FEASIBILITY STUDY
ON
SMALL-SCALE POWER PLANTS
REHABILITATION PROJECT
IN
THE REPUBLIC OF COLOMBIA

SAN CANCIO, INTERMEDIA AND MUNICIPAL HYDROELECTRIC POWER PLANTS

MARCH 1990

Japan International Cooperation Agency

MAP OF SOUTH AMERICA

NEW WORLD ATLAS
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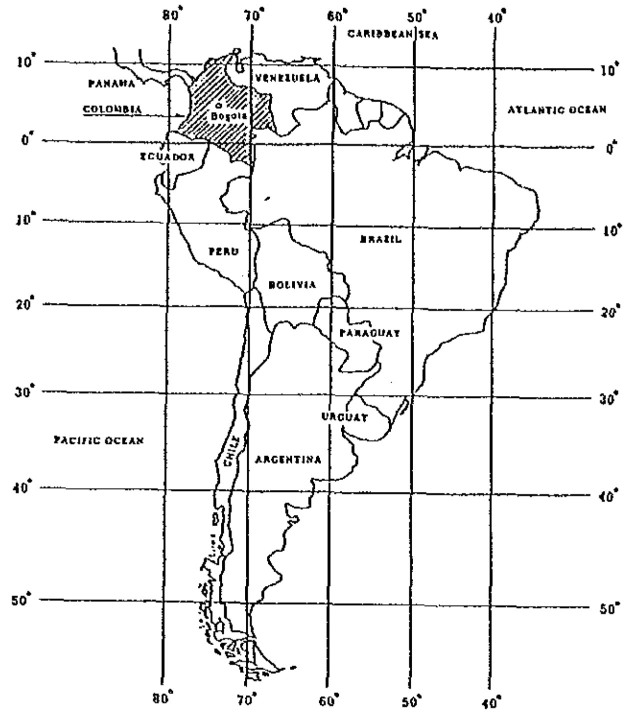
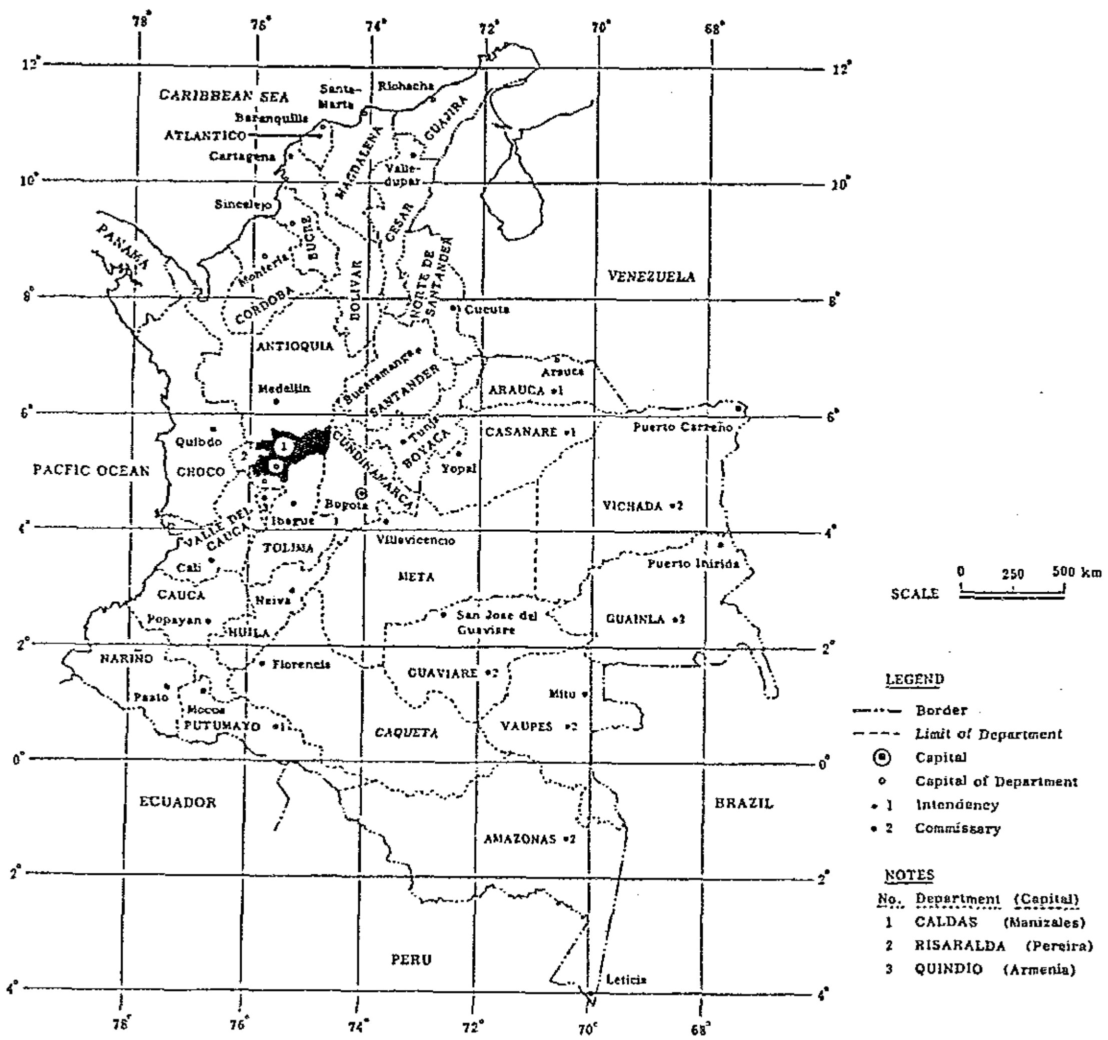
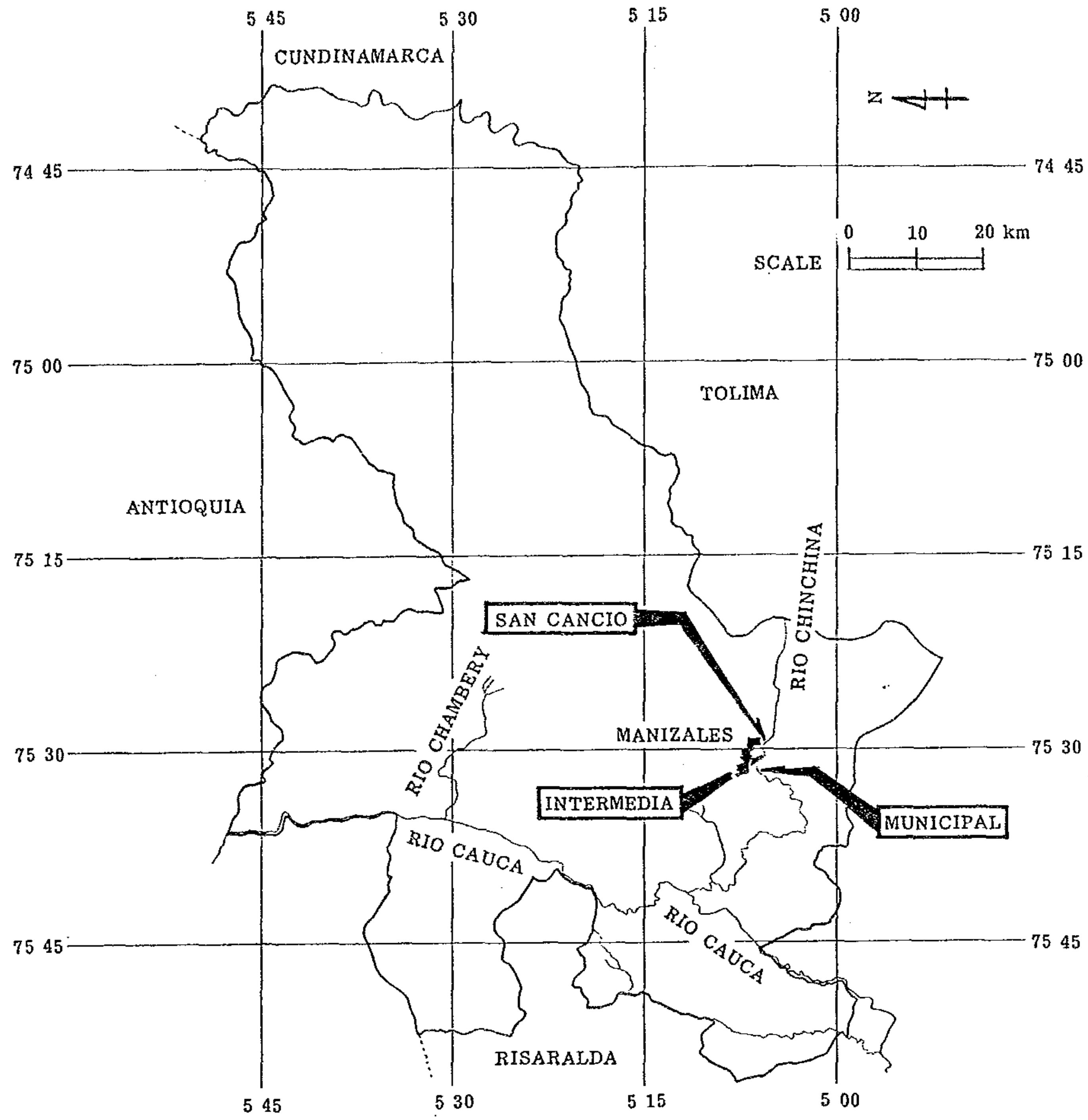


POLITICAL DIVISION IN THE REPUBLIC OF COLOMBIA





Location Map of Study Area

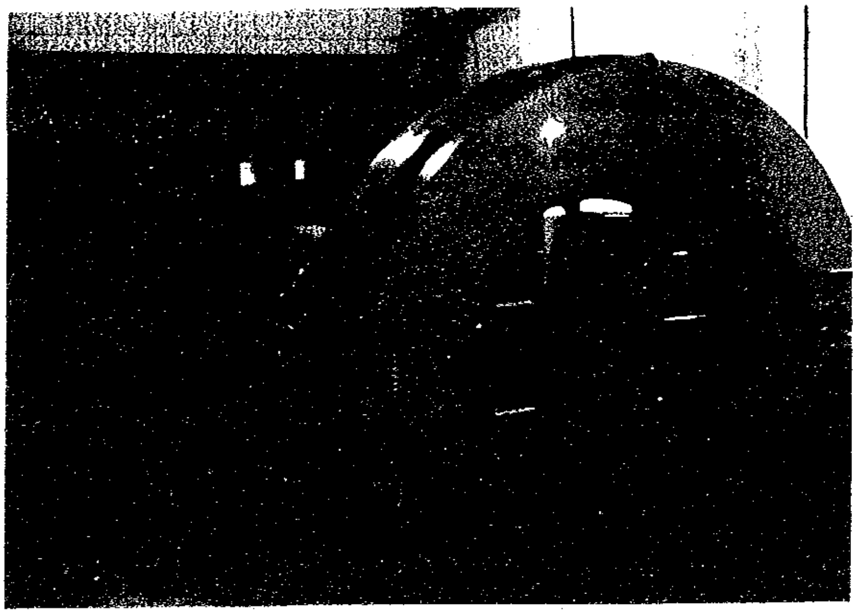
San Cancio Hydroelectric Power Plant

Rio Chinchina and Dam

Conduction channel

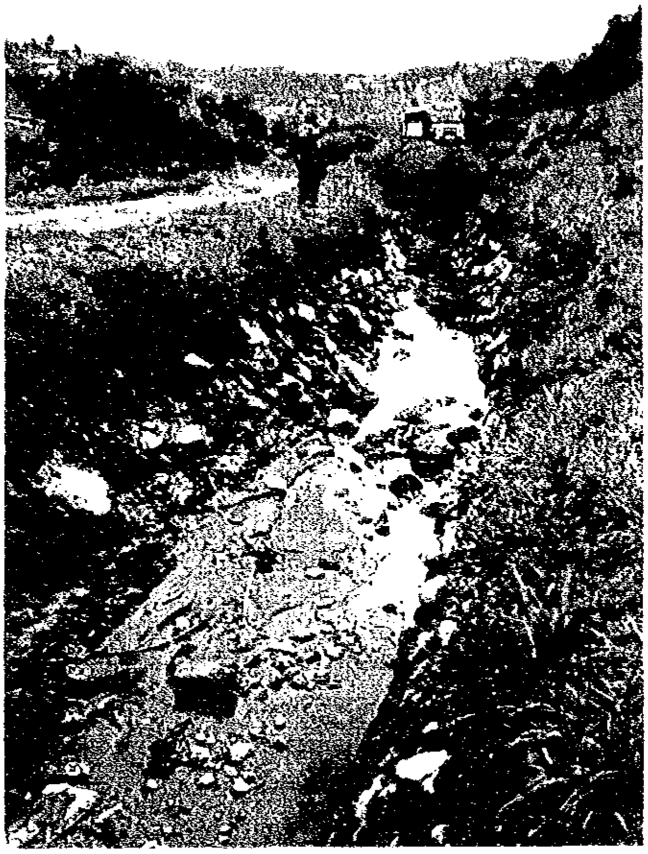
Powerhouse

Francis turbine and generator

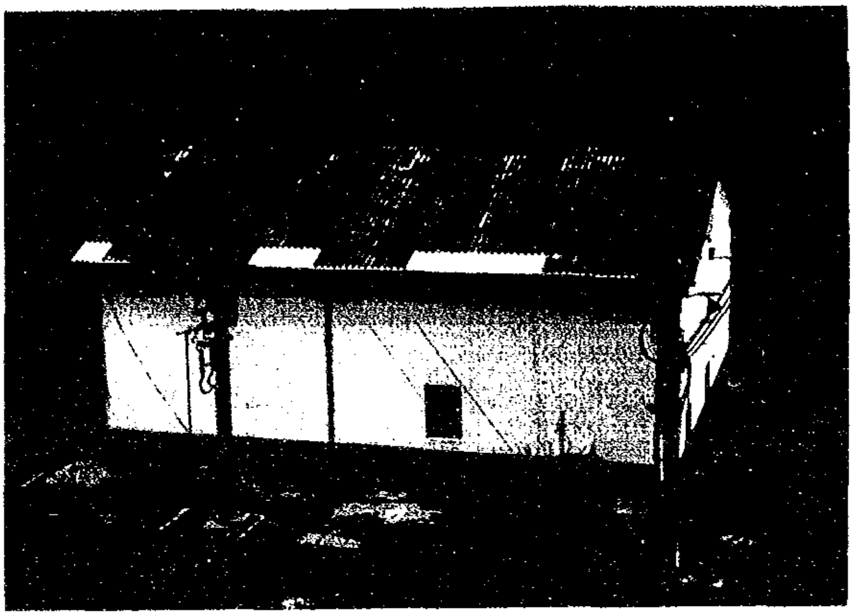


Pelton turbine and generator

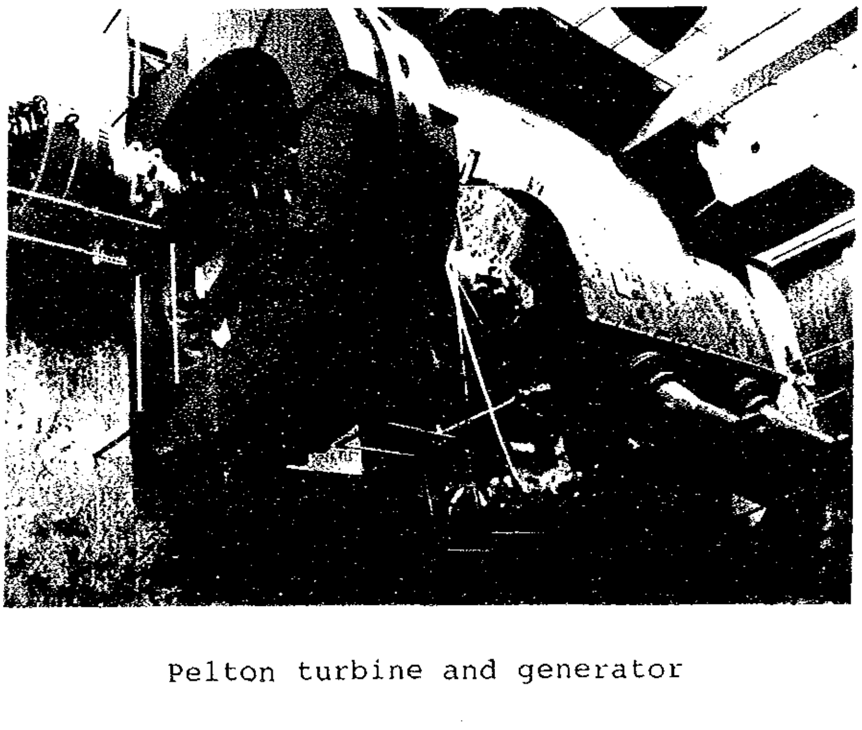
Intermedia Hydroelectric Power Plant



Conduction channel



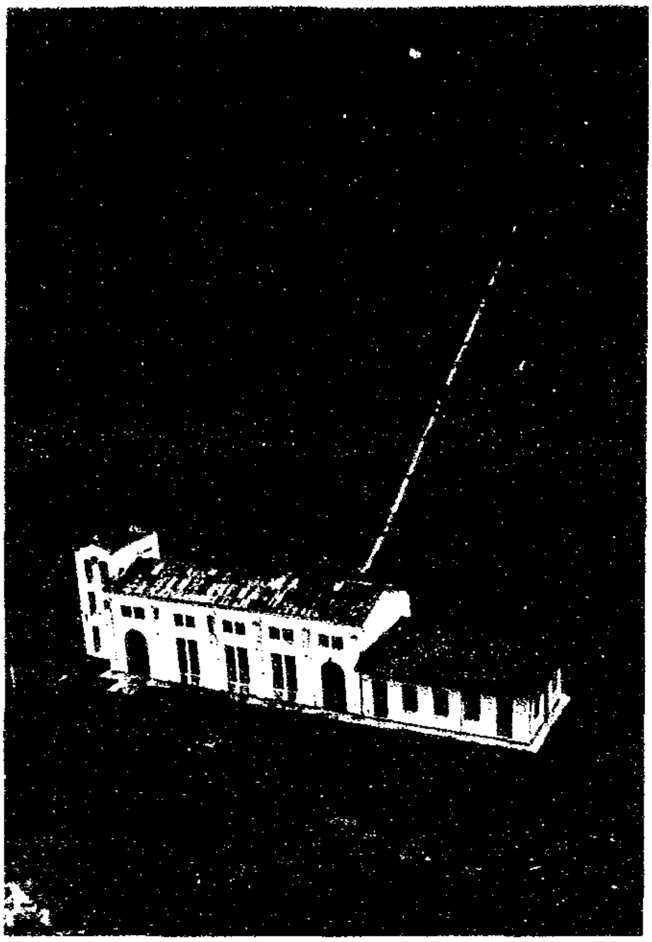
Powerhouse



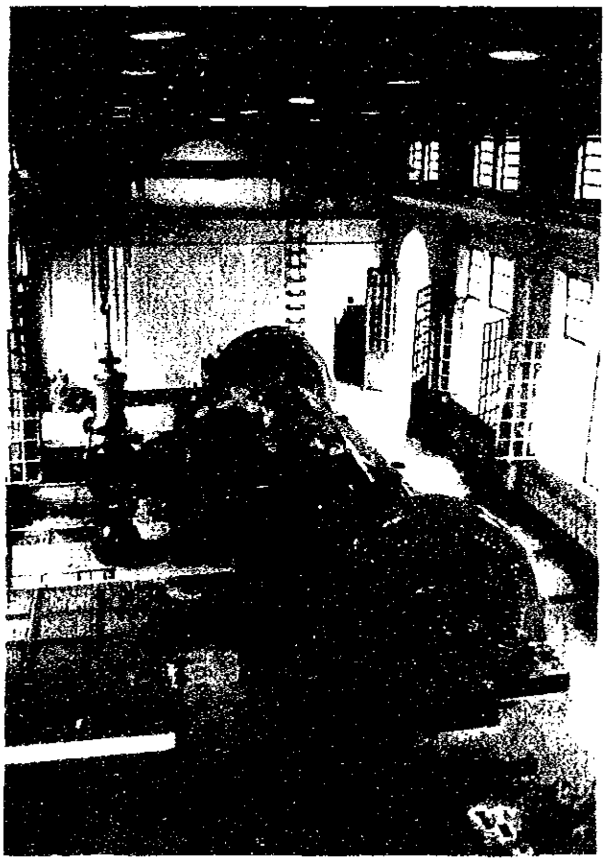
Pelton turbine and generator

Municipal Hydroelectric Power Plant

Conduction channel



Powerhouse and penstock



Pelton turbines

CONTENTS

CHAPTER 1 INTRODUCTION

The feasibility study (hereinafter referred to as the FS) for the rehabilitation plan of San Cancio, Intermedia and Municipal run-of-river type hydroelectric power plants (rated output of 5.552 MW) was conducted following the pre-FS that was carried out for eight months from November, 1987 to June, 1988. This report is prepared to summarize the results of the FS.

This FS was performed in accordance with the Scope of Work (S/W) agreed and signed in July 1988 between Japan International Cooperation Agency (JICA) and Instituto Colombiano de Energia-Electrica (ICEL). The study period was 17 months from November, 1988 to March, 1990.

From among 62 small-scale hydroelectric power plants operated by ICEL that were nominated for the study of the rehabilitation plan, these San Cancio, Intermedia and Municipal hydroelectric power plants (hereinafter referred to as San Cancio, Intermedia and Municipal P/Ps) were selected as a candidate for the FS for the following reasons:

1) Basic data relating to topography, river discharge and so on had been comparatively well organized
2) There is no possibility of environmental destruction, and water rights for power generation have already been acquired
3) Although there are insufficient data in design such as alignment and shape of channel, the existing headrace have been maintained in good condition
4) There is a gap between generated output calculated from theoretical output and existing generating facility's installed capacity and therefore generating scale has not been optimum.

From this FS, post-rehabilitation generating scale for which JICA Study Team proposes as an optimum rehabilitation plan as one package (San Cancio, Intermedia and Municipal P/Ps) is as follows:

- Maximum output : 9.4 MW
- Annual potential generated power : 73.0 GWh
- Facility utilization factor : 88 %

CHAPTER 2 SUMMARY OF STUDY RESULTS

These power plants are the run-off-river type hydroelectric ones of San Cancio (rated output: 320 kW), Intermedia (rated output: 1,120 kW) and Municipal (rated output: 2,112 kW) in the order from upstream side in Chinchina River in Caldas Department, and are owned by CHEC.

The following table shows the record of present maximum output in February 1989 and annual generated energy in 1988 in each power plant.

Power plant	Manufacturing date of generating equipment	Max. output as of Feb., 1989 (kW)	Output drop rate (%)	Annual generated energy in 1988 (MWh)
San Cancio	#1, 1929	750	▲23	6,175
	#2, 1947	1,000	▲26	
Intermedia	1947	900	▲20	3,279
Municipal	1945	1,400	▲34	5,448

(1) Present condition of generating facilities and their problems

Since the tailrace at the San Cancio P/P is directly connected to the headrace at the Intermedia, the maximum available discharge for both power plants is Q = 5.6 m/s.

The Municipal P/P has the facilities which can take the discharge of remaining river basin in the downstream section from the intake site of the San Cancio P/P in addition to the discharge (5.6 m^3/s) of the Intermedia P/P, but the official maximum available discharge has been recorded as same 5.6 m^3/s as both San Cancio and Intermedia P/Ps.

The headrace length at the San Cancio, Intermedia and Municipal P/Ps is approximately 2,400 m, 3,100 m and 2,400 m respectively. These are open channels, and there are some irregular shapes, dimensions and poor alignment, but generally, these have been maintained in good condition.

Since these channels run on conglomerate, there are some places where sand flows into due to collapse of flow face and small-scale landslide at the time of rain. Moreover, because of the unlined channel at the Intermedia P/P, it is recommended to change to the concrete channel.

The manufacturing date of the turbine is old, and such equipment has been used for 43 to 61 years. In the San Cancio P/P, two units of Pelton turbine (rated output: 1,120 kW) manufactured in 1929 and horizontal Francis turbine (rated output: 1,200 kW) manufactured in 1947 are installed in the same powerhouse building. One Pelton turbine (rated output: 1,120 kW) manufactured in 1935 and two Pelton turbines (rated output: 1,056 kW) manufactured in 1935 are installed respectively in the Intermedia P/P and the Municipal P/P.

In the Intermedia and Municipal power plants, there is a large gap between theoretically calculated generated output and existing facility's installed capacity. Installed capacity of these power plants is very small.

(2) Alternative rehabilitation plans

As seen from the river discharge-duration curve in the intake site at the San Cancio P/P (refer to Fig. 2.1), the value of planned available discharge ($Q = 5.6\ m^3/s$) is comparatively large design discharge as the run-or-river hydroelectric power plant. That means that the guaranteed number of dates throughout the year is equivalent to 55%, and if it is indicated by discharge utilization factor, it is the available discharge equivalent to 88%. Therefore, since it can be considered that comparative study for the maximum available discharge will not be required, the rehabilitation plan focussing on the following two points is studied.

① The gap between theoretically calculated generated output and existing facility's installed capacity should be eliminated.

	Q (m^3/s)	H (m)	Generated output P (kW)	Existing facility's installed capacity Po (kW)	P-Po (kW)
San Cancio	5.6	53.8	2,400	2,320	-80
Intermedia	5.6	56.8	2,500	1,120	1,380
Municipal	5.6	79.6	3,600	2,112	1,488
Total			8,500	5,552	2,948

② The generating equipment with same type and output should be installed, considering the standardization of operation, inspection, maintenance and management, advantage of interchangeability of spare parts, etc.

Fig-2.1-(1) TYPICAL FLOW DURATION CURVE AT INTAKE SITE

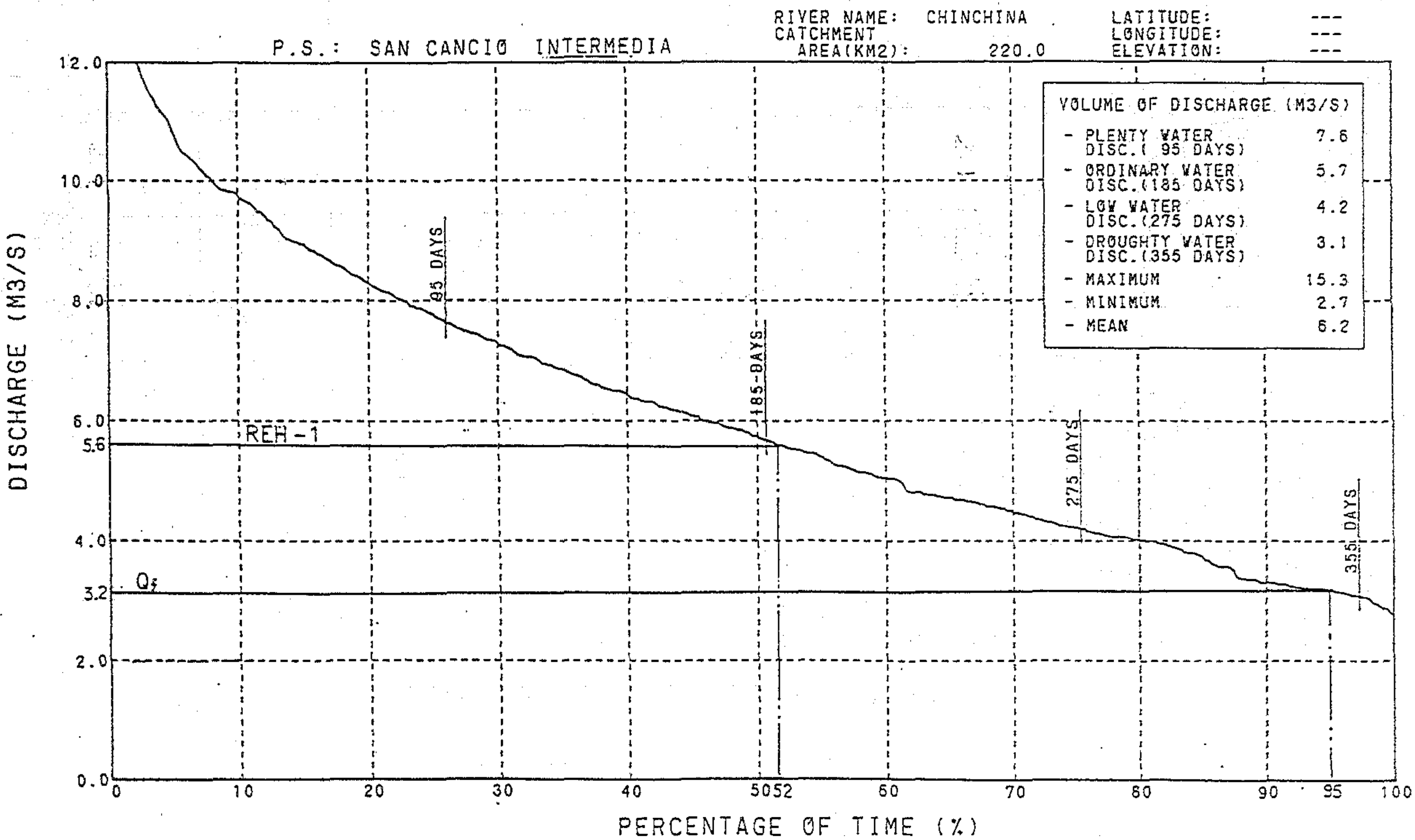


Fig-2.1-(2) TYPICAL FLOW DURATION CURVE AT INTAKE SITE

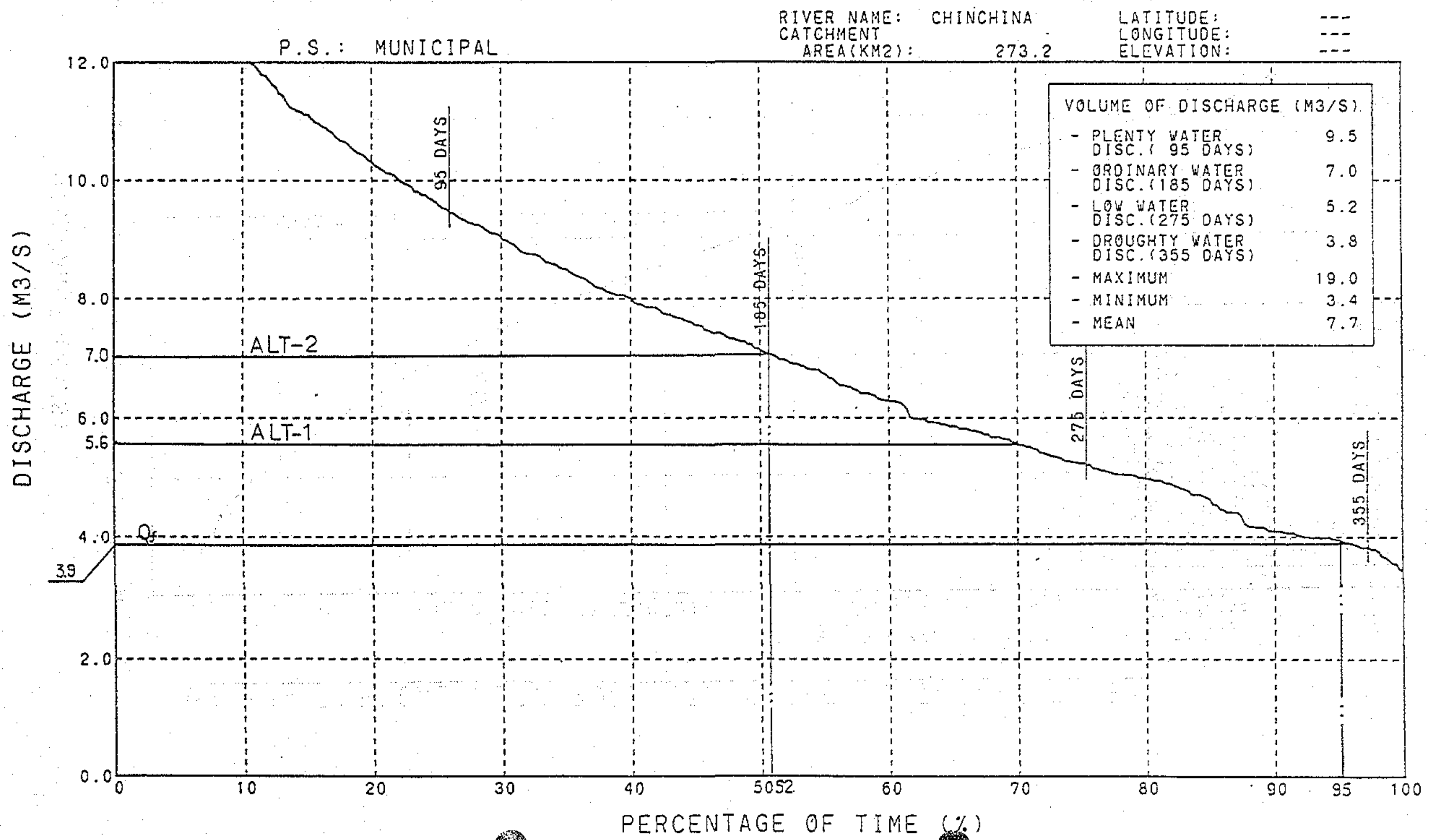


Table 2.1 shows the comparative alternative plan for rehabilitation plan, but the definite comparative object is determined depending upon the intake from remaining river basins in the Municipal P/P located at most downstream.

Table 2.1 Rehabilitation plans for San Cancio, Intermedia and Municipal Power Plants

Item		San Cancio	Intermedia	Municipal	
				ALT-1	ALT-2
Available discharge, Q (m^3/s)		5.6	5.6	5.6	7.0 (Discharge at remaining river basin: 1.4)
Maximum output, P (kW)		2,400	2,500	3,600	4,500
Facility utilization factor (%)		88	88	94.5	88
Rehabilitation and improve-ment plan	Diversion weir	Modify and install sand trap gate or facility	-	Leave as it is	Modify to permanent structure
	Intake	Make change in facility design to secure discharge of 5.6 m/s	Leave as it is	Leave as it is	Partial improvement
	Desilting basin	Partial improvement	Partial improvement (together with head tank)	Partial improvement	Partial improvement
	Conduction channel	Leave as it is except cover placement	Modify to concrete channel entirely	Leave as it is except cover placement	
	Head tank	Increase adjusting capacity by modification	Partial improvement	Modify to suitable scale	Modify to suitable scale
	Penstocks	Leave as it is	Leave as it is	Leave as it is	
	Generating Equipment	Replace with new one	Replace with new one	Replace with new one	
	Powerhouse building	Partially renovate the existing building and improve only foundation section for generating equipment.			

(3) Selection of optimum plan

Table 2.2 shows the study results regarding rehabilitation plans for San Cancio Intermedia and Municipal P/Ps, but the rehabilitation plans of these three hydroelectric power plants must be considered as a package.

The study results of Table 2.2 indicate that the basic design for ALT-2 plan, which remaining river discharge, 1.4 m^3/s, can additionally be secured at the Municipal P/P, must be conducted as described in Chapter 11.

Table 2.2 Comparison of Rehabilitation Plan for the San Cancio / the Intermedia / the Municipal Power Plant

Alternative Plan	① Specifications for Existing Generating Facilities					② Rehabilitation Plan							③ Recovered or Increased Energy	
	⑩	⑪	⑫	⑬ Present facility capacity		⑳	㉑	㉒	㉓	㉔	㉕	㉖	㉚	㉛
	Max. available discharge Qo (m³/s)	Net head Ho (m)	Rated output Po (kW)	⑭ Output Pe (kW)	⑮ Generated energy Ee (GWh)	Max. available discharge Ql (m³/s)	Standard net head Hl (m)	Theoretical output =9.8x⑳ x㉑ (kW)	Resultant efficiency η	Output =㉒x㉓ Pl (kW)	Annual probable generated energy El (GWh)	Facility utilization factor ε (%)	Output =㉔-⑭ ΔP (kW)	Annual probable generated energy ㉕-⑮ ΔE (GWh)
San Cancio	5.6	53.8	2,320	1,750	8.44	5.6	53.8	2,952	0.830	2,400	18.5	88	650	10.1
Intermedia	5.6	56.8	1,120	900	3.33	5.6	56.8	3,117	0.830	2,500	19.7	88	1,600	16.4
Municipal (ALT-1)	5.6	79.6	2,112	1,400	5.94	5.6	79.6	4,368	0.830	3,600	29.9	94	2,200	24.0
Municipal (ALT-2)	---	----	-----	-----	----	7.0	79.6	5,460	0.835	4,500	34.8	88	3,100	28.9
Total	---	----	5,552	4,050	17.71	---	----	10,437 11,529	-----	8,500 9,400	68.1 73.0	---	4,450 5,350	50.4 55.3

Alternative Plan	④ Rehabilitation Work Cost (US$1000)					⑤ Construction Cost per kW (US$/kW)		⑥ Total of Annual Cost at Generating Terminal (US$1000)					⑦ Average Generating Cost per kWh (mills/kWh)		⑧ Cost/Benefit	⑨
	㊵ Generating Equipment Cost			㊹	㊺	㊿	(51)	(60)	(61) Principal repayment amount for construction cost (25-year average)			(65)	(70)	(71)		
	㊶ Foreign currency portion C1f	㊷ Local currency portion C1ℓ	㊸ ㊶+㊷ C1	Civil work cost C2	㊸+㊹ C	Cost per ΔP =㊺/㉚ C/ΔP	Cost per Pl =㊺/㉔ C/Pl	Operation and maintenance costs AOM	(62) Foreign currency portion 2.610 x ㊶ ÷ 25	(63) Local currency portion 2.016 x [㊷+㊹] ÷ 25	(64) (62)+(63)	(60)+(64)	per El =(65)/㉕ ÷0.95	per ΔE =(65)/㉛ ÷0.95	C/B	Priority order
San Cancio	1,900	750	2,650	600	3,250	5,035	1,350	9.6	197	111	308	318	18	33	1.40	4
Intermedia	1,900	750	2,650	1,050	3,700	2,310	1,500	10.0	197	145	342	352	19	23	1.37	3
Municipal (ALT-1)	2,300	900	3,200	500	3,700	1,700	1,050	14.4	240	115	355	369	13	16	0.89	2
Municipal (ALT-2)	2,450	1,000	3,450	750	4,200	1,350	950	18.0	255	140	395	413	13	15	0.86	1
Total ALT-1	6,100	2,400	8,500	2,150	10,650	2,406	1,250	34.0	634	373	1,007	1,041	16	22		
Total ALT-2	6,250	2,500	8,750	2,400	11,150	2,100	1,200	37.6	649	397	1,046	1,084	16	21		

(Notes)

① : For the existing generating equipment specifications, refer to the facility register record attached to the pre-FS report.

⑦ : Generating cost = $\frac{\text{Total of annual average cost at generating terminal}}{\text{Annual average supplied electric power}}$

⑧ : C/B is the value of cost and benefit ratio calculated according to the financial analysis.

⑮ : Ee is computed according to the average annual operation record for 5 years from 1984 to 1988 .

㉓ : η is the resultant efficiency of turbine and generator.

㉕ : El(Energia Media)

㉖ : $\varepsilon = \frac{\text{Annual water amount for turbine } (m^3/s \cdot hr)}{Q_l \times 365 \times 24} \times 100(\%)$

(60) : The annual AOM is the amount which is equivalent to US$4 per kW.

(61) : Interest is calculated by a repayment of principal in equal annual amounts under the following conditions.

Foreign currency portion: Annual interest rate of 10%, unredeemable for 4 years, repayment over 25 years

Local currency portion : Annual interest rate of 21%, unredeemable for 1 year, repayment over 8 years

CHAPTER 3 STUDY PLAN

3.1 Organization of Study Team

3.1.1 JICA FS Study Team

JICA FS Study Team, listed below, includes the team leader and two members who participated in the pre-FS; engineers, geologists, a hydrologist and an economist.

Name	Position	Assignment
Masami Ono	Team leader	Total coordinator (civil engineer)
Murao Toyama	Team member	Power generation planner (civil engineer)
Susumu Nonaka	"	Hydrologist
Yoshio Kawasaki	"	Generating equipment planner (civil engineer)
Akira Takahashi	"	Generating equipment planner (mechanical engineer)
Masayuki Tamai	"	Generating equipment planner (electrical engineer)
Nobuhiko Uchiseto	"	Geologist
Takashi Inoue	"	Geologist
Masaaki Ueda	"	Economist

3.1.2 Counterpart Engineers from ICEL

Engineers who were engaged in this study as counterparts of the JICA FS Study Team are as follows:

Name	Field	Position
Juvenal Peñaloza Rosas	Civil Engineering	Head of Central Eng. Div.
Jairo E. Gonzalez Morales	Civil Engineering	Central Eng. Div.
Mario Gutierrez Ospina	Civil Engineering	Central Eng. Div.
Rafael Torres Mariño	Civil Engineering	Central Eng. Div.
Rafael Gomez Florez	Civil Engineering	Central Eng. Div.
Jorge E. Hurtado Muños	Civil Engineering	Central Eng. Div.

3.1.3 Supporting Technical Staff from CHEC

JICA FS Study Team obtained cooperation and support from the technical staff listed below, in conducting the site reconnaissance, collecting data and performing engineering consultation necessary for this study.

Name	Position
Alberto Naranjo A.	Director of MIEL Project
Hernando Duque Vargas	Manager of Small Plants
Jorge H. Garcia C.	Member of MIEL Project
Claudia M. Agudelo	Member of MIEL Project

3.2 Study Items and Study Schedule

This FS was conducted for 17 months from November, 1988 to March, 1990 in accordance with S/W agreed and signed in July, 1988 between JICA and ICEL.

3.2.1 Study Items

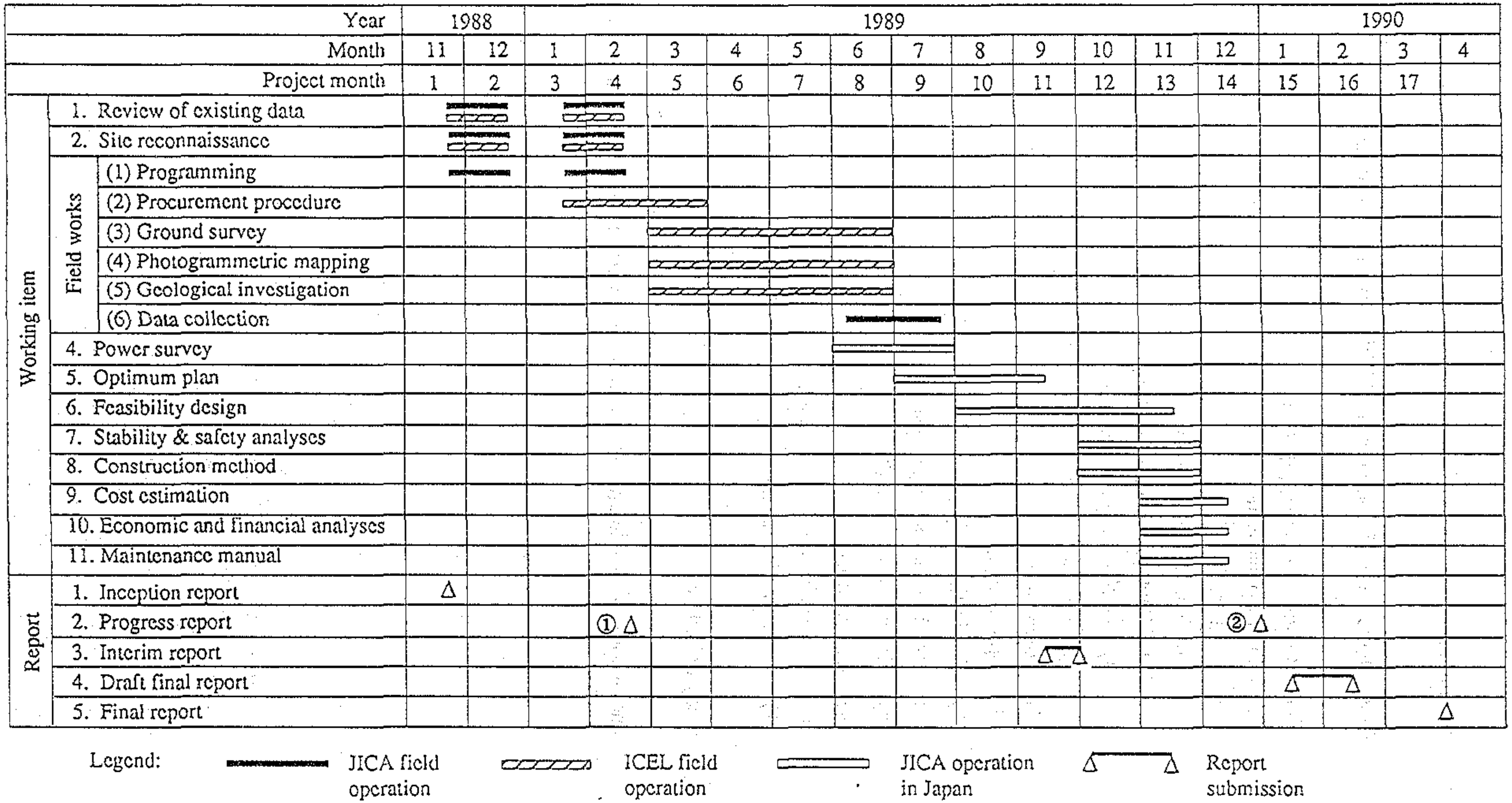
Study items for the FS as described in the S/W are as follows:

(1) Review of the existing data
(2) Site reconnaissance
(3) Field work
   1) Topographic survey
   2) Photogrammetric mapping
   3) Geological investigation
   4) Data collection
(4) Power survey
(5) Optimum plan
(6) Feasibility design
(7) Stability and safety analyses
(8) Construction method
(9) Cost estimation
(10) Economic and financial analyses
(11) Maintenance manual

3.2.2 Study Schedule

The overall study schedule as indicated in the S/W is shown in Table 3.1.

Table 3.1 Time Schedule of FS



Two field surveys were conducted at San Cancio, Intermedia and Municipal P/Ps, as shown in Table 3.2.

In the first site reconnaissance, one electrical engineer responsible for hydroelectric power generation planning conducted the present condition study of the existing facilities (mainly generating facilities) and collected necessary data.

In the second field survey, two engineers consisting of a geologist and hydroelectric power generation planner (civil engineer) gathered data relating to the geological survey.

Table 3.2 Field Survey Schedule

The first site reconnaissance

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
Feb. 13	Bogota → Manizales	Discussion at CHEC	J. Gonzales	Masayuki Tamai
Feb. 14		Same as above		
Feb. 15		Field Survey at San Cancio, Intermedia and Municipal P/Ps		
Feb. 16	Manizales → Bogota	Discussion at CHEC		

The second field survey

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
June 21	Bogota → Manizales	Discussion at CHEC	J. Gonzalez	Murao Toyama Nobuhiko Uchiseto
June 22		Field survey at San Cancio, Intermedia and Municipal P/Ps		
June 23		Discussion at CHEC		
June 24	Manizales → Bogota	Same as above		

3.3 Detail of Field Survey Work

The field survey work planned upon consultation between JICA Study Team and ICEL counterpart staff according to the results of the site reconnaissance includes topographic surveying and boring survey as described below, but did not include photogrammetric mapping.

Field Work Implementation Plan

Power plant	Topographic surveying	Geological surveying	Hydrological surveying
San Cancio	To map range shown in Fig. 3.1 by scale 1:200 and contour line 2 m pitch. To map horizontal section (every 25 m) and vertical section of channel. Set bench marks at position shown by B in Fig. 3.1.	To perform boring survey at position shown by BH in Fig. 3.1.	To perform floating debris and chemical analysis once a day at intake or hydrological gauging station.
Intermedia	To map range shown in Fig. 3.2 by scale 1:200 and contour line 2 m pitch. To map horizontal section (every 50 m) and vertical section of channel. To set bench mark at position shown by B in Fig. 3.2.	To perform boring survey at position shown by BH in Fig. 3.2.	
Municipal	To map range shown in Fig. 3.3 by scale 1:200 and contour line 2 m pitch. To map horizontal section (every 50 m) and vertical section of channel. To map horizontal section (every 25 m) and vertical section of penstock. To set bench mark at position shown by B in Fig. 3.3.	To perform boring survey at position shown by BH in Fig. 3.3.	

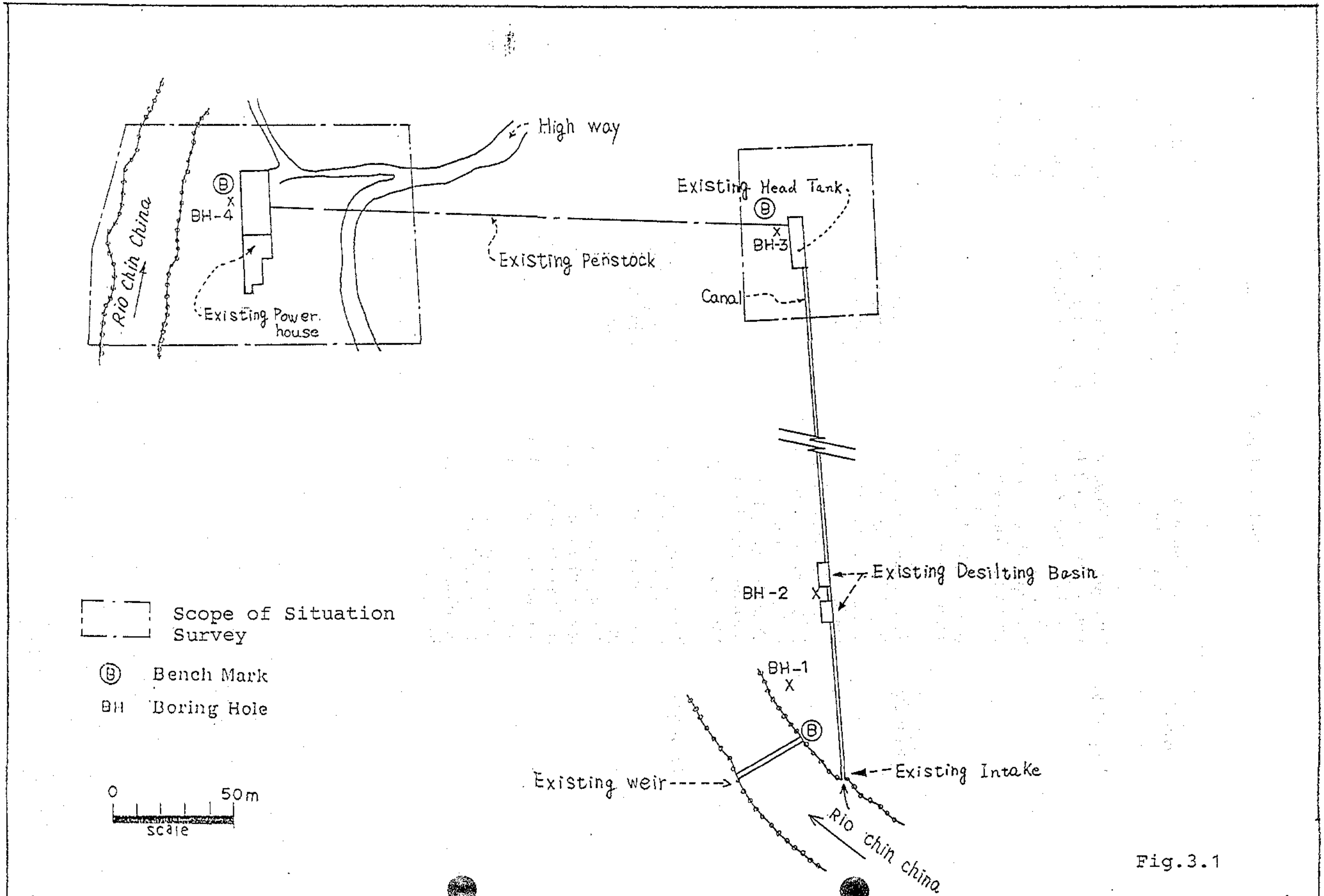

High way
Existing Head Tank
BH-3
BH-4
Rio chin china
Existing Power house
Existing Penstock
Canal
Existing Desilting Basin
BH-2
BH-1
Existing weir
Existing Intake
Rio chin china
Scope of Situation Survey
Bench Mark
BH Boring Hole
0
50m
scale

Fig.3.1

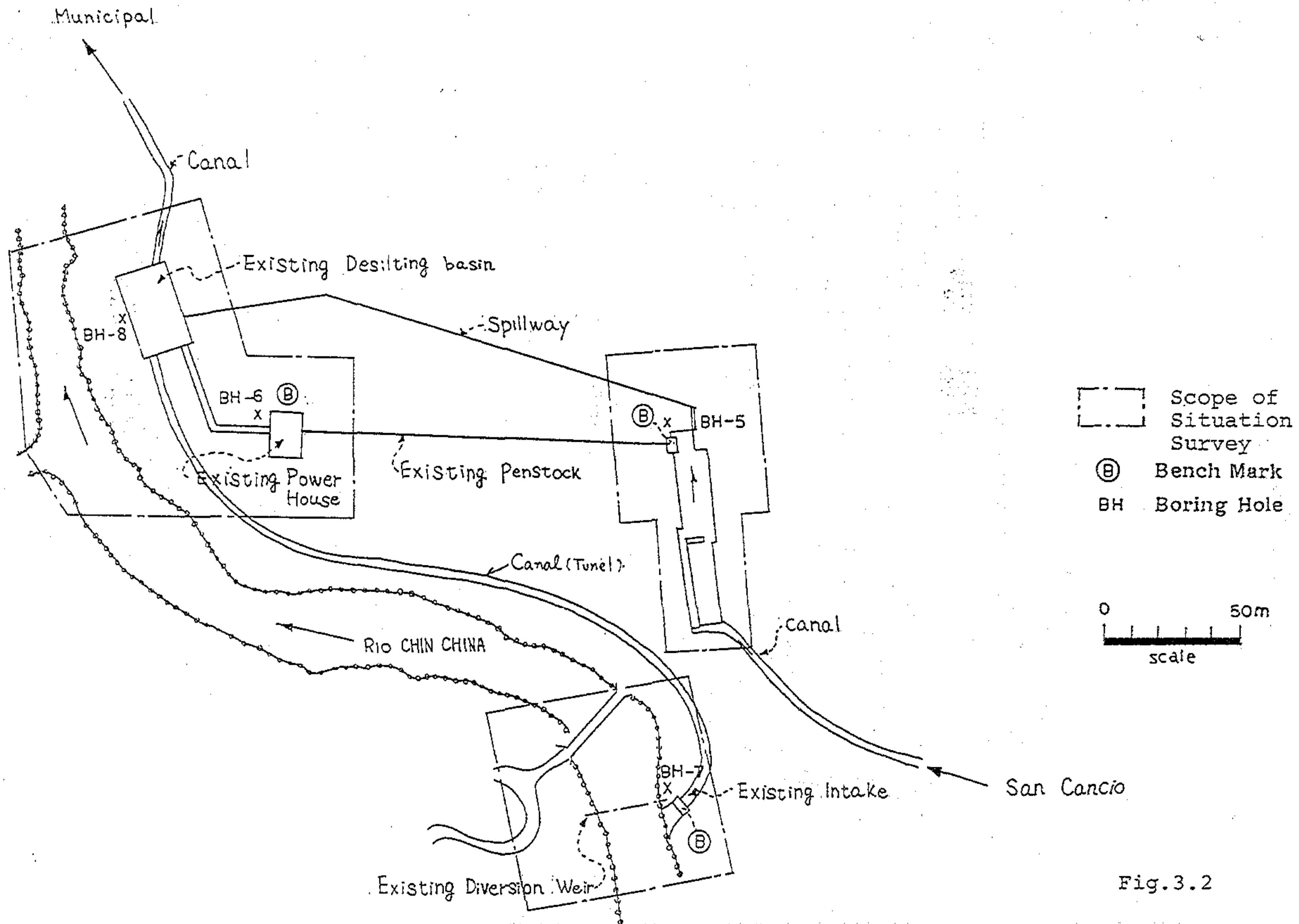
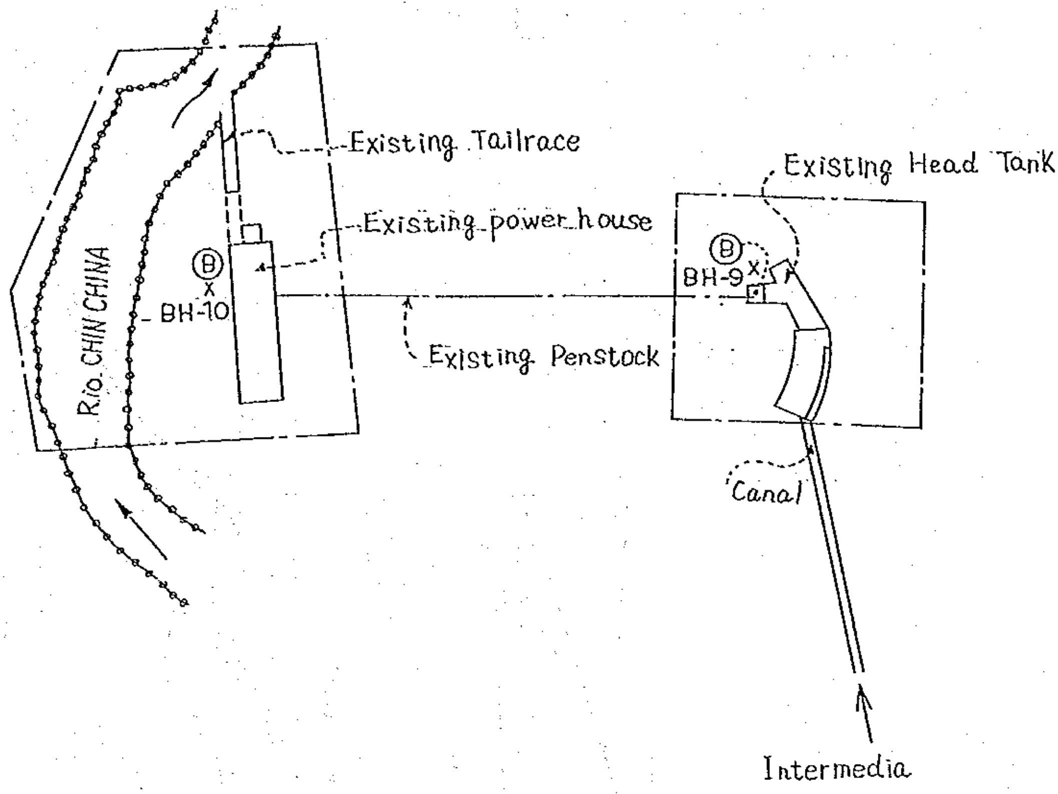

Municipal
Canal
Existing Desilting basin
BH-8
Spillway
BH-6
BH-5
Existing Power House
Existing Penstock
Canal (Tunel)
Canal
Rio CHIN CHINA
BH-7
Existing Intake
San Cancio
Existing Diversion Weir
Scope of Situation Survey
Bench Mark
BH Boring Hole
0
50m
scale

Fig.3.2



Scope of Situation Survey

Ⓑ Bench Mark

BH Boring Hole

0 50 m

scale

Fig.3.3

CHAPTER 4 PRESENT CONDITIONS OF THE STUDY AREA

4.1 Power Conditions in the Power Sector

Power conditions in the plant owned by the public electric power company being evaluated for rehabilitation (hereinafter called public electric power company) are described below.

4.1.1 Present Conditions of Power Supply and Demand

Table 4.1 shows figures for power supply and demand during the five years (from 1983 to 1987). In 1987, the peak demand was 325 MW, while the installed capacity was 197 MW (approx. 61%). In 1987, the electric power was 1,348 GWh, while the generated energy was 541 GWh (approx. 41%). The public electric power company bought electricity to cover the remaining 60% of total electric power.

The breakdown of power demand in 1987 shows that the power demand for residential, commercial, industrial and miscellaneous uses was 32%, 5%, 12% and 51% respectively. Power demand for residential use was high, while that for commercial was low.

Annual average rate of increase in power demand from 1983 to 1987 was 7.4%, the generated power decreased to -2.4%, and the rate of buying electricity greatly increased.

Table 4.1 Present Condition of Power Supply and Demand (1983 - 1987)

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate(%) *
DEMAND						
1. Peak Demand (MW)	279	275	294	301	325	3.9
2. Electric Energy (GWh)						
1) Residential	294	345	379	410	438	10.5
2) Commercial	47	55	60	65	71	10.9
3) Industrial	140	162	164	163	167	4.5
4) Miscellaneous	534	570	606	618	672	5.9
Total	1015	1132	1209	1256	1348	7.4
SUPPLY						
1. Installed Capacity (MW)	197	197	197	197	197	0
2. Generated Energy (GWh)	597	698	601	476	541	-2.4
3. Power Loss (GWh)	231	242	271	306	353	11.2

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

* Annual average increase rate is calculated as follows:

Example: When peak demand is 3.9%, $279 \times (1 + x)^4 = 325$

$x = 0.039$ (3.9%)

4.1.2 Present Conditions of Generating Facilities

(1) Generating facilities

Table 4.2 shows the total installed capacity of the public electric power company. Its generating system facilities include hydroelectric power.

Table 4.2 Present Condition of Total Installed Capacity (1983 - 1987)

(Unit: MW)

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate (%)
Total Installed Capacity						
1. Thermal	0	0	0	0	0	0
2. Hydroelectric	197	197	197	197	197	0
3. Others	0	0	0	0	0	0
Total	197	197	197	197	197	0

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

Table 4.3 shows condition of the power plants for which the FS was conducted.

Table 4.3 Conditions of P/Ps for which FS was conducted (1984 - 1988)

Item	1983	1984	1985	1986	1987	1988
1. San Cancio P/P						
1) Installed capacity (kW)	2,320	2,320	2,320	2,320	2,320	2,320
2) Generated energy (MWh)	8,781	9,202	9,447	9,912	7,481	6,175
3) Utilization factor (%)	43	45	46	49	37	30
2. Intermedia P/P						
1) Installed capacity (kW)	1,120	1,120	1,120	1,120	1,120	1,120
2) Generated energy (MWh)	3,110	5,661	4,366	0	3,334	3,279
3) Utilization factor (%)	32	58	45	0	34	33
3. *Municipal P/P*						
1) Installed capacity (kW)	2,112	2,112	2,112	2,112	2,112	2,112
2) Generated energy (MWh)	6,921	6,793	6,073	6,542	4,825	5,448
3) Utilization factor (%)	37	37	33	35	26	29

(Source: Data collected from CHEC)

(2) Transmission facilities

The public electric power company provides 115 kV transmission lines to its transmission and substation facilities at San Cancio, Intermedia and Municipal P/Ps owned by public electric power company. Voltage to be transmitted for these power plants are as follows:

San Cancio P/P	.....	4.16 kV
Intermedia P/P	.....	4.16 kV
Municipal P/P	.....	13.20 kV

4.1.3 Generating Cost and Electric Charges

Table 4.4 indicates the transition of generating cost and electric charges in the past five years from 1983 to 1987.

Table 3.5 indicates the actual operational results of the power plants subject of the FS performed from January to June, 1988.

Table 4.4 Generating Cost and Electric Charges

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate(%)
Generating Cost (Col$/kWh)	2.42	2.67	3.73	4.31	6.03	25.6
Electric Charge (Average): (COL$/kWh)						
1. Residential	2.41	2.47	3.22	4.15	5.36	22.1
2. Commercial	5.02	5.10	6.57	8.54	11.24	22.3
3. Industrial	4.10	4.15	5.47	7.12	9.32	22.8
4. Public use	3.18	3.27	4.47	5.82	7.50	23.9
5. Average	2.54	2.61	3.39	4.41	5.70	22.4
Breakdown of Power Demand by customer						
1. Residential	134,739	146,362	154,140	162,799	176,910	7.0
2. Commercial	9,151	9,546	9,982	10,280	11,474	5.8
3. Industrial	307	320	341	353	405	7.2
4. Others	2,089	2,445	1,586	1,674	1,821	-3.4
5. Total	146,286	158,673	166,049	175,106	190,610	6.8
Diffusion of Electricity						
1. Overall (1000 households)	1,141	1,158	1,176	1,193	1,118	-0.5
2. Power demand (1000 households)	610	663	698	737	801	7.0
3. Electrification rate (%)	54	57	59	62	72	7.5

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

Table 4.5 Actual Results of Power Plants which FS was Performed

No.	Item	Unit	Jan.	Feb.	Mar.	Apr.	May	June
I.	San Cancio P/P							
	1. Electric power	(MWh)						
	1) Gross		274.0	332.0	477.0	551.0	614.0	746.0
	2) Net		272.0	331.1	475.6	549.4	612.6	744.7
	2. Electric charge	(Col$/kWh)	7.95	8.06	8.26	8.39	8.56	8.63
	3. Revenues	(x1000 Col$)	2,169	2,668	3,929	4,609	5,244	6,427
	4. Expenditure	(x1000 Col$)						
	1) Operation		1,796	1,839	1,593	1,743	1,743	1,473
	2) Maintenance		2,726	652	7811	717	717	717
	3) Total		4,522	2,941	2,374	2,460	2,460	2,460
	5. Balance	(x1000 Col$)	-2,353	177	1,555	2,149	2,784	3,967
II.	Intermedia P/P							
	1. Electric power	(MWh)						
	1) Gross		398.0	90.0	2.0	373.0	411.0	267.0
	2) Net		398.5	90.0	2.3	373.4	410.6	266.9
	2. Electric charge	(Col$/kWh)	7.95	8.06	8.26	8.39	8.56	8.63
	3. Revenues	(x1000 Col$)	3,168	725	19	3,133	3,515	2,303
	4. Expenditure	(x1000 Col$)						
	1) Operation		1,702	1,582	2,062	1,782	1,782	1,782
	2) Maintenance		1,063	349	454	402	402	402
	3) Total		2,765	1,931	2,516	2,184	2,184	2,184
	5. Balance	(x1000 Col$)	403	-1,206	-2,497	949	1,331	119

(cont'd)

No.	Item	Unit	Jan.	Feb.	Mar.	Apr.	May	June
III.	Municipal P/P							
1.	Electric power	(MWh)						
	1) Gross		754.0	606.0	482.0	451.0	485.0	439.0
	2) Net		754.4	606.4	482.4	450.5	485.0	439.1
2.	Electric charge	(Col$/kWh)	7.95	8.06	8.26	8.39	8.56	8.63
3.	Revenues	(x1000 Col$)	5,997	4,888	3,985	3,780	4,151	3,789
4.	Expenditure	(x1000 Col$)						
	1) Operation		3,333	2,576	2,830	2,913	2,913	2,913
	2) Maintenance		1,364	323	323	323	323	323
	3) Total		4,697	2,899	3,153	3,236	3,236	3,236
5.	Balance	(x1000 Col$)	1,300	1,989	832	544	915	553

4.1.4 Forecast of Power Supply and Demand

Fig. 4.1 shows the results of the balance of power supply and demand forecasting up to 1995 based upon the present power supply and demand conditions shown in Table 4.1.

In the forecast, the annual average increase rate of electric power was set as follows.

1) The annual average increase rate of electric power demand is 7.4%
2) The annual average increase rate of generated energy is -2.4%
3) The annual average increase rate of power loss is 11.2%
4) The amount of electric power bought is calculated by the following formula.

The amount of electric power bought = (Demand electric power + Power loss) - Generated energy

(Calculation example)

The electric power demand in 1995 is calculated as follows:

$$1348 \times (1 + 0.074)^8 = 2{,}386 \text{ (GWh)}$$

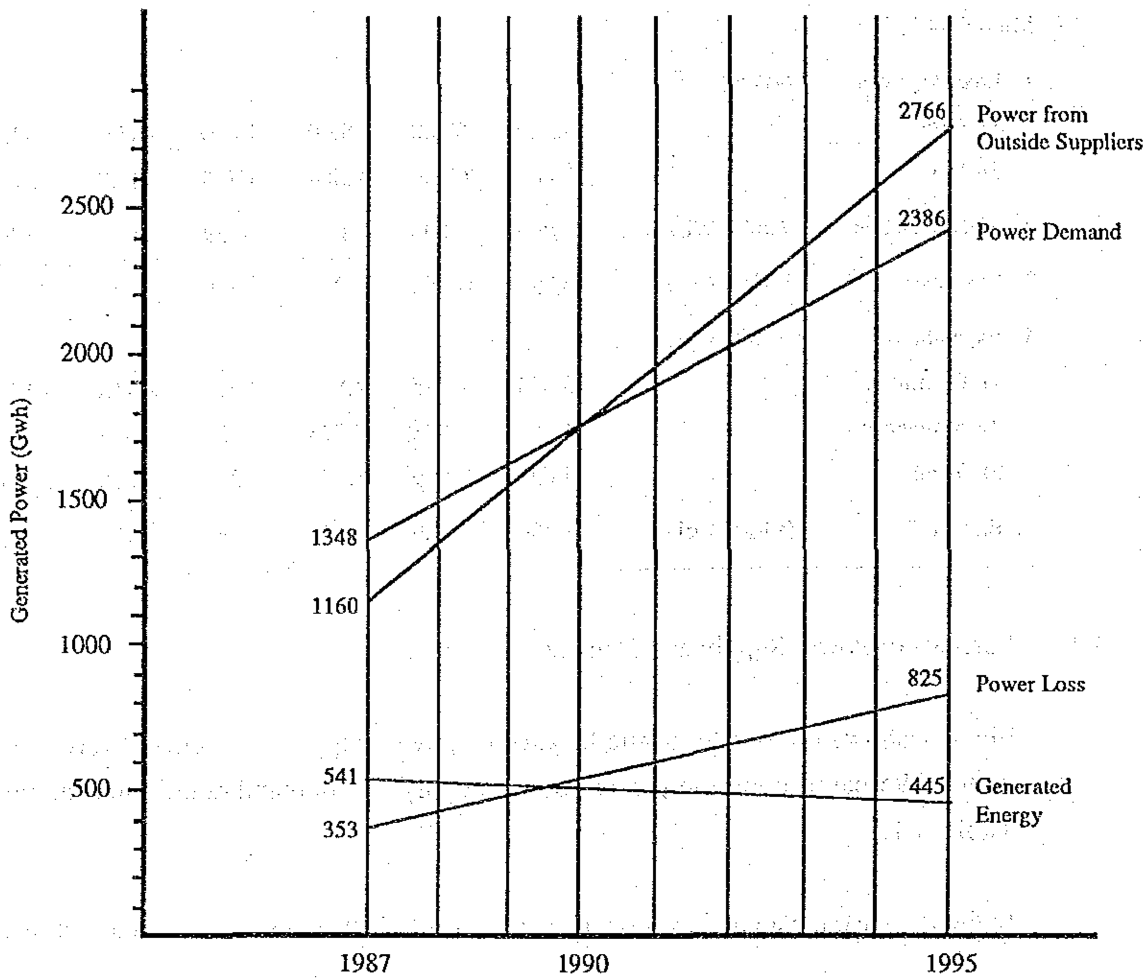


Fig. 4.1 Projected Power Supply and Demand

4.2 Operation Record of the Existing Power Plant

4.2.1 Generated Energy

The record of the generated energy at the San Cancio P/P during six years from 1983 to 1988 is shown in Table 4.6.

Operation has not been suspended for a long period of time during the past six years. The average value of utilization factor during the past six years was 42%, and it is presumed that the efficiency of water turbines has dropped.

The record of the generated energy at the Intermedia P/P during six years from 1983 to 1988 is shown in Table 4.7.

During the past six years, operation stopped for six months from January to June 1987 and December 1988.

The average value of utilization factor for five years except 1986 was 40%, and it is presumed that the efficiency of water turbines has dropped.

The record of the generated energy at the Municipal P/P during six years from 1983 to 1988 is shown in Table 4.8.

Operation has not been suspended for a long period of time during the six years. The average value of utilization factor during the past six years was 33%, and it is presumed that the efficiency of water turbines has dropped.

Table 4.6 Record of Generated Energy (San Cancio)

Year	Output indicated on nameplate (MW)	Generated Energy (MWh)	Facility utilization factor (%)
1983	2.32	8,781	43
1984	"	9,202	45
1985	"	9,202	46
1986	"	9,912	49
1987	"	7,481	37
1988	"	6,175	30

(Remarks)

1. The generated energy (MWh) indicates the gross.

2. Facility utilization factor (%) = $\frac{\text{Generated energy (MWh)}}{\text{8760 x output of nameplate}}$ x 100

Table 4.7 Record of Generated Energy (Intermedia)

Year	Output indicated on nameplate (MW)	Generated Energy (MWh)	Facility utilization factor (%)
1983	1.12	3,110	32
1984	"	5,661	58
1985	"	4,366	45
1986	"	0	0
1987	"	3,334	34
1988	"	3,279	33

(Remarks)

1. The generated energy (MWh) indicates the gross.

2. Facility utilization factor (%) = $\frac{\text{Generated energy (MWh)}}{\text{8760 x output of nameplate}}$ x 100

Table 4.8 Record of Generated Energy (Municipal)

Year	Output indicated on nameplate (MW)	Generated Energy (MWh)	Facility utilization factor (%)
1983	2.112	6,921	37
1984	"	6,793	37
1985	"	6,073	33
1986	"	6,542	35
1987	"	4,825	26
1988	"	5,448	29

(Remarks)

1. The generated energy (MWh) indicates the gross.

2. Facility utilization factor (%) = $\frac{\text{Generated energy (MWh)}}{8760 \times \text{output of nameplate}} \times 100$

4.3 General conditions of Generating Equipment and Civil Structures

4.3.1 General condition of Generating Equipment

(1) The present condition of the generating equipment for the San Cancio P/P is summarized below.

(a) Generating equipment

Francis and Pelton turbines, manufactured in 1947 and 1929, have been used for 43 years and 61 years respectively. Since these turbines have deteriorated, the average facility utilization factor in the recent six years was 42%.

Table 4.9 shows major defects of the generating equipment.

Table 4.9 Major Defects of Generating Equipment (San Cancio)

Equipment	No. 1 unit (Pelton turbine)	No. 2 unit (Francis turbine)
Water turbine	1) Bucket was worn out by sand 2) Nozzles and needles were worn out by sand.	1) Runner was slightly eroded by cavitation
Generator	Unreliable system	Unreliable system
Generator	1) Insulation resistance value of the coil has dropped. 2) Bearings were repaired every two years. 3) Since it is manual voltage regulator, an operator must always adjust voltage.	1) Same as left 2) Same as left 3) Same as left
Water turbine and generator control panel	1) Inaccurate instrument and protection relays.	1) Same as left

(b) Substation

Since San Cancio P/P is directly connected to distribution line on a generator voltage of 4.16 kV, there is no substation installed.

(c) Distribution line

4.16 kV distribution line (single line) is provided from this power plant to Marmato substation.

CHEC is planning to increase the distribution line voltage to 13.2 kV.

(2) *The present condition of the generating equipment for the Intermedia P/P is* summarized below.

(a) Generating equipment

The Pelton turbine, manufactured in 1947, has been used for 43 years.

Since this turbine has deteriorated, the average facility utilization factor in the recent five years was 40%.

Table 4.10 shows major defects of the generating equipment.

Table 4.10 Major Defects of Generating Equipment (Intermedia)

Equipment	Major defects
Water turbine	1) Bucket was worn out by sand. 2) Nozzles and needles were worn out by sand.
Governor	1) Unreliable system
Generator	1) Insulation resistance value of the coil has dropped. 2) Since it is manual voltage regulator, an operator must always adjust the voltage.
Water turbine and generator control panel	1) Inaccurate instruments and protection relays.

(b) Substation

This power plant is directly connected to distribution line on a generator voltage of 4.16 kV. There is no substation installed.

(c) Distribution line

4.16 kV distribution line (single line) is provided from this power plant to Marmato substation.

CHEC is planning to increase the distribution line voltage to 13.2 kV.

(3) The present condition of the generating equipment for the Municipal P/P is summarized below.

(a) Generating equipment

Two Pelton turbines, manufactured in 1945, have been used for 45 years.

Since these turbines have deteriorated, the average facility utilization factor in the recent six years was 33%.

Table 4.11 shows major defects of the generating equipment.

Table 4.11 Major Defects of Generating Equipment (Municipal)

Equipment	No. 1 unit	No. 2 unit
Water turbine	1) Bucket was worn out by sand. 2) Nozzle and needle were worn out sand.	
Governor	Governor was removed. Therefore frequency adjustment can not be performed.	
Generator	1) Insulation resistance value of winding has dropped. 2) Bearings have been repaired every 2 years. 3) Since it is manual voltage regulator, an operator must always adjust voltage	
Water turbine and generator control panel	1) Inaccurate instruments and protection relays.	

(b) Substation

13.2 kV outdoor substation has been installed at the place near this power plant.

No defect in the substation equipment was found.

(c) Distribution line

Two 13.2 kV distribution lines are provided from this power plant to Marmato substation.

No defect in the distribution lines was found.

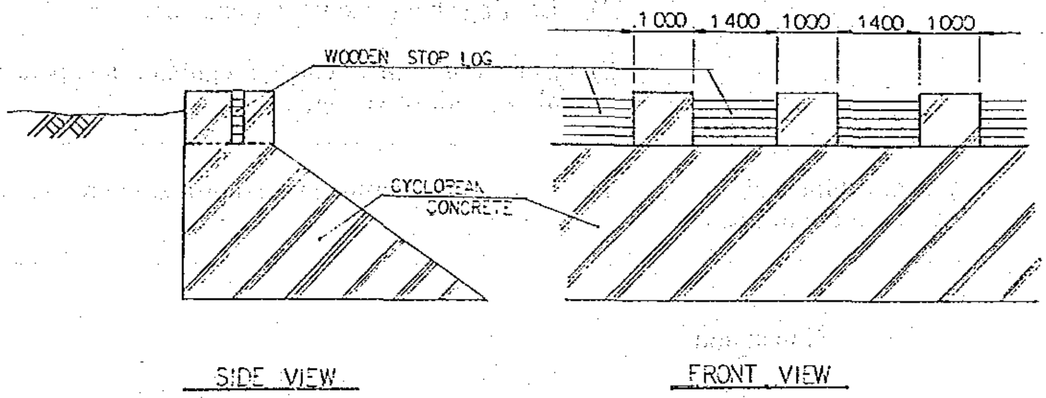
4.3.2 General Condition of Civil Structures

The general condition of civil structures for San Cancio, Intermedia and Municipal P/Ps is as follows:

(1) Civil structures for San Cancio P/P

(a) Intake facilities

The diversion weir is gravity type, constructed of cobble-mixed stone concrete, and its crown is made of wood. Its crest length and height are 17.7 m and approx. 4.0 m respectively.



The cobble concrete section has degraded, and sand accumulates near the crest crown in the crest front side.

The sand trap facility has been installed. The gate (1.8 mW and approx. 2.0 mH) does not function properly, because the sand trap width is small. Two intakes have been provided on the right bank, 10 m and 30 m upstream from the diversion weir, and are connected to conduction channel by an unlined tunnel.

(b) Desilting basin

Two desilting basins of No. 1 and No. 2 have been provided 200 m downstream from the intake and 150 m upstream from the head tank respectively. In No. 1 desilting basin, two head tanks with 9.9 m in width, 2.0 m in length and 2.0 m in depth have been arranged in series, accretion of sand in the tanks is alternately discharged. These basins are designed to avoid a generating failure, but they do not have the construction to function as two head tanks simultaneously, and the desilting function by only one tank is not sufficient.

Though the head tank structure itself is maintained in a rigid state, concrete surface has degraded.

The gates for sand discharge (1.10 m W x 1.0 m H) and for regulation (2.0 MW x 1.5 m H) have been installed, but are superannuated, and do not function.

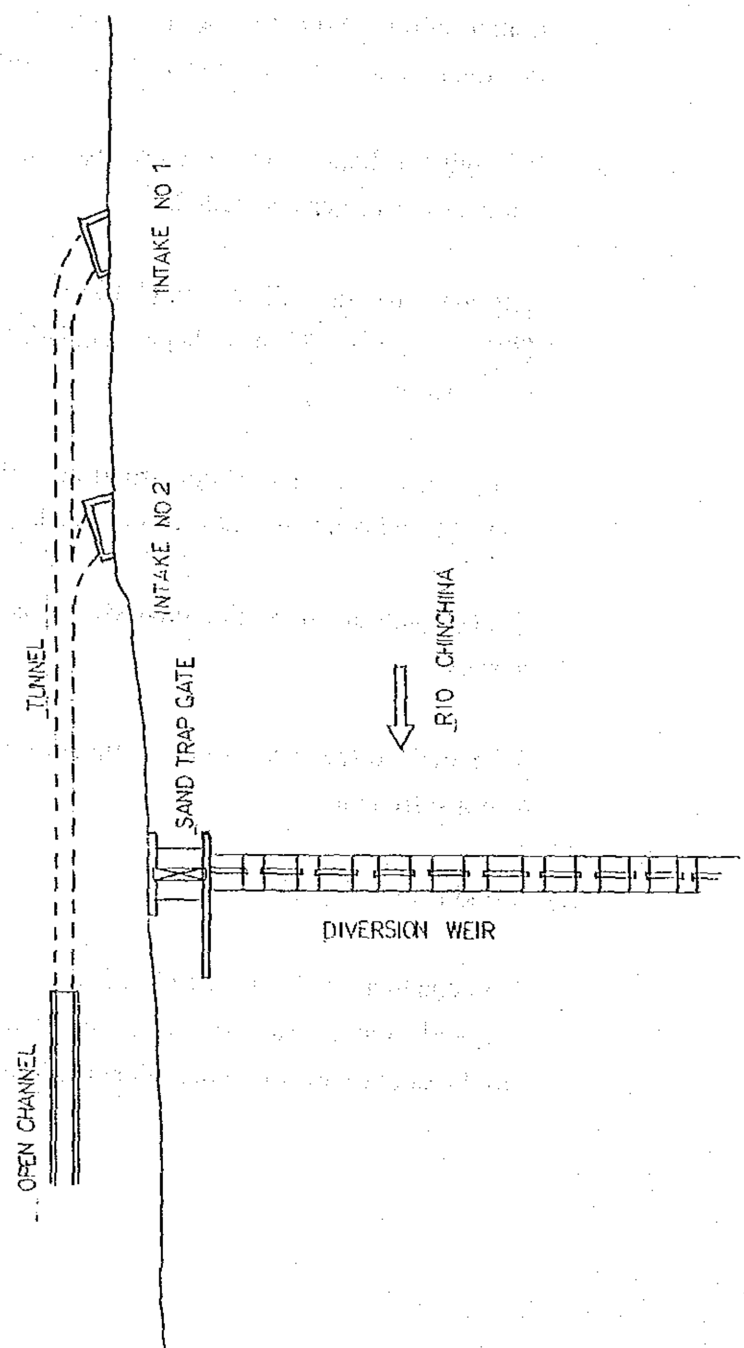
No. 2 head tank has a construction which hardly fulfills its design concept, and concrete and gate are also degraded.

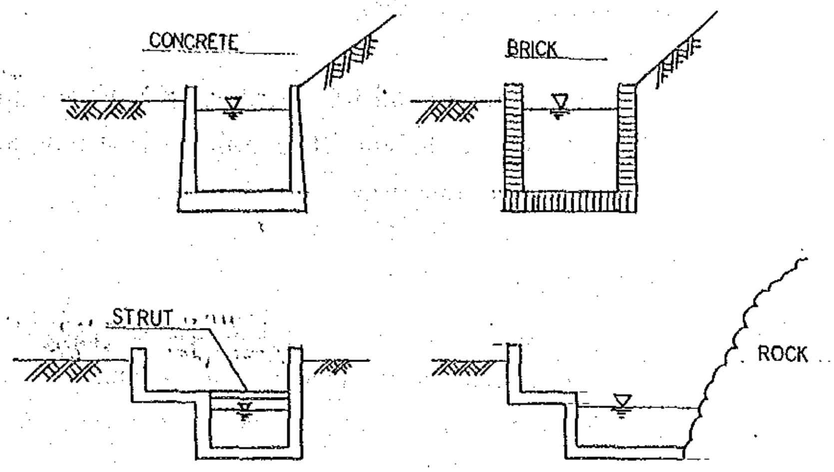
A large amount of sedimented sand was observed at the time of field survey.

It seems that the sand discharge function for No. 1 and No. 2 head tanks is not sufficient.

(c) Conduction channel

The conduction channels with 2.3 km in total length are an entirely open pit, and have a variety of vertical and cross sections. The cross sections are broadly divided into the following four shapes.


INTAKE NO 1
INTAKE NO 2
TUNNEL
SAND TRAP GATE
RIO CHINCHINA
DIVERSION WEIR
OPEN CHANNEL



Since entire channels are an open culvert, large amount of collapsed earth and vegetation flow into the channel, and the water is polluted.

Several overflow discharge gates have been installed on the way of channel, but sliding function is almost superannuated.

(d) Head tank

The head tank has a long vertical shape with 4.8 m in width and 27.0 m in length, and average depth is approx. 5.5 m.

The construction inside the tank is complex. The effective storage capacity is small, corresponding to a discharge of approx. 60 seconds.

(e) Penstock

The penstock with 1.24 m in diameter and 231 m in length is in good condition, and repair is not required.

(f) Powerhouse building

The building is an RC structure with 12.5 m in width, 40 m in length and 5.0 m in height. The building is strong, and housed two units of generating equipment.

(g) Tailrace

The tailrace is connected to the channel of the Intermedia P/P, and degradation at L section concrete is observed, but it is strong.

(2) Civil structures for Intermedia P/P

(a) Intake facilities

The tailrace of the San Cancio P/P is connected to the conduction channel of the Intermedia P/P, and there was no intake facilities.

(b) Conduction channel

Most of the conduction channel is an unlined channel, and partial section of 115 m near Pan American Highway is an RC box of 2.0 m x 2.5 m.

Since landsliding frequently occurs near the Pan American Highway, the blind drainage was installed at the slope face, but at the time of field survey, the entire RC box sections were buried by collapsed earth due to large-scale slope face collapse which occurred in the end of 1988.

Due to the unlined channel, a large amount of earth and vegetation is mixed, and the flow-down capacity of the channel is reduced as well as the water is polluted.

(c) Head tank

Strong desilting basin with 7.9 m in width, 29.95 m in length and 4.5 m in average depth and tank with 7.9 m width, 28.97 m in length and 4.5 m in average depth are arranged in series.

The storage capacity by only the head tank is insufficient, but it would be sufficient if the capacity including desilting basin is considered.

(d) Penstock

The steel conduit pipe 1.24 m in diameter and 154 m in length is in good condition, and repair is not required.

(e) Powerhouse building

RC building with 12.4 m in width and 8.75 m in height is strong, and one generating equipment has been installed.

(f) Tailrace

Strong RC tailrace is connected to the channel of the Municipal P/P.

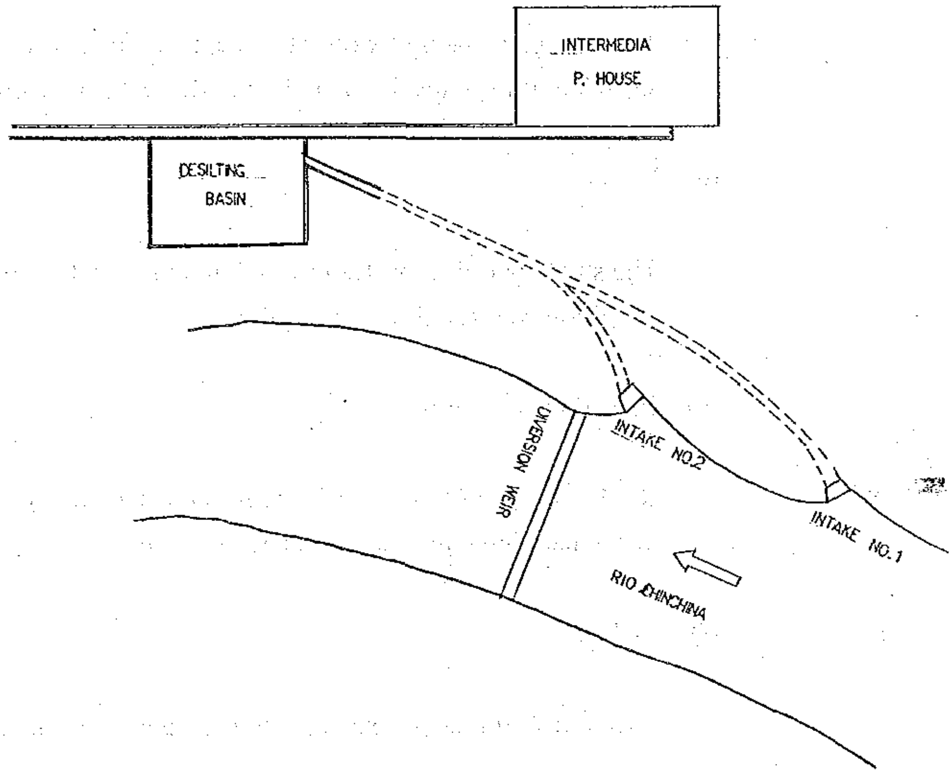
(3) Civil structures for Municipal P/P

(a) Intake facilities

The tailrace of the Intermedia P/P is directly connected to the channel of the Municipal P/P, and it flows down at a rate of 5.6 m^3/s. Due to intake of remaining river basin, there is strong RC diversion weir with 25.0 m in total length and 2.0 m in height, but no earth discharge facilities are available, and sand accumulates up to crest crown level.

There are two intakes at upstream right-bank side of diversion weir; No. 1 intake is 5.40 m in width and 2.80 m in height, No. 2 intake is 2.30 m in width and 1.70 m in height, and screen and gate are installed. The screen is strong, but the gate has deteriorated.

The unlined tunnel runs from intake to desilting basin, and it joints to discharge from Municipal at the desilting basin downstream.



(b) Desilting basin

The desilting basin has been provided approx. 200 m downstream from the Intermedia P/P.

The dimensions of desilting basin are 15.0 m in width, 27.0 m in length, with an average depth of 4.2 m .

Concrete has partly degraded and the gate has deteriorated, but the capacity for small amount of remaining river basin is sufficient.

(c) Channel

Entire channel of 2.4 km in total length is an open culvert, of width 2.15 m - 2.5 m, and approx. 1.7 m in depth.

Since entire channel is an open pit, large amount of earth flows into due to collapse of earth near the channel, and water is polluted.

(d) Head tank

Due to topographic restrictions, it is complex in shape, and the effective storage capacity is approx. 25 seconds which is very small. Because of topographic restrictions, the head tank capacity should be increased as much as possible, and large scale modification is necessary in order to get close to the target capacity.

(e) Penstock

The penstock with 1.54 m in diameter and 155 m in total length is in good condition, and repair is not required.

(f) Powerhouse building

The building is an RC structure with 12.0 m in width, 55.0 m in length and 8.75 m in height and which has sufficient space, and repair is not required.

CHAPTER 5 BASIC DATA COLLECTION

The pre-FS was conducted from November, 1987 to July, 1988. The FS followed in November, 1988 to collect topographical, geological, hydrometeorological and other related data as detailed below:

5.1 Topographic Maps

San Cancio, Intermedia and Municipal P/Ps, built along the Chinchina River of the Cauca River system, are located in the south of Manizales City, and the San Cancio P/P is most upstream, and the Intermedia and Municipal P/Ps are downstream.

In the collected data on the topographic maps, there are three kinds of maps with a scale of 1/25,000 - 1/250,000 issued by IGAC, topographic map with a scale of 1/2,000 issued by CRAMSA and a survey map of existing structures measured by CHEC in order to study these power plant sites.

(1) Topographic maps issued by IGAC

Scale	Drawing No.	Remarks
1:250,000	-	Entire map of Caldas Department
1: 25,000	205-IV-A,C	Power plants and river basin are covered.
	206-III-B,D	
	206-IV-A,C	
	224-II-A,C	
	225-I-B,D	
	225-II-A,B,C,D	

(2) Topographic maps issued by CRAMSA

Scale	Drawing No.	Remarks
1:2,000	15	Intermedia P/P and Municipal channel
"	16	Intermedia channel
"	20	Municipal channel
"	21	Intermedia channel
"	22	San Cancio P/P and channel
"	23	San Cancio channel and diversion weir
"	27B	Municipal P/P

(3) Structure drawings actually measured by CHEC

a) San Cancio P/P

Scale	Detail of Drawing
1/200	Plan and cross sectional view of diversion weir
"	Plan and cross sectional view of No.1 and 2 desilting basins
"	Plan and cross sectional view of head tank
H:1/2,500 V:1/500	Longitudinal sectional view of channel

b) Intermedia P/P

Scale	Detail of Drawing
1/200	Plan and cross sectional view of diversion weir and head tank
H:1/2,500 V:1/500	Longitudinal sectional view of channel

c) Municipal P/P

Scale	Detail of Drawing
1/200	Plan and cross sectional view of diversion weir
"	Desilting basin
"	Plan and cross sectional view of head tank
H:1/2,500 V:1/500	Longitudinal sectional view of channel

5.2 Geological Survey Data

Geological survey data collected for this survey are as follows:

- Aerial photographs of these power plants and vicinity
- Mapa Geologico de Colombia, 1988 INGEOMINAS

5.3 Hydrometeorological Data

JICA Study Team collected HIMAT's meteorological data when conducting this survey.

The river discharge at the Chinchina River which directly relates to this FS plan has been observed at the CHEC gauging station (Bocatoma), upstream from the intake site of San Cancio P/P.

The followings are the precipitation-observing record and the discharge-observing record collected.

Table 5.3 List of Data Collected Relating to Hydrometeorology

(1) Precipitation-observation record

Meteorological station		Controller	Location		Altitude (m)	Observation period
No.	Name		Latitude	Longitude		
2615004	SUB MARUMATO	HIMAT	0504	7531	2072	1974-87
2615006	ARAUCA	"	0507	7542	890	1970-87
2615016	ESPERANZA	"	0501	7521	3240	1970-87
2613017	POTREROS	"	2454	7533	2140	1970-87

(2) Discharge-observation record

Hydrological gauging station		River	Controller	Establish-ment	Location		Altitude (m)	Catchment area (km^2)	Observa-tion period
No.	Name				Latitude	Longitude			
6-939	Bocatoma	Chinchina	CHEC	1979-12	-	-	-	-	1979-87

(3) Water quality-observation record

JICA Study Team was unable to obtain the test results during their field survey.

(4) Sediment-observation record

Sand observation record

Primer Desarenador
Segundo Desarenador
Tanque de Carga

} The observation records as of April 28, 1989

5.4 Other Related Data

5.4.1 Construction Prices Data

As far as construction prices for civil works in Colombia are concerned, there is "Catalogo de Precios de Materiales de Construccion" in Cardas Department monthly published by CAMACOL (Camera Colombiano de la Construccion). However, the above publication was not published in all departments of Colombia. Considering the coordination to the power plant sites for which FS was conducted, construction prices used for this study are based on price data used within CHEC (refer to Table 5.2).

5.4.2 Power Condition Data

(1) JICA Study Team collected the following data for the purpose of examining CHES's power condition.

1) Schematic power diagram of CHEC

(2) JICA Study Team gathered the following data relating to San Cancio, Intermedia and Municipal P/Ps.

1) Single line diagram

2) Operation and maintenance personnel

3) Residual value

Table-5.2 UNIT PRICE LIST
表-5.2 建設工事単価表

	UNIT	EADE	CHEC	CEDELCA		E.CHOCO	CEDENAR	ESSA	ELECTROLIMA
				SILVIA	OVEJAS				
		NOV./88	FEB./89	JUN./89	JUN./89	MAR./89	JUN./89	APR./89	MAY/89
1. EARTH WORK (EARTH)	p/m^3	2,400	2,925	700	800	2,950	990	2,500	1,100
2. EARTH WORK (ROCK)	p/m^3		3,965				1,900		2,800
3. CONCRETE WORK (MASS CON.)	p/m^3	-	-	-	-	24,000	-	-	-
4. CONCRETE WORK (STRUCTURAL)	p/m^3	26,300	27,625	34,000	40,000	26,800	20,500	15,600	17,900
5. REINFORCING BAR	p/t	354,000	454,000	350,000	360,000	447,500	300,000	320,000	215,000
6. GATE	p/t	1,682,000	500,000	1,310,000	1,420,000	1,100,000	1,100,000	1,100,000	480,000
7. SCREEN	p/t	1,682,000	5,00,000	804,195	874,125	1,000,000	1,000,000	1,000,000	650,000
8. PENSTOCK	p/t	1,000,000	1,000,000	1,250,000	1,250,000	-	815,000	1,260,000	420,000
9. POWER HOUSE (REPAIR)	p/m^2	-	10,000	-	-	-	-	-	-
10. POWER HOUSE (NEW CONST.)	p/m^2	-	40,000	47,000	55,000	50,000	50,000	50,000	50,000
11. CYCLOPEAN CONCRETE	p/m^3	-	14,000	17,000	20,000	-	-	8,000	9,000
12. DEMOLITION CONCRETE	p/m^3	13,000	14,000	17,000	20,000	-	-	8,000	9,000
13. STEEL PIPE	p/t	-	-	-	1,250,000	-	-	-	-
14. GABION	p/m^3	-	-	8,800	-	-	-	-	-
15. TUNNEL EXCAVATION	p/m^3	-	-	-	-	-	-	-	19,600
16. TUNNEL CONCRETE	p/m^3	-	-	-	-	-	-	-	25,000

CHAPTER 6 PRESENT CONDITIONS OF TOPOGRAPHY AND GEOLOGY

6.1 Topography in the Planned Area

The fountainhead of the Chinchina River is at the northern slope of the Volcano Nevado del Ruiz, meanders and flows west-northwest down to the vicinity of the Manizales City of Caldas Department and flows southwest down from Manizales City to Chinchina City, changing its flow channel again near Chinchina City to flow northwest down thereafter to join the Cauca River. The project site is located on the upstream side of the Chinchina River and the topography in the vicinity of the project site forms a comparatively steep U-shaped valley with gentle slopes corresponding with surface of the old debris flow deposit on some of the mountain side slopes.

6.2 Geology in the San Cancio Area

6.2.1 Outline of Geology

The bedrock consists of green schist, andesite lava, andesitic conglomerate (old debris flow deposit) and the like on which terrace deposit, talus deposit and riverbed deposit overlay locally. (Refer to Fig. 6.1)

The stratigraphy in the vicinity of the project site is shown in Table 6.1.

Table 6.1 Stratigraphy in the Vicinity of Project Site

Era	Schematic column	Strata	Remarks
Quaternary period		Riverbed deposit	
		Talus deposit	
		Terrace deposit	
Tertiary		Andesite lava Andesitic conglomerate	
Paleozoic		Schist	

The schistosity of green schist which was observed near the division weir shows N18° ~ 33°W and 35° ~ 52°W. The whole, however, is presumed to be complexly folded.

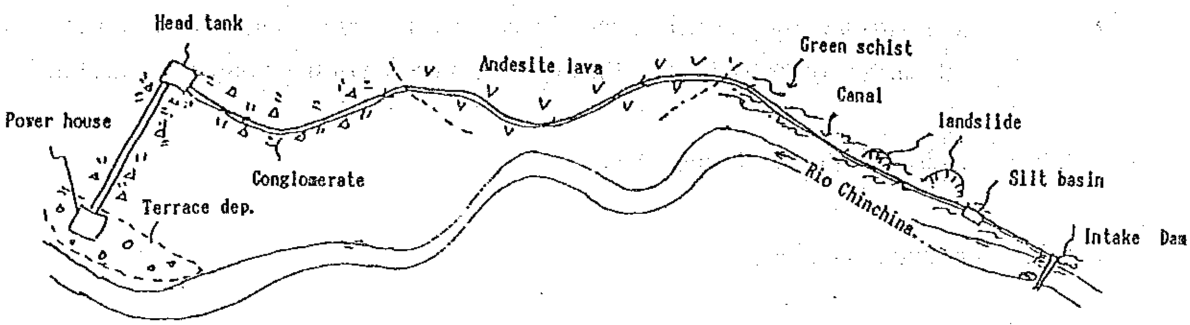


Fig. 6.1 Geographic Outline Drawing at San Cancio Area

6.2.2 Geology of Foundation for Structures

The outline of the geology of foundation for power plant and various structures is as follows:

(1) Division weir and desilting basin

Green schist is the base in the vicinity of diversion weir and desilting basin, on which terrace and talus deposits overlay by covering the bedrock. The thickness of the terrace deposit is estimated at about 3 m or less from the scale of the Chinchina River and the bedrock exposed on both of its left and right banks. The pit survey reveals the above desilting basin does not lie on the bedrock.

(2) Conduction channel

Green schist, andesite lava and andesitic conglomerate are the foundation for the conduction channel, but talus deposit is the foundation around the desilting basin.

(3) Head tank and penstock

The tank and penstock are based on andesitic conglomerate (old debris flow deposit). Andesitic conglomerate includes a number of poorly sorted gravels (maximum ϕ50 x 20 cm), and also the surface layer up to about 1.3 m is loose, while the deep section is well compacted.

(4) Power plant

Terrace deposit overlays andesitic conglomerate (old debris flow deposit) around the power plant. The pit survey reveals that the powerhouse buildings are based on terrace deposit and do not lie on the bedrock. Terrace deposit includes andesite round gravels of about ϕ20 cm and the matrix is constituted of loose fine sand, silt and clay.

6.2.3 Geotechnological Evaluation and its Problems

(1) Schist, andesite lava and andesitic conglomerate constituting the bedrock of the project site is hard and dense in fresh condition, and it has the bearing capacity and impermeability sufficient for foundations for about 10-meter high concrete dam and for various structures.

(2) The matrix of terrace deposit is composed of slightly loose sand and silt, but it can be utilized as the foundation for desilting basin or the like.

(3) Talus deposit is generally loose and not suitable for the foundation of important structures in terms of bearing capacity.

(4) Small-scale landslides are seen in several places in the 400 m downsteam side from the area near the desilting basin and landslides deform part of the conduction channel. These landslides are in the talus deposit overlaying area.

There are no fatal topographical and geological problems at this small-scale power plant project site. Several landslides, however, are seen along the conduction channel. Countermeasures are required for these landslides. Since the conduction channel was deformed due to landslides which occurred at the immediate downstream side of the desilting basin, water drain boring work was performed twice.

6.2.4 Distribution of Concrete Aggregate

The present riverbed deposit is sufficient for aggregate. The present river deposit consists of gravel, sand and silt, and the gravel contains andesite with $\phi 5 \sim 30$ cm and small amount of green shist and sandstone.

6.3 Geology in the Intermedia Area

6.3.1 Outline of Geology

The bedrock is composed of andesitic conglomerate (old debris flow deposit) on which terrace deposit, talus deposit and riverbed deposit overlay partially. These silt layers are intercalated locally in andesitic conglomerate. Andesitic conglomerate is well compacted, and is in good condition which about 100 m precipice forms, while the matrix of altered andesitic conglomerate turns to be clay and is liable to collapse.

The stratigraphy in the vicinity of the project site is shown in Table 6.2.

Table 6.2 Stratigraphy in the Vicinity of Project Site

Era	Schematic column	Strata	Remarks
Quaternary		Riverbed deposit	
		Talus deposit	
		Terrace deposit	
Tertiary		Andesitic conglomerate	

No particular large-scale faults are observed. Although andesitic conglomerate is poorly layered with bedding planes, the intercalated silt layers are laid horizontally.

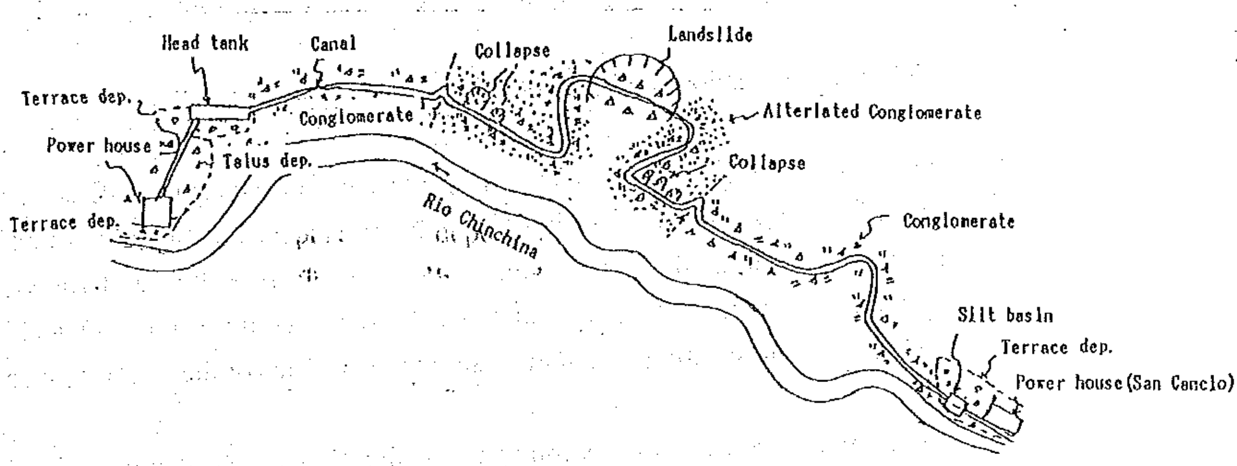


Fig. 6.2 Geographic Outline Drawing at Intermedia Area

6.3.2 Geology of Foundation for Structures

The outline of the geology of foundation for power plant and various structures is as follows:

(1) Conduction channel

The soil along the conduction channel is composed of andesitic conglomerate (old debris flow deposit), and except altered andesitic conglomerate overlaying in the middle portion of the conduction channel, all are composed of good andesitic conglomerate. Frequent collapses occur in the altered andesitic conglomerate overlaying area.

(2) Head tank

Terrace deposit overlays on andesitic conglomerate (old debris flow deposit) around the tank. The tank is based on terrace deposit constituted of a sand layer including a small layer of gravels.

(3) Penstock and power plant

The penstock is on the base consisting of high terrace deposit and andesitic conglomerate (old debris flow deposit), and the powerhouse buildings are on the base including green schist gravels.

6.3.3 Geotechnological Evaluation and its Problems

(1) The andesitic conglomerate constituting the bedrock of the project site is hard and dense in fresh condition, and it has the bearing capacity and impermeability sufficient for foundations for about 10 m high concrete dam and for various structures. The matrix of the deformed section, however, turns into clay, and is not suitable for the foundation of important structures in terms of the bearing capacity.

(2) The matrix of terrace deposit is composed of slightly loose sand and silt, but it can be utilized as the foundation for desilting basin.

(3) Talus deposit is generally loose and not suitable for the foundation of important structures in terms of bearing capacity.

(4) Collapses occur frequently in the altered andesitic conglomerate overlaying area which is limited to the intermediate section of the conduction channel.

Collapses frequently occur in the intermediate section of the conduction channel, and as a new collapse might occur in the future, these sections of the conduction channel should be covered with concrete.

6.4 Geology in the Municipal Area

6.4.1 Outline of geology

The bedrock consists of green schist, andesite lava, andesitic conglomerate (old debris flow deposit) and the like on which terrace deposit, talus deposit and riverbed deposit overlay locally. (Refer to Table 6.3)

The stratigraphy in the vicinity of the project site is shown in Table 6.3.

Table 6.3 Stratigraphy in the Vicinity of Project Site

Era	Schematic column	Strata	Remarks
Quaternary		Riverbed deposit	
		Talus deposit	
		Terrace deposit	
Tertiary		Andesitic conglomerate	
Paleozoic		*Sandstone*	
		Schist	

No particular large-scale faults are observed. Part of the schistosity of green schist strikes N20°W70° ~ 80°E and is presumably complexly folded as a whole. The relationship between green schist and sandstone is not clear.

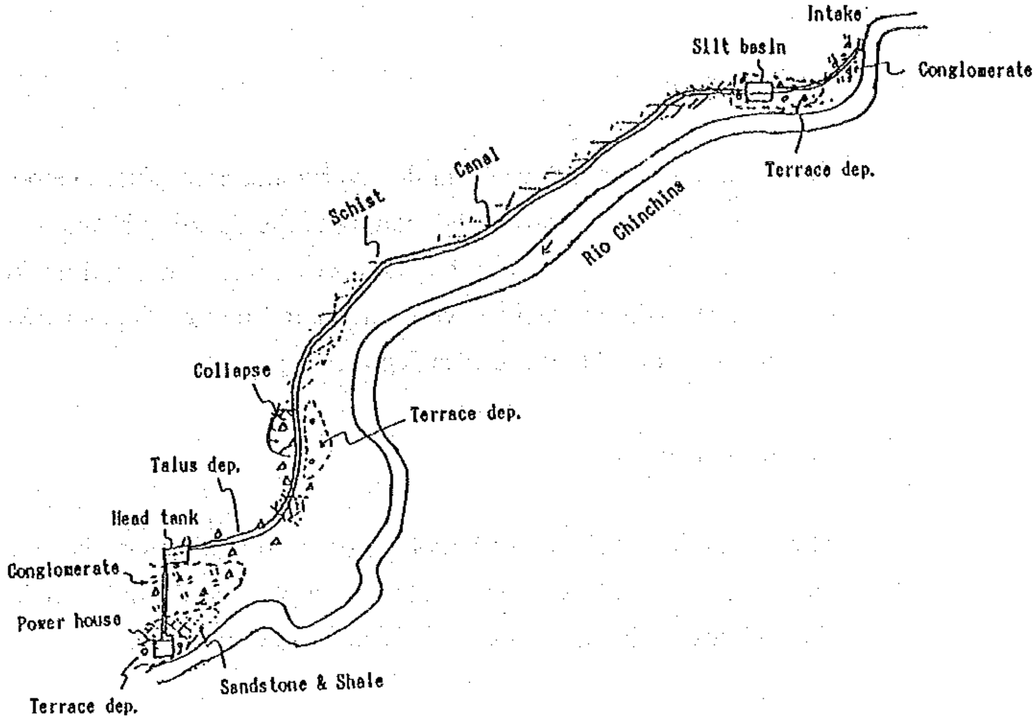


Fig. 6.3 Geographic Outline Drawing at Municipal Area

6.4.2 Geology of Foundation for Structures

The outline of the geology of foundation for power plant and various structures is as follows:

(1) Desilting basin

The desilting basin is located in the overlaying area of terrace deposit. From the conditions of the outcrops in the vicinity of the desilting basin, it is presumed to be directly on the bedrock, and the pit survey reveals that soil up to a depth of 1 m from the surface consists of well compacted terrace deposit. Rotten gravels of granite are included in the terrace deposit.

(2) Conduction channel

The soil in the district of 150 m of the downstream area of the conduction channel mainly consists of detritus and talus deposit, while the remaining conduction channel lies on the bedrocks (green schist and sandstone).

(3) Head tank

According to the pit survey, the tank is based on clay soil having about 3~5N value.

(4) Penstock and power plant

The penstock is based on andesitic conglomerate (old debris flow deposit), and the power plant is based on terrace deposit.

6.4.3 Geotechnological Evaluation and its Problems

(1) Schist, andesite lava and andesitic conglomerate constituting the bedrock of the project site is hard and dense in fresh condition, and it has a bearing capacity and impermeability sufficient for foundations of various structures.

(2) The matrix of terrace deposit is composed of sand and silt, is well compacted, and can be utilized as the foundation for desilting basin and the like.

(3) Talus deposit is generally loose and not suitable for the foundation of important structures in terms of bearing capacity.

(4) Detritus and talus deposits overlay all over the 150 m district in downstream side of the conduction channel. A collapse occurred in one place in May, 1989, and blocked the conduction channel.

Part of slope along the conduction channel has collapsed. Stabilization of the slopes and placement work for conduction channel covers are required at the above place.

6.4.4 Distribution of Concrete Aggregate

The riverbed deposit is suitable for aggregate. The riverbed deposit consists of gravel, sand and silt, and the gravel contains andesite with ϕ5~30 cm and small amount of green schist and sandstone.

CHAPTER 7 HYDROLOGICAL ANALYSIS

Fig. 7.1 shows the location of the existing gauging stations for monitoring precipitation and discharge in the watershed of the project site.

7.1 General Meteorology in the Planned Area

Caldas Department, in the northwest of Colombia, lies from 4°49' to 5°46' north latitude, near the equator.

Caldas Department, located in the Central Andes Mountain Range, is situated between the Cauca River to the west and the Magudalena River in the east.

One-third of Caldas Department is lowland with a tropical climate. It changes from a temperate to a frigid climate zone with increasing altitude. The temperature is 20°C in the lowland area and 12 - 18°C at an altitude of 1,800 to 2,800 m. The capital, Manizales City, is located at an altitude of 2,500 m, with an average temperture of 18°C.

Average rainfall is about 2,000 - 3,000 mm/year in the lowland and intermediate mountain area, but drops to 1,000 - 1,500 mm/year in the high altitude areas.

The Chinchina River originates in the Andes Mountain, flowing west through the project site which is south of Manizales City at an elevation of 1,850 m. The climate of the project site is temperate, with an average temperature of 20°C and annual rainfall of 2,000 mm. Rainfall fluctuates slightly from year to year. (Refer to Fig. 7.2)

Observation Item	Gauging Station		Latitude	Longitude
	No	Name		
Discharge	———	Bocatoma	———	———
Preciptation	2615-004	Sub Maramato	0504	7531
	2615-006	Arauca	0507	7542
	2615-016	Esperanza	0501	7521
	2613-017	Potreros	0454	7533

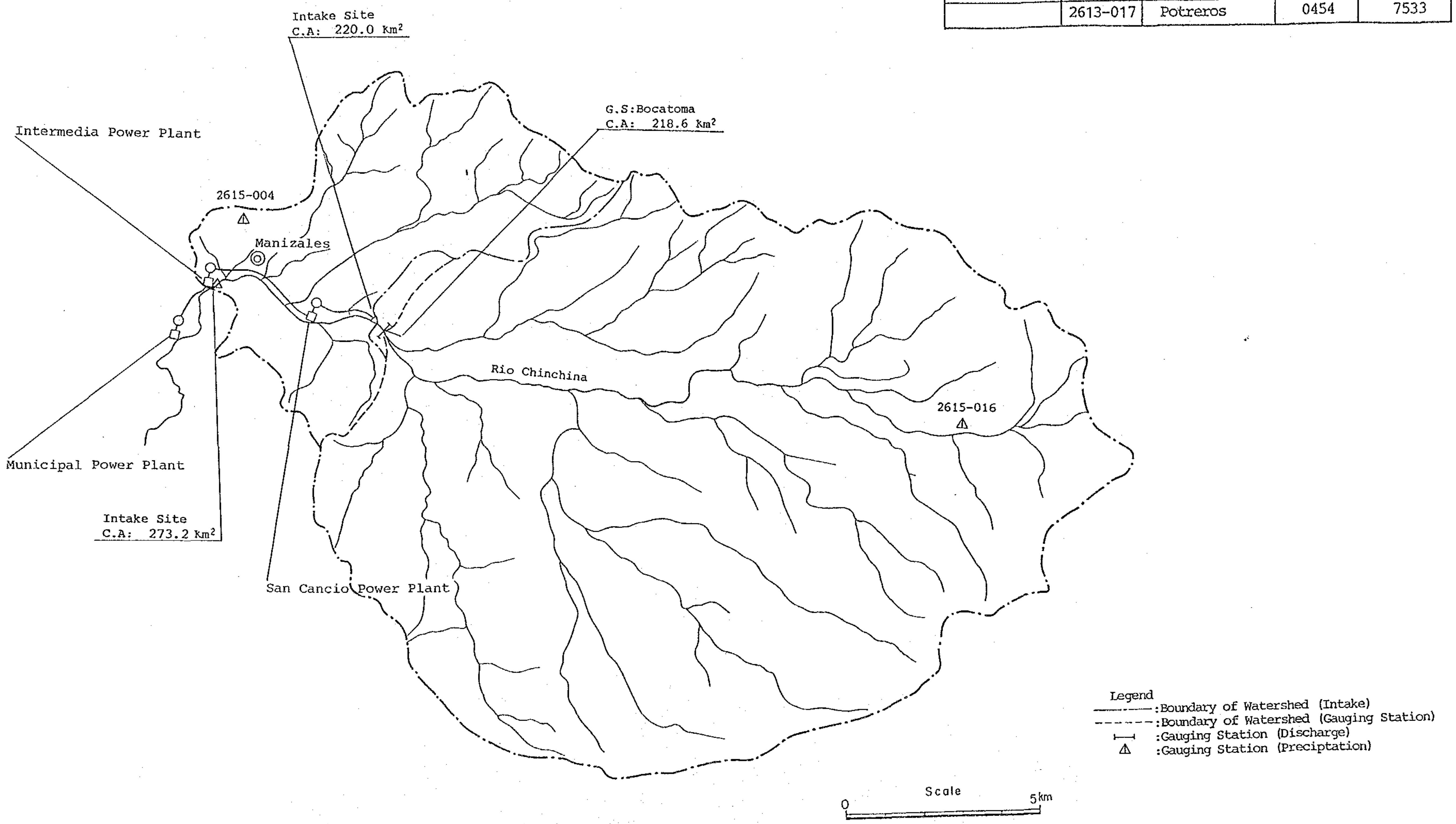


Fig-7.1 Location Map of Gauging Stations in The Watershed of The Study Area.

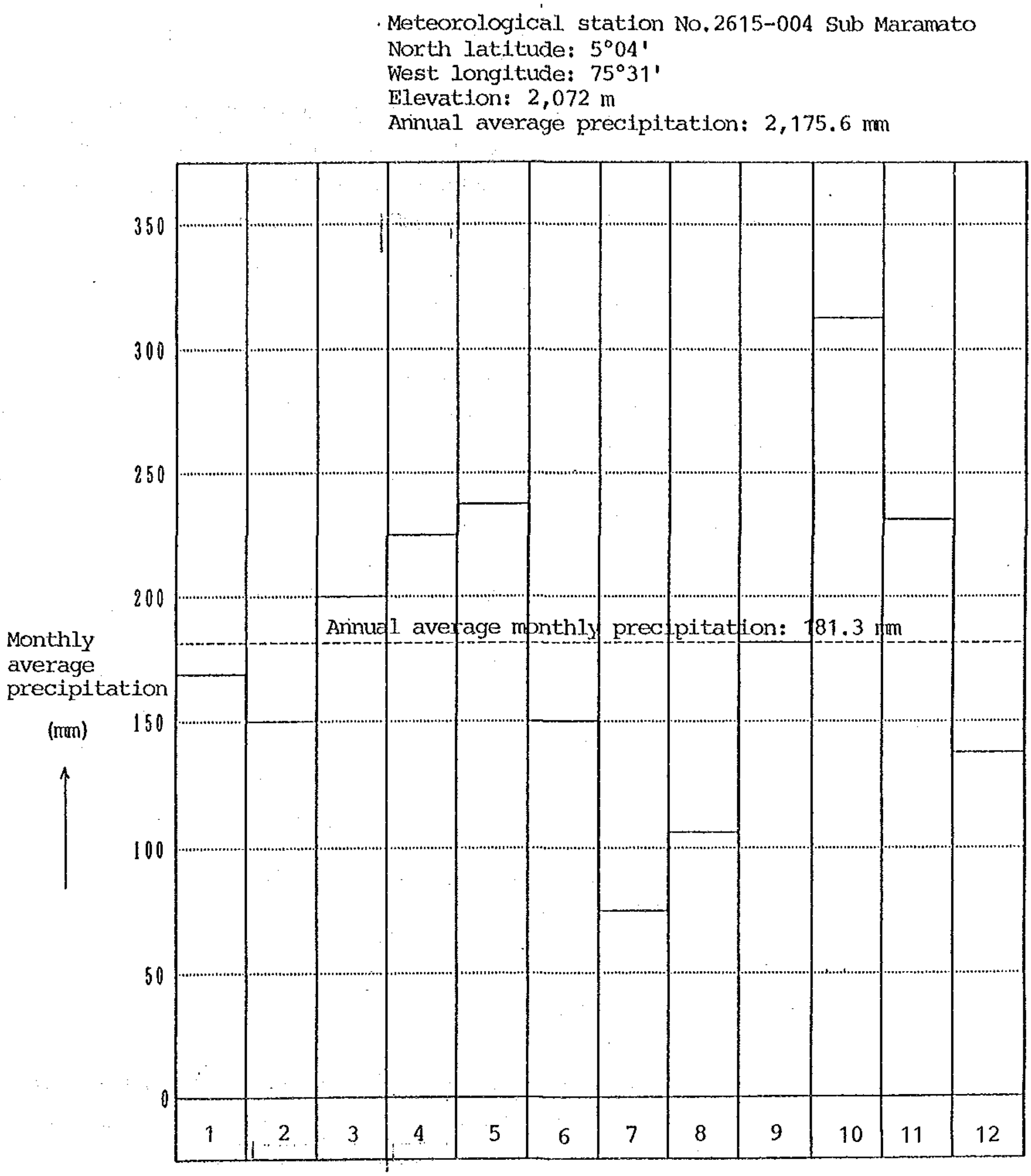


Fig.7.2 Monthly Average Precipitation in the Project Site (1974-87)

7.2 Discharge Analysis

Observations from 1979 to 1987 were compiled at the Bocatoma gauging station located 600 m upstream from the intake area of the San Cancio Power Plant. The discharge and flow duration curve for the project site were derived from this data. (See Drawing No. SC-H-01 and IN-H-01)

7.2.1 Collation of Discharge Observing Record

The Bocatoma gauging station was established in December, 1979. The JICA Study Team gathered observations recorded from 1979 to 1988. Observations were recorded year-round in 1981, 1983, 1985, 1986 and 1987. Non-recorded dates are noted in the discharge record, shown in Table 7.1.

Non-observed month: January, 1984

Table 7.1 Dates of Non-recorded Discharge

Year	
1980	December 18
1982	May 22, 23
1984	January 1 - 31

(Since non-observed days are few, this data can be interpolated from the existing observations.)

7.2.2 Collation to Catchment Area at the Gauging Station

The records for the catchment area of the Bocatoma gauging station are missing. Longitude, latitude and the catchment area for the gauging station are taken from the IGCA issued topographic map (scale: 1:100,000) and listed below.

Location and catchment area at Bocatoma gauging station

Latitude:	0502
Longitude:	7529
Catchment area:	218.6 km^2

7.2.3 Typical Flow-duration Curve Form

Year-to-year fluctuations of the river-duration curve occur at this site. In drawing a normal flow-duration curve, the following methods were considered:

a) Parallel method

The daily average discharge for 365 days is arranged in descending order and the flow-duration curve for each year is drawn and averaged.

b) Standard year method

Flow-duration curves for each year are drawn. The median curve is then selected and set as the flow-duration curve for a standard year.

c) Series method

Daily average discharge for 15 years is arranged in descending order with only the Y-axis adjusted for the one-year curve.

d) Curve insertion method

Average values from 355-day flow, 9-month flow, ordinary water discharge and three-month flow observed for a minimum of 10 years are calculated and plotted from a discharge handbook for the flow-duration curve.

Normal flow-duration curves are drawn based on the parallel-method. Non-observed years are not included. The X and Y axes are expressed as daily average discharge (m^3/s) and number of days (%), respectively.

7.2.4 Discharge and Flow-duration Curve at Bocatoma Gauging Station

Discharge data from the Bocatoma gauging station, located 0.6 km upstream from the intake site of San Cancio hydroelectric power plant, is arranged from the 7-year observation data, excluding non-observed dates, as shown in Table 7.2.

In calculating the monthly average discharge of Table 7.2, months in which the observation time was less than 10 days are excluded. A graphic representation of

Table-7.2 MONTHLY FLOW TABLE OF DAILY AVERAGE FLOW AT G.S. SITE

GAUGING ST.: 6-939 BOCA TOMA
RIVER NAME: CHINCHINA

(UNIT: M3/S)

GAUGING YEAR	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1979	MAX.	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	16.0	16.0
	MEAN	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	9.7	9.7
	MIN.	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	6.9	6.9
1980	MAX.	11.6	13.2	7.2	9.9	12.0	14.2	5.4	7.5	8.6	10.3	8.0	9.6	14.2
	MEAN	7.6	8.2	5.2	5.7	6.9	7.0	3.9	3.0	3.2	5.4	5.0	5.4	5.5
	MIN.	5.1	6.1	4.3	4.4	4.9	4.9	2.8	2.4	2.3	3.0	3.2	3.2	2.3
1981	MAX.	7.7	7.3	8.0	12.6	13.9	12.3	9.1	7.3	10.0	11.0	10.1	5.9	13.9
	MEAN	3.2	3.5	3.6	5.0	9.4	7.9	5.4	3.8	4.3	6.3	5.9	4.0	5.2
	MIN.	2.3	2.7	2.4	2.5	6.9	6.1	3.2	3.1	3.0	3.2	3.9	3.0	2.3
1982	MAX.	13.0	8.8	9.3	9.7	12.1	7.5	4.2	3.8	5.3	8.6	6.5	7.9	13.0
	MEAN	5.3	4.7	4.8	6.9	7.7	5.4	3.6	3.3	3.7	4.6	4.9	4.6	5.0
	MIN.	2.5	2.8	2.2	3.9	2.2	3.4	3.1	3.0	3.0	3.5	3.7	3.5	2.2
1983	MAX.	4.9	4.3	7.8	9.4	9.2	6.6	6.6	3.7	6.2	10.7	6.4	10.7	10.7
	MEAN	3.3	3.1	4.5	6.1	5.4	4.1	3.5	3.2	3.3	4.2	4.8	5.9	4.3
	MIN.	2.7	2.7	2.7	4.1	3.6	3.0	2.7	2.7	2.7	2.7	3.2	3.8	2.7
1984	MAX.	(1)	5.4	8.1	9.6	13.0	9.4	7.5	10.7	9.6	21.3	17.3	20.0	21.3
	MEAN	(1)	3.8	3.8	5.0	7.7	6.5	3.9	4.3	5.5	10.1	10.7	9.9	6.5
	MIN.	(1)	3.1	2.7	3.1	3.7	4.6	2.7	2.9	2.8	5.9	6.8	7.3	2.7
1985	MAX.	21.3	13.8	19.4	19.9	16.0	16.6	8.4	16.0	12.6	23.2	16.7	14.9	23.2
	MEAN	10.6	7.3	9.1	10.3	10.0	7.2	5.9	7.6	8.6	11.0	10.6	8.6	8.9
	MIN.	7.1	6.2	6.1	6.0	6.3	5.6	5.1	5.2	5.5	7.4	8.1	6.4	5.1
1986	MAX.	14.5	19.5	13.6	16.6	14.2	17.2	13.2	8.5	11.7	11.7	11.7	7.3	19.5
	MEAN	8.5	9.1	8.1	10.7	9.3	10.5	7.6	4.3	5.2	10.6	8.8	3.8	8.0
	MIN.	6.2	6.3	7.2	7.2	7.8	7.6	5.6	2.7	2.3	4.3	2.5	2.1	2.1
1987	MAX.	8.7	7.3	9.0	11.7	11.7	9.0	9.6	11.7	11.7	11.7	11.7	11.7	11.7
	MEAN	3.7	3.3	4.1	4.6	9.0	5.6	4.3	4.2	4.5	10.2	10.9	8.4	6.1
	MIN.	2.7	2.3	2.3	2.7	6.2	2.3	2.5	2.7	2.6	2.3	8.9	6.1	2.3
TOTAL	MAX.	21.3	19.5	19.4	19.9	16.0	17.2	13.2	16.0	12.6	23.2	17.3	20.0	23.2
	MEAN	6.0	5.4	5.4	6.8	8.2	6.8	4.8	4.2	4.8	7.8	7.7	6.7	6.2
	MIN.	2.3	2.3	2.2	2.5	2.2	2.3	2.5	2.4	2.3	2.3	2.5	2.1	2.1

NOTE) (1) ALL DATA MISSING

monthly average discharge, three-month flow periods can be clearly distinguished from drought periods in Drawing SC-H-01, (1).

However, from July to September (in summer) and January to March (winter) are considered drought periods.

Typical flow-duration curves calculated from the 7-year flow-duration curves from 1980 to 1987 (excluding 1984) according to the parallel method are indicated in Drawing SC-H-01 number (3). Periods of three-month flow, ordinary water discharge and nine-month flow in flow-duration curves are indicated by numerical values, as shown in Table 7.3.

The maximum discharge recorded at the Bocatoma gauging station during 19 years from 1979 to 1987 is shown in Table 7.4.

Table-7.3 FLOW DURATION TABLE AT GAUGING STATION SITE

GAUGING ST.: 6-939 BOCA TOMA
RIVER NAME: CHINCHINA

(UNIT: M3/S)

GAUGING YEAR	MAX. (1ST DAY)	PLENTY (95 DAY)	ORDINARY (185 DAY)	LOW (275 DAY)	DROUGHTY (355 DAY)	MIN. (LAST DAY)	MEAN
1980	14.2	6.7	5.2	3.8	2.5	2.3	5.5
1981	13.9	6.5	4.4	3.2	2.5	2.3	5.2
1982	13.0	5.9	4.3	3.6	2.9	2.2	4.9
1983	10.7	5.1	3.7	3.1	2.7	2.7	4.3
1985	23.2	10.2	8.1	6.6	5.4	5.1	8.9
1986	19.5	9.8	8.1	6.1	2.7	2.1	8.0
1987	11.7	8.7	5.6	2.7	2.7	2.3	6.1
MEAN	15.2	7.6	5.6	4.2	3.1	2.7	6.1

Table-7.4 MONTHLY ABSOLUTE MAXIMUM FLOW TABLE AT G.S. SITE

GAUGING ST. : 6-939 BOCATOMA
RIVER NAME: CHINCHINA

(UNIT: M3/S)

GAUGING YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1979	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	20.8	20.8
1980	20.6	20.6	9.2	20.6	17.7	20.8	6.7	8.7	12.6	12.6	16.3	20.5	20.8
1981	11.4	16.3	9.2	20.6	20.8	19.2	9.2	12.6	13.8	20.8	20.8	9.2	20.8
1982	20.8	9.2	19.2	19.2	19.2	8.1	4.8	3.7	5.3	8.6	6.5	7.9	20.8
1983	4.9	4.3	7.6	9.4	9.2	5.9	6.6	3.7	6.2	7.0	6.4	10.7	10.7
1984	(1)	5.3	5.3	6.7	13.0	9.4	7.5	8.4	9.6	24.0	24.0	24.0	24.0
1985	24.0	23.5	24.0	23.5	23.5	20.1	11.4	20.1	16.6	24.0	23.5	23.5	24.0
1986	24.0	23.5	23.5	20.1	20.1	24.0	13.1	10.4	(1)	(1)	(1)	9.5	24.0
1987	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
TOTAL	24.0	23.5	24.0	23.5	23.5	24.0	13.1	20.1	16.6	24.0	24.0	24.0	24.0

NOTE) (1) DATA MISSING

7.2.5 Discharge and Flow-Duration Curves at the Intake Site

(1) San Cancio and Intermedia P/Ps

Since the tailrace at the San Cancio Hydroelectric Power Plant and the headrace at the Intermedia Hydroelectric Power Plant are directly connected, the discharge volume at the San Cancio Hydroelectric Power Plant is the available discharge of Intermedia. Therefore, the discharge and flow-duration curves at the intake site are the same as the flow-duration curves at the intake site of San Cancio Hydroelectric Power Plant.

Since numerical values for the catchment area at the intake site of the San Cancio P/P are not officially approved, the value of 220 km^2 measured by JICA Study Team is adopted. Therefore, the ratio of the catchment area between the intake site of San Cancio P/P and the Bocatoma gauging station of CHEC is set to 220/218.6 = 1.01

Discharge and flow-duration curves at the intake site are shown in Drawings (SA and IN-H-01), and representative values for daily and monthly average, three-month flow, ordinary water, nine-month flow and 355-day flow discharge are shown in Table 7.5.

Table 7.5 Representative Discharge at the Intake Site of San Cancio and Intermedia P/Ps

1) Monthly average discharge

Item	Month												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Max. average discharge (m^3/s)	10.6	9.1	9.1	10.7	10.1	10.6	7.6	7.6	8.6	11.0	10.7	10.0	9.7
Daily average discharge (m^3/s)	6.1	5.4	5.4	6.8	8.2	6.8	4.8	4.2	4.8	7.8	7.7	6.7	6.2
Min. average discharge (m^3/s)	3.2	3.1	3.6	4.6	5.4	4.1	3.5	3.0	3.1	4.2	4.8	3.8	4.3

2) Typical discharge of flow-duration curve

Three-month flow (95-day flow)	Ordinary water discharge (185-day flow)	Nine-month flow (275-day flow)	355-day flow
7.6 m^3/s	5.7 m^3/s	4.2 m^3/s	3.1 m^3/s

The river utilization factor* of the available discharge to normal flow-duration curves at the intake and the facilitutilization factor** are represented graphically in Drawing SA and IN-H-01, No. 5.

* The ratio of total available discharge to total river discharge flowing into the intake.
** The ratio of total discharge of intake-water to the available discharge throughout the year.

(2) Municipal P/P

The water intake at the Municipal P/P is the total of the Intermedia P/P and remaining catchment discharges.

The flow-duration curve at the Municipal P/P is thus given by the discharge of the catchment at No. 2 intake site (Refer to Fig. 7.1).

Since numerical values of the catchment area at the No. 2 intake site are not officially approved, the value of 273.2 km^2 measured by the JICA Study Team is used. Therefore, a ratio of the catchment area between the intake site at Municipal P/P and the Bocatoma gauging station at San Cancio P/P is set to 273.2/218.6 ≒ 1.25

Discharge and flow-duration curves at the intake site converted by the catchment area ratio are shown in Drawing MU-H-01. If water intake does not occur at the No. 2 intake site, it is the same as the discharge and flow-duration curve at the San Cancio P/P. (Refer to Dwg. No.SC - H - 01.)

The representative values of daily and monthly average, three-month flow, ordinary water, nine-month flow and 355-day flow discharges at the intake site of Municipal P/P are indicated in Table 7.6.

Table 7.6 Representative Discharge at the No. 2 Intake Site of Municipal P/P

1) Average monthly discharge

Item	Month												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Max. average discharge (m^3/s)	13.3	11.4	11.4	13.4	12.5	13.1	9.5	9.5	10.7	13.7	13.6	12.3	12.1
Daily average discharge (m^3/s)	7.5	6.75	6.75	8.5	10.2	8.5	6.0	5.2	6.0	9.8	9.6	8.4	7.7
Min. average discharge (m^3/s)	4.0	3.9	4.4	5.7	6.8	5.1	4.2	3.8	4.0	5.3	6.0	4.7	5.4

2) Typical discharge of flow-duration curve

Three-month flow (95-day flow)	Ordinary water discharge (185-day flow)	Nine-month flow (275-day flow)	355-day flow
7.6 m^3/s	5.7 m^3/s	4.2 m^3/s	3.1 m^3/s

The river utilization factor* of the available discharge to normal flow-duration curves at the intake and the facility utilization factor** are represented graphically in Drawing SA and IN-H-01, No. 5.

* The ratio of total available discharge to total river discharge flowing into the intake.

** The ratio of total discharge of intake-water to the available discharge throughout the year.

7.3 Flood Runoff Analysis

Flood discharge is important to maintain the safety of the facilities. The designed flood discharge is obtained from the observation of discharge at Bocatoma and Montevideo gauging stations and statistically processed and converted with the catchment area ratio.

7.3.1 Frequency of Flood

(1) Data Collected at the Bocatoma Gauging Station

In order to obtain potential flood discharge, annual maximum discharge (Table 7.7) is summarized according to the discharge data.

Table 7.7 Annual Flood Discharge

Year Observed	Maximum Discharge (m^3/sec)
1979	20.8
1980	20.8
1981	20.8
1982	20.8
1983	10.7
1984	24.0
1985	24.0
1986	24.0
1987	11.7

The observation data recorded over 9 years is a comparatively short sample. There are several methods to calculate potential flood, but the following three methods are considered.

1. Logarithm normal distribution method (slade method)
2. Order probability method
3. Gumbel method

For the order probability method and Gumbel method, Thomas plot and Hazen plot are studied.

Figs. 7.3 and 7.4 show that maximum yearly discharge is plotted on the X-axis and that percentage of excess probability calculated is plotted on the Y-axis by using extreme probability data. Table 7.8 shows the potential flood discharge for major years of return period from the probability curve shown in the figure.

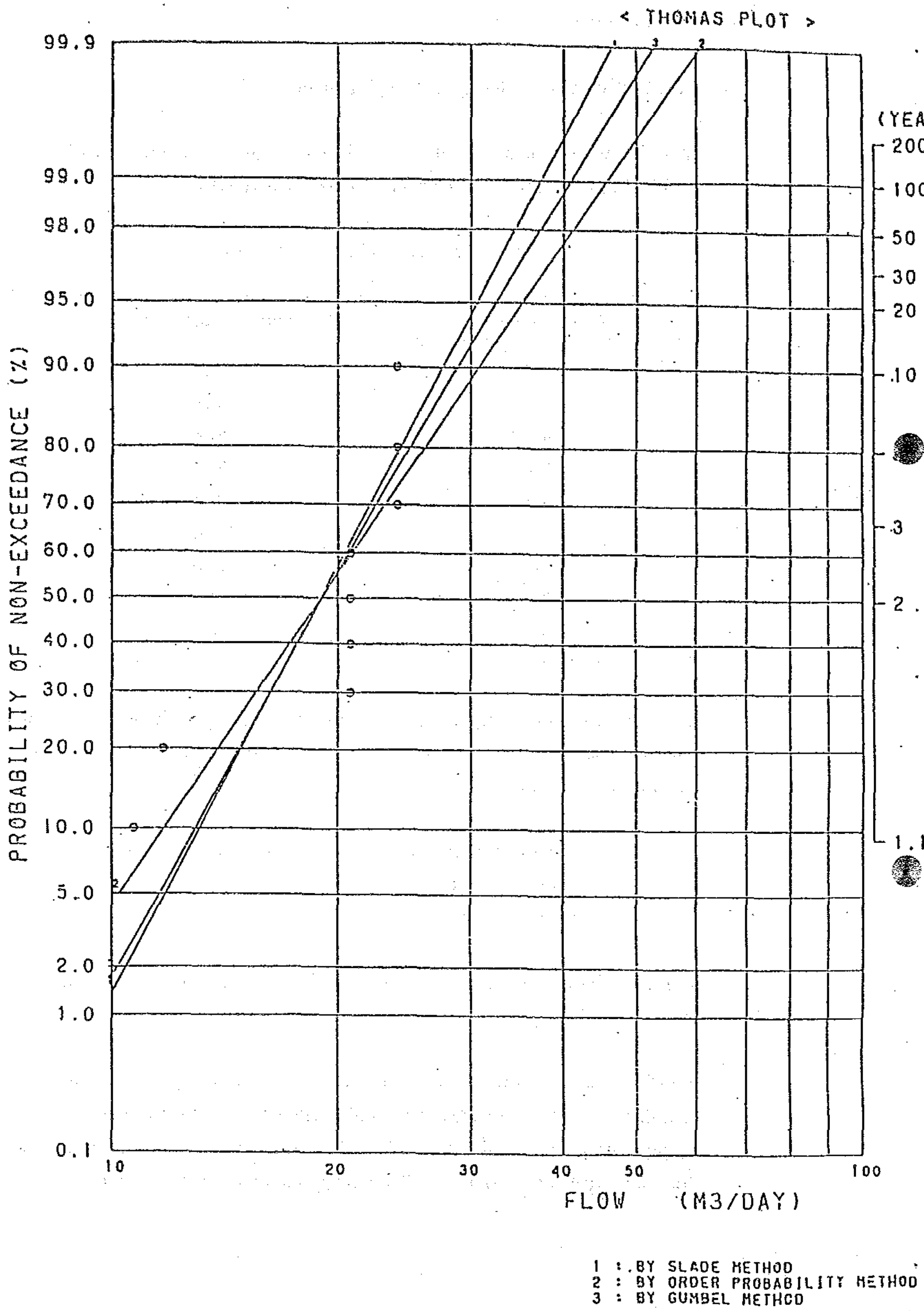


Fig. 7.3 Probability Curve (Thomas Plot)

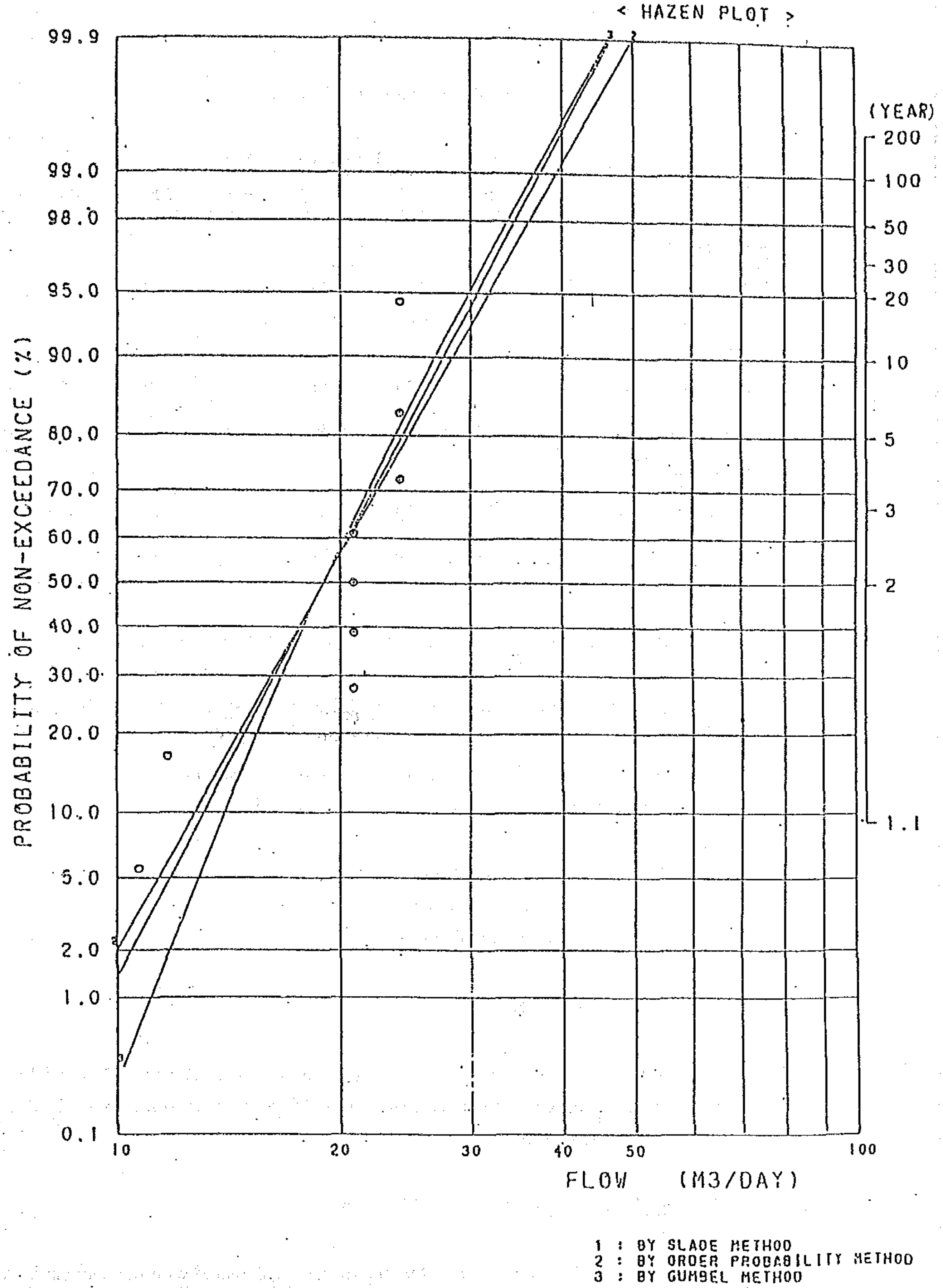


Fig. 7.4 Probability Curve (Hazen Plot)

Table 7.8 Probable Flood Discharge

Method	Return Period in Years							
	5	10	20	50	100	200	500	1000
Logarithm normal distribution method (m^3/s)	24	28	31	35	37	40	43	61
Order probability method:								
Thomas plot (m^3/s)	26	31	35	41	46	50	56	61
Hazen plot (m^3/s)	25	28	32	36	39	43	47	50
Gumbel method:								
Thomas plot (m^3/s)	25	29	33	37	41	44	49	53
Hazen plot (m^3/s)	24	27	30	34	37	40	43	46

(2) Data collected in Bocatoma Montevideo (6-901) Gauging Station

The following equations are obtained from the analysis conducted by CHEC.

$Q = 123.1 - 62.04\ L[-L(1-1/T]$ Gumbel method
$Q = 75.319 + 84.706\ L.T$ Approximation

Where Q = probable flood discharge (m^3/s)
T = probable time (years)
L = natural logarithm

7.3.2 Design Flood Discharge

Referring to generalized design criteria for water-control structures*, the 100-year probability discharge is employed from 50 to 100 years of the return period, which is applied to the structures.

* Applied Hydrology, editor: Ven Te Chow

The design flood discharge (Q) in the intake site is calculated with the catch area ratio.

	Q (Bocatoma) m^3/s	Q (Montevideo) m^3/s
San Cancio	46 x 1.04 = 48	465 x 220.0/461 = 222
Intermedia	46 x 1.24 = 56	465 x 228.8/461 = 230
Municipal	46 x 1.26 = 58	465 x 273.2/461 = 276

As a result of the above calculations, the design flood discharge at respective power plants are set as follow:

San Cancio	Q = 230 m^3/s
Intermedia	Q = 230 m^3/s
Municipal	Q = 280 m^3/s

The specific discharge per catchment area (km^2) will be q = 1.01 m^3/s from the design flood discharge. The corresponding value obtained from the Creager curve of (Fig.7.5) indicating the relationship between specific discharge and catchment area is C = 7.

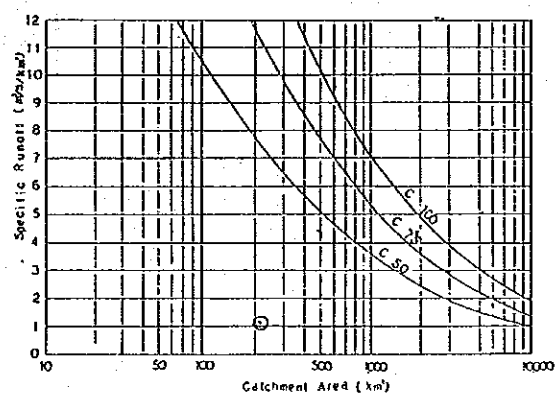


Fig. 7.5 Design Flood Discharge and Creager Curve

7.4 Sediment Analysis

The debris produced at the mountain catchment flows down to the intake point, and flows further downstream via a channel and a river. The debris flow process is shown in Fig. 7.6, and the debris flow volume is studied with this process.

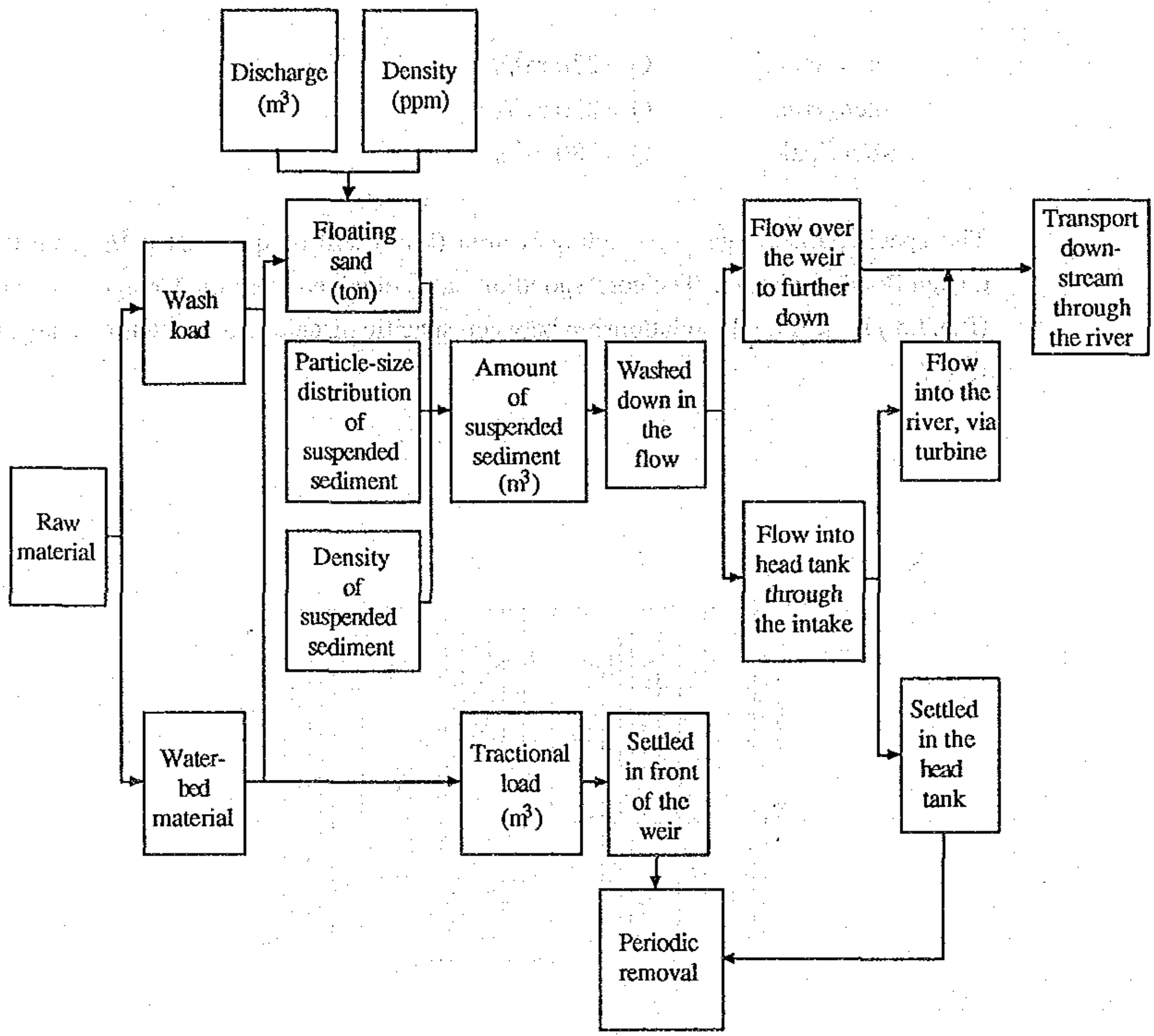


Fig. 7.6 Mechanism of Debris Flow and Calculation Flow of Volume

7.4.1 Debris Flow Status

The catchment at the Chinchina River includes the urban district of Monizales City. The upstream area near the watershed is a comparatively steep ravine. The vegetation of the catchment is good. The debris flowing from this catchment is mainly debris and city waste generated by city development, erosion of the riverbed and bank, gully erosion from terrace collapse, etc.

The suspended sediment curve has been prepared by referring to the basic shape of the rating curve of the Rio Nas and is shown in Fig. 7.7.

The suspended sediment (ton/year) at the gauging station spot is shown below.

River	Catchment Area (km^2)	River Discharge Rate			Concentration		Suspended Sediment Rate
		Total 10^6 m^3/year	Max. (m^3/s)	Min. (m^3/s)	Max. (ppm)	Min. (ppm)	10^3 tons/year
Chinchina	218.6	195	24.0	2.1	-	-	39

The suspended sediment flowing into the gauging station on the Chinchina River reaches 200 tons/km^2 per year for each catchment area, and annual average suspended sediment concentration of the Chinchina River is 200 ppm.

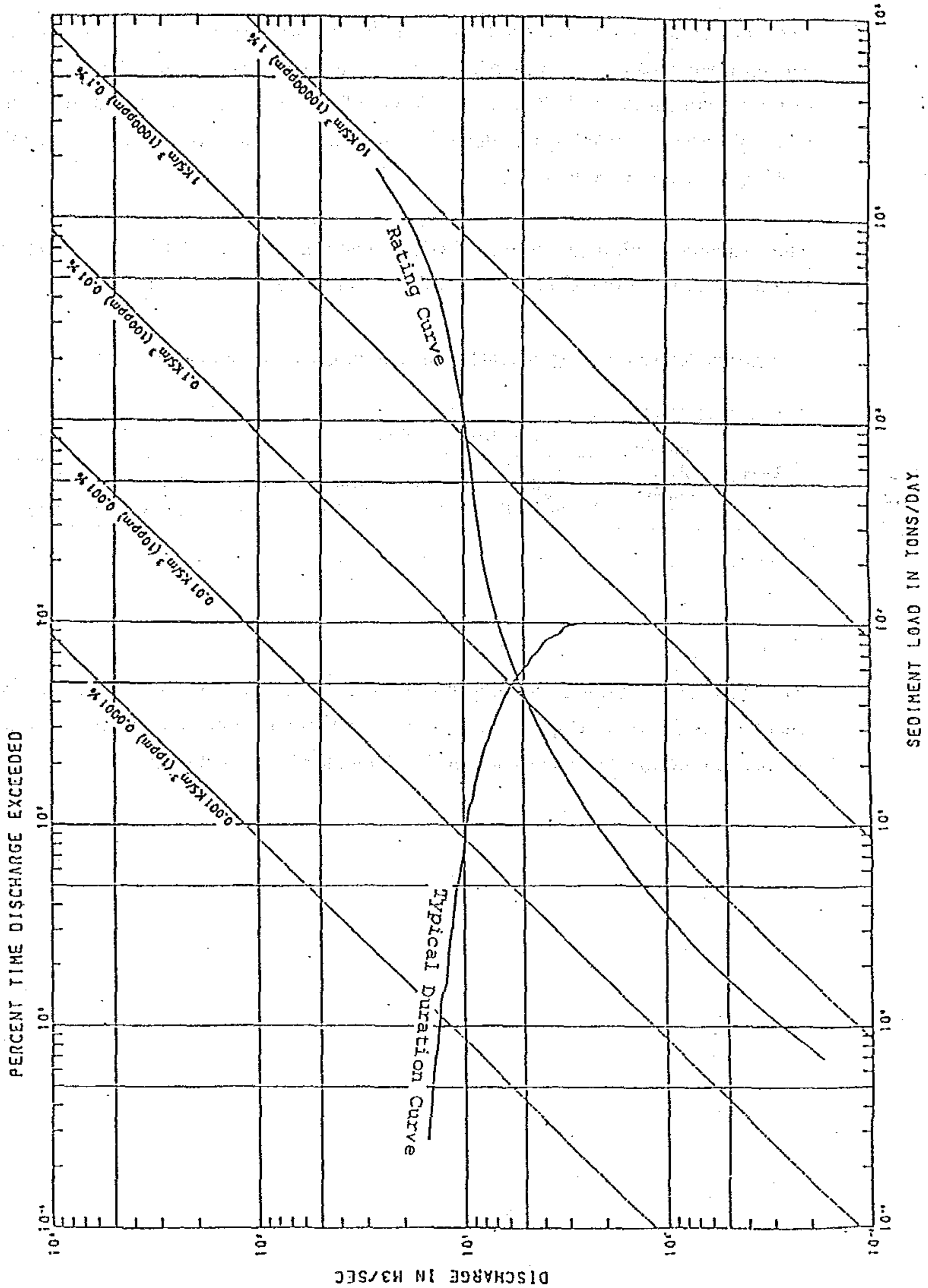


Fig. 7.7 Suspended Sediment Rating Curve

7.4.2 Assumption of Sediment Rate

(1) Major physical properties

(a) Grain size distribution

The grain size distribution of settled sediment was observed, but JICA Study Team was unable to obtain either the suspended sediment data or bed-load data. For the suspended sediment, the grain size distribution is assumed from past data regarding sediment at the reservoir, and shown in Fig. 7.8. The grain size constitution is as follows:

Gravel = 10% Sand = 80% Silt = 10%

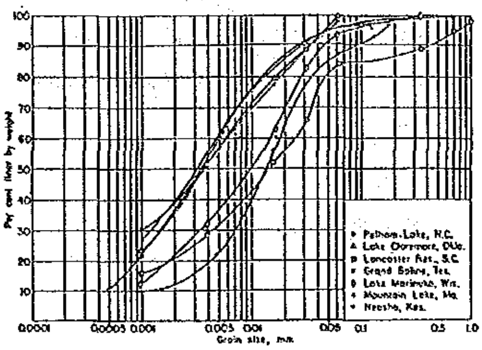


Fig. 7.8 Grain Size Constitution of Suspended Sediment *

* Handbook of Applied Hydrology

(b) Unit volume weight

JICA Study Team obtained unit volume weight of sand and silt data. Unobtainable data will be determined from existing studies.

The unit volume weight of sand and gravel affects the consolidation load, but the consolidation is completed in a comparatively short time. However, fine particles of clay, colloid, etc. will require a longer time. From the past case, the unit volume weight ranges in value according to the grain size of the sediment at the reservoir and the active conditions (under or above water) of the load at that time, as shown in Table 7.9.

Table 7.9 Range of Unit Volume Weight*

(units: ton/m^3)

Grain	Almost submerged	Above water
Clay	0.64 - 0.96	0.96 - 1.28
Silt	0.88 - 1.20	1.20 - 1.36
Mix of clay and silt (equal volume)	0.64 - 1.04	1.04 - 1.36
Mix of sand and silt (equal volume)	1.20 - 1.52	1.52 - 1.76
Mix of clay, silt and sand (equal volume)	0.80 - 1.28	1.28 - 1.60
Sand	1.36 - 1.60	1.36 - 1.60
Gravel	1.36 - 2.00	1.36 - 2.00
Sand and gravel	1.52 - 2.08	1.52 - 2.08

* Handbook of Applied Hydrology

(2) Discharge rate of sediment

When the discharge rate of sediment at the intake is examined, the suspended sediment and the bed-load are also considered. Suspended sediment can be calculated from the sediment record (concentration measurement) and the discharge record. The quantitative record for the flown sand has not been obtained.

Generally flowing sand is 10 to 50% of total sediment rate, and the flowing sand of the Colorado River is 12 to 50% of total sediment rate. The World

Bank study team estimates the flowing sand of the Indus River at the Tarubera dam (Pakistan) spot is 5% of suspended sediment.

(3) Yearly flowing sediment rate

The yearly flowing sediment rate at the intake spot is obtained by converting values taken from the gauging station into catchment area ratios.

Power Plant	Catchment Area (km^2)	River Discharge Rate (10^6 m^3)	Suspended Sediment Rate (10^3 ton)	Flown Sand Rate (10^3 ton)	Sediment Rate (10^3 ton)
San Cancio	220.0	203	40	4	44
Intermediate	228.8	242	48	5	53
Municipal	273.2	246	49	5	54

Average grain size of the flowing sediment is calculated from the unit weight by average grain size diameter as follows.

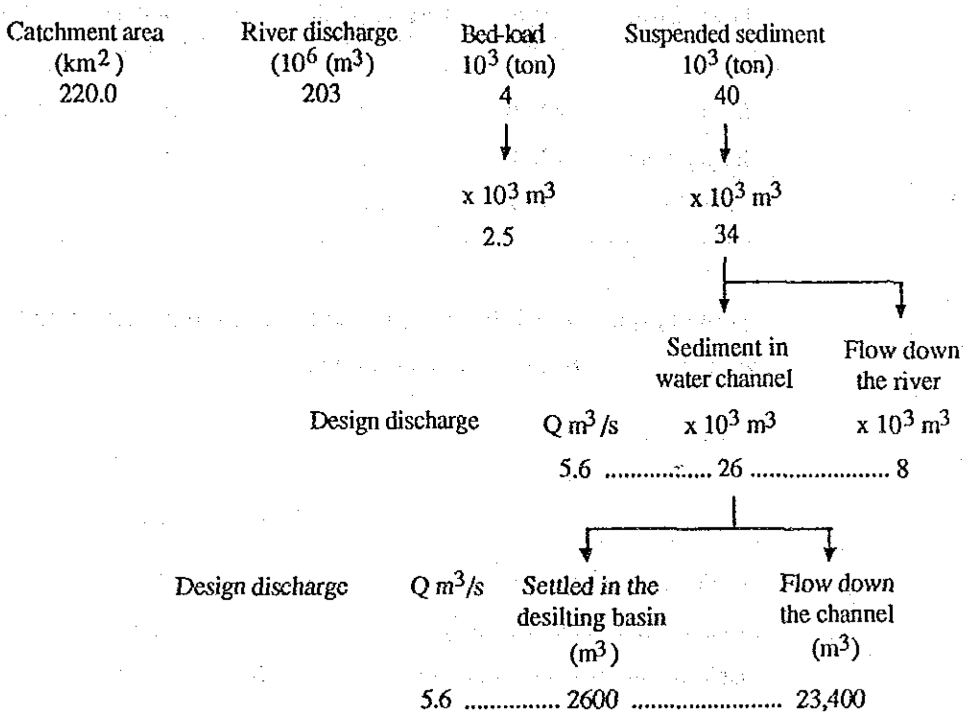
	Bed-load			
	Gravel	Sand	Silt	Total
Grain size constitution(%)	10	80	10	100
Unit volume weight (ton/m^3)	1.70	1.65	1.25	
Unit weight per grain size (ton/m^3)	0.170	1.32	0.125	1.615... 1.62

	Suspended Sediment			
	Sand	Silt	Clay	Total
Grain size constitution(%)	10	60	30	100
Unit volume weight (ton/m^3)	1.65	1.25	0.80	
Unit weight per grain size (ton/m^3)	0.165	0.175	0.155	1.16

All the flowing sands are deposited at the diversion weir and in front of the intake, and do not flow into the channel.

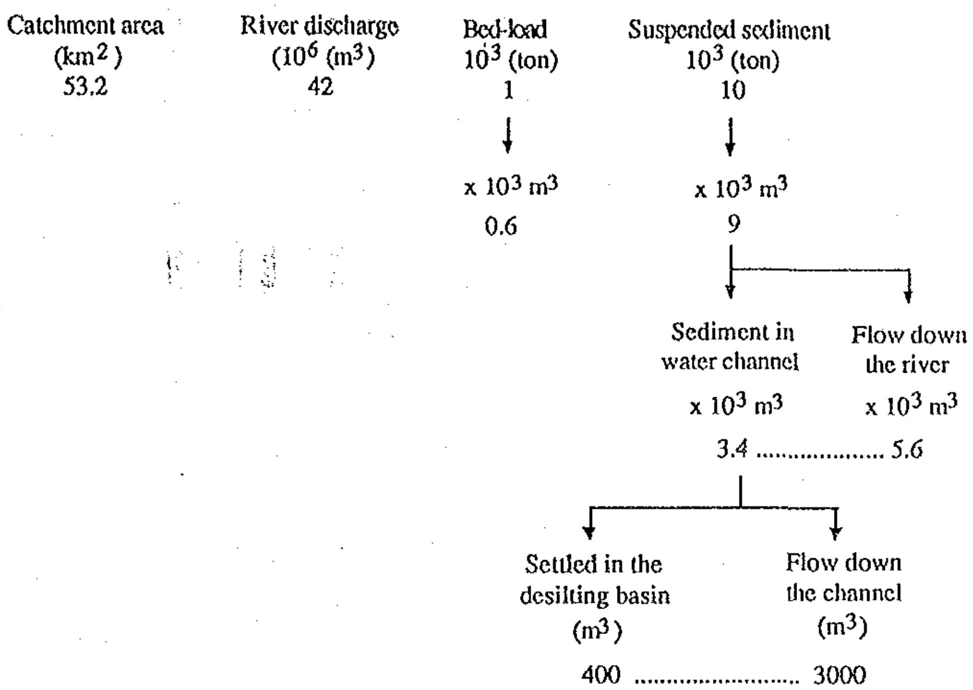
The suspended sediment is contained in the discharge within the range of design discharge, and flows down the channel from the intake. Partial rough particles in the suspended sediment flowing into the channel are removed at the desilting basin, and the remaining suspended sediment is discharged into the river by a water wheel with discharge. Suspended sediment contained in the river discharge exceeding the designed discharge overflows the diversion weir and flows down into the river.

San Cancio



From this analysis, the annual average sediment in front of the diversion weir is calculated to be about 7 m^2/day and sediment settled in the desilting basin 7 m^3/day (if available discharge is 5.6 m^3/s). A counterplan for removing the sediment is under consideration.

Municipal (remaining watershed)



From this analysis, the annual average sediment in front of the diversion weir is calculated to be 7 m^2/day and sediment settled in the desilting basin 2 m^3/day (if available discharge is 1.4 m^3/s). A counterplan for removing the sediment is under consideration.

7.5 Water Quality Analysis

The acidity of the Chinchina River was pH 6.7, but the water has been polluted by waste water from Manizales City, located in the area of the watershed, so the water quality needs to be tested immediately.

CHAPTER 8 GENERATION PLAN

Generation Plan of San Cancio P/P

The planned maximum available discharge of the existing power plant is 5.6 m^3/s. Since the river water utilization factor and the facility utilization factor are 79.5 % and 88.0%, respectively, as shown by the normal flow-duration curve of the intake. This indicates a large discharge capacity, so the study team accepts these values.

Therefore, the rehabilitation of this hydroelectric power plant should increase both the operating capacity and annual generated energy, as well as standardize opertion, inspection, maintenance and management of the facility. Furthermore, equipment wil be standardized to allow for the interchanging of parts with the Intermedia and Municipal power plants (with the same output), located downstream.

Generation Plan of Intermedia P/P

The planned maximum available discharge of the existing power plant is 5.6 m^3/s. Since the river water utilization factor and the facility utilization factor are 79.5 % and 88.0%, respectively, as shown by the normal flow-duration curve of the intake. This indicates a large discharge capacity, so the study team accepts these values.

Therefore, the rehabilitation of this hydroelectric power plant should increase both the operating capacity and annual generated energy, as well as standardize operation, inspection, maintenance and management of the facility. Furthermore, equipment wil be standardized to allow for the interchanging of parts with the San Cancio and Municipal power plants (with the same output), located downstream.

Generation Plan of Municipal P/P

Since the water at the San Cancio P/P is also used for power generation at the Municipal P/P and the Intermedia P/P, the maximum available discharge of (Q = 5.6 m^3/s) for these three P/P is the same. However, since the Municipal P/P is located 5 km downstream from the intake at San Cancio, the downstream catchment area needs to be examined. Based on the rated discharge of 5.6 m^3/s, the maximum available discharge should be set so the facility utilization factor is not less than 50% in the normal flow-duration curve at the intake. The generated output and annual generated energy should be calculated accordingly, so the optimum generation plan can be adopted.

In the existing power plant, there is difference between the theoretically calculated generated output and the existing installed capacity, and operation efficiency is low. These problems should be solved. The standardization of operation, inspection, maintenance and management and advantage of interchangeability of spare parts with upstream-side two power plants should be considered.

8.1 Study of the Alternative Plans

1) San Cancio and Intermedia P/Ps

As previously stated, it is not possible to increase the maximum available discharge of these power plants. Thus, existing facilities should be renovated or replaced without changing the present discharge value of 5.6 m^3/s. Since the installed capacity at the Intermedia P/P is significantly lower than its output, so its installed capacity should be increased accordingly.

2) Municipal P/P

The following two points should be considered for the rehabilitation of this power plant.

- Imbalance between power output and installed capacity

  As in the Intermedia P/P, the installed capacity of this power plant is significantly lower than the output so the installed capacity should be increased accordingly.

- Handling of remaining riverbasin

  As in the San Cancio and Intermedia P/Ps, the designed discharge of the Municipal P/P is 5.6 m^3/s. There are intake facilities for water intake from the remaining riberbasin.

Therefore, the comparative study for the following two cases is conducted.

- Designed discharge: 5.6 m^3/s
- Case that considers the remaining riverbasin

(1) Maximum Available Discharge

Since the intake at the Intermedia P/P is directly connected to the tailrace at the San Cancio P/P, the maximum available discharge at the San Cancio and Intermedia P/Ps becomes equal.

As seen in the typical river flow-duration curve at the intake site of the San Candio P/P (Fig. 8.1 (1)), the value of the maximum available discharge (Q = 5.6 m^3/s) at existing power plant is close to the upper limit as the available discharge of run-of-river type hydroelectric power plant. The results of hydrological analysis indicate that the water flow capacity of the existing open channel is assumed to be equivalent to 5.6 m^3/s.

Therefore, the maximum available discharge at the San Cancio and Intermedia P/Ps is limited to Q = 5.6 m^3/s (present plan).

The available discharge at the Municipal P/P is set to the following two cases:

- Q = 5.6 m^3/s, the maximum available discharge of the present plan (discharge rate in the Intermedia P/P)
- Q = 7.0 m^3/s to which the remaining riverbasin discharge is added

Q = 7.0 m^3/s is the same as maximum available discharge at the San Cancio and Intermedia P/Ps, and corresponds to the discharge which might guarantee 52% throughout the year. (Refer to Fig. 8.1-(2))

Fig-8.1-(1) TYPICAL FLØW DURATIØN CURVE AT INTAKE SITE

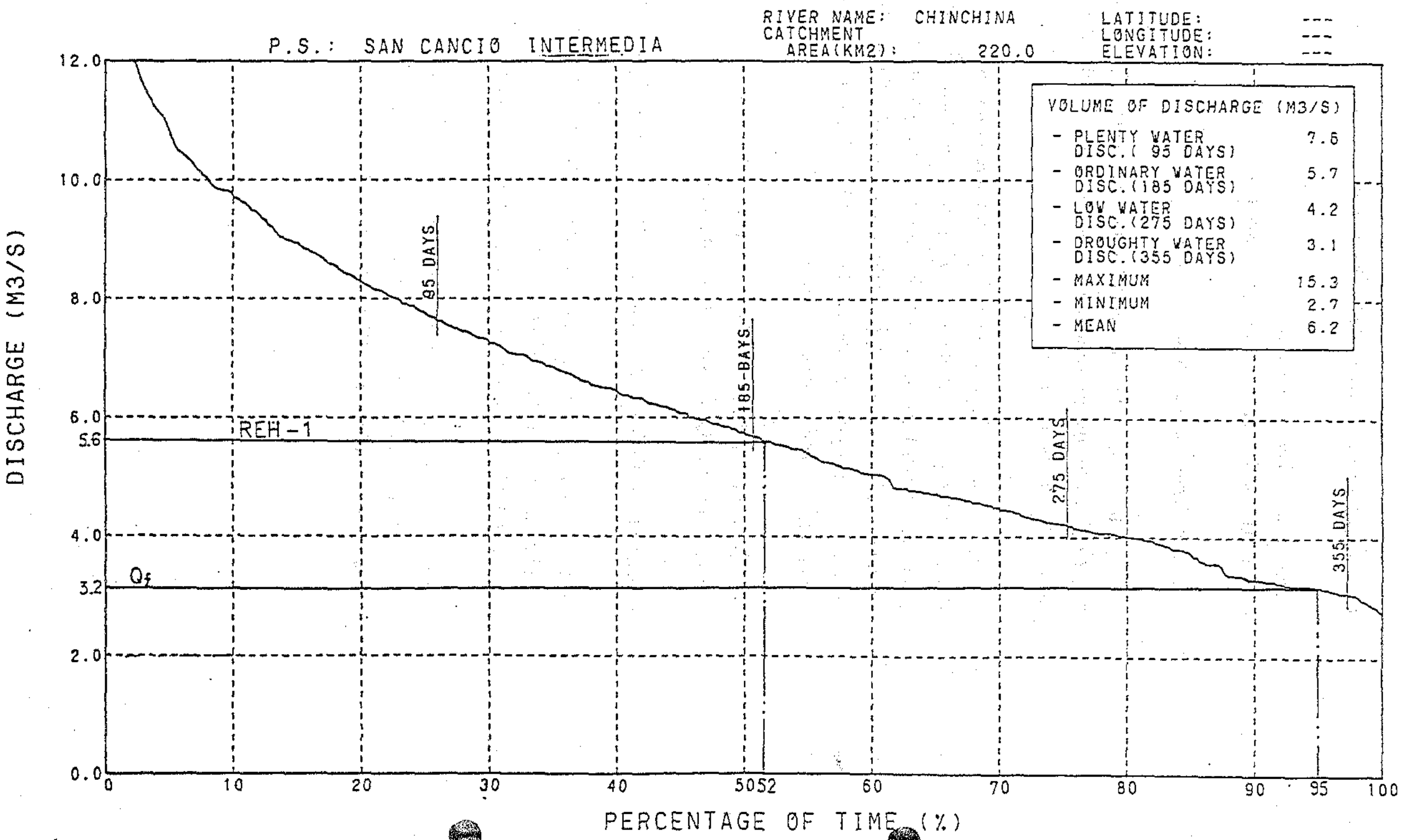
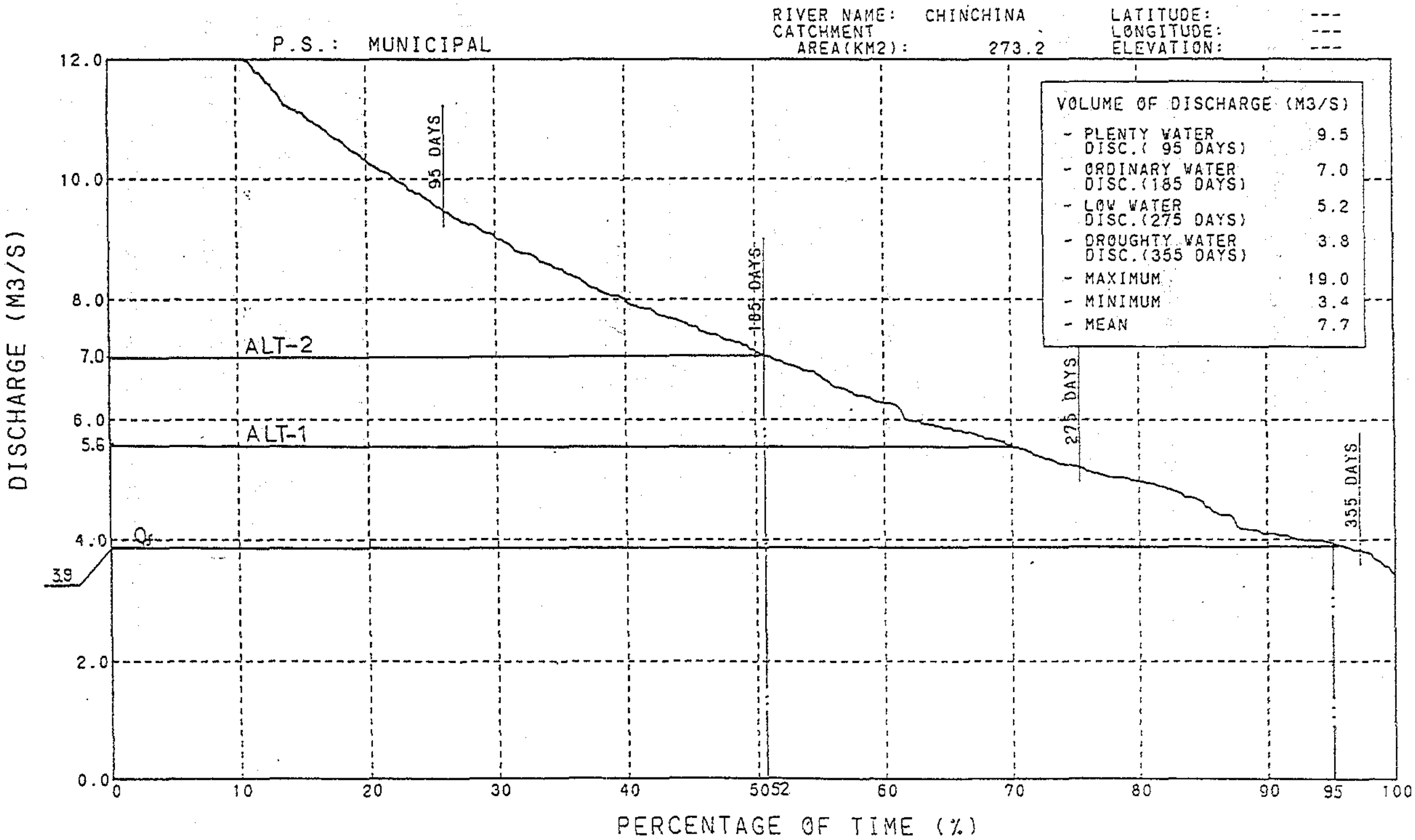


Fig-8.1-(2) TYPICAL FLOW DURATION CURVE AT INTAKE SITE



(2) Net head

Assuming that the net head for determining the turbine output and calculating annual generated energy is constant, the standard net head is calculated as follows:

The net head (He) is calculated by the following formula.

$$He = Hg - H$$

$$H = v^2/2g\,(1+f_1 + f_2I/D + fm) + h = v^2/2g\,(1.85 + f_2I/D) + h$$

where:

- Hg = gross head
- H = total loss of head (m)
- $V^2/2g$ = velocity head (m)
- f_1 = coefficient of inflow loss; 0.1
- f_2 = coefficient of frictional loss; $124.6\,n^2/D^{1/3}$
- I = penstock length (m)
- D = penstock diameter (m)
- fm = loss coefficient at the branched part; 0.75
- h = margin (m)
- n = coefficient of roughness; 0.012

1) San Cancio

Hg = Headtank water level (1906.73) - Discharge level (1846.99)
= 59.74 m

Table 8.1 Calculated Result of Net Head

Q (m/s)	D (m)	I (m)	V (m/s)	$v^2/2g$ (m)	f_2I/D	$v^2/2g(\Sigma f)$ (m)	h (m)	H (m)	He (m)
5.6	1.24	231.1	4.64	1.097	3.11	5.44	0.50	5.94	53.80

Accordingly, the net head is calculated to be 53.80 m.

2) Intermedia

Hg = Headtank Water Level (1841.74) - Discharge level (1780.22)
= 61.52 m

Table 8.2 Calculated Result of Net Head

Q (m/s)	D (m)	I (m)	V (m/s)	$v^2/2g$ (m)	$f_2 l/D$	$v^2/2g(\Sigma f)$ (m)	h (m)	H (m)	He (m)
5.6	1.24	153.5	4.64	1.098	2.07	430	0.42	4.72	56.80

Accordingly, the net head is calculated to be 56.80 m.

3) Municipal

Hg = Headtank water level (1777.00) - Discharge level (1694.80)
= 82.20 m

Table 8.3 Calculated Result of Net Head

Q (m/s)	D (m)	I (m)	V (m/s)	$v^2/2g$ (m)	$f_2 l/D$	$v^2/2g(\Sigma f)$ (m)	h (m)	H (m)	He (m)
5.6	1.52	157.8	3.09	0.487	16.2	1.69	0.51	2.20	80.00
7.0	1.52	157.8	3.86	0.760	1.62	2.64	0.46	3.10	79.10

Accordingly, the net head is calculated to be 79.60 m.

8.2 Generated Output

Theoretical output obtained from available discharge (Q) and the standard net head (H_e) is multiplied by the resultant efficiency coefficient of the equipment, and the generated output is calculated by the following formula.

$$P = 9.8 \times Q \times H_e \times \eta$$

where:

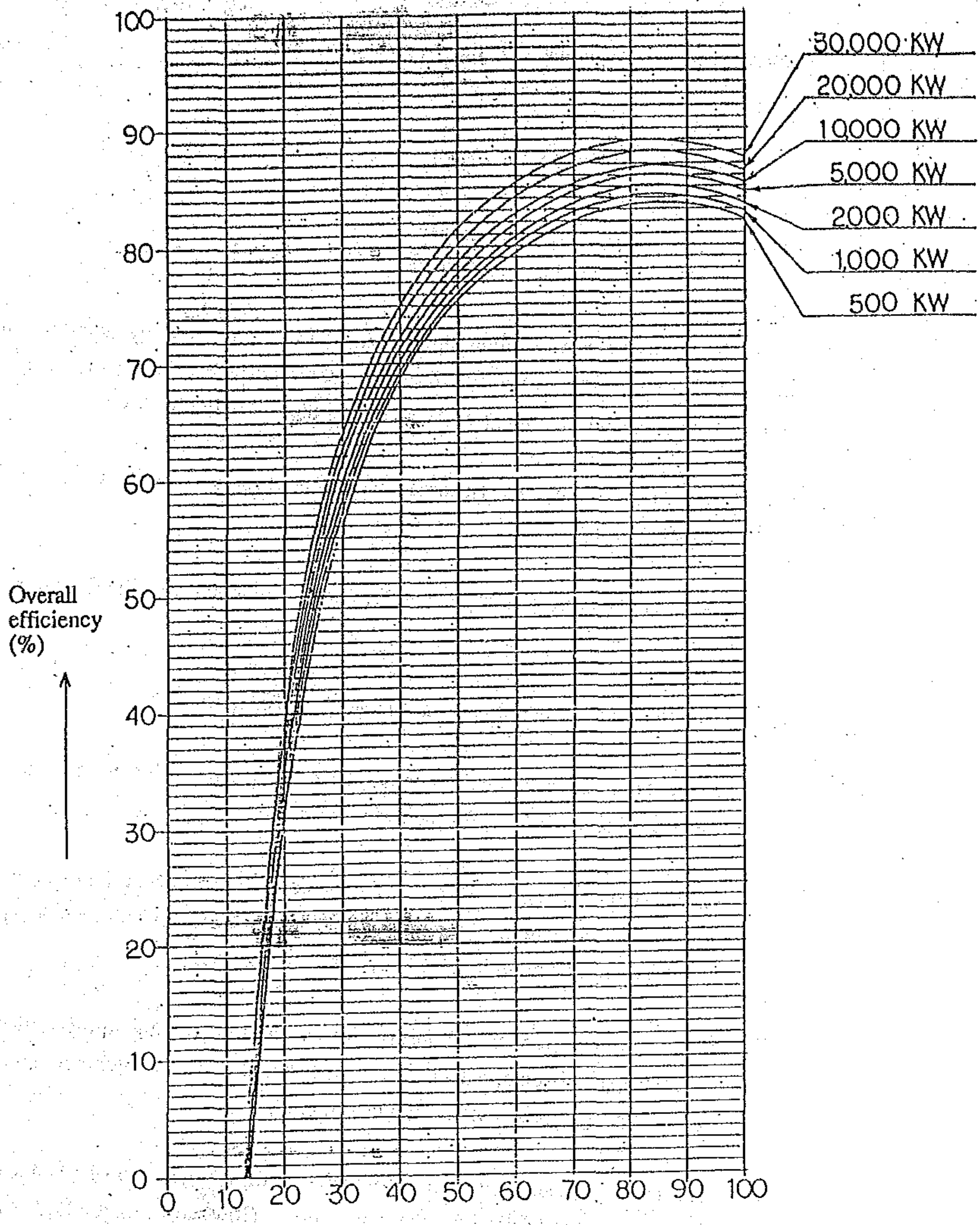
P	=	generated output (kW)
Q	=	arbitrary available discharge (m^3/s)
He	=	standard net head (m)
η	=	resultant efficiency of turbine and generator
9.8	=	constant (acceleration of gravity, m/s^2)

Resultant efficiency (η) is the value representing total efficiency multiplied by turbine efficiency (ηt) and generator efficiency (ηg), and corresponds to the value of the maximum available discharge ratio 100% in the resultant efficiency curve as shown in Fig. 8.2. Table 8.4 shows the calculation result of the generated output for the alternative plans.

Table 8.4 Calculation of Generated Output

Item / Alternative plan	①	②	③	④	⑤
	Available discharge Q (m^3/s)	Standard net head He (m)	9.8 x ① x ② Theoretical output (kW)	Resultant efficiency η	③ x ④ Generated output P (kW)
San Cancio	5.6	53.8	2,952	0.830	2,400
Intermedia	5.6	56.8	3,117	0.830	2,500
Municipal (ALT-1)	5.6	79.6	4,368	0.830	3,600
Municipal (ALT-2)	7.0	79.6	5,460	0.835	4,500

Fig. 8.2 Resultant Efficiency Curve of Francis Turbine and Generator



(Source: The above curve is drawn according to the study standard for formulation of hydroelectric development plan (March, 1981).

8.3 Annual Potential Generated Energy

Generated energy is calculated by the following formula.

$$E = P \times t \text{ (kWh)}$$
$$= 9.8 \times Q \times He \times \eta \times t$$

where: P = generated output (kW)
t = operation time (hour)

Assuming that the power plant operation is not interrupted by accident, nor suspended for maintenance, inspection and repair purposes during the year, the annual potential generated energy is calculated by the following methods.

(1) Using daily discharge in discharge data plus net head and resultant efficiency at that daily discharge

(2) Combining hydrological regime and resultant efficiency from the flow-duration curve

(3) Using the generating output-to-available discharge ratio

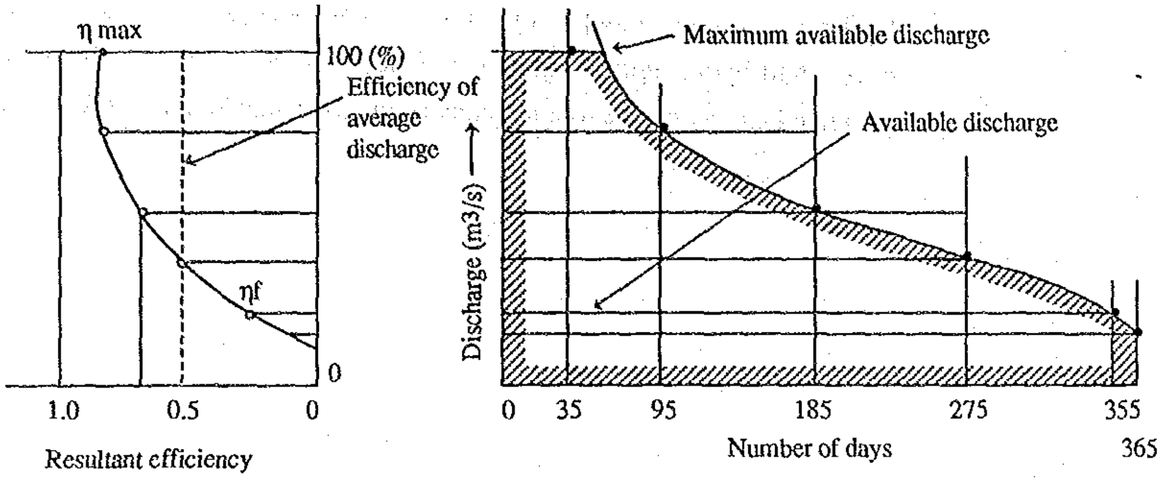
For the calculation of the annual potential generated energy at this project site, item (2) as mentioned above is used for the following reasons.

① Instead of recorded observations at the intake site of this power plant, converted data from the Bocatoma gauging station operated by CHEC which is located at about 0.6 km upstream is used as discharge data.

② Since there are no recorded observations at the Bocatoma gauging station and the intake site, discharge data is converted according to the catchment area ratio at the above gauging station and intake site.

③ The average generating output-to-available discharge ratio of (3) and flow-duration curve are used for the calculation. However, this method is not as accurate as method (2).

Hydrological regime and resultant efficiency are combined from the flow-duration curve, and hydrological regime-efficiency method, by which the annual potential generated energy can be roughly calculated, is calculated in the following.



Max. available discharge = m³/s Net head = m

① Day	② Number of days	③ Available discharge (m^3/s)	④ Burden ratio Available discharge / Max. available discharge	⑤ Resultant efficiency η	⑥ Generating power (kW)	⑦ Average power (kW)	⑧ Generated energy (kWh)
Max.							
95	95-						
185	185-95 = 90						
275	275-185 = 90						
355	355-275 =80						
365	365-355 = 10						
Total	365					( )	

① Possible intake-water days of maximum available discharge are inserted for the day order ①.
② Represents the difference of the day order of calculation stage and right above stage. This example employed hydrological regime representative days as a matter of convenience.
③ The discharge of the day order topped out by maximum available discharge shall be an available discharge.
④ Available discharge divided by maximum available discharge shall be input load factor, and the resultant efficiency ⑤ shall be read and entered.
⑥ $9.8 \times Q \times H \times \eta$
⑦ Mean value of generated output of calculation stage and right above stage.
⑧ ⑦ x ② x 24 is the generated energy for calculated days, and the total value becomes yearly possible generated energy.

Fig. 8.3 Calculation Procedure of Annual Potential Generated Energy by Hydrological Regime-Efficiency Method

8.3.1 Calculation of Annual Potential Generated Energy

The annual potential generated energy for respective alternative plans is calculated according to the hydrological regime-efficiency method, with the following results.

Table 8.5 Annual Potential Generated Energy

Item / Alternative plan	Max. available discharge (m^3/s)	Rated output (kW)	Number of units	Annual potential generated energy (MWh)
San Cancio	5.6	1,200	2	18,471
Intermedia	5.6	1,250	2	19,743
Municipal (ALT-1)	5.6	1,800	2	29,944
Municipal (ALT-2)	7.0	2,250	2	34,767

Table 8.6-(1) Calculation of Annual Potential Generated Energey (San Cancio)

Max. available discharge: 2.8 m^3/s x 2 units
Standard net head (H): 53.8 m

Turbine type: Francis turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	187	5.6	1.000	0.830	2,450	2,450	10,995
192	5	5.5	0.982	0.832	2,412	2,431	291
200	8	5.4	0.964	0.835	2,377	2,394	459
205	5	5.3	0.946	0.837	2,333	2,357	282
210	5	5.2	0.928	0.839	2,300	2,319	278
215	5	5.1	0.910	0.840	2,258	2,279	273
220	5	5.0	0.892	0.841	2,217	2,237	268
225	5	4.8	0.857	0.844	2,135	2,176	261
234	9	4.7	0.839	0.843	2,088	2,111	455
244	10	4.6	0.821	0.842	2,042	1,022	245
252	8	4.5	0.803	0.841	1,995	2,018	387
258	6	4.4	0.785	0.840	1,948	1,971	283
265	7	4.3	0.767	0.837	1,897	1,922	322
270	5	4.2	0.750	0.836	1,851	1,874	224
277	7	4.1	0.732	0.833	1,800	1,825	306
289	12	4.0	0.714	0.831	1,752	1,776	511
298	9	3.9	0.696	0.827	1,700	1,726	372
304	6	3.8	0.678	0.823	1,648	1,674	241
310	6	3.7	0.660	0.820	1,599	1,623	233
315	5	3.6	0.642	0.814	1,545	1,572	188
320	5	3.4	0.607	0.805	1,443	1,494	179
325	5	3.3	0.589	0.798	1,388	1,415	169
335	10	3.2	0.571	0.791	1,334	1,361	326
348	13	3.1	0.553	0.786	1,284	1,309	433
356	8	3.0	0.535	0.777	1,228	1,256	241
360	4	2.9	0.517	0.767	1,172	1,200	115
365	5	2.7	0.482	0.750	1,067	1,119	134
Total	365	-	-	-	-	(1,181)	18,471

Table 8.6-(2) Calculation of Annual Potential Generated Energey (Intermedia)

Max. available discharge: 2.8 m³/s x 2 units
Standard net head (H): 56.8 m

Turbine type: Francis turbine

Day	Number of days	Available discharge (m³/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	187	5.6	1.000	0.830	2,587	2,587	11,610
192	5	5.5	0.982	0.832	2,547	2,567	308
200	8	5.4	0.964	0.835	2,509	2,528	485
205	5	5.3	0.946	0.837	2,469	2,489	298
210	5	5.2	0.928	0.839	2,428	2,448	293
215	5	5.1	0.910	0.840	2,384	2,406	288
220	5	5.0	0.892	0.841	2,340	2,362	283
225	5	4.8	0.857	0.844	2,255	2,297	275
234	9	4.7	0.839	0.843	2,205	2,230	481
244	10	4.6	0.821	0.842	2,155	2,180	523
252	8	4.5	0.803	0.841	2,106	2,130	408
258	6	4.4	0.785	0.840	2,057	2,081	299
265	7	4.3	0.767	0.837	2,003	2,030	341
270	5	4.2	0.750	0.836	1,954	1,978	237
277	7	4.1	0.732	0.833	1,901	1,927	323
289	12	4.0	0.714	0.831	1,850	1,875	540
298	9	3.9	0.696	0.827	1,795	1,822	393
304	6	3.8	0.678	0.823	1,740	1,767	254
310	6	3.7	0.660	0.820	1,688	1,714	246
315	5	3.6	0.642	0.814	1,631	1,659	199
320	5	3.4	0.607	0.805	1,523	1,577	189
325	5	3.3	0.589	0.798	1,465	1,494	179
335	10	3.2	0.571	0.791	1,408	1,436	344
348	13	3.1	0.553	0.786	1,356	1,382	431
356	8	3.0	0.535	0.777	1,297	1,326	254
360	4	2.9	0.517	0.767	1,238	1,267	121
365	5	2.7	0.482	0.750	1,127	1,182	141
Total	365	-	-	-	-	(1,953)	19,743

Table 8.6-(3) Calculation of Annual Potential Generated Energey (Municipal)

① Alternative Plan (ALT-1)

Max. available discharge: 2.8 m^3/s x 2 units — Turbine type: Francis turbine
Standard net head (H): 79.6 m

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	252	5.6	1.000	0.830	3,625	3,625	21,924
256	6	5.5	0.982	0.832	3,569	3,597	345
262	4	5.4	0.964	0.835	3,517	3,543	510
265	3	5.3	0.946	0.837	3,460	3,488	251
271	6	5.2	0.928	0.839	3,403	3,431	494
277	6	5.1	0.910	0.840	3,341	3,372	485
285	8	5.0	0.892	0.841	3,280	3,310	635
295	10	4.9	0.875	0.842	3,218	3,249	779
301	6	4.8	0.857	0.844	3,160	3,189	459
305	4	4.7	0.839	0.843	3,090	3,125	300
310	5	4.6	0.821	0.842	3,021	3,055	366
315	5	4.4	0.785	0.840	2,883	2,952	354
320	5	4.2	0.750	0.836	2,739	2,811	337
326	6	4.1	0.732	0.833	2,664	2,701	388
335	9	4.0	0.714	0.831	2,592	2,628	567
346	11	3.9	0.696	0.827	2,515	2,553	673
352	6	3.8	0.678	0.823	2,439	2,477	356
358	6	3.7	0.660	0.820	2,366	2,402	345
360	2	3.6	0.642	0.814	2,285	2,325	111
365	5	3.4	0.607	0.805	2,135	2,210	265
Total	365					(3,002)	29,944

Table 8.6-(4) Calculation of Annual Potential Generated Energey (Municipal)

② Alternative Plan (ALT-2)

Max. available discharge: 3.5 m^3/s x 2 units
Standard net head (H): 79.6 m

Turbine type: Francis turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	185	7.0	1.000	0.835	4,559	4,559	20,241
190	5	6.9	0.985	0.838	4,510	4,534	544
195	5	6.8	0.971	0.840	4,455	4,482	537
200	5	6.7	0.957	0.843	4,405	4,430	531
205	5	6.6	0.942	0.846	4,355	4,380	525
210	5	6.4	0.914	0.848	4,233	4,294	515
216	6	6.3	0.900	0.850	4,177	4,205	605
222	6	6.2	0.885	0.850	4,111	4,144	596
225	3	6.0	0.857	0.850	3,978	4,044	291
230	5	5.9	0.842	0.850	3,912	3,945	473
240	10	5.8	0.828	0.850	3,845	3,878	930
246	6	5.7	0.814	0.850	3,779	3,812	548
252	6	5.6	0.800	0.850	3,713	3,746	539
260	8	5.5	0.785	0.849	3,642	3,677	705
265	5	5.3	0.757	0.845	3,493	3,567	428
271	6	5.2	0.742	0.843	3,419	3,456	497
277	6	5.1	0.728	0.841	3,345	3,382	487
285	8	5.0	0.714	0.839	3,272	3,308	635
295	10	4.9	0.700	0.835	3,191	3,231	775
301	6	4.8	0.685	0.832	3,081	3,136	451
305	4	4.7	0.671	0.829	3,039	3,060	293
310	5	4.6	0.657	0.825	2,960	2,999	359
315	5	4.4	0.628	0.818	2,807	2,883	345
320	5	4.2	0.600	0.808	2,647	2,727	327

(con'd)

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
326	6	4.1	0.585	0.803	2,568	2,568	369
335	9	4.0	0.571	0.799	2,493	2,530	546
346	11	3.9	0.557	0.793	2,412	2,452	647
352	6	3.8	0.542	0.787	2,332	2,372	341
358	6	3.7	0.528	0.781	2,254	2,293	330
360	2	3.6	0.514	0.774	2,173	2,213	106
365	5	3.4	0.485	0.760	2,015	2,094	251
Total	365					(2,360)	34,767

CHAPTER 9 REHABILITATION PLAN

Since the present facilities-rehabilitating and output increase plans are not based on scrap and build methods, the power-generating capacity will be recovered or improved by making maximum use of existing facilities. The rehabilitation plan will be formulated according to standards established by ISA (Interconexion Electrica SA) in June, 1987.

9.1 Formulation of Rehabilitation Plans

As previously stated in 4.3, three P/Ps, with the exception of the penstocks, needs to be improved or newly constructed. The generating facilities and transformers also require new procurement or replacement with the new ones.

In the rehabilitation plan, the period when the rehabilitation construction suspends the operation of the P/Ps must be minimized because they are presently in operation. In addition, P/P located on the down stream side should be rehabilitated earlier to avoid any trouble which the construction for rehabilitating the P/P located upstream may cause to the P/P located downstream.

Shown below are the constructions which may suspend the P/Ps for a long time.

- Removal/reconstruction of the existing generating equipment, and removal/replacement of the foundation
- Repair of intake facilities in the San Cancio P/P
- Expansion of head tank in the San Cancio P/P
- Reconstruction of conduction channel in the Intermedia P/P
- Expansion of head tank in the Municipal P/P

Since it is impossible to continue to supply electricity during the repair of the generating equipment and the foundation, other civil structures will be rehabilitated at the same time. It must be taken into consideration that this may not suspend the operation of the power plant on the downstream.

Intake Facilities in the San Cancio P/P

As the concrete structure of the intake facilities in the San Cancio P/P is in poor condition and sand accumulates to the top of the crest, the intake facilities require repairing.

Since they are located upstream from the Intermedia and Municipal P/Ps, the repair may stop the operations of all three power plants. However, this situation will be avoided if they are newly constructed downstream from the present position while the existing diversion weir is used as a dam built to arrest the shifting of the sand.

Head Tank in the San Cancio P/P

To avoid the suspension, the head tank will be expanded while a bypass is built and water flows through the existing spillway.

Conduction Channel in the Intermedia P/P

Since there is unlined conduction channel in the Intermedia P/P, the conduction channel should be constructed of concrete with covers, using concrete.

There are two ways to built a concrete conduction channel. One is by lining the existing channel with concrete, and the other is by newly constructing a channel along the existing channel.

Table 9.1 shows the comparison between the above two ways.

Table 9.1 Comparison of Alternative Rehabilitation Plans

	Lining Plan	New Channel Plan
Construction period (Intermedia & Municipal)	34 months	23 months
Power generation-stoppage period		
Intermedia	7 units/month	14 units/month
Municipal	15 units/month	32 units/month
Loss caused by selling electricity (1)	60.8 x 10^6 pesos	30.4 x 10^6
Conduction channel construction	Excavation amount is smaller compared with New Channel Plan	10,000 m^3 needed to be more excavation compared with Lining Plan
Direct cost for conduction channel construction in Intermedia P/P (2)	227.0 x 10^6 pesos	262.1 x 10^6 pesos
(1) + (2)	287.8 x 10^6 pesos	292.5 x 10^6 pesos
Processes of constructions	Various constructions should be completed in a short period	Constructions will not concentrate for a short period
Investing period	A few years	Same as left

Taking the above data into account, the New Channel Plan is adopted though it will cost higher than the other plan.

Table 9.2 shows the rehabilitation plans of the San Cancio and Intermedia P/Ps (when Q is set to 5.6 m^3/s) and the Municipal P/P (when Q is set to 5.6 or 7.0 m^3/s).

For each rehabilitation plan the total costs, including construction costs per kW output and generating costs are calculated and compared. The optimum rehabilitation plan is then chosen.

Table 9.2 Rehabilitation plans for San Cancio, Intermedia and Municipal Power Plants

Item		Power Plant			
		San Cancio	Intermedia	Municipal	
				ALT-1	ALT-2
Available discharge, Q (m^3/s)		5.6	5.6	5.6	7.0 (Discharge at remaining river basin: 1.4)
Maximum output, P (kW)		2,400	2,500	3,600	4,500
Facility utilization factor (%)		88	88	94	88
Rehabilitation and improvement plan	Diversion weir	Modify and install sand trap gate or facility	-	-	Modify to permanent structure
	Intake	Change in facility design to secure discharge of 5.6 m/s	Leave as it is	Leave as it is	Partial improvement
	Desilting basin	Partial improvement	Partial improvement (together with head tank)	Partial improvement	Partial improvement
	Conduction channel	Leave as it is except cover placement	Modify to concrete channel entirely	Leave as it is except cover placement	
	Head tank	Increase adjusting capacity by modification	Partial improvement	Modify to suitable scale	Modify to suitable scale
	Penstocks	Leave as it is	Leave as it is	Leave as it is	Leave as it is
	Generating Equipment	Replace with new one	Replace with new one	Replace with new one	Replace with new one
	Powerhouse building	Partially renovate the existing building and improve only foundation section for turbine.			

9.2 Estimated Rehabilitation Construction Costs

The estimated construction costs can be calculated from the estimated costs for generating equipment and civil construction. This can then be divided into the foreign currency portion and the local currency portions and calculated at the current exchange rates (Sep. 1989), based on the U.S. dollar.

9.2.1 Estimated Generating Equipment Costs

According to the ISA valuation standard, CIF costs of generation equipment are calculated based on the FOB from Japan. The generating equipment specifications and FOB costs are shown in Table 9.3.

The CIF/FOB ratio for the CIF costs is 1.12, as shown in Table 9.4

Table 9.3 Generating Equipment Specifications and FOB Costs

Item	Alternative			
	San Cancio	Intermedia	Municipal	
			ALT-1	ALT-2
1. Specifications				
Design discharge (m^3/s)	2.8	2.8	2.8	3.5
Net head (m)	53.8	56.8	79.6	79.6
Theoretical output (kW)	1,476	1,558	2,184	2,730
Turbine type	HF*	HF*	HF*	HF*
Turbine output (kW)	1,360	1,360	1,900	2,400
Generator power factor	0.9	0.9	0.9	0.9
Generator output (kVA)	1,400	1,400	2,000	2,500
Main transformer capacity (kVA)	2,800	2,800	4,000	5,000
2. FOB costs (US$ 1000)				
Generating Equipment				
(1) Turbine etc.	370.7	370.7	461.45	497.85
(2) Generator etc.	200.7	200.7	242.85	249.25
(3) = (1)+(2) Sub-total:	571.4	571.4	704.3	747.1
(4) Number of units	2	2	2	2
(5) = (3)x(4) Subtotal:	1,142.8	1,142.8	1,408.6	1,494.2
(6) 4.16 kV switchgear etc.	97.9	97.9	97.9	97.9
(7) transformer	72.8	72.8	92.8	107.1
(8) = (5)+(6)+(7) Total:	1,313.5	1,313.5	1,599.3	1,699.2

HF: Horizontal Francis

Table 9.4 Implementation Cost of Generating Equipment

(Units: US$1,000)

		Alternative							
		San Cancio		Intermedia		Municipal			
						ALT-1		ALT-2	
		A	B	A	B	A	B	A	B
1) FOB cost		1,313.5	-	1,313.5	-	1,599.3	-	1,699.2	-
2) Transportation costs, insurance	1) x 0.12	157.6	-	157.6	-	191.9	-	203.9	-
3) Tax	1) x 0.223	-	292.9	-	292.9	-	356.6	-	378.9
4) Value-added tax	1) x 0.134	-	176.0	-	176.0	-	214.3	-	227.7
5) Others	1) x 0.22	-	289.0	-	289.0	-	351.8	-	373.8
6) Subtotal		1,471.1	757.9	1,471.1	757.9	1,791.2	922.7	1,903.1	980.4
7) Contingency	1) x 0.17	223.3	-	223.3	-	271.9	-	288.9	-
8) Eng. fees	1) x 0.149	195.7	-	195.7	-	238.3	-	253.2	-
9) Subtotal	6) + 7) + 8)	1,890.1	757.9	1,890.1	757.9	2,301.4	922.7	2,455.2	980.4
10) Total		2,648		2,648		3,224.1		3,425.6	

Note: A = foreign currency portion
B = local currency portion

9.2.2 Estimation of Civil Construction Cost

The work volume for the rehabilitation or improvement of the main structures is multiplied by the unit costs (as shown in Table 5.2) as decided by CHEC. The civil construction cost estimates are in the local currency base.

The total civil construction costs for each rehabilitation plan are calculated and compared as shown in Table 9.5.

Table 9.5 Estimation of Civil Construction Cost

(unit: 10^6 pesos)

Item	San Cancio	Intermedia	Municipal	
			ALT-1	ALT-2
Diversion weir and intake construction	61.1	0	0	31.9
Desilting basin construction	12.4	0	9.8	9.8
Conduction channel construction	43.6	262.1	46.9	76.6
Head tank construction	25.6	9.3	55.6	63.3
Penstock construction	0	6.2	0	0
Foundation of equipment construction	13.3	14.6	17.9	19.4
Powerhouse building construction	1.2	2.2	1.2	1.2
Temporary facility construction	0	0	0	0
Other construction	3.0	3.0	3.2	3.2
① Subtotal	160.2	297.4	134.6	205.4
② Contingency (① x 0.15)	24.0	44.6	20.2	30.8
③ Engineering fees ((① + ②) x 0.10)	18.4	34.2	15.5	23.6
④ Total (① + ② + ③)	202.6	376.2	170.3	259.8
⑤ Output loss	28.0	10.6	19.8	19.8
⑥ Grand total (④ + ⑤)	230.8	386.8	190.1	279.6

9.3 Comparison of Economic Indices

To compare the economic indices of the construction cost per kW and the generating cost per kW, the basic conditions for all the alternative plans are as follows.

(1) Exchange rate based on September 1989, is as follows.

US$ 1 = ¥140
US$ 1 = 369.4 pesos
1 peso = ¥0.379

(2) The life of new generating equipment, as well as repaired and reconstructed structures is 25 years.

(3) The interest rate is divided into the foreign currency and local currency portions under the following conditions.

- The foreign currency portion is based on an annual interest rate of 10% (unredeemable for 4 years), with repayment of the principal in equal annual amounts over 25 years.

- The local currency portion is based on an annual interest rate of 21% (unredeemable for 1 year), with repayment of the principal in equal annual amounts over 8 years.

(4) The operation, maintenance and management costs of hydroelectric power plants per year is US$4 per installed-capacity (kW).

9.3.1 Comparison of Construction Cost per kW

A comparison of the construction cost per kW is shown in Table 9.6. The Municipal's ALT - 2 plan calls for US$ 1,350/kW per increase in power output, which is the lowest cost.

Table 9.6 Comparison of Construction Costs per kW

Item		Alternative Plans			
		San Cancio	Intermedia	Municipal	
				ALT-1	ALT-2
Existing equipment output (kW)					
Rated output	Po	2,320	1,120	2,112	2,112
Available output	Pe	1,750	900	1,400	1,400
Post-rehabilitation output	P_1 (kW)	2,400	2,500	3,600	4,500
Recovered/increased output $\Delta P = P_1 - Pe$ (kW)		650	1,600	2,200	3,100
Rehabilitation work cost	(US$1,000)				
Foreign currency portion Cf		1,900	1,900	2,300	2,450
Local currency portion C		1,350	1,800	1,400	1,750
Total C = Cf + C		3,250	3,700	3,700	4,200
Construction cost per kW	(US$/kW)				
C/P_1		1,350	1,500	1,050	950
$C/\Delta P$		5,035	2,310	1,700	1,350

9.3.2 Comparison of Generating Cost per kWh

The generating cost per kWh is calculated from the following equation:

$$\text{Generating cost} = \frac{\text{Total cost at generating terminal}}{\text{Supplied output per year}}$$

where

the supplied output per year = annual potential generated energy (E) x utilization factor
= 0.95 E

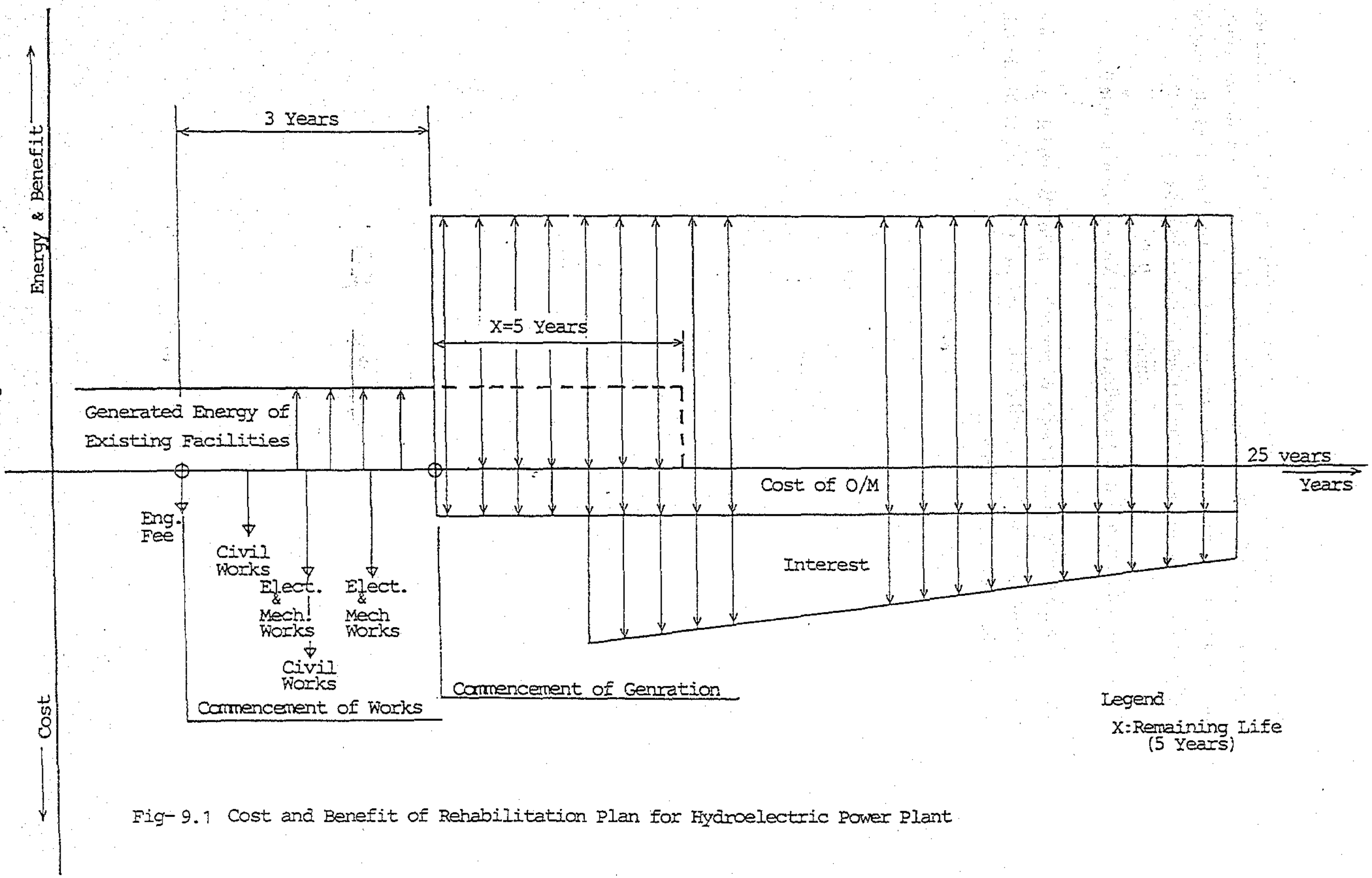


Fig- 9.1 Cost and Benefit of Rehabilitation Plan for Hydroelectric Power Plant

The annual total cost at generating terminal is shown in Figure 9.1. Since the estimated service life of the hydroelectric power plant is 25 years, the operation, maintenance and management costs (AOM per year = US$4 per kW) plus interest payments for the construction are totaled and divided by 25 years.

The results of the calculation of generating cost per kWh are shown in Table 9.7.

The generating cost per annually supplied power is 13 mills/kWh and the generating cost per increased-power is 15 mills/kWh according to ALT - 2 of Municipal, showing the lowest costs repectively.

Table 9.7 Comparison of Generating Cost per kWh

Item		Alternative Plans			
		San Cancio	Intermedia	Municipal	
				ALT-1	ALT-2
Existing equipment capacity:					
Power output	Po (kW)	2,320	1,120	2,112	2,112
Energy	Ee (GWh)	8.44	3.33	5.94	5.94
Rehabilitation plan:					
Power output	P_1 (kW)	2,400	2,500	3,600	4,500
Generated energy	E_1 (GWh)	18.5	19.7	29.9	34.8
Recovered/increased power					
Output	$\Delta P = P_1 - Pc$ (kW)	650	1,600	2,200	3,100
Energy	$\Delta E = E_1 - Ec$ (GWh)	10.1	16.4	24.0	28.9
Total of expenses at generating terminal: (US$ 1,000)					
Construction work cost					
Foreign currency portion Cf_1		1,900	1,900	2,300	2,450
Local currency portion $C\ell_1$		1,350	1,800	1,400	1,750
Construction cost total $C_1 = Cf_1 + C\ell_1$		3,250	3,700	3,700	4,200
Interest payment C_2					
Foreign currency portion Cf_2		3,043.1	3,043.1	3,705.3	3,936.8
Local currency portion $C\ell_2$		1,404.8	1,833.9	1,460.3	1,765.1
Total $C_2 = Cf_2 + C\ell_2$		4,447.9	4,877	5,165.6	5,701.9
AOM C_3 = US$4 x Pl x 25 years		240	250	360	450
Total $\Sigma Ci = C_1 + C_2 + C_3$		7,960.7	8,822.1	9,264.3	10,334.4
Average annual cost $C = \Sigma Ci/25$		318.4	352.9	370.6	413.3
Generating cost per annually supplied energy (mills/kWh)					
Per E_1	$C/(E_1 \times 0.95)$	18	19	13	13
Per ΔE	$C/(\Delta E \times 0.95)$	33	23	16	15