IVORY COAST

BANDAMA RIVER PROJECT

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by

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There are discharge records for the Bandama at Beoumi from March, 1954. However, this station is some distance upstream of the proposed dam site at Kossou and to determine the river flow at the dam site gauging was started in June, 1962 at Duibo near Kossou. The flows at Duibo for the period 1954 to 1962 could be estimated from the flows at Beoumi provided a satisfactory relationship could be found between the two flows after 1962.

Based on the limited amount of data available in 1963, a simple ratio of 1.18 was originally obtained between the flows at Duibo and Beoumi. Subsequent records available, up to March 1968, suggest that overall this figure is too high and that there is a significant variation month by month. It is necessary therefore to determine whether this variation is to be expected from the hydrology of the river basin or whether it is consequent on errors in gauging at the two stations.

The flow data on which the analysis is based have been derived as far as possible from the original records of stage using rating tables derived from flows measured by current meter. There are 58 months between June 1962 and March 1968 for which flow data exist for both stations. These are listed in the first two columns of Table 5. The flows in parenthesis involve some interpolation on several days during the month. However, in the cases listed the interpolation is judged to have not significantly reduced the reliability of the data.

A study of the rainfall pattern over the catchment area suggests a possible cause of the variation in the flow ratio. Average monthly rainfall in Table 1 (from selected stations in table IV-1) plotted against latitude in Fig.1 shows a variation in rainfall pattern through the year. The months November to February are relatively dry; in no month does rainfall exceed the estimated evaporation loss in table 2 (from table IV-7). The months March - June are wetter, rainfall being in excess of evaporation losses, and significantly there is more rain in the south of the area than in the north. Rainfall minus evaporation is four times greater at the southern limit of the area than at the northern limit, with a uniform variation between. The months July to October have the heaviest rainfall with considerably more rain in the north than in the south. Rainfall minus evaporation is five times greater at the northern limit of the area than at the southern limit. Again the variation is approximately uniform between these limits.

When the run-off hydrograph for the year is considered together with the rainfall variation described above, it is possible to define three four month seasons.

November to February	The dry season during which the river flow recedes from its peak flow in October to its minimum flow in February.
March to June	A season of some rain mainly in the south with highly variable river flows.
July to October	The rainy season with considerably more rain in the north than in the south. The river flow rises rapidly in July and August to a peak sustained during September and early October.

The flow data have been assembled according to these seasons in Table 3. The Beoumi records are incomplete for some months in 1966 and 1967. Only those months with records from both stations have been used and the figures in parenthesis indicate the number of months record represented in the seasonal total when the data are incomplete.

The observed seasonal runoff ratios appear to have a logical connection with rainfall distribution. With heavier rainfall in the north in the July to October season, the contribution to flow at Duibo of the area between Duibo and Beoumi should be less than the average contribution from the whole catchment. Thus the flow ratio should be less than the simple ratio of areas (1.23). Conversely in the March to June season the heavier rainfall is in the south and the flow ratio should be greater than the area ratio. During the November to February season there is little rain and flows are derived from ground water storage; the flow ratio should therefore be approximately equal to the area ratio assuming that the catchment storage is uniform throughout the area.

The flow ratios for individual seasons are more highly variable for the March to June season than for the July to October season. The former are associated generally with low flows, the latter with high flows. The variability almost certainly reflects the accuracy of the flow records which are normally least reliable at low flows especially when these are based on a single rating curve rather than curves for individual years. In addition it could reflect the areal variability of the rainfall which will be particularly great in seasons when the overall rainfall is comparatively low.

The simplicity of the seasonal average rainfall distribution Fig.2 allows a simple but approximate calculation of the average run-off for the parts of the catchment above Beoumi and between Beoumi and Duibo. The catchment has been divided into latitude zones and the average run-off from each zone is assumed to be proportional to the average rainfall minus evaporation losses. The calculations are shown in Table 4.

The results for the March to June and July to October seasons show substantial agreement with the actual flow ratios. This suggests that the latter are real and not on average the result of systematic errors in gauging. No result was obtained for the November to February season as evaporation exceeded rainfall throughout the catchment in this period. It has been noted that this is the recession season when a result approximately equal to the area ratio might be expected.

For comparison with the result based on seasons, the flow at Duibo was plotted against the corresponding flow at Beoumi on a monthly basis, Figs. 3 and 4 and fitted by linear and logarithmic equations:

$$Y = 7.42 + 1.07\,X \quad (r = 0.996 \;\; S.E.E.\; 22.9 \; \frac{M^3}{Sec})$$

and

$$Y = 1.509\,X^{0.947} \quad (r = 0.988)$$

where Y is the flow at Duibo and X the flow at Beoumi in M^3/sec.

The predicted flows at Duibo are given in Table 5 corresponding to the seasonal prediction and predictions based on the two equations above. Table 6 shows the sums of squares of the differences between observed and predicted flows for each case. The lowest value is obtained from the seasonal prediction though the difference bwtween methods on this basis is small. The figure of 28,600 for the sum of squares of differences for 58 values corresponds to a standard error of estimate for individual monthly values of about 10%.

The prediction based on seasons has been shown to have a physical basis and it gave the best result based on comparison of the sum of squares of the differences between observed and predicted flows at Duibo. It is also the simplest method to apply in practice.

It is therefore recommended that the flows at Duibo be derived from those at Beoumi using the following factors.

July to October	1.09
November to February	1.16
March to June	1.40

Table 7 gives the result for the period 1954 to 1962. Flows at Duibo for the period prior to 1954 could be computed following a re-examination of the rainfall run-off relationship at Beoumi.

TABLE 1

AVERAGE MONTHLY RAINFALL.

(MM)

	Latitude °N	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Tingrela	10.50	1	4	22	72	124	168	306	365	239	98	51	57	1507
Ovangolodougov	9.96	4	20	44	96	123	179	204	338	218	108	23	13	1370
Ferkossedongou	9.60	5	21	46	92	144	157	188	299	248	115	34	9	1358
Boundiali	9.52	7	17	42	81	115	161	255	306	243	133	43	9	1412
Korhogo	9.48	4	14	47	105	123	159	197	313	270	132	39	11	1414
Tafire	9.06	7	19	52	86	111	143	136	218	281	122	59	25	1259
Katiola	8.13	14	36	57	157	116	171	107	130	219	131	39	26	1203
Mankone	8.06	17	37	77	115	127	139	142	187	252	139	40	12	1284
Bouate	7.68	14	43	92	139	146	140	98	106	217	142	37	21	1195
Beoumi	7.66	10	53	98	129	139	143	106	120	224	132	58	24	1236
Boufle	6.97	20	64	120	153	168	192	91	118	221	145	54	33	1379

TABLE 2

MONTHLY ESTIMATED EVAPORATION LOSSES

(MM)

Jan	75
Feb	60
Mar	55
Apr.	70
May	95
June	110
July	100
Aug	80
Sept	75
Oct	95
Nov	95
Dec	90

TABLE 3

SEASONAL FLOWS

(M^3/sec)

		Flow at Duibo		Flow at Beoumi		Ratio
	Mar - June	18	(1)	8	(1)	2.25
1962	July - Oct	1245		1161		1.07
	Nov - Feb	253		239		1.06
	Mar - June	54	(3)	30	(3)	1.80
1963	July - Oct	2127		1766		1.20
	Nov - Feb	546		452		1.21
	Mar - June	119		72		1.65
1964	July - Oct	2374		2216		1.07
	Nov - Feb	496		441		1.12
	Mar - June	129		113		1.14
1965	July - Oct	2151		2040		1.05
	Nov - Feb	308		271		1.14
	Mar - June	43	(3)	34	(3)	1.26
1966	July - Oct	1040	(2)	952	(2)	1.09
	Nov - Feb	242	(2)	202	(2)	1.20
	Mar - June	15	(1)	13	(1)	1.15
1967	July - Oct	1407	(3)	1307	(3)	1.08
	Nov - Feb	152	(3)	120	(3)	1.27

TOTAL FLOWS AND RATIOS FOR EACH SEASON

Season	Flow at Duibo	Flow at Beoumi	Ratio
July - Oct	10344	9442	1.09
Nov - Feb	1997	1725	1.16
Mar - June	378	270	1.40

TABLE 4

CALCULATION OF THE THEORETICAL FLOW RATIO

Area B above Beoumi

Latitude Zone °N	Catchment Area in Zone Km^2	(MM) Seasonal Rainfall Nov-Feb	Mar-June	July-Oct	(MM) Rainfall - Evaporation Nov-Feb	Mar-June	July-Oct	$X\ 10^4$ MM.Km^2 Area (Rainfall - Evaporation) Nov-Feb	Mar-June	July-Oct
10.25-10.0	1450	58	400	976	-	70	626	-	10	91
10.0 - 9.5	6760	70	419	910	-	89	560	-	60	379
9.5 - 9.0	7570	85	442	831	-	112	481	-	85	364
9.0 - 8.5	5260	100	465	753	-	135	403	-	71	212
8.5 - 8.0	4030	116	488	674	-	158	324	-	64	131
8.0 - 7.5	1130	131	511	596	-	181	246	-	20	28
								-	310	1205

Area A between Duibo and Beoumi

Latitude Zone °N	Catchment Area in Zone Km^2	(MM) Seasonal Rainfall Nov-Feb	Mar-June	July-Oct	(MM) Rainfall - Evaporation Nov-Feb	Mar-June	July-Oct	$X\ 10^4$ MM.Km^2 Area (Rainfall - Evaporation) Nov-Feb	Mar-June	July-Oct
8.5 - 8.0	170	116	488	674	-	158	324	-	3	6
8.0 - 7.5	3080	131	511	596	-	181	246	-	56	76
7.5 - 7.0	2750	147	533	518	-	203	168	-	56	46
								-	115	128

March - June flow ratio $= \frac{310 + 115}{310} = 1.37$

July - October flow ratio $= \frac{1205 + 128}{1205} = 1.11$

TABLE 5

MONTHLY OBSERVED AND PREDICTED FLOWS AT BEOUMI AND DUIBO

(M^3/sec)

		Observed flow at Beoumi	Observed flow at Duibo	Predicted flow at Duibo by seasonal method	Predicted flow at Duibo by linear regression	Predicted flow at Duibo by logarithmic regression
1962	June	8	18	11	16	11
	July	28	40	30	38	35
	Aug	133	134	145	150	154
	Sept	551	578	601	599	593
	Oct	449	492	489	490	489
	Nov	149	161	173	168	172
	Dec	58	67	67	70	70
1963	Jan	21	18	24	30	27
	Feb	11	7	13	19	15
	Mar	10	8	14	18	13
	Apr.	(4)	13	6	12	6
	May	(16)	33	22	25	21
	June					
	July	134	225	146	151	156
	Aug	314	357	342	345	348
	Sept	653	743	712	709	697
	Oct	665	802	725	722	709
	Nov	329	(408)	382	361	364
	Dec	(83)	89	96	97	99
1964	Jan	28	36	32	38	35
	Feb	12	13	14	20	16
	Mar	4	6	6	12	6
	Apr.	4	6	6	12	6
	May	17	27	24	26	22
	June	47	80	66	58	58
	July	43	79	47	54	53
	Aug	(428)	440	466	467	467
	Sept	1025	1072	1117	1109	1068
	Oct	720	783	785	781	764
	Nov	200	207	232	222	227
	Dec	138	149	160	156	160

Table 5 continued:

1965	Jan	68	89	79	80	82
	Feb	35	51	41	45	44
	Mar	19	17	27	28	24
	Apr.	(20)	29	28	29	26
	May	11	14	15	19	15
	June	63	69	88	75	76
	July	264	266	288	291	296
	Aug	410	466	447	448	449
	Sept	684	686	745	742	728
	Oct	682	733	743	740	726
	Nov	177	193	205	198	202
	Dec	55	72	64	66	67
1966	Jan	25	30	29	34	32
	Feb	14	13	16	22	18
	Mar	6	7	8	14	8
	Apr.	11	20	15	19	15
	May	17	16	24	26	22
	June					
	July					
	Aug					
	Sept	475	504	518	518	516
	Oct	477	536	520	520	518
	Nov	186	228	216	207	212
	Dec					
1967	Jan					
	Feb	16	14	18	25	21
	Mar					
	Apr.					
	May	13	15	18	21	17
	June					
	July					
	Aug	262	245	286	289	294
	Sept	597	640	651	649	640
	Oct	448	522	488	489	488
	Nov	98	124	114	113	116
	Dec					
1968	Jan	12	14	14	20	16
	Feb	10	14	12	18	13

TABLE 6

ANNUAL TOTALS OF OBSERVED AND PREDICTED FLOWS AT BEOUMI AND DUIBO

(M $^3/_{sec}$)

		Observed flow at Beoumi	Observed flow at Duibo	Predicted flow at Duibo by seasonal method	by linear regression	by logarithmic regression
1962	June-Dec	1376	1491	1516	1531	1516
1963	Excl.June	2240	2704	2482	2489	2482
1964	Complete year	2666	2898	2955	2955	2955
1965	Complete year	2488	2685	2770	2761	2770
1966	Jan-May Sept-Nov	1211	1354	1346	1360	1346
1967	Feb,May, Aug-Nov	1434	1560	1575	1586	1575
1968	Jan-Feb	22	28	26	38	26
	Total	11437	12720	12670	12720	12541
Sum of squares of differences betwenn observed and predicted monthly flows.				28631	29369	29559

TABLE 7

MONTHLY DISCHARGES OF THE BANDAMA RIVER AT DUIBO.

(M^3/sec)

	M	A	M	J	J	A	S	O	N	D	J	F	Total
1954-55	23	44	101	102	107	370	813	648	350	148	71	32	2809
1955-56	23	17	11	94	242	640	877	758	281	143	47	24	3157
1956-57	31	30	33	54	34	40	370	403	96	48	16	7	1162
1957-58	7	21	22	115	189	572	1114	1069	414	133	65	45	3766
1958-59	34	84	35	30	13	9	122	230	67	38	9	3	674
1959-60	6	5	27	108	162	176	815	626	122	60	21	6	2134
1960-61	5	23	23	42	54	256	946	693	176	72	39	12	2341
1961-62	5	1	4	28	59	78	347	268	60	16	4	2	872
1962-63	1	0.4	4	10	26	145	598	489	170	63	24	12	1542

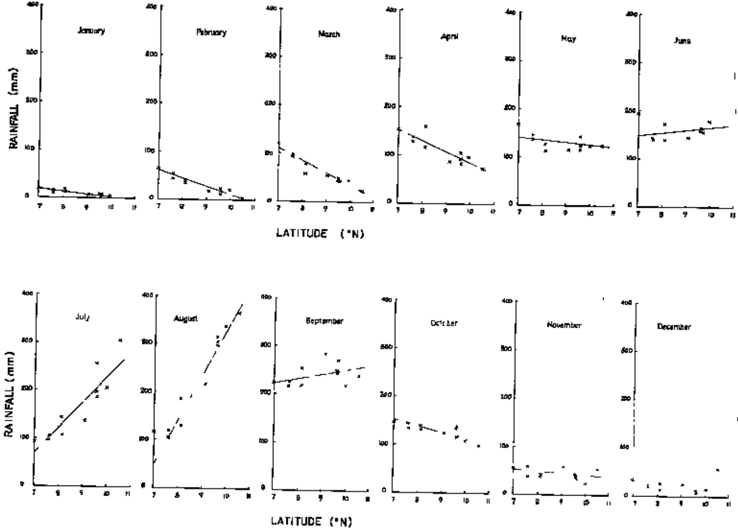

FIG 1 THE VARIATION OF AVERAGE MONTHLY RAINFALL WITH LATITUDE

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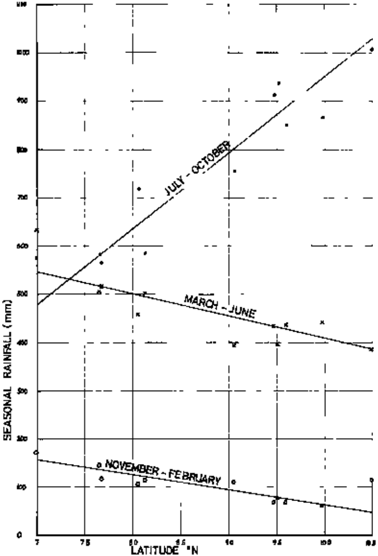

FIG 2 THE VARIATION OF AVERAGE SEASONAL RAINFALL WITH LATITUDE

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SCALE	DATE	DRAWN	Drawing Number

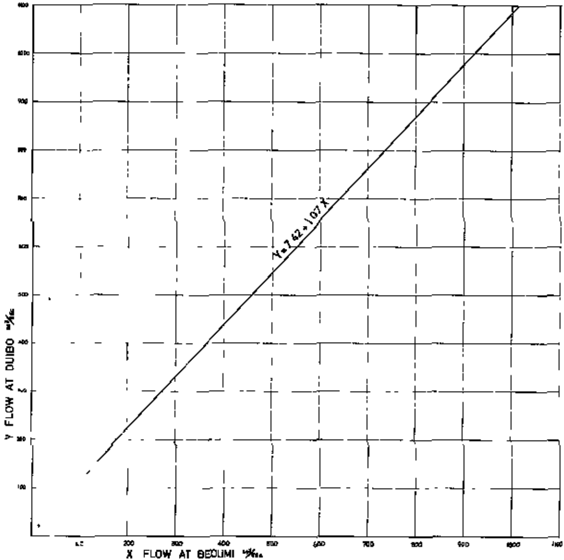

FIG 3 RELATION BETWEEN FLOW AT DUIBO AND FLOW AT BEOUMI

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SCALE	DATE MAY 1968	DRAWN PAL	Drawing Number

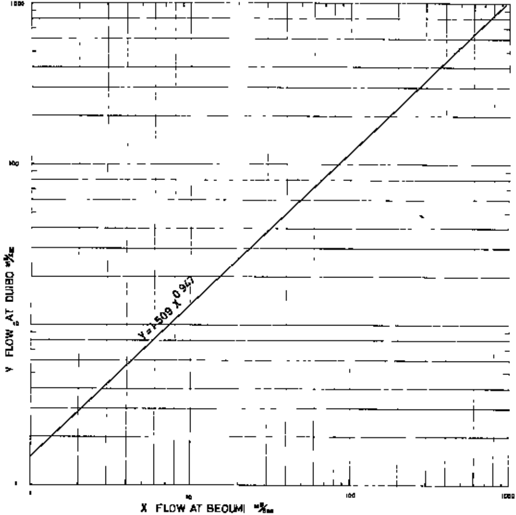

FIG 4 RELATION BETWEEN FLOW AT DUIBO AND FLOW AT BEOUMI

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