

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

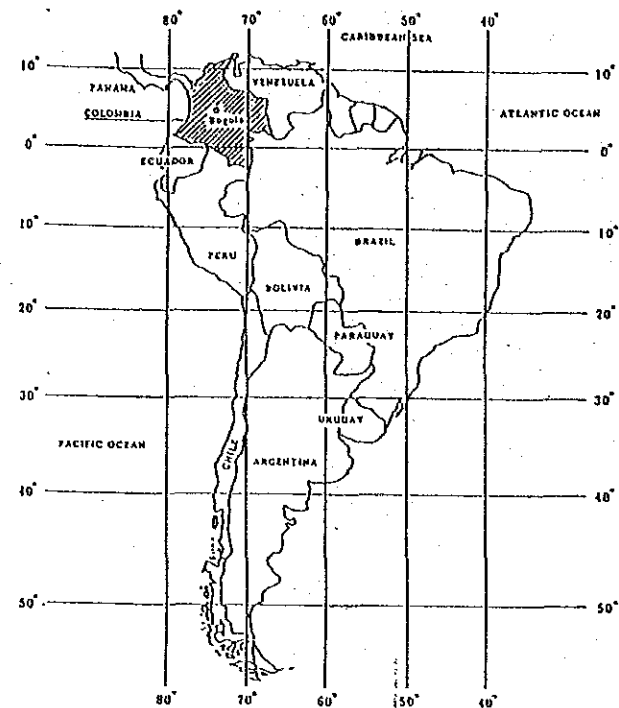
**SILVIA HYDROELECTRIC
POWER PLANT**

MARCH 1990

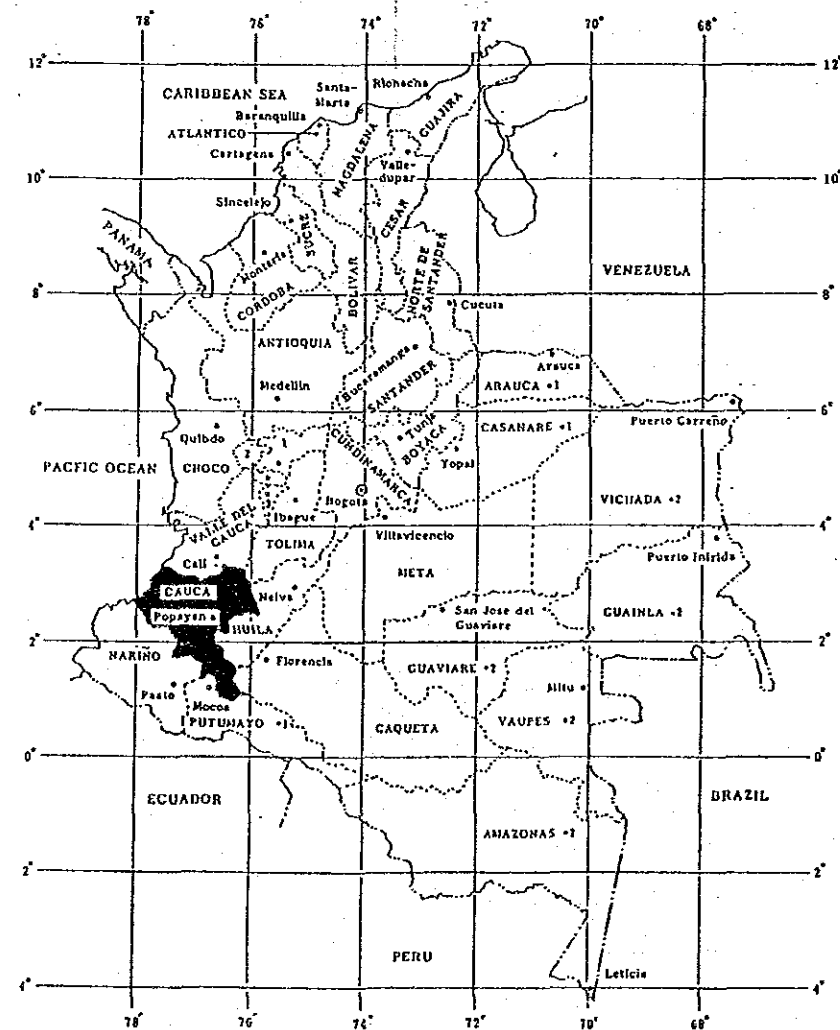
Japan International Cooperation Agency

MAP OF SOUTH AMERICA

NEW WORLD ATLAS
J. H. MASON CO., LTD.
(1977)



POLITICAL DIVISION IN THE REPUBLIC OF COLOMBIA



- LEGEND**
- Border
 - - - Limit of Department
 - ⊙ Capital
 - Capital of Department
 - 1 Intendency
 - 2 Commissary

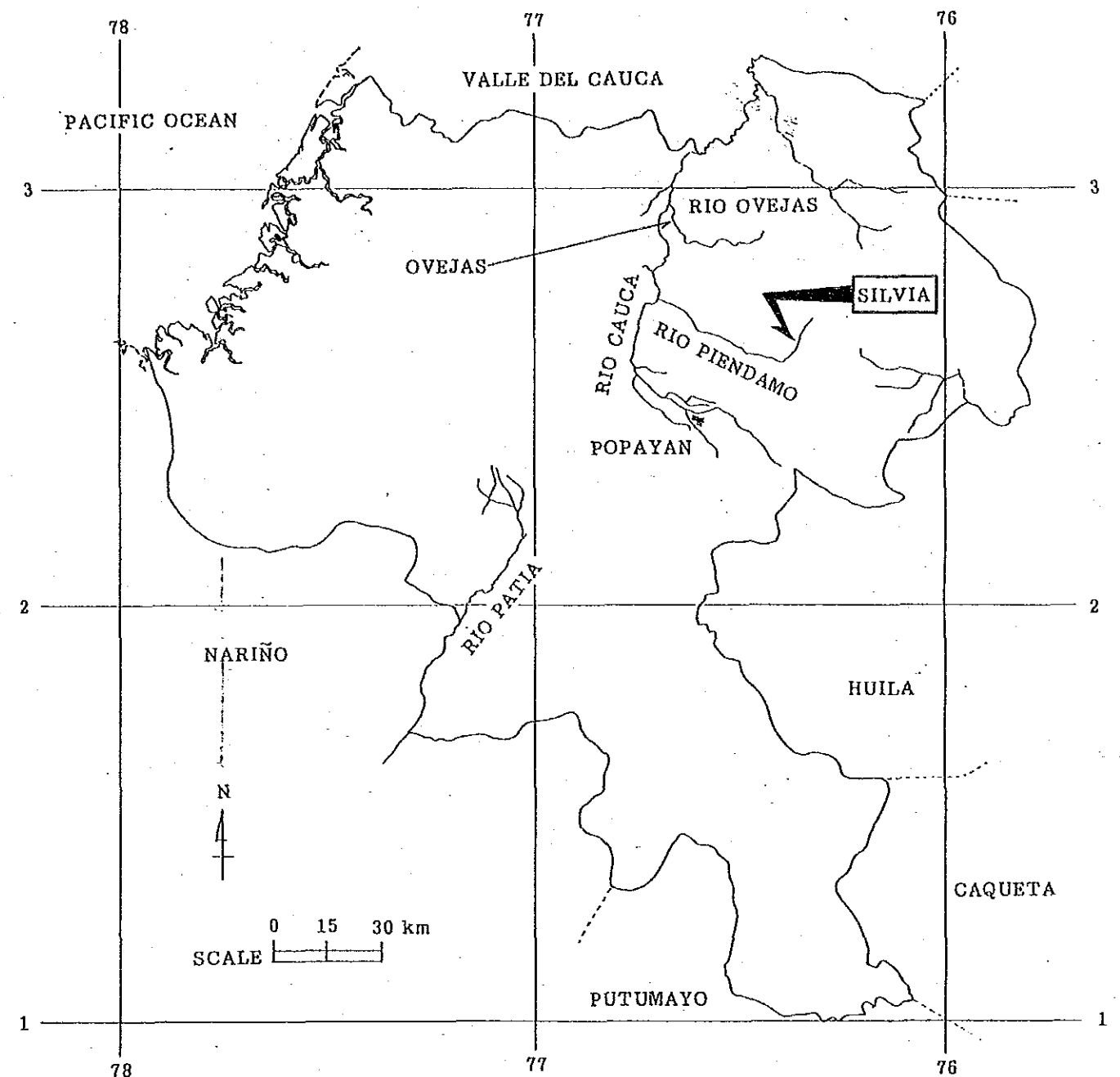
NOTES

No. Department (Capital)

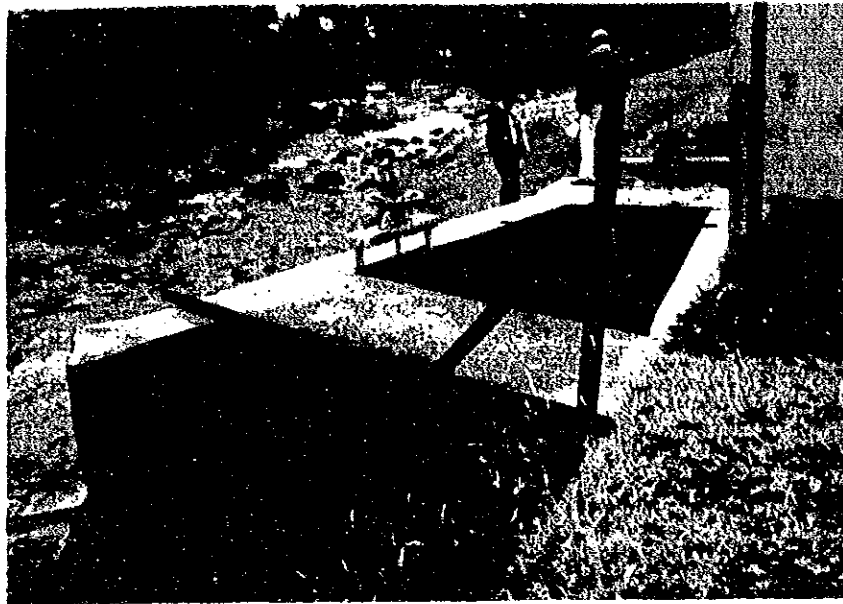
1 CALDAS (Manizales)

2 RISARALDA (Pereira)

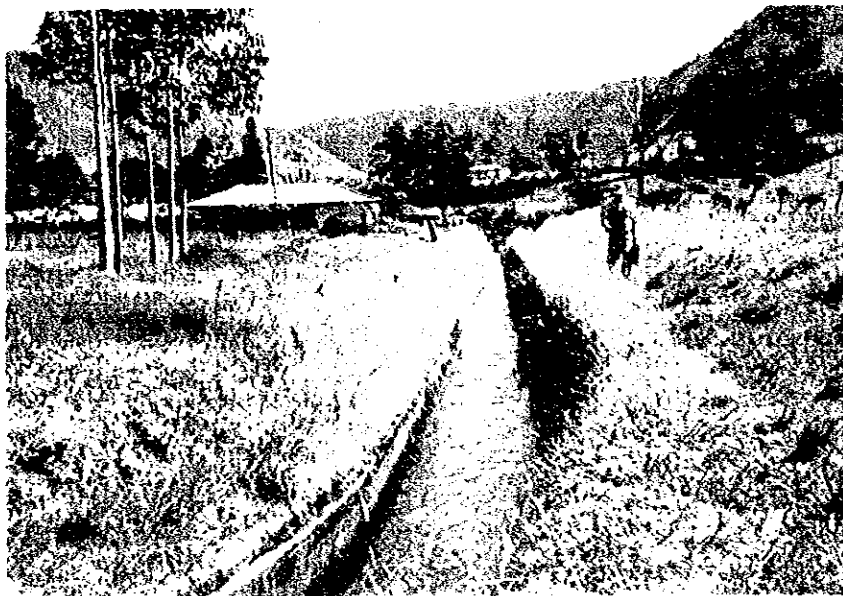
3 QUINDIO (Armenia)



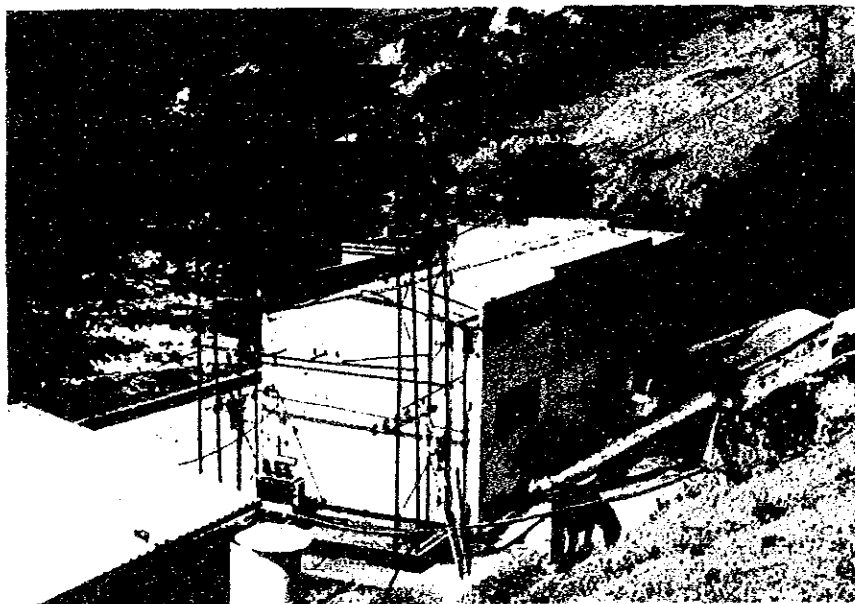
Location Map of Study Area



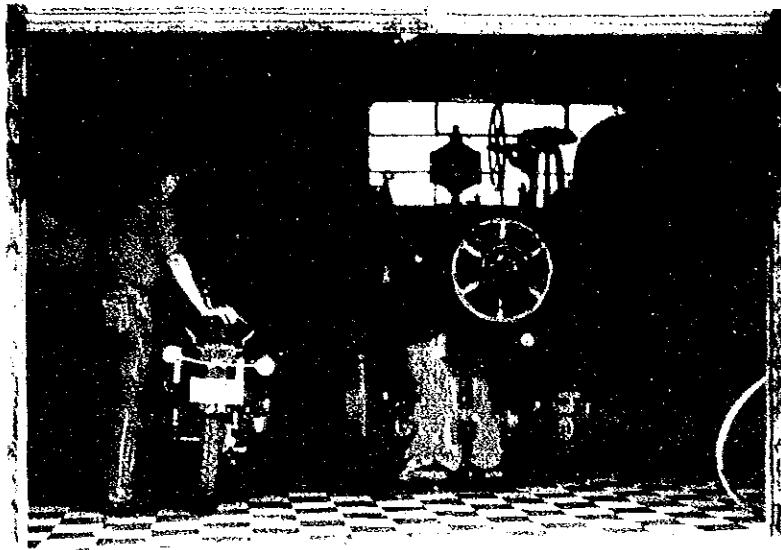
Rio Piendamo and Intake



Conduction channel



Powerhouse



500kW Francis turbine and generator



100kW Francis turbine and generator

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 Silvia run-of-river type hydroelectric power plant (rated output of 0.604 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 for 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, Silvia hydroelectric power plant (hereinafter referred to as Silvia P/P) was selected as a candidate for the FS for the following reasons.

No. 1 unit (rated: 500 kW) broke down in 1972, and for the next 18 years it has been left unrepaired.

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

- Maximum output : 0.24 MW
- Annual potential generated power : 2.1 GWh

CHAPTER 2 SUMMARY OF STUDY RESULTS

The power plant owned by CEDELCA is a run-of-river type (the rated output: 604 kW) and is located along the Piendamó River in Cauca Department.

Civil structures such as the diversion weir, intake, open channel (total length: 609 m), desilting basin and head tank, and penstock have been kept in rigid state. But the horizontal shaft Francis type turbine (rated output: 500 kW), manufactured in 1954, has been left unattended for 18 years without any repairing since it broke down in 1972. Only the horizontal shaft Francis type turbine with the rated output of 104 kW has been in operation.

(1) Rehabilitation plan

The rehabilitation plan for the Silvia P/P is limited to replacement work of the No. 1 turbine having the rated output of 500 kW which has been left unattended, and any other alternative plan cannot be considered.

Judging from the stream regime of the intake site shown in Fig. 2.1, the planned available discharge of $Q=1.5 \text{ m}^3/\text{s}$ might be the appropriate rate for the run-of-river type hydroelectric power plant.

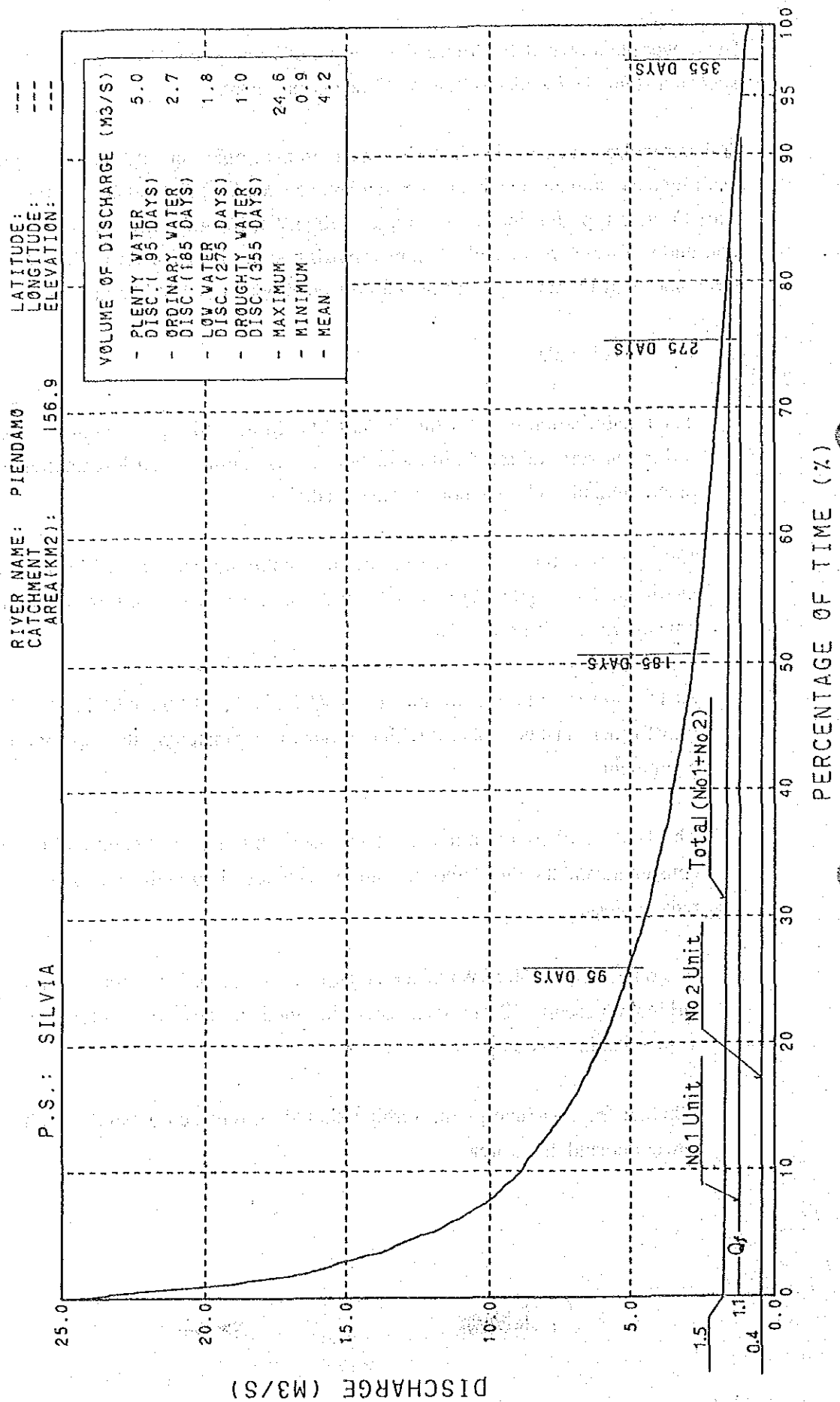
At the present, one transformer (480 V/13.2 kV, 142.5 kVA) is installed, but this transformer must be replaced with the transformer matching the capacity of generating equipment.

The 13.2 kV distribution line connects between this power plant and the neighboring consumers and the Piendamó substation. This distribution line can be used without any rehabilitation.

The rated output (500 kW) of the non-functioning No. 1 horizontal shaft Francis type turbine represents 260 kW of excessive installed capacity. A new replacement can only have a maximum output of 240 kW.

Whether the non-functioning turbine should be replaced depends on the increase of power demand in the area.

Fig-2.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



[illegible]

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 a counterpart 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 CEDELCA

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

Supporting Staff	Position
Fernando Iragorri Cajiao	President
Jose Horales M.	Vice President
Larry Guzman M.	Civil Engineer

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.

Table 3.1 Time Schedule of FS

[illegible]

Two field surveys were conducted at Silvia 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, the study team leader, a geologist and a hydroelectric power generation planner gathered the data relating mainly to the geological survey.

Table 3.2 Field Survey Schedule

The first site reconnaissance

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
Jan. 31	Pasto → Popayan	Discussion at CEDELCA, and data collection	J. Gonzalez	Murao Toyama Yoshio Kawasaki
Feb. 1		Field survey at Silvia P/P		
Feb. 2		Field Survey at Ovejas P/P		
Feb. 3		Discussion at CEDELA		
Feb. 4	Popayan → Bogota	Travelling		

The second field survey

Date	Schedule	Detail of Study Item	Member	
			ICEL	JICA
July 12	Bogota → Pasto	Discussion at CEDELA, and field survey at Silvia P/P	--	Masami Ono Yoshio Kawasaki Takashi Inoue
July 13		Field survey at Ovejas P/P		
July 14		Same as above		
July 15	Pasto → Bogota	Travelling		

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 and Boring Survey

The scope of topographic and boring survey is shown in Figure 3.1. The scales for the topographic maps are as follows:

- (1) The diversion weir, intake, head tank and powerhouse building are drawn on a scale of 1/200 with contour lines of 2 m. Main structures for the existing facilities and positions of bench marks and boring holes are indicated in the above drawings.

- (2) Conduction channel

Longitudinal section of the conduction channel is drawn on a scale of 1/1,000 (plan) and 1/100 (section). This section is also drawn on a scale of 1/100, and with 20 m wide and 50 m pitch.

- (3) Bench mark

The bench marks shall be set up at the three locations.

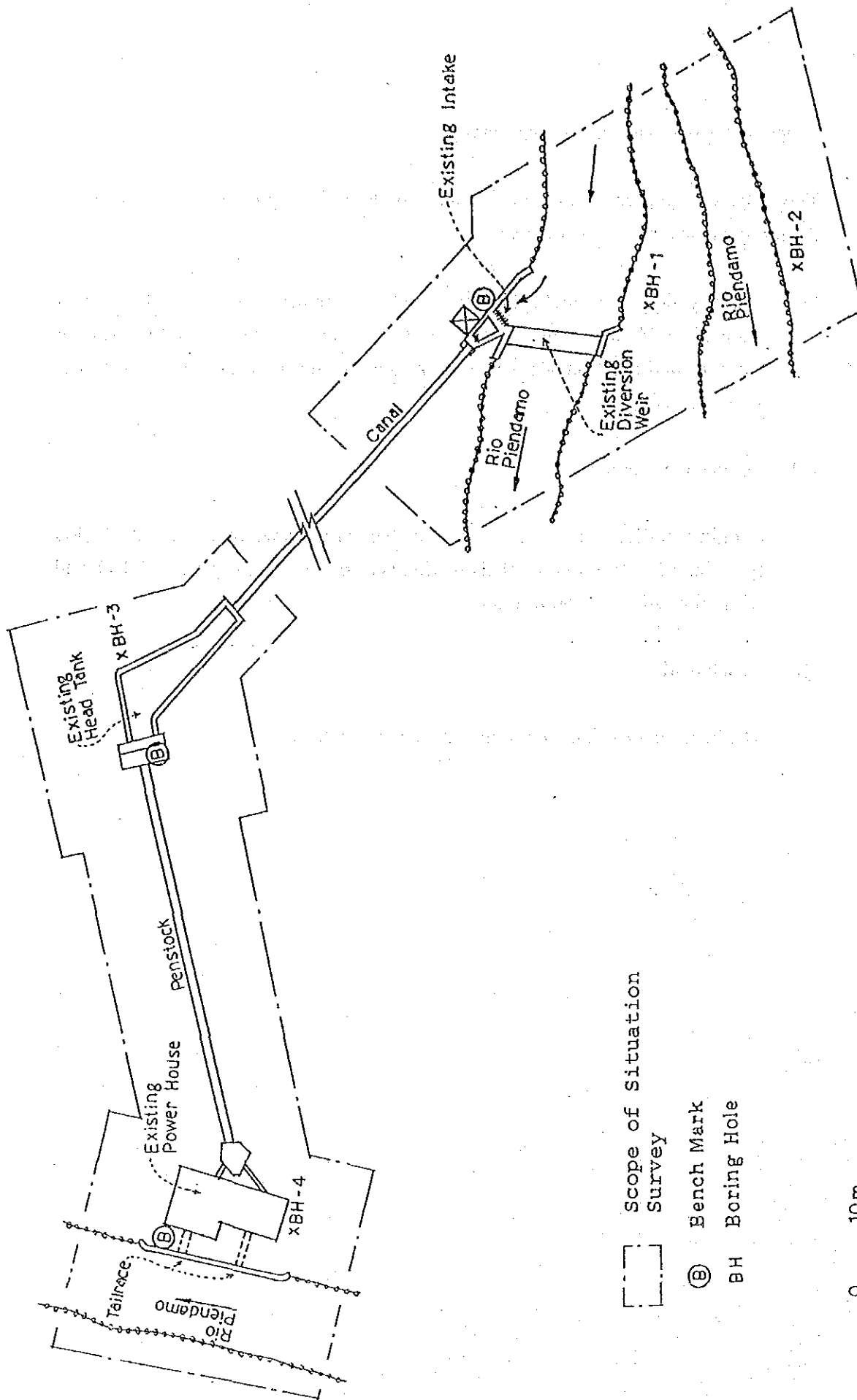


Fig. 3.1

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, 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 76 MW, while installed capacity was 33 MW (about 43%). In 1987, electric power was 204 GWh, while supplied power was 114 GWh, representing about 56% of total electric power. The public electric power company bought electricity to cover the remaining 211 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 73%, 6%, 9% and 12% respectively. Power demand for residential use was high, while that for commercial use was low.

Annual average rate of increase in power demand from 1983 to 1987 was 5.1%, while that of generated energy, 3.4%, showing decrease. The ratio of buying electricity has 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)	50	56	69	68	76	11.0
2. Electric Power (GWh)						
1) Residential	125	144	142	144	148	4.3
2) Commercial	11	12	12	12	12	2.2
3) Industrial	9	15	13	17	18	18.9
4) Miscellaneous	22	21	18	17	26	4.3
Total	167	192	185	190	204	5.1
SUPPLY						
1. Installed Capacity (MW)	33	33	33	33	33	0
2. Generated Energy (GWh)	131	121	120	127	114	-3.4
3. Power Loss (GWh)	60	66	94	114	121	19.2

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

* Annual average increase rate is calculated as follows:

Example: When peak demand is 11.0%,

$$50 \times (1 + x)^4 = 76$$

$$x = 0.11 \text{ (11.0\%)}$$

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 diesel power.

**Table 4.2 Total Installed Capacity of the Public
Electric Power Company (1983-1987)**

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate (%)
Total Installed Capacity (MW)						
1. Diesel	0.6	0.6	0.6	0.6	0.6	0
2. Hydroelectric	32.8	32.8	32.8	32.8	32.8	0
3. Others	0	0	0	0	0	0
Total	33.4	33.4	33.4	33.4	33.4	0

(Source: INFORME ESTADISTICO: RESUMEN 1983-87)

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

**Table 4.3 Conditions of Silvia Power Plant
(1984-1988)**

Item	1984	1985	1986	1987	1988
1) Installed capacity (kW)	104	104	104	104	104
2) Generated energy (MWh)	865	848.5	816.3	702.6	854.9
3) Utilization factor (%)	95	93	90	77	94
4) Operating time (%)	98	95	96	80	91

(Source: DATA COLLETED BY CEDELCA)

(2) Transmission facilities

The public electric power company provides 115 kV transmission lines to its transmission and substation facilities. Voltage to be transmitted from Silvia P/P is 13.2 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 4.4 Generating Cost and Electric Charges

Item	1983	1984	1985	1986	1987	Annual Average Increase Rate(%)
Generating Cost (COL \$/kWh)	3.30	4.36	6.41	8.18	10.40	33.2
Electric Charge (Average): (COL\$/kWh)						
1. Residential	2.63	3.33	4.44	5.68	7.05	28.0
2. Commercial	4.09	5.29	6.64	8.77	11.85	30.5
3. Industrial	5.21	5.71	7.21	9.27	13.46	26.8
4. Public use	2.98	3.80	5.45	7.39	9.85	34.8
5. Average	2.89	3.65	4.53	6.26	7.96	28.8
Breakdown of Power Demand by customer						
1. Residential	47,936	54,389	59,719	64,565	70,953	10.3
2. Commercial	1,573	1,542	1,690	1,695	1,776	3.1
3. Industrial	246	251	268	287	310	6.0
4. Others	941	993	974	987	1,013	1.9
5. Total	50,696	57,175	62,651	67,534	74,052	9.9
Diffusion of Electricity						
1. Overall (1000 households)	759	777	796	814	833	2.4
2. Power demand (1000 households)	213	241	265	287	315	10.3
3. Electrification rate (%)	28	31	33	35	38	7.9

(Source: INFORME ESTADISTICO: RESUMEN 1983-87)

4.1.4 Forecast of Power Supply and Demand

CEDELCA's forecast for the power supply and demand from 1990 to 2000 is shown in the following table.

Year	Electric Power (GWh)			Peak Demand (MW)		
	Generated Energy	Electricity-buying	Total	Generated Energy	Electricity-buying	Total
1988	118.51	232.62	351.13	28.7	55.00	83.70
1989	118.51	255.01	423.48	28.7	70.48	99.18
1990	118.51	415.64	534.15	28.7	92.14	120.84
1991	118.51	466.47	584.98	28.7	105.18	133.88
1992	118.51	522.81	641.32	28.7	119.74	148.44
1993	118.51	520.45	703.76	28.7	136.02	164.72
1994	118.51	654.45	772.96	28.7	154.22	182.92
1995	118.51	731.15	849.66	28.7	174.55	203.25
1996	118.51	816.15	934.66	28.7	197.27	225.97
1997	118.51	910.36	1,028.87	28.7	222.67	251.37
1998	448.51	684.77	1,133.28	113.7	166.05	279.75
1999	448.51	800.49	1,249.00	113.7	197.77	311.47
2000	448.51	863.95	1,312.46	113.7	233.21	346.91

4.2 Operation Record of the Existing Power Plant

4.2.1 Generated Energy

Two turbines with rated output of 104 kW and 500 kW are installed. 500 kW turbine has not been operated since 1972.

Record of generated energy of 500 kW turbine during five years from 1984 to 1988 is shown in Table 4.5.

Silvia P/P has not been suspended continuously for the past five years.

The average value of the utilization factor in the past five years was 90%, and the average operation factor was 92%.

Table 4.5 Record of Generated Energy and Running Time

Year	Output inscribed on the name plate (MW)	Generated Energy (MWh)	Running Time (hour)	Facility Utilization Factor (%)*	Operation Factor (%)**
1984	0.104	865.0	8,578	95	98
1985	0.104	848.5	8,363	93	95
1986	0.104	816.3	8,371	90	96
1987	0.104	702.6	7,008	77	80
1988	0.104	854.9	7,983	94	91

(Note)

$$* \text{ Facility utilization (\%)} = \frac{\text{Generated energy (MWh)}}{8760(\text{hr}) \times \text{output inscribed on the name plate (MW)}} \times 100$$

$$** \text{ Operation factor (\%)} = \frac{\text{Running hour (hr)}}{8760 (\text{hr})} \times 100$$

4.2.2 Operation and Maintenance Costs

Record of Silvia P/P's operation and maintenance costs for five years from 1984 to 1988 is shown in Table 4.6.

Operation and maintenance costs per generated energy fluctuate, but average 5,077 pesos/MWh.

Table 4.6 Record of Operation and Maintenance Costs

Year	Generated energy (MWh)	Operation & Maintenance Costs (pesos)	Peso MWh
1984	865.0	2,337,439	2,702
1985	848.5	3,003,018	3,539
1986	816.3	3,649,022	4,470
1987	702.6	3,521,515	5,012
1988	854.9	8,240,381	9,639
Total	4,087.3	20,751,375	5,077

4.3 General Condition of Generating Equipment and Civil Structures

4.3.1 General Condition of Generating Equipment

The present condition of the generating equipment is summarized below:

(1) Generating equipment

Since the turbine (104 kW), manufactured in 1960, has been used only for 30 years, the facility utilization factor during the latest five years is 90%, and the operation rate of the facility is 92%. According to a survey conducted by CEDELCA, no defect was found in the turbine and generator. On the other hand, the turbine (500 kW) manufactured in 1954 has not been used and left unattended for 18 years since its breakdown in 1972, it might not be reused.

(2) Substation

142.5 kVA main transformer corresponding to the turbine (104 kW) is installed outside. According to the survey conducted by CEDELCA, no significant defect was found in the transformer.

(3) Distribution line

13.2 kV distribution lines connected to the Silvia P/P are connected to consumers in the surrounding area of the power plant and the Piendamó substation. According to

the survey conducted by CEDELCA, no significant defect was found in the distribution lines.

4.3.2 General Condition of Civil Structures

(1) Intake facilities

There is a small island formed by sandbank in the central area of the Piendamo River. The RC diversion weir is installed in the right bank of the river. Its dam length and height are 12.0 m and 2.3 m, respectively. This weir is in good condition, but there is no sandtrap facility installed. The intake (3.2 m wide, 2.2 m high) is installed at a right angle to the river flow. The gate and screen function properly.

(2) Conduction channel

The RC open culvert (609 m long, 1.3 m wide, 0.9 m deep) has been maintained in rigid state. Conduction channels are constructed in the flat area, enabling easy accessibility.

(3) Desilting basin

The RC desilting basin (9.0 m wide, 20.0 m long, 1.2 m deep) has been maintained in rigid state, and does not need rehabilitation.

(4) Head tank

Plan shape of the head tank is triangle. The head tank (average width: 6.0 m, length: 16.0 m, average depth: 3.0 m) has been maintained in rigid state. The head tank's storage capacity is sufficient. The head tank, including the screen, does not need to be rehabilitated.

(5) Penstock

The maintenance of the penstocks ($\phi 0.91\text{m}$, $L=72.1\text{m}$) has been done properly, and this makes it unnecessary for the penstocks to be rehabilitated.

(6) Powerhouse building

The powerhouse building size is 15.5 m(W) x 8.0 m(D) and its floor height is 5.5 m. There is sufficient space available. The powerhouse building has been maintained in rigid state.

CHAPTER 5 BASIC DATA COLLECTION

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

5.1 Topographic Maps

JICA Study Team collected the following topographic data for the Silvia P/P.

- Topographic maps (scale: 1/25,000 - 1/400,000) published by IGAC
- Topographic survey maps that were actually measured by CEDELCA for the study of this power plant
- As-built drawings

(1) Topographic maps published by IGAC

Scale	Drawing No.	Description
1/400,000		the whole area of Cauca Department
1/100,000	343	the upstream area of the power plant
1/ 25,000	343-I-A,B,C,D	Power plant and vicinity
	343-II-A,B,C,D	the upstream area of the power plant
	343-III-A,B,C,D	Power plant and vicinity
	343-IV-A,C,D	the upstream area of the power plant

(2) Topographic maps actually measured by CEDELCA

Scale	Drawing No.	Description
1/200	-	Plan of intake facilities and vicinity
1/200	-	Plan of head tank & powerhouse building
1/100 - 1/1000	-	Plan and profile of conduction channel

(3) As-built drawings

Scale	Drawing No.	Description
1/50	0146 Nov./'58	Structural drawing of intake facilities
1/100	- Oct./'77	Structural drawing of head tank and powerhouse building

5.2 Geological Survey Data

Geological survey data that was collected for this survey is as follows:

- Mapa Geologico de Colombia: 1988 INGEOMINAS
- Aerial photographs of this power plant and vicinity
- Informe de Resultados de Perforaciones y Ensayos de Suelos para las Pequeñas Centrales, Hidroelectricas de Silvia y Ovejas, 1989 Estudio de Suelos Ltda

5.3 Hydrometeorological Data

Since Silvia P/P does not have the monitoring facilities for discharge, JICA Study Team gathered HIMAT's hydrometeorological data in conducting this survey.

HIMAT's meteorological and gauging stations and the duration of monitoring record are listed below: Discharge on the Piendamó River which is directly related to this FS was monitored at two places of Cortijo El and Pte Carretera.

Table 5.3 List of Data Collected Relating to Hydrometeorology

(1) Precipitation-observation record

Metcorological station		Controller	Location		Altitude (m)	Observation period
No.	Name		Latitude	Longitude		
2105020	Esc Riosucio	HIMAT	0231	7614	2700	1981-94
2105025	Altamira	HIMAT	0232	7610	2235	1975-85
2601007	Lagna San Rafael	HIMAT	0223	7625	3420	1970-87
2602002	Silvia Pta Electri	HIMAT	0237	7622	2650	1970-87
2602003	Piendamó	HIMAT	0241	7632	1840	1970-87

(2) Discharge-observation record

Hydrological gauging station		River	Controller	Establishment	Location		Altitude (m)	Catchment area (km ²)	Observation period
No.	Name				Latitude	Longitude			
2602709	Cortijo El	Piendamó	HIMAT	1961-05	0236	7622	2630	180	1977-87
2602710	Pte Carretera	Piendamó	HIMAT	1963-12	0237	7630	1770	392	1975-85

(3) Water quality data

As the water quality observation has not been conducted along the Piendamó River, no such data was available.

(4) Sediment data

No sediment observation has been conducted along the Piendamó River and no such data was available.

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)" monthly published by CAMACOL (Camera Colombiana de la Construccion) in Cauca Department. However, the above publication is not published in all departments of Colombia. To coordinate the data of the power plant site where the FS was conducted, construction prices used for this study are based on price data used within CEDELCA (refer to Table 5.2).

5.4.2 Power Condition Data

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

- 1) CEDELCA's actual record and forecast for power demand from 1970 to 2000
- 2) CEDELCA power schematic diagram

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

- 1) One line diagram
- 2) Residual value
- 3) Operation and maintenance personnel

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	2,800
2. EARTH WORK (ROCK)	p/m ³		3,965				1,900			
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 and Geology in the Area

6.1.1 Topography

The source of the Piendamó River is located in the western slope of central Cordillera, 40 km northwest of Popayan, the capital of Cauca Department. It flows downward, west to the Cauca River in western Morales City.

The project site is located upstream of the Piendamó River. The topography in the vicinity of the project site forms undulating valleys with wide ravines.

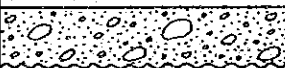

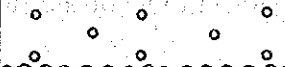
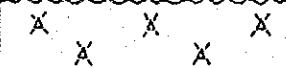
6.1.2 Geology

The bedrock is composed of tertiary pyroclastic rocks on which talus deposit and riverbed deposit are widely distributed. New pyroclastic rocks are very compact, while weathered pyroclastic rocks are loose and soft.

It is difficult to distinguish from the upper covering layer of pyroclastic rocks, because the matrix sections will be washed away if the boring work is conducted.

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		Riverbed deposit	
		Talus deposit	
		Terrace deposit	
Tertiary		Pyroclastic rocks	

6.1.3 Geological Structure

According to the geology of the surrounding area, the Silvia-Totoro active fault runs through the vicinity of Silvia in the NE~SW direction, which was not confirmed by the field survey.

6.2 Geology in the Project Site

The geological conditions of the foundations for the power plant and the various civil structures are described below: (Refer to Dwg. No. SI-G-01)

(1) Diversion weir

Terrace and riverbed deposits are thickly distributed around the diversion weir. The diversion weir is presumed not to lie on the bedrock.

(2) Conduction channel

The conduction channels are built mainly on the pyroclastic rocks. The conduction channel near the most upstream side is built on the thick terrace deposit.

(3) Head tank, penstock and desilting basin

The head tank and the desilting basin are built on pyroclastic rocks. The penstocks are built on talus deposit. A small spring was observed at a low elevation area.

(4) Powerhouse

Talus deposits are distributed over on the pyroclastic rocks in the vicinity of the powerhouse. The powerhouse building is built on talus deposit and backfilled gravel. The rock surface is presumed to be of the same level as the existing riverbed.

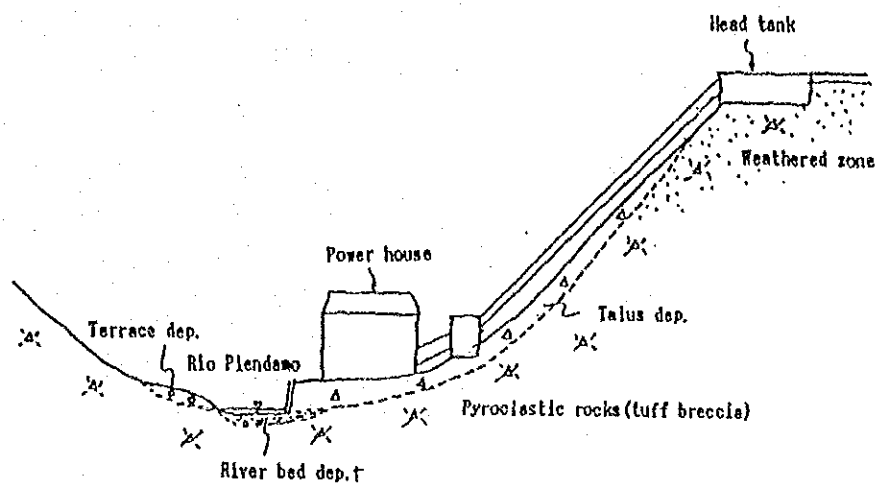


Fig. 6.1 Schematic Geological Profile

CHAPTER 7 HYDROLOGICAL ANALYSIS

Fig. 7.1 shows the locations 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

Cauca Department, in the southwest part of Colombia, lies at $3^{\circ}00'$ ~ $3^{\circ}20'$ north latitude, near the equator.

Generally, the lowland areas enjoy a tropical climate and have hot and very humid rainy season. The lowland areas have an average temperature of 24°C , while the highland areas (at an altitude of 1,800 to 2,800 m) range from 12 to 18°C .

Popayan, the capital of the department, lying in the highland at an altitude of 1,500 m, has an average temperature of about 15°C . This temperature level remains constant throughout the year.

The precipitation in the high land is 1,000 - 2,000 mm/year while 3,000 mm in the low land. However, the annual maximum precipitation recorded in of the west slope area of West Andes Mountain Range exceeds 6,000 mm.

The project site with the elevation of about 2,600 m above sea level is situated in the northeast of Popayan and lies on the Central Andes Range. The annual precipitation in the project site is 1,000 - 2,000 mm. Though it fluctuates from year to year, rainy and dry seasons are comparatively clear. (Refer to Fig.7.2.)

Observation Item	Gauging Station		Latitude	Longitude
	No	Name		
Discharge	2602-709	Cortijo El	0236	7622
	2602-710	Pte Carretera	0237	7630
Preciptation	2105-020	Esc Riosucio	0231	7614
	2105-025	Altamira	0232	7610
	2601-007	Laguna San Rafael	0223	7625
	2602-002	Silvia Pte Electri	0237	7622
	2602-003	Piendamo	0241	7632

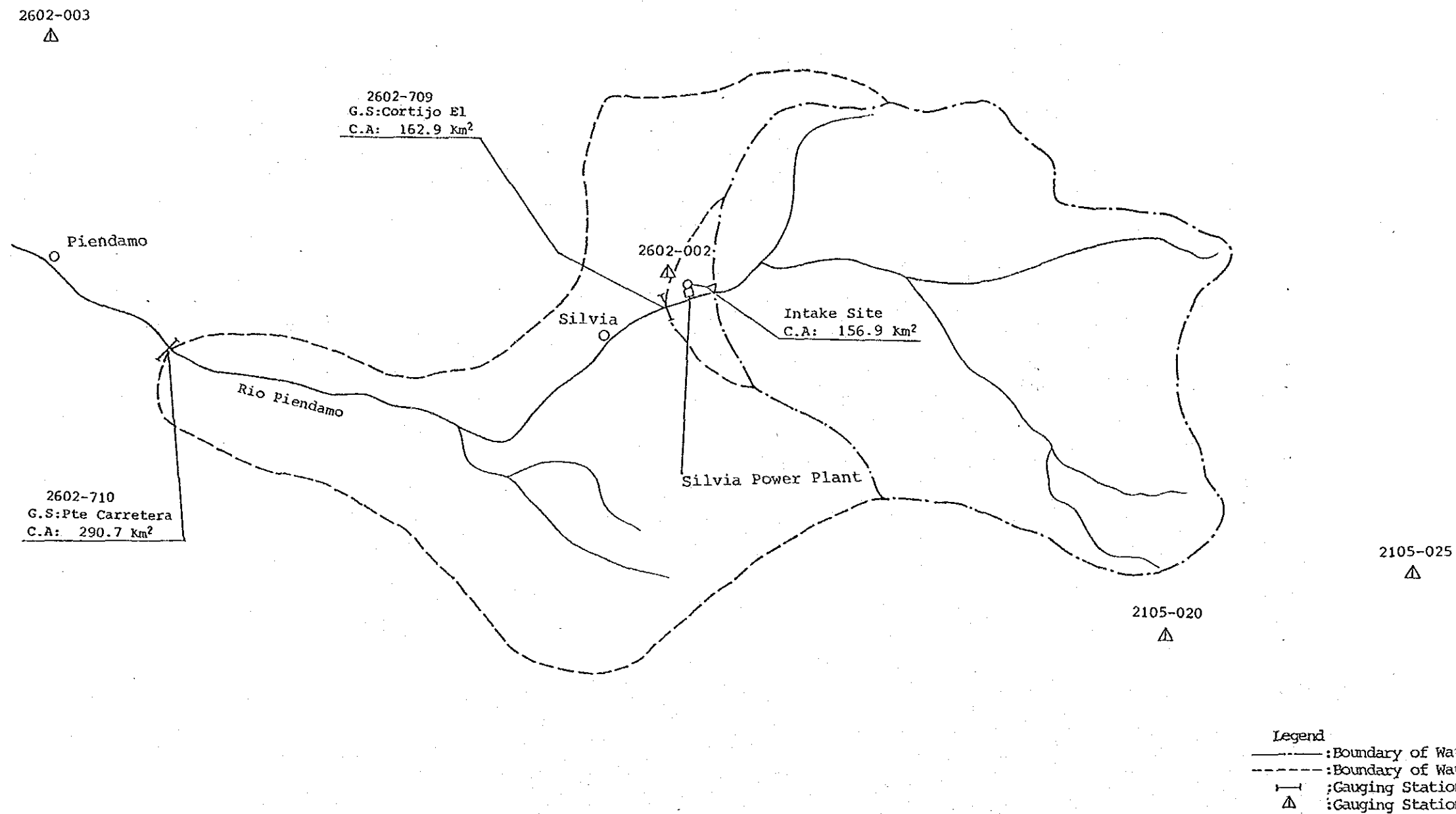


Fig-7.1 Location Map of Gauging Stations in The Watershed of The Study Area.

Meteorological station No.2602-002 Silvia pte Electri
 North latitude: 2°37'
 West longitude: 76°22'
 Elevation: 2,560 m
 Annual average precipitation: 1,360.1 mm

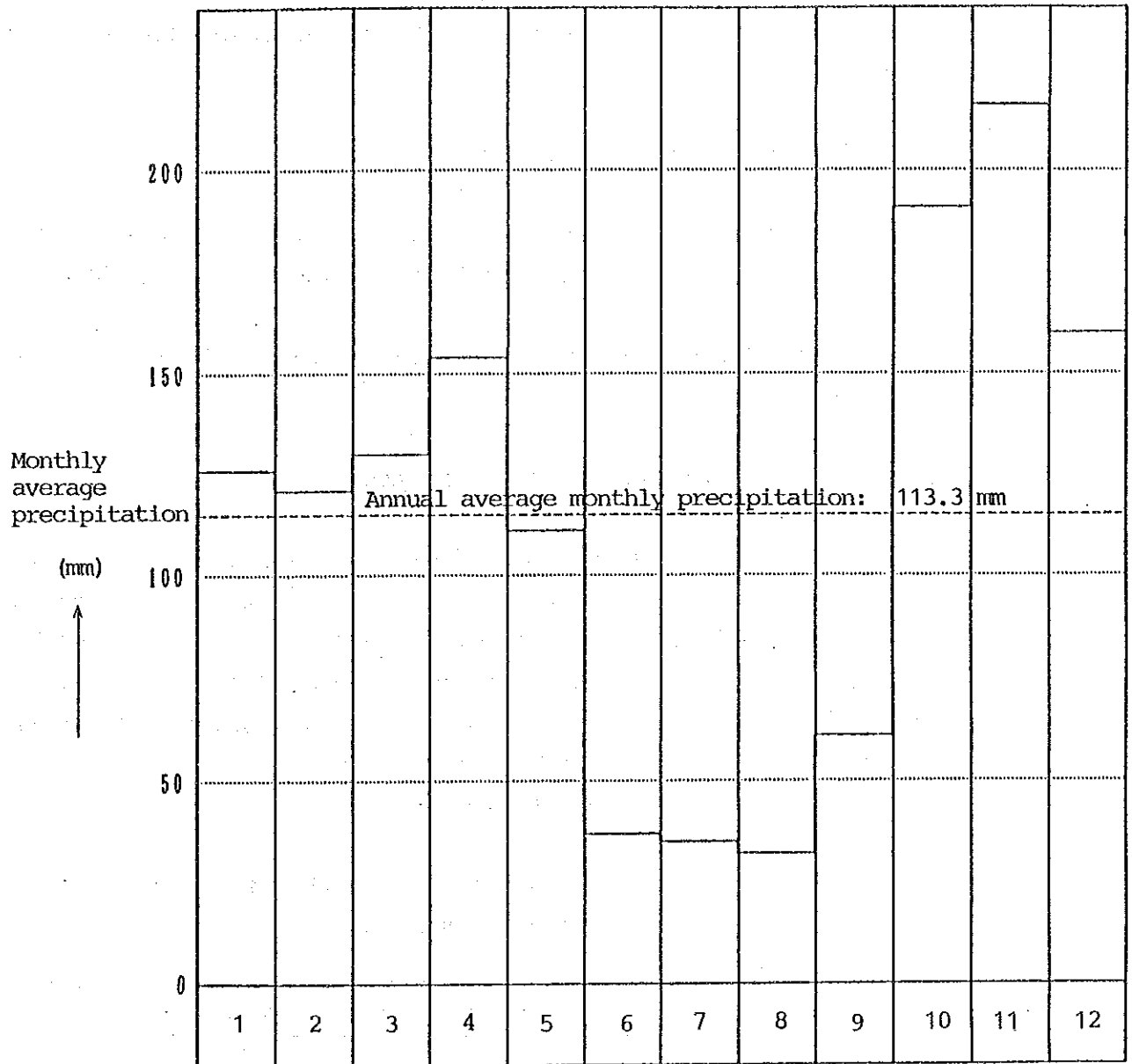


Fig.7.2 Monthly Average Precipitation in the Project Site (1970-87)

7.2 Discharge Analysis

The Study Team gathered, compiled observations recorded at the Cortijo El gauging station during 11 years from 1977 to 1987, and then prepared discharge and flow-duration curves according to reliable 11-year data out of the above record by converting river basin. (Refer to Drawing No. SI-H-01.)

7.2.1 Comparing Discharge Observation Record

Though the Cortijo El hydrological gauging station was established in May, 1961, the Study Team gathered observations recorded during 11 years from 1977 to 1987.

Since non-recorded dates are included in the data obtained, it can be used as a complete discharge observation data.

7.2.2 Comparing to Catchment Area at the Gauging Station

To confirm the present location of the existing Cortijo E1 gauging station, the longitude and latitude indicated on HIMAT's gauging register are plotted on the topographic map (1/400,000) published by IGAC. However, there was a difference in latitude from the location of gauging station observed by the Study Team through the field reconnaissance. Therefore, the Study Team compared the catchment area at the gauging station using the topographic map (scale: 1/400,000) published by IGAC. As a result, there was great difference in the catchment area as shown in Table 7.1.

Table 7.1 Result of Comparison of the Cortijo El Gauging Station
Location and Catchment Area

Item	Latitude	Catchment area (km ²)
HIMAT register	2°36'	180.0
Observation value	2°37'	162.9
Difference	01'	17.1

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 Cortijo El Gauging Station

Discharge data from the Cortijo El gauging station, located 1.5 km downstream from the intake site of Silvia hydroelectric power plant, is arranged using the 11-year observation data, excluding non-observed dates, as shown in Table 7.2.

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

GAUGING ST.: 2602-709 CORITIJ0 EL
RIVER NAME: PIENDAM0

(UNIT: M3/S)

GAUGING YEAR	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1977	MAX.	1.6	4.1	3.0	17.6	16.8	20.5	15.7	13.2	16.2	8.9	10.7	6.5	20.5
	MEAN	1.2	1.6	1.5	4.3	5.0	7.4	5.9	4.2	6.5	4.1	4.4	2.1	4.0
	MIN.	1.0	0.9	1.1	1.5	2.0	2.4	2.3	1.8	2.4	2.1	1.8	1.3	0.9
1978	MAX.	20.9	4.3	4.9	12.8	9.0	16.4	15.6	24.1	6.9	5.9	4.8	10.1	24.1
	MEAN	3.9	1.7	2.1	5.1	3.5	5.8	4.7	5.6	2.9	3.0	1.8	3.0	3.6
	MIN.	1.4	1.1	1.2	2.4	1.7	1.6	1.8	2.0	1.8	1.6	1.2	1.3	1.1
1979	MAX.	2.1	3.0	6.0	22.7	11.2	19.3	13.9	10.6	6.0	15.5	11.7	11.6	22.7
	MEAN	1.3	1.2	2.5	5.8	3.4	6.7	4.2	3.6	2.6	3.7	4.6	4.3	3.7
	MIN.	1.1	0.7	1.4	1.3	1.8	2.4	1.6	1.5	1.7	1.6	1.8	1.9	0.7
1980	MAX.	8.4	5.9	12.4	23.3	8.0	21.9	20.4	17.1	14.5	25.4	9.5	9.4	25.4
	MEAN	3.0	3.4	3.4	5.4	3.9	6.8	6.4	4.2	3.6	4.4	2.5	2.2	4.1
	MIN.	1.5	1.6	1.6	1.7	2.1	2.1	1.9	1.7	1.3	1.6	1.5	1.3	1.3
1981	MAX.	5.7	5.3	4.6	9.9	19.5	9.2	22.5	7.5	11.0	9.1	14.6	6.6	22.5
	MEAN	1.6	1.7	1.9	4.0	6.2	3.8	7.5	3.2	3.2	2.5	5.5	2.8	3.7
	MIN.	1.0	1.0	1.1	1.0	2.5	1.6	1.6	1.6	1.1	1.1	1.2	1.6	1.0
1982	MAX.	18.0	11.3	8.4	16.4	15.2	16.9	35.3	16.4	17.5	13.2	14.7	12.5	35.3
	MEAN	5.3	3.9	3.4	5.5	5.7	4.4	10.4	7.3	4.6	3.9	3.5	4.7	5.2
	MIN.	1.5	1.3	1.5	1.9	2.1	1.6	1.8	3.0	1.4	1.3	1.6	1.9	1.3
1983	MAX.	10.0	6.8	14.3	22.9	7.9	9.2	20.2	23.3	8.6	19.3	14.7	12.8	23.3
	MEAN	2.6	2.1	4.1	8.6	3.9	3.4	5.4	6.1	3.0	4.9	3.8	5.6	4.6
	MIN.	0.6	0.5	0.6	1.2	2.0	1.6	1.7	2.6	1.5	2.0	1.6	2.0	0.6
1984	MAX.	16.5	8.3	6.0	16.7	17.6	15.6	16.2	13.8	15.6	25.0	15.1	5.5	25.0
	MEAN	5.8	2.6	2.1	3.1	5.9	5.7	6.6	4.3	5.1	6.4	8.0	2.6	4.8
	MIN.	1.9	1.7	0.8	1.2	1.7	2.2	2.0	1.7	1.3	2.5	3.7	1.5	0.8
1985	MAX.	6.7	2.6	5.5	8.7	25.5	19.7	31.0	21.2	12.6	10.7	9.4	19.3	31.0
	MEAN	2.6	1.2	1.4	2.2	6.8	8.6	10.2	7.2	4.4	4.0	4.0	3.5	4.7
	MIN.	1.2	0.6	0.6	0.6	1.4	2.8	2.7	2.3	1.2	1.3	2.1	1.3	0.6
1986	MAX.	15.5	17.8	15.5	10.4	7.0	30.2	31.9	18.0	8.0	16.5	22.1	5.4	31.9
	MEAN	3.1	3.8	6.5	3.0	2.4	11.2	11.5	4.0	3.4	5.0	3.9	2.4	5.0
	MIN.	1.2	1.3	2.1	1.5	1.0	2.1	2.1	1.5	0.6	1.8	1.5	0.6	0.6
1987	MAX.	2.2	9.9	2.9	13.7	13.5	17.0	16.2	17.5	8.2	10.7	18.8	10.4	18.8
	MEAN	1.2	2.0	1.4	4.2	5.1	4.7	7.0	7.4	2.4	4.3	4.3	3.7	4.0
	MIN.	0.8	0.9	0.8	1.1	1.7	1.8	1.9	2.2	1.4	1.4	1.1	0.9	0.8
TOTAL	MAX.	20.9	17.8	15.5	23.3	25.5	30.2	35.3	24.1	17.5	25.4	22.1	19.3	35.3
	MEAN	2.9	2.3	2.8	4.7	4.7	6.2	7.3	5.4	3.8	4.2	4.2	3.3	4.3
	MIN.	0.6	0.6	0.6	0.6	1.0	1.6	1.6	1.5	0.6	1.1	1.1	0.6	0.6

In calculating the monthly average discharge, months in which the observation time was less than 10 days are excluded. A graphic representation of monthly average discharge, three-month flow periods can not be clearly distinguished from drought periods in Drawing SI-H-01 number (1).

However, from June to August is considered wet periods and from September to May is considered drought periods.

Typical flow-duration curves calculated from the 11-year flow-duration curves from 1977 to 1987 according to the parallel method are indicated in Drawing SI-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 Cortijo El gauging station during 11 years from 1977 to 1987 is shown in Table 7.4.

7.2.5 Discharge and Flow-Duration Curves at the Intake Site

Discharge and flow-duration curves at the intake of this project site are calculated by multiplying respective catchment area ratio by recorded observations at the existing Cortijo El gauging station located about 1.5 km downstream from the intake site.

Since numerical values for the catchment area at the intake site are not officially approved, the value of 156.9 km², measured by the Survey Team, is adopted. Therefore, a ratio of catchment area between Silvia P/P's intake site and HIMAT's Cortijo El gauging station is set at $156.9 / 162.9 = 0.96$.

Discharge and flow-duration curves at the intake site converted according to the catchment area ratio are shown in Drawing SI-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 7.6.

Table-7.3 FLOW DURATION TABLE AT GAUGING STATION SITE

GAUGING ST.: 2602-709 CORITIJ0 EL		(UNIT: M3/S)					
RIVER NAME: PIENDAMO		PLENTY	ORDINARY	LOW	DROUGHTY	MIN.	MEAN
GAUGING YEAR	MAX. (1ST DAY)	(95 DAY)	(185 DAY)	(275 DAY)	(355 DAY)	(LAST DAY)	
1977	20.5	4.9	2.9	1.6	1.0	0.9	4.0
1978	24.1	4.3	2.7	1.8	1.2	1.1	3.6
1979	22.7	4.1	2.7	1.7	1.0	0.7	3.7
1980	25.4	4.6	2.7	1.8	1.4	1.3	4.1
1981	22.5	4.6	2.5	1.6	1.0	1.0	3.7
1982	35.3	6.8	3.4	2.2	1.5	1.3	5.2
1983	23.3	5.5	3.2	2.2	0.6	0.6	4.7
1984	25.0	6.1	3.3	2.2	1.4	0.8	4.9
1985	31.0	5.5	2.9	1.6	0.6	0.6	4.7
1986	31.9	5.5	2.8	1.9	1.2	0.6	5.0
1987	18.8	5.5	2.2	1.6	0.9	0.8	4.0
MEAN	25.5	5.2	2.8	1.8	1.1	0.9	4.3

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

GAUGING ST.: 2602709 CORITIJ0 EL RIVER NAME: PIENDAMO (UNIT: M3/S)													
GAUGING YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
1977	1.6	5.4	3.4	40.7	23.0	21.6	21.6	21.6	24.5	22.3	19.5	12.3	40.7
1978	26.8	5.6	11.6	18.9	17.9	24.5	23.8	32.1	15.0	11.3	6.2	23.0	32.1
1979	2.2	6.0	16.6	29.0	23.4	21.6	22.3	16.9	8.9	21.6	15.0	23.0	29.0
1980	20.2	20.6	22.3	31.3	17.6	36.8	27.9	30.5	19.5	30.5	14.7	19.9	36.8
1981	8.4	12.0	7.2	29.4	27.9	9.9	23.0	9.5	19.5	9.5	24.9	9.5	29.4
1982	23.4	21.3	13.3	21.6	24.1	20.6	40.3	21.3	28.3	31.7	22.7	34.1	40.3
1983	25.7	13.2	31.7	48.9	22.0	17.5	25.7	30.5	17.1	28.7	27.5	26.4	48.9
1984	32.5	12.5	11.7	24.6	26.1	23.8	26.4	20.5	22.7	36.4	24.6	6.6	36.4
1985	11.0	3.2	23.5	17.5	45.6	32.1	36.8	28.3	14.7	20.1	18.6	27.5	45.6
1986	29.0	23.1	24.6	20.1	17.1	39.9	41.5	21.6	11.7	19.4	32.5	8.4	41.5
1987	5.2	14.1	5.4	24.3	19.4	21.6	20.8	24.9	12.3	17.7	40.5	25.7	40.5
TOTAL	32.5	23.1	31.7	48.9	45.6	39.9	41.5	32.1	28.3	36.4	40.5	34.1	48.9

Table 7.6 Representative Discharge at the Intake Site

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)	5.5	3.8	6.3	8.3	10.3	10.7	11.1	7.9	6.3	6.2	7.7	5.4	3.4
Daily average discharge (m ³ /s)	2.8	2.2	2.7	4.5	4.5	6.0	7.0	5.2	3.7	4.0	4.0	3.2	4.1
Min. average discharge (m ³ /s)	1.1	1.1	1.3	2.2	2.3	3.3	4.0	3.1	2.4	2.5	1.7	2.0	5.0

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
5.0 m ³ /s	2.7 m ³ /s	1.8 m ³ /s	1.0 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 SI-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.

CHAPTER 8 GENERATION PLAN

The generation plan is made based on the planned maximum available discharge at Silvia P/P of 1.5 m³/s. From the hydrological regime at the intake site as shown in Fig. 8.1, this discharge rate would be appropriate, so alternative plans are not considered. Accordingly, the rehabilitation plan is limited to the replacement of non-functioning No. 1 turbine (output: 500 kW) which has been left unattended.

8.1 Maximum Available Discharge

As stated above, the rehabilitation plan of Silvia P/P is limited to the replacement of No. 1 turbine (output: 500 kW). From the hydrological regime at the intake site, the planned available discharge of 1.5 m³/s is considered appropriate rate for the run-of-river type hydroelectric power plant. Since discharge allocation for No. 1 and No. 2 turbine is not clear with no measured values, the maximum available discharge of No. 2 unit is assumed to be 0.4 m³/s. The generation plan is made based on the maximum available discharge at No. 1 unit of 1.1 m³/s.

8.2 Standard net head

Assuming that the net head for determining the turbine output and calculating annual generated energy is constant, the standard net head calculated under the following standard is used.

$$H_e = H_g - H$$

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

where:

$$H_g = \text{gross head}$$

$$\text{Head tank water level (2,569.50 m) - discharge water level (2,536.76 m) = 32.74 m}$$

$$H = \text{total loss of head (m)}$$

$$v^2/2g = \text{velocity head (m)}$$

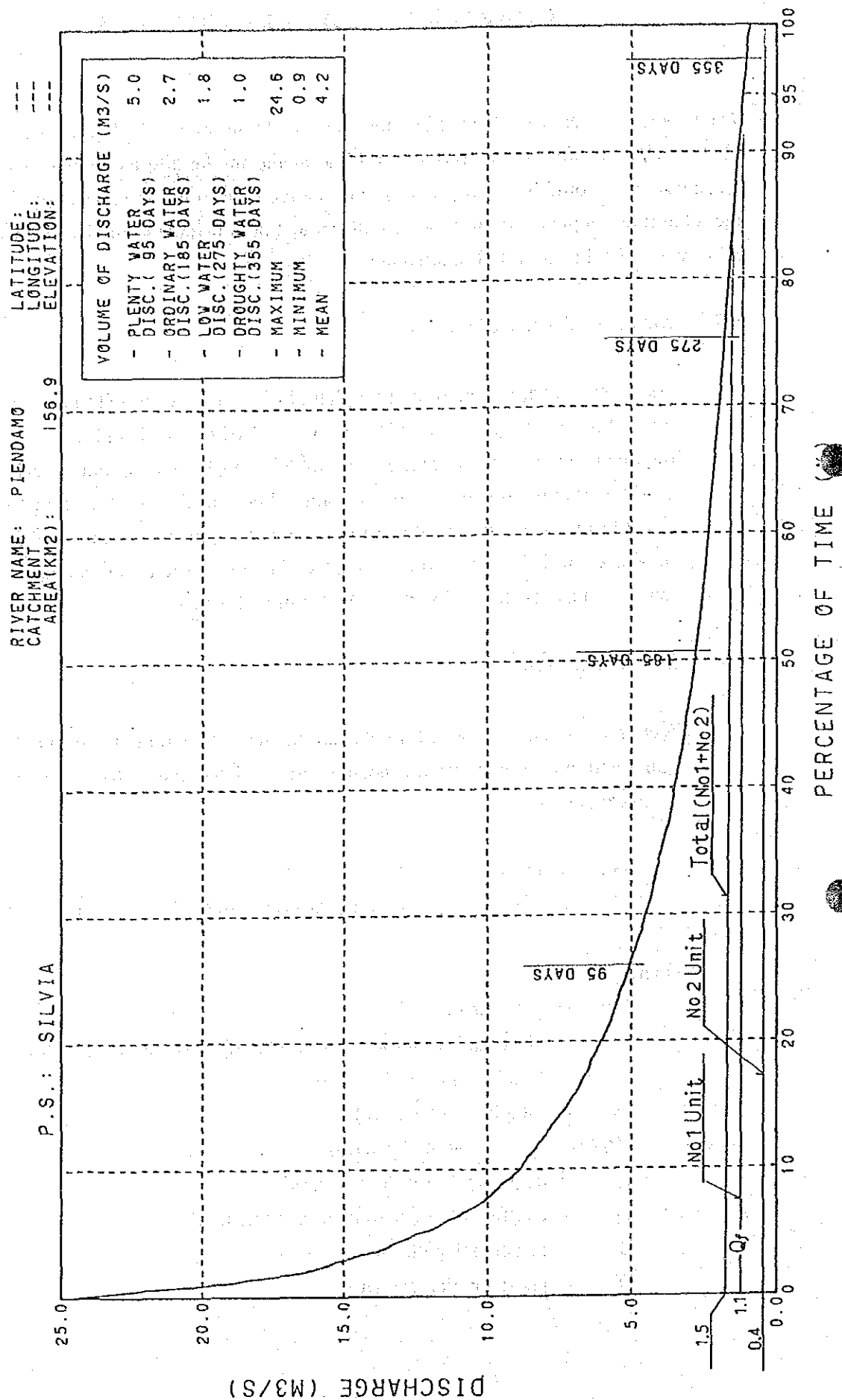
$$f_1 = \text{coefficient of inflow loss; 0.1}$$

$$f_2 = \text{coefficient of frictional loss; } 124.6 n^2/D^{1/3}$$

$$L = \text{penstock length (m)}$$

$$D = \text{penstock diameter (m)}$$

Fig-8.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



- f_m = loss coefficient at the branched part, 0.75
 h = margin (m)
 n = coefficient of roughness, 0.012

Table 8.1 Calculation Result of Standard Net Head

Q (m^3/s)	D (m)	L (m)	V (m/s)	$v^2/2g$ (m)	$f_2 L/D$	$v^2/2g(\Sigma f)$ (m)	h (m)	H (m)	H_e (m)
1.5	0.91	72.1	2.30	0.271	1.47	0.90	0.84	1.74	31.00

Accordingly, the standard net head is calculated to be 31 m.

8.3 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)
 H_e = 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) is the value representing total efficiency, and this value is obtained by the following formula.

$$\eta = \eta_t \times \eta_g$$

where:

η_t = turbine efficiency

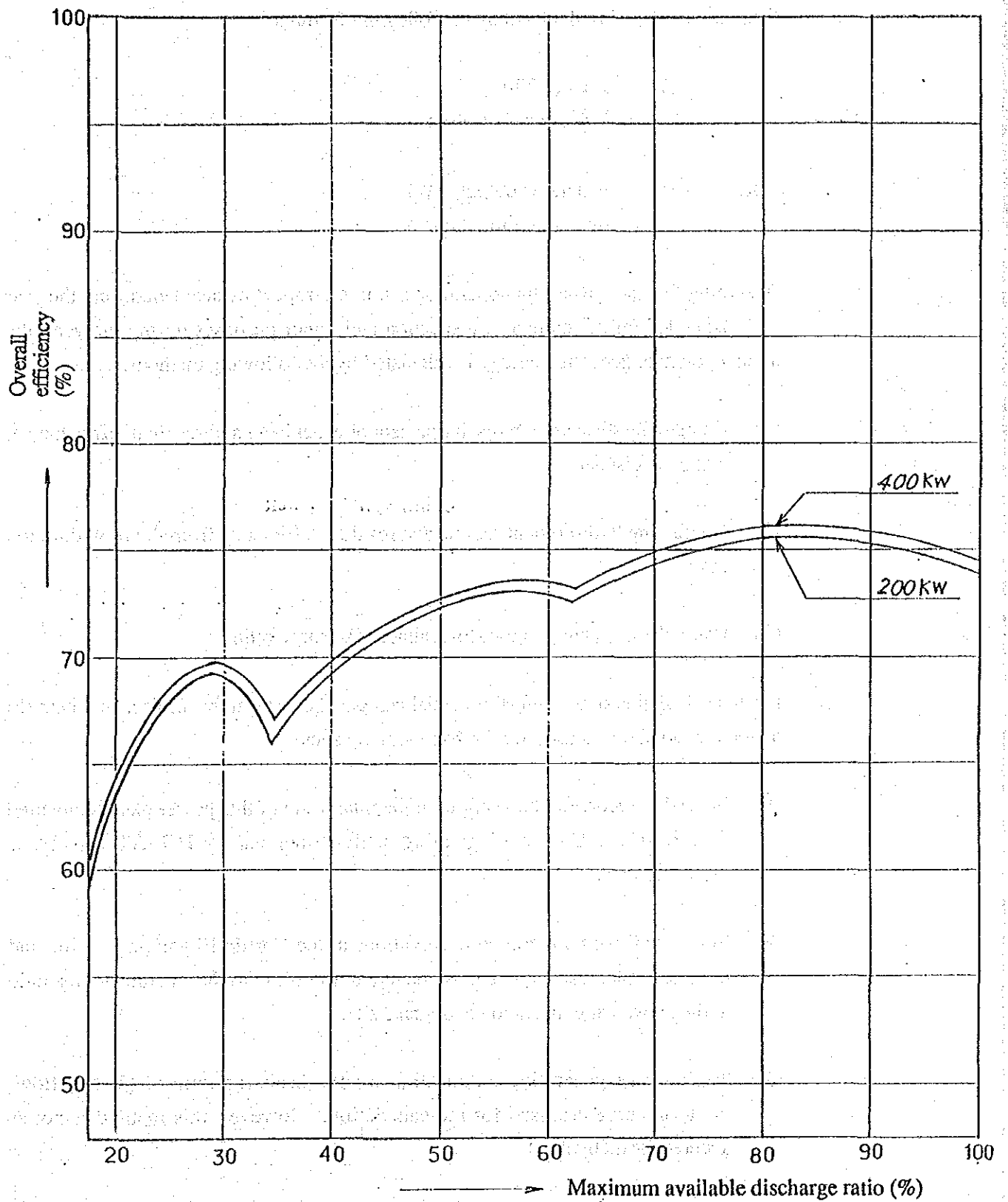
η_g = generator efficiency

Resultant efficiency corresponds to the value of the maximum available discharge ratio 100% in the resultant efficiency curve as shown in Fig. 8.2. Table 8.2 shows the calculation result of the generated output for the alternative plans.

Table 8.2 Calculation of Generated Output

Item Alternative plan	①	②	③	④	⑤
	Available discharge Q (m ³ /s)	Standard net head H _e (m)	9.8 x ① x ② Theoretical output (kW)	Resultant efficiency η	③ x ④ Generated output P (kW)
No. 1 Unit	1.10	31.0	334	0.740	240

Fig. 8.2 Resultant Efficiency Curve of Cross Flow Turbine and Generator



(Source: The above curves are drawn according to the study standard for mini hydro-power generating plan, Structure Improvement Bureau, Ministry of Agriculture, Forestry and Fishery).

8.4 Annual Probable Generated Energy

Generated energy is calculated by the following formula.

$$\begin{aligned} E &= P \times t \text{ (kWh)} \\ &= 9.8 \times Q \times H_e \times \eta \times t \end{aligned}$$

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

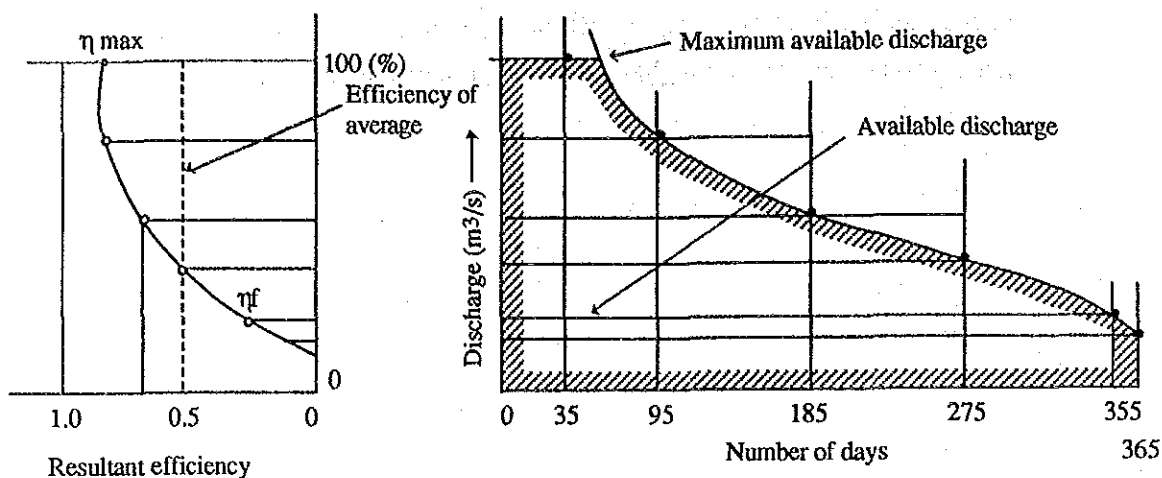
Assuming that the power plant operation is not interrupted by accident during the year nor suspended for maintenance, inspection and repair purposes during the year, the annual potential generated energy is calculated by the following methods.

- (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 Cortijo El gauging station operated by HIMAT is used as discharge data.
- ② Since there are no recorded observations at the Cortijo El 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 below.



Max. available discharge = m^3/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 $9.8 \times Q \times H_e \times \eta$
- ⑦ Mean value of generated output of calculation stage and right above stage.
- ⑧ $⑦ \times ② \times 24$ 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

8.4.1 Calculation of Annual Potential Generated Energy

The annual potential generated energy for No.1 unit is calculated according to the hydrological regime and efficiency method, with the following results.

Table 8.3 Calculation of Guaranteed Energy

Max. available discharge: 1.1 m³/s

Standard net head (H_e): 31.0 m

Turbine type: Cross Flow

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.	347	1.1	1.0	0.740	247	247	2,057
355	8	1.0	0.909	0.753	228	237	45
363	8	0.9	0.818	0.757	206	217	41
365	2	0.9	0.818	0.757	206	206	9
Total	365					(226)	2,152

CHAPTER 9 REHABILITATION PLAN

The rehabilitation plan of this power plant is limited to the replacement of No. 1 turbine, as stated previously. In addition, the foundation of powerhouse building, and tailrace should be reconstructed. Substation equipment should be replaced with new one.

9.1 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 (September 1989), based on the U.S. dollar.

9.1.1 Estimated Generating Equipment Costs

According to the ISA valuation standard, CIF costs of generating equipment are calculated based on the FOB from Japan. The generating equipment specifications and FOB costs are shown in Table 9.1.

The CIF/FOB ratio for the CIF costs is 1.12, as shown in Table 9.2.

Table 9.1 Generating Equipment Specifications and FOB Costs

Item	Rehabilitation of the existing facilities
1. Specifications	
Design discharge (m ³ /s)	1.1
Net head (m)	31.0
Theoretical output (kW)	334
Turbine type	Cross Flow
Turbine output (kW)	260
Generator power factor	0.9
Generator output (kVA)	280
Main transformer capacity (kVA)	280
2. FOB costs (US\$1,000)	
Generating equipment	
(1) Turbine etc.	91.4
(2) Generator etc.	72.9
(3) = (1)+(2) Sub-total:	164.3
(4) Number of units	1
(5) = (3)x(4) Subtotal:	164.3
(6) 480 V switchgear etc.	61.4
(7) Transformer and switchgear	92.9
(8) = (5)+(6)+(7) Total:	318.6

Table 9.2 Implementation Cost of Generating Equipment

(units: US\$10³)

Item	Rehabilitation of the existing facilities	
	A	B
1) FOB cost	318.6	-
2) Transportation costs, insurance		
1) x 0.12	38.2	-
3) Tax	1) x 0.223	71
4) Value-added tax	1) x 0.134	42.7
5) Others	1) x 0.22	70.1
6) Subtotal	356.8	183.8
7) Contingency	1) x 0.17	-
8) Engineering fees	1) x 0.149	-
9) Subtotal	6) + 7) + 8)	183.8
10) Grand total	642.3	

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

9.1.2 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 CEDELCA. The civil construction cost estimates are in the local currency base.

The civil work costs estimated are shown in Table 9.3.

Table 9.3 Estimation of Civil Construction Cost

(unit: 10³ pesos)

Item	Rehabilitation of the existing facilities
Equipment foundation reconstruction	4,498
Tailrace reconstruction	2,566
Substation foundation construction	2,705
① Subtotal	9,769
② Contingency (① x 0.15)	1,465
③ Engineering fees ((① + ②) x 0.10)	1,123
④ Total (① + ② + ③)	12,357

9.2 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 for on September 1989 is adopted 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).

9.2.1 Comparison of Construction Cost per kW

As shown in Table 9.4 the cost of increased power output is US\$2,800/kW.

Table 9.4 Comparison of Construction Costs per kW

Item		Rehabilitation of the existing facilities
Existing equipment output (kW)		
Rated output	Po	500
Available output	Pe	0
Post-rehabilitation output	P ₁ (kW)	240
Recovered/increased output $\Delta P = P_1 - P_e$ (kW)		240
Rehabilitation work cost	(US\$1,000)	
Foreign currency portion Cf		458
Local currency portion C		218
Total C = Cf + C		676
Construction cost per kW	(US\$/kW)	
C/P ₁		2,800
C/ ΔP		2,800

9.2.2 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

$$\begin{aligned} \text{the supplied output per year} &= \text{annual potential generated energy (E) x} \\ &\quad \text{utilization factor} \\ &= 0.95 E \end{aligned}$$

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 calculation results of generating cost per kWh are shown in Table 9.5. The generating cost per annually supplied energy is 33 mills/kWh.

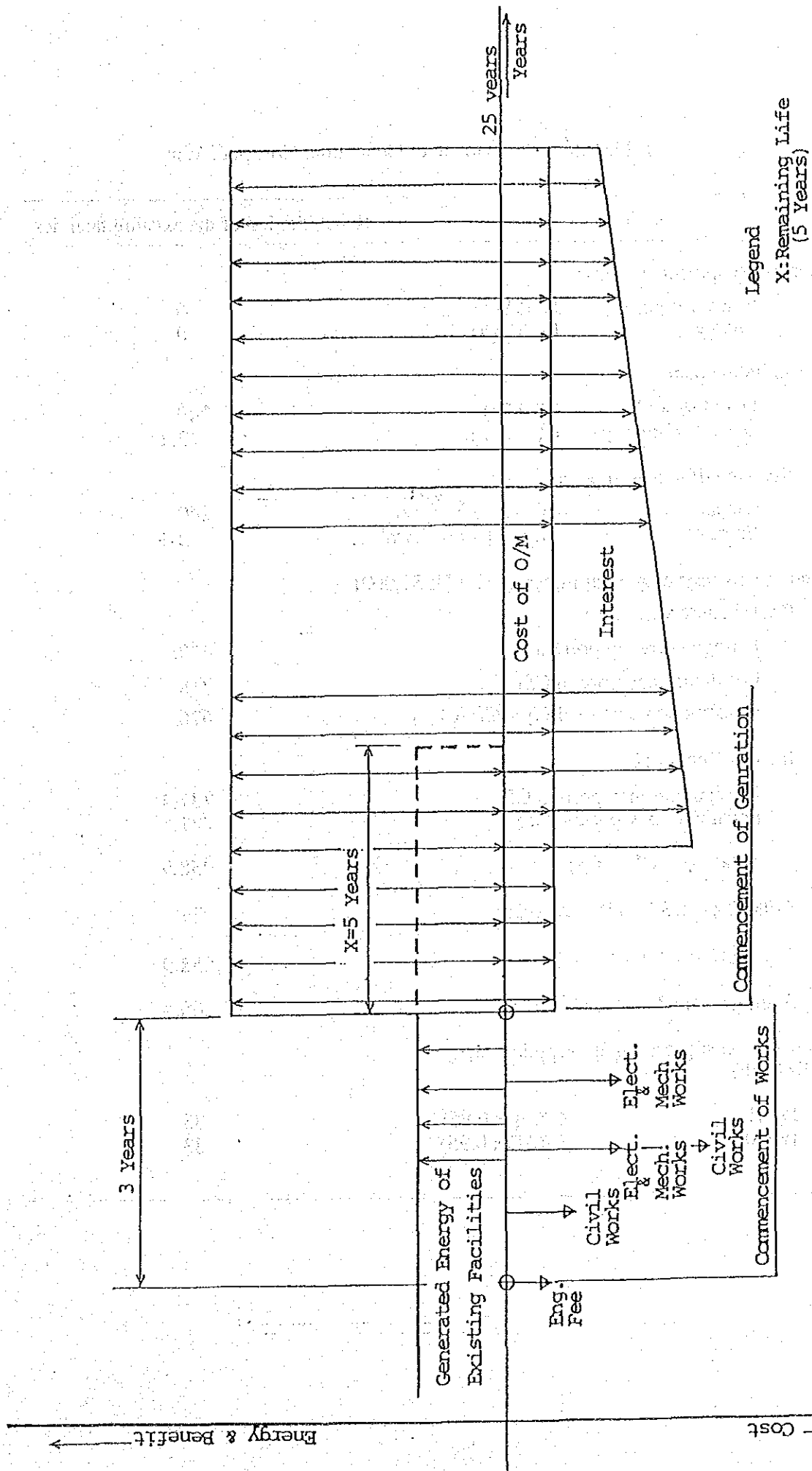


Fig-9.1 Cost and Benefit of Rehabilitation Plan for Hydroelectric Power Plant

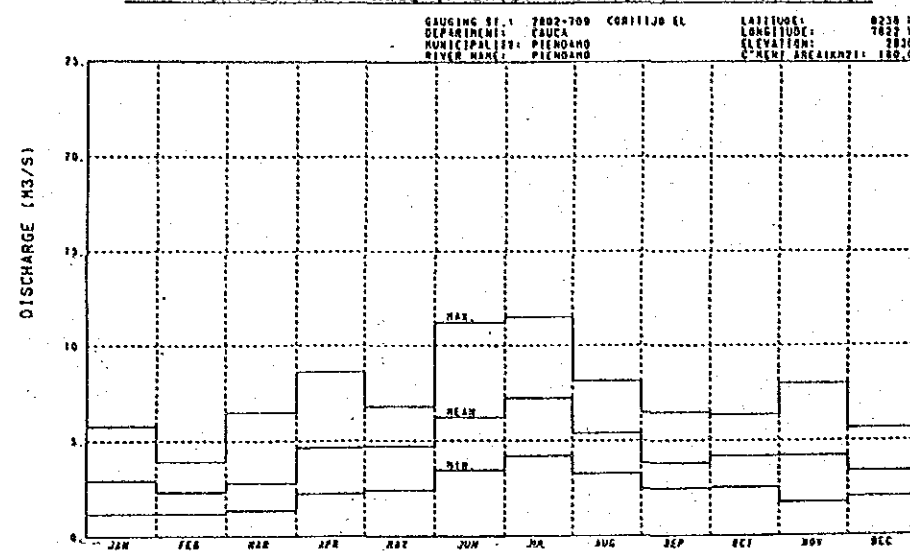
Table 9.5 Comparison of Generating Cost per kWh

Item		Rehabilitation of the existing facilities
Existing equipment capacity:		
Power output	Pe (kW)	0
Energy	Ee (Gwh)	0
Rehabilitation plan:		
Power output	P1 (kW)	240
Generated energy	E1 (Gwh)	2.1
Recovered/increased power		
Output	$\Delta P = P_1 - P_e$ (kW)	240
Energy	$\Delta E = E_1 - E_e$ (Gwh)	2.1
Total of expenses at generating terminal: (US\$1,000)		
Construction work cost		
Foreign currency portion Cf ₁		458
Local currency portion Cl ₁		218
Construction cost total C ₁ = Cf ₁ + Cl ₁		676
Interest payment C ₂		
Foreign currency portion Cf ₂		737.4
Local currency portion Cl ₂		221.5
Total C ₂ = Cf ₂ + Cl ₂		958.9
AOM C ₃ = US\$4 x P ₁ x 25 years		24
Total $\sum C_i = C_1 + C_2 + C_3$		1,658.9
Average annual cost C = $\sum C_i / 25$		66.4
Generating cost per annually supplied energy (mills/kWh)		
Per E ₁	C/(E ₁ x 0.95)	33
Per ΔE	C/(ΔE x 0.95)	33

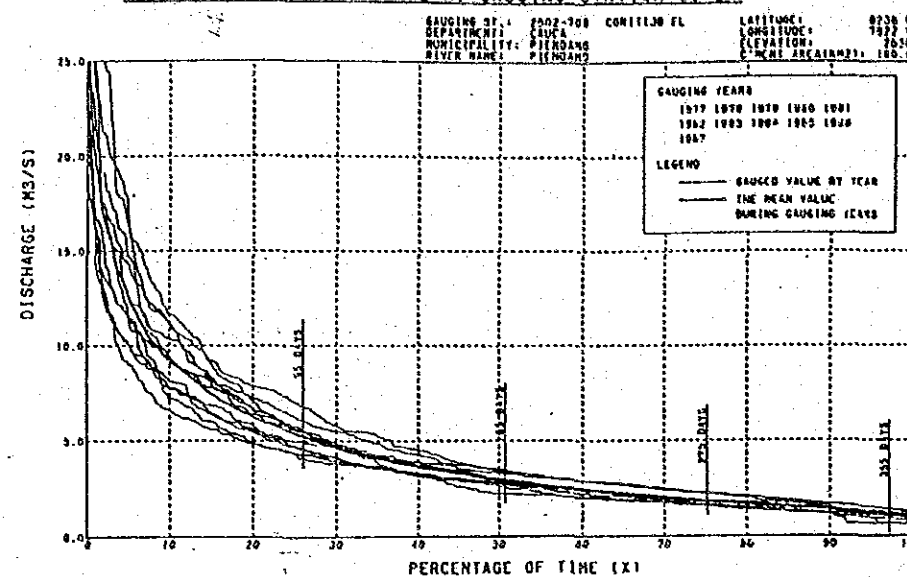
Drawings

Title	Drawing No.
Duration Curves	SI-H-01
Geological Plans	SI-G-01

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



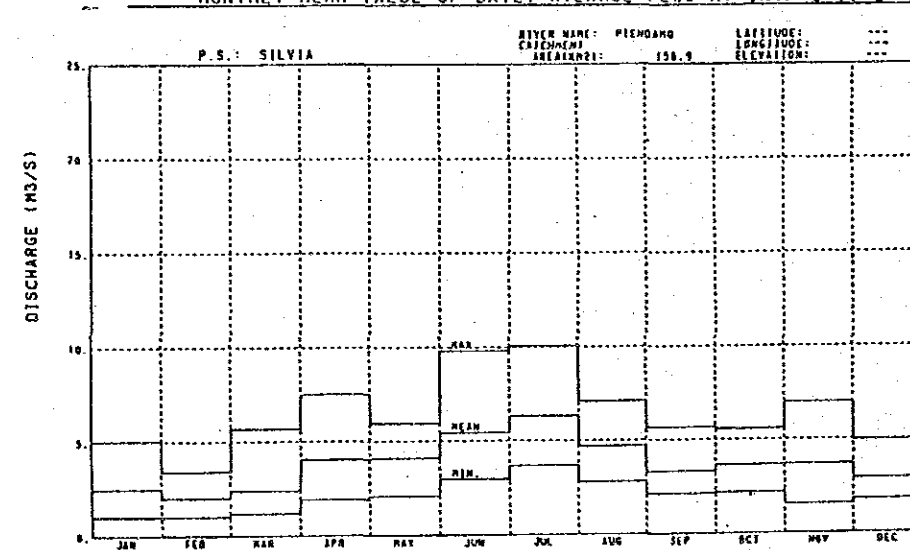
(3)
FLOW DURATION CURVE AT GAUGING STATION SITE



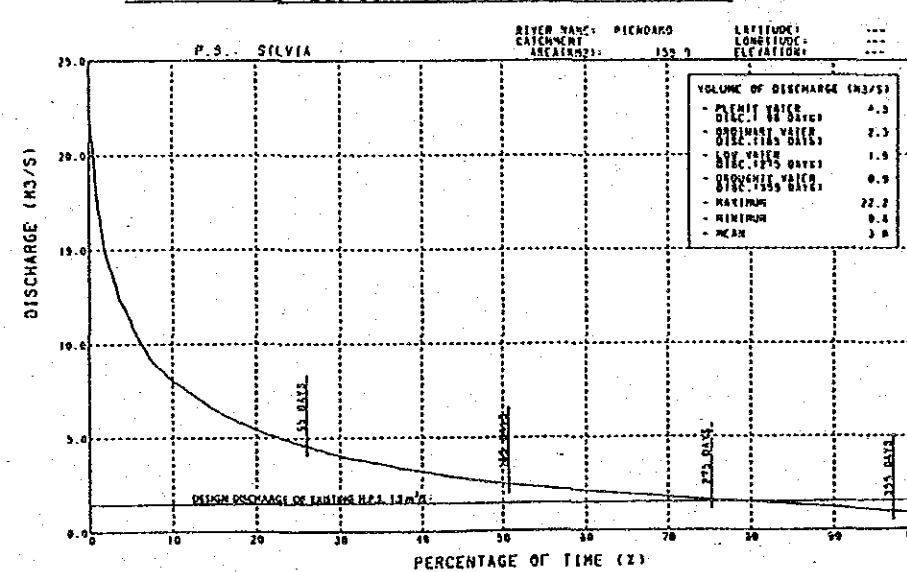
Data of Hydrological Gauging Station

No. of Station	2602 - 709
Name of Station	Cortijo El
River	Piendamó
Management	HIMAT
Installation Year - Month	1961 - 05
Coordinates (Deg. - Min.)	
Latitude	0236
Longitude	7622
Above Sea Level s.n.m. (m)	2630
Long River (km)	18
Catchment Area (km²)	180.0
Water Shed (m)	3300
Observation Period	1977 - 1987

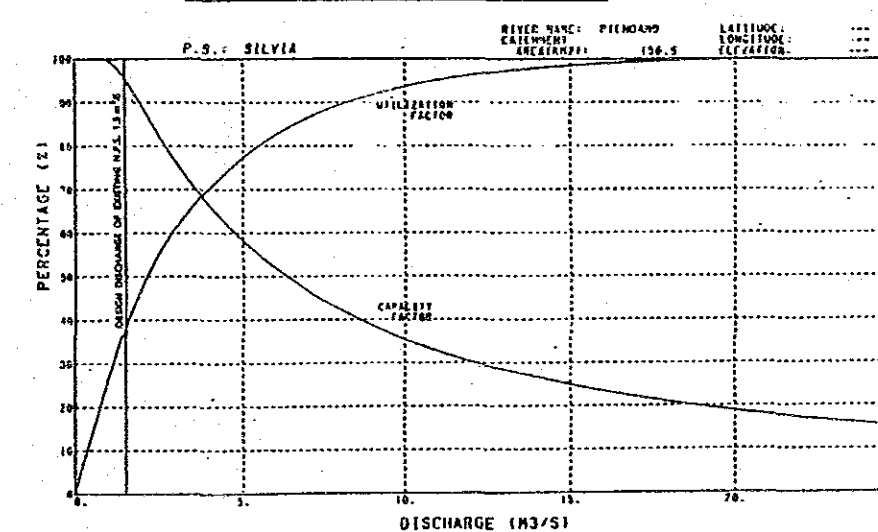
(2)
MONTHLY MEAN VALUE OF DAILY AVERAGE FLOW AT INTAKE SITE



(4)
TYPICAL FLOW DURATION CURVE AT INTAKE SITE



(5)
UTILIZATION & CAPACITY FACTOR



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

DURATION CURVES

DRAWING NO. S I - H - 0 1

SCALE --- DATE



Attached Data

1. Facility Register for the Existing Power Plant
2. Survey Record

Facility Register for the Existing Power Plant

Power Plant	Silvia
Electric Power Company	CEDELCA
Location	Silvia/Cauca
River	Piendamo
Generating Method	Run-of-River
Year Installed	1960
Years in Service	1960
Installed Capacity	604 kW
Available Capacity	100 kW

Civil

Item	Data
1. Dam	
1) Type	concrete , gravity
2) Height (m)	23
3) Crest length (m)	12.0
4) Height of overflowing crest (m)	2570.6
5) Width of overflowing crest (m)	12.0
6) Depth of overflowing crest (m)	no data available
2. Intake Gate	
1) Type	sluice
2) Number of gates	1
3) Dimensions (W x H)(m)	1.1 x 1.0
3. Intake	
1) Intake sill height (m)	2,569.45
2) Number of intake	1
3) Dimensions (W x H)(m)	3.2 x 2.2
4. Desilting Basin	
1) Dimensions (W x L x H)(m)	9.0 x 20.0 x 1.2
5. Sand Trap Gate	
1) Type	sluice
2) Number of gates	1
3) Dimensions (W x H)(m)	no data available
6. Headrace	
1) Type	open - U - channel
2) Dimensions (W x H)(m)	1.3 x 0.9
3) Length (m)	609

Civil

Item	Data
7. Reservoir Tank	
1) Dimensions (W x H x D)(m)	6.0 x 16.0 x 3.0
8. Forebay	
1) Dimensions (W x H)(m)	no data available
9. Penstock	
1) Number of lines	1
2) Penstock diameter (d)(m)	0.91
3) Penstock length (L)(m)	72.1
10. Tailrace	
1) Dimensions (W x H)(m)	1.5 x 1.9

Equipment		
Item	Data	
	#1	#2
1. Water Turbine		
1) Manufacturer's name	<i>Gilbert</i>	<i>Kendall</i>
2) Year manufactured	<i>1960</i>	<i>1954</i>
3) Type	Francis	Francis
4) Output (kW)	150BHP	<i>no data available</i>
5) Revolution (rpm)	900	<i>1</i>
6) Ancillary equipment		
a) Type of governor		
b) Inlet valve		
- Type	<i>Manual</i>	
- Diameter (mm)	<i>16 inch</i>	<i>1</i>
2. Generator and Exciter		
1) Manufacturer's name	<i>Brown Boveri</i>	<i>Westinghouse</i>
2) Year manufactured		
3) Type	Synchro.	Synchro.
4) Capacity (kVA)	130	625
5) Power factor (%)	80	80
6) Voltage (V)	480-276	6,900
7) Frequency (Hz)	60	60
8) Revolution (rpm)	900 -1,750	720
9) Method of neutral earthing	<i>no data available</i>	
10) Type of exciter	<i>1</i>	

Equipment	
Item	Data
3. Transformer	
1) Manufacturer's name	<i>AEG (Type JDUF 132/20)</i>
2) Year manufactured	<i>Outdoor, ONAN</i>
3) Type	<i>no data available</i>
4) Capacity (kVA)	<i>142.5</i>
5) Primary voltage (kV)	<i>0.48</i>
6) Secondary voltage (kV)	<i>13.2 ± 5%</i>
7) Number of unit	<i>1</i>
8) Vector-group symbol	<i>no data available</i>
9) Impedance (%)	<i>4</i>
10) Purpose for use	<i>Step-up</i>
4. Circuit Breaker	<i>no data available</i>
1) Manufacturer's name	
2) Year manufactured	
3) Type	
4) Voltage (kV)	
5) Rated current (A)	
6) Rupturing capacity (kA)	
7) Purpose for use	
5. Transmission Line	<i>no data available</i>
1) Destination	
2) Length (m)	
3) Voltage (kV)	
4) Number of circuit	
5) Number of pylons	
6) Size of conductors	
7) Materials of conductors	

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

Survey Records

Silvia Hydroelectric Power Plant

I. RECORDS BY VISUAL INSPECTION AND HEARING SURVEY

Unit No.: /

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 3) Presence of vibration
	Runner	1) Existence of corrosion 2) Occurrence of porosity by sand pitting
	Shaft	1) Shaking of shaft axis
	Bearing	1) Oil shortage on bearing surface 2) Lack of oil viscosity
	Governor control	1) Control by belt-driven type 2) Speed detection device 3) Speed regulation system 4) Installation of load limiter 5) Accuracy of governor speed regulation
		1) X 2) X 3) 1) X 2) X 1) X 2) 1) X 2) 3) 4) X 5) <i>Good</i>

Generating Facilities	Check item by visual inspection and hearing	Results
Francis Turbine	Oil pressure equipment	1) X 2)
	Inlet valve	1) <i>Manual</i> 2) <i>Regular</i> 3)
	Guide vanes	1) X 2) X 3)
	Sealing device	1) X 2) X

Unit No. /

Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) X 2) 3)
	Stator winding	1) 2) X 3)
	Bearing	1) 5 years 2) 3)
	Exciter	1) 2) Good
	Voltage regulator	1) Automatic 2) Good, 0.2 sec.

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
	Runner	3) Presence of vibration 1) Existence of corrosion 2) Occurrence of porosity by sand pitting
	Shaft	1) Shaking of shaft axis
	Bearing	1) Oil shortage on bearing surface 2) Lack of oil viscosity
	Governor control	1) Control by belt-driven type 2) Speed detection device 3) Speed regulation system
		4) Installation of load limiter
		5) Accuracy of governor speed regulation

Generating Facilities	Check item by visual inspection and hearing	Results
Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) 2)
Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) 2) 3)
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) 2) 3)
Sealing device	1) Sufficiency of water sealing for shaft 2) Sufficiency of packing for shaft seal	1) 2)

Francis Turbine

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
	Stator winding	1) Frequency of burning trouble or repair 2) Reduction of insulation resistance 3) Rust and erosion of core
	Bearing	1) Occurrence of deformation on metal surface 2) Lack of oil lubrication 3) Occurrence of temperature rise
	Exciter	1) Exchange frequency of brushes worn out 2) Sufficient stock of spare brush
	Voltage regulator	1) Operation method of voltage regulator 2) Response of voltage detection for load variation

Generating Facilities	Check item by visual inspection and hearing	Results
Control Board	Metering equipment	1) Sufficiency of accuracy for instruments 2) Lack of necessary instruments 3) Items constantly recorded
	Protection equipment	1) Lack of relays to be installed 2) Operation method in case of accident in transmission lines 1) <i>Automatic by overcurrent and</i> 2) <i>overvoltage</i>
	Remote control equipment	1) Control method for turbine and generator operation 2) Control method for voltage and speed control 3) Operation method of synchronized switching
	Power system	1) Power supply voltage (kV) after rehabilitation work
		1) X 2) 3) 1) — 2) — 3) — 1)

Generating Facilities	Check item by visual inspection and hearing	Results
Indoor Switchgear	Insulation level Accessibility and Safety	1) Sufficiency of insulation level 2) Unification of insulation level 3) Reduction of insulation resistance 1) X 2) <i>Regular</i> 3) <i>Manual</i>
	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	

Generating Facilities	Check item by visual inspection and hearing	Results
Outdoor Equipment	Transformer	1) -
	Circuit breaker	1) - 2) -
	Line switch	1) Fuse 2) -
	Insulator	1) -
	Structural steel	1) - 2) -
	Line protection	1) <i>Not adequate</i>

II. ACTUAL GENERATED ENERGY AND OPERATION TIME

Unit No.: 1

Installed Capacity of Generator: 130 KVA

Type of Turbine: Francis

YEAR		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL	REMARKS
1983	MWH														
	OPE. TIME														
1984	MWH	73.4	67.9	74	71.4	70.7	72	74.4	74.4	70.6	73.6	70.8	71.8	86.5	
	OPE. TIME	717	682	725	709	707	715	743	740	701	710	708	721	8,578	
1985	MWH	63.1	66.2	72	71.4	74.4	70.5	74.4	68.8	68.5	73.9	71.6	73.7	848.5	
	OPE. TIME	630	660	736	714	744	705	744	546	688	739	720	737	8,363	
1986	MWH	73.3	67	73.5	71.4	73.4	71.4	69.8	60.7	46.2	68	67.2	74.4	816.3	
	OPE. TIME	733	669	735	707	733	710	694	733	537	683	695	742	8,371	
1987	MWH	74.4	67.2	71	70.4	74.4	72	74	24	0	28.9	71.9	74.4	702.6	
	OPE. TIME	733	665	538	649	742	646	560	744	0	289	699	743	7,008	
1988	MWH	74.4	69.6	54.4	72	73.7	72.3	74.4	73.6	72	72.1	72	74.4	854.9	
	OPE. TIME	740	684	538	701	727	705	584	704	710	566	597	727	7,983	

(Note) 1. MWH : Gross
2. OPE. TIME : Hour

III. REPAIR RECORDS

No.	Study Item	Results
	<p>The past records concerning the following items shall be obtained to evaluate reliability of generating facilities.</p> <ol style="list-style-type: none"> 1) Repaired locations and method for repairing 2) Causes for damage/defect 3) Duration of repairing and power supply stoppage 4) Repaired by; <ol style="list-style-type: none"> a) staff in Power Plant b) manufacturer c) other 5) Repair cost 6) Operation life after the completion of repairing work 	<ol style="list-style-type: none"> 1) Wear of pieces by erosion 2) Impeller, bucket, shaft, etc. 3) 3 months 4) Repaired by workshop 6) 5 years

IV . SITUATION OF STOCK SPARE PARTS

No.	Study Item	Results
	<p>Data on the situation of stock spare parts shall be obtained to evaluate maintainability of generating facilities.</p>	<p>Without available informations</p>

V. CEDELCA'S INTENTION FOR REHABILITATION

No.	Study Item	Results
	<p>Mark with/ in pertinent columns</p> <ul style="list-style-type: none"> - Inlet valve - Turbine, governor, auxiliary equipment - Generator, exciter - Control panel - Switchgear - Transformer - Substation equipment (Circuit breaker, Isolator, etc.) - Transmission tower, conductor and insulator - Power House 	<p>Leaving as it is Repair work Replacement Notes</p>

