4.4 Reservoir Operation Plan

4.4.1 Main Function of the Proposed Dam

The proposed dam, Vaza Barris Dam has the functions of not only "Storing Water" but also "Improvement of Reservoir Water" as follows:

1) Storing water in the dam reservoir for the purpose of:
   - Maintenance of river and riparian environment
   - Domestic/Industrial water supply
   - Irrigation water supply
   - Dilution of water quality
2) Improvement of reservoir water with the new system of low flow bypass:
   - High saline concentration water is bypassed around the dam reservoir.
   - Clean or low saline concentration water is stored in the dam reservoir.

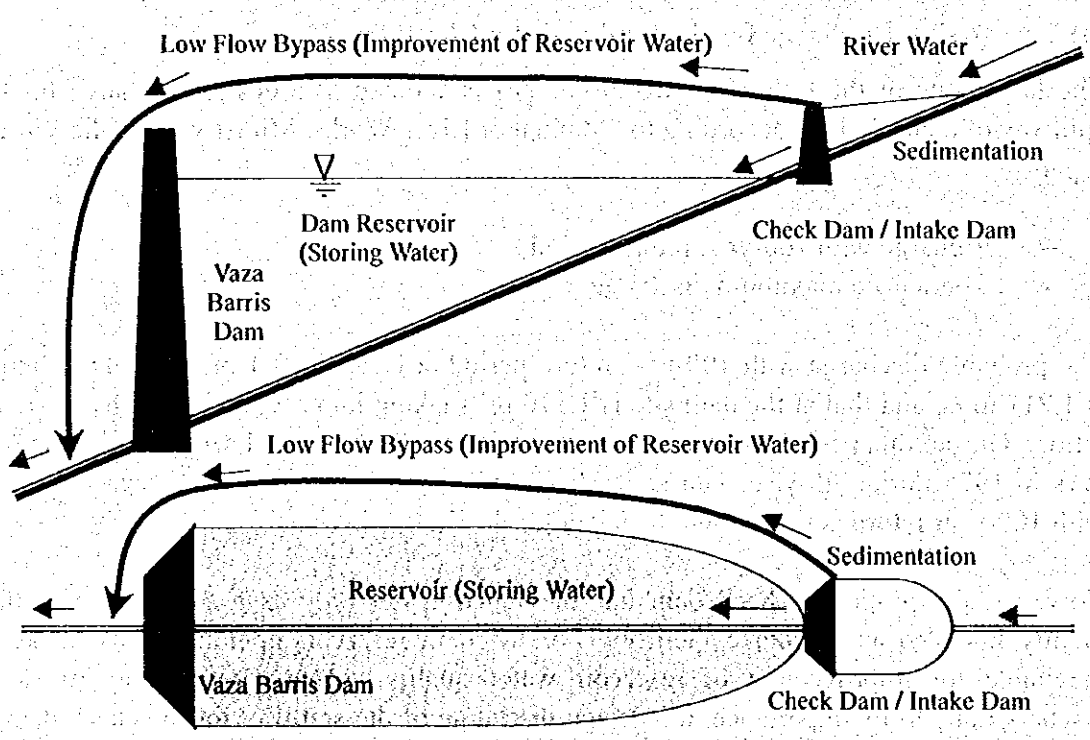


Figure-4.3 Main Function of Vaza Barris Dam

River water of the main stream has large potential of water resources but has not been able to be utilized as potable and irrigation water due to high concentration of chloride. After elaborate investigation of water quality, however, it was found that river flow has high chlorine concentration only during low flow condition but not during flood. Considering such condition of the water quality in Vaza Barris River, the following dam plan with the new system of a low flow bypass was established:

1) Low flow with high concentration of chloride from the upstream is bypassed around the dam reservoir to the downstream.
2) River water during flood is stored in the dam reservoir.

Then,

3) Dam reservoir water is kept clean and is utilized as potable and irrigation water.

4.4.2 Reservoir Operation Model

(1) Concept of Reservoir Operation Model

The concept of the reservoir operation model is shown as a flow chart in Figure-4.5. The reference points for the reservoir operation plan were set at the check dam site and the main dam site, because the hydrological reference point in the most downstream, Fazenda Belem is located in the very near downstream of the dam. The both catchment area of the dam site (C.A.=15,560 km^2) is close to that of Fazenda Belem (C.A.=15,740 km^2). Given conditions in this model are listed as follows:

- Daily Discharge (Refer to Hydrological Model)
  1) Main dam: Q_D, 2) Check dam: Q_{CD}, 3) Reservoir inflow: Q_D - Q_{CD}
- Development Water Amount at the Dam Site
  1) Compensation (Maintenance) discharge: 0.44 m^3/s
  2) Domestic/Industrial water use: 0.887 m^3/s
  3) Irrigation water use: Maximum 2.912 m^3/s
  Average 1.507 m^3/s
- Physical Precondition
  1) H-V curve of the dam reservoir: Refer to Figure-4.4.
  2) Capacity of the check dam reservoir: 10,000,000 m^3 at the level of EL. 63.0 m
  3) Bypass discharge: 0 – 2.0 m^3/s (Assumption cases in trial calculation)
- Initial Condition
  1) Initial reservoir volume: Full of capacity
  2) Reservoir water quality:
  Average water quality according to the average flow during 1986-1995
  : Main Dam Reservoir: Cl=200 mg/l, EC= 0.90 dS/m, Q_{AVE}=8.74 m^3/s
  : Check Dam Reservoir: Cl=330 mg/l, EC= 1.40 dS/m, Q_{AVE}=4.65 m^3/s

Elevation (EL.m)	Area (m^2)	Volume (m^3)	Accumulated Volume (m^3)
20	0	0	0
25	113,241	283,103	283,103
30	844,695	2,394,840	2,677,943
35	2,980,121	9,562,040	12,239,983
40	5,884,332	22,161,133	34,401,115
45	8,295,946	35,450,695	69,851,810
50	10,665,979	47,404,813	117,256,623
55	13,049,208	59,287,968	176,544,590
60	15,527,046	71,440,635	247,985,225

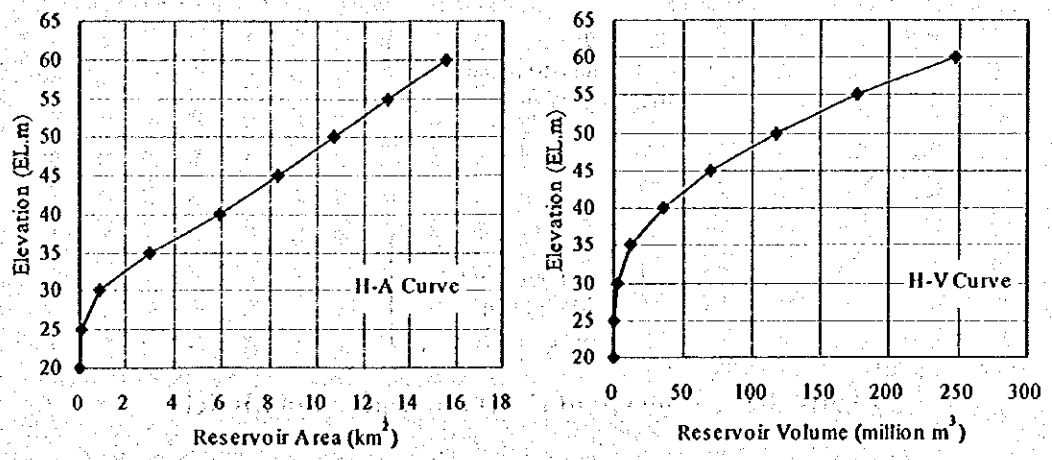


Figure-4.4 H-A and H-V Curve of Main Dam Reservoir

Based on the given conditions above, following water volume/flow and water quality are simulated:

1) Check Dam Reservoir
   - Inflow: Natural Flow
   - Outflow to Dam Reservoir and Low Flow Bypass
2) Main Dam Reservoir
   - Inflow: Natural Flow to Reservoir, Flow from Check Dam
   - Outflow: Dam Draw-off, Spillway Discharge, Evaporation
   - Intake Flow: Municipal/Industry Water, Irrigation Water

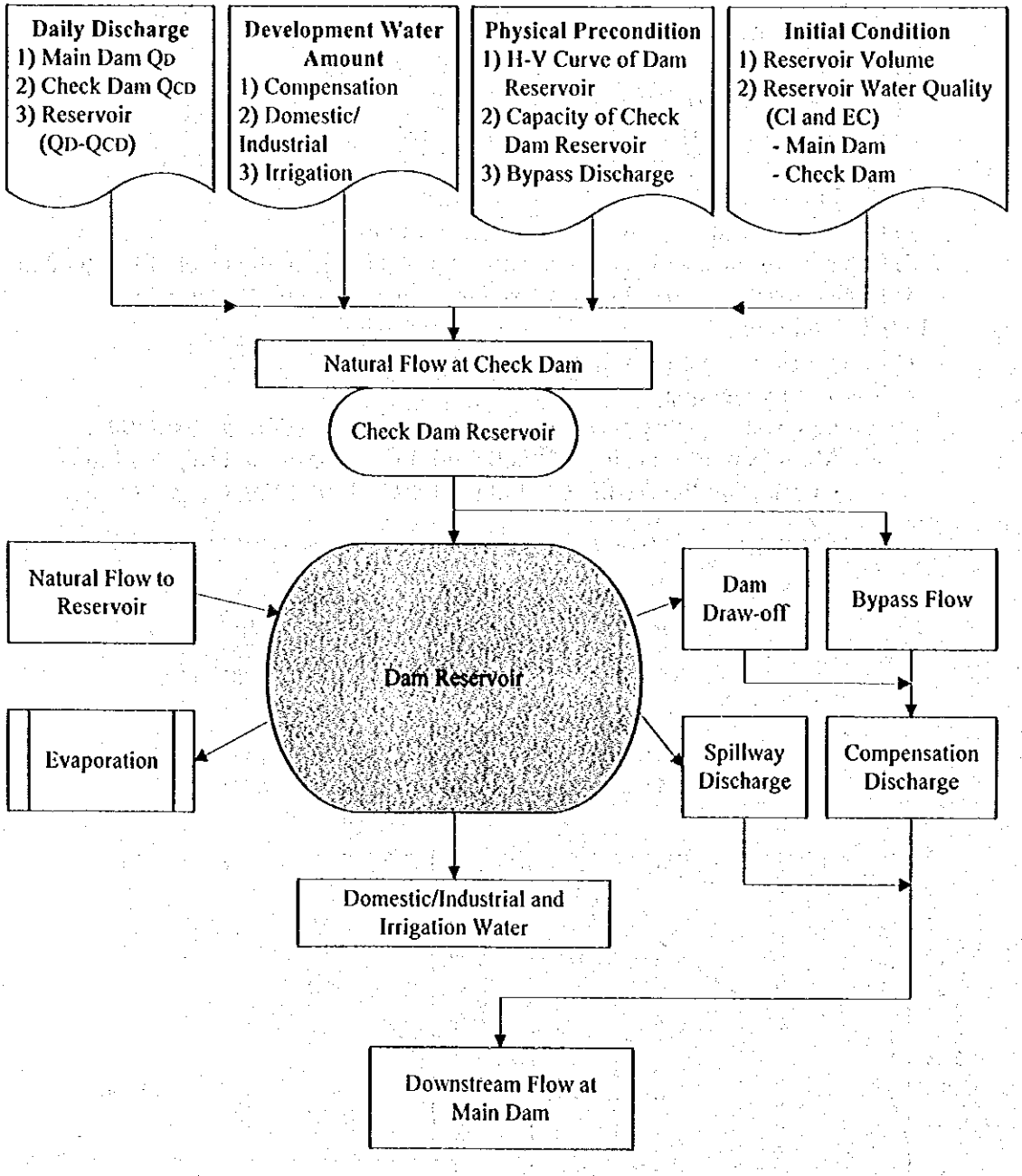


Figure-4.5 Concept of Reservoir Operation Model

4.4.3 Runoff Model

Runoff model of reservoir operation simulation is presented in Figure-4.6 and Table-4.4. Hydrological reference points were set at the check dam and the main dam, of which daily discharge is calculated based on the discharge at Ponte SE-302 (Q_{PSE}) and Fazenda Belem (Q_{FB}). The daily discharge from the basin B, C and D is calculated introducing "Runoff Contribution Factors", which were estimated as the following equations, based on the basin areas, the basin mean rainfalls and the runoff rates of the basins of B, C and D.

[Runoff Contribution Factors] = [Basin Ratio] * [Basin Rainfall Ratio] * [Runoff Rate Ratio]

Then, the runoff contribution factors were obtained as 0.24, 0.54 and 0.22 for the basins of B, C and D respectively, and discharges from these basins could be calculated by following equations:

$$Q_B = 0.24 \cdot (Q_{FB} - Q_{PSE}) \quad Q_C = 0.54 \cdot (Q_{FB} - Q_{PSE}) \quad Q_D = 0.22 \cdot (Q_{FB} - Q_{PSE})$$

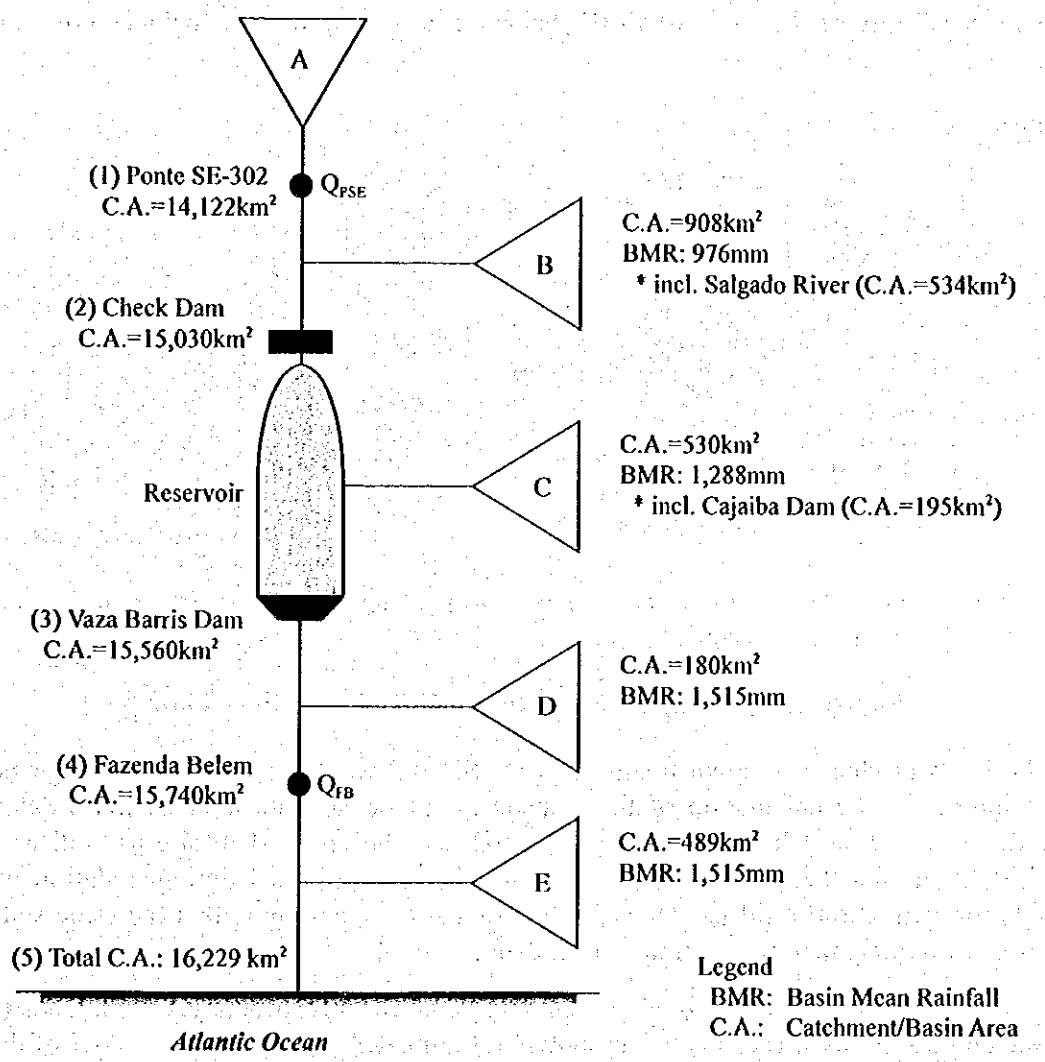


Figure-4.6 Runoff Model for Reservoir Operation Simulation

Table-4.4 Basin Division

River Basin					Reference Point		
No.	Basin Name	Basin Area. (km^2)	Basin Mean Rainfall (mm)	Runoff Rate	No.	Point Name	Basin Area (km^2)
A	Upstream (Bahia)	14,122	500-800	-	(1)	Ponte SE-302	14,122
B	Ponte – Check Dam	908	976	0.07	(2)	Check Dam	15,030
C	Dam Reservoir	530	1,288	0.21	(3)	Vaza Barris dam	15,560
D	Dam – F. Belem	180	1,515	0.21	(4)	Fazenda Belem	15,740
E	Most Downstream	489	1,515	-	(5)	River Mouth	16,229
Total/Average of B, C & D		1,618	1,138	0.14			

4.4.4 Water Quality Model

In Vaza Barris River of Sergipe State, the Cl loads that is drained from the basin can be basically distinguished in two origins: one came from the main river (river itself) and other from the tributaries (rain water), carrying the salts retained on the soil surface. According to available water quality data, it can be found a good relationship between Cl/EC and river flow, as can be seen in Figure-4.7 established in Ponte SE-302 and Fazenda Belem, showing feasibility of the study of Cl/EC behavior according to mass balance concept in these basins.

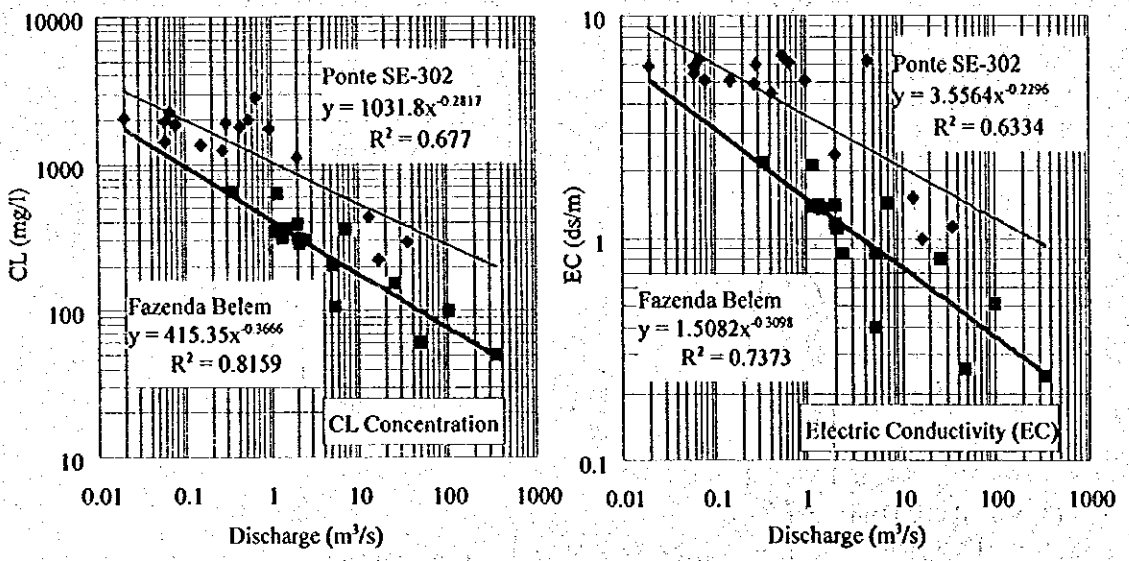


Figure-4.7 Relationship between Cl/EC and River Flow

All the loads produced in downstream of Ponte SE-302 were assumed as diffuse or non-point sources. The calculation of these loads might be held through Cl mass balance procedures in the stretch between Ponte SE-302 and the check dam site as well as the check dam site and Fazenda Belem. The data obtained on São Domingos station were applied for estimation of diffuse loads for this first stretch, assuming that the same station represents water characteristics in the check dam location.

Based on observation data at Fazenda Belem and Ponte SE-302, tributaries basin loads (Cl) between both stations was estimated as shown in Figure-4.8. Assuming that 80% of these loads be produced from the basin between Ponte SE-302 and the check dam site, and 20 % be produced from the check dam site and Fazenda Belem, water quality equations of both basin loads is estimated as follows:

Between Ponte SE-302 and the check dam site: $[Cl]_{PSE\text{-}CH} = 590.43*Q^{-0.3557}$
Between the check dam site and Fazenda Belem: $[Cl]_{CD\text{-}FB} = 78.059*Q^{-0.3557}$

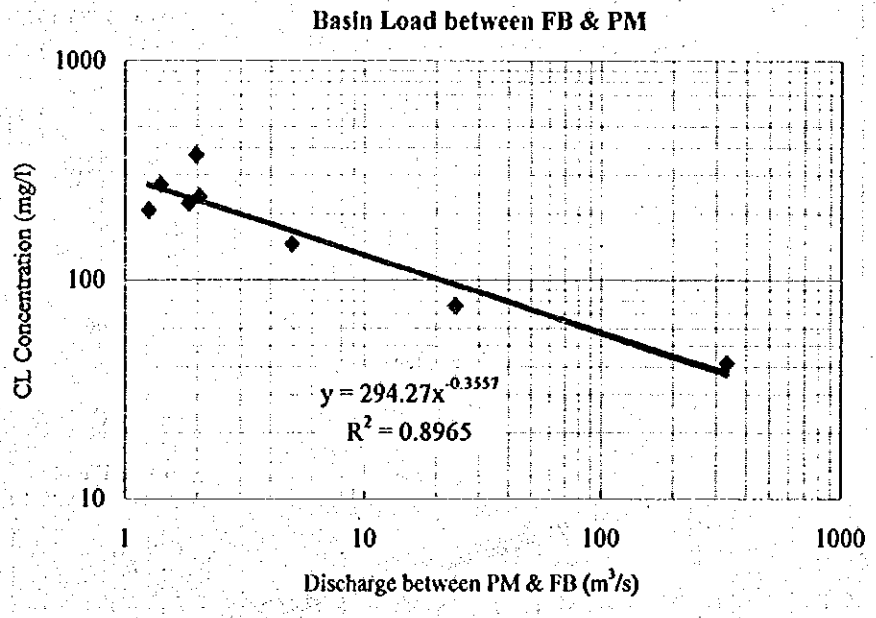


Figure-4.8 Tributaries Basin Load (Cl) between Fazenda Belem and Ponte SE-302 (Relationship between Cl and Discharge)

On the other hand, in Trairas River located in the basin between the check dam site and the main dam site, river water quality was observed to be about 80 mg/l of chloride concentration (Cl) and 0.4 ds/m of electric conductivity (EC) when river flow is about 1 m^3/sec. When the same indexes of the equation at Fazenda Belem is employed as the trend of decreasing of Cl and EC according to the discharge decreasing, tributaries basin load of Trairas River could be estimated as following equations:

$$[Cl]_{TRAIRAS} = 80*Q^{-0.37}$$
$$[EC]_{TRAIRAS} = 0.4*Q^{-0.31}$$

This equation for Cl concentration is very similar with the equation estimated before.

Based on the above equations and main river equation at Fazenda Belem (Figure-4.7), the water quality (Cl and EC) at the main dam and the check dam could be calculated using the following equations:

$$[\text{Water Quality Cl and EC}]_{MD} = ([Load]_{FB} - [Load]_{MD\text{-}FB}) / Q_{MD}$$
$$[\text{Water Quality Cl and EC}]_{CD} = ([Load]_{MD} - [Load]_{CD\text{-}MD}) / Q_{CD}$$

Applying the hydrological model to the year of 1985 – 1995, the relationships between Cl/EC and discharge are obtained as shown in Figure-4.9 and Figure-4.10. As the dam site is very near from Fazenda Belem, daily calculation results of water quality are concentrated to the one line (Figure-4.9). However the water quality results at the check dam (Figure-4.10) are scattered with in the specific range due to daily deference of the water contribution from the basin between the check dam and Fazenda Belem. As Figure-4.9 is presented with the equation at Sao Domingos located 5 km upstream of the check dam site, Cl concentration by this equation is almost within the range and locates in upper or average part of the rage.

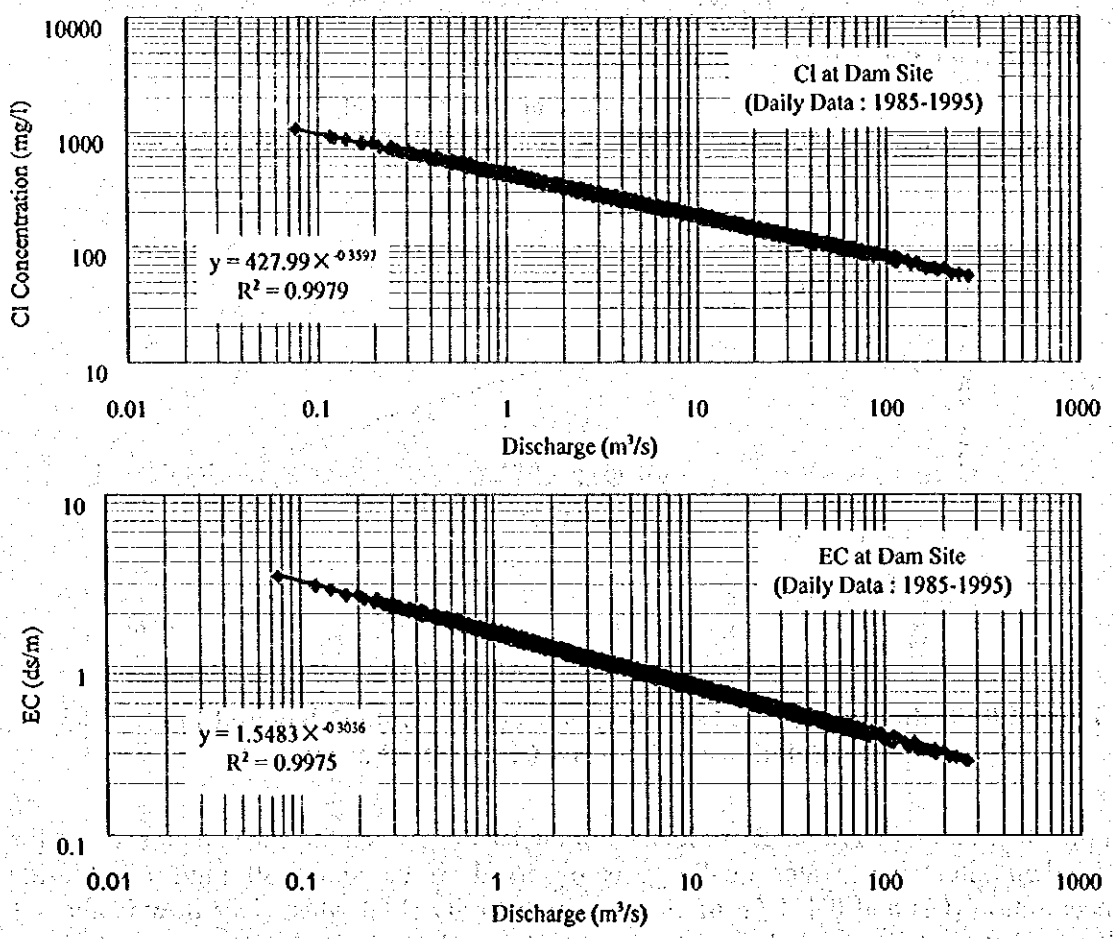


Figure-4.9 Estimation of Daily Water Quality (Cl and EC) at the Main Dam Site

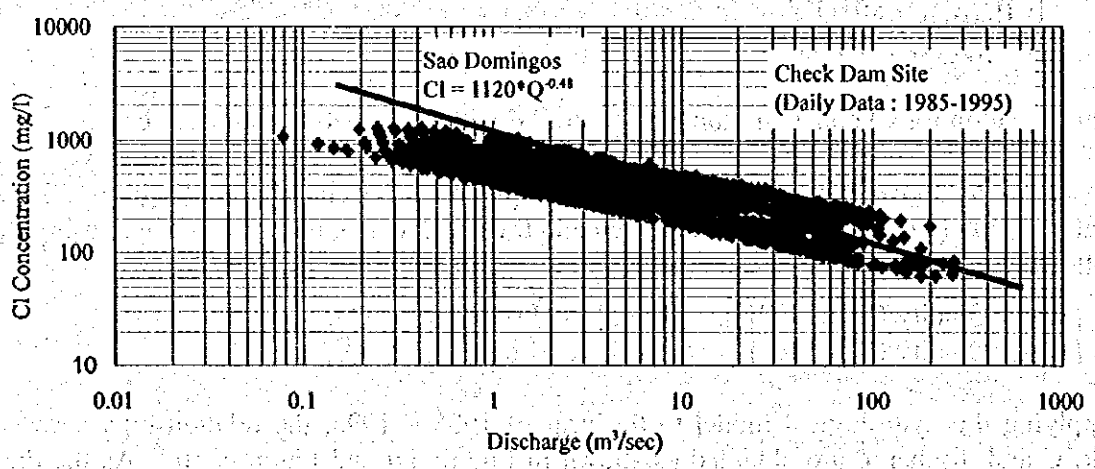


Figure-4.10 Estimation of Cl Concentration at the Check Dam Site

Based on the above study, Water Quality Model of reservoir operation simulation is formulated as shown in Figure-4.11 and Table-4.5. River water quality of Sodium (Na), Magnesium (Mg) and Calcium (Ca) could be estimated applying the correlation equations to EC, of which equations were formulated based on the water quality observation data at Ponte SE-302 and Fazenda Belem.

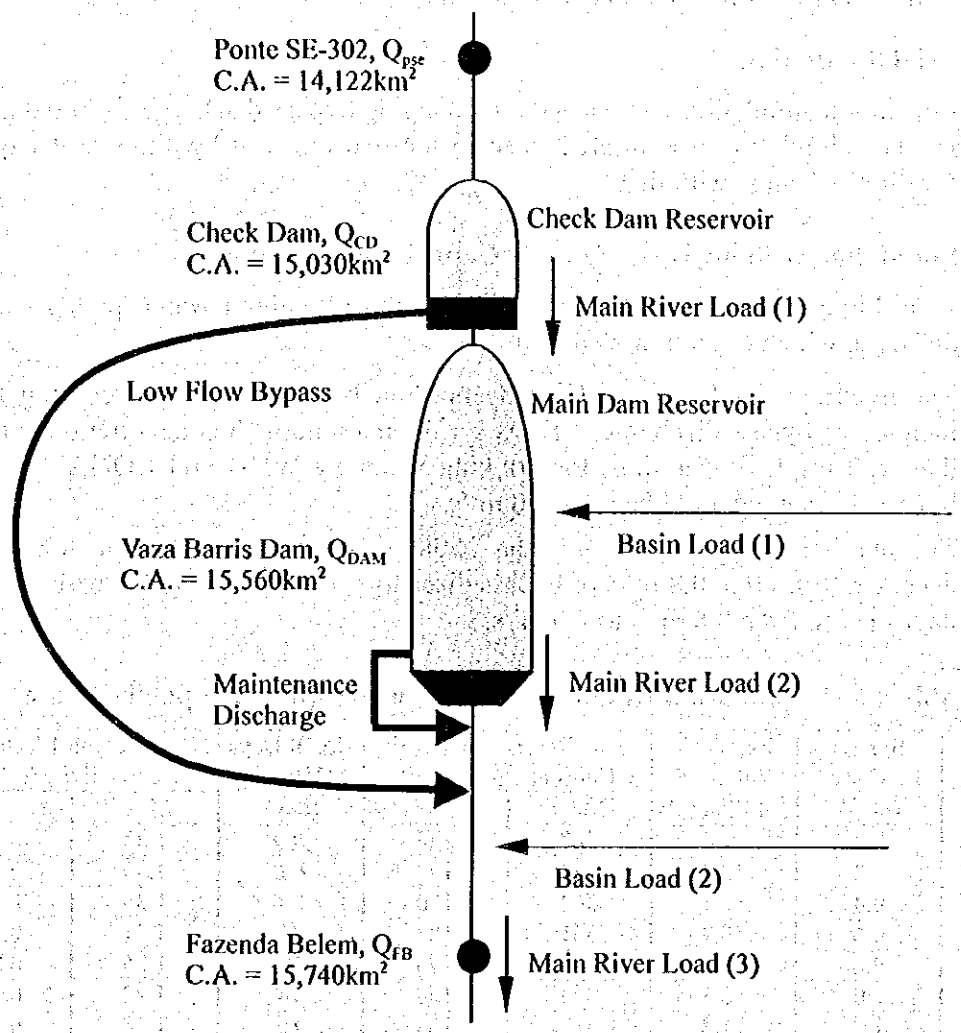


Figure-4.11 Water Quality Model for Reservoir Operation Simulation

Table-4.5 Water Quality Estimation Equation

Load	Point/Basin	Cl (mg/l)	EC (ds/m)
Main River Load	(1) Check Dam (CD)	$[Cl \text{ or } EC]_{CD} = ([Load]_{MD} - [Load]_{CD\text{-}MD}) / Q_{CD}$	
	(2) Main Dam (MD)	$[Cl]=427.99*Q^{-0.3597}$	$[EC]=1.5483*Q^{-0.3036}$
	(3) Fazenda Belem (FB)	$[Cl]=415.35*Q^{-0.3666}$	$[EC]=1.5082*Q^{-0.3098}$
Tributary Basin Load	(1) Between CD and MD	$[Cl]=80*Q^{-0.37}$	$[EC]=0.4*Q^{-0.31}$
	(2) Between MD and FB	$[Cl]=80*Q^{-0.37}$	$[EC]=0.4*Q^{-0.31}$

Water Quality Items	Correlation equation with EC (ds/m)
Na (mg/l)	[Na] = 104.53*[EC]
Mg (mg/l)	[Mg] = 35.514*[EC]
Ca (mg/l)	[Ca] = 56.833*[EC]

4.4.5 Simulation Result of Reservoir Operation

(1) Trial Simulation

Reservoir operation simulation was carried out changing bypass discharge from 0.0 m^3/s to 10.0 m^3/s. The simulation was implemented in the two cases of "without water quality capacity for dilution" and "with that".

(a) Simulation without Water Quality Capacity for Dilution

Table-4.6 and Figure-4.12 shows the simulation result of "without water quality capacity for dilution" case, which is summarized as follows:

1) The maximum and average Cl concentration become smaller according to the increase of bypass discharge. However the maximum Cl concentration is higher than 250 mg/L (upper limit for drinking water by WHO and CONAMA), until bypass discharge would be set as 10 m^3/s.
2) The number of the days more than 250mg/L of Cl concentration dramatically decreases from 0 to 0.8 m^3/s of bypass discharge, but almost no decrease (19 to 17 days in case from 0.8 m^3/s to 2.0 m^3/s.

Table-4.6 Simulation Result of "without water quality capacity" Case

Case	Bypass Discharge (m^3/s)	Reservoir Volume * (Million m^3)	Reservoir Cl Concentration (mg/l)		No. of Days > 250 mg/l (day)	Reservoir Electric Conductivity (dS/m)	
			Max.	Ave		Max.	Ave
1	0.0	52.4	387	204	969	1.43	0.83
2	0.2	52.4	377	197	770	1.39	0.81
3	0.4	52.4	364	190	366	1.35	0.78
4	0.6	58.9	351	182	76	1.31	0.75
5	0.8	65.0	335	175	19	1.25	0.73
6	1.0	68.8	324	168	18	1.22	0.71
7	1.2	71.8	312	163	18	1.18	0.69
8	1.4	74.2	302	157	18	1.14	0.67
9	1.6	75.9	294	152	18	1.12	0.65
10	1.8	77.2	288	148	17	1.10	0.63
11	2.0	78.3	285	144	17	1.08	0.62
12	3.0	82.1	279	127	11	1.06	0.56
13	10.0	87.5	248	94	0	0.95	0.44

* Includes sediment volume of 2,000,000 m^3.

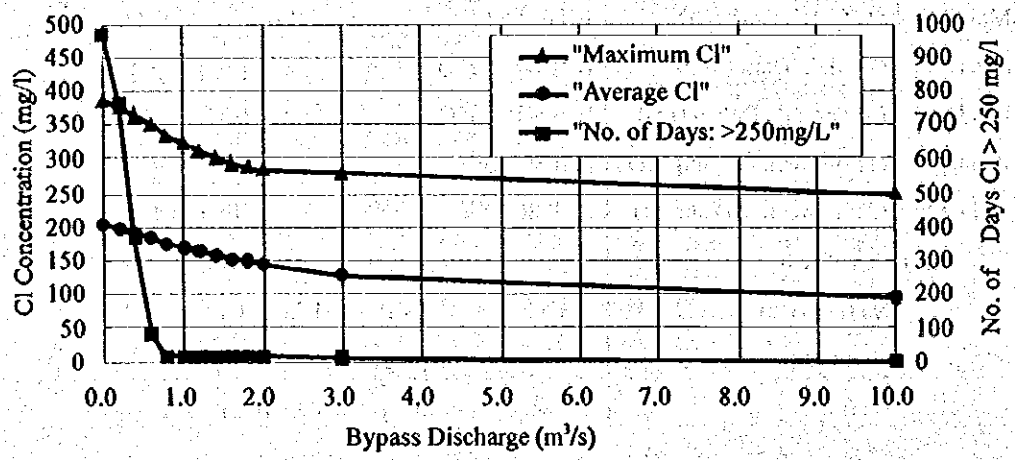


Figure-4.12 Simulation Result of "without water quality capacity" Case

(2) Simulation with Water Quality Capacity for Dilution

It is found that no dilution water volume causes these phenomena mentioned above when the reservoir is almost vacant of water. Then water quality capacity for dilution was introduced to this reservoir planning. Total necessary reservoir volume was calculated so as to be less than 250 mg/l of chloride concentration. The simulation result of "with water quality capacity for dilution" is shown in Table-4.7 and Figure-4.13 and is summarized as follows:

1) In case of no low flow bypass, total reservoir volume 634 million m^3 is needed.
2) Total reservoir volume is dramatically decreased according to the increase of bypass discharge from 0 to 0.7 m^3/s, but very small change in case from 0.7 to 3.0 m^3/s of bypass discharge.
3) The average Cl concentration is gradually decreased according to the increase of bypass discharge.
4) Total reservoir volume which is necessary to make reservoir water less than 250mg/l, is the smallest (84.9 million m^3) when bypass discharge is 1.3-1.5m^3/s, and increases when bypass discharge is lower and higher than that.

Table-4.7 Simulation Result of "with water quality capacity for dilution" Case

Case	Bypass Discharge	Reservoir Volume (Mm^3)			Reservoir Cl Concentration (mg/l)		Reservoir Electric Conductivity (dS/m)	
		Total Volume*	Dilution Volume	Other Volume	Max.	Ave.	Max.	Ave.
1	0.0	634.0	519.0	115.0	250	198	1.07	0.84
2	0.2	514.0	409.0	105.0	250	192	1.07	0.82
3	0.4	384.0	291.4	92.6	250	186	1.06	0.79
4	0.6	236.0	153.1	82.9	250	179	1.05	0.76
5	0.65	180.0	102.2	77.8	250	177	1.04	0.75
6	0.7	95.2	27.5	67.7	250	176	1.01	0.74
7	0.75	92.3	23.8	68.5	250	175	1.00	0.73
8	0.8	90.2	21.0	69.2	250	173	0.99	0.73
9	0.9	87.6	17.1	70.5	250	171	0.98	0.72
10	1.0	86.2	14.5	71.7	250	168	0.98	0.71
11	1.1	85.4	12.5	72.9	250	165	0.98	0.70
12	1.2	85.0	11.0	74.0	250	163	0.98	0.69
13	1.3	84.9	9.8	75.1	250	160	0.97	0.68
14	1.4	84.9	8.9	76.0	250	157	0.97	0.67
15	1.5	84.9	8.1	76.8	250	155	0.97	0.66
16	1.6	85.0	7.5	77.5	250	153	0.97	0.65
17	1.8	85.2	6.6	78.6	250	148	0.97	0.64
18	2.0	85.4	5.9	79.5	250	144	0.97	0.62
19	3.0	86.7	3.8	82.9	250	128	0.97	0.56

* Includes sediment volume of 2,000,000 m^3.

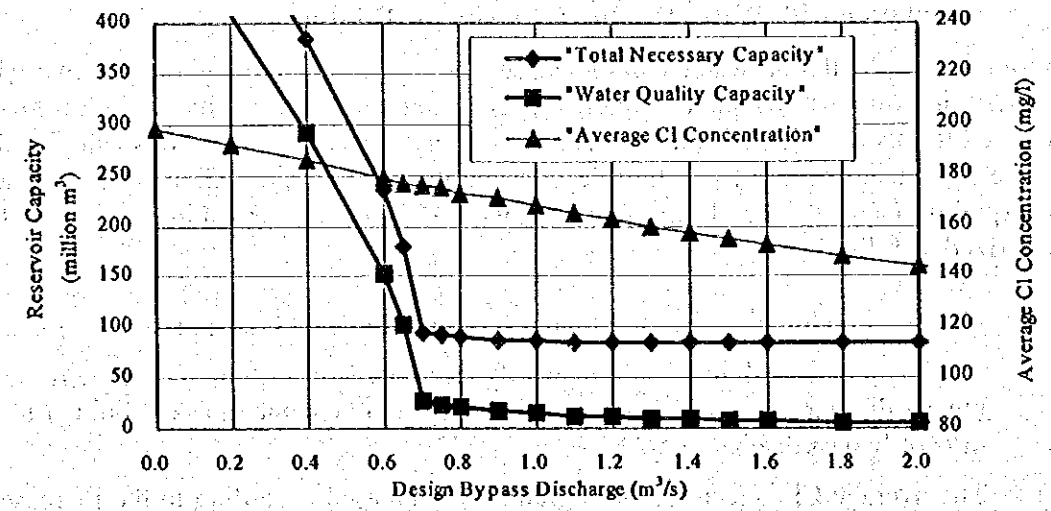


Figure-4.13 Simulation Result of "with water quality capacity for dilution" Case

(3) Decision of Bypass Discharge and Reservoir Volume

The result of the above trial simulations of reservoir operation indicates feasibility to use the reservoir water plenty for domestic and irrigation supply. Based on the result, the following sets of bypass discharge and total reservoir volume are proposed as alternatives of Vaza Barris Dam plan.

Design Bypass Discharge: Q_{BP} =0.7-1.3 m^3/s
Total Reservoir Volume: V_{RES} =85-96 million m^3

It is apparent that the larger scale of bypass discharge and total reservoir volume are the higher cost of the low flow bypass and the dam. Table-4.8 shows rough cost comparison with the alternative scales of the low flow bypass and the dam. In the comparison, based on the study of design and cost estimate, it was assumed that the type of low flow bypass is a box culvert and the dam type is a concrete dam.

Table-4.8 Comparison with the Alternatives of Low Flow Bypass and Dam

Bypass Discharge (m^3/s)	Total Reservoir Volume (M m^3)	Reservoir N.W.L (EL.m)	Low Flow Bypass Pipeline		Concrete Dam		Total Cost (M R$)
			Dimension of Channel (mm)	Cost *1 (M R$)	Volume (m^3)	Cost (M R$)	
0.70	96	47.8	1,050 x 1,050	31.6	222,000	29.1	60.7
0.75	93	47.5	1,050 x 1,050	31.6	219,000	28.7	60.3
0.80	91	47.2	1,100 x 1,100	36.6	216,000	28.3	64.9
0.90	88	46.9	1,150 x 1,150	37.7	213,000	27.9	65.6
1.00	87	46.8	1,200 x 1,200	38.7	212,000	27.8	66.5
1.10	86	46.7	1,200 x 1,200	38.7	211,000	27.6	66.3
1.20	85	46.6	1,250 x 1,250	44.3	210,000	27.5	71.8
1.30	85	46.6	1,300 x 1,300	45.4	210,000	27.5	72.9

Consequently, the most economical alternative was adopted and the design discharge of the low flow bypass and the total reservoir capacity are set as follows:

Design Discharge for Low Flow Bypass: 0.75 m^3/s
Total Reservoir Volume (N.W.L): 93000,000 m^3 (EL. 47.50 m)

4.4.6 Reservoir Operation Plan

The simulation result of the reservoir operation for Vaza Barris Dam is shown in Figure-4.14 and Figure-4.15. These figures show variation of reservoir water volume, inflow, chlorine concentration (Cl) and electric conductivity (EC). To identify the effect of low flow bypass, the simulation result in the case of no bypass is also presented in the same figures. Table-4.9 shows the maximum and the average of reservoir water quality during the calculation period of 1986 to 1995.

On the other hand, river flow and its water quality at the downstream of the dam shall be changed after construction of the dam. Figure-4.16 shows these changes on them.

Table-4.9 Summary of Water Quality in Vaza Barris Dam Reservoir

Low Flow Bypass Discharge / Parameter		Q_{BP} = 0.75 m³/s		Q_{BP} = 0.0 m³/s	
		Maximum	Average	Maximum	Average
Chloride: Cl	(mg/l)	250	175	312	199
	(me/l)	7.1	4.9	8.8	5.6
Electric Conductivity: EC	(dS/m)	1.00	0.73	1.20	0.82
Sodium: Na	(mg/l)	104	77	126	85
	(me/l)	4.5	3.3	5.5	3.7
Calcium: Ca	(mg/l)	57	42	68	46
	(me/l)	2.8	2.1	3.4	2.3
Magnesium: Mg	(mg/l)	35	26	43	29
	(me/l)	2.9	2.1	3.5	2.4
Sodium Absorption Rate: SAR		2.7	2.3	2.9	2.4
Carbonic Acid: HCO_3 *	(mg/l)	50 - 180			
	(me/l)	0.8 - 3.0			
pH *		6.9 - 8.3			

* HCO_3 and pH are not dependent on discharge.

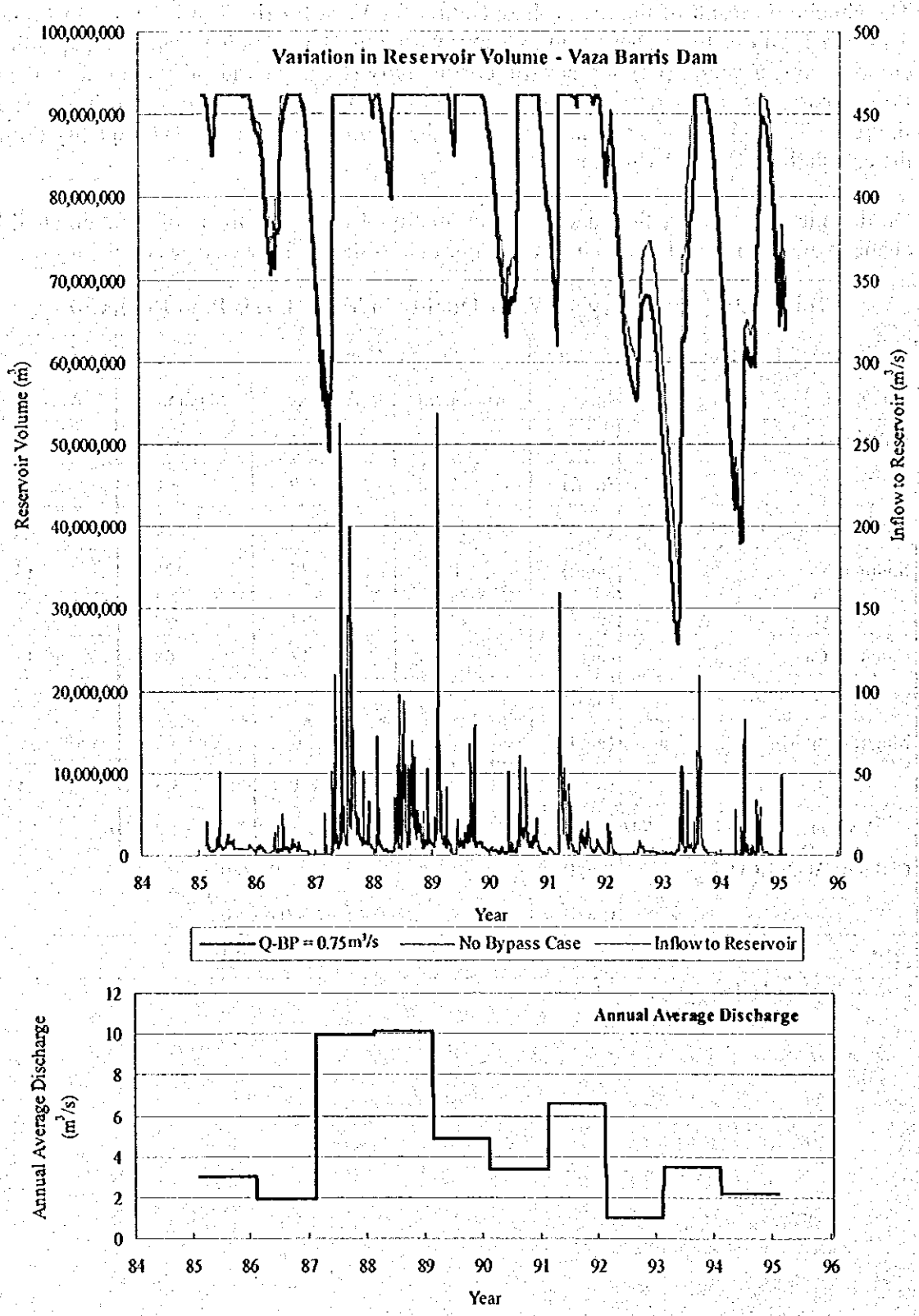
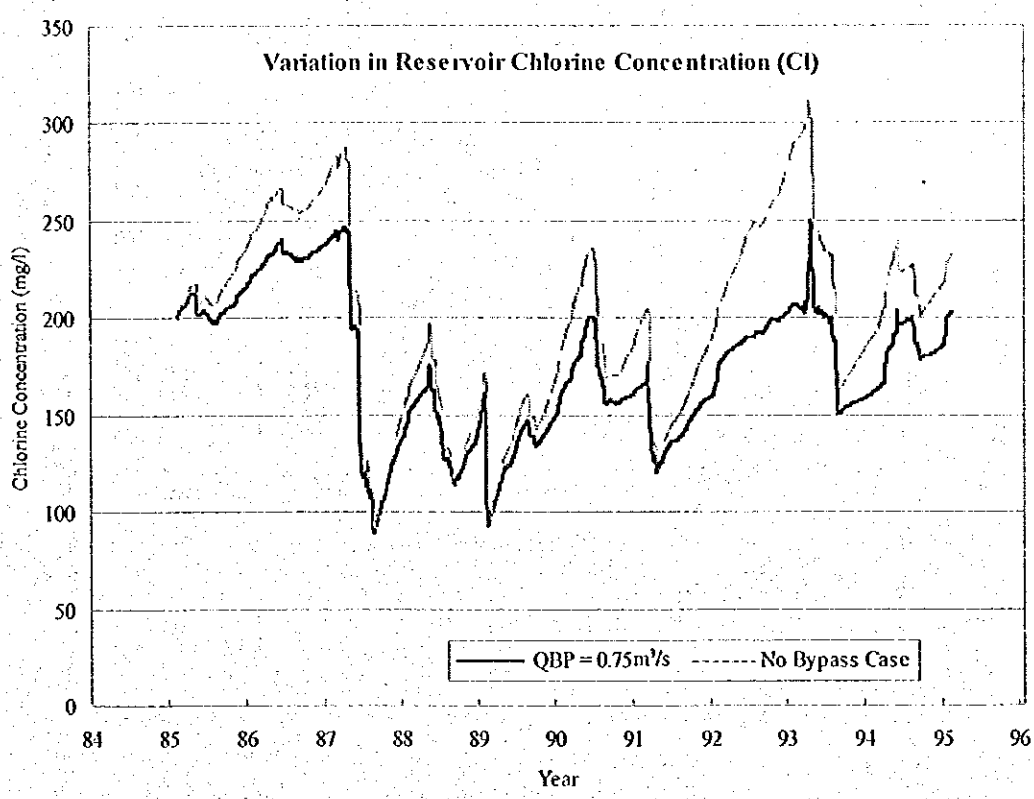


Figure-4.14 Variation of Reservoir Volume and Inflow



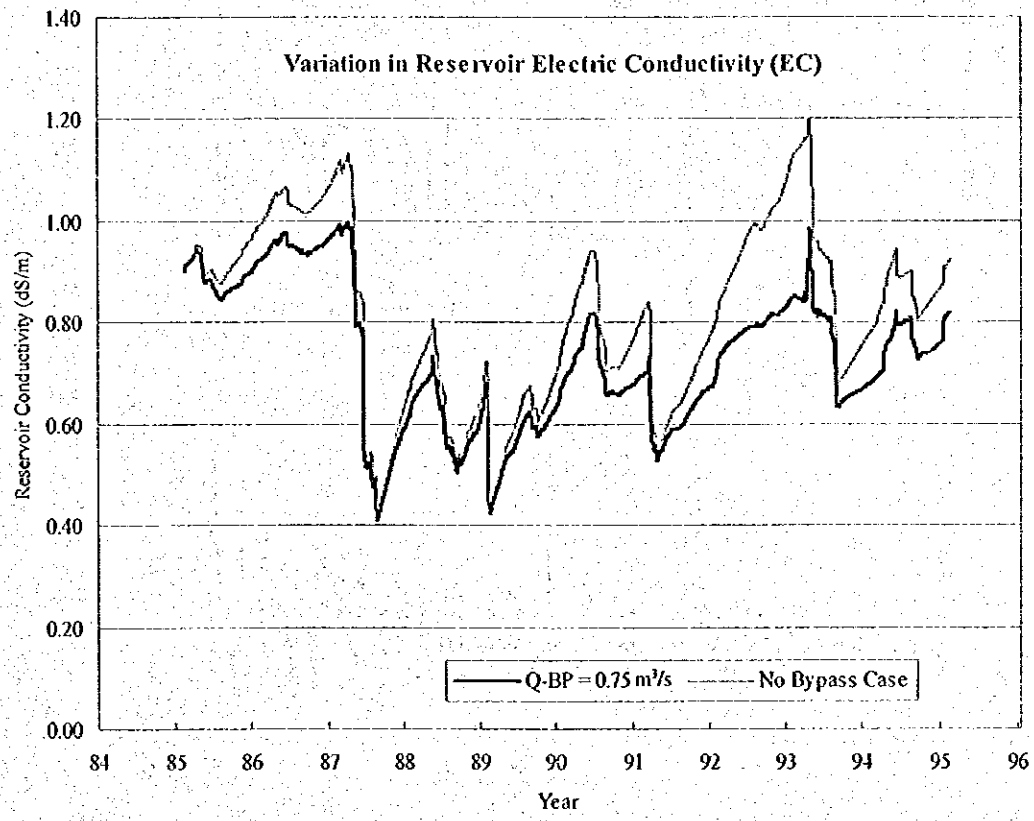


Figure-4.15 Variation of Chlorine Concentration and Electric Conductivity in the Vaza Barris Dam Reservoir

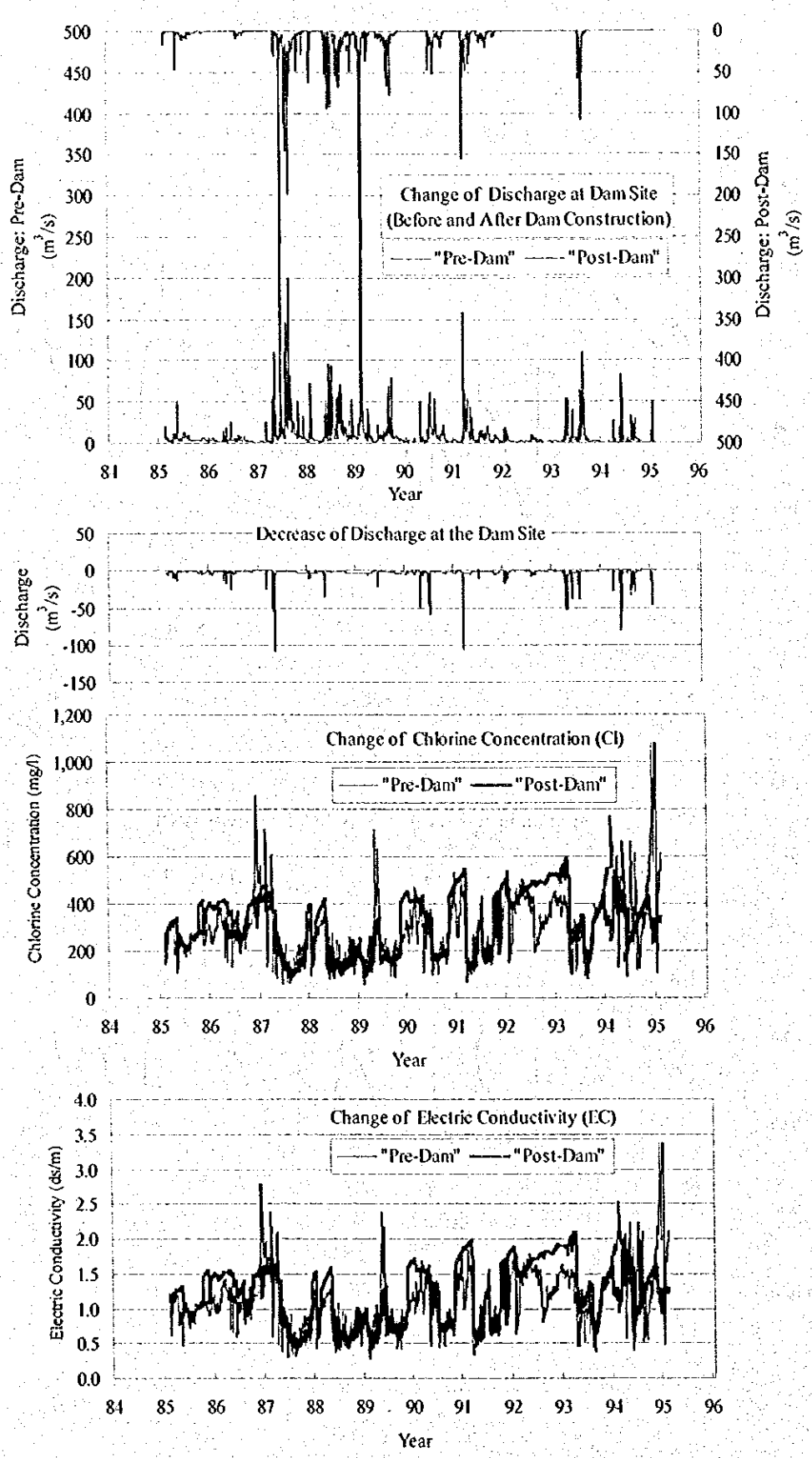


Figure-4.16 Changes on River Flow and Water Quality at the Dam Site Before and After Construction of the Dam

4.4.7 Specifications of the Plan of Vaza Barris Dam

Based on reservoir operation simulation, reservoir capacity distribution was set as shown in Figure-4.17.

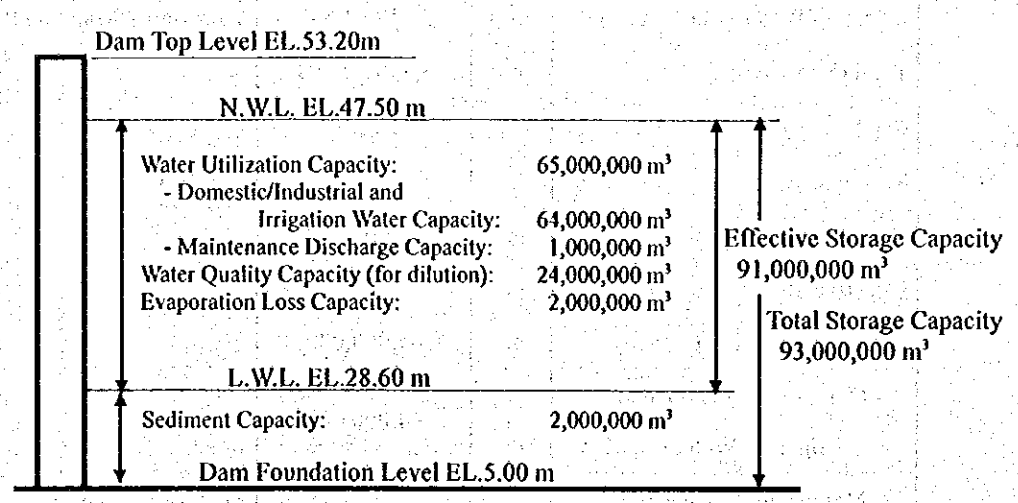


Figure-4.17 Schematic Description of Capacity and Planning Water Level

Planned specification of Vaza Barris Dam on development discharge, dam reservoir allocation, Dam/Spillway, check dam, low flow bypass is summarized in Table-4.11.

4.4.8 Single Purpose Dam

Vaza Barris Dam was designed as a multi-purpose dam in terms of domestic/industrial and irrigation water supply. In this section, two single dams for the each purpose are planned for estimating the cost of the single-purpose dam.

Assuming that bypass discharge is same as 0.75 m^3/s of Vaza Barris Dam, reservoir operation simulation was carried out and necessary reservoir volume was determined so that chloride concentration of reservoir water becomes less than 250 mg/l. Table-4.10 shows the reservoir capacity distribution plan for each single-purpose dam.

Table-4.10 Specification of Single-purpose Dam

Items	Domestic/Industrial Water Supply Dam	Irrigation Water Supply Dam
Total Storage Capacity	42,900,000 m^3	59,500,000 m^3
Effective Storage Capacity	40,900,000 m^3	57,500,000 m^3
Water Utilization Capacity	11,100,000 m^3	34,300,000 m^3
- Domestic/Industrial Water Capacity	10,100,000 m^3	-
- Irrigation Water Capacity	-	33,300,000 m^3
- Maintenance Discharge Capacity	1,000,000 m^3	1,000,000 m^3
Water Quality Capacity (for dilution)	28,600,000 m^3	21,700,000 m^3
Evaporation Loss Capacity	1,200,000 m^3	1,500,000 m^3
Sediment Capacity	2,000,000 m^3	2,000,000 m^3
Normal Water Level (N.W.L.)	EL. 41.20 m	EL. 43.60 m
Low Water Level (L.W.L.)	EL. 28.60 m	EL. 28.60 m
Dam Top Level	EL. 46.90 m	EL. 49.30 m
Dam Height	41.90 m	44.30 m

Table-4.11 Planed Specification of Vaza Barris Dam

Items		Unit	Specification	Remarks
Development Discharge	Domestic and Industrial Water	m^3/s	0.887	
	Irrigation Water (Max. /Ave.)	m^3/s	2.912 / 1.507	Vaza Barris Irrigation Project
	Total (Max. /Ave.)	m^3/s	3.799 / 2.394	
Dam Reservoir	Catchment Area	km^2	15,560	
	Reservoir Area	ha	950	at N.W.L.
	Total Storage Capacity	m^3	93,000,000	
	Effective Storage Capacity	m^3	91,000,000	
	Water Utilization Capacity	m^3	65,000,000	
	- Domestic/Industrial and Irrigation Water Capacity	m^3	64,000,000	
	- Maintenance Discharge Capacity	m^3	1,000,000	Maintenance Discharge: 0.44 m^3/s
	Water Quality Capacity (for dilution)	m^3	24,000,000	
	Evaporation Loss Capacity	m^3	2,000,000	
	Sediment Capacity	m^3	2,000,000	10 m^3/km^2/year, 100 years (10Mm^3 into Check Dam)
	Normal Water Level (N.W.L.)	EL.m	47.50	
	Low Water Level (L.W.L.)	EL.m	28.60	Sediment Level
Dam and Spillway	Design Flood Discharge	m^3/s	3,600	Probable Maximum (10,000-yr. Return Period)
	Design Discharge of Energy Dissipater	m^3/s	1,200	100-year return period
	Design Discharge of Diversion Channel during Construction	m^3/s	Concrete Dam:200 Fill Dam: 720	2-year return period 20-year return period
Check Dam	Dam Type	-	Concrete Dam	
	Dam Top Level	EL.m	63.00	
	Design Discharge of Spillway	m^3/s	1,400	1.2 times of 100-year return period
	Sediment Capacity	m^3	10,000,000	Level at EL.63.0m
Low Flow Bypass	Design Discharge	m^3/s	0.75	

4.5 Designs of Dam and Spillway

4.5.1 Geology of Dam Site

(1) Topography and Geology of Dam Sites

(a) Topography

The watercourse of the Vaza Barris River at the proposed dam site is located at a top of an arc, whose tangent coincides almost with a direction of NW to SE, this direction is in accordance with the general trend dominant in western Sergipe. There can be seen some outcrops along the watercourse, but they are quite sporadic and hill slope is also covered with weathered materials. The altitude of the site is about 22m at the riverbed. Several lineaments parallel to this direction can be seen. Small valleys dissecting almost perpendicular to the general direction exist on the right bank with an interval of 300m. Whereas, the left valley is almost smooth in shape.

(b) Geology

Geology of proposed dam site mainly consists of meta-phyllite of Proterozoic system, with the direction of around N45-60W and the dip of 70-80NE. The meta-phyllite is an alternance of psammitic schist and pelitic schist, severely weathered along slightly-opened planes of schistosity. The direction of schisosity is also parallel to the regional geological structure, which includes ordinary reverse faults and regional thrusts of large scale. Such important structures involving large fractured zone or altered zones are not found in the proposed dam site area. On the top of peneplain around the Vaza Barris dam site, it was reported an existence of unconsolidated Tertiary sedimentary rocks, but in this area, it is a kind of loose conglomerate to gravel layer just alike a terrace deposit. Its thickness is estimated to have an order of 10m .

(2) Geological Condition of Dam Site

Based on the result of the boring survey, rock classification was carried out for the dam site and spillway site. The result of rock classification is shown in
Figure-4.18. The evaluation of foundation of the dam is based on the criterion adopted by the Ministry of Construction of the Japanese Government. The main geological features of the dam site are as follows:

(a) Rock Quality and Rock Mass Classification

- This site consists of highly weathered rocks at the surface part. Assumed rock surface may have an irregular form.
- Rock itself is quite hard and stiff if sound, its deterioration is caused mainly by weathering and shearing. Whereas the former is universal along its surface, the latter is quite restricted along sporadic zones.
  The weathered zone is somehow shallow at the river floor (see Figure-4.18), and extends flat or in a lower gradient than that of hill slope into the ground.
- On the valley wall, the weathered zone is rather thin compared with hill-slope, therefore, sound rock (C_M or C_H) can be found just under the river bed sediments with a intervention of thin layer of rock of low grade (C_L).

- On both hill slopes, rock of low grade (C_L) extends into the abutments in a low gradient corresponding to the lower boundary of weathered zone. This means that rock of low grade (C_L) is relatively thick at the abutments, and sound rock cannot be found until at the depth of about 20 m. This tendency is more remarkable in the right bank than in the left bank.

(b) Permeability and Groundwater Level of Dam Site

Pervious zone is limited to the ground surface and mainly at less than 10m of depth, and any highly pervious zone at more than 10m of depth has not been encountered, this means that any deep conduits can not exist. Groundwater level is considerably low on both abutments, this is considered to show the deepness of weathering front.

(c) Groundwater Seepage

Small valleys dissecting the right bank exist parallel in the direction of NE-SW and in the distance of about 300m. These valleys must be filled up to the height of storage water level to avoid any occurrences of seepage flow through the ground that may cause piping and may eventually cause a failure of foundation. Small cols exist on a ridgeline between these small valleys. These cols overlie just on the lineament that causes a fractured zone. There is a possibility that this zone may act as a drainage conduit, and must not be neglected.

(3) Availability of Quarry Site

(a) Earth Materials

It seems to be difficult to find earth materials such as soils for embankment dams in the proposed dam area, partly because of unsuitable properties of highly weathered meta-phyllites, partly because of thinness of weathered portion of massive rocks around the dam site. Another earthy material conventionally used in this region is tertiary sediment. This sediment seems to be rather thin (under several m) around the proposed Vaza Barris dam site.

(b) Rocky Materials

Meta-phyllite or other metamorphic rocks near the dam site area are difficult to fulfill the standard demand for aggregates of concrete or shell of embankment dams, because of its flatness in shape and poor abrasion resistance. This series outcropping near the dam site or the future reservoir are judged to be quite unsuitable for construction material. On the other hand, granites or migmatites in the basin of the Itabaiana Dome are sound and stiff, and suitable for construction materials in quality and occurrence volume.

Geological Cross Section

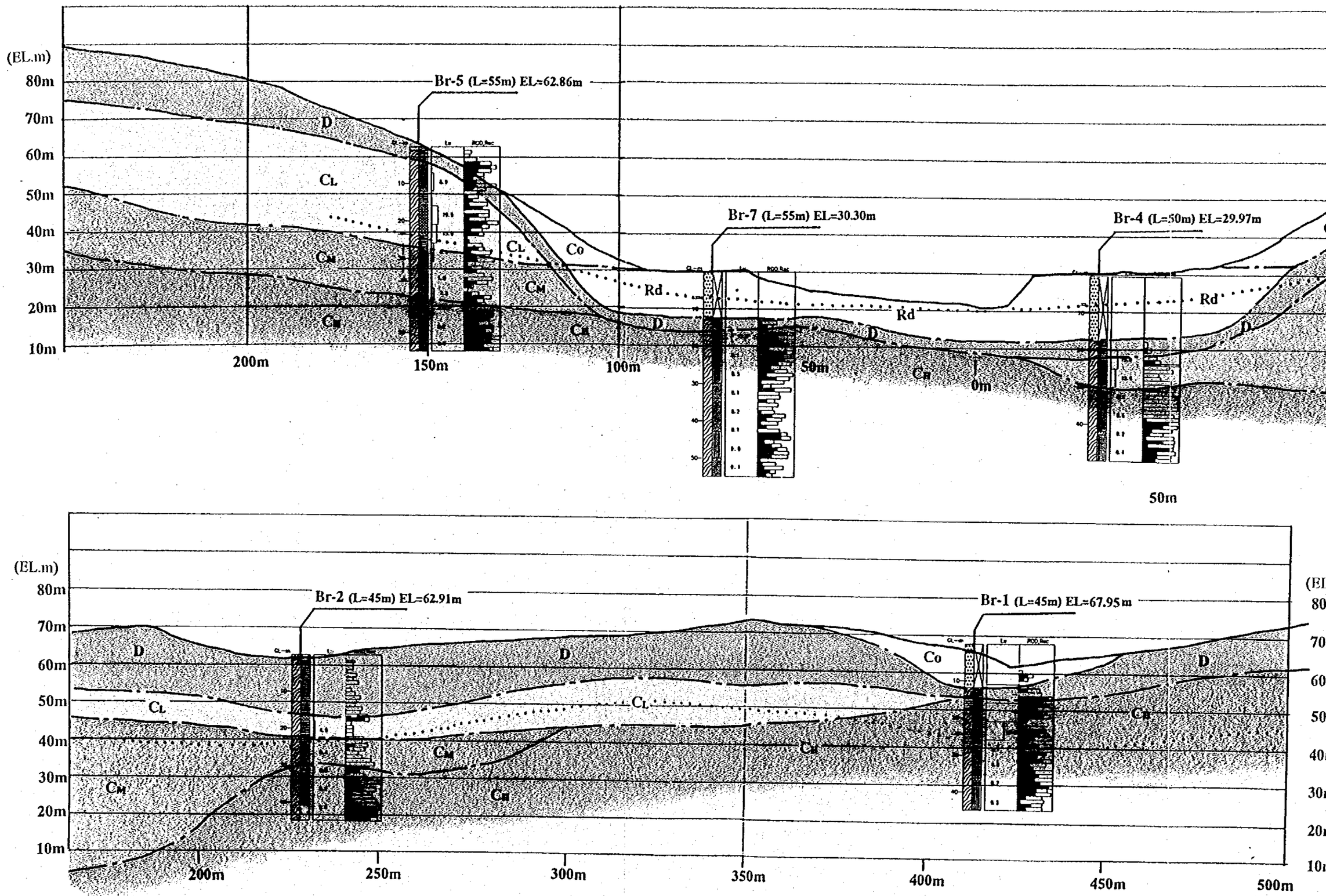


Figure-4.18 Geological

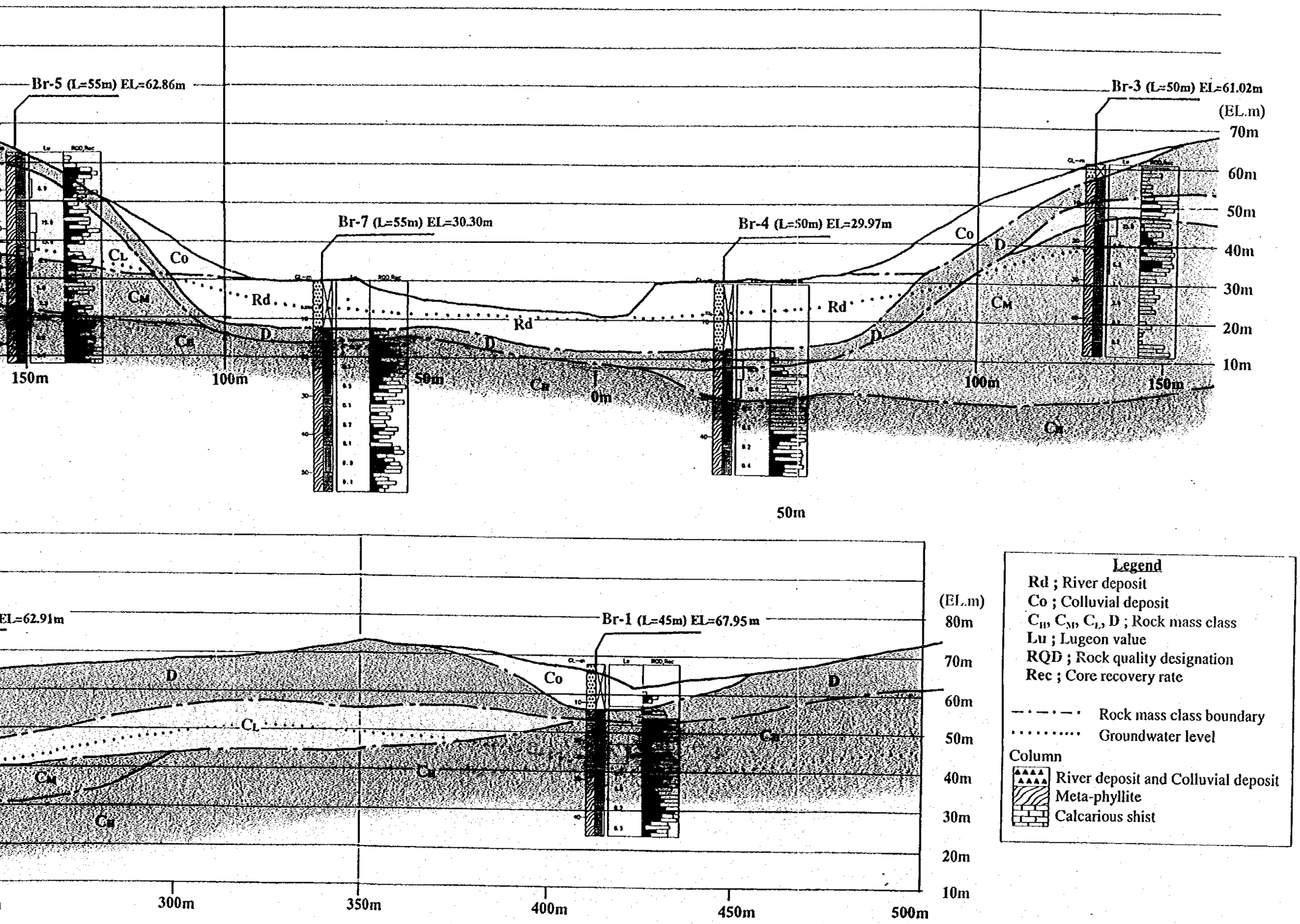


Figure-4.18 Geological Cross Section of Vaza Barris Dam Site

4.5.2 Alternative Designs of Dam Body and Spillway

(1) Main Structures

Main structures of Vaza Barris Dam are:

1) Dam body to store water of river: Highest elevation of dam top is EL.60m. Dam is put on base rock. Dam suffices design safety factor.
2) Spillway to safely spill design flood discharge: Design flood discharge = 3,600 m^3/s (1/10,000-year).
3) Low Flow Outlet to discharge maintenance flow: Between N.W.L and L.W.L, outlet discharge of 0.44 m^3/s.

(2) Flowchart of Dam Design

Flowchart of dam design is shown in Figure-4.19.

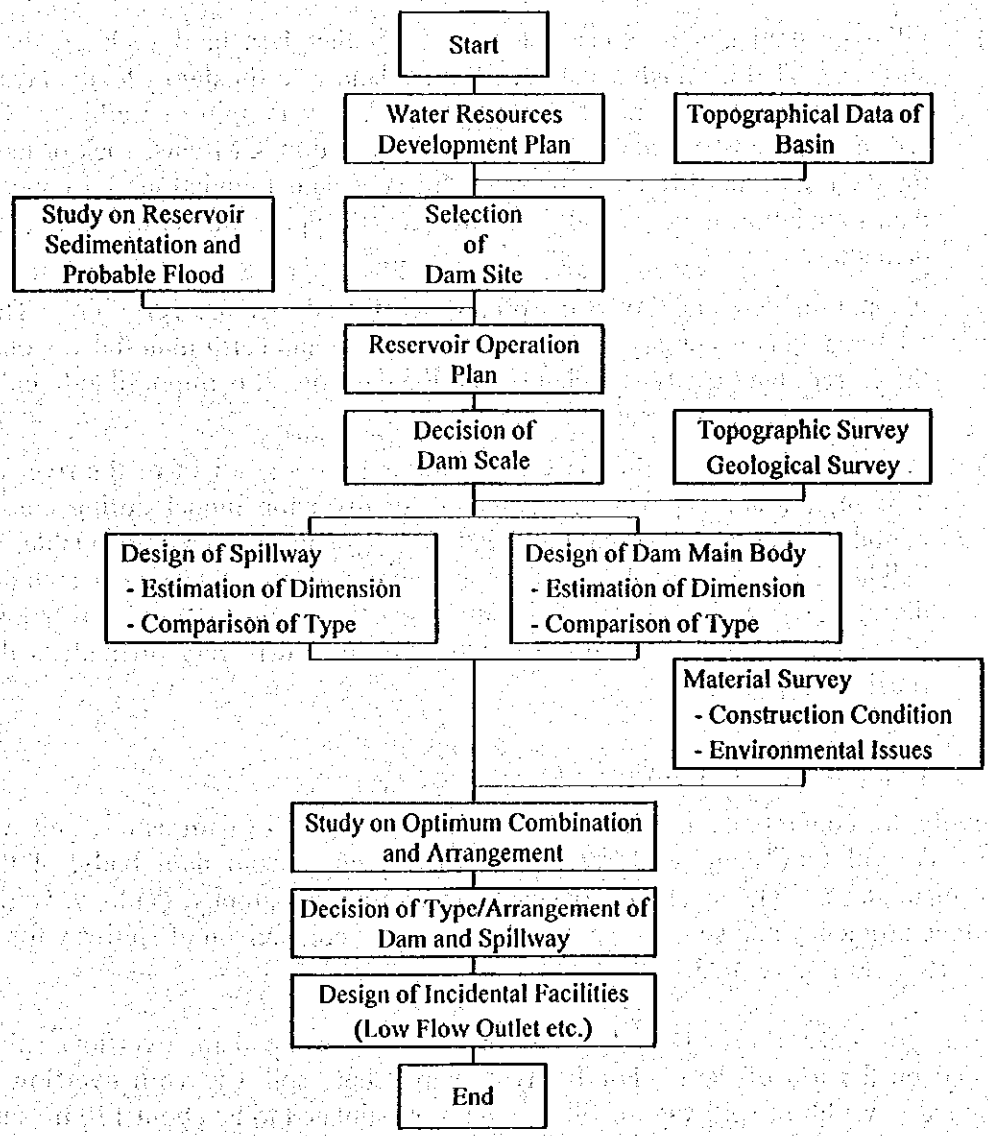


Figure-4.19 Flowchart of Dam Design

(3) Comparison of Dam Type

Four (4) dam types: gravity concrete dam, rock-fill dam with zone type, rock-fill dam with concrete facing type and earth-fill dam are compared. Refer to Table-4.12 and Figure-4.20, Figure-4.21, Figure-4.22. Type of Vaza Barris Dam: ***Gravity Concrete Dam Type*** is decided due to low cost and workability of construction under the following considerations:

1) Rock material and concrete aggregate are procured at the existing quarry site located near the Cajaiba Dam and 15 km far from the dam site. As necessary material volume is minimum, concrete type dam, is advantageous.

2) Due to big design flood discharge for spillway, a large scale of spillway facility is necessary. Fill type dam requires large volume of concrete for spillway facility. Spillway for concrete type dam can be installed easily on the dam body. Concrete type dam is advantageous from viewpoints of construction cost and construction workability.

3) Fill type dam can be constructed on the rather less hard rock on the ground surface. That is an advantage of fill type dam. At the dam site, the layer of this rather less hard rock, namely CL-class rock is very thin or nothing. Concrete type dam is constructed on the hard rock foundation: CM-class rock or more. At the dam site, the difference between fill type dam foundation and concrete type dam foundation is very small. Therefore, fill type dam has no advantage at the dam site.

4) Around the dam site, layers of soil and weathered rock are very thin. Therefore, a large area is necessary to collect core material and earth material. Considering the current land use (pastureland) near the dam site, it is impossible to collect soil material in the wide areas.

5) Water depth in flood time is very high due to low gradient of the river channel. This high water depth is disadvantage for diversion tunnel during construction period. Therefore, partial bulkhead for diversion is recommendable. Partial bulkhead method is applicable for concrete type dam because the design diversion discharge is small and concrete dam is resistant against dam-top overflow. For fill type dam, diversion during construction period is very difficult at the Vaza Barris dam site.

(4) Comparison of Spillway

Generally, for concrete dam, spillway is installed on the top of dam as one unit with dam body. For fill type dam, spillway is constructed, apart from dam body, at the most appropriate place. The location is decided considering topography, geology, workability, economic efficiency and so on. Table-4.13 shows the comparison of spillway for fill type dam. Refer to Figure-4.23.

Spillway for Vaza Barris Dam has no gate. For concrete dam, overflow spillway is installed on the top of dam. For fill type dam, Chute spillway with overflow inlet is employed. Width of spillway for fill type dam is estimated to be about 130 m, supposing overflow depth: about 6 m. From the comparison result of spillway location for fill type dam, Left-Bank plan is most recommendable.

Table-4.12 Comparison of Dam Type

Items	Gravity Concrete Dam	Rock-fill Dam		Earth Dam
		Zone Type	Concrete Facing Type	
Dam Foundation	Dam foundation at the site is possible for construction of any type of dam.			
	○	○	○	○
Material for Dam Body	Rock material including aggregate are not available near the dam site. The material for embankment and concrete has to be purchased form the existing quarry site, 15 km far from the dam site. Near the dam site, acquisition of soil material is very difficult.			
	1) Concrete Aggregate, Cement, Fly ash, Admixture	1) Core 2) Filter 3) Rock	1) Concrete 2) Transition 3) Rock	1) Earth
	○	△	○	X
Location of Spillway	Upper part of main dam	Left bank side, apart from dam body		
	○	△	△	△
Location of Low Flow Outlet	Inside of main dam	Outlet pipe cannot be installed in the dam body. Pipe and other related facilities are constructed apart from dam body.		
	○	△	△	△
Resistance against dam top overflow	Safety due to concrete structure.	Weak	Weak but better than zone type rock fill dam	Very weak
	○	X	△	X
Diversion Discharge	Q=200 m³/s (1/2 year probability)	Q=720 m³/s (1/20 year probability) For concrete facing type, design discharge can be decreased.		
	○	X	△	X
Diversion Method	- Partial bulkhead - Temporary hole in dam body	No practical method, due to very large scale of diversion tunnel	- Partial bulkhead - Temporary hole in dam body	No practical method, due to very large scale of diversion tunnel
	○	X	○	X
Construction Facilities	One system including concrete batch and concrete place	Total two systems: - Embankment system for dam body - Concrete batch and concrete place system for spillway		
	○	△	△	△
Dam Height	Base rock for fill type dam is D-class or CL-class. Base rock for concrete dam is CM-class. The rock layers of D-class and CL-class are very thin at the dam site. The dam height for concrete type and fill type is almost same, 50 m – 55 m.			
Dam Volume	275,000 m³ (1.0)	899,000 m³ (3.3)	697,000 m³ (2.5)	1,100,000 m³ (4.0)
Spillway Concrete Volume	0 m³	37,500 m³	37,500 m³	37,500 m³
Excavation Volume	373,000 m³ (1.0)	2,113,000 m³ (5.7)	1,926,000 m³ (5.1)	2,301,000 m³ (6.2)
Total Evaluation	1) Due to min. volume of dam, material cost inc. transportation is cheaper than fill type dam. 2) Good workability due to one unit inc. dam, spillway and outlet. 3) Due to big resistance against flood over top of dam, cost for diversion can be decreased.	1) Due to big diversion discharge and small slope of river channel, cost for diversion facilities is extremely expensive. 2) Acquisition of core material is difficult. 3) Cost for spillway is very larger than that of concrete type dam.	1) Due to remote quarry site, cost for rock material is very high. 2) Cost for spillway is very larger than that of concrete type dam.	1) Due to big diversion discharge and small slope of river channel, cost for diversion facilities is extremely expensive. 2) There is no earth material near dam site. 3) Cost for spillway is very larger than that of concrete type dam.
	○ (Very Good)	X (Not Good)	△(Fair)	X (Not Good)
	Probable dam types are gravity concrete and rock-fill with concrete facing. Due to cost and workability of construction, the most promising dam type is gravity concrete dam for Vaza Barris Dam.			

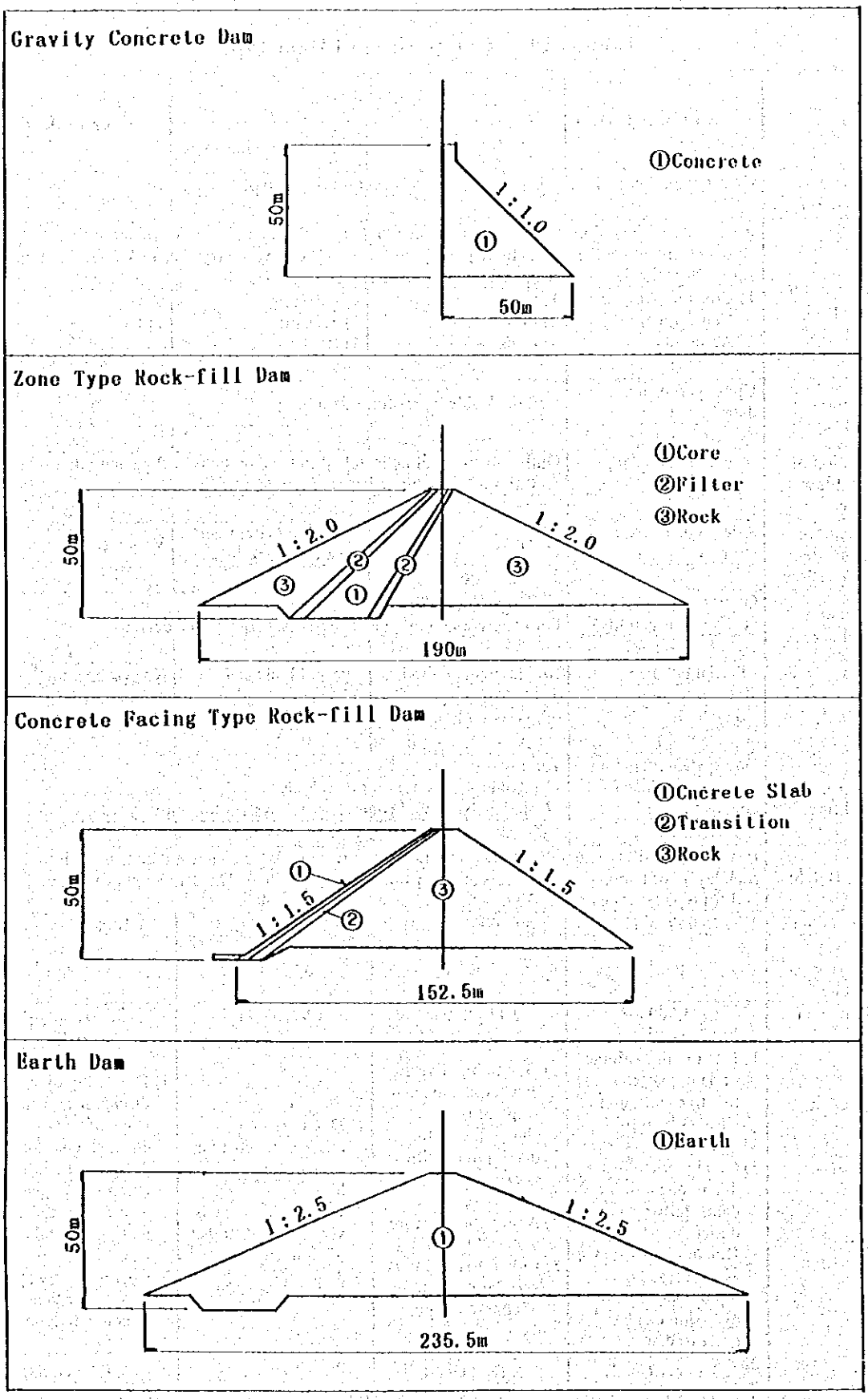
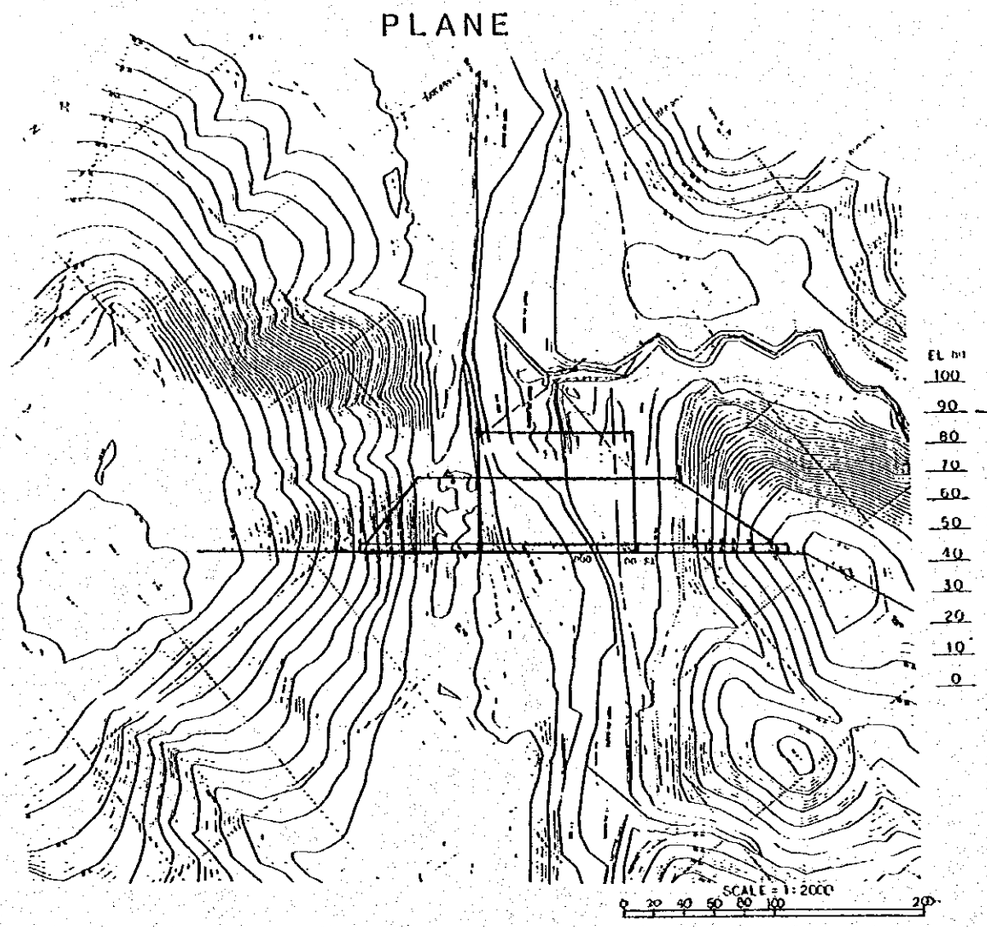
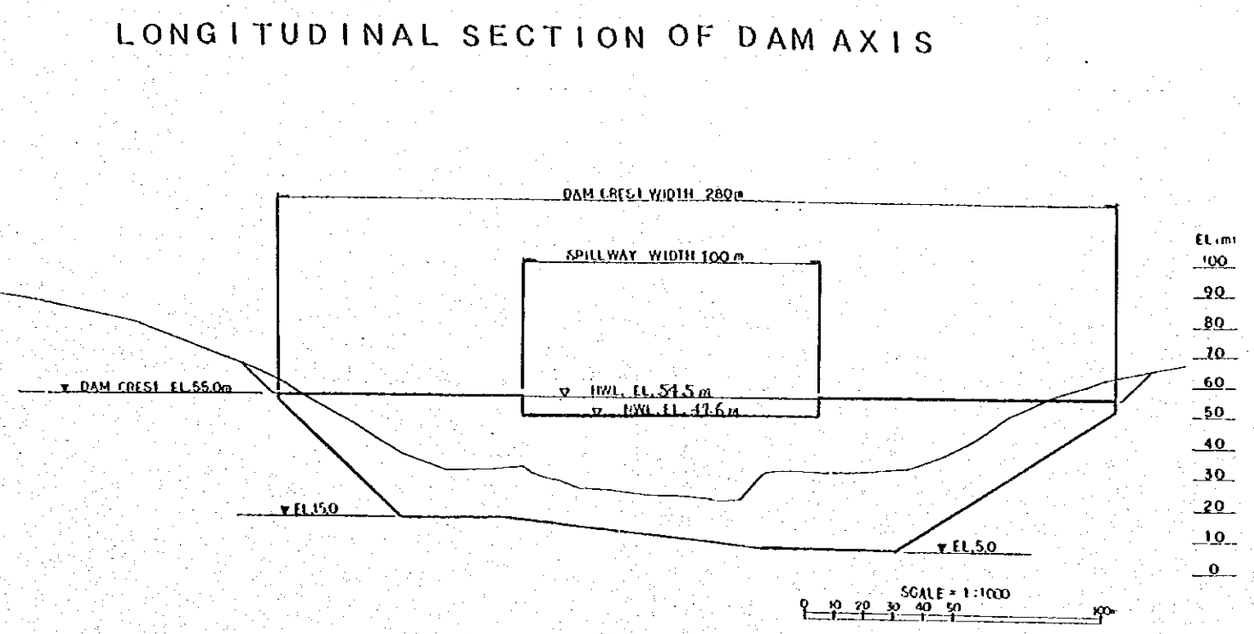


Figure-4.20 Type of Dam





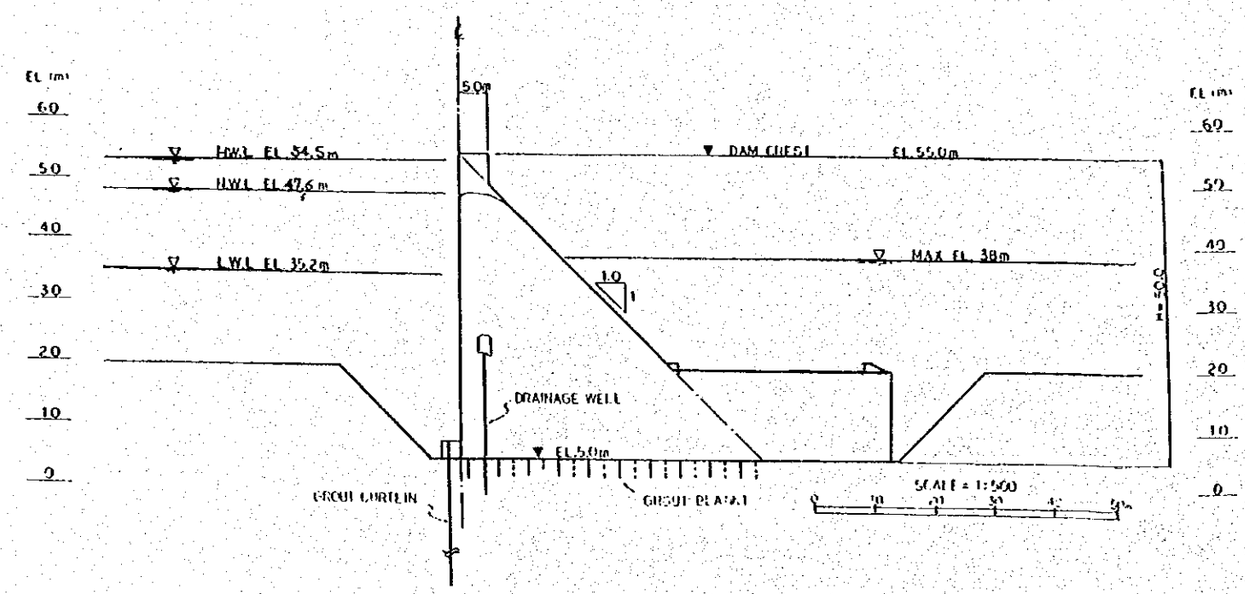
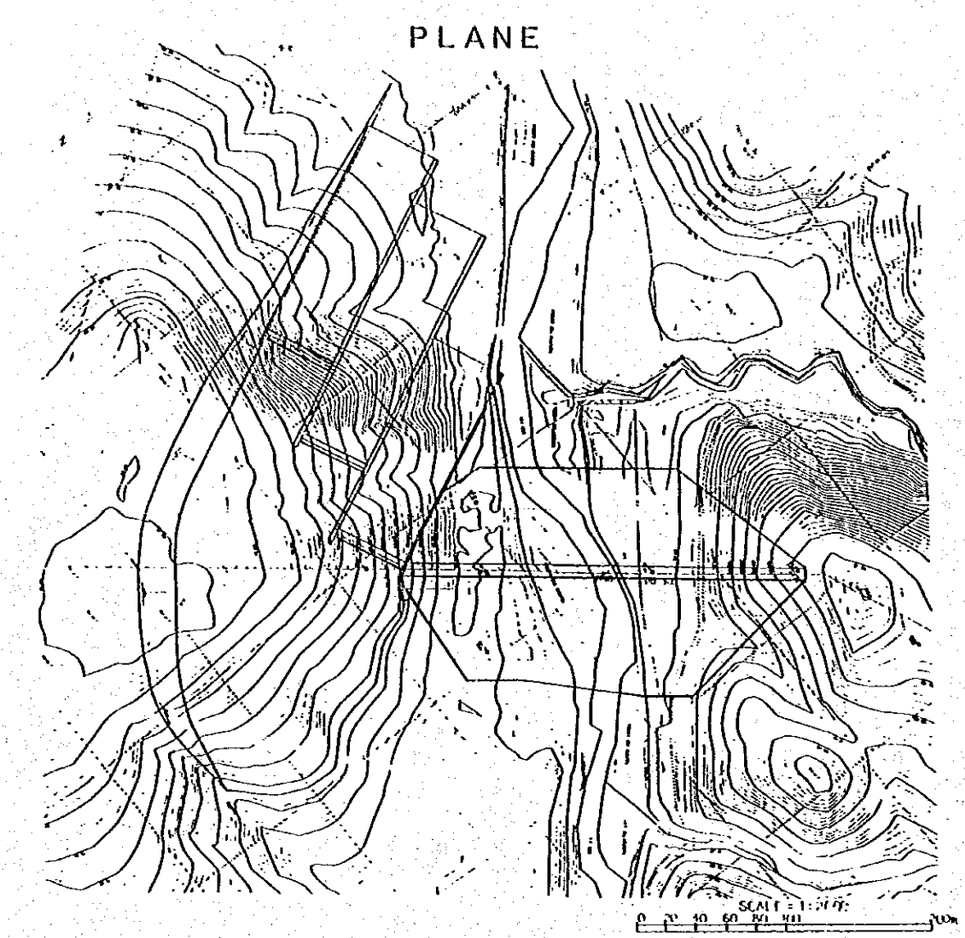
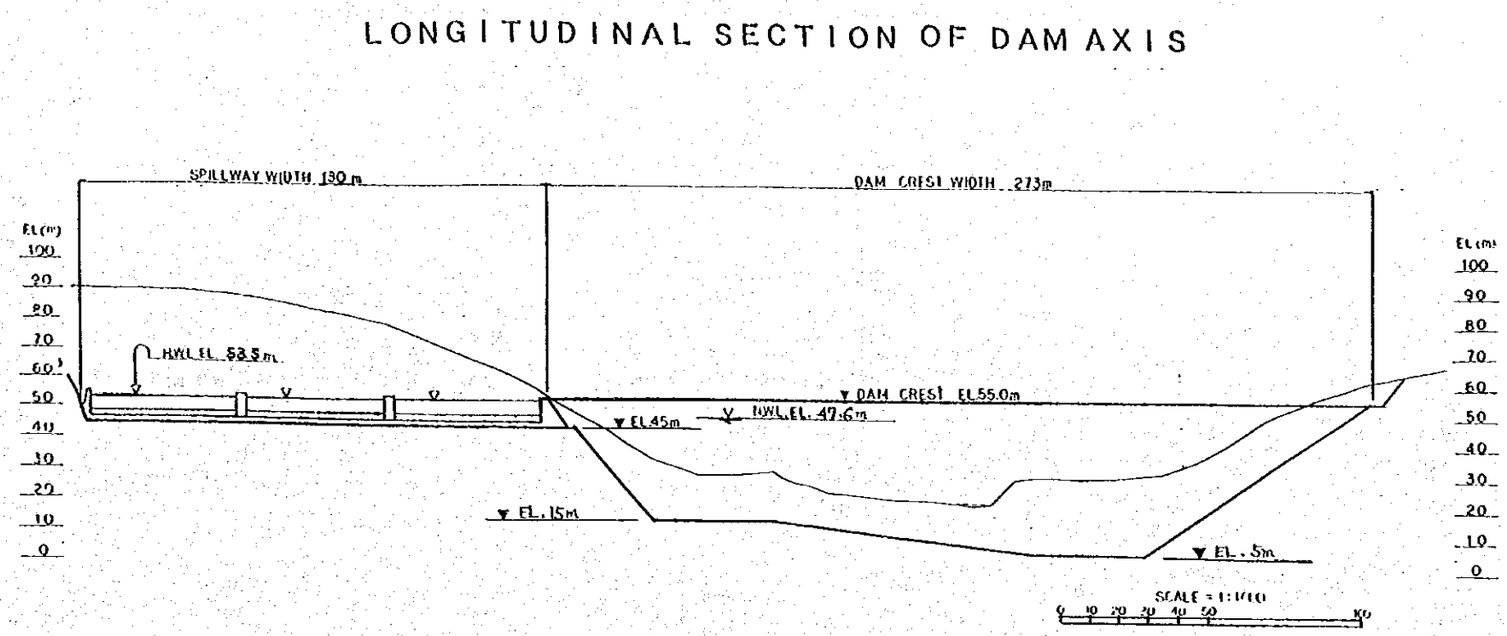
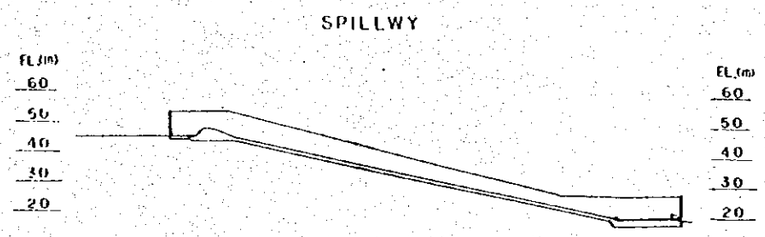


Figure-4.21 Alternative Plan (Gravity Concrete Dam)







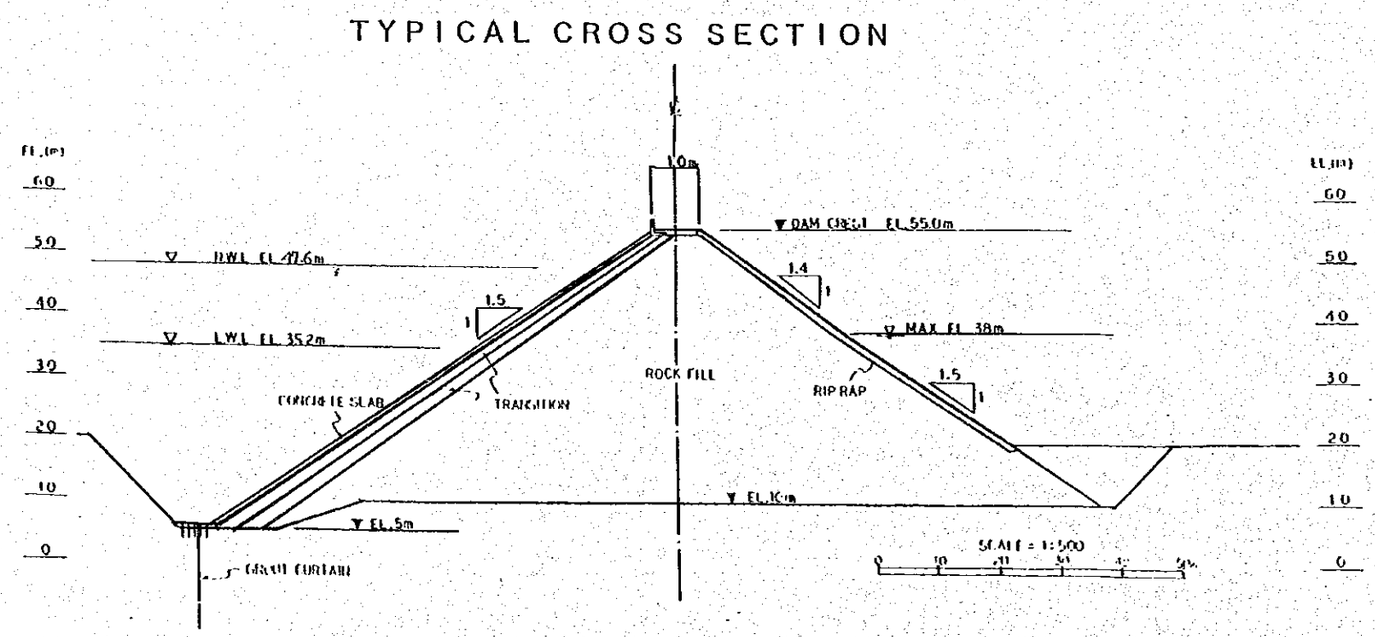


Figure-4.22 Alternative Plan (Concrete Facing Type Rock Fill Dam)

Table-4.13 Comparison of Spillway for Fill-Type Dam

Items	Left-Bank Plan	Right-Bank Plan	Separated Plan
Topography and Geology	Topographically, left bank mountain body is large enough to install spillway. There is no geological problem.	Right bank is thin ridge. Line of the ridge is inclined upstream at 30 degree from dam axis. Weathered layer is 10 – 20 m. Hill top, el. 61 m, located at the top of right abutment, is obstacle to spillway.	Location is saddle of ridge. Weathered layer is 15 m. At the downstream valley, sedimentation depth seems 15 m.
Foundation of Spillway	Inlet level is normal water level of reservoir. At the normal water level, CL – class rock is distributed. This class rock is strong enough for foundation of spillway.		
Connection to Downstream River Channel	The center line of spillway crosses the river channel at 25 degree. No special problem.	Spilled water is directly discharged to the tributary which meets right angles to the river channel	The end of valley where spillway is installed, is flat land. No special problem.
Length of Spillway	Approx. 150 m	Approx. 100 m + 200 m training channel	Approx. 1000 m
Hydraulic Points	No special problem.	Arrangement of stilling pool is difficult due to topographic reason.	Curved chute is not appropriate to discharge supercritical flow.
Other Points	Large scale of spillway needs a large amount of excavation	Due to thin ridge and existence of lineament, there is a weak point of leakage. To prevent this leakage, there is a plan to fill the valley (upstream side of the ridge) with dumping soil material. It is not appropriate to install spillway near the dumping place.	Similar existing dams have chute with natural channel and inlet with concrete. Due to frequency of flood, large discharge and thick layer of sedimentation, natural channel – chute is not preferable.
Total Evaluation	Few problem	Large scale of spillway can not be installed.	Few merit
	○ (Applicable)	X (Not applicable)	X (Not applicable)

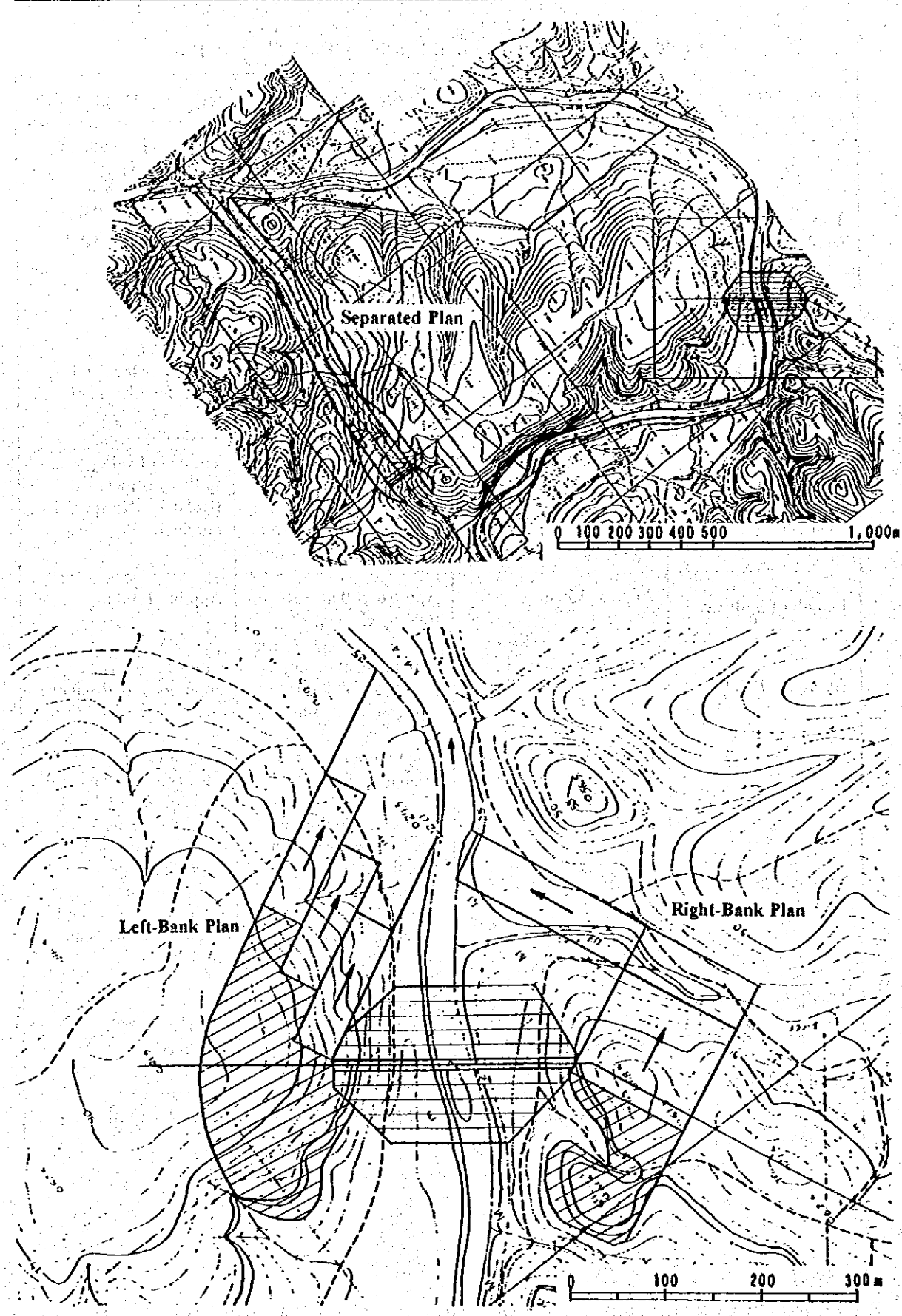


Figure-4.23 Comparison of Spillway