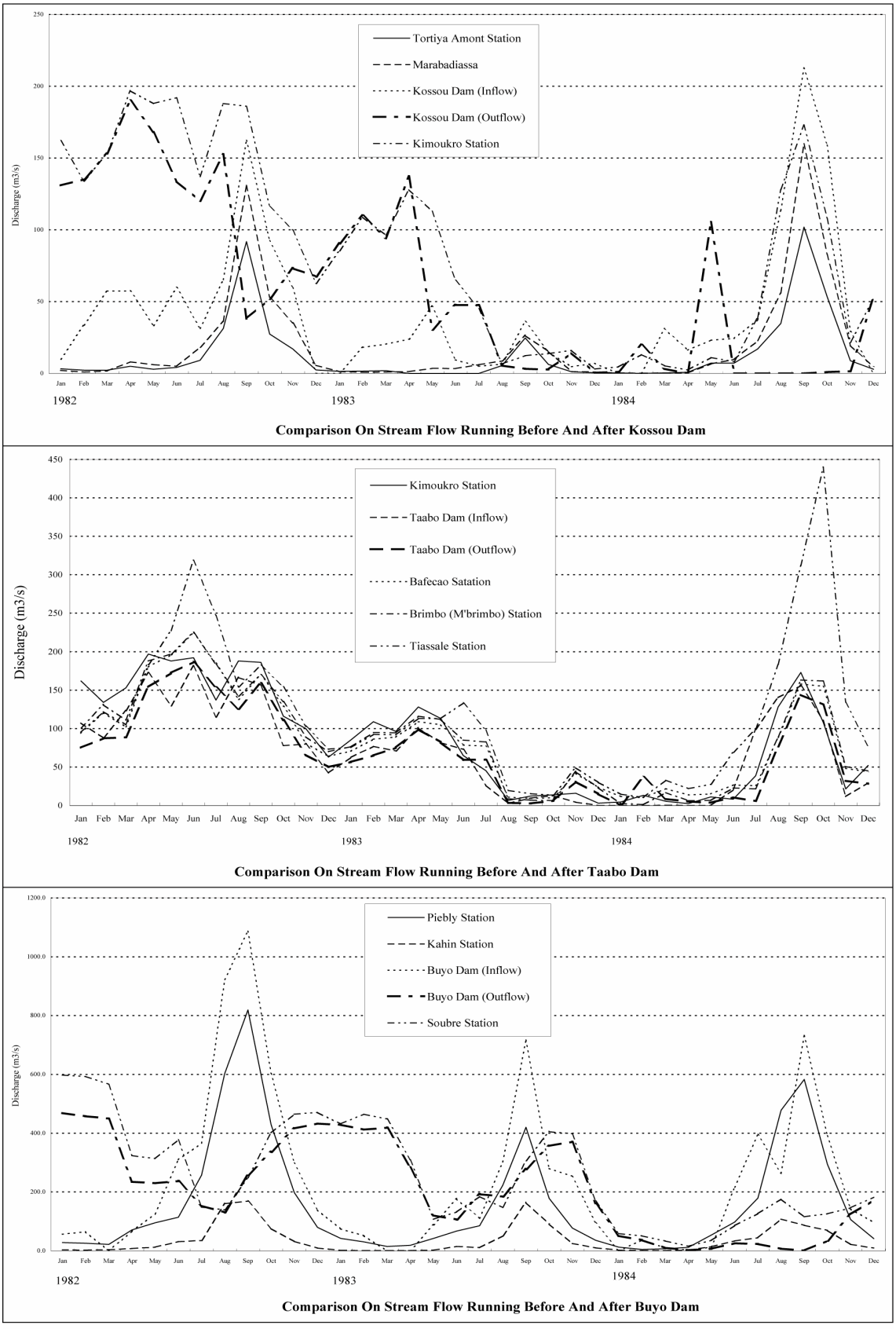

Figure 4.2-5 Comparison on Steam Flow Running before and after Dams

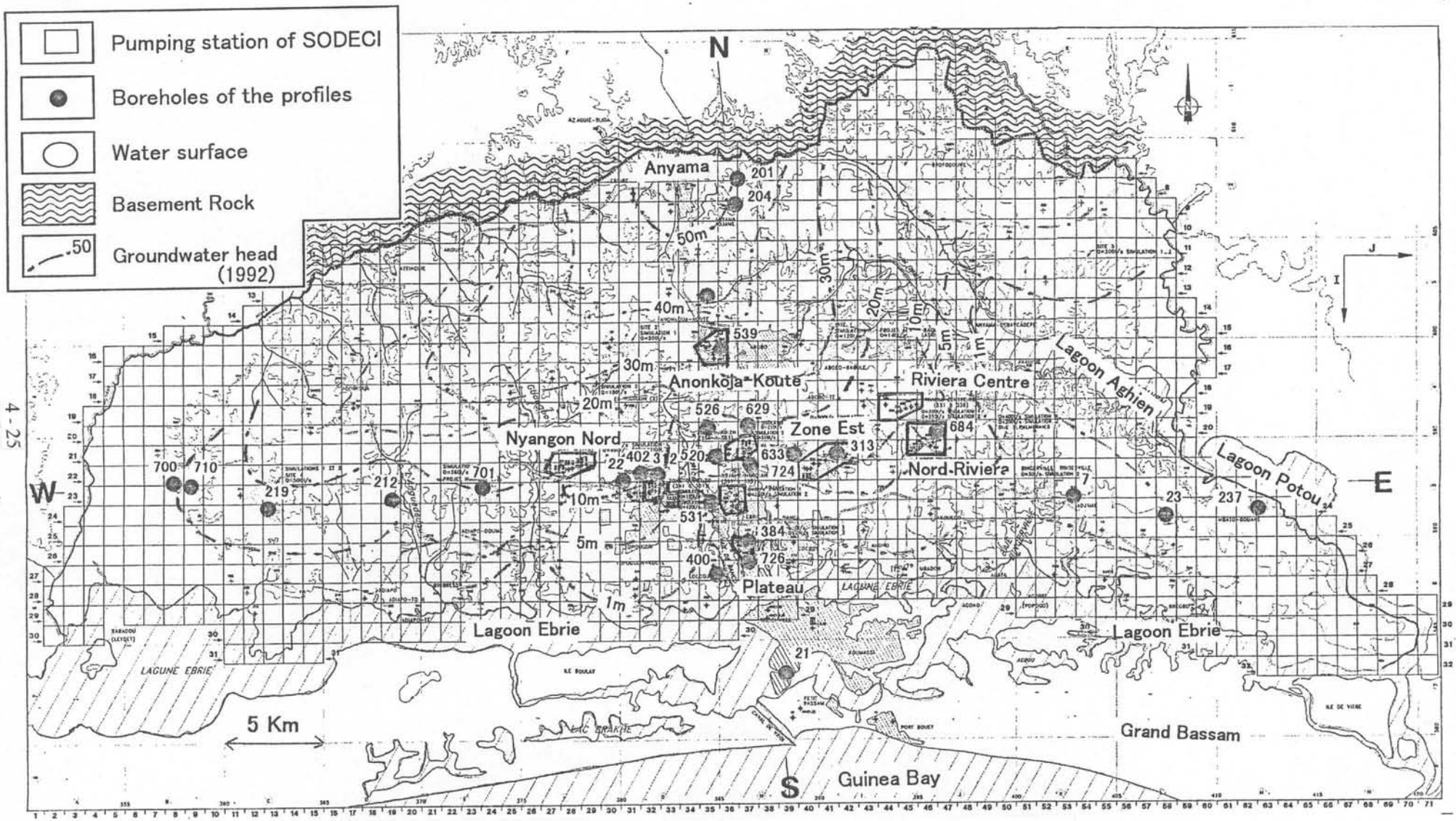

Figure 4.3-1 Location of Pumping Station and Main Borehole of Abidjan Area

Quoted from Final report of "Etude de la gestion et de la protection de la nappe assurant l'alimentation en eau potable d'Abidjan" (by BNETD & MIE/DH 1997)

CHAPTER 5 RIVERS AND RIVER BASINS

5.1 Division of the Country based on River Basins

5.1.1 General Division of the Country based on River Basins

In Cote d'Ivoire, there seems to be no definite division of the country based on the river basins, which are established for common/official uses. It is necessary to divide the whole country based on the river basins for the definite explanation of the rivers and river basins. The study on the divisions is carried out from overall viewpoints, but in reference to some examples taken by the government agencies/offices concerned.

The territory of Cote d'Ivoire is to be divided into eleven (11) areas based on major river basins as listed as follows:

Table 5.1-1 Primary Division of the Country based on River Basins

No. of Division	Name of Division	Remarks
I	Sassandra	One of four major rivers
II	Bandama	One of four major rivers
III	Comoe	One of four major rivers
IV	Cavally	One of four major rivers
V	Nuon	Inland river (in Cote d'Ivoire)
VI	Niger	Inland river (in Cote d'Ivoire)
VII	Black Volta	Inland river (in Cote d'Ivoire)
VIII	Bia	Coastal rivers
IX	Agneby	Coastal rivers
X	Boubo	Coastal rivers
XI	San Pedro	Coastal rivers

The numbering of divisions is made in the following manner:

- No.I to No.III: Three major rivers with large part of basin in Cote d'Ivoire, from west to east.
- No. IV: One more major river with large part of basin outside Cote d'Ivoire.
- No.V to No. VII: Inland rivers in clockwise order
- No.VIII to No.XI: Coastal rivers from east to west (continuation of clockwise order)

The primary division is shown in Figure 5.1-1.

5.1.2 Secondary Division based on Sub-basins

The secondary divisions with number are listed in the following table:

Table 5.1-2 Secondary Division of the Country based on River Basins

No.			Name of River
Sassandra River			
I	-	MR	Sassandra /Feredougouba (Upstream)
I	-	T1	Davo
I	-	T2	Lobo
I	-	T3	Nzo
I	-	T4	Kouin
I	-	T5	Bafing
I	-	T6	Boa
Bandama River			
II	-	MR	Bandama
II	-	T1	N'zi
II	-	T2	Marahoue
II	-	T3	Bou
II	-	T4	Solomougou
II	-	T5	Badenou
Comoe River			
III	-	MR	Comoe
III	-	T1	Manzan
III	-	T2	Beki
III	-	T3	Ba
III	-	T4	Diore
III	-	T5	Segbono
III	-	T6	Kinkene
III	-	T7	Kongo
III	-	T8	Iringou
III	-	T9	Kolonkoko
III	-	T10	Bawe
III	-	T11	Leraba
Cavally River			
IV	-	MR	Cavally
IV	-	T1	Hane
IV	-	T2	N'ce
Nuon River			
V	-	MR	Nuon /Cestos/ Nipoue
V	-	T1	Boang
Nijar Tributaries			
VI	-	T1	Bagoe
VI	-	T2	Kankelaba/Mahandiabani
VI	-	T3	Degou
VI	-	T4	Baoule
VI	-	T5	Sankarani/Kourou Kele
VI	-	BA	Border Area

Black Volta and Tribuatries			
VII	-	T1	Koulda
VII	-	T2	Kolodio
VII	-	T3	Bineda
VII	-	T4	Kohodio
VII	-	BA	Border Area
Bia and Other Coastal Rivers			
VIII	-	M1	Bia
VIII	-	M2	Tano
VIII	-	CA	Coastal area
Agneby and Other Coastal Rivers			
IX	-	M1	Agneby
IX	-	M2	Me
IX	-	CA	Coastal area
Boubo and Other Coastal Rivers			
X	-	M1	Boubo
X	-	M2	Go
X	-	M3	Niouniourou
X	-	M4	Bolo
X	-	CA	Coastal area
San Pedro and Other Coastal Rivers			
XI	-	M1	San Pedro
XI	-	M2	Brime
XI	-	M3	Niero/Nero
XI	-	M4	Dodo
XI	-	M5	Tabou
XI	-	CA	Coastal area

Note: T means a major Tributary

M means a Mainstream with minor tributaries.

MR means a Remaining area along the Mainstream with minor tributaries. BA is Border Area(s), which is a remaining area not selected as a unit of basin.

CA is Coastal Area, which is a remaining area not selected as a unit of basin.

The secondary division of the country based on the river basins is shown in Figure 5.1-2.

5.2 Features of Rivers and River Basins

5.2.1 International and Boundary Rivers

The country of Cote d'Ivoire is surrounded by Ghana on the east, Burkina Faso and Mali on the north, Guinea and Liberia on the east, and the Atlantic ocean on the south. Many rivers in the country are international/boundary rivers, that is, coming-in rivers from a neighboring country, going-out rivers from a neighboring country, and boundary rivers formulating a national boundary with a neighboring country. They are listed as follows:

Table 5.2-1 International/Boundary Rivers

River Division No.	Name of River (Main stream)	Mainstream or Tributary (in other country)	Relation to Neighboring country	Remarks
I	Sassandra	Mainstream & Tributaries	Coming in (to Cote d'Ivoire)	From Guinea
		Main & Tri.	Boundary	Of Guinea
III	Comoe	Main & Tri.	Coming in	From Burkina Faso
		Main & Tri.	Boundary	Of Burkina Faso
IV	Cavally	Main & Tri.	Coming in	From Guinea & Liberia
		Mainstream	Boundary	Of Liberia
V	Nuon	Mainstream	Boundary	To Liberia
VI	Niger	Tribuatries	Going out (from Cote d'Ivoire)	To Mali & Guinea
		Tributaries	Boundary	Of Mali
VII	Black Volta	Tributaries	Going out	To Ghana
		Mainstream	Boundary	Of Ghana
VIII	Bia	Main & Tri.	Coming in	From Ghana
	Tano	Main & Tri.	Coming in	From Ghana
		Mainstream	Boundary	Of Ghana

The general river system including the international rivers is shown in Figure 5.2-1.

5.2.2 Basin Area of Major Rivers

The river basin area of major rivers is obtained on the basis of the GIS maps and some other existing maps and summarized in the following table:

Table 5.2-2 Basin Areas of Major Rivers

No.			Name of River	Area (km^2)	
				Total	Within Cote d'Ivoire
I			Sassandra	75,000	67,000
I	-	T1	Davo	7,000	7,000
I	-	T2	Lobo	12,600	12,600
I	-	T3	Nzo	7,500	7,500
I	-	T4	Kouin	2,100	2,100
I	-	T5	Bafing	8,800	5,300
I	-	T6	Boa	10,400	9,200
II			Bandama	99,700	99,700
II	-	T1	Nzi	35,000	35,500
II	-	T2	Marahoue	21,600	21,600
II	-	T3	Bou	5,100	5,100
II	-	T4	Solomougou	1,600	1,600
II	-	T5	Badenou	2,400	2,400

III			Comoe	78,000	57,300
III	-	T1	Manzan	3,500	2,000
III	-	T2	Beki	700	700
III	-	T3	Ba	7,400	6,100
III	-	T4	Diore	5,000	5,000
III	-	T5	Segbono	1,200	1,200
III	-	T6	Kinkene	3,200	3,200
III	-	T7	Kongo	2,400	2,400
III	-	T8	Iringou	6,700	5,600
III	-	T9	Kolonkoko	1,800	1,800
III	-	T10	Bawe	2,300	1,000
III	-	T11	Leraba	11,200	4,900
IV			Cavally	30,000	16,600
IV	-	T1	Hane	4,400	4,400
IV	-	T2	Nce	1,200	1,200
V			Nuon	12,700	2,300
V	-	T1	Boang	1,000	1,000
VI			Niger	2,092,000	22,600
VI	-	M1	Bagoe	—	7,500
VI	-	M2	Kankelaba/Mahandiabani	—	3,900
VI	-	M3	Degou	—	1,100
VI	-	M4	Baoule	—	5,800
VI	-	M5	Sankarani/Kourou Kele	—	2,700
VII			Black Volta	149,000	12,500
VII	-	T1	Koulda	1,500	1,500
VII	-	T2	Kolodio	1,500	1,500
VII	-	T3	Bineda	2,100	2,100
VII	-	T4	Kohodio	2,800	2,600
VIII			Bia and Others	6,800	6,800
VIII	-	M1	Bia	10,100	3,200
VIII	-	M2	Tano	16,100	1,200
IX			Agneby and Others	16,000	16,000
IX	-	M1	Agneby	8,900	8,900
IX	-	M2	Me	4,300	4,300
X			Boubo and Others	12,400	12,400
X	-	M1	Boubo	5,100	5,100
X	-	M2	Go	2,200	2,200
X	-	M3	Niouniourou	2,100	2,100
X	-	M4	Bolo	1,300	1,300
XI			San Pedro and Others	12,400	12,400
XI	-	M1	San Pedro	3,400	3,400
XI	-	M2	Brime	1,200	1,200
XI	-	M3	Niero	1,300	1,300
XI	-	M4	Dodo	800	800
XI	-	M5	Tabou	800	800

Note: Figures of basin area are roughly rounded at a level of 100 km^2.

Basin area is mostly taken from the measurement on GIS map prepared by JICA Study Team. However, some areas are taken from a document prepared in the past or roughly measured on a map, especially for the areas outside of Cote d'Ivoire.

5.2.3 River System Diagram

The actual river systems in Cote d'Ivoire are very complicated. Accordingly the river system diagrams are prepared in eleven divisions. The river system diagrams of the major three representative river basins are shown in Figures 5.2- 2 to 4. These river system diagrams are based on the divisions of river basins in consideration of the river runoff analyses. There are some different types of river system diagrams. Two examples of the other types of diagram are shown together with the river discharge data in the following sub-section.

5.2.4 River Discharge

(1) Mean Discharge

The mean discharge will be one of most useful information of rivers and give an average scale of flow at a section of a river. The mean discharges in m^3/s at the control points in eleven rivers are shown in Figures 5.2- 5 to 15, which are river models/diagrams to be prepared to easily understand the relation between the river system and locations of control points. The catchment area in km^2 and the mean yield in mm are shown together in the figures. The control points (which are definitely explained in PART 4 " Water Balance Study") are the basic points established not only for river/water-resources management but also for checking the hydrological conditions in the JICA Study.

The mean discharge at the river mouth (or at the boundary of the country) of major/main stream(s) in eleven divisions, are summarized as follows:

Table 5.2-3 Mean Discharge of Major Rivers

No. of Division	Name of River	Mean Discharge in m^3/s
I	Sassandra	407
II	Bandama	171
III	Comoe	113
IV	Cavally	483
V	Nuon	Not available*
VI	Bagoe(Niger)	46
VII	Black Volta	100 (at Vonkoro)
VIII	Bia	45
IX	Agneby	Not reliable
X	Boubo	12
XI	San Pedro	33

Note: Mean discharge at the river mouth (lowest point), which is converted in proportion to the basin areas at two points (river mouth and a gauging station).

(2) Runoff Coefficient

The runoff coefficient from rainfall to rivers is low in most rivers. The annual mean-runoff coefficient in the whole country is less than 0.1. The rate in the western divisions/basins is generally higher (0.1 – 0.3) and that of eastern divisions is generally lower (0.05 or lower).

The mean runoff coefficient in eleven divisions, in a lower reach of mainstream(s), are calculated from a long term records and summarized as follows:

Table 5.2-4 Mean Runoff Coefficient

No. of Division	Name of Division	Mean Runoff Coefficient
I	Sassandra	0.125
II	Bandama	0.05
III	Comoe	0.045
IV	Cavally	0.26
V	Nuon	No record
VI	Niger	0.11 – 0.23
VII	Black Volta	No available record
VIII	Bia	0.08 – 0.11
IX	Agneby	0.03
X	Boubo	0.06 – 0.13
XI	San Pedro	0.22 – 0.26

(3) Specific Discharge

The rainfall is higher in the western and coastal regions (1,600 mm – 2,500 mm) and lower in the middle & northeast regions (1,000 – 1,300 mm). The specific discharge is also higher in the western rivers (Cavally and Sassandra Rivers) and lower in eastern rivers (Bandama and Comoe Rivers). The specific discharge in the western large rivers (at a lowest point of mainstream) is generally 0.005-0.0161 $m^3/s/km^2$ and that in the eastern large rivers is generally lower than $0.0015m^3/s/km^2$ except some coastal rivers. The specific discharge generally becomes bigger in a smaller basin or in tributaries.

The specific discharges in $m^3/s/100km^2$ at the control points in eleven rivers are prepared and those of three representative major basins are shown in Figures 5.2- 16 to 18. In general, the specific discharge is lower in a lower reach in the same river, as far as the natural conditions in the basins are similar. The specific discharge is useful to find a kind of discrepancy in records as well.

In addition, the specific discharges in eleven divisions, at a point of lower reach of mainstream(s), are separately calculated from a long term records and summarized as follows:

Table 5.2-5 Specific Discharge

No. of Division	Name of Division	Mean Runoff Rate
I	Sassandra	0.54 $m^3/s/100km^2$
II	Bandama	0.17 $m^3/s/100km^2$
III	Comoe	0.15 $m^3/s/100km^2$
IV	Cavally	1.61 $m^3/s/100km^2$
V	Nuon	No record
VI	Niger	0.38-0.95 $m^3/s/100km^2$
VII	Black Volta (Vonkoro)	0.09 $m^3/s/100km^2$
VIII	Bia	0.45 $m^3/s/100km^2$
IX	Agneby	0.10 $m^3/s/100km^2$
X	Boubo	0.24-0.54 $m^3/s/100km^2$
XI	San Pedro	0.98-1.48 $m^3/s/100km^2$

(4) Monthly Variation of River Flow

Many small tributaries are dried up in dry season, especially in the northern regions. The difference of discharge between rainy season and dry season is remarkably high, except the rivers located in the western regions.

The monthly variation of discharge is different by regions mainly due to the variation of monthly rainfall. Although the mixed pattern is seen in transitional areas, there are four hydrological zones (or rainfall and flow patterns) in general as summarized as follows:

Table 5.2-6 Monthly Variation of River Flow

Zone Name	Location	High Flow Month	Low Flow Month
Northern zone	Northern part of Côte d'Ivoire	August, September and October	From November to May
Southern (coastal) zone	Southern side of the country	June and July (First) and October and November (Second)	December to March (Lowest in February) and August to September.
Middle zone	Mixed-up zone located between the northern zone and southern zone	From May to November. (Higher in September and October)	Not clear
West mountain zone	Mountainous western zone	April to October (Highest in September)	January and February

5.2.5 Other Features of Rivers

(1) Flow Direction of Rivers

Mainstream of major rivers mostly runs down from north to south in general. The tributaries join to the mainstream generally from northeast/east or northwest/west direction. There are some exceptions in the area of Division VI (Niger tributaries), where major rivers run down from south-to-north or west-to-east direction, and in the upstream of Division I (Sassandra River), where the mainstream runs from the west to the east.

(2) Flood and Inundation

The flood inundation is not serious issue in the country. No remarkable flood inundation was recorded in the past. The happening of inundation is limited in a local narrow area and the damage is not remarkable.

(3) Natural River

Rivers are almost natural, that is there are very limited locations of river improvement works such as dike and revetment. The area along river is mostly covered with forest, bush, swamp or grasses. However, comparatively many dams (nearly 600 dams) are located in rivers. These dams are mostly earth-fill or rock-fill-type, accordingly, they look like natural lakes several years after the construction. In addition, some intake structures are seen in some rivers.

(4) River Profile

The land is mostly flat with gentle undulation and isolated low mountains, except mid-western mountainous area near the boundaries to Liberia and Guinea. The river profile is generally gentle according to the topography. For example, the elevation of the upstream area of the Bandama River is more or less El. 350 – 400 m. The river is a little longer than 1,000 km and accordingly the average gradient is at most 0.4 m down per 1 km.

(5) River-Mouth and Lagoons

The river mouth is mostly clogged and narrowed by sand bar. The coastal bar does not extend to the sea but along the sea and formulate lagoons. The lagoons are extended widely along the coast. Accordingly, more than half rivers in the territory of Cote d'Ivoire have actual river mouth in lagoon as seen in Figure 5.2-19.

(6) Natural Lakes and Ponds

There are no large or remarkable lakes or ponds in the country. All the large inland storage areas are man-made reservoirs.

5.3 Lagoons and Canals

The development of lagoons is one of major distinguished topography in Cote d'Ivoire, which has coastal line of nearly 500 km long. The whole surface area of lagoons becomes approximately 1,400 km^2 with shoreline of longer than 1,500 km. On the western coast, between Sassandra and Fresco, comparatively small lagoons are seen at some locations. While on the eastern coast, a series of large lagoons extends along the coastal zone, which is nearly 300 km long in total. This 300 km-zone is connected as a continuous waterway, by natural lagoons and some canals.

The general locations of lagoons and canals are shown in Figure 5.3-1. A series of lagoons and connected canals in the 300 km waterway is briefly explained as follows:

(A) Grand-Lahou Lagoon

Grand-lahou lagoon is the smallest one of all, with a total length of 50 km and an area of 190 km^2. It consists of 4 small lagoons including Mackey lagoon and Tagba lagoon..

(B) Ebrie Lagoon

Ebrie lagoon, with 566 km^2, an average width of 7 km and a length of 150 km has its average depth of 4 m. This lagoon is generally divided into some sections by two lagoons of Abjin and Potou, Assinie canal, Abidjan City and Vridi canal.

(C) Aby Lagoon

With a total area of 427 km^2, Aby lagoon complex is 56 km wide from east to west and 24 km long from north to south, then spreading over along the coastline.

The complex can be divided into 3 sectors: Aby lagoon, Tendo lagoon and Ehy lagoon.

There are three major canals connecting lagoons and mainly used for navigation system.

(A) Agneby Canal

The Agneby canal has constructed between 1912 and 1918. The length is about 17 km. The canal has been enlarged in 1922 and connected to Ebrie lagoon and Grand-Lahou lagoon.

(B) Groguida Canal

This small canal (1 km) connects two elements of Grand-Lahou lagoon. It is the most recent one and deeper (2.5 m) than Agneby canal.

(C) Assinie Canal

It connects Ebrie lagoon and Aby Lagoon. It has been opened in 1957. It is 48 km long and between 1.5 and 7 m deep.

In addition to the above, it is noted that there is one canal constructed for the outlet (to the sea) of Ebrie lagoon at Abidjan: Vridi Canal, which was opened in 1950. The canal is significant as an only large port in Cote d'Ivoire, Abidjan port, is located in the Ebrie lagoon. The Virdi canal is 2.7 km long, 230 m wide, and 12 m deep on an average.

5.4 Dams and Other River Structures

5.4.1 Dams and Reservoirs

The total storage capacity of all dams in the country is approximately 38 billions m^3 at the full water level. The volume is almost equivalent to the annual average discharge of surface water in the whole country, although the actual storage capacity is much less in dry season.

There are nearly 600 dams (578 dams at the inventory survey in 1999) in Cote d'Ivoire. Most of them are middle to small dams, but two dams (Kossou and Buyo) are huge and another three dams (Taabo and Ayame I & II) are large. These large dams are all for hydroelectric power generation.

The table below shows the number of dams in eleven divisions.

Table 5.4-1 Number of Dam in 11 Divisions

No. of River Division	Name of River Division	Number of dams (%)
I	Sassandra	10 (2%)
II	Bandama	267 (46%)
III	Comoe	99 (17%)
IV	Cavally	1 (0%)
V	Nuon	0 (0%)
VI	Niger	73 (13%)
VII	Black Volta	43 (8%)
VIII	Bia	2 (0%)
IX	Agneby	82 (14%)
X	Boubo	0 (0%)
XI	San Pedro	1 (0%)
Total		578 (100%)

(Inventory Survey in 1999)

The table below shows the maximum storage capacity of dams in eleven divisions:

Table 5.4-2 Storage Capacity of Dam in 11 Divisions

No. of River Division	Name of River Division	Total storage capacity of dams In million m^3 (%)
I	Sassandra	8,336.6 (22%)
II	Bandama	28,796.4 (75%)
III	Comoe	37.3 (0%)
IV	Cavally	0.0 (0%)
V	Nuon	0 (0%)
VI	Niger	31.7 (0%)
VII	Black Volta	3.0 (0%)
VIII	Bia	969.0 (3%)
IX	Agneby	24.0 (0%)
X	Boubo	0 (0%)
XI	San Pedro	25.0 (0%)
Total		38,223.0 (100%)

(Inventory Survey in 1999)

The table below shows the number of dams classified by main purposes to use:

Table 5.4-3 Number of Dams in Classification of Main Purpose

Use	Number of dams	
Livestock	361	63.1 %
Agriculture	120	21.0 %
Fish culture	25	4.4 %
Domestic water	19	3.3 %
Hydro-electricity	4	0.7 %
Mixed	37	6.5 %
Other	6	1.0 %
Total	572	100 %

(Inventory Survey in 1995)

A dam project is generally planned and constructed by an office or an agency of governmental department. The multi-purpose dam is scarce, however, a certain number of dams are used for secondary purpose such as follows:

(a) Dams for irrigation are occasionally used for livestock as well

(b) Many reservoirs are used for fishery, but mostly small in scale used by local farmers.

Although there are nearly 600 dams, the large-scale dams are limited to those for hydroelectric purpose. They are listed as follows:

(a) Buyo dam (Sassandra River)
(b) Kossou dam (Bandama River)
(c) Taabo dam (Bandama River)
(d) Ayame dam I (Bia River)
(e) Ayame dam II (Bia River)
(f) Faye dam (San Pedro River)

The specific features of six dams for hydroelectric power are summarized in Table 5.4 – 4.

Some dams for water supply are also large, but not like major dams for hydroelectric power. Most dams used for agriculture are comparatively small, especially those for livestock.

Table 5.4-4 General Features of Dams for Hydro-Electric Power

	Unit						
River Division No.		I	II	II	VIII	VIII	XI
Name of dam/reservoir		Buyo	Kossou	Taabo	Ayame I	Ayame II	Faye (Grah)
Name of river		Sassandra	Bandama	Bandama	Bia	Bia	San Pedro
Latitude (North)	° ′	6°14′	7°01′	6°12′	5°36′	5°35′	4°58′
Longitude (West)	° ′	7°01′	5°29′	5°05′	3°10′	3°10′	6°39′
Sub-prefecture (dam)		Soubre	Yamoussoukro	Tiassale	Aboisso	Aboisso	San Pedro
Main Purpose		Electricity	Electricity	Electricity	Electricity	Electricity	Electricity
Other purpose		Fishery	Fishery	None	None	None	(Water supply?)
Year of construction		1980	1972	1977/1979	1959	1975	
Office in charge of O & M		CIE	CIE	CIE	CIE	CIE	CIE
Basin area at damsite	km^2	46,250	32,400	57,700	9,320	9,330	2,424
Reservoir HWL	m	200	206	124	90.5	69	23.1
Reservoir LWL	m	186.5	184(181)*	118	83	60.5	19.6
Reservoir volume (HWL)	million m^3	8,300	30,211	630	900	69	25
Reservoir volume (LWL)	million m^3	1,300	4,410(3,249)*	290	54	1	
Reservoir effective volume (HWL-LWL)	million m^3	7,000	25,801(26,962)	340	849	68	
Reservoir area (HWL)	km^2	895	1,780	69	180	1	
Reservoir area (LWL)	km^2	240	478	43	55		
Dam type		Fill type	Fill type	Fill type	Gravity, Fill type	Gravity	Gravity/Fill
Dam height	m	37	58	34	30	35	10
Dam volume	million m^3	6.9	5.2	9.8	0.15	0.05	
Dam crest EL	El. m	204	209	127	92.5	70.5	
Dam crest length	m	6,290	1,800	8,100	610	310	2,630
Annual mean rainfall (nearest site)	mm	1,600	1,180	1,370	1,850	1,850	1,900
Installed power generating capacity	MW	165	174	210	20	30	5
Annual production (Planned, Average year)	GWH	900	450 (50)**	960(380)**	80	120	22

* : ( ) Revised after the completion.

** : ( ) In case that Kossou reservoir can not store the volume in design.

5.4.2 Other River Structures

River structures other than dams and the appurtenant facilities such as spillway, intake, etc. are limited and not remarkable. However, the brief explanation on these river structures are presented as follows:

(A) Diversion/Intake Weir and Intake/Pumping Tower

There are not a few intake structures/facilities in rivers, however the detailed data are not available. There are generally the following types:

- Diversion weir with pumping intake
- Diversion weir with gravity intake (without pumps)
- Pumping type Intake (without diversion weir)
- Run-of River type Intake (without pumps , without diversion weir)

Among them, pumping type intake (without diversion weir) is most common.

(B) Stream Gauging Equipment

There are 157 gauging stations in rivers, although some (20 or more stations) of them are not functioning at present. Most of them have only staff gauges. Gauging station with automatic recorder are limited.

(C) Quay for Ferry Service

There are 15 ferry services operated by the government. Most of them have concrete quay on both banks.

(D) River-bank Protection/Revetment/Dike

The river bank protection is very limited in Cote d'Ivoire. The revetment works are seen only at locations of some river structures such as bridges or dams/power stations. That is, the river bank protection is mostly used as an appurtenant structure. The river dikes are also not seen except very limited parts connecting to bridge.

(E) Bridge (including submerged bridge)

The transportation system on road is widely developed in Cote d'Ivoire. Accordingly there are many bridges crossing rivers. For example, there are 7 bridges in the mainstream of the Sassandara River, 13 bridges in the mainstream of the Bandama River and 8 bridges in the mainstream of the Comoe River. The bridges located in the mainstreams (especially in the lower reach) are generally large/long, comparing with those located in the tributaries. Most of them are concrete bridges.

(F) Others

Other types of river structures such as spur, dike, ground-sill, revetment, sluice gate and navigation lock are very partial or do not exist.

5.5 Present Issues on Rivers and River Structures

The present issues related to river and river structures, including related meteorological and hydrological conditions, are presented as follows:

(A) Flood & Inundation

The issue of flood & inundation is not serious concern in Cote d'Ivoire. Although there are many rivers and the discharge in rainy season becomes high, it was informed from the department of water as follows:

(a) There is no habitual inundation area.

(b) No remarkable flood damages are recorded in the past.

(c) Inundation in Agboville town caused by flooding of Agneby River was informed a couple of years ago. But, the damage was not serious and the inundation area was limited in a part of river channel section where some temporary houses were built.

(d) The other inundation may happen, during heavy rainy period, in low and partial areas where no villages are located.

(e) There is no definite governmental office, which is in charge of flood control. It would not be necessary to establish such office in Cote d'Ivoire.

The reasons of such situation are considered as follows:

(a) The heavy rainfall generally happens in a limited area. That is, the heavy rainfall does not happen simultaneously in a whole basin. The flood volume may be large but the flood peak is not sharp.

(b) The run-off rate is low due to high infiltration to the ground. The most area of each river basin is covered with natural or semi-natural land, where the drainage system is not developed. In addition, there are many natural retarding basins and man-made reservoirs in the country.

(F) Others

Other types of river structures such as spur, dike, ground-sill, revetment, sluice gate and navigation lock are very partial or do not exist.

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(c) The river is mostly natural and the river dike is not constructed. Accordingly the flood water level will increase gradually, even if the flood water level becomes higher than the top of river-banks, and accordingly the sudden attack of high velocity of flood will not happen.

(d) The lowest land areas with comparatively many villages and towns are located along the coastal zone. But, in the coastal zone, there are lagoons or lakes and they have function to regulate the increase of flood water level due to their storage capacity.

Concerning the flood inundation in Agboville town, the field reconnaissance was carried out to confirm the actual conditions. It was found that the flood inundation is habitual and more serious for the inhabitants living there than the information from the department. Although the detailed survey could not carried out, the conditions are like as follows:

(a) The flood inundation occurs almost every year and the inundation period continues for two or three months, in a period from June to August.

(b) The inundation area is not partial. Although no specific survey was made, the inundation area seems to be some hundreds meters wide. There are not a few houses in the area.

(c) The inundation generally happens in the upstream area of the bridge crossing Agbo (Agneby) River. The flood water level occasionally reachs to the top of road passing the bridge and flows over the road to the downstream side.

As far as the temporary observation by the river engineer, it is probable that the inundation is caused by bridge. That means a kind of man-made cause is considerable. The Abneby River suddenly becomes narrow at the bridge section and the section below the bridge may not have enough capacity during the high flood season. Then the upstream area of the bridge section may be inundated by the back-water. It should be surveyed more in detail and take countermeasures as early as possible.

In addition to the above, it is noted that the inundation was happened in Abidjan (Cocode) in 1996 and the damage was more or less serious. But, it is not a flood from a river. It was caused by insufficient drainage system.

(B) Boundary Rivers

The country of Cote d'Ivoire borders with Ghana (640 km), Burkina Faso (490 km), Mali (370km), Guinea (610km), and Liberia (580 km). And the coastline covers about 500 km facing the Gulf of Guinea

And large parts of boundaries are located along rivers. As far as the information obtained from the department of water, there is no definite agreement or treaty for these rivers with the neighboring countries. The use of these rivers is now limited only for ferry services and there is no bridges crossing the river at the border. However, in the future, it will be necessary to use the border rivers for the other purposes such as irrigation, hydroelectric power and navigation. It would be desirable for Cote d'Ivoire and the neighboring countries to establish the general agreement as early as possible to avoid the selfish use of water by one side, for more effective use of water resources.

(C) Trans-Boundary Rivers

This issue of transboundary rivers, which run down to or from the neighboring countries, would be similar to the issue mentioned above for the bordering rivers. There are rivers running down to or from the neighboring countries.

At present, the water use can be made by respective country inside their territories, without discussion with the neighboring country. That is, the upstream country has priority to use the river without consideration of the effect to the downstream side.

It is noted that Cote d'Ivoire is a member country of Niger River Authority, which was established by riparian countries of Niger River basin: Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria and Chad.

(D) Insufficient Survey Data for Rivers

The survey data of rivers in Cote d'Ivoire are limited. The existing survey is limited only for stream-flow discharge measurement and water quality monitoring respectively at major representative points. There is no data of river profile and cross sections. In addition, the data for sediment loads are also not available at present. It would be necessary to establish the database system of rivers and the river-related sectors as early as possible.

(E) Dams not Used

There are nearly 600 dams in the country and some/many of them are not used at present. Although no detailed records are obtained, some dams may be abandoned some years after the construction. The dam is generally constructed by spending a large amount of expense. It does not seem to be reasonable to leave them without using or poorly used. The example are Gbemou dam (near Bondiali), a dam located a few km south of Abenjourou, a dam located about 5 km north (near Goly) of Bondoukou, Setao dam near Daoukro and a dam located a few km south of Quall. These dams are found by chance by the river engineer during field reconnaissance. The engineer visited only more or less 20-25 dams including six large dams for hydroelectric power. According to the information from PNR, there are many other dams (for agricultural/livestock use), which are not used at present.

(F) Reliability of Stream Flow Data

There are nearly 157 stream-flow gauging stations (137 stations are functioning at present). The problematic conditions observed during the site reconnaissance are as follows:

(a) The location of gauging station is not appropriate due to the following:

- Unstable river section
- Difficult to measure the discharge
- Access is not easy
- Water level gauging station is located in a range of backwater by a river structure
- Water level gauges is located very close to pumping facilities

(b) The maintenance of staff gauges and recorders looks poor at some stations. Damages and rusting of equipment are seen.

(c) The discharge measurement during flood seems to be not enough. For preparation of rating curve, it is essential to have actual measurement data for flood.

(d) It seems that the verification of records and measurement methods is not carried out sufficiently.

(G) River Mouth Clogging and Sedimentation in Lagoon

The most rivers become narrow at the mouth and clogged by sand bar along the coast. This condition is not problematic matter at present as the flood inundation is not serious in Cote d'Ivoire. But it would be an issue for river use in the future. For example, the sediments in lagoon will cause difficulties of navigation, especially for larger boat, which needs a certain draft.

(H) Shortage of Water in Dry Season

Although the country is generally abundant in water resources, the shortage of water happens during dry season. In many rivers, the discharge in dry season decreases remarkably. This unbalanced discharge is more common in areas with less annual mean discharge. The runoff rate from rainfall to surface water is less than 10 % on an average. and estimated at only approximately 120 mm of yield against the annual mean rainfall of approximately 1,400 mm.

In general, nearly 90 % or more of the annual runoff is concentrated in the rainy season, while nearly 85% of annual rainfall is in the rainy season.

(I) Unexpected Less Storage in Kossou Reservoir

According to explanation by Ivoirean engineers, the Kossou reservoir get remarkably less inflow from the estimated one used for the design of structures. It was informed that the inflow becomes much less than before (decreased by approximately 25 %) after the completion of dam. As seen in Figure 5.5-1, the annual power generation in the past is more or less one fourth or one fifth on an average of the planned generation (approximately 500Gwh). There are some probable causes as listed as follows:

- Many storage-dams constructed in upper reaches
- Rainfall decrease
- Large evaporation from the reservoir
- Forest decrease
- Leakage from reservoir bottom
- Inappropriate plan (overestimate of inflow, uneconomical design, etc.)

It may be sure that the average discharge is decreased after the dam construction. The double mass-curve at Tiassale shows that the discharge was surely decreased since 1970, while that at Bada (upstream river of reservoir) shows the reduction started in 1975. The detailed study based on meteorological and hydrological data in a wide area will be necessary to find the cause of remarkable decrease of discharge. The other probable causes also need the study for confirmation and verification. A schematic explanation of reservoir water levels is shown in Figure 5.5-2, for a reference of further study.

Besides the matter of discharge decrease, it seems that the original plan & design itself is not appropriate. That is, the scale of dam and reservoir may be too large.

It is a matter of concern that the Kossou dam & reservoir should be used as it is or not. It is desirable to review the original design/study in detail and take countermeasures (such as construction of diversion channel from Marahoue River and control of dams located in the upper basin) for effective use of existing structures and equipment.

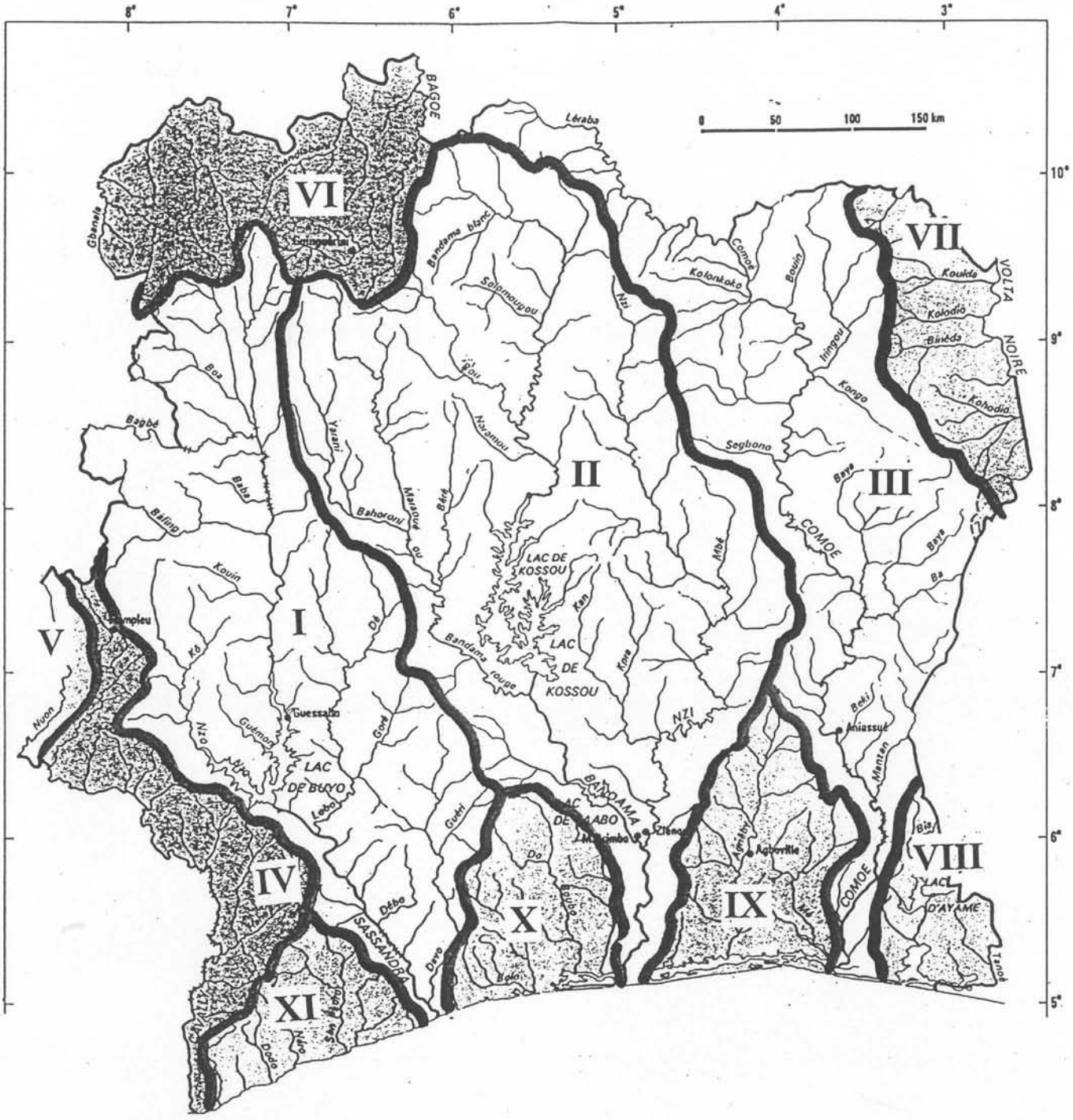


Figure 5.1-1 Primary Division of Cote d'Ivoire Based on River Basins

Figure 5.1-2 Secondary Division of the Country based on River Basins

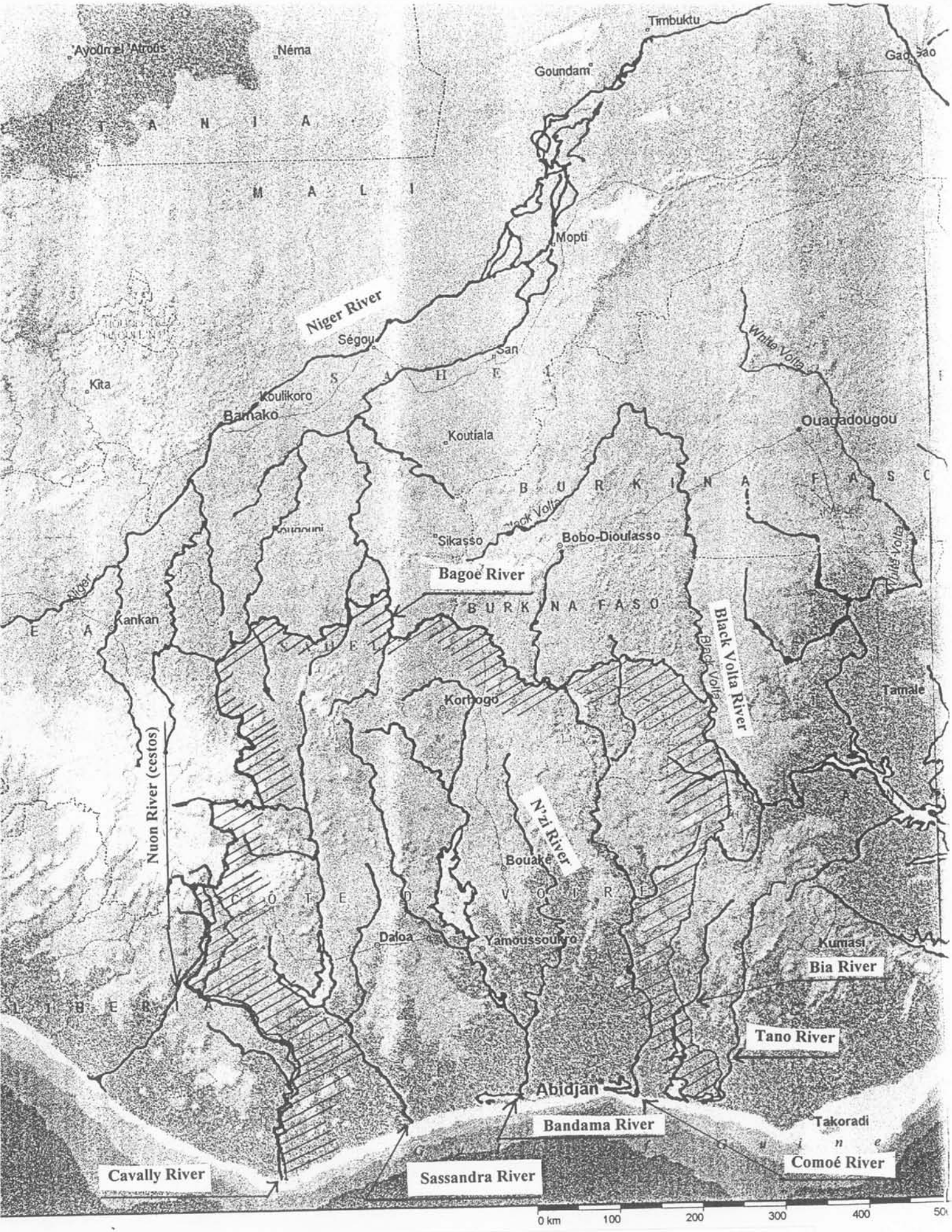


Figure 5.2-1 General River System in Cote d'Ivoire Including Transboundary Rivers

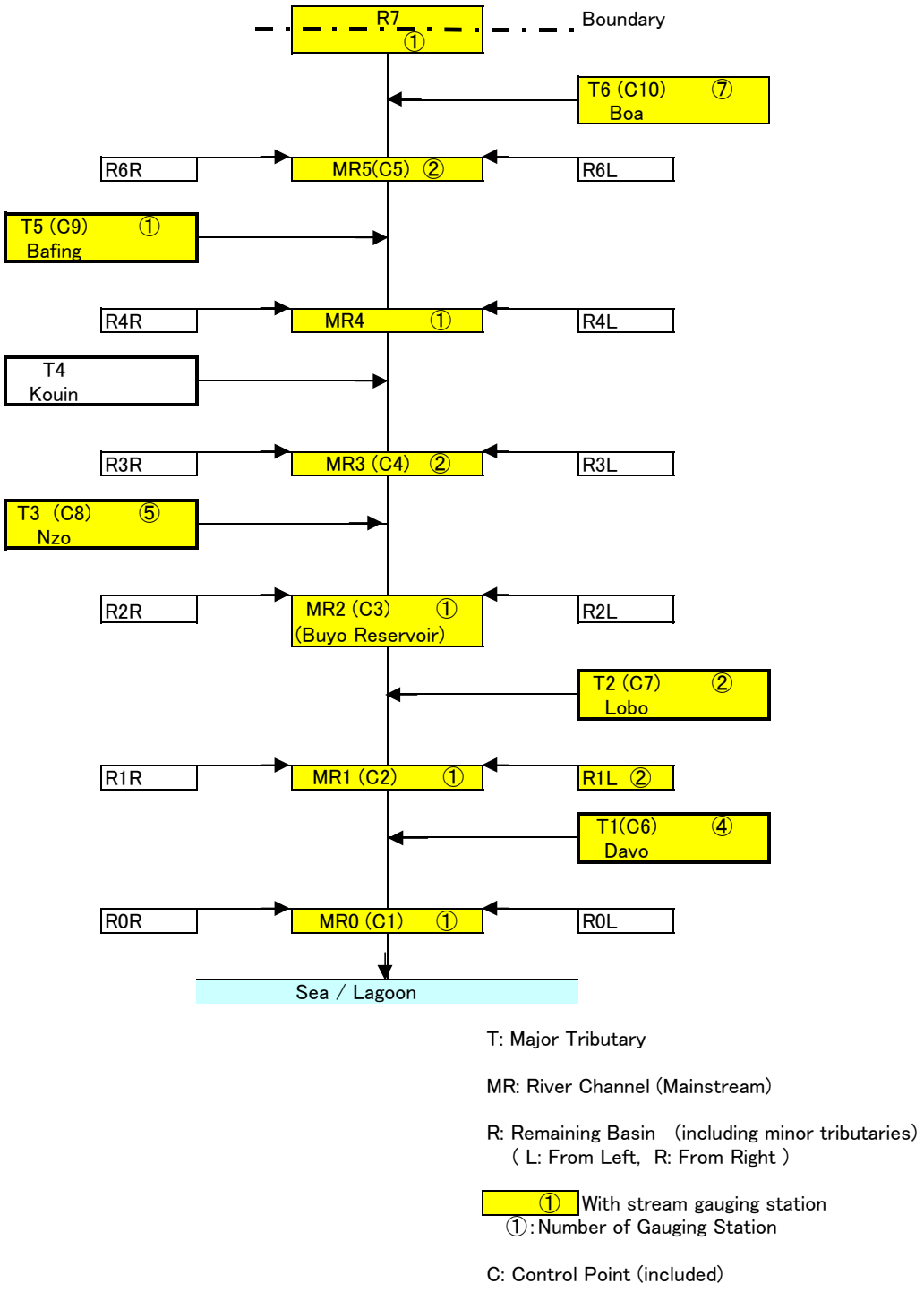


Figure 5.2 -2 River System Diagram of Division I (Sassandra River)

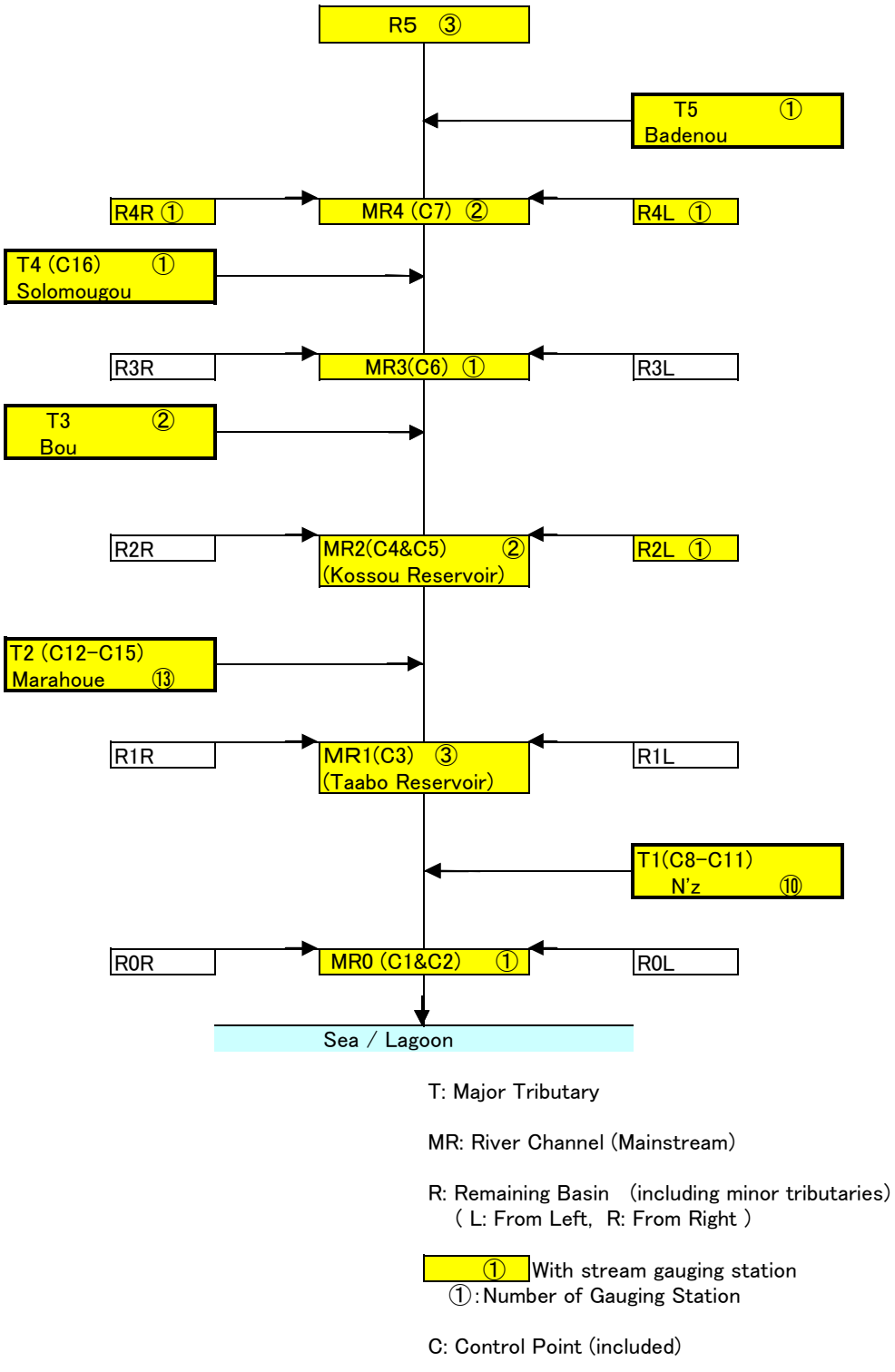


Figure 5.2-3 River System Diagram of Division II (Bandama River)

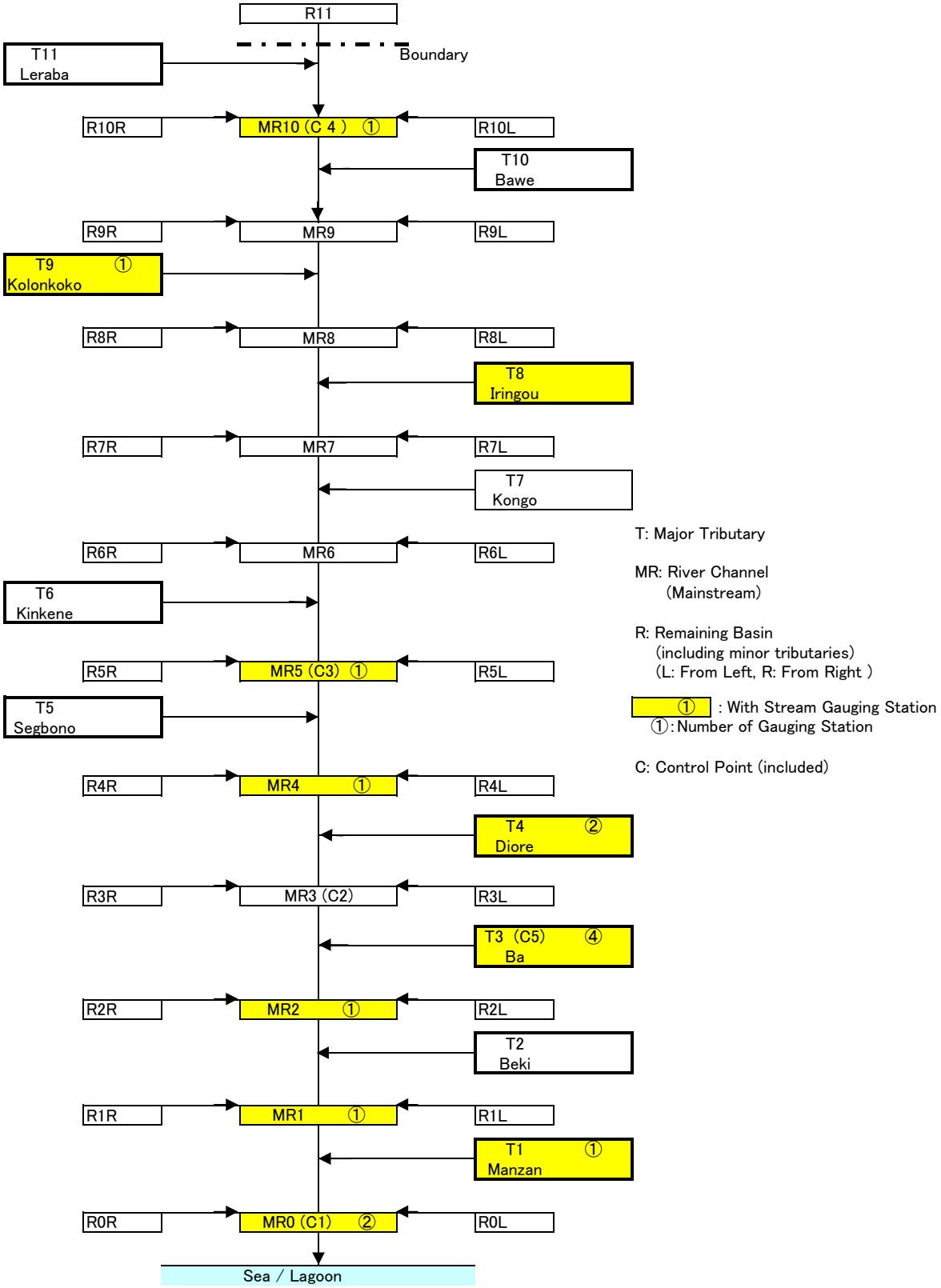


Figure 5.2-4 River System Diagram of Division III (Comoe River)

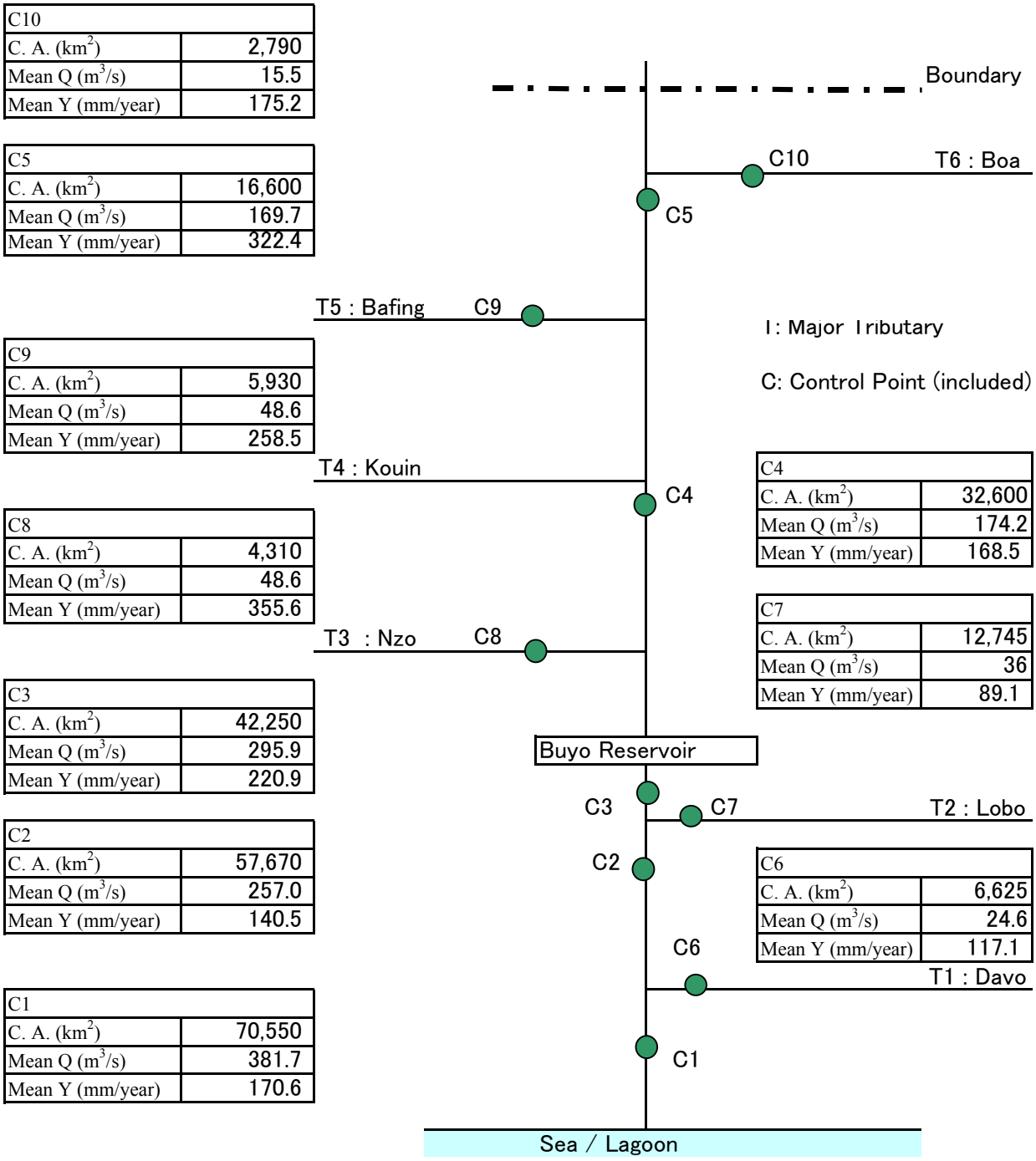


Figure 5.2-5 River Model with Control Point of Division I (Sassandra River)
(With Mean Discharge/Yield at CP)

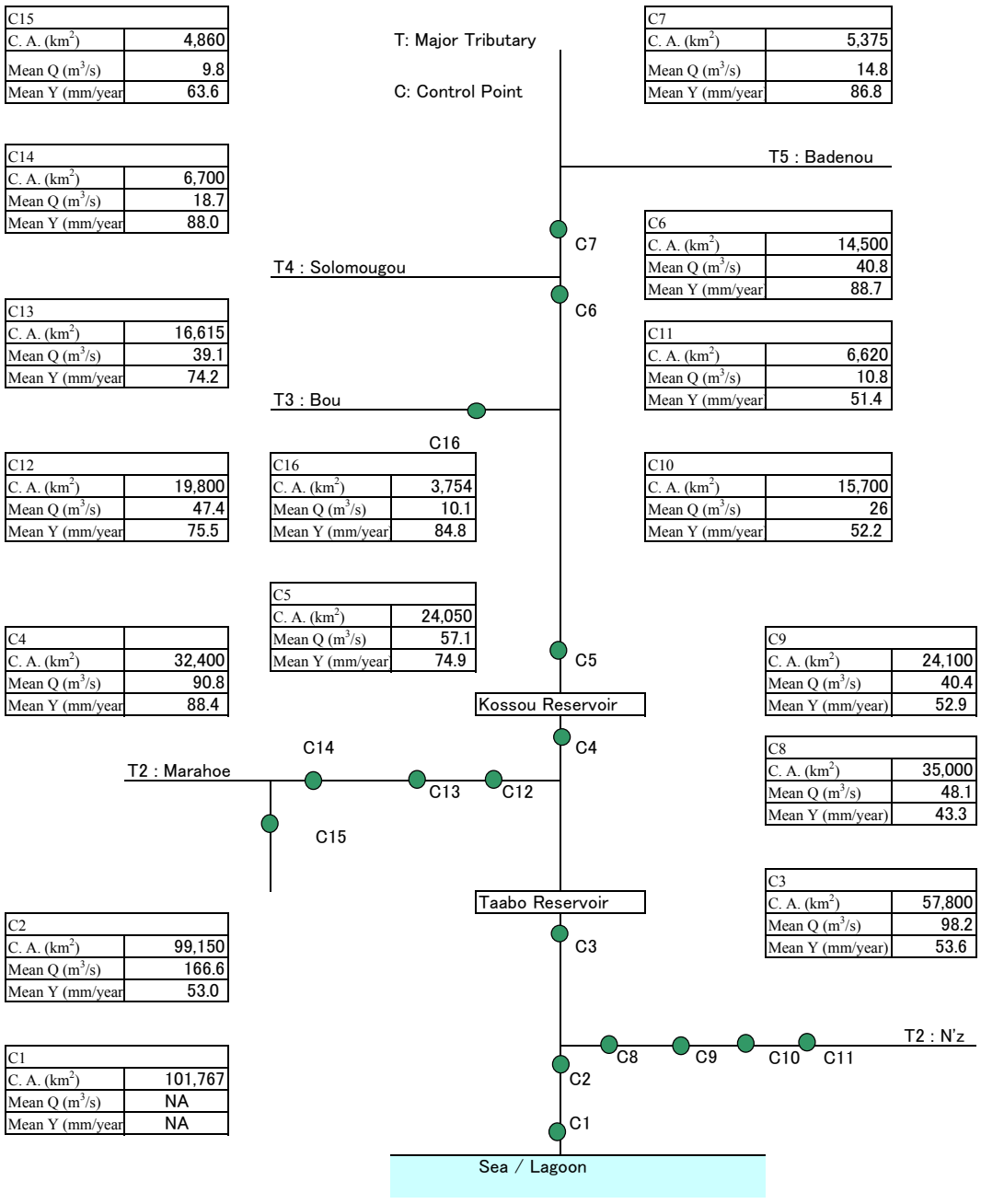


Figure 5.2-6 River Model with Control Point of Division II (Bandama River) (With Mean Discharge/Yield at CP)

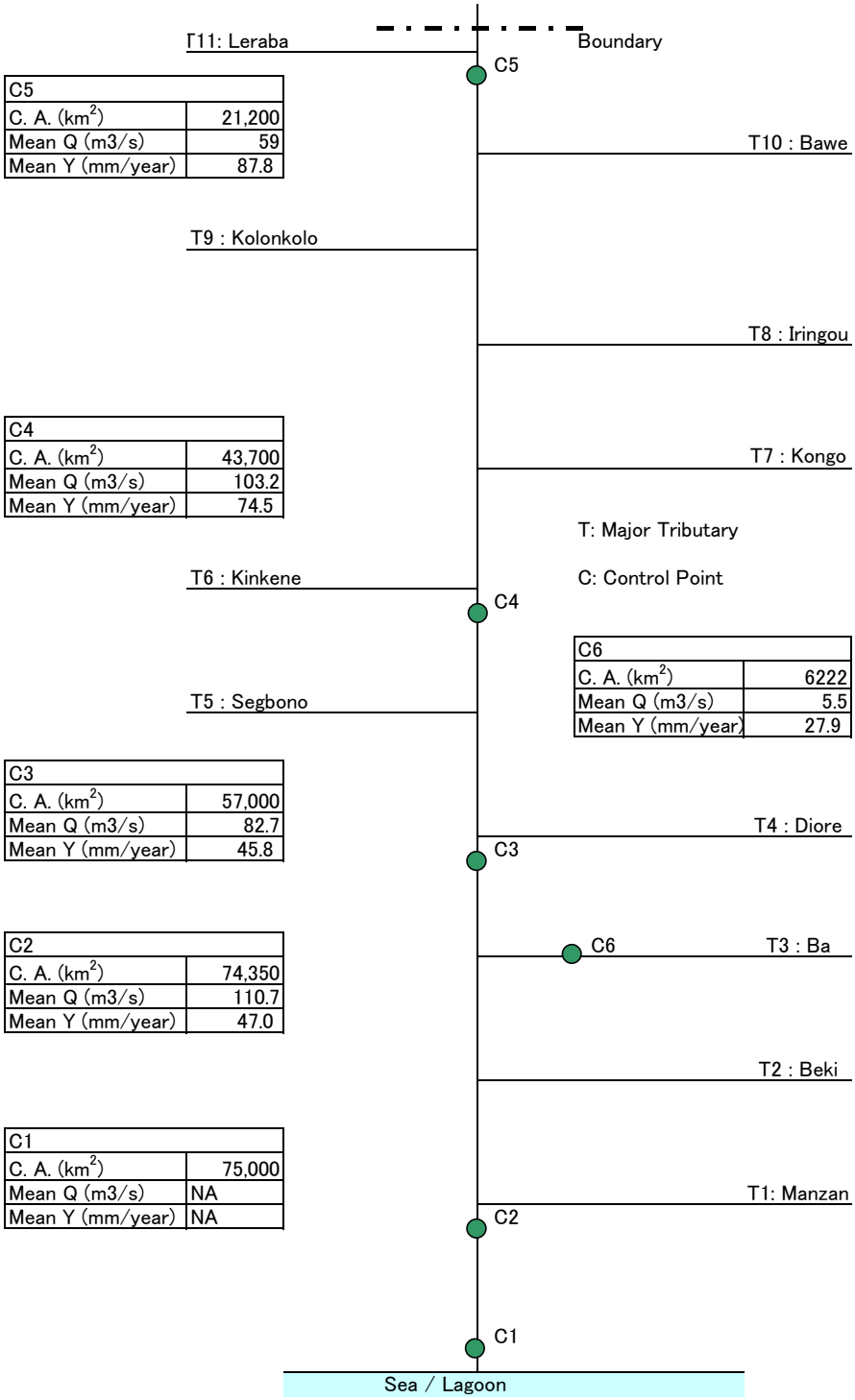
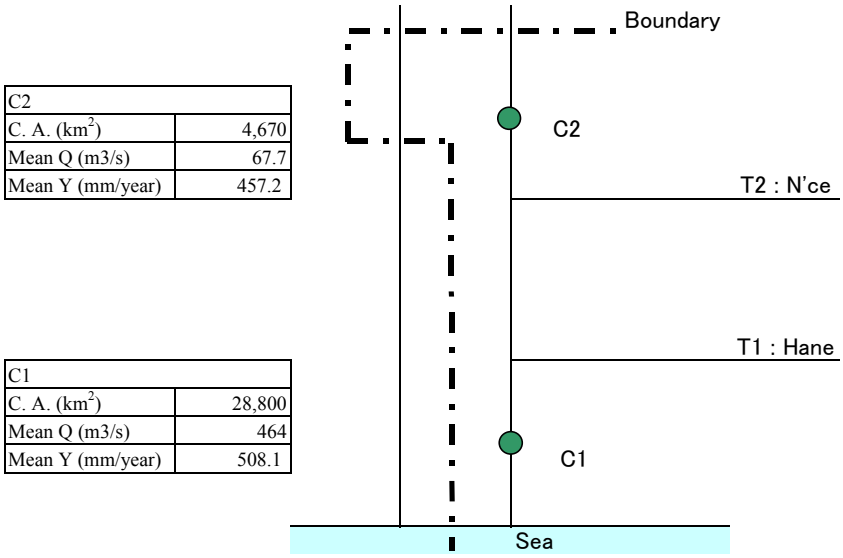


Figure 5.2-7 River Model with Control Point of Division III (Como (With Mean Discharge/Yield at CP)

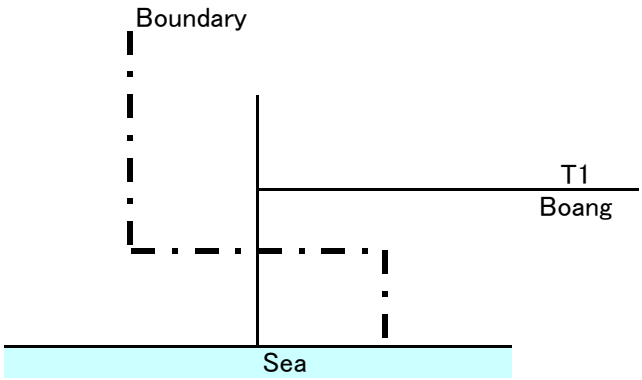


C2	
C. A. (km^2)	4,670
Mean Q (m3/s)	67.7
Mean Y (mm/year)	457.2

C1	
C. A. (km^2)	28,800
Mean Q (m3/s)	464
Mean Y (mm/year)	508.1

T: Major Tributary
C: Control Point

Figure 5.2-8 River Model with Control Point of Division IV (Cavally River)
(With Mean Discharge/Yield at CP)



T: Major Tributary
C: Control Point

Figure 5.2-9 River Model with Control Point of Division V (Nuon River) (With Mean Discharge/Yield at CP)

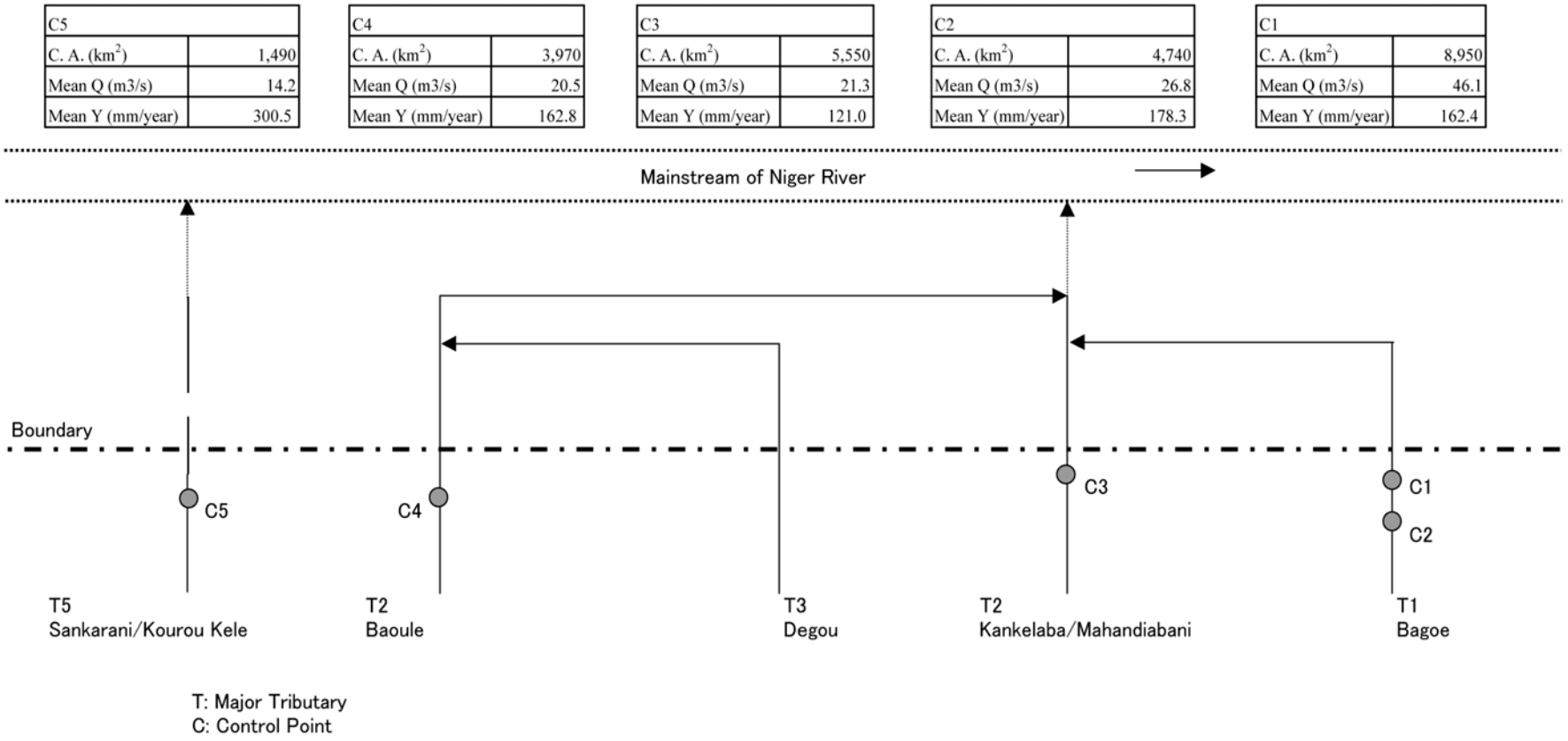


Figure 5.2-10 River Model with Control Point of Division VI (Niger River) (With Mean Discharge/Yield at CP)

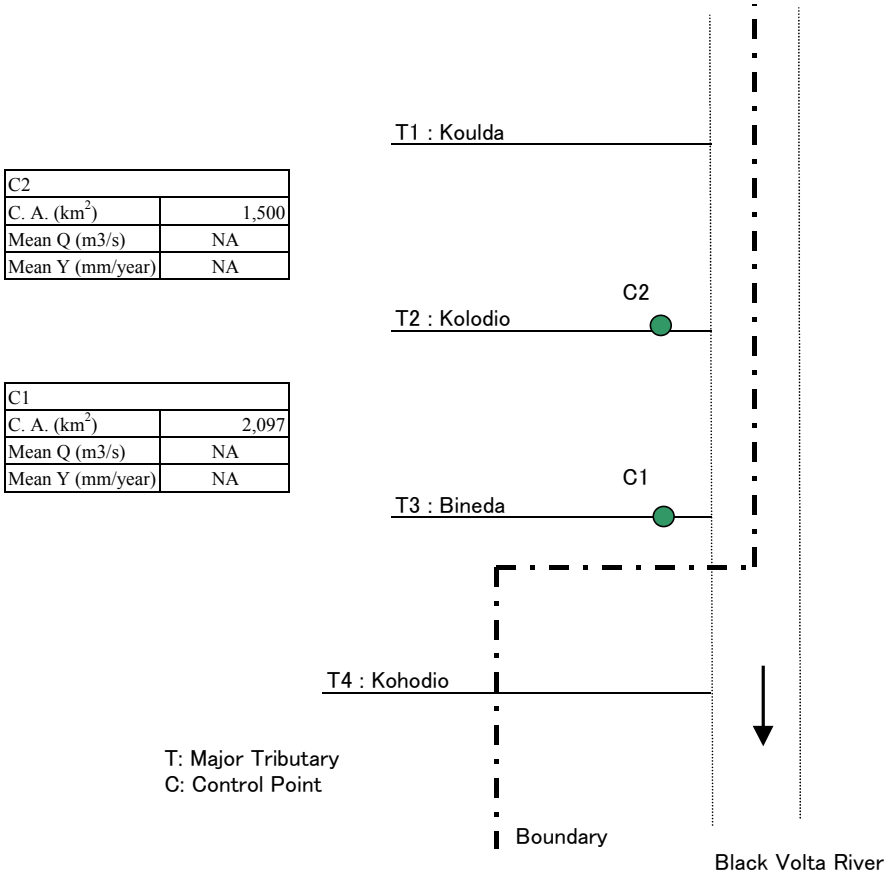


Figure 5.2-11 River Model with Control Point of Division VII (Black Volta River) (With Mean Discharge/Yield at CP)

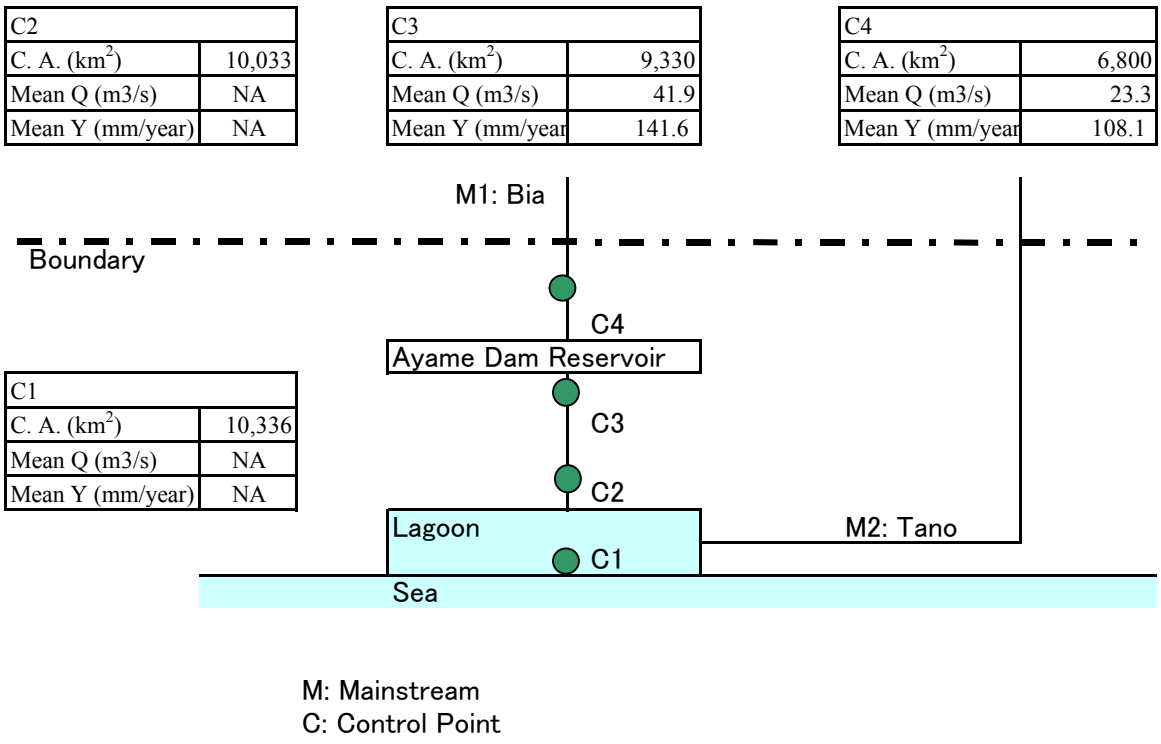


Figure 5.2-12 River Model with Control Point of Division VIII (Bia River)
(With Mean Discharge/Yield at CP)

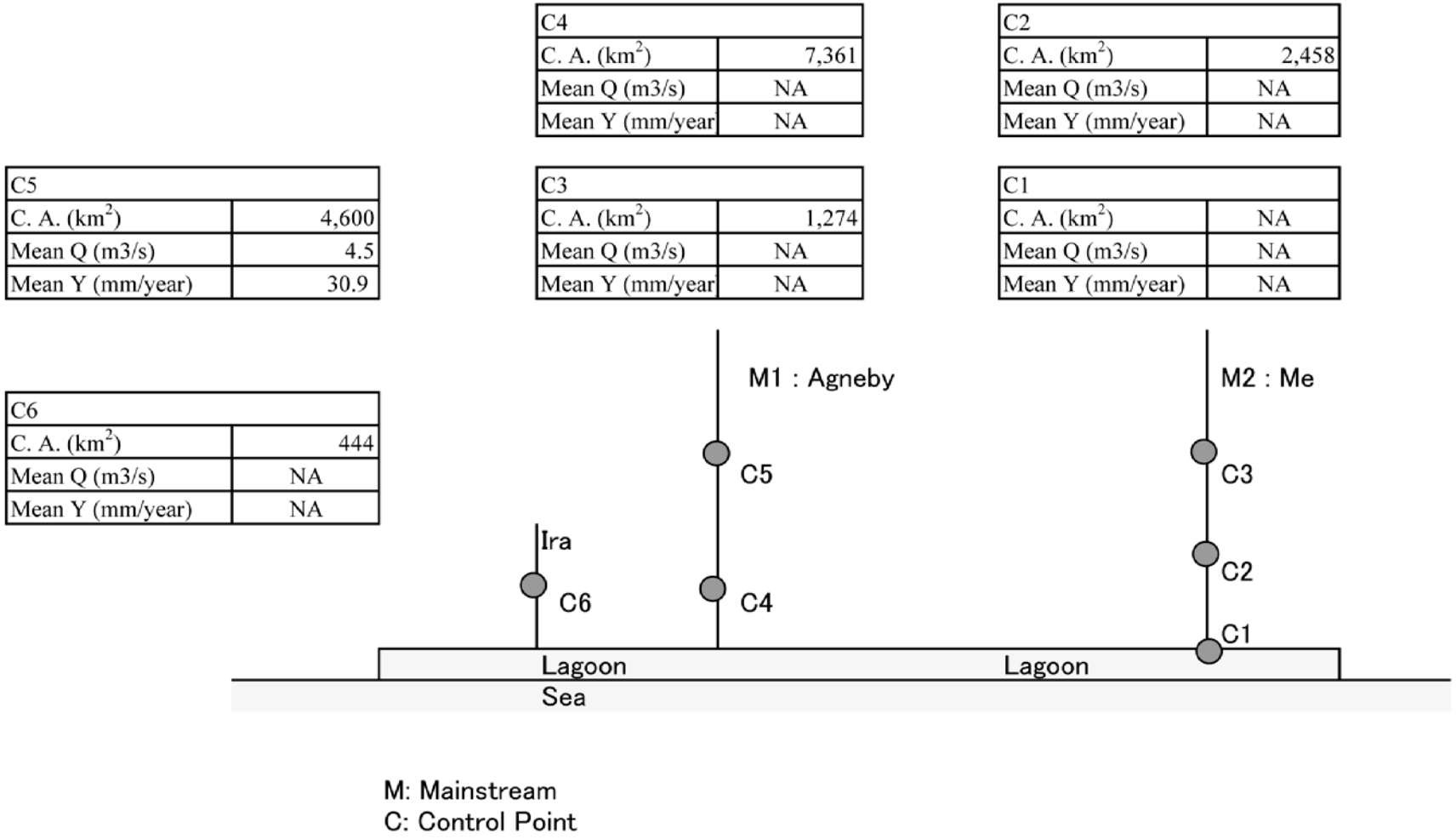


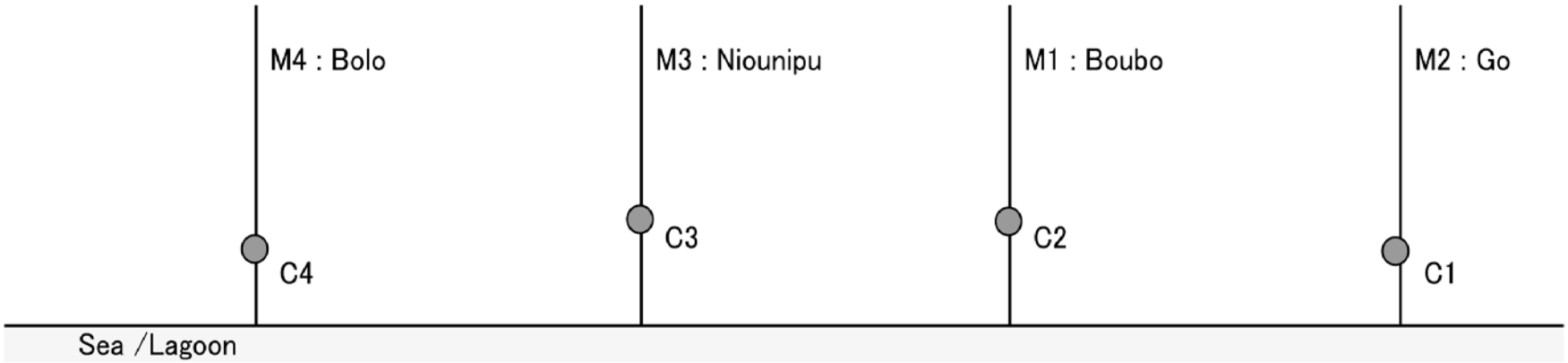
Figure 5.2-13 River Model with Control Point of Division IX (Agneby River)
(With Mean Discharge/Yield at CP)

C4	
C. A. (km^2)	1,330
Mean Q (m3/s)	NA
Mean Y (mm/year	NA

C3	
C. A. (km^2)	2,112
Mean Q (m3/s)	11.3
Mean Y (mm/year	168.7

C2	
C. A. (km^2)	4,702
Mean Q (m3/s)	11.2
Mean Y (mm/year	75.1

C1	
C. A. (km^2)	2,192
Mean Q (m3/s)	NA
Mean Y (mm/year)	NA



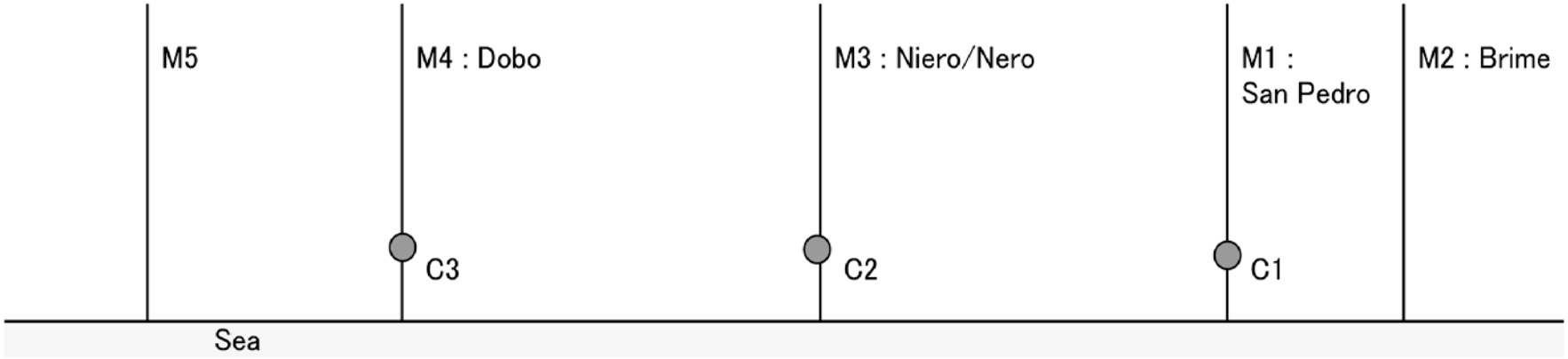
M: Mainstream
C: Control Point

Figure 5.2-14 River Model with Control Point of Division X (Boubo River)
(With Mean Discharge/Yield at CP)

C3	
C. A. (km^2)	649
Mean Q (m3/s)	9.6
Mean Y (mm/year)	466.5

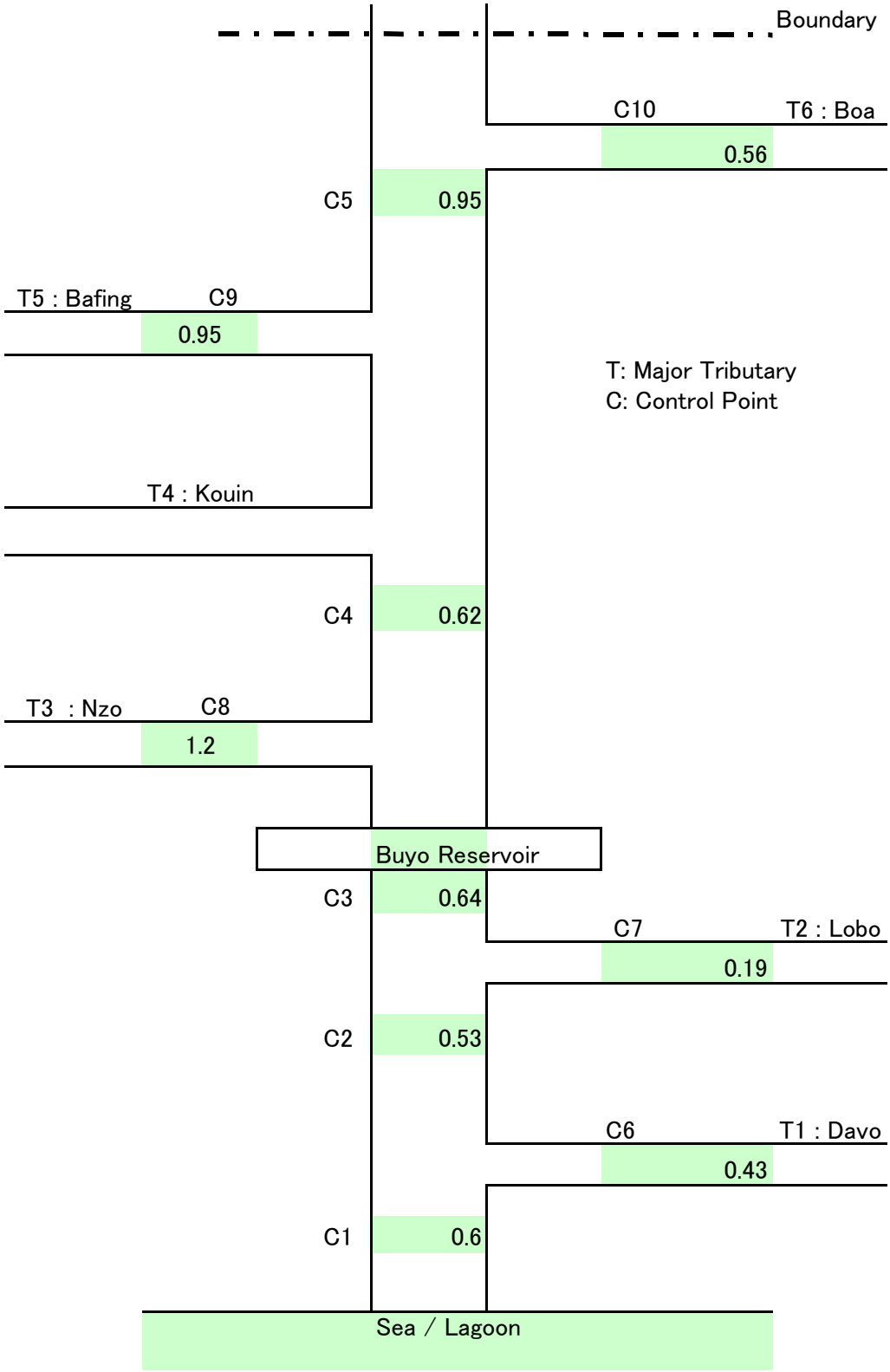
C2	
C. A. (km^2)	1,266
Mean Q (m3/s)	15.1
Mean Y (mm/year)	376.1

C1	
C. A. (km^2)	3,320
Mean Q (m3/s)	32.5
Mean Y (mm/year)	308.7



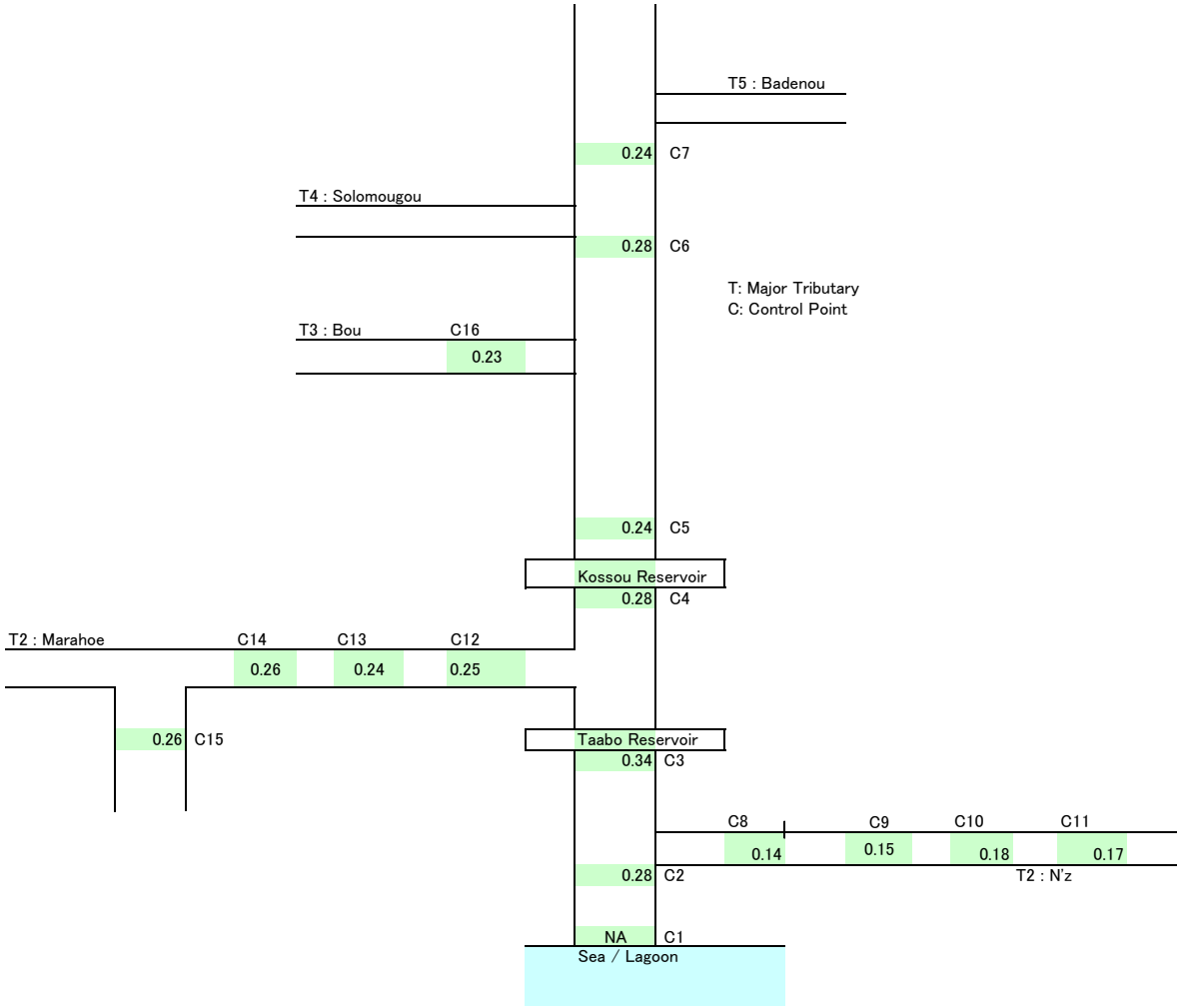
M: Mainstream
C: Control Point

Figure 5.2-15 River Model with Control Point of Division XI (San Pedro River) (With Mean Discharge/Yield at CP)



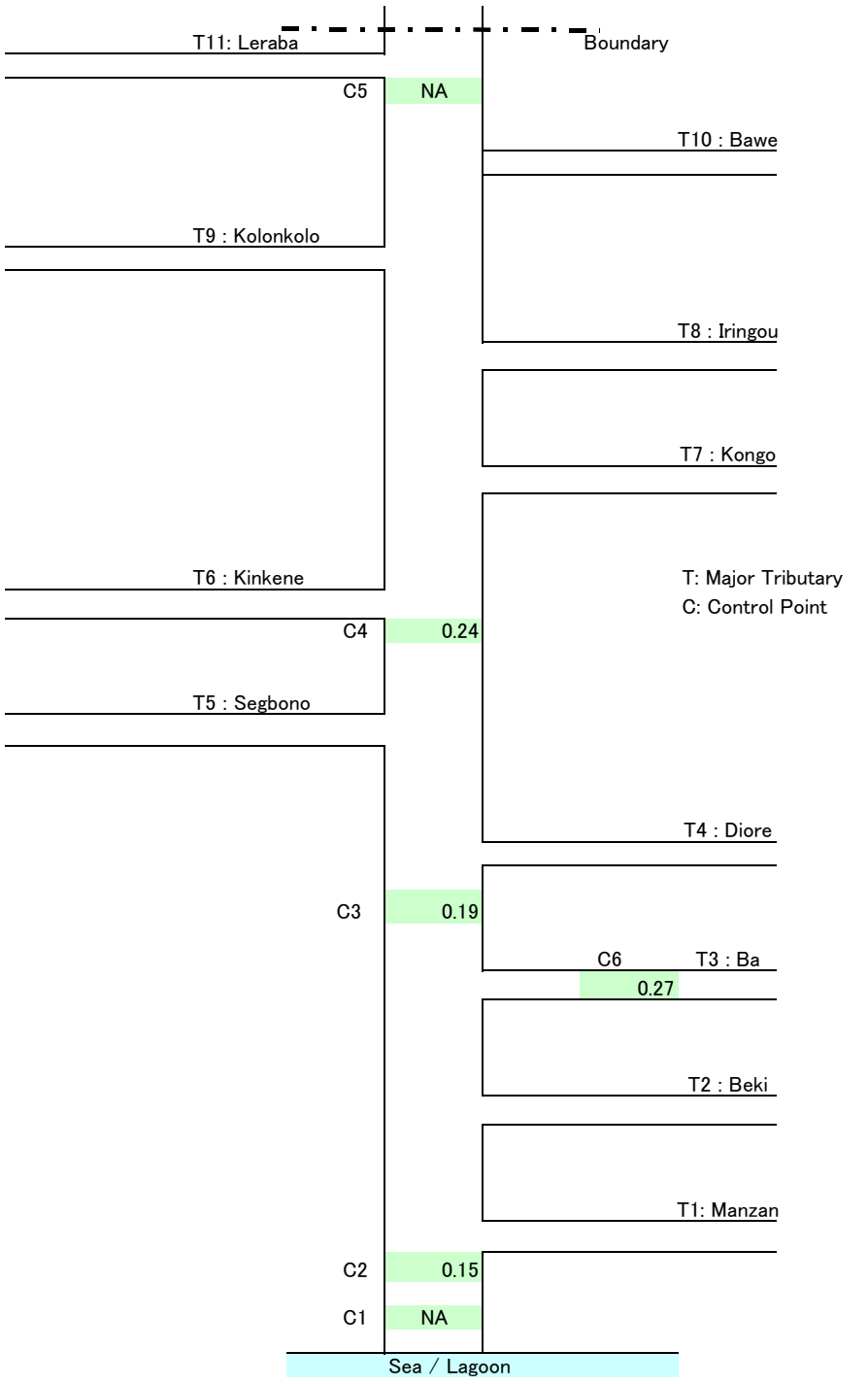
Specific Discharge (of Long term mean) at Control Points ($m^3/s/ 100 km^2$)
NA:Not available.

Figure 5.2-16 Specific Discharge of Division I (Sassandra River)



Specific Discharge (of Long term mean) at Control Points ($m^3/s/ 100 km^2$)
NA:Not available.

Figure 5.2-17 Specific Discharge of Division II (Bandama River)



Specific Discharge (of Long term mean) at Control Points (100 $m^3/s/km^2$)
NA:Not available.

Figure 5.2-18 Specific Discharge of Division III (Comoe Rive River)

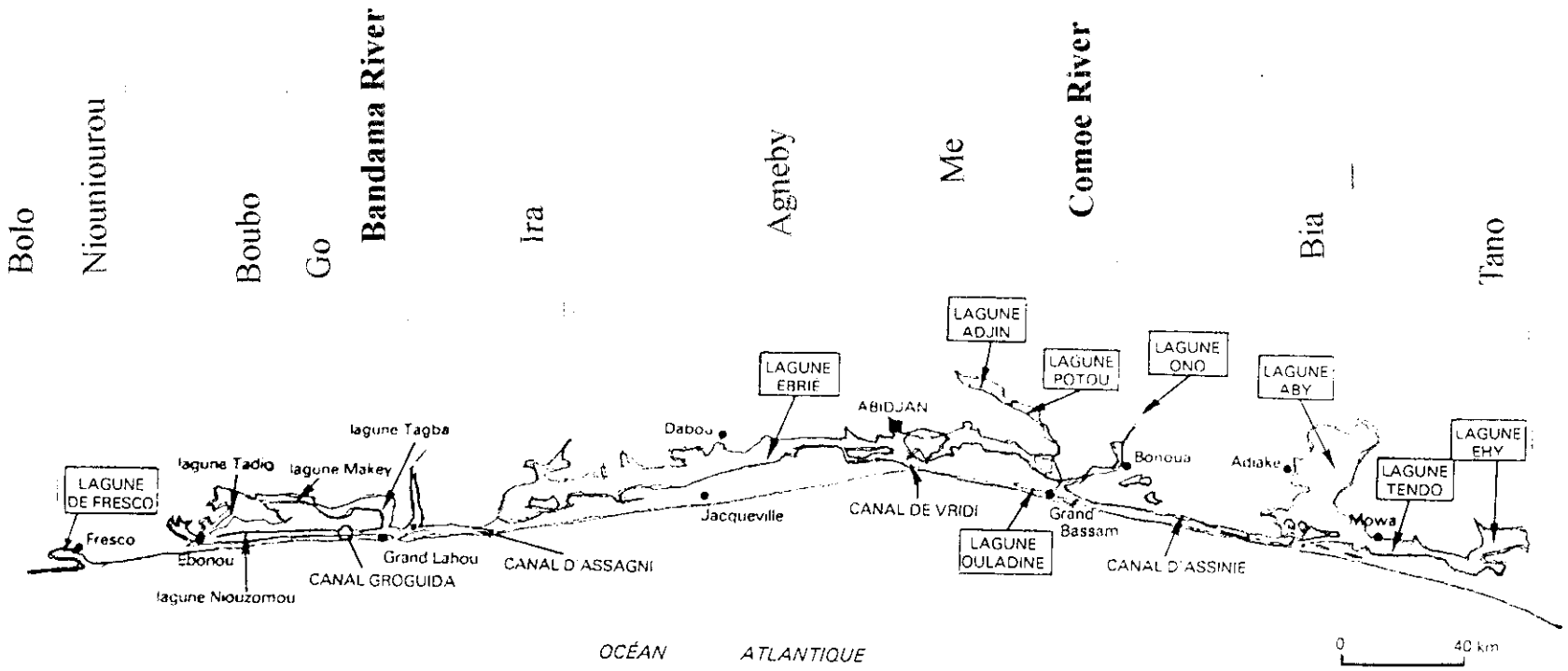


Figure 5.2-19 Rivers with River Mouth in Lagoon

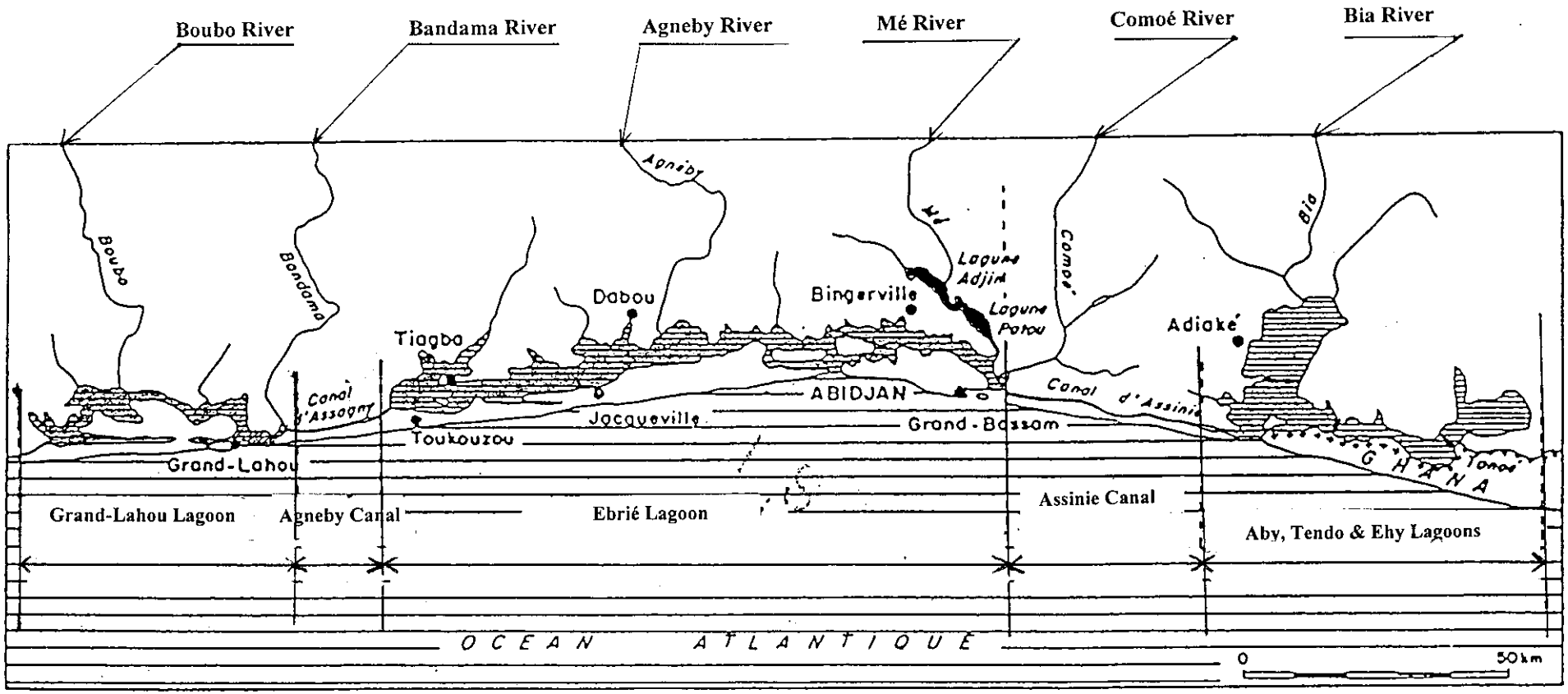


Figure 5.3 – 1 Location Map of Major Lagoons and canals

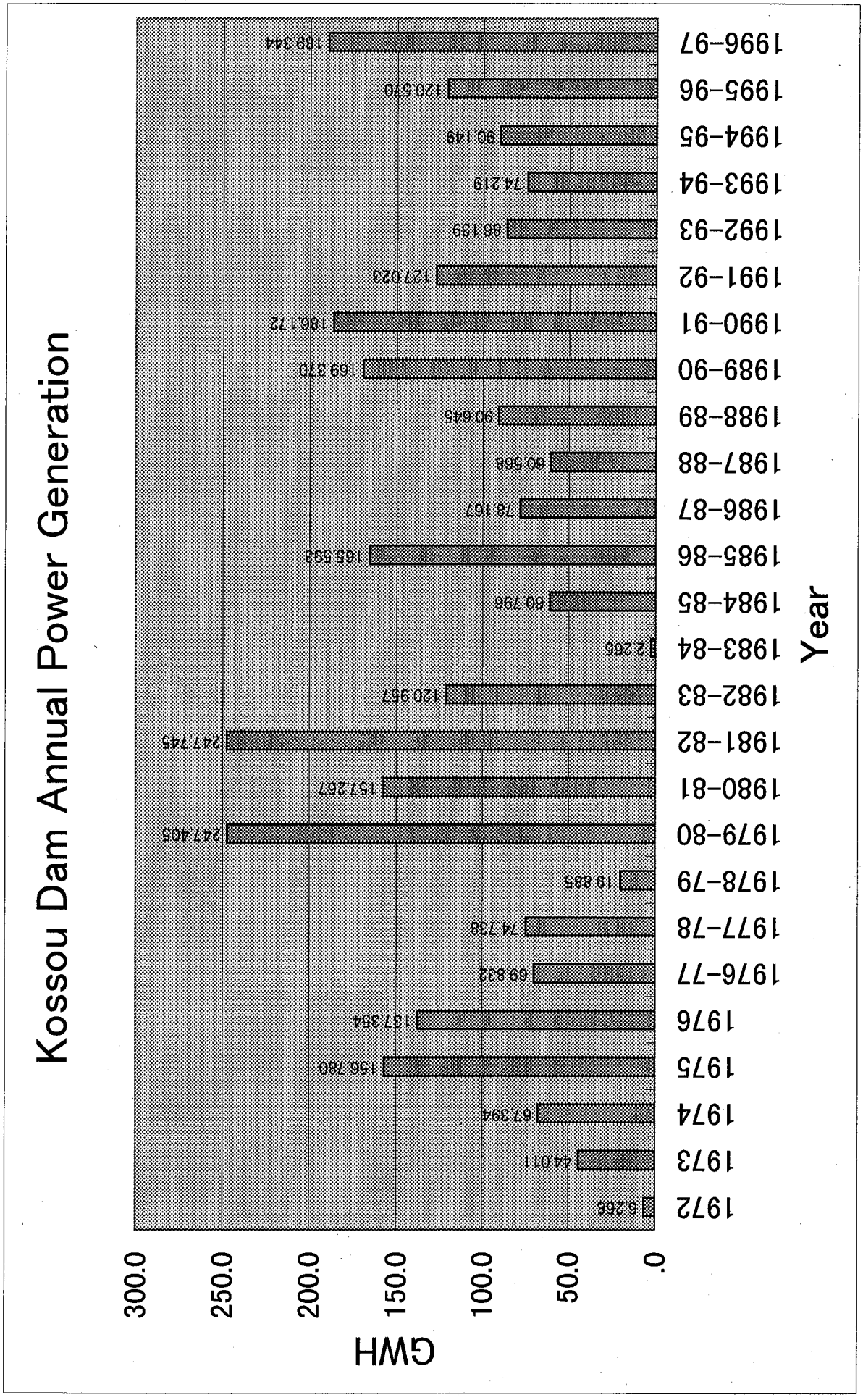


Figure 5.5-1 Annual Power Generation of Kossou Dam

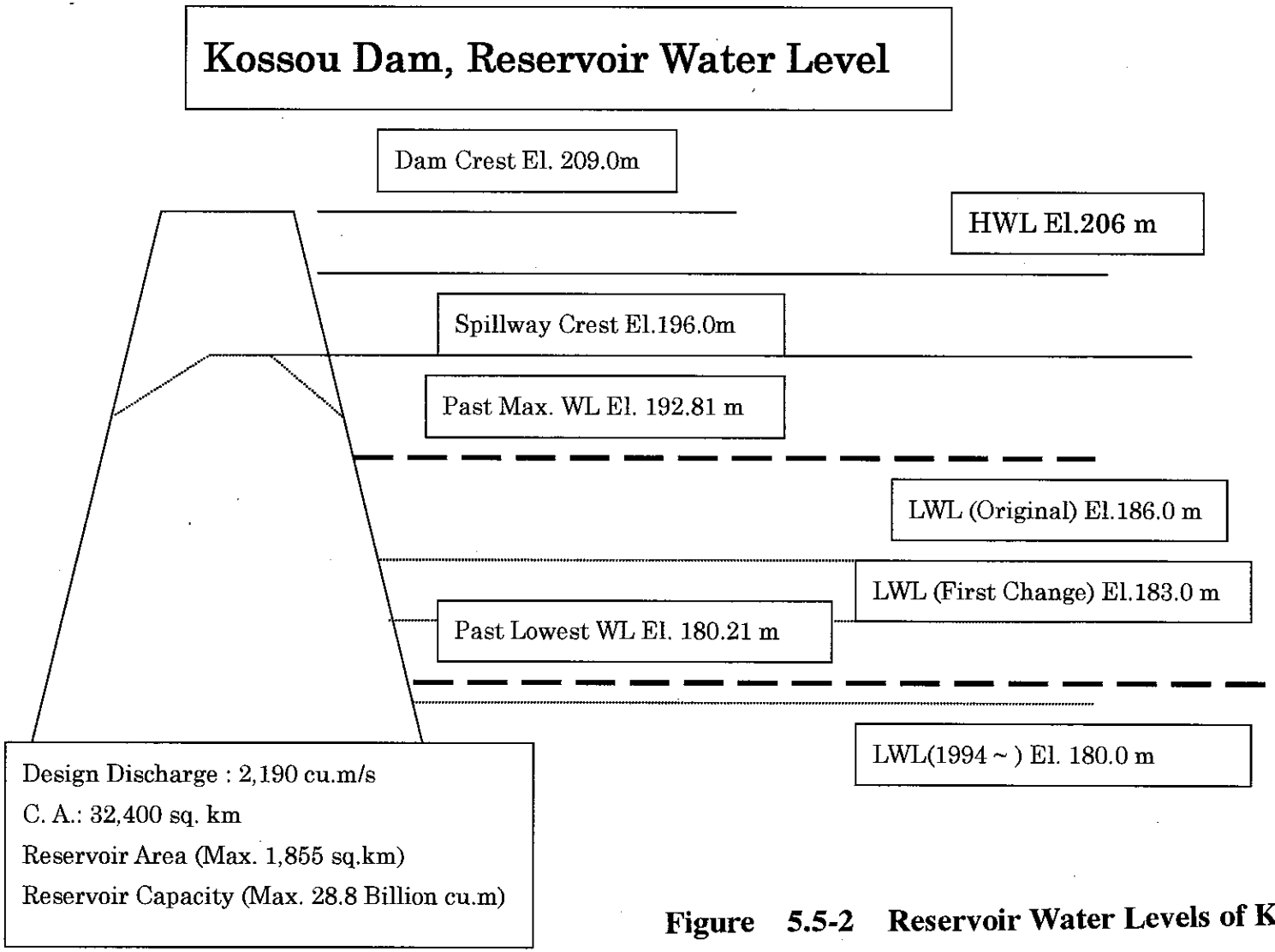


Figure 5.5-2 Reservoir Water Levels of Kossou Dam