

**GHANA WATER RESOURCES MANAGEMENT STUDY**

**INFORMATION BUILDING BLOCK**

**VOLTA BASIN SYSTEM**

**SURFACE WATER RESOURCES**

**Most tables, maps and computation tables are missing in this scanned version**

By

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## **ABSTRACT**

Provision of information on surface water resources of the country is essential for the orderly and sustainable development and management of water resource systems.

The study looked at the data collection network and its adequacy in providing the necessary information. The problems confronting this national activity were investigated and solutions presented. Some of the problems identified were breakdown of equipment and lack of spare parts needed for maintenance. These have left considerable gaps in the data sets. Adequate funds are requested to be made available if the quality of hydrological data collection should be raised from the present level.

Surface runoff characteristics of the major rivers in terms of means, minimum and maximum flows were established. Surface water resources in the river basins were also computed and compared with the results of the earlier studies in the late 1960s. The major observation was that the inflows of the Volta river into the country have reduced in the later period. The low flows as indicated by the flows exceeded 95% of the time were found to be unreliable for water supply without adequate storage facilities.

Sediment loadings of the rivers were computed and found to be comparable to results in other parts of the West African Sub-region.

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## H1. INTRODUCTION

Data and information study of runoff and surface water of the country are very essential for the orderly development of the resources in the various basins of the country. The data and information will indicate the quantity of surface water resources that could be harnessed for the socio-economic development of the country.

Fluvial sediment loads can pose a lot of problems like siltation to water resources systems and the study therefore incorporates sediment yield analysis from the basins. The report covers these two areas: runoff and surface water resources and sediment yield.

### H1.1 Surface Water

A number of surface water resources assessment studies have been undertaken in the country for specific development projects in the various parts of the country (Nippon Koei, 1967a; 1967b; USSR State Committee on Power Engineering and Electrification, 1964; Hydropojekt Czechoslovakia, 1964; Wakuti, 1968; Howard and Humphreys and Sons, 1970; Acres International Ltd., 1985). These projects were limited in scope since they were carried out for specific development.

There were other studies which were carried out with the view to providing inputs for over all national development and these include the study by Nathan Consortium (1970) and research studies of Water Resources Research Institute (Ayibotele, 1974a; Okutu, 1978; Opoku-Ankomah, 1986; Ontoyin and Opoku-Ankomah; to mention a few). Most of these studies need to be updated with addition of a few data. Further, the scope need to be widened and presented in detail for a comprehensive national development. This need is what the present study attempts to meet.

Surface water resources in the country are derived from runoffs from streams and rivers to a large extent. Assessment of the resources therefore depends on the runoffs from streams and rivers. Natural lakes could also be a possible source of surface water but only few exist in the country.

Runoffs vary within the years according to the seasonal rainfall variation in the catchment. Variations among total annual flows also exist due to occurrences of droughts and floods. Study therefore looks at both monthly and annual flow characteristics to identify the intra and inter annual variations in flow regimes.

The runoff characteristics considered include maximum, mean and minimum flows. Flow durations were also derived for the flows. The information on the flows are presented under the three river systems in the country, viz. the Volta system, the South-western system and the Coastal system. The present report deals with the Volta system and its basins. The data set used in deriving the basic information is described in section H2.

### **H1.2 Sediment Yield**

No operational sediment network exists in the country, though several proposals have been made for the establishment of such a network (Nathan Consortium, 1969; Ayibotele, 1973; Ayibotele, 1974b; Akraasi, 1985).

Information on fluvial sediment loads of some rivers in the country have been obtained from two main activities - ad-hoc and more systematic sediment studies.

The ad-hoc sediment studies involved the gathering of sediment information in connection with specific water related projects (AESC, 1959; FAO, 1967; Hydroprojekt Czechoslovakia, 1964; Hydroproject USSR, 1964; NEDECO, 1959; Nippon Koei, 1967a; Nippon Koei, 1967b). Such studies usually covered only a few months and produced limited results - the data were usually inadequate to produce sediment rating curves, for example.

The more systematic sediment studies were often undertaken with the aim of providing enough information for the establishment of sediment rating curves for stations on selected rivers. Such studies provided data covering a year or more, though, in most cases, sediment sampling was made only once a month. The Water Resources Research Institute (WRRI) of the Council for Scientific and Industrial Research (CSIR) has been the only organisation that has undertaken any meaningful systematic fluvial sediment studies in the country (Akraasi and Amisigo, 1993a; Akraasi and Amisigo, 1993b; Ayibotele and Tuffour-Darko, 1974; Ayibotele and Tuffour-Darko, 1979). Unfortunately, the sampling stations were closed after the necessary sediment information was obtained. The last 5 stations established by WRRI in the Upper Volta basin were closed in September, 1996.

## **H2. DATA**

## H2.1 Data Collection and Compilation

The primary data used in the analysis were daily discharges collected from Hydrology Division (HD) of Ministry of Works and Housing. The data were compiled from the Division's office files.

Few discrepancies exist between this data set and the one extracted by Acres International Limited using gauge heights and rating curves derived by the Hydrology Division (Acres, 1985). In view of this, the data set collected from HD and considered authoritative was solely used.

Gaps of varying lengths exist in the data collected. Gaps of few days to whole months and even years were found in the data sets. The data from some stations were so poor that they could not be used for a fair assessment of flow at those sections of the rivers. Such data sets were not included in this study. Stations whose data sets were used in the study are presented in Table 1 for the Volta River System. In the case of the Lower Volta basin, the sub-basins where the stations are found are stated in brackets. The catchment areas above the stations and the periods of record are indicated in the Table. Figure 1 shows the locations of the stations on Ghana map.

Table 1. List of Selected Gauging Stations

**WHITE VOLTA BASIN**

Station	Catchment Area (km <sup>2</sup> )	Period of Records
Yarugu	41,619	1958/59 - 1970/77
Pwalugu	57,397	1952/53 - 1977/78
Nawuni	96,957	1953/54 - 1989/90
Nangodi	10,974	1958/59 - 1975/76
Yagaba	10,456	1958/59 - 1970/71
Wiase	12,546	1962/63 - 1990/91
Nasia	5,053	1967/68 - 1989/90

**BLACK VOLTA BASIN**

Station	Catchment Area (km <sup>2</sup> )	Period of Records
Lawra	90,658	1951/52 - 1976/77
Bamboi	128,759	1951/52 - 1990/91
Bui	121,025	1954/55 - 1992/91

**OTI BASIN**

Station	Catchment Area (km <sup>2</sup> )	Period of Records
Oti	54,890	1953/54 - 1990/91

**LOWER VOLTA BASIN**

Station	Catchment Area (km <sup>2</sup> )	Period of Records
Ekumdipe (Daka)	6,586	1963/64 - 1974/75
Ahamansu	1,344	1979/80 - 1991/92
(Asukawkaw)	477	1956/57 - 1960/61
Hohoe (Dayi)	308	1967/68 - 1989/90
Aframso (Afram)	1,121	1956/57 - 1973/74
Pruso (Pru)		

## H2.2. The Database

The daily discharges collected were entered on a software for developing a hydrologic database. The software is HYDATA developed by the Hydrology Institute of Wellingford in U.K. The software is menu-driven and easy to use. Data files on the gauging stations are identified by station numbers.

Some of the data sets were entered on Quattro spreadsheets and transferred to HYDATA. The data sets originally collected were in cusecs (cubic ft. per second) but were converted to cumes (cubic metres per second) on HYDATA by specification of the conversion factor.

## H2.3. Infilling of Gaps in the Data

Gaps in a data series can reduce the effective length of the data set. However, this effect can be minimised if these gaps are filled for example by transferring information from nearby river gauging stations with similar characteristics to the flow at that station.

Several methods have been suggested for filling data gaps and they include simple interpolation, regression, auto regressive models and sophisticated hydrologic models. The choice of the method depends on many factors and it includes the length of the gap, the information and resource available and the season in which the gaps are found. Improper methods or lack of adequate information for filling the gaps may introduce unnecessary noise in the data sets without any added information.

In this study, gaps of lengths 1 to 5 days were filled by simple interpolation. Gaps of lengths more than 5 days were filled by 2 methods depending on the season (Gyau-Boakye, 1993). In the dry season, the gaps were filled by a recession method. The method assumes that there is no contribution to streamflow from rainfall input and the only contribution to the flow is from groundwater store.

The model for the recession is

$$q_t = q_0 k^t \text{----- (1)}$$

Where  $q_t$  is the daily discharge at time equals to  $t$ ,

$q_0$  is the discharge at time equals to 0 and  $k$  the recession constant.

Taking logarithms of equation (1) gives

$$\log q_t = \log q_0 + t \log k \text{----- (2)}$$

A plot of  $\log q_t$  against  $t$  yields straight line segments where  $k$  can be estimated from the gradient  $\log k$ , of each type of flow - direct runoff, interflow and baseflow. For the Volta Basins, the dry season extended from about November to early part of April and the method was found to be suitable.

The wet season gaps which extended beyond five days were filled using multiple regression. The dependent variable is the discharge of the station with missing records and the independent variables are the discharges of nearby stations and daily rainfall amount from stations in the basin. The method requires some amount of data for reliable results. The data estimated were added to the data sets and then flagged.

### **H3. INFORMATION ON RUNOFF AND SURFACE WATER RESOURCES**

The following runoff statistics: maximum, mean and minimum flows were computed for monthly and annual runoffs. The computations were derived from the daily discharges or flows. Flow durations were also computed for the flows and duration curves subsequently plotted.

The data and information on the surface runoff are presented in the order of basins and sub-basins.

The Volta System consists of 4 main basins: the White Volta, the Black Volta, the Lower Volta and the Oti Basins. The Red Volta is a sub-basin of the White Volta. The data and information on flow at the selected gauging stations are presented for evaluation of water resources available at those sites.

#### **H3.1. The White Volta Basin**

##### **H3.1.1. Mean, Maximum and Minimum Flows**

The runoff statistics of mean, maximum and minimum flows are presented. The long-term mean flows give an indication of the potential of flow at the site. The maximum and minimum flows provide the range of flows.

The statistics on the flows at each of the gauging stations are given in Table 2. The data lengths used for the computations are not the same for all the stations as indicated in Table 1.

The mean monthly flows are shown in Figure 2 and Figure 3 for Yarugu and Nawuni, an upstream and a downstream station respectively. The plots show uni-modal distribution of the flows typical of the rainfall distribution in the catchment. The mean peak flow occurs in August for the upstream station and September for the downstream station.

##### **H3. 1.2. Flow Duration**

The flow duration curves are plots of cumulative frequency of discharges. They indicate the percentage of time that the discharges are exceeded. These plots are useful since they help in the investigation of low flow dependability for water resources.

The flow duration curves are shown in Figures 4 to Figure 10. The logarithmic scale was used

for the discharges to show the low flows. The computed values as shown in the plots indicated that the flows that were exceeded 95% of time were zero for all the runoffs at selected stations with the exception of Nawuni. At Nawuni, a downstream station, the flow exceeded 95% of the time, 0, 95, was 2.24m<sup>3</sup>/s. this 0, 95 discharge amount is only 1% of the mean annual discharge of 230m<sup>3</sup>/s and thus very insignificant. The low flows in this basin are in general unreliable.

### H3. 1.3 Surface Water Resources

The surface water resources in the basin consist of flows from outside the country and flows from within the country. The discharges entering the country are estimated from the border gauging stations. In the White Volta Basin, the following rivers: Nasia, Kulpawn and the latter's tributary Sisili originate from within the country. They join the White Volta downstream. The Red Volta and the White Volta originate from outside the country. The catchment area of Red Volta outside the country is 10.782 km<sup>2</sup> which is about 95% of the whole basin area. In the case of the White Volta, the area of the catchment outside the country is 57.516 km<sup>2</sup> which is also about 54% of the total basin area (WRI, 1975).

The border station on the Red Volta is Nangodi and on the White Volta is Yarugu. The computed annual inflow volumes at Nangodi and Yarugu are 969 and 2.523 million m<sup>3</sup> respectively.

The proportion of inflows of the White Volta Basin from outside the country to the total flow in the basin was estimated as follows. Discharges of White Volta at Nawuni and Mole River at Lankatere were used to estimate the total basin discharge. White Volta at Nawuni has good records. However, Mole river joins the White Volta downstream of this station. Mole discharge at Lankatere and White Volta discharge at Nawuni were therefore summed up for the computation of the White Volta Basin discharge. Discharges at .Yapei could have been used to represent the whole basin discharge but the station has been flooded by the Volta Lake created by the Akosombo dam. The Table for computation is shown below.

Table 3. Water Resources in the White Volta Basin

Station	River	Annual Discharge	Dry Season	Wet Season
---------	-------	------------------	------------	------------

		m <sup>3</sup> /s	Discharge m <sup>3</sup> /s	Discharge m <sup>3</sup> /s
Nangodi Yarugu	Red Volta White Volta	30.72 80.00	0.34 2.17	61.12 157.00
Total Inflow	-	110.72	2.51	218.12
Nawuni Lankatere	White Volta Mole	229.98 73.31	18.95 15.78	440.05 131.33
Total Outflow	White Volta	303.29	34.73	571.38
Total Flow From within the Catchment in Ghana	-	192.57	32.22	353.26
% Total Inflow/ Total Outflow		36.5	7.2	38.0

Total annual discharge of inflow to the basin is 110.72 m<sup>3</sup>/s (sum of flows at Nangodi and Yarugu) and total annual discharge of the White Volta basin is 303.29 m<sup>3</sup>/s (sum of flows at Nawuni and Lankatere). Then the percentage of flow from outside the country to the total flow is 36.5. The period of estimation of discharge is different for each river and that could introduce some degree of error in the estimated value if the records are not long enough. A defined period when data were available for all the stations could be used but that maybe of shorter length and may limit the information on the flows at the sites to that period.

The results of the computed annual discharges and the proportions of flow from outside the country and the total flow were compared with the results estimated from shorter records by Nippon Koei (1967a). It is observed that Nippon Koei data gave an inflow proportion of total flow of about 56.2% as opposed to the 36.5% obtained in this study. This maybe explained by the downturn of rainfall magnitudes in the Sahel in the high latitudes of West Africa since the seventies (Nicholson, 1983). Other factors may also be due to high evaporation rates from rivers and surface waters during these dry years experienced and increase in consumptive use of water in the parts of the basin outside the country. These issues need to be addressed

in a research study.

The percentages of flows from within and outside the country were also calculated for six "dry" months starting from November to April and six "wet" months from May to October for comparisons. The results from the computations are also shown in Table 3. The results show that in the dry season, the percentage of flow from outside the country to the total flow is only 7.2 whereas that of the wet season it is 38. The wet season results are close to the annual results since a large proportion of surface water resources in the whole year is received in the wet season.

### H3. 2. The Black Volta Basin

#### H3.2.1. Mean, Maximum and Minimum Flows

The statistics of flows on the three selected stations in the basin are presented in Table 4. The monthly mean flows of Black Volta at Lawra and Bamboi are plotted in Figures 11 and 12.

#### H3.2.2. Flow Duration

The flow duration curves for the 3 selected stations are shown in Figure 13 to Figure 15. . The 95 percentile flow durations for Lawra Bui and Bamboi are 3.521, 2.137, 6.167 m<sup>3</sup>/s. The decrease in 0,95 at Bui from a higher value at Lawra an upstream stations, may be due to high evaporative loses during the dry seasons. An increase in the Bamboi 0,95 flow on the other hand may be due to the northward flowing tributary of Tain to the Black Volta. Tain takes its source from a more humid climate in the south.

#### H3.2.3. Surface Water Resources

The surface water resources of the Black Volta basin consist of runoff from outside and within the country. The inflow into the country can be estimated from the discharges measured at Lawra which is near the border. Similarly, the total discharge in the basin can be estimated from Bamboi, the southern-most gauging station. The mean annual flows of Black Volta at Lawra and Bamboi are 103.75 and 218.97 m<sup>3</sup>/s. There are some small tributaries which join the Black Volta downstream Bamboi. These streams include Yerada, Lambo and Sorri which joins Laboni. Laboni is gauged at Kalbrupe but has poor records. In order to estimate the total

flows from the catchment. The catchment areas of Black Volta at Bamboi and for the whole catchment were taken into consideration. The proportion of the former area to the latter is approximately 90%. Thus the catchment outflow discharges were estimated on the areal weighted ratio and shown in Table 5. The percentage of discharge into the country to the total basin discharge is 42.6 as shown in the Table. Compared to the White Volta, the proportion of flow from outside the country is higher for the Black Volta.

The percentage of flow from outside the country to the total flow is 76.5 when data in Table 1 of Nippon Koei (1967a) are used. This figure is much greater than the 42.6 obtained here and the reasons presented in section 3.1.3 may also be valid in this circumstance.

The proportion of seasonal discharges are also computed for the Lawra and the total catchment discharges as shown in Table 5.

Table 5. Water Resources in the Black Volta Basin

<b>Station</b>	<b>Annual, m<sup>3</sup>/s</b>	<b>Dry Season Discharge m<sup>3</sup>/s</b>	<b>Wet Season Discharge m<sup>3</sup>/s</b>
Lawra (Inflow)	103.75	34.75	172.13
Bamboi	218.97	62.83	373.79
Catchment Outlet (Outflow)	243.30	69.81	415.32
Flow from within the Catchment in Ghana	139.55	35.06	243.19
% Inflow/Total Outflow	42.64	49.7	41.45

The result in Table 5, show that the proportion of flow from outside and within the country for the wet season is similar to the magnitude of the annual flows. However, the dry season proportion of inflow to total outflow shows a magnitude of around 50%. This is in contrast to the results obtained in the White Volta basin where the dry season flows were found to be insignificant proportion of the total annual flow. This is confirmed by the 095 flow in the White

Volta basin which were all zero apart from the flow at Nawuni. This is quite significant information for planning water resources conservation and utilisation in the country. Further, the percentage of dry season flow to annual flow at a given station, whether upstream or downstream is over 28 which is quite significant.

### H3.3. The Oti Basin

#### H3.3.1. Mean, Maximum and Minimum Flows

The only gauging station with adequate records in this basin for use is the Saboba gauging station. The statistics on the flow at this station are presented in Table 6. The plot of mean flows at the station is also shown in Figure 16.

#### H3.3.2. Flow Duration

The flow duration analysis indicated a 95 percentile flow 0,95 of 1.587 m<sup>3</sup>/s. This flow is less than 1% of the mean annual flow. The flow duration curve is shown in Figure 17.

#### H3.3.3. Surface Water Resources

The border gauging station of the Oti river is Saboba and its discharges are used to assess the inflows of the river into the country. The mean annual inflow of the river into the country is 276.4 m<sup>3</sup>/s. The catchment area of Oti at Saboba is about 75% of the whole catchment area. It could be assumed that the inflow into the country is about 75% of the total flow if we assume constant specific yield of flow throughout the Oti catchment. The southern part of the basin has slightly higher specific yield than the northern part due to increase in rainfall southward of the basin (Opoku-Ankomah, 1986). In assuming constant specific yield the total flow in the catchment could be estimated as 365.5 m<sup>3</sup>/s with 89.1 m<sup>3</sup>/s from within the country.

### H3.4. The Lower Volta Basin

The Lower Volta Basin is located below the confluence of the Black Volta and the White Volta rivers excluding the Oti river drainage area. The sub-basins constituting the Lower Volta basin are tabulated along with their catchment areas in Table 7.

Table 7. The Sub-basins of the Lower Volta and estimated annual flows

<b>Sub-Basin</b>	<b>Area (km<sup>2</sup>)</b>	<b>Specific Yield (m<sup>3</sup>/s/km<sup>2</sup>) x 10<sup>3</sup></b>	<b>Estimated Annual Basin Flow (m<sup>3</sup>/s)</b>
Daka	8.283	7.996	66.2
Kularakum	5.931	8.000*	47.4
Pru	8.728	2.176	19.0
Sene	5.366	2.176*	11.7
Obosom	3.620	2.176*	7.9
Dayi	1.898	8.289	15.7
Asukawkaw	2.233	8.081	18.0
Alabo	1.023	3.086	3.2
Afram	11.396	8.766	99.9
Total flow from the tributaries	48.478		289.0

(\*Assumed specific yield)

#### H3. 4.1. Mean, Maximum and Minimum Flows

The statistics of flows at the selected stations are shown in Table 8. all these stations are located on the primary tributaries to the Lower Volta.

#### H3.4.2. Surface Water Resources

The surface water resources from within the Lower Volta Basin were estimated from the annual flows of the primary tributaries listed in Table 7. The flows from the primary tributaries were first computed from available gauging station discharges.

In the situation where there was no gauging station on the primary tributary, the specific yield of flow (defined as discharge per square km) was estimated from nearby sub-basins and used for the computation of the annual flow.

The specific yields estimated for the sub-basins with the exception of Pruso at Pru showed values around  $8 \times 10^{-3} \text{m}^3/\text{s}/\text{km}^2$ . The yield for Pruso on Pru river was  $2.176 \times 10^{-3} \text{m}^3/\text{s}/\text{km}^2$ . The mean annual discharge for Pruso on Pru and for Hohoe on Dayi were taken from Moniod

et al (1977).

The annual flow from within the Lower Volta Basin is estimated to be around 289 m<sup>3</sup>/s as shown in Table 7. This magnitude is higher than the value of about 141 m<sup>3</sup>/s estimated by Nathan Consortium. Summary of flows from outside the country, within the country but outside the Lower Volta basin and within the Lower Volta Basin are shown in Table 9. Magnitudes of flows presented in Nathan Consortium are also presented for comparisons.

From the above Table, the total inflows into the Lower Volta basin is 912 m<sup>3</sup>/s as compared to 1015 m<sup>3</sup>/s estimated earlier by Nathan Consortium. Thus the percentage of current flows into the Lower Volta Basin is about 90% of the amount estimated in the earlier report. The major observation here is that the flows that originate from outside the country into the Volta Basin have considerably reduced while the flows in the country have increased by 46%. The flow estimated from within the Lower Volta is also high. Some of the sub-basins did not have discharge data and where data existed, the records were poor. As data collection improves in these basins a more reliable estimate should be made for the Lower Volta Basin.

Table 9. Water Resources in the Lower Volta Basin

	River	Study (m <sup>3</sup> /s)	Nathan Consortium (m <sup>3</sup> /s)
Flows that originate from outside the Country	White Volta	110.70	152.06
	Black Volta	103.75	186.32
	Oti	276.40	389.34
	Total	490.85	727.72
Flows from within the country but outside the Lower Volta	White Volta	192.57	118.65
	Black Volta	139.55	57.20
	Oti	89.10	111.85
	Total	421.22	287.70
Total inflows into the Lower Volta Basin		912.07	1015.44
Flows from within the Lower Volta	Total	289.00	140.73



## H4. SEDIMENT YIELD AT SELECTED STATIONS IN THE VOLTA BASIN

### H4.1 Method of Analysis

#### H4.1.1. The Flow Duration - Sediment Rating Curve

##### Method of Computing Annual Sediment Yield

In the absence of a continuous record of suspended sediment (hourly records, for example), the flow duration - sediment rating curve method has been found to provide reasonable estimates of sediment yield. The method has been widely used (Miller, 1951; Piest, 1964; Walling, 1971). The technique involves the use of a flow duration curve to obtain average stream flow rates for a series of duration increments. These rates are then applied to a sediment rating curve and the corresponding sediment discharges determined. The discharges are then multiplied by the respective durations and summed to obtain the average daily sediment load. The annual yield is computed by multiplying the daily loads by the number of days in a year. The step by step description of the method is outlined in Miller (1951) and Tilrem (1979).

Miller (1951) and Piest (1964) have provided standard tables of duration increments that have been widely used in sediment load computations. The table by Piest is more detailed than that by Miller and has been shown by Walling (1977) to provide more accurate sediment yield calculations. This table was therefore used in the sediment yield computations carried out in this work.

#### H4.1.2. Sediment Yield Computations

The flow duration-sediment rating curve method was employed in computing sediment yields at 5 stations in the Upper Volta basin using the Piest duration limits. The stations are Lawra and Bamboi on the river Black Volta. Pwalugu and Nawuni on the river White Volta and Saboba on the river Oti (Figure 1). The computations for each of the 5 stations are summarized in Tables 10 – 14, following Tilrem (1979).

Daily stream flow data available at the WRRI were used with the Hydata software to construct flow duration curves (Figures 5, 6, 13, 15 and 17) for the various stations. Flow duration tables were then extracted from these curves and used to obtain the average runoff rates ( $O_w$ ) for each duration increment. The associated suspended sediment discharge for a duration increment was obtained from the rating equation:

$$O_s = aO_w^b$$

Where  $O_w$  = average stream flow for a duration increment. m<sup>3</sup>/s

$O_s$  = corresponding suspended sediment discharge. tonnes/day

a, b = constants

The values of a and b for the stations were obtained from Akrafi and Amisigo (1993a). The rest of the computations were as described in Tilrem (1979). 365 was taken as the number of days in a year in computing the annual sediment yield.

Walling (1984) has indicated that the bed-load for African rivers is about 10% of the total sediment load carried by the rivers. Also Ayibotele and Kuffour (1970) suggest that the bed-loads for rivers in southern Ghana fall between 5-10% of suspended sediment discharge. It was therefore assumed that for the rivers in the Volta basin the contribution of bed-load to the total sediment yield will not exceed 10% of suspended sediment yield. This percentage was thus applied to the annual suspended sediment yield to obtain the bed-load contribution.

#### H4.2 Sediment Yield Results

Tables 10-14 in the Appendix show the average annual gross and specific suspended bed-load and total sediment yield for the individual stations. The annual specific suspended sediment yield for all the stations are also shown in Table 15 together with the corresponding catchment areas. The specific suspended sediment yields are found to vary from 8 to about 28 tonnes/yr/km<sup>2</sup>. and decrease with catchment area. The sediment yield values compare with values of 3.9 to 85 tonnes/yr/km<sup>2</sup> obtained for some major river in various parts of West Africa (Walling, 1984).

## H5. CONCLUSIONS

The study shows that the hydrological network for collecting data is adequate. Unfortunately, there are considerable gaps in the data, especially during the 1980s when there were some serious droughts in the country. Efforts should be made to provide the basic logistics for the continuous data collection.

Data collection, transmission, storage and retrieval need to be modernized to facilitate the delivery of hydrological services in the country.

Flows that originate from outside the country in the Volta Basin System have reduced by about 30% either through climate variation or consumptive use of the water resource outside the country.

In the White Volta Basin dry season flow into the country is only about 7% of the total seasonal flow in the basin. In contrast, the dry season inflow in the Black Volta Basin is about 50% of the total seasonal flow.

There appears to be an increase in the flows of the Volta Basin System within the country. Further study is needed to explain this as well as the observation in (3).

The flows that were exceeded 95% of the time in the White Volta and the Oti were not more than one per cent of the mean annual discharge. The low flows in these basins are in general unreliable without storage for water supply.

No operational sediment network currently exists in the country. The annual sediment yield obtained from limited data for the selected catchments in the Upper Volta basin are low and compare with values obtained for some catchments in the sub-region of West Africa. Despite some missing flow data in the available records they were considered good enough to provide fairly reliable sediment yields for the river catchments at the stations. However, no monthly sediment yields were computed because the available data were inadequate.

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