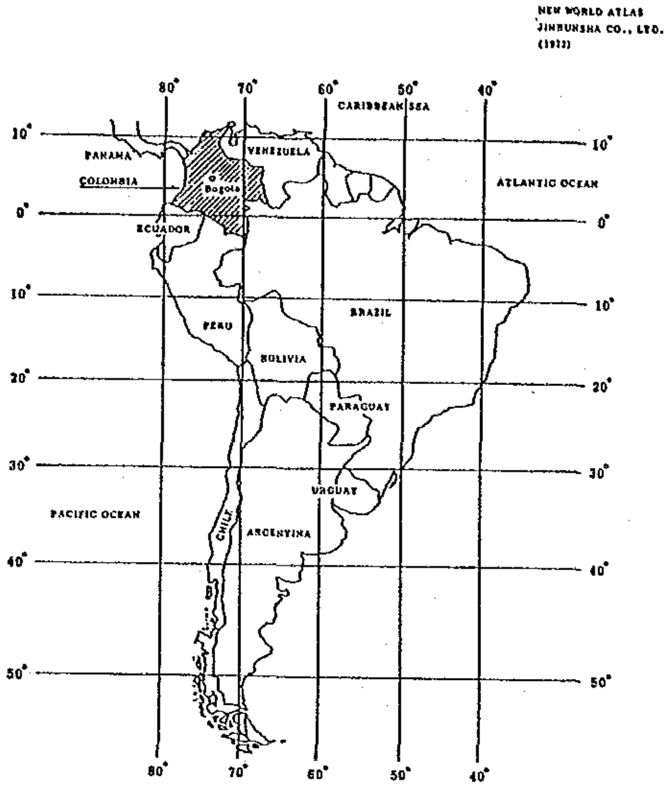
FEASIBILITY STUDY
ON
SMALL-SCALE POWER PLANTS
REHABILITATION PROJECT
IN
THE REPUBLIC OF COLOMBIA

ZARAGOZA HYDROELECTRIC POWER PLANT

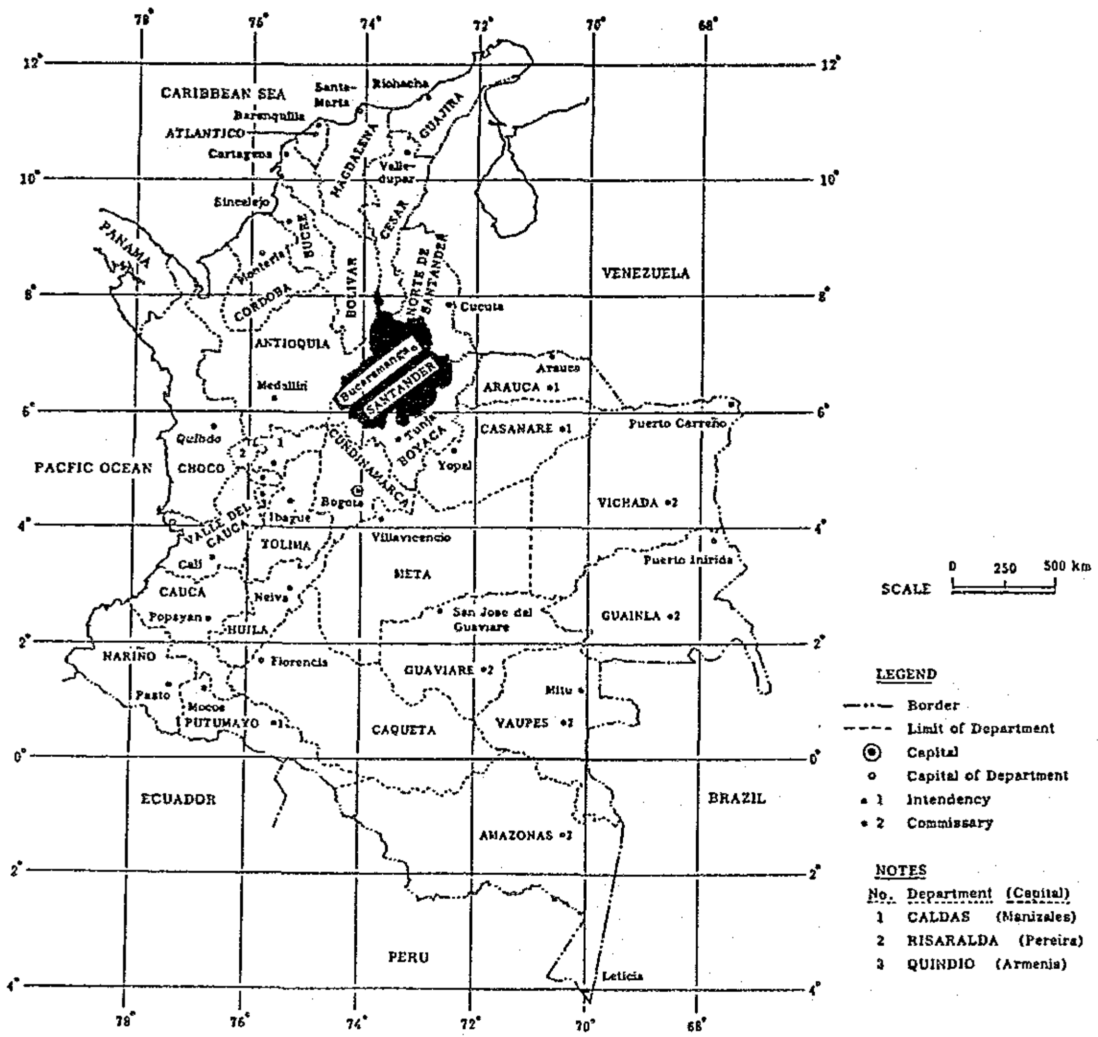
MARCH 1990

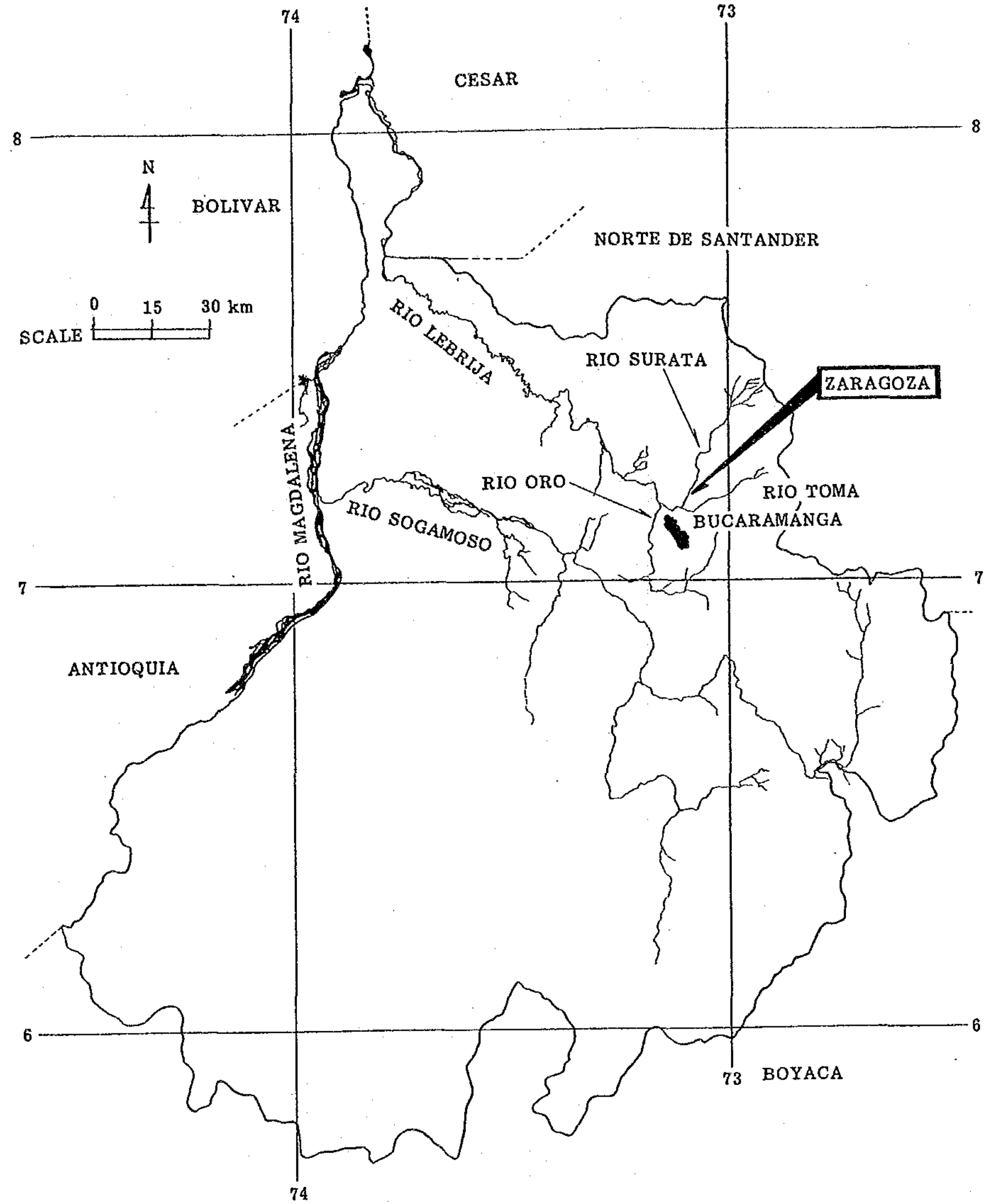
Japan International Cooperation Agency

MAP OF SOUTH AMERICA

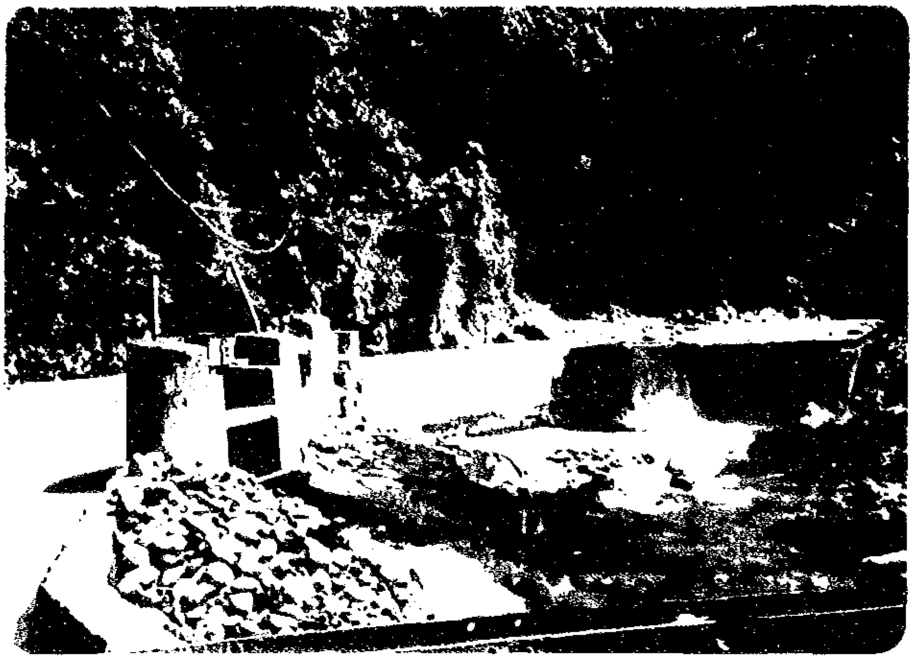


POLITICAL DIVISION IN THE REPUBLIC OF COLOMBIA



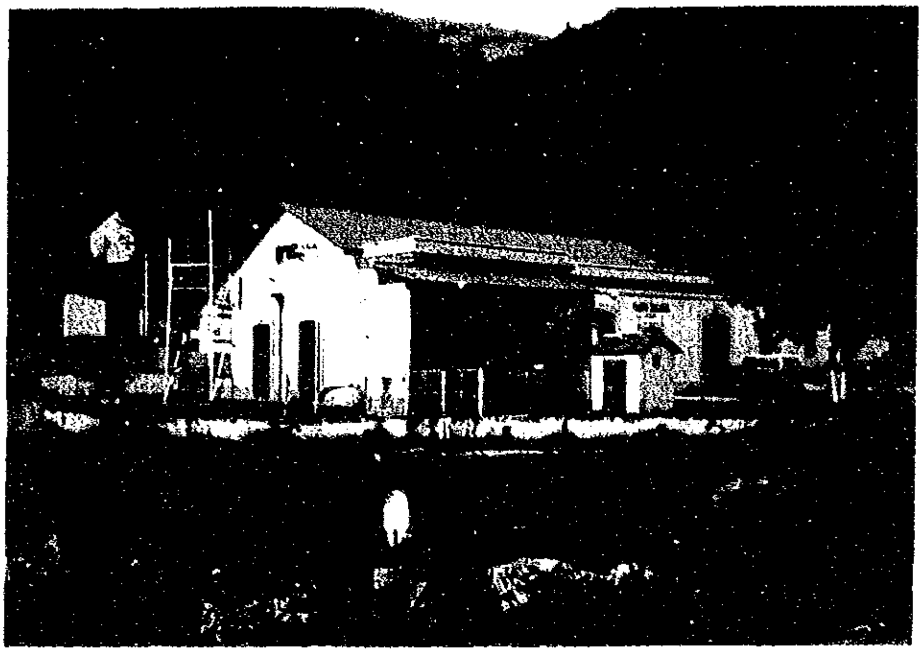


Location Map of Study Area

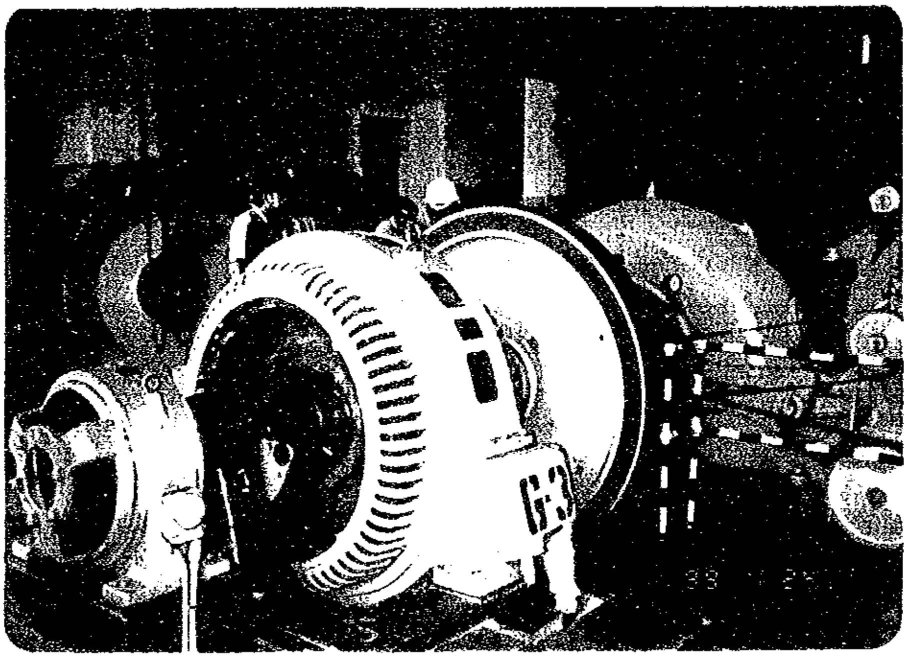


Rio Surata and Diversion weir

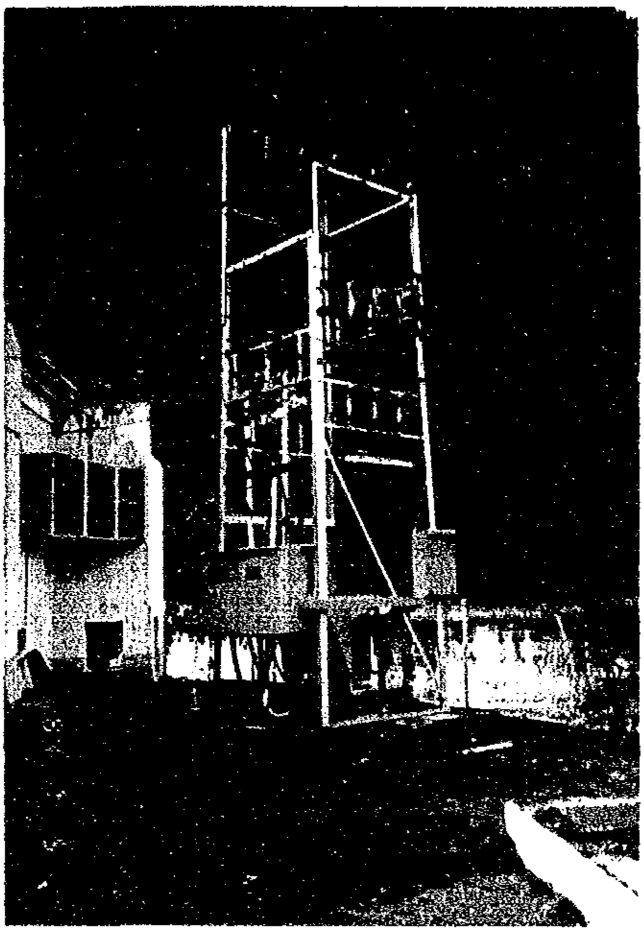
Conduction channel



Powerhouse



Francis turbine



Substation

Location Map of Study Area
Photographs

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CHAPTER 1 INTRODUCTION

The feasibility study (hereinafter referred to as the FS) for the rehabilitation plan of Zaragoza run-of-river type hydroelectric power plant (rated output of 1.56 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 was conducted during 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, Zaragoza hydroelectric power plant (hereinafter referred to as Zaragoza P/P) was selected as a candidate for the FS for the following reasons:

1) Although the rated output is 1,560 kW, the present output has dropped to 1,200 kW.

2) An increase in generated output, estimated from the discharge and hydrological regime of the Suratá River, is anticipated.

From this FS, post-rehabilitation generating scale at Zaragoza P/P for which JICA Study Team proposes as an optimum rehabilitation plan is as follows:

- Maximum output : 2.6 MW
- Annual potential generated power : 18.4 GWh
- Facility utilization factor : 78%

CHAPTER 2 SUMMARY OF STUDY RESULTS

The power plant owned by ESSA, is the run-of-river type (rated output: 1,560 kW), located along the Surata River in Santander Department.

There are three horizontal shaft type Francis turbines, each with an output of 520 kW and manufactured in 1932, 1937 and 1950, respectively. In September, 1989 the output was 77% (1,200 kW) of rated output. Furthermore, the annual generated energy in 1988 was recorded as 4,870.3 MWh.

(1) Present condition of generating facilities and their problems

At the intake site a longitudinal dike, instead of a diversion weir, is installed obliquely across the river to lead the water to the intake. The intake equipment has been repeatedly broken and repaired making it possible to maintain machine potential but difficult to claim it to be a well designed structure. The 1,700-meter-long headrace (open culvert) was constructed along a steep slope down a mountain side along narrow space. The capacity of the head tank is small.

For repair purposes the turbines have been occasionally stopped, although all three turbines (#1, #2 and #3) are still in operation. However, the recorded annual generated energy shows that the equipment utilization ratio is very low, at 36-57%.

Year	Annual generated energy (GWh)	Equipment utilization ratio (%)
1984	6,882.4	50
1985	7,757.5	57
1986	6,883.7	50
1987	5,067.9	37
1988	4,870.3	36

Downstream from the power plant's tailrace, the diversion weir for Bucaramanga City's water supply system and its water purification plant are built. The Study Team gathered site of the water purificant plant. However, many non-observed dates are contained in the first five years. Only the 1987 and 1988 records can be used as year-round data.

The existence of an active fault, running in the N30°W direction, has been confirmed at a point 300 m downstream from the powerhouse, but this is not directly related to the rehabilitation plans.

(2) Alternative rehabilitation plans

The flow-duration curve for the intake at Zaragoza hydroelectric power plant (see Fig. 2.1) indicates that the existing power plant's maximum available discharge, Q=6.5 m^3/s, is a suitable value for the design discharge of a run-of-river power plant, but a plan for increasing the maximum available discharge to 10 m^3/s is studied for the purpose of comparison.

Table 2.1 shows the summary of alternative rehabilitation plans.

Fig-2.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE

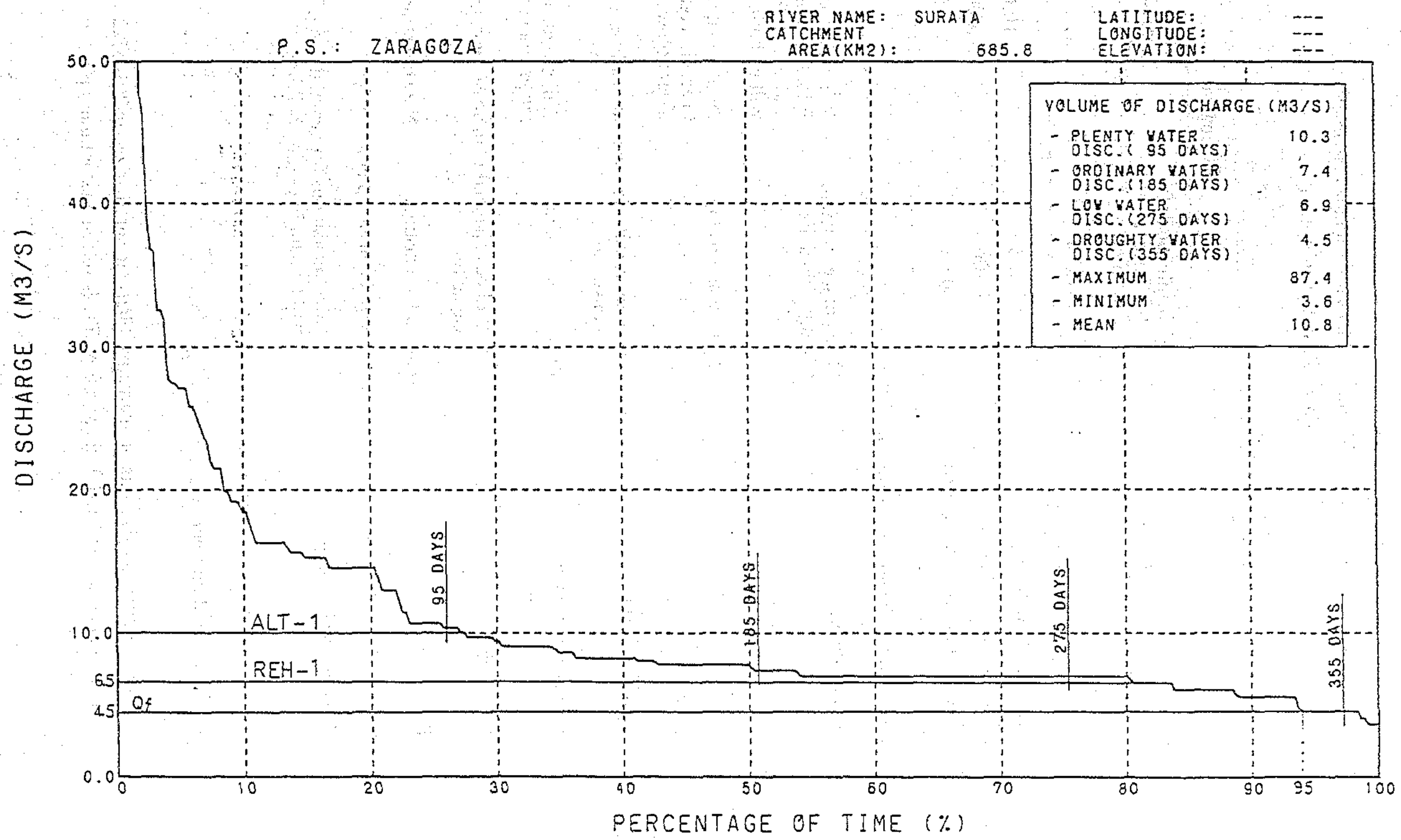


Table 2.1 Alternative Plans for Zaragoza Hydroelectric Power Plant Rehabilitation

Item	Alternative: Rehabilitation of the existing facilities	Alternative: Increase of power output
	REH-1	ALT-1
Discharge, Q (m^3/s)	6.5	10.0
Max. output, P (kW)	1,700	2,600
Facility utilization factor (%)	96.5	78
Rehabilitation and improvement plan:		
Diversion weir	Maintain the structure of longitudinal dike.	Will be reconstructed into diversion weir and sand flush gate will be built.
Intake	Maintain as existing.	Design will be changed to accommodate diversion weir.
Desilting basin	A new, suitable-sized one will be constructed.	
Conduction channel	Maintain as existing.	Will be extended and reconstructed.
Head tank	Will be expanded to increase storage capacity.	
Penstocks	Maintain as existing.	New construction.
Generating equipment	Will be installed new 2 units.	
Powerhouse building	New foundations for generating equipment will be built in exsting building.	

(3) Selection of optimum plan

Comparative study results of alternative plans are summarized in Table 2.2. ALT-1 has more benefits than REH-1, therefore ALT-1 is selected as optimum plan.

Table2.2 Comparison of Rehabilitation Plan for the Zaragoza 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 (m^3/s)	Net head Ho (m)	Rated output Po (kW)	(14) Output Pe (kW)	(15) Generated energy Ee (GWh)	Max. available discharge Q1 (m^3/s)	Standard net head H1 (m)	Theoretical output =9.8x(20) x(21) (kW)	Resultant efficiency η	Output =(22)x(23) P1 (kW)	Annual probable generated energy E1 (GWh)	Facility utilization factor ε (%)	Output =(24)-(14) ΔP (kW)	Annual probable generated energy (25)-(15) ΔE (GWh)
REH-1	6.5	30.0	1,560	1,200	6.29	6.5	32.8	2,089	0.830	1,700	14.7	96.5	500	8.4
ALT-1						10.0	32.8	3,214	0.830	2,600	18.4	78	1,400	12.1

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 P1 =(45)/(24) C/P1	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 E1 =(65)/(25) ÷0.95	per ΔE =(65)/(31) ÷ 0.95	C/B	Priority order
REH-1	2,100	850	2,950	400	3,350	6,650	1,950	6.0	220	98	318	324	23	40	1.91	2
ALT-1	2,250	900	3,150	1,000	4,150	2,900	1,600	10.4	236	154	390	400	23	35	1.74	1

(Notes)

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

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

(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) : E1(Energia Media)

(26) : $\varepsilon = \frac{\text{Annual water amount for turbine } (m^3/s \cdot hr)}{Q_1 \times 365 \times 24} \times 100(\%)$

(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 ESSA

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.

Supporting Staff	Position
Hernando Uribe Niño	President
Ruben Gelves Diaz	Director of Operations

3.2 Study Items and Study Schedule

The 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

Table 3.1 shows the overall study schedule as indicated in the S/W.

Two field surveys were conducted at Zaragoza P/P, as shown in Table 3.2.

In the first site reconnaissance, two civil engineers conducted the present-condition study of the existing facilities (mainly civil structures) and collected necessary data.

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

Table 3.1 Time Schedule of FS

Year	1988		1989												1990			
Month	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
Project month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Working item																		
1. Review of existing data																		
2. Site reconnaissance																		
Field works: (1) Programming																		
Field works: (2) Procurement procedure																		
Field works: (3) Ground survey																		
Field works: (4) Photogrammetric mapping																		
Field works: (5) Geological investigation																		
Field works: (6) Data collection																		
4. Power survey																		
5. Optimum plan																		
6. Feasibility design																		
7. Stability & safety analyses																		
8. Construction method																		
9. Cost estimation																		
10. Economic and financial analyses																		
11. Maintenance manual																		
Report																		
1. Inception report	Δ																	
2. Progress report				① Δ										② Δ				
3. Interim report											Δ	Δ						
4. Draft final report															Δ	Δ		
5. Final report																		Δ

Legend: JICA field operation; ICEL field operation; JICA operation in Japan; Δ——Δ Report submission

Table 3.2 Field Survey Schedule

The first site reconnaissance

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
Jan. 23	Bogota → Bucaramanga	Discussion at ESSA, and data collection	R. Torres	Murao Toyama Yoshio Kawasaki
Jan. 24		Field survey at Zaragoza P/P		
Jan. 25		Discussion at ESSA, and data collection		

The second field survey

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
July 7	Bogota → Bucaramanga	Discussion at ESSA, and field survey at Zaragoza P/P	R. Torres	Yoshio Kawasaki Takashi Inoue
July 8	Bucaramanga	Field survey at Zaragoza P/P		

3.3 Detail of Field Survey Work

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

3.3.1 Scope of Topographic Surveying

The scope of topographic surveying is shown in Fig. 3.1. The scales for the topographic maps are as follows:

(1) The diversion weir, conduction channel, desilting basin, head tank and powerhouse building are drawn on a scale of 1/200 with contour lines of 2 m. The bench marks were set up at three locations.

3.3.2 Boring Survey Work Plan

The boring survey was conducted at four locations as shown in Fig. 3.1.

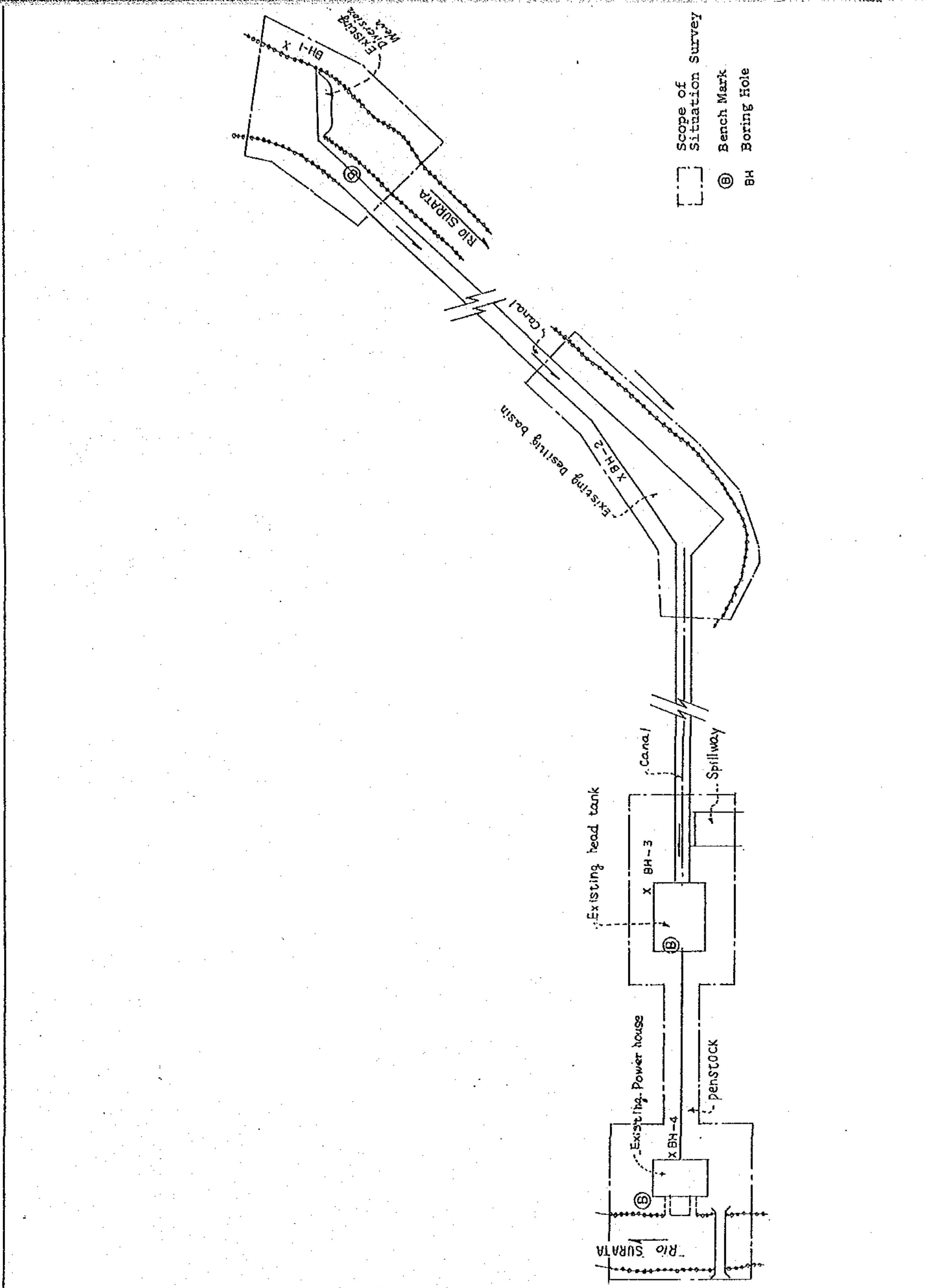

Scope of Situation Survey
B Bench Mark
BH Boring Hole
Existing Diversion Weir
BH-1 X
Rio SURATA
Canal
Existing desilting basin
X BH-2
Canal
Spillway
Existing head tank
X BH-3
Existing Power house
penSTOCK
X BH-4
Rio SURATA

Fig. 3.1

CHAPTER 4 PRESENT CONDITIONS OF THE STUDY AREA

4.1 Power Conditions in the Power Sector

Power conditions in the public electric power company, operating the power plant under study for rehabilitation (hereinafter called public electric power company) are described below.

4.1.1 Balance 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, peak demand was 151 MW, while installed capacity was 135 MW (89%). In 1987, electric power was 599 GWh, while supplied power was 234 GWh, representing about 39% of total electric power. The public electric power company bought electricity to cover electric power of 545 GWh from an other electric power company.

The breakdown of power demand in 1987 indicates that power demand for residential, commercial, industrial, and miscellaneous uses was 50%, 15%, 23% and 12% respectively. Power demand for residential was high, while that for commercial was low.

Annual average rate of increase in power demand from 1983 to 1987 was 5.0%, while that of generated energy dropped to -15.2%, and the rate of electricity buying increased.

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

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate(%) *
DEMAND						
1. Peak Demand (MW)	106	125	144	137	151	9.2
2. Electric Power (GWh)						
1) Residential	245	266	281	291	298	5.0
2) Commercial	74	84	87	86	89	4.7
3) Industrial	105	129	144	127	135	6.5
4) Industrial	68	131	119	69	77	3.2
Total	492	610	631	573	599	5.0
SUPPLY						
1. Installed Capacity (MW)	159	159	135	135	135	-4.0
2. Generated Energy (GWh)	453	451	530	191	234	-15.2
3. Power Loss (GWh)	94	77	100	163	180	17.6

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

* Annual average increase rate is calculated as follows:

Example: When peak demand is 9.2%,

$106 \times (1 + x)^4 = 151$

$x = 0.092$ (9.2%)

4.1.2 Present Conditions of Generating Facilities

(1) Generating facilities

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

Table 4.2 Total Installed Capacity of the Public Electric Power Company (1983 - 87)

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate (%)
Total Installed Capacity (MW)						
1. Thermal	133	133	109	109	109	-4.9
2. Hydroelectric	26	26	26	26	26	0
3. Others	0	0	0	0	0	0
Total	159	159	135	135	135	-4.0

(Source: INFORME ESTADISTICO: RESUMEN 1983-87)

Table 4.3 shows conditions of Zaragoza power plant for which this FS was conducted.

Table 4.3 Conditions of Zaragoza Power Plant (1984-1988)

Item	1984	1985	1986	1987	1988
1) Installed capacity (kW)	1,560	1,560	1,560	1,560	1,560
2) Generated energy (MWh)	6,883	7,757	6,884	5,068	4,870
3) Utilization factor (%)	50	57	50	37	36
4) Operating time (%)	63	69	62	45	45

(Source: ESSA)

(2) Transmission facilities

The public electric power company provides 115 kV transmission lines. The voltage transmitted is 11.4 kV.

4.1.3 Generating Cost and Electric Charges

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

Table 4.4 Generating Cost and Electric Charges

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate(%)
Generating Cost (COL $/kWh)	4.30	4.50	5.67	7.84	9.33	21.4
Electric Charge (Average): (COL$/kWh)						
1. Residential	2.95	3.25	3.23	5.93	7.93	28.0
2. Commercial	4.85	5.70	7.00	9.77	12.45	26.6
3. Industrial	3.16	3.48	3.99	9.48	11.71	38.7
4. Public use	3.29	3.92	4.62	6.86	8.78	27.8
5. Average	3.27	3.55	4.08	7.35	9.49	30.5
Breakdown of Power Demand by customer						
1. Residential	140,211	155,422	174,494	185,247	197,318	8.9
2. Commercial	13,823	14,932	14,891	15,269	14,979	2.0
3. Industrial	1,617	1,717	1,656	1,551	1,532	-1.3
4. Others	2,686	2,944	3,253	4,496	3,292	5.2
5. Total	158,337	175,015	194,294	206,563	217,121	8.2
Diffusion of Electricity						
1. Overall (1000 households)	1,381	1,408	1,438	1,467	1,497	2.0
2. Power demand (1000 households)	670	743	834	885	943	8.9
3. Electrification rate (%)	49	53	58	60	63	6.5

(Source: INFORME ESTADISTICO: RESUMEN 1983-87)

4.1.4 Forecast of Power Supply and Demand

The supply and demand balance until 1995 are estimated, as shown Fig. 4.1, based on the conditions of supply and demand as shown in Table 4.1. The estimated annual average increase in electric power is as follows.

1) the annual average increase rate in power demand is 5.0%
2) the annual average increase in generated power is -15.2%
3) the average increase in power loss is 17.6%
4) the amount of electricity to be bought is calculated by the following formula: Electricity to be bought = (demand + power loss) - generated power

As an example, the power demand in 1995 will be as follows:

$$599 \times (1 + 0.05)^8 = 885 \text{ GWh}$$

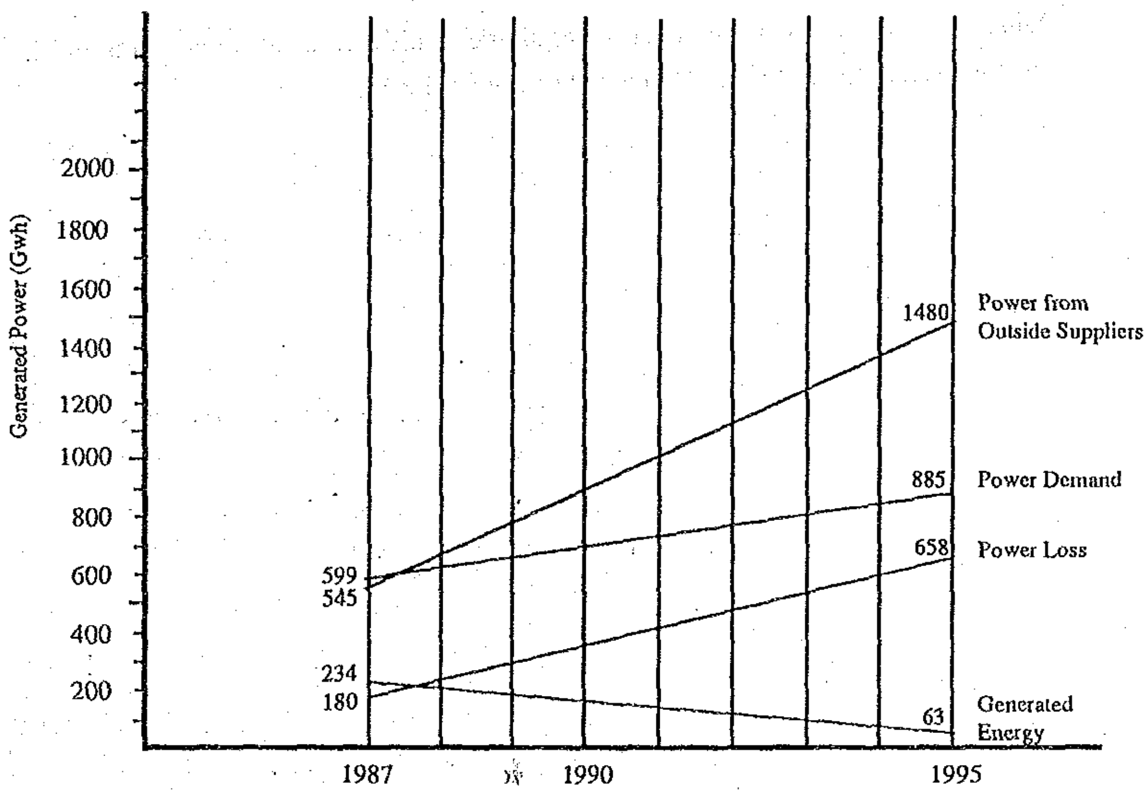


Fig. 4.1 Estimation of Power Demand

4.2 Operation Record of the Existing Power Plant

4.2.1 Generated Energy

Records of generated energy and operating time during five years from 1984 to 1988 are shown in Table 4.5. Long stoppage periods during these five years were as follows;

Unit 1: Mar. - Apr. 1985
Jan. 1986
Jun. - Aug. 1987

Unit 2: Oct. - Dec. 1988

Unit 3: Nov. 1986 - June 1988
Aug. - Sept. 1988

During these five years the average equipment utilization ratio was 46% and it is presumed that the turbine's efficiency has been reduced.

Table 4.5 Record of Generated Energy and Running Time

Year	Unit No.	Output inscribed on the name plate (MW)	Generated energy (MWh)	Total generated energy (MWh)	Running time (hour)	Total running period (hour)	Facility utilization factor (%)	Total facility utilization factor (%)	Operation factor (%)	Total operation factor (%)
1984	1	0.52	2,181.4	6,882.4	5,385	16,680	48	50	61	63
	2	0.52	2,801.0		6,495		61		74	
	3	0.52	1,900.0		4,800		42		55	
1985	1	0.52	1,592.2	7,757.5	3,982	18,150	35	57	45	69
	2	0.52	3,312.6		7,429		73		85	
	3	0.52	2,852.7		6,739		63		77	
1986	1	0.52	1,831.0	6,883.7	4,684	16,266	40	50	53	62
	2	0.52	3,080.0		7,045		68		80	
	3	0.52	1,972.7		4,537		43		52	
1987	1	0.52	1,947.2	5,067.9	4,602	1,869	43	37	53	45
	2	0.52	3,120.7		7,267		69		83	
	3	0.52	0.0	0		0		0		
1988	1	0.52	2,764.0	4,870.3	6,647	11,724	61	36	76	45
	2	0.52	1,650.0		3,921		36		45	
	3	0.52	456.3		1,156		10		13	

(Note)

1. Facility utilization (%) = $\frac{\text{Generated energy (MWh)}}{\text{8,760(hr) x Output inscribed on the name plate (MW)}} \times 100$

2. Operation factor (%) = $\frac{\text{Running time (hr)}}{\text{8,760 (hr)}} \times 100$

4.3 General Condition of Generating Equipment and Civil Structures

4.3.1 General Condition of Generating Equipment

Conditions of generating equipment are summarized below:

(1) Generating equipment

The turbines were manufactured in 1950 (#1 unit), 1932 (#2 unit) and 1937 (#3 unit) and so are 40, 58 and 53 years old respectively. Since they are old machines, equipment utilization ratio in the latest five years has been 46% and it is presumed that the turbine's efficiency has decreased. According to an ESSA survey, it is reported that the casing and runner of each of the three units have been worn out by sand and therefore ESSA need replacements with more efficient new equipment.

(2) Substation

Four transformers are installed next to the powerhouse building, and these boost the generator voltage of 11.4 kV for distribution to two locations. These transformers are 60 years old but are still in working condition.

(3) Distribution line

Distribution lines of 11.4 kV run from this plant to Principal substation, Matanza Surata, California, etc. These distribution lines are in working condition.

4.3.2 General Condition of Civil Structures

(1) Intake facilities

Instead of the diversion weir, the longitudinal dike (65 m long, 3 m high) is installed obliquely across the river to lead the water to the intake. The longitudinal dike is provided with two wooden stop gates (2.0 m(W) x 3.0 m) and one 2 m wide metal gate. The wooden gates were damaged, but the metal gate does not function properly.

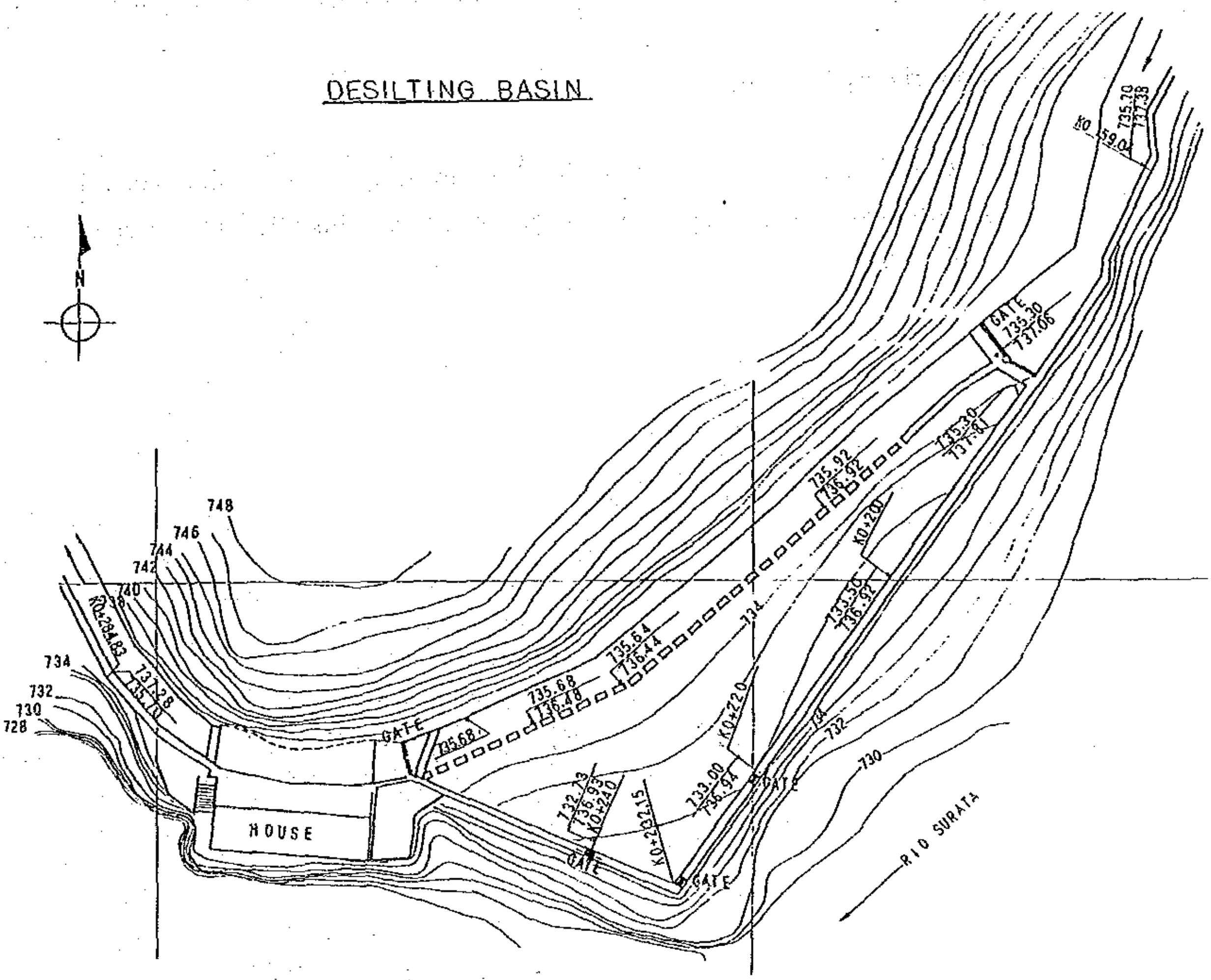
Only the screens are installed at the intake. There is no regulating gate installed. Intake facilities have been damaged and rehabilitated. Though they are maintained in good condition, their structures are not fairly designed.

(2) Conduction channel

The open culvert (3.0 m wide, 1.5 m deep, 1,685 m long) is built on a steep slope on the lower part of the mountain. Because of steep longitudinal gradient, the water tends to flow obliquely in the channel. Because of geological restrictions, the expansion of the channel is not advisable for the rehabilitation.

(3) Desilting basin

The overflow type desilting basin is located 180 m downstream from the intake.



The desilting basin (average width: 13.0 m, length: 60.0 m, average depth: 2.9 m) has sufficient capacity to the designed discharge of 6.5 m^3/s. But gates have deteriorated.

(4) Head tank

The effective storage capacity of the head tank (width: 2.6~11.0 m, length: 35.5 m, depth: 2.1 m) is about 450 m^3 which is equivalent to a 70-second capacity; 1/2 of targeted capacity (120 seconds).

(5) Penstock

The maintenance of the penstocks (ϕ = 1.52 m, L = 107.3 m) has been done properly, and this makes it unnecessary for the penstocks to be rehabilitated.

(6) Powerhouse building

The RC building (14.0 m wide, 26.0 m long, 7.0 m high) has been maintained in rigid state. Three generators are installed in the spacious building.

CHAPTER 5 BASIC DATA COLLECTION

The pre-FS was conducted from November, 1987 to July, 1988. It was followed by the FS from November, 1988, to collect topographical, geological and hydrometeorological data, detailed in the following.

5.1 Topographic Maps

Zaragoza P/P is located north of Bucaramanga City, and the intake is 1 km downstream from where the Toma River and the Surata River meet.

The JICA study team collected the following topographic data.

- Topographic maps (scale 1:25,000 - 1:400,000) published by IGAC

- Topographic maps from measurements taken by ESSA for this study.

(1) Topographic maps published by IGAC

Scale	Drawing No.	Description
1:100,000	109	vicinity of power plant
1:100,000	110	vicinity of power plant
1:100,000	120	downstream area of power plant
1:100,000	121	downstream area of power plant
1:25,000	109-IV-B,C,D	vicinity of power plant
1:25,000	110-III-C	vicinity of power plant
1:25,000	120-II-B	downstream area of power plant
1:25,000	121-I-A	downstream area of power plant

(2) Topographic Maps Measured by ESSA

Scale	Drawing No.	Description
H:1/1000	1 de 6	Plan and profile of conduction channel (1/2)
V:1/100	2 de 6	Plan and profile of conduction channel (2/2)
1/200	3 de 6	Plan of intake facilities and vicinity
"	4 de 6	Plan of desilting basin and vicinity
"	5 de 6	Plan of head tank ~ power plant
"	6 de 6	Longitudinal section of conduction channel

5.2 Geological Survey Data

Geological survey data collected for this survey is as follows:

- Mapa Geologico de Colombia 1988, INGEOMINAS
- Aerial photographs of this power plant and vicinity
- Optimization planta de Zaragoza de la electrificadora de Santander 1989, Ingenieria de Suelos Ltda

5.3 Hydrometeorological Data

Since Zaragoza P/P does not have the facilities for monitoring precipitation levels and discharge, JICA Study Team gathered hydrometeorological data from HIMAT and CAMBSA (Compaña del Acueducto Metropolitano de Bacaramanga S.A.) when conducting this survey.

Precipitation observation and gauging stations, and the duration of monitoring records are listed below. JICA Study Team obtained discharge observation recorded for 7 years from 1982 to 1988 on the Surata River which is directly related to this FS.

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		
2319-036	Portachuelo	HIMAT	0720	7310	800	1971-86
2319-034	Matajira	"	0713	7304	996	1967-86
2319-035	Llano de Polmas	"	0715	7312	778	1967-86
2319-504	Unive Ind. Santander	"	0708	7306	1018	1961-85

(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			
2319729	Cafe Madrid	Lebrija	HIMAT	1968-12	0717	7308	600	1284	1975-85
	Zaragoza	Surata	CAMBSA	-	-	-	700	-	1982-88

(3) Water quality data

The observation data of water quality for the Surata River which was controlled by CAMBSA was obtained.

1) pH : Oct. 1981 ~ Dec. 1983, Mar. ~ Apr., 1989
2) Conductivity : May 19 ~ May 26, 1989
3) S : 1982, Jan. ~ Dec. 1983
4) Fe : 1982, 1983
5) Cℓ : March 1982 ~ May 1989

In addition, the water quality data for the Lebrija River was obtained.

Observation period : Nov. 30, 1983 ~ Dec. 15, 1984
Observation items : pH, $C\ell$, HCO_3, etc.

(4) Sediment data

JICA Study Team collected records relating to sediment at the places listed below, along the Surata River controlled by CAMBSA.

Place	Observation year	Altitude (MSNH)
Zaragoza	1986 ~ 1989	700
Bahondo	1987 ~ 1989	-
Matajira	1987 ~ 1989	950
Siparas	1986 ~ 1989	1,140
Charta	1986 ~ 1989	1,600
Unagato	1986 ~ 1989	1,725
Povedas	1986 ~ 1989	1,930
La Baja	1987 ~ 1989	2,000

5.4 Other Related Data

5.4.1 Construction Prices Data

Construction prices for civil works in Colombia are based on "Catalogo de Precios de Materiales de Construccion (Catalog of Construction Material Prices)" published by CAMACOL (Camera Colombiano de la Construccion) in Santander Department. However, the above publication is not published in all departments of Colombia. To coordinate the data of the power plant sites where the FS was conducted, construction prices used for this study are based on price data used within ESSA (refer to Table 5.2).

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

5.4.2 Power Condition Data

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

1) ESSA's power schematic diagram

(2) JICA Study Team gathered the following data relating to Zaragoza P/P.

1) Residual value

CHAPTER 6 PRESENT CONDITIONS OF TOPOGRAPHY AND GEOLOGY

6.1 Topography and Geology in the Area

6.1.1 Topography

The source of the River Surata is in the western slope of the northern part of the east mountain range, and flows southwest to join the Lebrija River, a tributary of the Magdalena River near Bucaramanga City, the capital of Santander Department.

The project site is situated halfway downstream of the Surata River. The topography around the project site is formed by relatively steep V-shaped valleys.

6.1.2 Geology

The bedrock consists of pre-cambrian gneiss, on which laterized terrace, talus and riverbed deposits are distributed locally. The Bucaramanga Active Fault is located 300 m west of the power plant site in a NNW-SSE direction. 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 deposits Debris flow deposits	
		Talus deposits	
		Terrace deposits	
Pre-Cambrian		Gneiss	

6.1.3 Geological Structure

The topography to the west of the power plant has a clear contour, corresponding to the Bucaramanga Fault. According to a survey there are gneiss outcrops at least

300 m west of the power plant. From here the fault line runs in a westward direction.

6.2 Geology in the Project Site

The general conditions for the various geological bases for the foundations of the power plant are outlined below.

1) Diversion weir

While there are gneiss outcrops on the right bank of the river, there are no outcrops on the left bank. Upstream, on the right bank, there is a deep swamp and near the mouth of the swamp the gneiss is overlain by debris flow deposits. The riverbed deposits are about 2 m thick so that the diversion weir is not directly on rock.

2) Conduction channel

The conduction channel is built on gneiss, and terrace and talus deposits are distributed on both the mountain side and river-side of the channel.

3) Desilting basin

In the vicinity of the desilting basin, a good terrace deposit covers the gneiss. Thus, the desilting basin has a good rock foundation.

4) Head tank and penstock

The head tank is built on gneiss while the penstock is built on talus deposit. In the vicinity of the head tank the gneiss is well-weathered and decomposed.

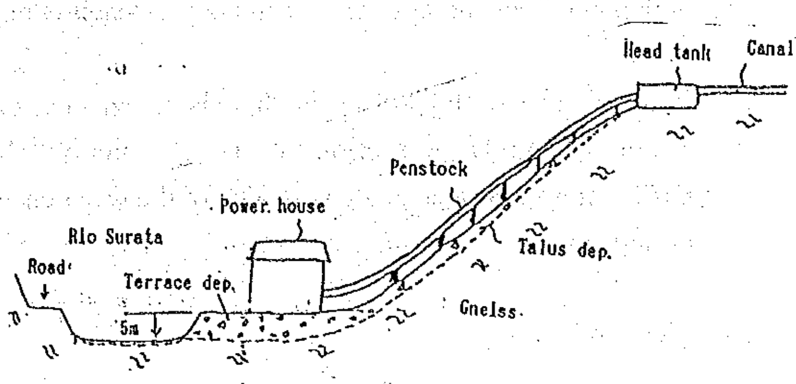


Fig. 6.1 Schematic Geological Profile

5) Powerhouse

In the powerhouse area, terrace deposits cover gneiss. The powerhouse structure is built on terrace deposits. According to a boring survey the level of bedrock under the terrace is the same as the riverbed level.

6.3 Distribution of Concrete Aggregates

Both the riverbed and the debris flow deposits are suitable for aggregates.

6.4 Geotechnological Evaluation

1) The project site has generally thin-layered deposits overlying a deep bedrock. The bedrock is a pre-cambrian gneiss, which is hard and fine grained in a natural state. The foundations for the various buildings and a 10 m high concrete dam have sufficient bearing capacity and impermeability.

2) Civil structures, except the diversion weir, have no geological problems since they are built on bedrock. It is presumed that the diversion weir is built on the 2 m thick riverbed deposits.

According to an on-site survey, the riverbed deposits have a sufficient bearing load to support a dam of the existing size. However, a new dam will need to be built on bedrock, because of load and impermeability requirements.

3) In the vicinity of the project site there is no evidence of large-scale landslides, although one large section of the conduction channel has collapsed. Furthermore at a steep gradient section of the water channel there is evidence of falling stones.

6.5 Geological Problems

1) Regional literature suggests that the Bucaramanga Fault is still active. At the detailed design stage, a region survey will evaluate the activity. It will also be necessary to design the various buildings to resist earthquakes.

2) Countermeasures to prevent falling stones and further collapse of the conduction channel will need to be implemented.

CHAPTER 7 HYDROLOGICAL ANALYSIS

The locations of the gauging stations for monitoring precipitation and discharge at the watershed of this project site are shown in Table 7.1.

7.1 Meteorological Conditions of the Site

Santander Department, in north Colombia, lies at 5°43'~8°11' north latitude, near the equator. Tolima Department is mainly divided into mountainous and plain areas.

Generally, the lowland has a tropical climate, with a humid and rainy area. It changes from a temperate to a frigid climate zone with increasing altitude. The temperature is 28° C in the lowland area, dropping to 12° C at an elevation of 1800 - 2800 m, and around 10° C over 3000 m. The capital, Bucaramanga City, is located at an elevation of 1000 m with an average temperature of 20° C.

Annual average rainfall is recorded at 2000 - 3000 mm in the lowland areas, but drops to 1000 - 2000 mm at higher elevations.

The Surata River originates on the western slope of the Andes Mountain range, flowing downward to the south, and branches into the Oro River, near Bucaramanga City and Lebrija River in the northwest. Including Magudalena River, the Surata River is about 45 km long.

Bucaramanga City is located at an elevation of 800 m, in a temperate climate with an average temperature of 20° C and annual rainfall of 1000 m - 2000 m. Rainfall fluctuates year to year, though the rainy and dry seasons are not readily distinguishable (refer to Fig. 7.2).

Observation Item	Gauging Station No	Gauging Station Name	Latitude	Longitude
Discharge	2319-729	Cafe Madrid	0717	7308
	-----	Zaragoza	-----	-----
Preciptation	2319-036	Portachuelo	0720	7310
	2319-034	Matjira	0713	7304
	2319-035	Llano De Palmas	0715	7312
	2319-504	Unive Ind Santander	0708	7306

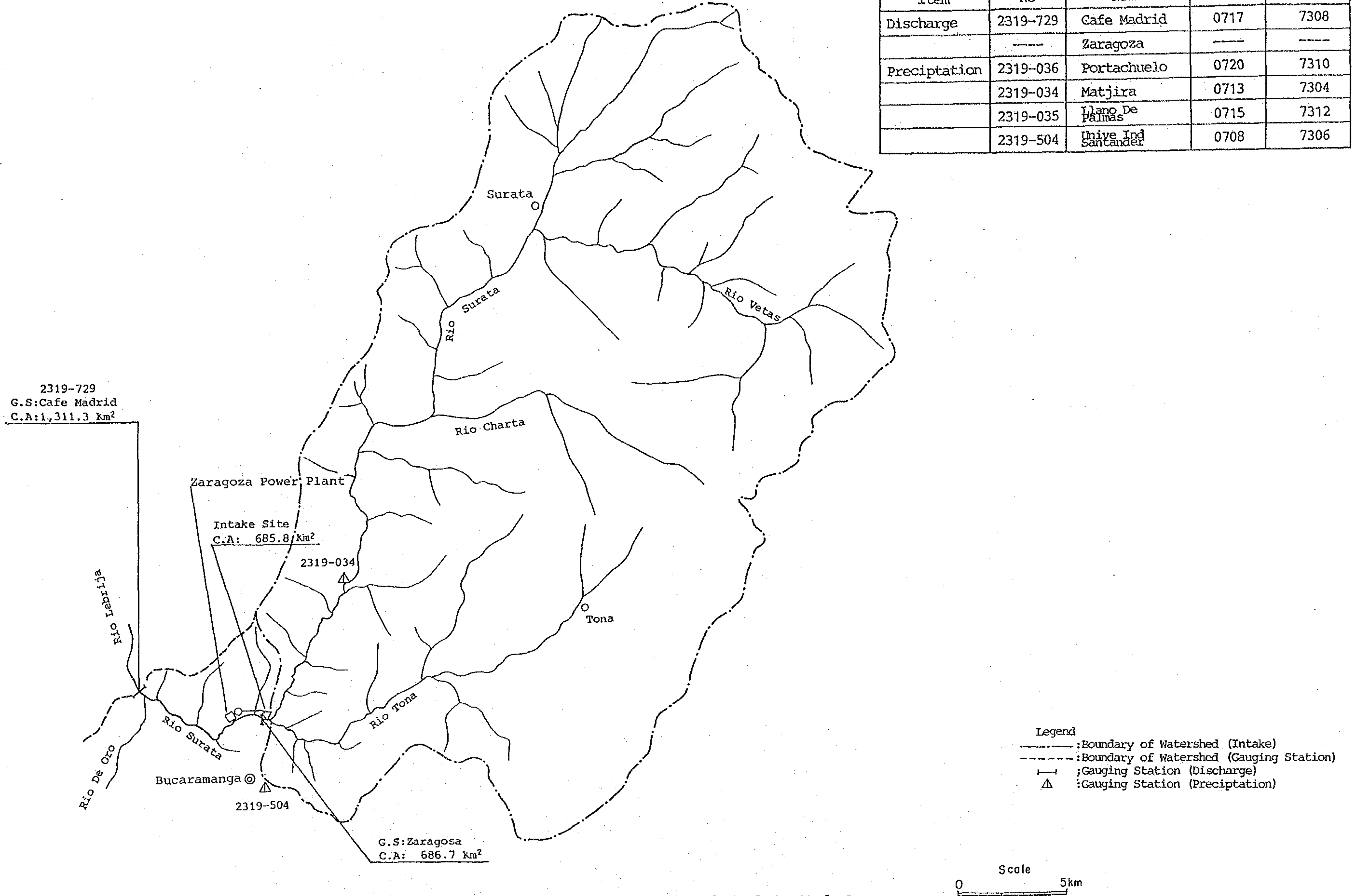


Fig-7.1 Location Map of Gauging Stations in The Watershed of The Study Area.

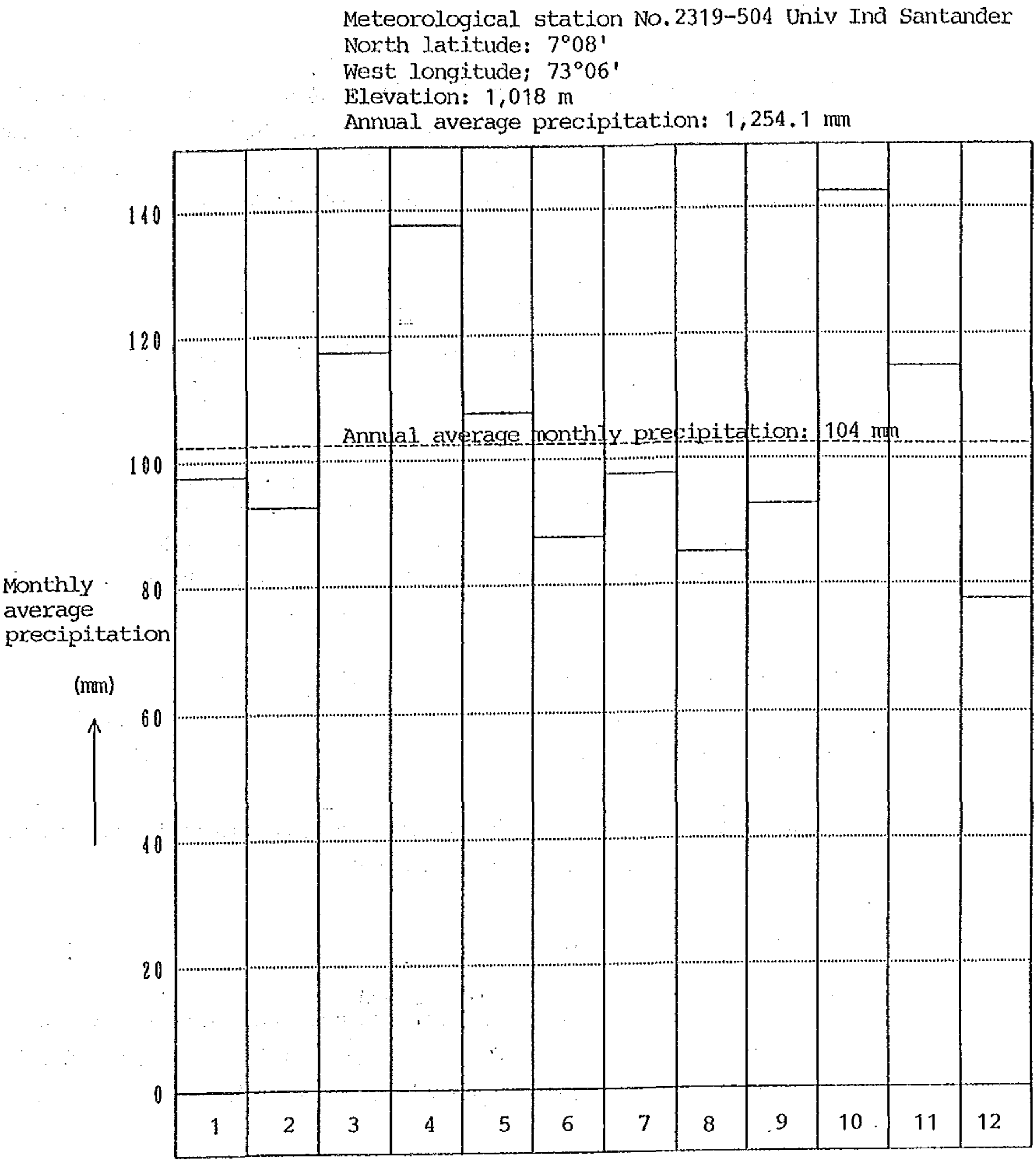


Fig.7.2 Monthly Average Precipitation in the Project Site (1961-85)

7.2 Discharge Analysis

The discharge and flow duration curves in the project site were compiled by comparing the records of Cafe Madrid and Zaragoza gauging stations. One-year observations recorded at Zaragoza in 1987 were used as the basis for data, after adjustments for the river basin, since it is located very near Zaragoza's intake site.

7.2.1 Collation of Discharge Data

The observation periods for the discharge data collected by the JICA Study Team are as follows:

Gauging Station	Date established	Observations period
Zaragoza	N/A	1982 - 1988
Cafe Madrid	December, 1968	1975 - 1985

Since there were many non-surveyed days during the seven-year period at the Zaragoza gauging station along the Surata River, the application of runoff data is restricted to data collected in 1987 - 88.

All eleven years of observation at Cafe Madrid gauging station at the Surata River can be used as observations were recorded year-round.

(1) Collation of Catchment Area

Since there are no records for the catchment area from HIMAT, the JICA Study Team site survey confirmed the location of the catchment area and plotted the points on IGAC-published topographic maps, scale 1:100,000, as shown in Fig. 7.1.

Table 7.1 Gauging Station Location and Catchment Area Collation

Item	Cafe Madrid Gauging Station		
	Latitude	Longitude	Catchment area (km^2)
HIMAT ledger	0717	7308	1284
CAMB S.A	-	-	-
Observation value	0710	7309	1311.3
Difference	0007	0001	27.3

(2) Collation of Unit Flow Duration Curve per 100 km^2

Since only 2-year's discharge data from Zaragoza station is available, it is not considered very reliable. Thus, a comparison of Zaragoza gauging station flow duration curve per 100 km^2 to the Cafe Madrid gauging station flow duration curve per 100 km^2 is shown in Fig. 7.3. The fluctuation of annual rainfall during the two-years of data is noted, and the average unit flow duration curve per 100 km^2 for 1987 at Zaragoza is comparable to that of Cafe Madrid.

Cafe Madrid Gauging Station vs Zaragoza Gauging Station

(Comparison of 11-year average flow-duration curve at Cafe Madrid gauging station and year-to-year average flow-duration curves at Zaragoza gauging station)

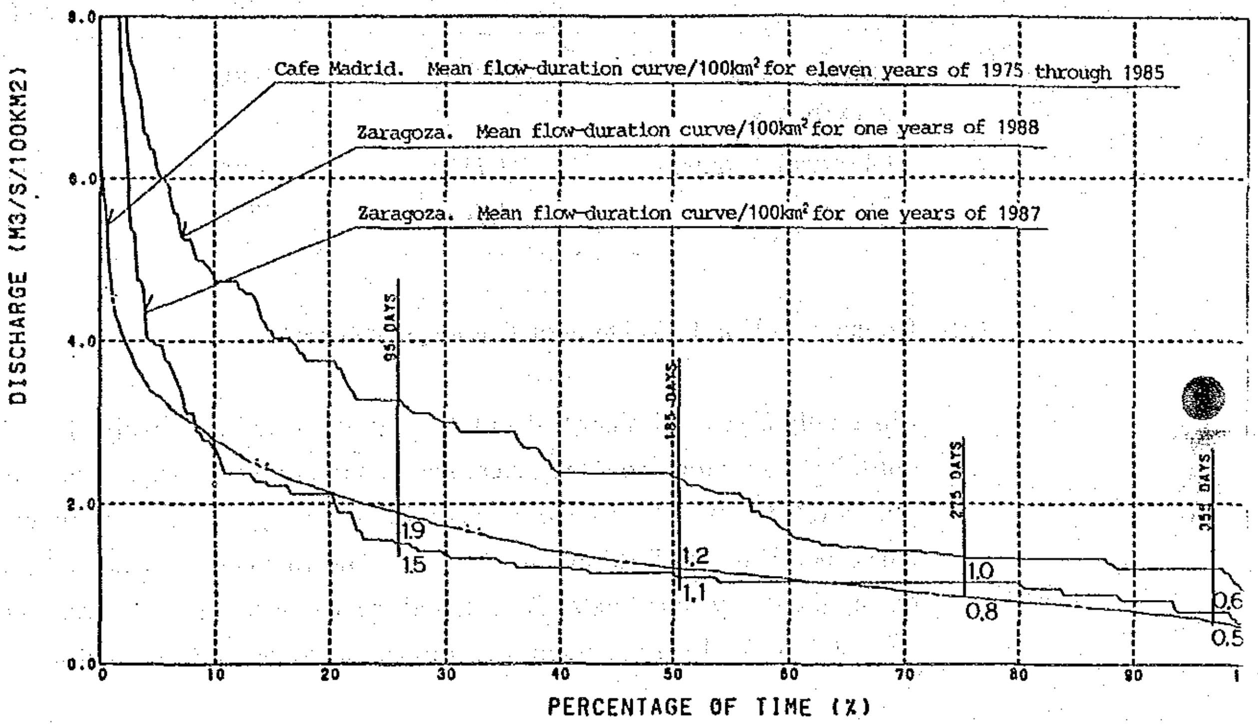


Fig. 7.3 Comparison of Unit Flow-duration Curve per 100 km^2

7.2.2 Standard Flow-Duration Curve

Year-to-year fluctuations of the river flow-duration curve occur at the same site. To draw a standard flow-duration curve for a particular site, the following methods are considered.

(a) Parallel method

Daily average discharge for 365 days is arranged in descending order, and the flow-duration curves for each year are drawn and averaged.

(b) Standard year method

Flow-duration curves for each year are drawn. From these curves, the median curve is selected and used as the flow-duration curve in the standard year.

(c) Series method

Daily average discharge for 5 years is arranged in descending order, with only the Y-axis adjusted for the one-year curve.

(d) Curve insertion method

Average values of 355-days flow, nine-month flow, ordinary water discharge and three-month flow for long periods (minimum 10 years) are calculated, plotted and drawn according to a discharge handbook.

Standard flow duration curves are drawn according to the parallel method. The X-axis is labeled as daily average discharge (m^3/s), and the Y-axis as number of days (%).

7.2.3 Discharge and Flow-Duration Curve of Zaragoza Gauging Station

Discharge data from the Zaragoza gauging station, located 1.9 km downstream from the intake of Zaragoza power plant, are arranged using 2-year data, as shown in Table 7.3.

In calculating monthly average discharge in Table 7.3, the months with fewer than 10-days of observation data are excluded. From the graphic representation of the monthly average discharge (Drawing No. ZA-H-01, No.1), September to December is determined to be the flow period, while January through August is the drought period.

Using the parallel method, standard flow-duration curves for 1987 are calculated, as shown in Drawing No. ZA-H-01. Flow-duration curves for three-month flow, ordinary flow, nine-month flow and 355-days flow periods are indicated in numerical values, as shown in Table 7.4.

Table-7.3 MONTHLY FLOW TABLE OF DAILY AVERAGE FLOW AT G.S. SITE

GAUGING ST.: --- ZARAGOZA
RIVER NAME: SURATA

(UNIT: M3/S)

GAUGING YEAR	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1987	MAX.	8.2	8.0	9.0	9.0	67.1	9.7	9.0	9.4	27.4	57.9	87.5	16.3	87.5
	MEAN	7.3	6.5	5.7	6.1	13.5	7.6	6.9	7.3	8.5	22.8	24.3	13.1	10.8
	MIN.	7.0	4.0	3.6	3.6	6.0	6.0	4.5	4.5	5.6	8.9	10.6	9.0	3.6
1988	MAX.	10.2	33.9	13.0	32.5	39.3	34.2	19.8	47.8	62.9	50.1	99.5	32.5	99.5
	MEAN	9.0	11.3	9.1	11.0	12.7	12.4	16.6	20.5	29.4	26.1	43.2	20.7	18.5
	MIN.	8.2	8.2	6.5	8.2	8.2	7.8	14.6	14.5	11.8	14.7	21.4	16.3	6.5
TOTAL	MAX.	10.2	33.9	13.0	32.5	67.1	34.2	19.8	47.8	62.9	57.9	99.5	32.5	99.5
	MEAN	8.1	8.9	7.4	8.5	13.1	10.0	11.8	13.9	18.9	24.5	33.7	16.9	14.6
	MIN.	7.0	4.0	3.6	3.6	6.0	6.0	4.5	4.5	5.6	8.9	10.6	9.0	3.6

Table-7.4 FLOW DURATION TABLE AT GAUGING STATION SITE

GAUGING ST.: --- ZARAGOZA
RIVER NAME: SURATA

(UNIT: M3/S)

GAUGING YEAR	MAX. (1ST DAY)	PLENTY (95 DAY)	ORDINARY (185 DAY)	LOW (275 DAY)	DROUGHTY (355 DAY)	MIN. (LAST DAY)	MEAN
1987	87.5	10.3	7.4	7.0	4.5	3.6	10.8
MEAN	87.5	10.3	7.4	7.0	4.5	3.6	10.8

7.2.4 Discharge and Flow Duration Curves for the Intake Site

The discharge and flow duration curve for the intake site located 1.9 km downstream from the Zaragoza gauging station are calculated by multiplying the catchment area ratio with measurements taken at the gauging station. Since there is no set numerical value for the catchment area, the JICA Study Team's measurement of the watershed area will be adopted. Thus, the ratio of the Zaragoza Power Plant's intake to the gauging station catchment area is set to 685.6/686.7 ≑ 1.00.

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)	9.0	11.3	9.1	11.0	13.5	12.4	16.6	20.5	29.4	26.1	43.2	20.7	18.5
Daily average discharge (m^3/s)	8.1	8.9	7.4	8.5	13.1	10.0	11.8	13.9	18.9	24.5	33.7	16.9	14.6
Min. average discharge (m^3/s)	7.3	6.5	5.7	6.1	12.7	7.6	6.9	7.3	8.5	22.8	24.3	13.1	10.8

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
10.3 m^3/s	7.4 m^3/s	6.9 m^3/s	4.5 m^3/s

The river utilization factor* of a certain available discharge to typical flow-duration curves at the intake site and facility utilization factor** are shown graphically in Drawing No. ZA-H-01 (5).

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

** The ratio of total discharge of water that can flow into the intake to the available discharge throughout the year.

CHAPTER 8 GENERATION PLAN

Since this generation plan is based on a maximum discharge of 6.50 m^3/s at the existing plant, to effectuate this plan technologically and economically, the power output and annual output will be calculated from the maximum discharges using the standard discharge-duration curves of the intake site, provided that the facility utilization factor for all of the maximum discharge is not less than 50%.

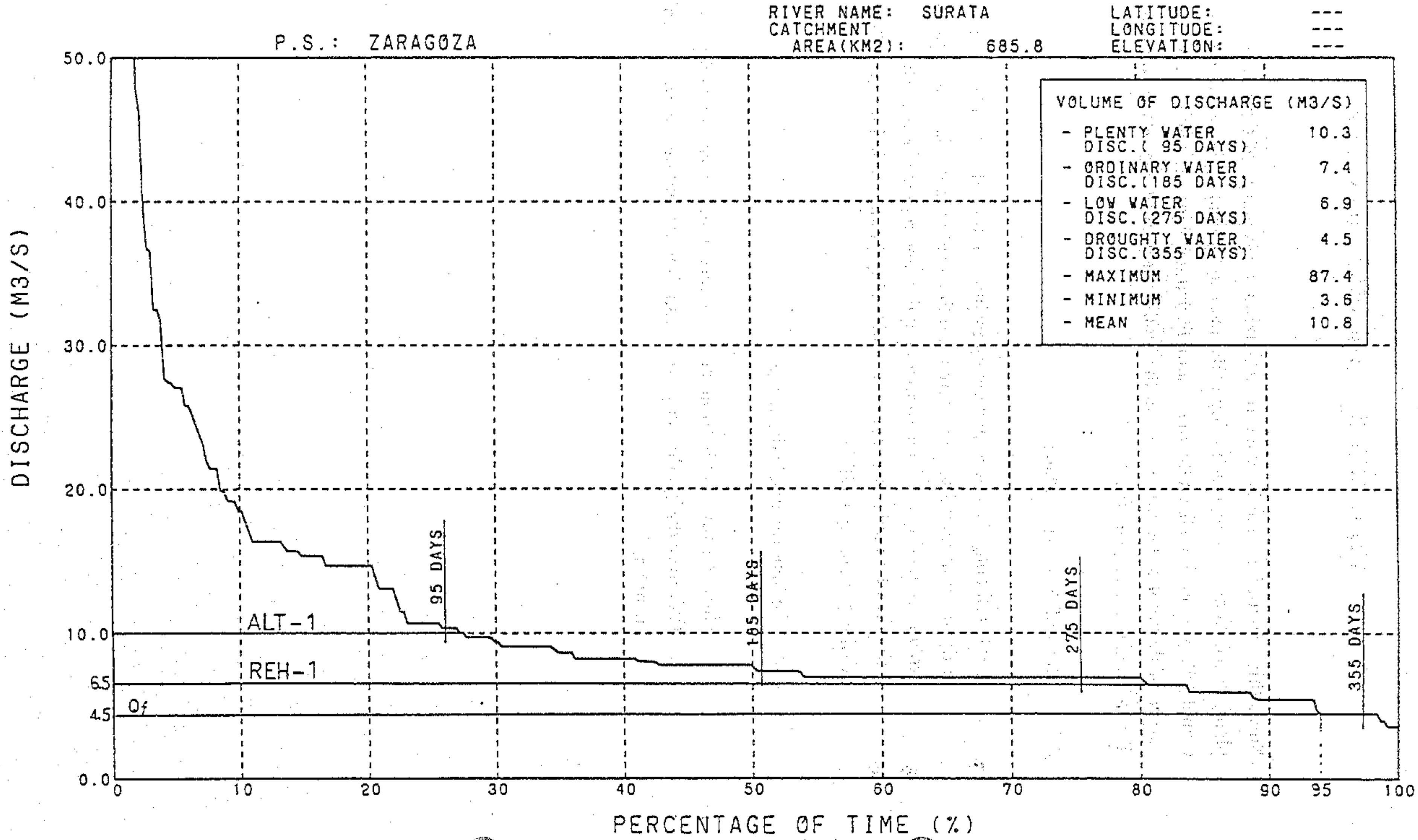
8.1 Study of Alternative Plans

In rehabilitating the power generating facilities at this site, the intake structure and part of the headrace need to be restored and the head tank needs to be expanded, and the generating facility and transformers require new replacements. Thus, a comparative study will be made of generation-optimizing plans, including the rehabilitation of *existing generating facilities.*

(1) Maximum available discharge

The existing conduction channel has a discharge capacity of 6.5 m^3/s. Therefore design discharge of 6.5 m^3/s is set and the alternative value is set at 10 m^3/s.

Fig-8.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



(2) Standard net head

Assuming the net head for determining the turbine output and calculating the generating energy is constant, the standard net head (He) is calculated accordingly.

$$He = Hg - H$$

$$H = v^2/2g\ (1+f_1 + f_2.L/D + fm) + h = v^2/2g\ (1.85 + f_2.L/D) + h$$

where:

- Hg = gross head
  Head tank water level (732.32 m) - tailrace water level (697.40 m) = 34.92 m
- 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/D
- L = 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

Table 8.1 Calculated Result of Standard Net Head

Q (m^3/s)	D (m)	L (m)	V (m/s)	$v^2/2g$ (m)	f.l/D	$v^2/2g(\Sigma f)$ (m)	h (m)	H (m)	He (m)
6.5	1.52	124.5	3.58	0.654	1.28	2.05	0.47	2.52	32.40
10.0	2.10	124.5	2.89	0.426	0.83	1.14	0.48	1.62	33.30

Accordingly, the standard net head is set at 32.8 m.

8.2 Generated Output

The theoretical output, extrapolated from available discharge (Q) and standard net head (He) is multiplied by the resultant equipment efficiency coefficient as follows.

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

where:

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

Resultant efficiency (η) represents total efficiency, and is calculated as follows.

$$\eta = \eta t \times \eta g$$

where:

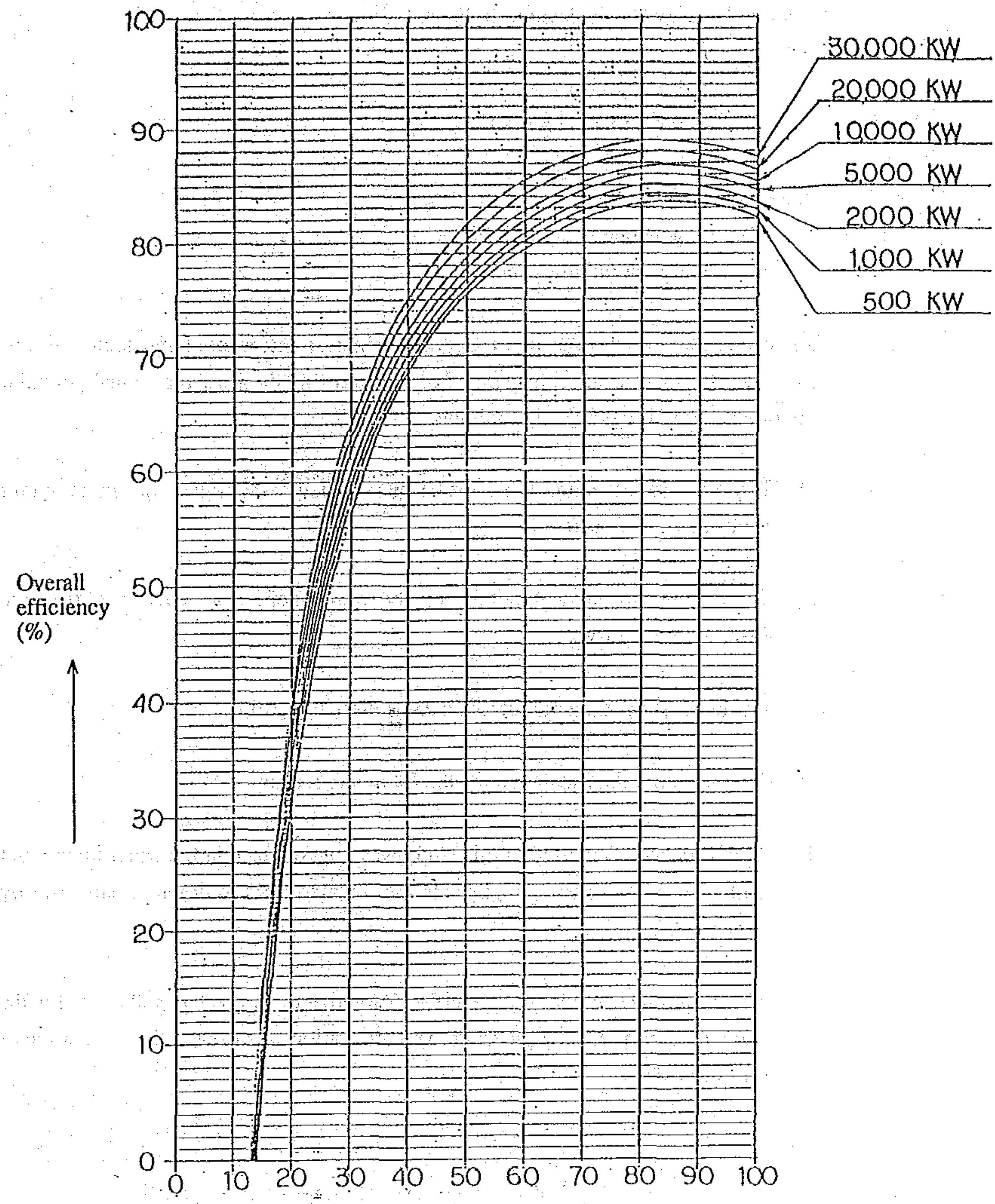
ηt	=	turbine efficiency
ηg	=	generator efficiency

Resultant efficiency corresponds to the value of the maximum available discharge ratio in the resultant efficiency curve shown in Fig. 8.2. Table 8.2 shows the calculation result of the generated output for the alternative plans.

Table 8.2 Generated Output Calculations

Item / Alternative plan	① Available discharge Q (m^3/s)	② Standard net head H (m)	③ 9.8 x ① x ② Theoretical output (kW)	④ Resultant efficiency η	⑤ ③ x ④ Generated output P (kW)
Plan for rehabilitating existing facilities (REH-1)	6.5	32.8	2,089	0.830	1,734
Power output increase (ALT-1)	10.0	32.8	3,214	0.830	2,667

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 as follows.

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

where:

P = generated output (kW)

t = operation time (hour)

Assuming that the power plant operation in not interrupted by accident, nor suspended for maintenance, inspection or repair during the year, the annual potential generated energy is calculated as follows:

(1) From the runoff data, daily discharge is added to net head and the resultant efficiency coefficient.

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

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

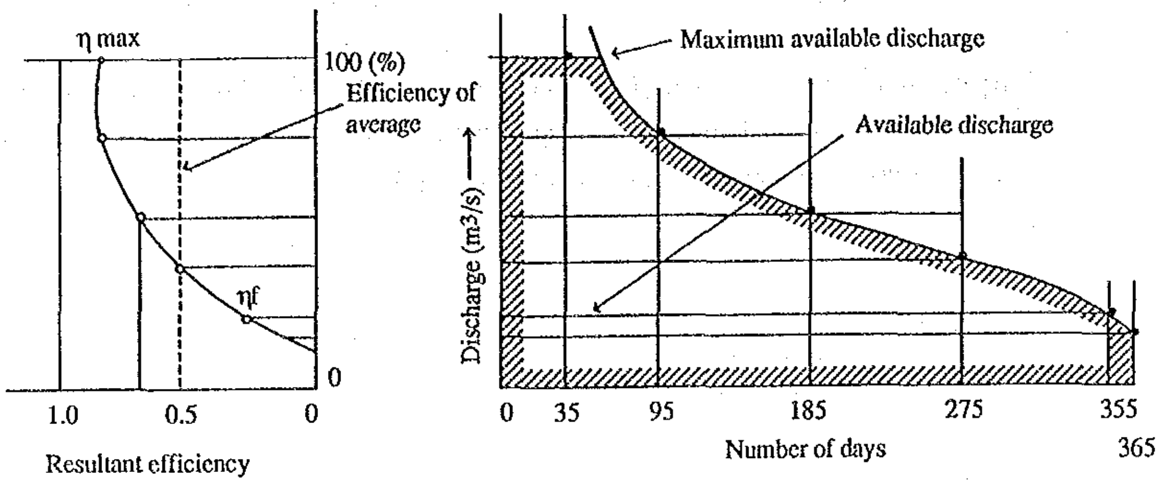
Item (2) is used in this calculation for the following reasons.

(1) The discharge data used in this study was not collected at the water intake, but collected at Zaragoza gauging station, located 1.9 km down stream, run by CAMB S.A.

(2) Since there are no records for either Zaragoza or the water intake site for the same time period, a simple catchment area ration was used in the calculation of discharge data.

(3) A flow duration curve is also used in (3), but it is not as accurate as (2).

By combining the resultant efficiency coefficient and flow duration data from the flow duration curve, annual potential generated energy can be estimated. Calculation using the hydrological regime-efficiency method is as follows.



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

① Day	② Number of days	③ Available discharge (m^3/s)	④ Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	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 $9.8 \times Q \times He \times \eta$
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 of Annual Potential Generated Energy According to the 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 and efficiency method, with the following results.

(1) The annual potential generated energy for the rehabilitation plan of the existing facilities (max. available discharge = 3.25 m^3/s x 2 units):

14.7 GWh (96.5%)

(2) The annual potential generated energy for the alternative plan 1 (ALT-1) (max. available discharge = 5.0 m^3/s):

18.4 GWh (78%)

Table 8.3 Calculation of Annual Potential Generated Energy

(1) Rehabilitation plan of existing facilities (REH-1)

Max. available discharge Q = 3.25 m^3/s x 2 units
Standard net head He = 32.8 m
Turbine type: Francis turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	294	6.5	1.000	0.830	1,734	1,734	12,235
306	12	6.0	0.923	0.840	1,620	1,677	482
324	18	5.6	0.861	0.842	1,515	1,567	676
341	17	5.5	0.846	0.842	1,488	1,501	612
359	18	4.5	0.692	0.827	1,196	1,342	579
365	6	3.5	0.538	0.779	876	1,036	149
Total	365					(1,476)	14,733

(2) Alternative plan 1 (ALT-1)

Max. available discharge: $Q = 5.0\ m^3/s \times 2$ units
Standard net head (He): 32.8 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.	99	10.0	1.00	0.830	2,667	2,667	6,336
105	6	9.7	0.97	0.834	2,600	2,633	379
110	5	9.3	0.93	0.839	2,508	2,554	306
125	15	9.0	0.90	0.840	2,430	2,469	888
130	5	8.6	0.86	0.842	2,327	2,378	285
135	5	8.2	0.82	0.842	2,219	2,273	272
150	15	8.0	0.80	0.841	2,162	2,190	788
155	5	7.9	0.79	0.840	2,133	2,147	257
182	27	7.8	0.78	0.840	2,106	2,119	1,373
195	13	7.4	0.74	0.835	1,986	2,046	638
292	97	6.9	0.69	0.826	1,832	1,909	4,444
294	2	6.5	0.65	0.817	1,707	1,769	84
306	12	6.0	0.60	0.802	1,546	1,626	468
324	18	5.6	0.56	0.788	1,418	1,482	640
341	17	5.5	0.55	0.784	1,386	1,402	572
359	18	4.5	0.45	0.731	1,057	1,221	527
365	6	3.5	0.35	0.645	725	891	128
Total	365					(1,986)	18,385

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 stated in 4.3, channel structures, except for the desilting basin, penstock and powerhouse building, need to be reconstructed or newly constructed. The generating equipment and transformer require new procurement or replacement with new equipment. To compare the maximum available discharge, the following two rehabilitation plans are shown in Table 9.1.

$Q = 6.5\ m^3/s$
$Q = 10.00\ m^3/s$

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 9.1 Comparison of Alternative Rehabilitation Plans

Item	Alternative	
	Rehabilitation of the existing facilities	Increase of power output
	REH-1	ALT-1
Discharge, Q (m^3/s)	6.5	10.0
Max. output, P (kW)	1,700	2,600
Facility utilization factor (%)	96.5	78
Rehabilitation and improvement plan:		
Diversion weir	Maintain the structure of longitudinal dike.	Will be reconstructed into diversion weir and sand flush gate will be built.
Intake	Maintain as existing.	Design will be changed to accommodate diversion weir.
Desilting basin	A new, suitable-sized one will be constructed.	
Conduction channel	Maintain as existing.	Will be expanded and reconstructed.
Head tank	Will be expanded to increase storage capacity.	
Penstocks	Maintain as existing.	New construction.
Generating equipment	Will be installed new 2 units.	
Powerhouse building	New foundations for generating equipment will be built in exsting building.	

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 and local currency portions which are calculated at current exchange rates (September 1989), based on the U.S. dollar.

9.2.1 Estimated Generating Equipment Costs

According to the ISA valuation standard, generating equipment CIF costs are calculated based on the FOB from Japan. The generating equipment specifications and FOB costs are shown in Table 9.2.

The CIF/FOB ratio for the CIF costs is 1.12, as shown in Table 9.3.

Table 9.2 Generating Equipment Specifications and FOB Costs

Item	Alternative	
	REH-1	ALT-1
1. Specifications		
Design discharge (m^3/s)	3.25	5.0
Net head (m)	32.8	32.8
Theoretical output (kW)	1,045	1,607
Turbine type	HF*	HF*
Turbine output (kW)	920	1,400
Generator power factor	0.9	0.9
Generator output (kVA)	1,000	1,500
Main transformer capacity (kVA)	2,000	3,000
2. FOB costs (US$1,000)		
Generating equipment		
(1) Turbine etc.	421.45	437.15
(2) Generator etc.	227.1	242.85
(3) = (1)+(2) Sub-total:	648.55	680
(4) Number of units	2	2
(5) = (3)x(4) Subtotal:	1,297.1	1,360
(6) Generator switchgear etc.	97.9	97.9
(7) Main transformer, switchgear	67.1	111.4
(8) = (5)+(6)+(7) Total:	1,462.1	1,569.3

* HF = horizontal Francis

Table 9.3 Implementation Cost of Generating Equipment

(units: US$ 10^3)

Item		Alternative			
		REH-1		ALT-1	
		A	B	A	B
1) FOB cost		1,462.1	-	1,569.3	-
2) Transportation costs, insurance	1) x 0.12	175.5	-	188.3	-
3) Tax	1) x 0.223	-	326.0	-	350.0
4) Value-added tax	1) x 0.134	-	196.0	-	210.3
5) Others	1) x 0.22	-	321.7	-	345.2
6) Subtotal		1,637.6	843.7	1,757.6	905.5
7) Contingency	1) x 0.17	248.6	-	233.8	-
8) Eng. fees	1) x 0.149	217.9	-	233.8	-
9) Subtotal	6) + 7) + 8)	2,104.1	843.7	2,258.2	905.5
10) Total		2,947.8		3,163.7	

Note: A = foreign currency
B = local currency

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 ESSA. 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 9.4.

Table 9.4 Estimation of Civil Construction Cost

(unit: 10^6 pesos)

Item	Alternative	
	REH-1	ALT-1
Diversion weir and intake construction	20.6	76.4
Desilting basin construction	17.6	20.3
Conduction channel construction	0	48.8
Head tank construction	36.5	42.8
Penstock construction	6.4	63.4
Foundation of equipment construction	5.1	10.8
Powerhouse building construction	-	-
Temporary facilities construction	5.6	5.6
Other construction	3.9	3.9
① Subtotal	95.7	272.0
② Contingency (① x 0.15)	14.4	40.8
③ Engineering fees ((① + ②) x 0.10)	11.0	31.3
④ Total (① + ② + ③)	121.1	344.1
⑤ Output loss	17.7	24.6
Grand total ④ + ⑤	138.8	368.7

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 expected 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 9.5. The ALT-1 plan calls for US$2,900 /kW per increase in power output, which is the lowest cost.

Table 9.5 Comparison of Construction Costs per kW

Item		Alternative	
		REH-1	ALT-1
Existing equipment output (kW)			
Rated output	Po	1,560	1,560
Available output	Pe	1,200	1,200
Post-rehabilitation output	P_1 (kW)	1,700	2,600
Recovered/increased output			
$\Delta P = P_1 - Pe$ (kW)		500	1,400
Rehabilitation work cost	(US$1,000)		
Foreign currency portion Cf		2,100	2,250
Local currency portion C		1,250	1,900
Total C = Cf + C		3,350	4,150
Construction cost per kW	(US$/kW)		
C/P_1		1,950	1,600
$C/\Delta P$		6,650	2,900

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

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 intrest payments for the construction are totaled and divided by 25 years.

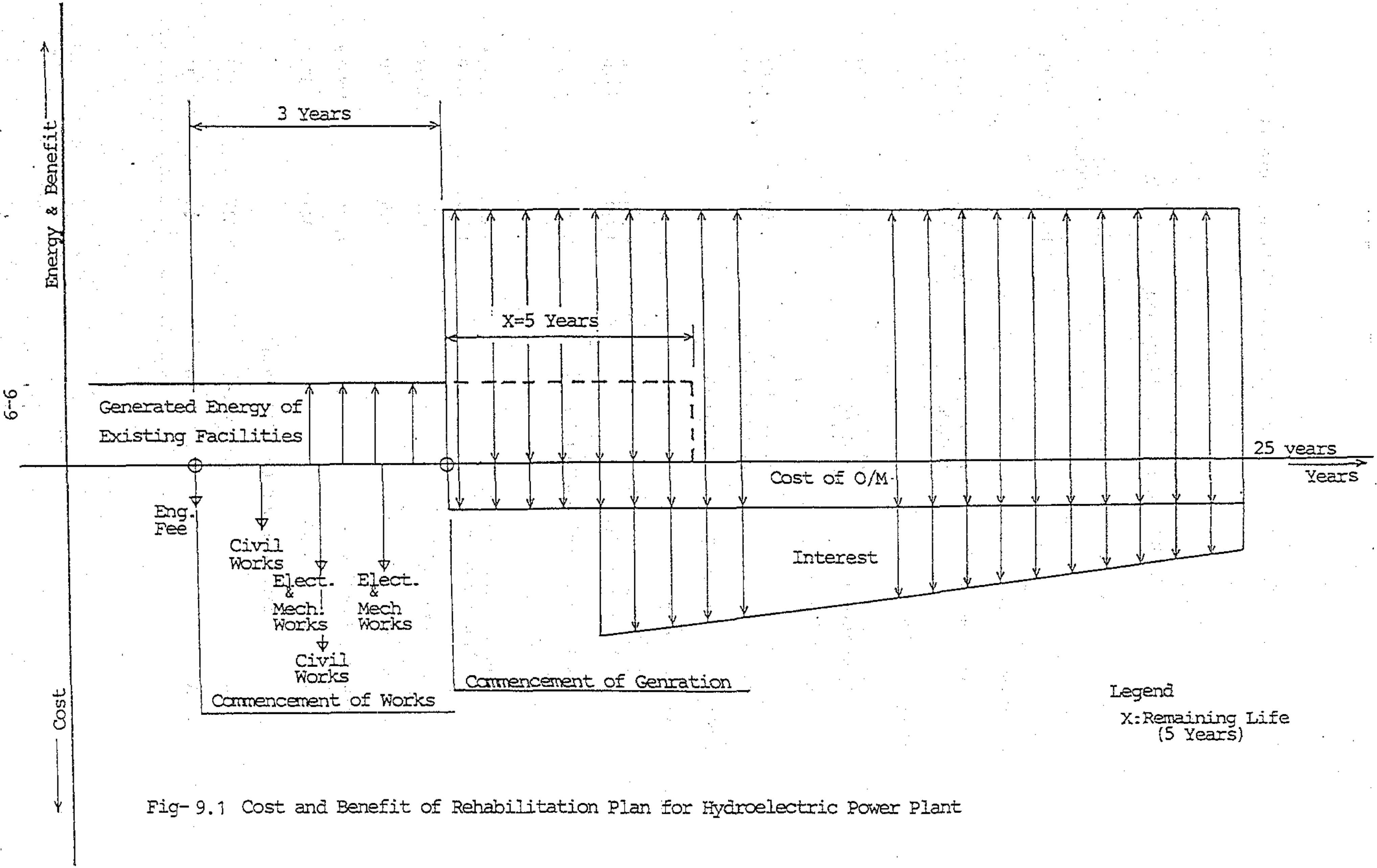


Fig- 9.1 Cost and Benefit of Rehabilitation Plan for Hydroelectric Power Plant

The results of calculation of generating costs per kWh are shown in Table 9.6.

Table 9.6 Comparison of Generating Cost per kWh

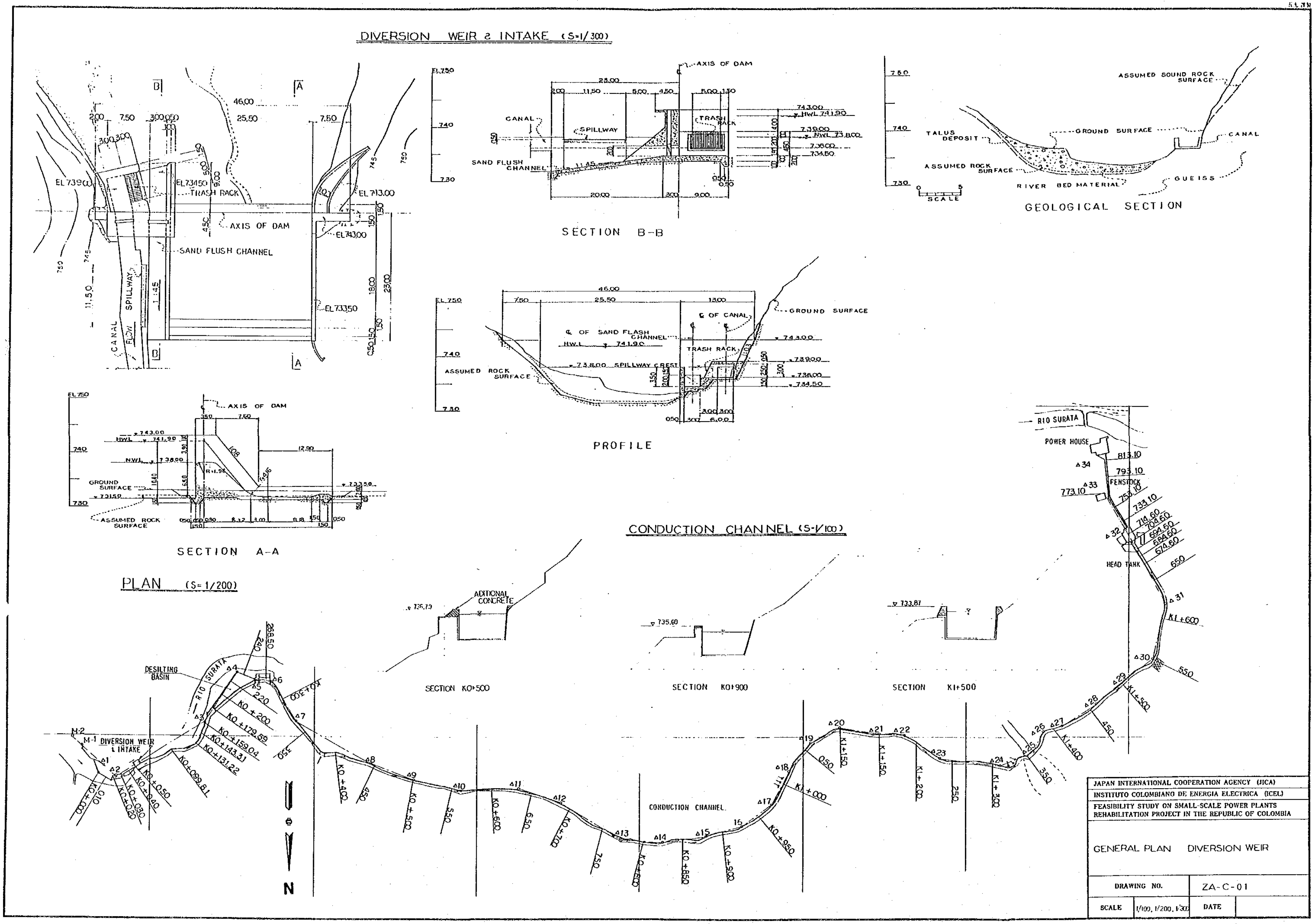
Item		Alternative	
		REH-1	ALT-1
Existing equipment capacity:			
Power output	Po (kW)	1,560	1,560
Energy	Ec (Gwh)	6.29	6.29
Rehabilitation plan:			
Power output	P_1 (kW)	1,700	2,600
Generated energy	E_1 (Gwh)	14.7	18.4
Recovered/increased power			
Output	$\Delta P = P_1 - Pe$ (kW)	500	1,400
Energy	$\Delta E = E_1 - Ee$ (Gwh)	8.4	12.1
Total of expenses at generating terminal: (US$1,000)			
Construction work cost			
Foreign currency portion Cf_1		2,100	2,250
Local currency portion $C\ell_1$		1,250	1,900
Construction cost total $C_1 = Cf_1 + C\ell_1$		3,350	4,150
Interest payment C_2			
Foreign currency portion Cf_2		3,381	3,622.5
Local currency portion $C\ell_2$		1,270	1,930.4
Total $C_2 = Cf_2 + C\ell_2$		4,651	5,552.9
AOM C_3 = US$4 x Pl x 25 years		170	260
Total $\Sigma Ci = C_1 + C_2 + C_3$		8,171	9,962.9
Average annual cost $C = \Sigma Ci/25$		326.8	398.5
Generating cost per annually supplied energy (Mills/kWh)			
Per E_1	C (E_1 x 0.95)	23	23
Per ΔE	C (ΔE x 0.95)	40	35

9.3.3 Overall Evaluation

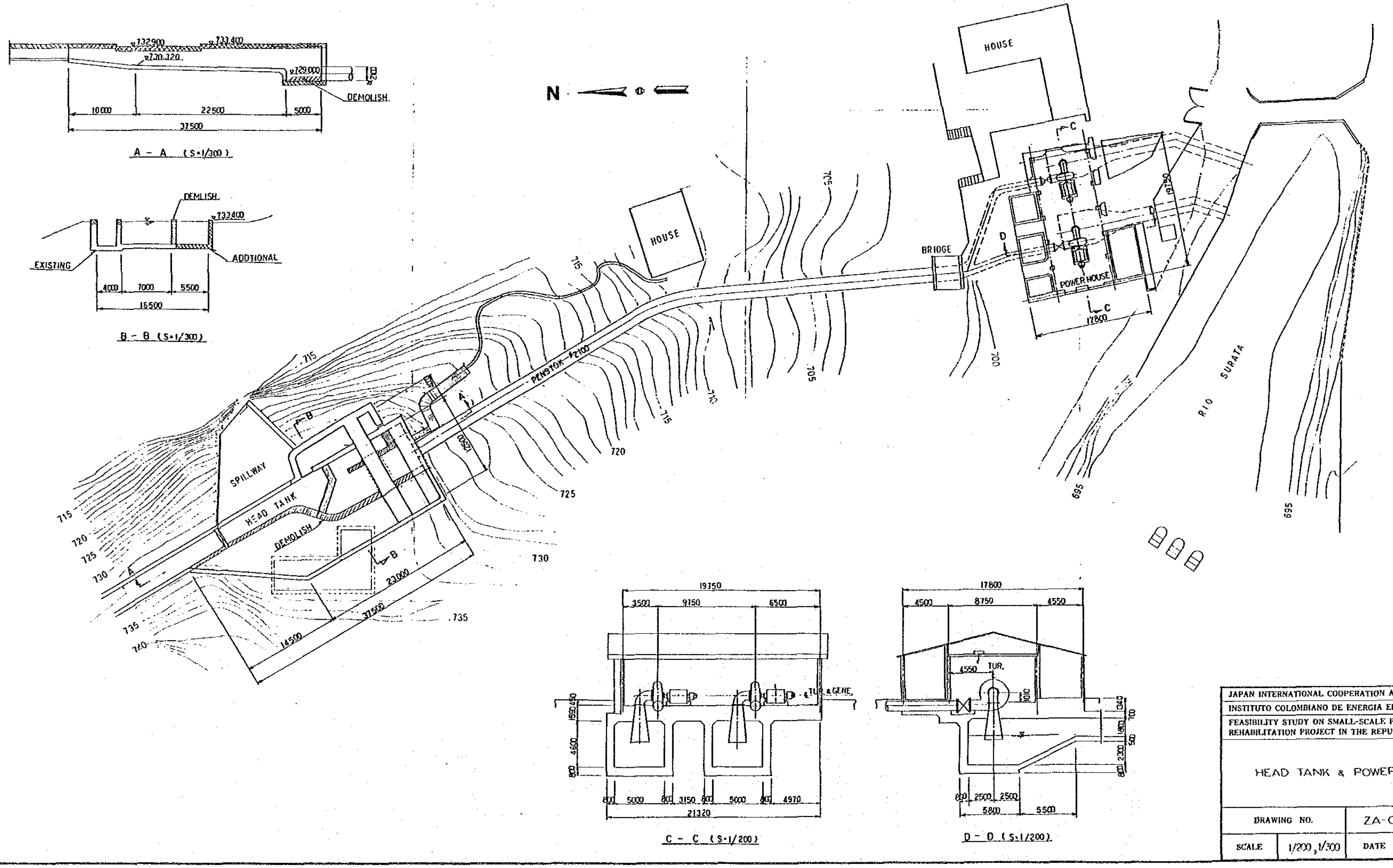
ALT-1 plan is thus selected as the optimum plan taking the construction costs per kW and generating costs per kWh for each alternative plan into account in the cost-benefit analysis.

Drawings

Title	Drawing No.
General Plan of Diversion Weir	ZA-C-01
Head Tank & Powerhouse	ZA-C-02
Duration Curve	ZA-H-01
Geological Plan	ZA-G-01
One Line Diagram (ALT-1)	ZA-E-01


DIVERSION WEIR & INTAKE (S=1/300)
SECTION B-B
GEOLOGICAL SECTION
ASSUMED SOUND ROCK SURFACE
GROUND SURFACE
CANAL
TALUS DEPOSIT
ASSUMED ROCK SURFACE
RIVER BED MATERIAL
GUEISS
SCALE
AXIS OF DAM
TRASH RACK
SAND FLUSH CHANNEL
SPILLWAY
PROFILE
SECTION A-A
PLAN (S=1/200)
CONDUCTION CHANNEL (S=1/100)
SECTION K0+500
SECTION K0+900
SECTION K1+500
ADITIONAL CONCRETE
DESILTING BASIN
RIO SURATA
DIVERSION WEIR & INTAKE
CONDUCTION CHANNEL
POWER HOUSE
PENSTOCK
HEAD TANK
N
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA
GENERAL PLAN DIVERSION WEIR
DRAWING NO. ZA-C-01
SCALE 1/100, 1/200, 1/300
DATE

PLAN OF HEAD TANK, PENSTOCK & POWER HOUSE (S=1/300)



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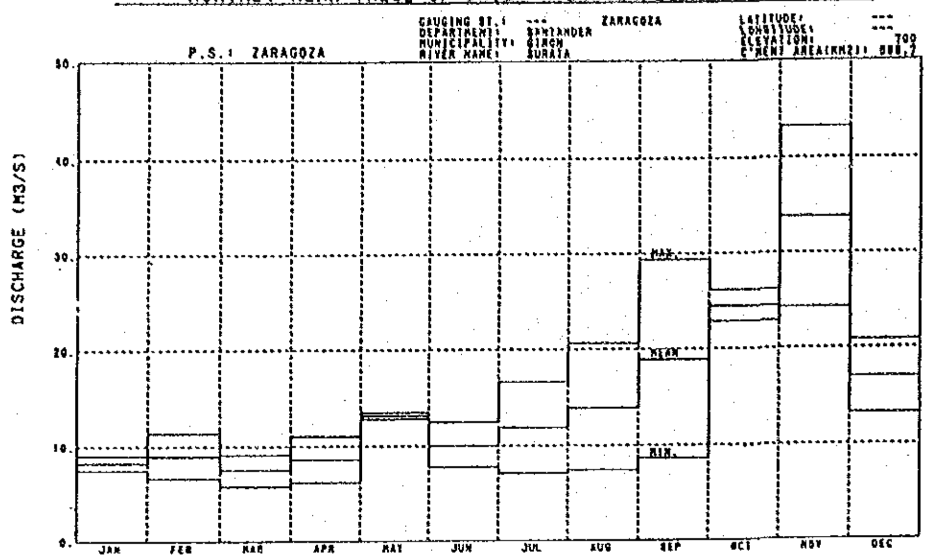
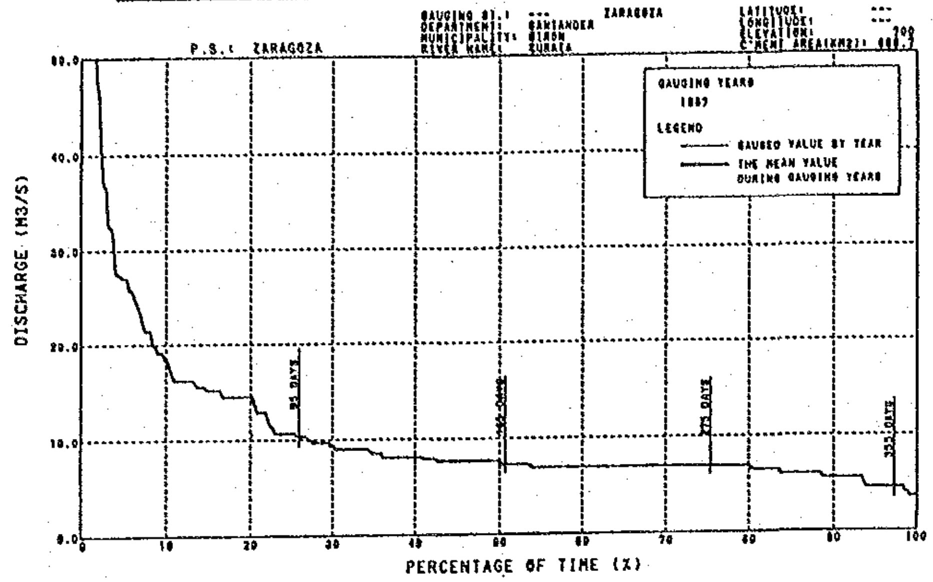
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
HEAD TANK & POWER HOUSE	
DRAWING NO.	ZA-C-02
SCALE	1/200, 1/300
DATE	

(1)
MONTHLY MEAN VALUE OF DAILY AVERAGE FLOW AT G.S. SITE



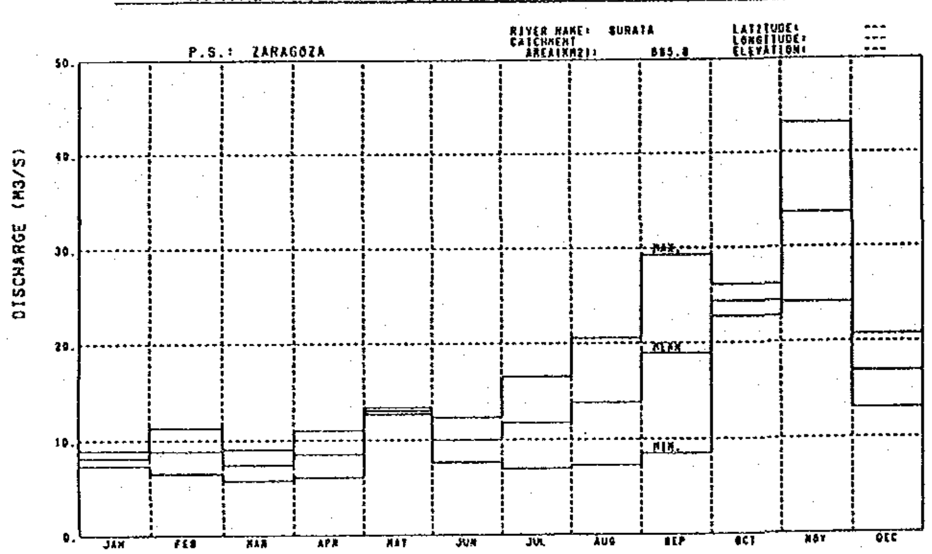
(3)
FLOW DURATION CURVE AT GAUGING STATION SITE



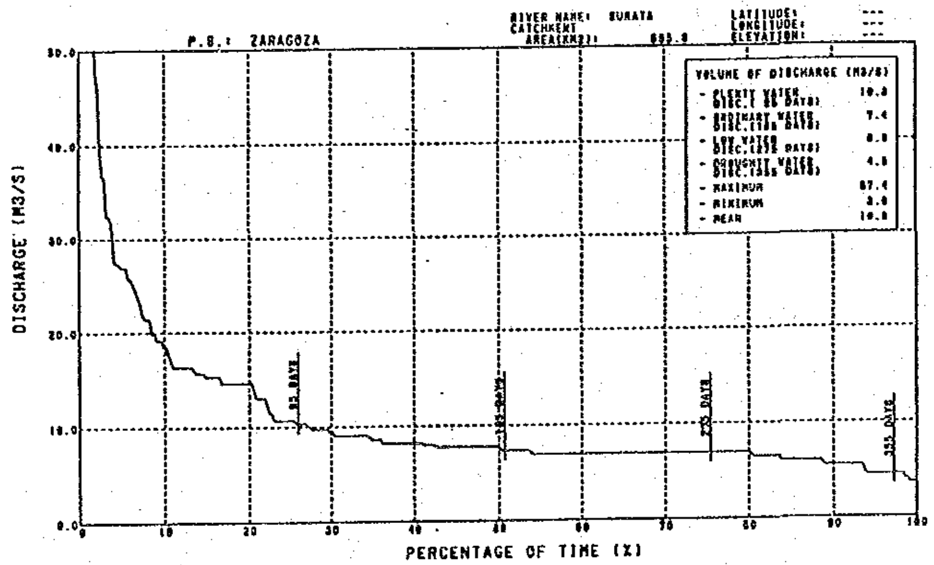
Data of Hydrological Gauging Station

No. of Station	— —
Name of Station	Zaragoza
River	Surata
Management	CAMB S.A
Installation Year – Month	— —
Coordinates (Deg. – Min.)	
Latitude	— —
Longitude	— —
Above Sea Level s.n.m. (m)	— —
Long River (km)	— —
Catchment Area (km²)	— —
Water Shed (m)	700
Observation Period	1982 — 1988

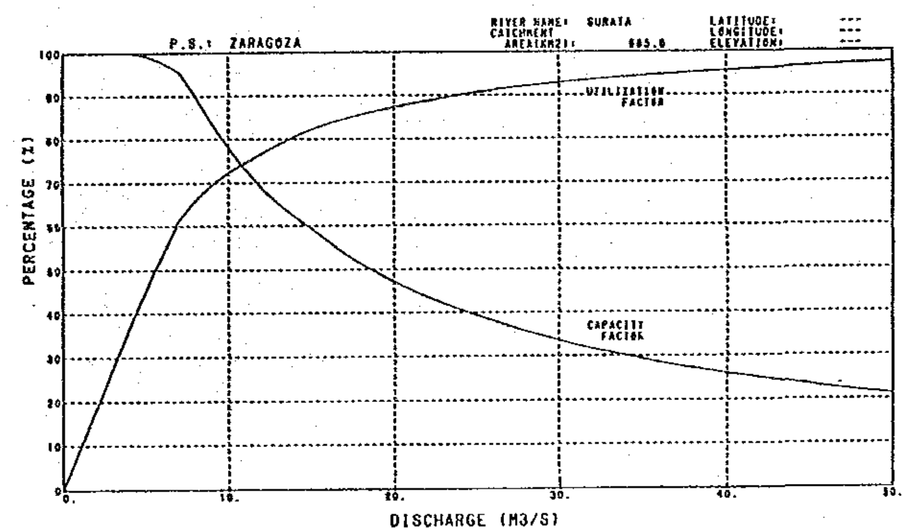
(2)
MONTHLY MEAN VALUE OF DAILY AVERAGE FLOW AT INTAKE SITE



(4)
TYPICAL FLOW DURATION CURVE AT INTAKE SITE



(5)
UTILIZATION & CAPACITY FACTOR



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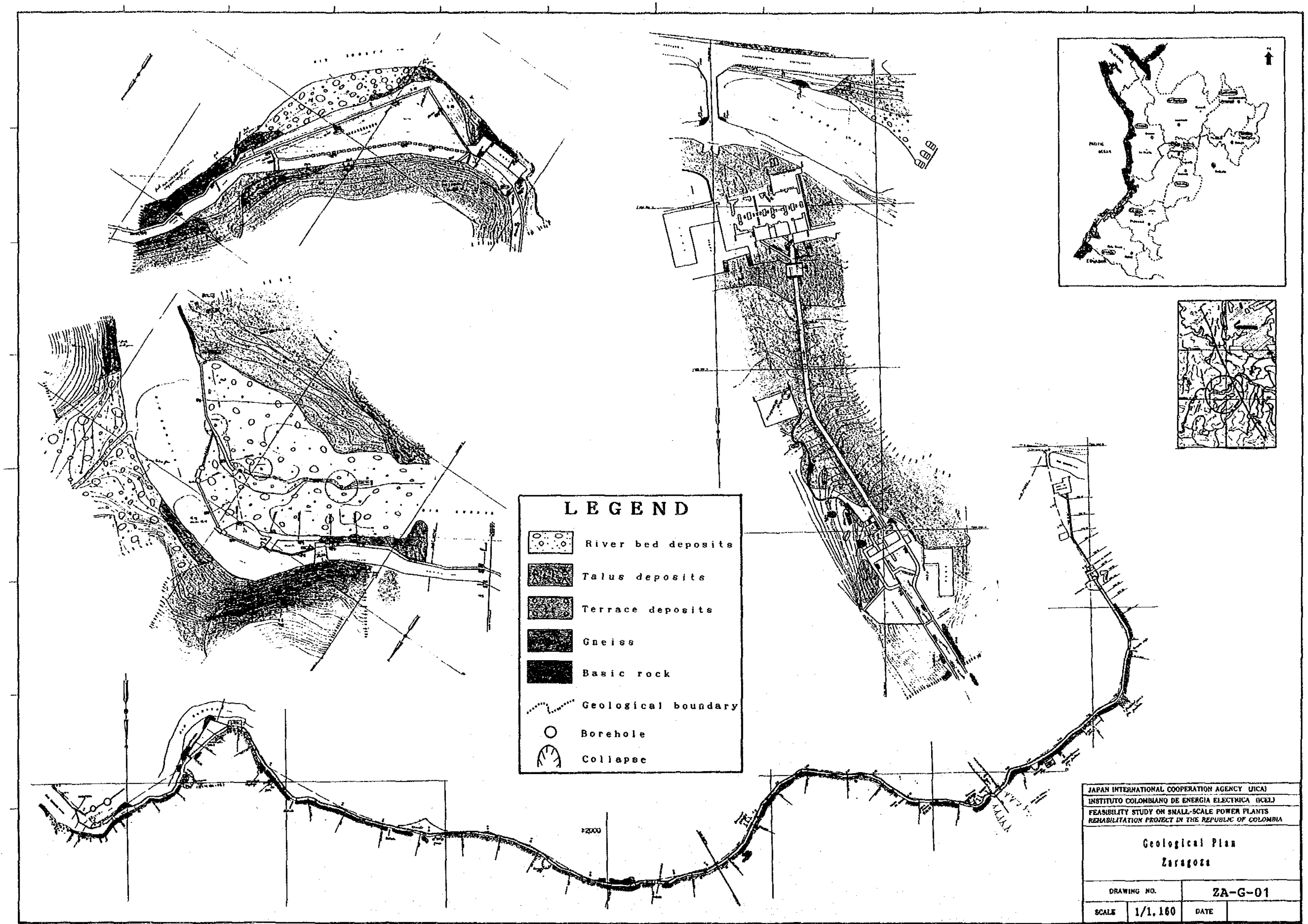
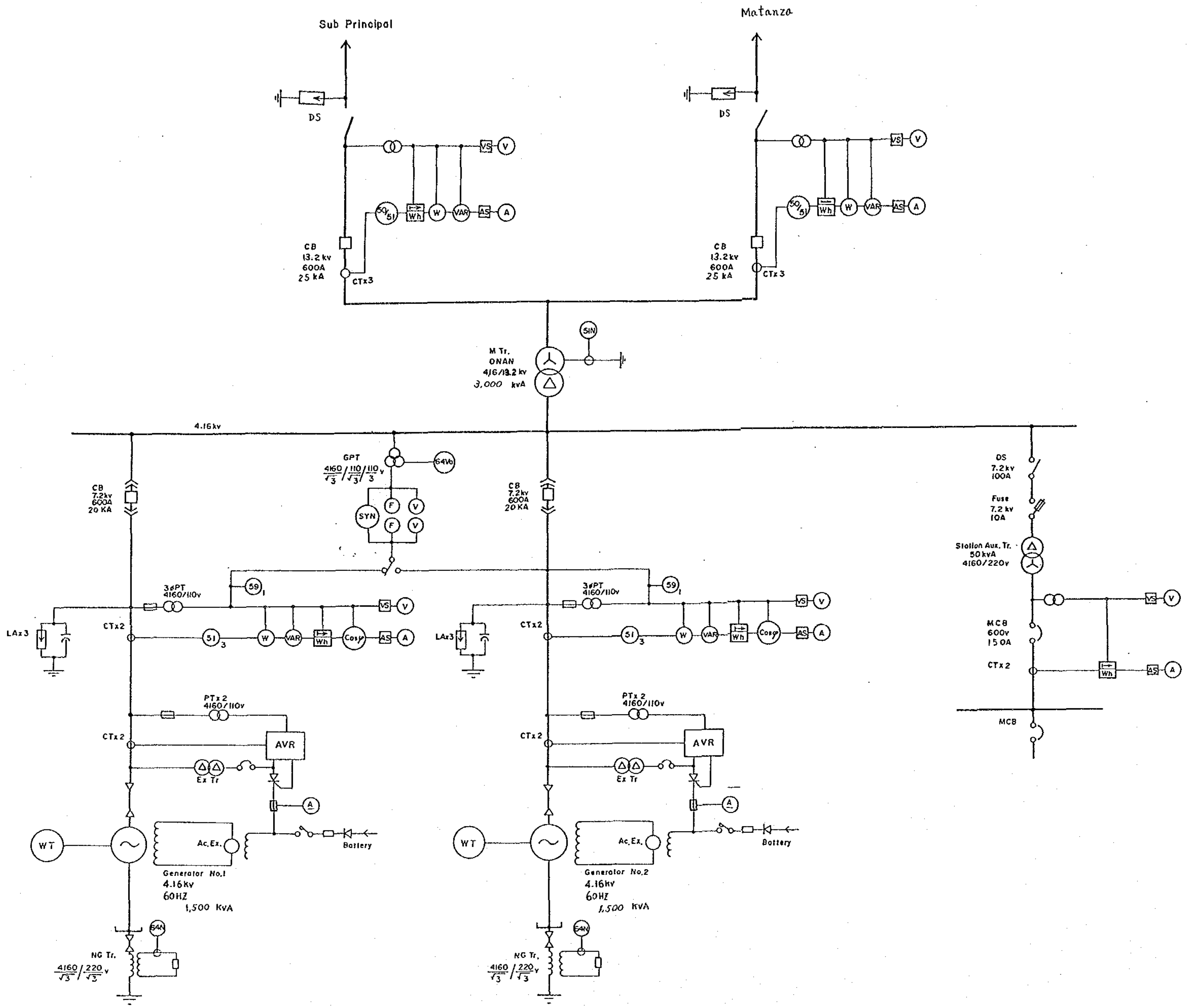
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
DURATION CURVES	
DRAWING NO.	ZA – H – 01
SCALE	——
DATE	


LEGEND
River bed deposits
Talus deposits
Terrace deposits
Gneiss
Basic rock
Geological boundary
Borehole
Collapse
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS
REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA
Geological Plan
Zaragoza
DRAWING NO.
ZA-G-01
SCALE
1/1,160
DATE



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

ONE LINE DIAGRAM
(ALT-1)

DRAWING NO.		ZA-E-01	
SCALE	---	DATE	

Attached Data

1. Facility Register for the Existing Power Plant

2. Survey Record

Facility Register for the Existing Power Plant

Power Plant	Zaragoza
Electric Power Company	ESSA
Location	Zaragoza/Santander
River	Surata
Generating Method	Run-of-River
Year Installed	1931/1935/1948
Years in Service	1931
Installed Capacity	1,560 kW
Available Capacity	800 kW

Civil		
Item	**Data**	
1. Dam		
1) Type	concrete	
2) Height (m)	3.0	
3) Crest length (m)	65.0	
4) Height of overflowing crest (m)	737.8	
5) Width of overflowing crest (m)	65.0	
6) Depth of overflowing crest (m)	no data available	
2. Intake Gate		
1) Type	〃	
2) Number of gates	〃	
3) Dimensions (W x H)(m)	〃	
3. Intake		
1) Intake sill height (m)	no data available	
2) Number of intake	1	
3) Dimensions (W x H)(m)	4.0 × 2.0	
4. Desilting Basin		
1) Dimensions (W x L x H)(m)	13.0 × 60.0 × 2.9	
5. Sand Trap Gate		
1) Type	wood	metal sluice
2) Number of gates	2	1
3) Dimensions (W x H)(m)	2.0 × 3.0	2.0 × 2.0
6. Headrace		
1) Type	conc. open channel	
2) Dimensions (W x H)(m)	3.0 × 1.5	
3) Length (m)	1,685	

Civil	
Item	Data
7. Reservoir Tank	
1) Dimensions (W x L x H)(m)	2.6 ~ 11.0 x 35.5 x 2.1
8. Forebay	
1) Dimensions (W x H)(m)	no data available
9. Penstock	
1) Number of lines	1
2) Penstock diameter (d)(m)	1.52
3) Penstock length (L)(m)	107.3
10. Tailrace	
1) Dimensions (W x H)(m)	no data available

Equipment			
Item	Data		
	#1	#2	#3
1. Water Turbine			
1) Manufacturer's name	Aktiebolaget	Finshvttans	Brunk "Suecia"
2) Year manufactured	1950	1932	1937
3) Type	Francis	Francis	Francis
4) Output (kW)	520	520	520
5) Revolution (rpm)	720	720	720
6) Ancillary equipment			
a) Type of governor	Kt-Aktiebolaget		Finshvttans
b) Inlet valve			
- Type	Gate	Gate	Gate
- Diameter (mm)	700	700	700
2. Generator and Exciter			
1) Manufacturer's name	ASEA	ASEA	ASEA
2) Year manufactured	1950	1932	1937
3) Type	Synchro.	Synchro.	Synchro.
4) Capacity (kVA)	650	650	650
5) Power factor (%)	80	80	80
6) Voltage (V)	2,300	2,300	2,300
7) Frequency (Hz)	60	60	60
8) Revolution (rpm)	720	720	720
9) Method of neutral earthing	One resistance (266 ohm) for three generators		
10) Type of exciter	no data available		

Equipment				
Item	Data			
3. Transformer				
1) Manufacturer's name	ASEA	ASEA	ASEA	ASEA
2) Year manufactured	1930	1930	1930	1940
3) Type	TKL	TKL	TKL	TKL
4) Capacity (kVA)	500	500	500	500
5) Primary voltage (kV)	2.3	2.3	2.3	2.3
6) Secondary voltage (kV)	11.4	11.4	11.4	11.4
7) Number of unit	1	1	1	1
8) Vector-group symbol	Y/Y OA_2	Y/Y OA_2	Y/Y OA_2	Y/Y OA_2
9) Impedance (%)	5.52	5.44	5.44	5.30
10) Purpose for use	Step-up	Set-up	Set-up	Set-up
4. Circuit Breaker				
1) Manufacturer's name	GE		ASEA	
2) Year manufactured	1925		1928	
3) Type	FK-192-4.16-25		HL 813/150	
4) Voltage (kV)	4.16		13.2	
5) Rated current (A)	100		100, 150	
6) Rupturing capacity (kA)	0.6		0.4 at 13kV	
7) Purpose for use	Generator		Transformer and 11.4kV bar	
5. Transmission Line				
1) Destination				
2) Length (m)	8,000			
3) Voltage (kV)	11.4			
4) Number of circuit	2			
5) Number of pylons	no data available			
6) Size of conductors	1/0			
7) Materials of conductors	Copper			

Equipment	
Item	**Data**
6. Battery 1) Manufacturer's name	N/A
2) Year manufactured	
3) Capacity (AH/HR)	
4) DC voltage (V)	
5) Type	
7. Battery Charger 1) Manufacturer's name	N/A
2) Year manufactured	
3) Capacity	
4) Incoming voltage (V)	
8. Overhead Crane 1) Weight (ton)	no data available
2) Method of operation	"
3) Span (m)	"

Survey Records

Zaragoza Hydroelectric Power Plant

I. RECORDS BY VISUAL INSPECTION AND HEARING SURVEY

Unit No.: 1

Type of Turbine: Francis

	Generating Facilities	Check item by visual inspection and hearing	Results
Francis Turbine	Casing	1) Existence of corrosion	1) No
		2) Wear in thickness	2) Yes
		3) Presence of vibration	3) No
	Runner	1) Existence of corrosion	1) No
		2) Occurrence of porosity by sand pitting	2) Yes
	Shaft	1) Shaking of shaft axis	1) No
	Bearing	1) Oil shortage on bearing surface	1) No
		2) Lack of oil viscosity	2) No
	Governor control	1) Control by belt-driven type	1) Yes
		2) Speed detection device	2) Yes
		3) Speed regulation system	3) Yes
		4) Installation of load limiter	4) No
		5) Accuracy of governor speed regulation	5) Yes

Generating Facilities		Check item by visual inspection and hearing	Results
Francis Turbine	Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) No 2) Yes
	Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) Manual 2) Good 3) Yes
	Guide vanes	1) Smoothness of control 2) Presence of water leakage from casing when guide vanes are closed 3) Break frequency of shear pins	1) Yes 2) No 3) No
	Sealing device	1) Sufficiency of water sealing for shaft 2) Sufficiency of packing for shaft seal	1) Yes 2) Yes

Unit No. 1

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat	1) No
		2) Existence of erosion for core	2) No
		3) Fitness of between rotor and shaft	3) No
	Stator winding	1) Frequency of burning trouble or repair	1) No
		2) Reduction of insulation resistance	2) No
		3) Rust and erosion of core	3) No
	Bearing	1) Occurrence of deformation on metal surface	1) No
		2) Lack of oil lubrication	2) No
		3) Occurrence of temperature rise	3) No
	Exciter	1) Exchange frequency of brushes worn out	1) Yes
		2) Sufficient stock of spare brush	2) Yes
	Voltage regulator	1) Operation method of voltage regulator	1) Automatic
		2) Response of voltage detection for load variation	2) Constant load

Unit No.: 2

Type of Turbine: Francis

	Generating Facilities	Check item by visual inspection and hearing	Results
Francis Turbine	Casing	1) Existence of corrosion 2) Wear in thickness	1) No 2) Yes
		3) Presence of vibration	3) No
	Runner	1) Existence of corrosion 2) Occurrence of porosity by sand pitting	1) No 2) Yes
	Shaft	1) Shaking of shaft axis	1) No
	Bearing	1) Oil shortage on bearing surface	1) No
		2) Lack of oil viscosity	2) No
	Governor control	1) Control by belt-driven type 2) Speed detection device 3) Speed regulation system	1) Yes 2) Yes 3) Yes
		4) Installation of load limiter	4) No
		5) Aoouracy of governor speed regulation	5) Yes

Generating Facilities		Check item by visual inspection and hearing	Results
Francis Turbine	Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) No 2) Yes
	Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) Manual 2) Good 3) Yes
	Guide vanes	1) Smoothness of control 2) Presence of water leakage from casing when guide vanes are closed 3) Break frequency of shear pins	1) Yes 2) No 3) No
	Sealing device	1) Sufficiency of water sealing for shaft 2) Sufficiency of packing for shaft seal	1) Yes 2) Yes

Unit No. 2

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat 2) Existence of erosion for core 3) Fitness of between rotor and shaft	1) No 2) No 3) No
	Stator winding	1) Frequency of burning trouble or repair 2) Reduction of insulation resistance 3) Rust and erosion of core	1) No 2) No 3) No
	Bearing	1) Occurrence of deformation on metal surface 2) Lack of oil lubrication 3) Occurrence of temperature rise	1) No 2) No 3) No
	Exciter	1) Exchange frequency of brushes worn out 2) Sufficient stock of spare brush	1) Yes 2) Yes
	Voltage regulator	1) Operation method of voltage regulator 2) Response of voltage detection for load variation	1) Automatic 2) Constant load

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Unit No.: 3

Type of Turbine: Francis

	Generating Facilities	Check item by visual inspection and hearing	Results
Francis Turbine	Casing	1) Existence of corrosion 2) Wear in thickness	1) No 2) Yes
		3) Presence of vibration	3) No
	Runner	1) Existence of corrosion 2) Occurrence of porosity by sand pitting	1) No 2) Yes
	Shaft	1) Shaking of shaft axis	1) No
	Bearing	1) Oil shortage on bearing surface	1) No
		2) Lack of oil viscosity	2) No
	Governor control	1) Control by belt-driven type 2) Speed detection device 3) Speed regulation system	1) Yes 2) Yes 3) Yes
		4) Installation of load limiter	4) No
		5) Aoouracy of governor speed regulation	5) Yes

Generating Facilities		Check item by visual inspection and hearing	Results
Francis Turbine	Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) No 2) Yes
	Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) Manual 2) Good 3) Yes
	Guide vanes	1) Smoothness of control 2) Presence of water leakage from casing when guide vanes are closed 3) Break frequency of shear pins	1) Yes 2) No 3) No
	Sealing device	1) Sufficiency of water sealing for shaft 2) Sufficiency of packing for shaft seal	1) Yes 2) Yes

Unit No. 3

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat	1) No
		2) Existence of erosion for core	2) No
		3) Fitness of between rotor and shaft	3) No
	Stator winding	1) Frequency of burning trouble or repair	1) No
		2) Reduction of insulation resistance	2) No
		3) Rust and erosion of core	3) No
	Bearing	1) Occurrence of deformation on metal surface	1) No
		2) Lack of oil lubrication	2) No
		3) Occurrence of temperature rise	3) No
	Exciter	1) Exchange frequency of brushes worn out	1) Yes
		2) Sufficient stock of spare brush	2) Yes
	Voltage regulator	1) Operation method of voltage regulator	1) Automatic
		2) Response of voltage detection for load variation	2) Constant load

	Generating Facilities	Check item by visual inspection and hearing	Results
Control Board	Metering equipment	1) Sufficiency of accuracy for instruments	1) Good
		2) Lack of necessary instruments	2) No
		3) Items constantly recorded	3) No
	Protection equipment	1) Lack of relays to be installed	1) No
		2) Operation method in case of accident in transmission lines	2) Manual
	Remote control equipment	1) Control method for turbine and generator operation	1) Manual
		2) Control method for voltage and speed control	2) Automatic
		3) Operation method of synchronized switching	3) Manual by synchroscope and lamp
	Power system	1) Power supply voltage (kV) after rehabilitation work	1) 13.8KV

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Generating Facilities		Check item by visual inspection and hearing	Results
Indoor Switchgear	Insulation level	1) Sufficiency of insulation level 2) Unification of insulation level 3) Reduction of insulation registance	1) Yes 2) Yes 3) No
	Accessibility and Safety	1) Accessibility to high voltage devices 2) Sufficiency of protection for high voltage cable terminals 3) Method and reliability of operation for synchronizing circuit breaker	1) Yes 2) Yes 3) Good

	Generating Facilities	Check item by visual inspection and hearing	Results
Outdoor Equipment	Transformer	1) Presence of over load operation	1) No
	Circuit breaker	1) Situation of tripfor outgoing feeder breaker in case of accident on transmission line 2) Fitness of maintenance in case of oil circuit breaker	1) Yes 2) Yes
	Line switch	1) Operation method 2) Reliability of operation	1) Manual 2) Yes
	Insulator	1) Presence of damage and dusts	1) No
	Structural steel	1) Occurence of erosion due to rust 2) Presence of injury	1) No 2) No
	Line protection	1) Existence of adequate protection relays to connect to RED	1) Yes

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II. ACTUAL GENERATED ENERGY AND OPERATION TIME

Unit No.: 1

Installed Capacity of Generator: ________ KVA

Type of Turbine: ________

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL	REMARKS
1983	MWH														
	OPE. TIME														
1984	MWH	165.8	107.4	76.5	76.4	76.5	221.5	131.9	293.4	261.8	277.9	220.1	272.2	2,181.4	
	OPE. TIME	484:12	309:27	117:06	174:12	117:06	612:24	366:00	674:24	663:00	618:06	552:42	696:35	5385:14	
1985	MWH	286.0	23.9	0	0	37.7	249.0	302.8	123.7	167.2	83.3	277.7	40.9	1,592.2	
	OPE. TIME	738:15	62:30	0	0	141:12	628:24	683	342:30	430:36	208:36	652:24	95:04	3,982:31	
1986	MWH	0	21.9	120.8	202.9	107.5	164.1	32.2	30.5	271.4	249.8	299.3	330.6	1,831	
	OPE. TIME	0	62	495:18	486:24	356:18	490:48	115	78:54	674:06	557:36	638:54	729:18	4,684:36	
1987	MWH	326.5	227	168.8	254.1	168.8	0	0	0	126.1	97.9	280.4	297.6	1,947.2	
	OPE. TIME	736	618:12	375:10	588:54	375:10	0	0	0	338:35	225:42	648:42	696:6	4,602:31	
1988	MWH	299.9	76.5	47.9	269.3	300.4	285.8	294.4	281.8	191.2	299.2	154.57	263.157	2,764.127	
	OPE. TIME	706:48	178:18	132:24	669:18	686:54	627:14	720:51	662:09	445:20	688:40	400	729:18	6,647:14	

Unit No.: 2

Installed Capacity of Generator: __________ KVA

Type of Turbine: __________

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL	REMARKS
1983	MWH														
	OPE. TIME														
1984	MWH	122.05	227.372	144.628	166.3	144.628	289.256	282.586	301.127	271.7	290.928	249.464	310.908	2,800.967	
	OPE. TIME	239:12	526:18	321:24	377:18	321:24	693:12	689:00	712:30	663:00	673:30	578:12	700:20	6,495:20	
1985	MWH	289.925	293.942	311.986	318.838	176.191	283.237	236.671	320.3	303.47	238.3	277.635	262.1	3,312.595	
	OPE. TIME	703:30	643	712:12	687:24	389:36	643:24	520:06	705:24	675:06	513:30	622:06	614	7,429:18	
1986	MWH	319.8	296.195	307.146	247.456	177.817	117.374	283.655	334.316	262.76	191.11	297.61	294.78	3,080.019	
	OPE. TIME	698	661:30	706:36	559:54	457:06	348:30	671:48	706:54	614:48	413:48	639:30	567:24	7,045:48	
1987	MWH	333.313	253.726	224.55	147.5	224.5	316.4	257.237	334.985	261.25	227.476	269.108	270.697	3,120.742	
	OPE. TIME	735:42	631:42	501:30	362:36	501:30	662:12	616:15	735:48	688:54	527:48	648:12	655:24	7,267:33	
1988	MWH	289.841	74.822	40.044	264.343	286.242	256.903	255.732	121.220	60.860	0	0	0	1,650.007	
	OPE. TIME	708:18	177:42	129:42	620:12	677:24	590:41	625:47	304:40	86:57	0	0	0	3,921:23	

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Unit No.: 3

Installed Capacity of Generator: ________ KVA

Type of Turbine: ____________

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL	REMARKS
1983	MWH														
	OPE. TIME														
1984	MWH	162.184	44.308	65.178	90.200	65.178	144.628	183.92	127.072	222.376	275.88	225.72	293.603	1,900.247	
	OPE. TIME	441:12	103:12	155:00	187:30	155:00	392:24	513:00	346:18	579:00	667:06	552:12	708:15	4,800:09	
1985	MWH	277.97	271.967	288.153	321.84	245.127	253.726	162.769	208.6	185.76	231.0	172.55	233.2	2,852.662	
	OPE. TIME	716:30	663	714:18	679:42	548:30	598:36	345	603:24	402:54	475:48	428	563:18	6,739	
1986	MWH	324.3	283.738	198.634	39.543	54.424	244.697	234.247	320.522	151.82	120.8	0	0	1,972.725	
	OPE. TIME	687:54	611:36	464:06	85:48	150:12	621:54	612:00	662:24	368:36	273	0	0	4,537:30	
1987	MWH	0	→	→	→	→	→	→	→	→	→	→	0	0	
	OPE. TIME	0	→	→	→	→	→	→	→	→	→	→	0	0	
1988	MWH	0	→	→	→	→	0	9.8648	0	0	168.788	24.996	252.629	456.278	
	OPE. TIME	0	→	→	→	→	0	39:19	0	0	378:24	60:55	678	1,156:38	

III. REPAIR RECORDS

No.	Study Item	Results
	The past records concerning the following items shall be obtained to evaluate reliability of generating facilities.	
	1) Repaired locations and method for repairing	1) Intake
	2) Causes for damage/defect	2) Damage in the dam by increasing of the river
	3) Duration of repairing and power supply stoppage	3) 2 years
	4) Repaired by;	4) Staff of the Enterprise (civil work, electric maintenance and staff of the power plant)
	a) staff in Power Plant	
	b) manufacturer	
	c) other	
	5) Repair cost	5) ฿ 20,000,000
	6) Operation life after the completion of repairing work	6) 6 years

The economic losses by the damage in intake were in following form :

1) Loss of generation 1200KW/h	.....	$150.000.000
2) Purchase of this energy to the interconnected system	......	$150.000.000
3) Repair cost (dam)	......	$ 10.000.000
4) Repair of various canal conductions	......	$ 1.000.000
5) General maintenance of turbines, generators and electric equipments		$ 4.000.000
6) Other expenses	......	$ 5.000.000
T o t a l	......	$320.000.000

IV. SITUATION OF STOCK SPARE PARTS

No.	Study Item	Results
	Data on the situation of stock spare parts shall be obtained to evaluate maintainability of generating facilities.	The power plant hasn't stock spare parts for maintenance of generating facilities. The maintenances are realized by the staff of same Enterprise, reconstructing their wasted components.

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V. ESSA's INTENTION FOR REHABILITATION

Mark with in pertinent columns.

No.	Study Item	Leaving as it is	Repair work	Replacement	Notes
–	Inlet valve	✓			Good
–	Turbine, governor, auxiliary equipment			✓	Bigger efficiency
–	Generator, exciter			✓	Bigger efficiency
–	Control panel			✓	Modernization
–	Switchgear			✓	New system fitting
–	Transformer			✓	Expansion of load
–	Substation equipment (Circuit breaker, Isolator, etc.)			✓	Expansion
–	Transmission tower, conductor and insulator			✓	Increasing of capacity
–	Power House			✓	Adaptations