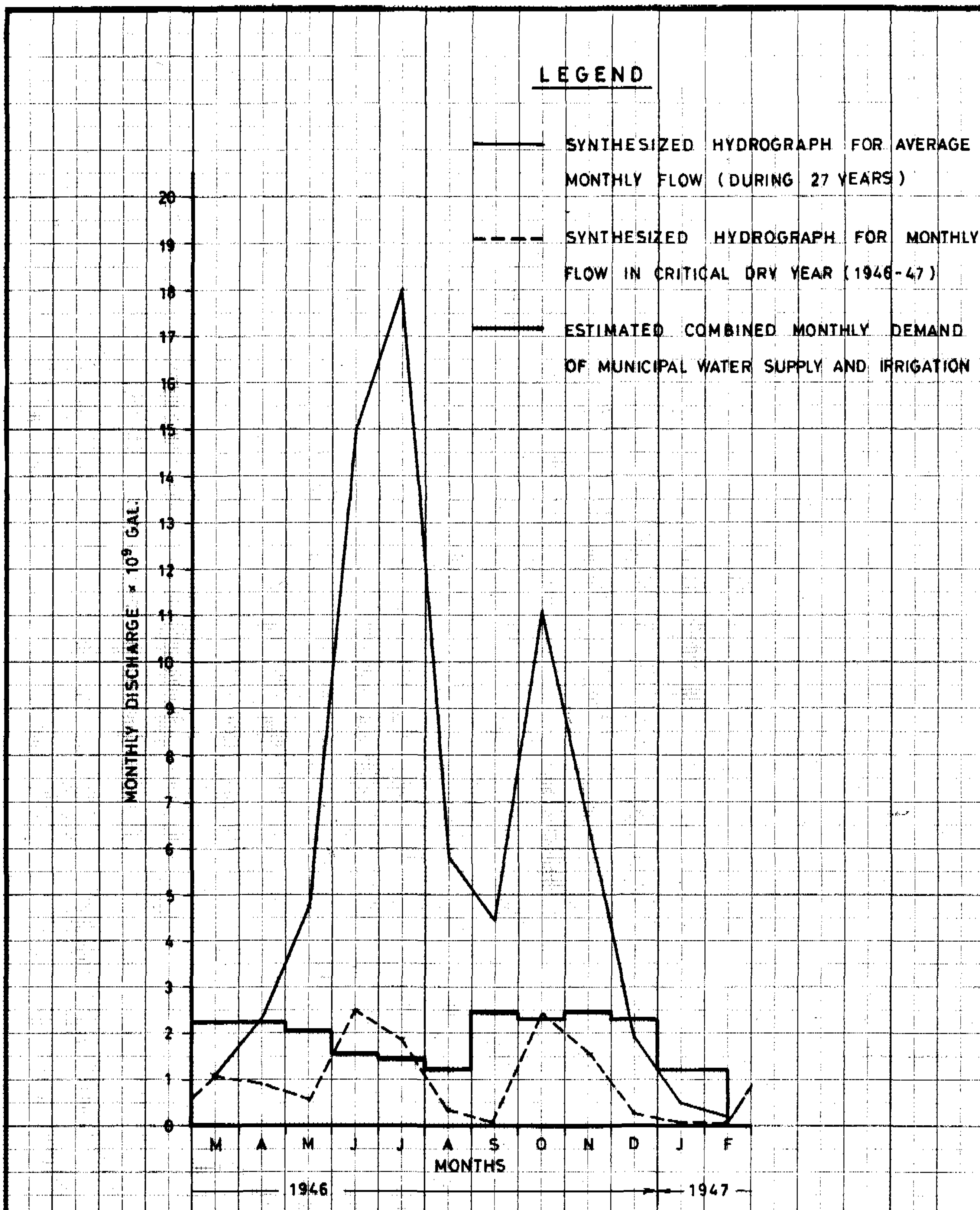


FIGURE 6

WEIJA IMPOUNDING RESERVOIR
AREA CAPACITY CURVE



RIVER DENSU — TOTAL DEMAND VERSUS AVERAGE AND MINIMUM FLOW exact reproduction are very small indeed. On the other hand, a study of the rainfall records in Table 5 shows that the year 1946-47 had less rain than 1950-51, judged either by the average of Nsawam, Suhum and Tafo (43.9 inches against 48.5 inches) or by the average of all the 7 stations for which records are available (44.6 inches against 47.4 inches). Hence, everything else being equal, 1946-47 should have a lower flow than 1950-51, and this is indicated by the synthesis. Another argument in favour of relying on the magnitude of the synthesized flows is that although the records at Nsawam Water Works for the period 1945-46 to 1948-49 have been ruled out as unreliable, their common feature - that they are systematically lower than the respective synthesized flows - can be used to estimate the actual flow during 1946-47. If the recorded value of 7 mg during 1946-47 is multiplied by the ratio of the synthesized to recorded flows during the 4 year period (37/22 = 1.7, see Table 7) the result is 12 mg at Nsawam (against 11 mg - synthesized). It is concluded that although the flow during 1946-47 was probably not exactly as synthesized, nevertheless the magnitude of the synthesized flow is within close range of the actual.

4. Reservoir Operation Study

After hypothetical inflow data for 27 years have been obtained, the required capacity can be found by a monthly reservoir operation study. The information needed to make the calculation is as follows:

(a) A capacity versus elevation graph for the proposed reservoir (Fig. 6).

(b) A list of monthly water demands for municipal supply and for irrigation (Table 11).

(c) Monthly evaporation, rainfall and seepage values (Table 12).

(d) An allowance for dead storage - 500 mg

(e) Upstream consumption*

Based on the synthesized flows* at Weija and on the above information, it is found that the critical period would have started in January 1946 and ended 15 months later in April 1947. The capacity of the reservoir would have to be 20,800 mg (reservoir normal water elevation at 45.0') in order to provide for the required water demands during the entire critical period (see Table 13).

TABLE 11: MONTHLY WATER DEMAND FROM WEIJA RESERVOIR

Month	Water demand (mg)		
	Municipal	Irrigation**	Total
March	1,200	1,040	2,240
April	1,200	1,040	2,240
May	1,200	840	2,040
June	1,200	350	1,550
July	1,200	260	1,460
August	1,200	-	1,200
September	1,200	1,225	2,425
October	1,200	1,080	2,280
November	1,200	1,225	2,425
December	1,200	1,040	2,240
January	1,200	-	1,200
February	1,200	-	1,200
Total	14,400	8,100	22,500

40 mgd

** Source: Report on Irrigation Feasibility in the Densu Basin from the Proposed Reservoir at Weija, Appendix B.

* The synthesized flow figures are in fact the total flows in the Densu at Weija, less the actual consumption upstream, which is estimated at about 2 mgd.

TABLE 12: ASSUMED EVAPORATION, RAINFALL AND SEEPAGE AT WEIJA RESERVOIR DURING THE CRITICAL PERIOD

Year	Month	Evaporation* inches	Rainfall** inches	Seepage*** inches	Net losses	
					inches	feet
1945	Nov.	-5.1	+3.1	-1.0	-3.0	-0.2
	Dec.	-4.8	+1.0	-1.0	-4.8	-0.4
1946	Jan.	-4.8	+0.1	-1.0	-5.7	-0.5
	Feb.	-5.2	+0.8	-1.0	-5.4	-0.5
	Mar.	-6.2	+3.5	-1.0	-3.7	-0.3
	Apr.	-4.9	+1.6	-1.0	-4.3	-0.4
	May	-5.0	+3.1	-1.0	-2.9	-0.2
	June	-4.1	+1.3	-1.0	-3.8	-0.3
	July	-3.5	+0.4	-1.0	-4.1	-0.3
	Aug.	-4.0	+0.1	-1.0	-4.9	-0.4
	Sept.	-4.6	+1.0	-1.0	-4.6	-0.4
	Oct.	-5.4	+2.0	-1.0	-4.4	-0.4
	Nov.	-5.1	+1.2	-1.0	-4.9	-0.4
	Dec.	-4.8	+0.6	-1.0	-5.2	-0.4
1947	Jan.	-4.8	-	-1.0	-5.8	-0.5
	Feb.	-5.2	+1.8	-1.0	-4.4	-0.4
	Mar.	-6.2	+4.6	-1.0	-2.6	-0.2
	Apr.	-4.9	+2.4	-1.0	-3.5	-0.3
	May	-5.0	+3.0	-1.0	-3.0	-0.2
	June	-4.1	+2.1	-1.0	-3.0	-0.2
	July	-3.5	+1.3	-1.0	-3.2	-0.3
	Aug.	-4.0	+1.5	-1.0	-3.5	-0.3
	Sept.	-4.6	+2.1	-1.0	-3.5	-0.3
	Oct.	-5.4	+2.0	-1.0	-4.4	-0.4

* Evaporation as per Table 6

** Rainfall at Nsawam multiplied by 0.5

*** Assumed

TABLE 13: RESERVOIR OPERATION DURING THE CRITICAL PERIOD

	Month	Initial volume mg	Inflow mg	Water supply mg	Spill mg	Balance mg	Water level ft	Net losses ft	Water level ft	Balance mg
Hydrological year 1945-46	11	20,790	5,161	-2,430	2,731	20,790	44.9	-0.2	44.7	20,470
	12	20,470	3,108	-2,240	548	20,790	44.9	-0.4	44.5	20,150
	1	20,150	558	-1,200	-	19,508	44.1	-0.5	43.6	18,710
	2	18,710	107	-1,200	-	17,617	42.9	-0.5	42.4	16,820
Hydrological year 1946-47	3	16,820	1,059	-2,240	-	15,639	41.6	-0.3	41.3	15,115
	4	15,115	914	-2,240	-	13,789	40.4	-0.4	40.0	13,150
	5	13,150	613	-2,040	-	11,723	38.9	-0.2	38.7	11,500
	6	11,500	2,551	-1,550	-	12,501	39.5	-0.3	39.2	12,125
	7	12,125	1,880	-1,460	-	12,545	39.5	-0.3	39.2	12,125
	8	12,125	344	-1,200	-	11,269	38.5	-0.4	38.1	10,750
	9	10,750	69	-2,430	-	8,389	36.0	-0.4	35.6	7,910
	10	7,910	2,428	-2,280	-	8,058	35.7	-0.4	35.3	7,580
	11	7,580	1,525	-2,430	-	6,675	34.4	-0.4	34.0	6,250
	12	6,250	300	-2,240	-	4,310	31.9	-0.4	31.5	3,975
	1	3,975	61	-1,200	-	2,836	30.1	-0.5	29.6	2,430
	2	2,430	12	-1,200	-	1,242	27.2	-0.4	26.8	1,070
Hydrological year 1947-48	3	1,070	1,649	-2,240	-	479	24.6	-0.2	24.4	430
	4	430	4,238	-2,240	-	2,428	29.6	-0.3	29.3	2,230
	5	2,230	1,896	-2,040	-	2,086	29.0	-0.2	28.8	1,950
	6	1,950	5,620	-1,550	-	6,020	33.8	-0.2	33.6	5,850
	7	5,850	5,876	-1,460	-	10,266	37.7	-0.3	37.4	9,910
	8	9,910	4,488	-1,200	-	13,198	40.0	-0.3	39.7	12,760
	9	12,760	9,749	-2,430	-	20,079	44.5	-0.3	44.2	19,670
	10	19,670	11,103	-2,280	7,703	20,790	44.9	-0.4	44.5	20,150

5. Dry Period Frequency Study (see Figs. 7 and 8)

The weakness in the above derived capacity value is three-fold:

(i) it is greatly dependent on the accuracy of the synthesized flows during the critical period;

(ii) it does not provide for future needs in the Densu Basin upstream of Weija. In the Feasibility Study a flow of 30 mgd has been provided for upstream demand;

(iii) it represents, at most, a guarantee against an event which has occurred only once in 27 years.

To overcome these problems, the final decision should place greater reliance on a frequency analysis of dry period flows than on what has actually happened (or could have happened) during any one period. The length of the dry period whose frequency is being sought should be at least 15 months, as indicated by the above operation studies.

Since it is difficult to make a frequency analysis of a 15 month period, it was decided to use an approximation. First, the distribution of the annual flows were analyzed, using the California method for plotting position and a normal probability paper for extrapolation (see Fig. 7). The annual flow (equal or less than) at a frequency of, say, 1 percent (once in 100 years) is read from Fig. 7 as about 20 mgd, or 7,300 mg annually (March to February, inclusive). Secondly, in order to arrive at a low flow period of 15 months duration, the monthly flows at both ends of the critical period (January and February 1946, and March 1947) are added to the above annual value. This procedure yields a 15 months inflow value of 9,614 mg whose chances of occurrence are approximately 1 percent. This procedure has been repeated several times for various return periods, reservoir heights and upstream consumption. The results are summarized in Table 14.

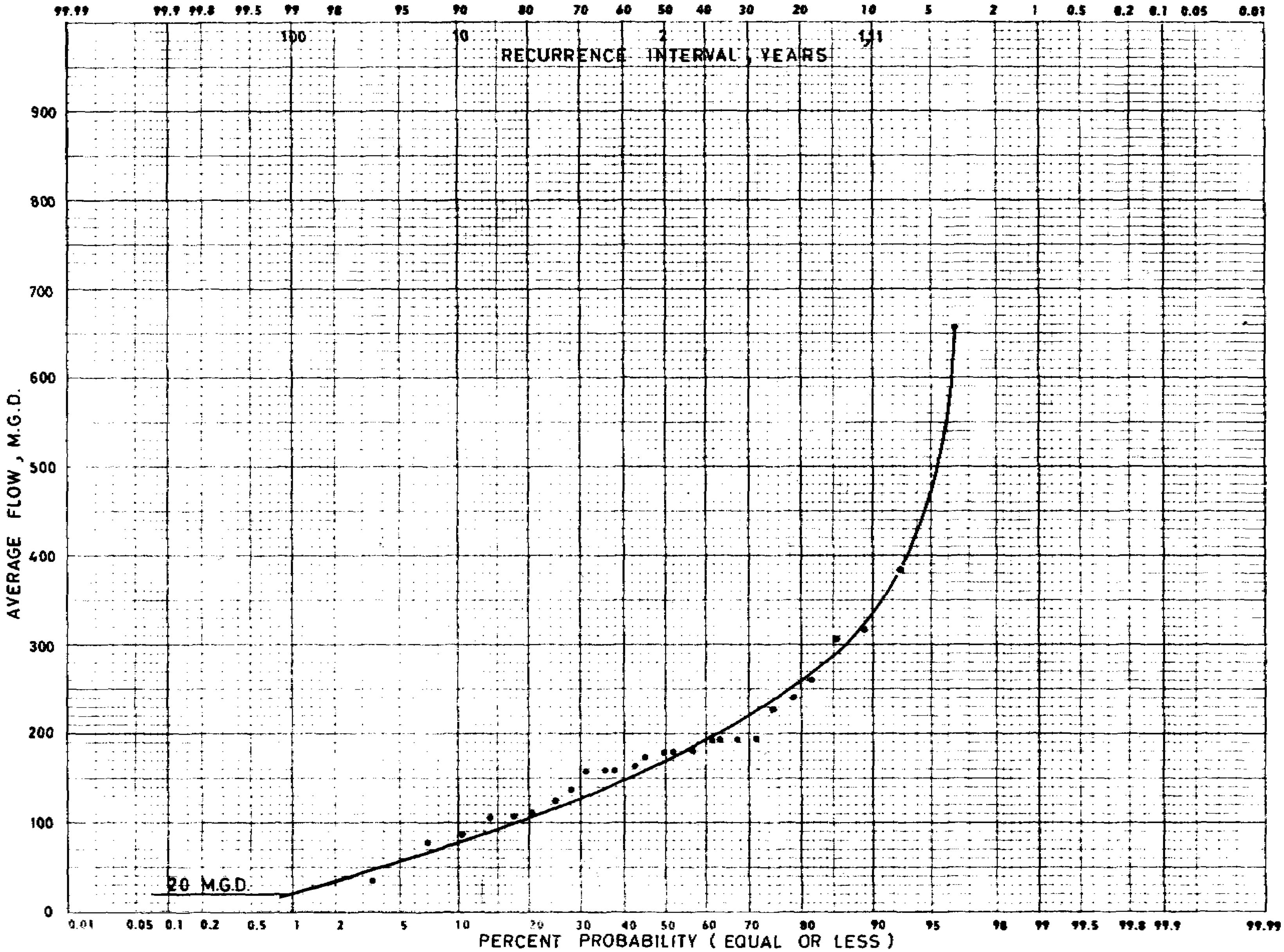
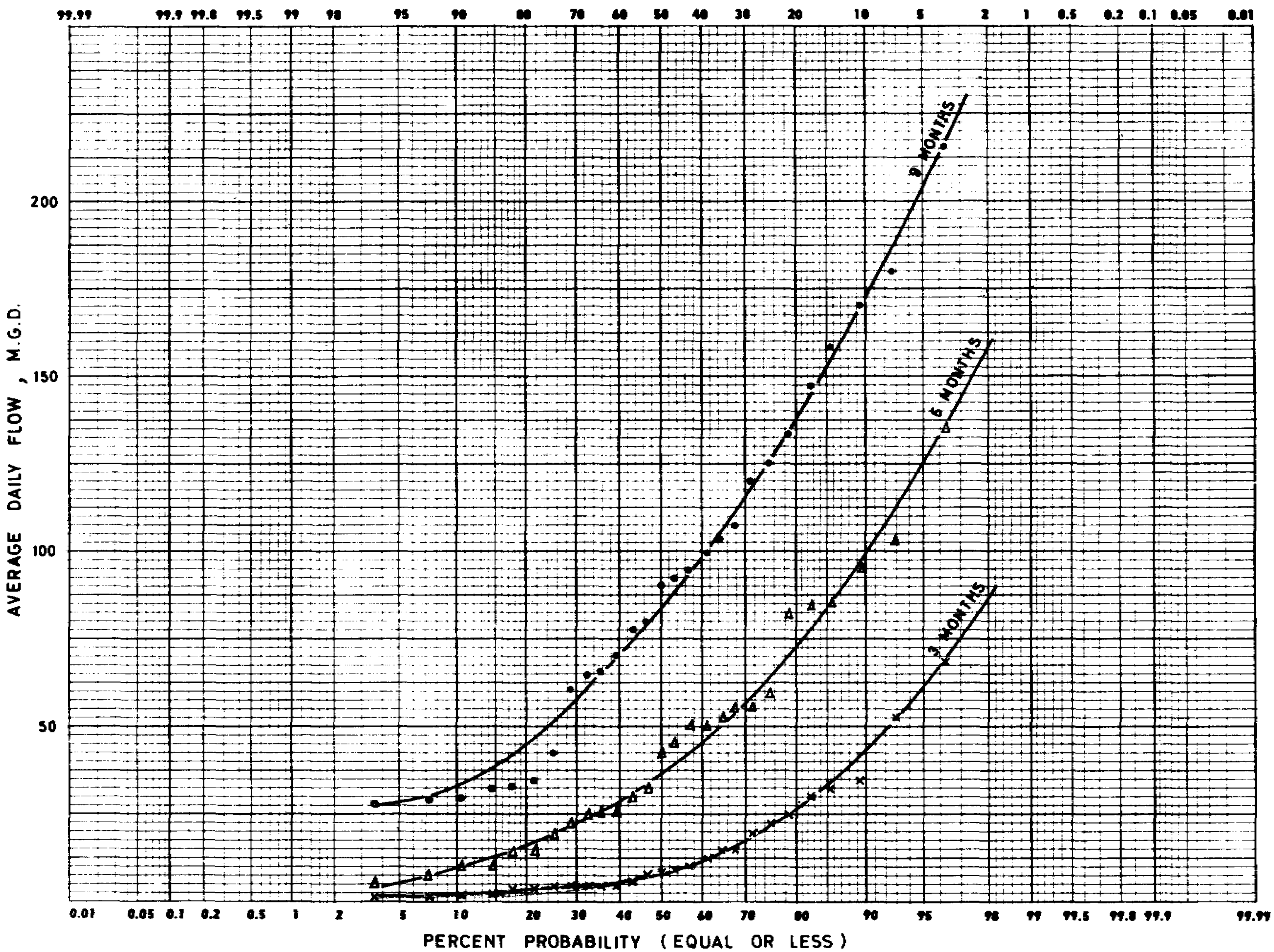


FIGURE 7

RIVER DENSU — FREQUENCY CURVE OF ANNUAL FLOWS AT WEIJA

EXPRESSED AS AVERAGE DAILY DISCHARGES

(BASED ON SYNTHESIZED AVERAGE FLOWS DURING 27 YEARS)



RIVER DENSU — FLOW FREQUENCY CURVES OF DRY PERIODS AT WEIJA

FIGURE 8

TABLE 14: DENSU RIVER - CONTROLLED BY WEIJA IMPOUNDING RESERVOIR - SAFE YIELDS

Reservoir NWL	Reservoir gross capacity mg	Return period of shortage*	Municipal supply from Weija mgd	Irrigation from Weija Reservoir mg/year	Upstream consumption mgd	Total annual utilization mg
41 ft O.D.	14,700	1 in 100 yrs.	40.0	-	2.0	15,400
		1 in 30 yrs.	40.0	-	20.0	22,000
45 ft O.D.	20,800	**	40.0	8,100	2.0	23,500
47 ft O.D.	25,000	1 in 100 yrs.	40.0	8,100	2.0	23,500
		1 in 30 yrs.	40.0	8,100	18.0	29,200
		1 in 30 yrs.	47.0	8,100	10.0	29,200
		1 in 10 yrs.	60.0	8,100	30.0	41,000***
		1 in 30 yrs.	70.0	-	10.0	29,200
48 ft O.D.	26,800	1 in 30 yrs.	40.0	8,100	25.0	31,400
		1 in 30 yrs.	55.0	8,100	10.0	31,400
		1 in 30 yrs.	75.0	-	10.0	31,400

* From probability curve

** The critical year 1946/47 in 27 years of observation

*** 57 percent of average annual flow

6. Required Capacity

The reservoir capacity proposed in this report is based on the study of the results shown in Table 14. In deciding the capacity, the fact that a major city such as Accra-Tema cannot tolerate protracted periods of water rationing should not be overlooked.

It is recommended to build Weija Dam with a normal water level of 47 ft O.D. to provide a gross storage of 25,000 mg. This storage will ensure a supply of 40 mgd to Accra-Tema, an annual supply of 8,100 mg (30,000 acre ft) for irrigation, and the present upstream requirements of about 2 mgd, with a risk of water shortage occurring once in 100 years. In the mid-'seventies Accra is expected to receive its water mainly from the Densu source, while Tema will probably obtain its entire supply from Kpong. However, the system will also make it possible to supply Accra partially from the Kpong Works. The system with the proposed 25,000 mg reservoir therefore gives a high security of supply.

It is assumed that the third stage of Accra-Tema water supply scheme will be developed during the second half of the 'seventies. At that time consumers in the Densu Basin, upstream of Weija, will probably increase their demands. The demand upstream of Weija could eventually reach 18 mg, while Weija reservoir can supply the municipal demand of 40 mgd together with 8,100 mg annually for irrigation, and still have a high security, with a risk of shortage once in thirty years. The reduced security of supply from Weija in this stage is considered justified, as at that time Accra will already be receiving an additional supply of water from the Volta River where the question of shortages does not arise. The security of supply from the Densu River to Accra may, justifiably, be reduced still further, as the supply from the Volta increases. Based on a return period of shortage of once in ten years, it can be seen from Table 14 that this reservoir can supply a total of 90 mgd for Accra and upstream uses in addition to the 8,100 mg to be supplied annually for irrigation.

To decide on the final allocation for Accra from Densu River is regarded at present as premature since this decision depends on many factors, such as: upstream demand, irrigation demand, the rate of increase of the Accra consumption, the development of a new source for Accra, and the information to be obtained concerning the hydrological potentialities of the Densu River.

However, it is clear from the above that the storage of 25,000 mg created by raising the dam to a NWL of 47 ft O.D. could supply, with a very high degree of security, the municipal and irrigation demands as defined above. The proposed storage of 25,000 mg could provide, in the future, a flexible allocation of supply to all potential consumers on the Densu River with the possibility of increasing the supply to Accra above the present allocation.

It is not practical to reduce the storage by applying a lower safety factor for irrigation alone as it is impossible to forecast the occurrence of a critical year during the first part of the rainy season and thus to ration water for irrigation. On the other hand, as can be seen from Table 14, there is little to be gained by raising the dam above NWL of 47 ft.

E. WEIJA NEW DAM

1. General

The Feasibility Study* on the Weija Reservoir prepared by Tahal in November 1966 recommends the construction of a storage reservoir at Weija on the Densu River, which will store 9,500 mg (35,000 acre ft) at a NWL of 38 ft, to supply 40 mgd of water to the Accra-Tema area.

New hydrological data and computations indicate that the storage capacity for supplying 40 mgd should be enlarged to 14,700 mg with a reservoir normal water level at 41 ft O.D.

more than 50%+

The use of Weija Dam for the irrigation of 4,200 acres in addition to municipal water supply of 40 mgd requires a reservoir with a capacity of 25,000 mg (the requirements for irrigation are equal to 30,000 acre ft or 8,100 mg per annum, see Irrigation Report**). The normal water level for these conditions is 47 ft O.D. with dam crest level at 53 ft O.D.

2. Preliminary Design

The preliminary design of the Weija New Dam, providing storage for water supply and irrigation, is based on the design criteria and principles described in the Feasibility Study, 1966, Volume One, Chapter IX (see Figures 12 and 13).

The proposed dam has been located, for the purpose of this report, on the same axis as the dam described in the Feasibility Study. The new dam, with a normal water level of 47 ft O.D., will inundate the area on the left abutment on which the following buildings are situated: West German pumping station, transformer house, garage, power house, workshop chemical stores, offices and other buildings of a temporary nature.

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* See Footnote page 3
** See Footnote page 3

With the construction of a dam, having NWL of 47 ft O.D., it will be necessary to site the required pumping installation in the proposed low and high lift pumping stations to compensate for the inundation of the existing West German pumping station and the transformer house. New chemicals stores and offices have been included in the design of the new treatment works and no direct damage need be considered as resulting from the inundation of the old stores and offices. The same applies to the power house, as the installations are due to be dismantled (see Report on the Rationalization of Weija Water Works, September 1967). It is proposed to provide a new workshop at the proposed site for the treatment works and to include the cost of building it and erecting the existing machines in the cost calculation for the new dam.

The sole objective of the preliminary design of the new dam as shown on Figures 12 and 13, is to serve as a basis for the cost estimate of the construction of the dam on the same design principles as are described in the Feasibility Study.

However, during the course of the investigations and during the detailed design phase, two other alternatives which would prevent the inundation of the buildings will be checked. The first alternative calls for the construction of a protecting wall in front of the West German pumping station and the transformer house; the second alternative would require the relocation of the left embankment upstream of the West German pumping station.

The following Table 15 compares the main features of the dam of NWL, 41 ft O.D., with the main features of the dam of NWL, 47 ft O.D.

TABLE 15: COMPARISON OF THE MAIN FEATURES OF THE 41 FT NWL DAM AND THE 47 FT NWL DAM

Description	Dam for municipal supply NWL 41 ft O.D.	Dam for municipal supply and irrigation NWL 47 ft O.D.
Reservoir and Dam		
Gross capacity	14,700 mg (54,000 acre ft)	25,000 mg (92,000 acre ft)
Full reservoir level	41 ft	47 ft
Dam crest	47 ft	53 ft
high Free board	6 ft	6 ft
Length of right abutment	170 ft	270 ft
Length of left abutment	750 ft	840 ft
Crest of spillweir	23 ft	29 ft
Gates	5 x (18 ft x 35 ft)	5 x (18 ft x 35 ft)
Intake and Low-Lift Pumping Station		
Max. water level at intake	39 ft	48 ft
Number of pumps	3 units	4 units
Installed capacity	48 mgd	64 mgd
Operational capacity	32 mgd	48 mgd
Steel discharge main	42" dia.	45" dia.
High-Lift Pumping Station		
Number of pumps	3 units	4 units
Installed capacity	48 mgd	64 mgd
Operational capacity	32 mgd	48 mgd
Steel discharge main	42" dia.	45" dia.

In the preliminary design, provision has been made for an irrigation outlet in the right bank to supply water for Block No. 2 which comprises 700 acres of land (see Irrigation Report). The detailed outlet works for Block No. 2 will be finalized in cooperation with the Ministry of Agriculture and will be incorporated in the contract drawings.

By raising the dam and the spillway sill by 9 ft the flow conditions over the spillway will probably be improved. Hence, if the design principles of the Feasibility Study are followed, the spillway structure could be somewhat smaller than that shown on Figures 12 and 13. However, since the actual tail water conditions have not yet been calculated, and investigations along the river course downstream of the dam are now being carried out, it is not considered practical, at the present stage, to determine whether or not there will be any improvement in flow condition over the spillway.

3. Cost Estimates

The cost estimates included in this report are based on the same unit rates as are given in the Feasibility Study.

The following table compares the cost of three dams, that proposed in the Feasibility Study with NWL of 38 ft O.D., the dam required for municipal water supply with NWL at 41 ft O.D. and the dam required for municipal water supply and irrigation with NWL at 47 ft O.D.

TABLE 16: COSTS OF THREE DAMS COMPARED
(in dollars)

Description	Dam as per Feasibility Study NWL 38 ft O.D.	Dam for municipal supply NWL 41 ft O.D.	Dam for municipal supply and irrigation NWL 47 ft O.D.
Weija Dam	2,320,900	2,560,000	3,160,000
Weija intake chamber and low-lift pumping station	794,000	823,000	1,010,000
Weija high-lift pumping station	945,000	945,000	1,177,000
Intake for irrigation	-	-	30,000
Improvement and completion of West German pumping station*	230,000	230,000	-
Total	4,289,900	4,558,000	5,377,000

* Estimate of cost based on recommendations for renovation of West German pumping station in the Report on the Rationalization of Weija Works (Tahal, P.N. 804, 1967)

The total estimated cost of increasing the capacity of the reservoir for irrigation purposes is about $5,377,000 - $4,558,000 = $819,000.

The cost of storage to supply 1 mg per annum from a reservoir with NWL at 41 ft, for municipal demand only is:

$$C_1 = \frac{2,560,000}{14,600} = \$176/mg$$

The cost of storage to supply 1 mg per annum from a reservoir with NWL at 47 ft, for municipal demand and irrigation is:

$$C_2 = \frac{3,160,000}{22,700} = \$140/mg$$

The marginal cost of storage to supply 1 mg per annum for irrigation purposes is:

$$C_3 = \frac{819,000}{8,160} = \$100/mg$$

F. CONCLUSIONS

1. Weija Reservoir - Required Capacity

Very low precipitation, or even completely dry months during the first part of the rainy season do not necessarily indicate a drought year ahead. Hence a decision taken during the rainy season to ration water for irrigation could eventually be found to be incorrect. It is therefore recommended that Weija Dam should provide storage large enough to supply both municipal and irrigation needs even during the critical year, i.e. 40 mgd for Accra-Tema municipal supply and an annual supply of 8,100 mg (30,000 acre ft) for irrigation.

The recommended storage of 25,000 mg will meet the municipal demands of Accra-Tema and the irrigation demands even in a critical period. This storage can be regarded as safe for a city such as Accra-Tema.

2. Densu River - Hydrological Investigations

According to the design curve of municipal water demand, the proposed capacity at Weija will be fully exploited only in the mid-seventies; the demand for the irrigation supply will also commence at about that time. It is recommended that advantage should be taken of this interim period to continue hydrological investigations along the River Densu in order to obtain additional data on the river flows. The following steps should be taken:

(i) The installation of rain recording gauges in the Densu Basin rainfall stations.

(ii) The installation of water level recorders along the Densu River at Nsawam Bridge, Manhia Station and below Weija Dam.

(iii) The establishment of an evaporation station, a rainfall station and a reservoir level recorder at the Weija Dam site.

In a few years' time on the basis of these data, it will be possible to make an accurate evaluation of the permissible annual withdrawal from the river. A decision can then be made concerning the final exploitation pattern for municipal and agricultural use of this source, upstream of Weija and at Weija.

3. Weija Reservoir for Irrigation

If, for any reason, the proposed irrigation project discussed in the present report is cancelled altogether, the water in the Weija Reservoir earmarked for irrigation could then be supplied to the increasing municipal demand of Accra-Tema. The additional supply to Accra-Tema from Weija could be achieved by extending the second stage water works whenever required. It is proposed to take this possibility into consideration during the design of the second stage water works.