FEASIBILITY STUDY

ON

SMALL-SCALE POWER PLANTS REHABILITATION PROJECT

IN

THE REPUBLIC OF COLOMBIA

MAIN REPORT

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the Republic of Colombia and on the basis of the result of a Pre-Feasibility Study on Small-Scale Power Plants Rehabilitation Project conducted by Japan International Cooperation Agency (JICA) from November 1987 to June 1988, the Japanese Government decided to conduct a feasibility study on the above-mentioned Project and entrusted the study to JICA. JICA sent to Colombia a study team headed by Mr. Masami Ono, President of Yachiyo Engineering Co., Ltd. from November 1988 to February 1990.

The team had discussions on the Project with the officials concerned of the Government of Colombia and conducted field surveys in the relevant areas in Colombia. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of Colombia for their close cooperation extended to the team.

March 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

Mr. Kensuke Yanagiya, President
Japan International Cooperation Agency
(JICA) Tokyo, Japan

March 1990

Dear Sir :

LETTER OF SUBMISSION

We hereby take pleasure in submitting you the Final Report of "The Feasibility Study on Small – Scale Power Plants Rehabilitation Project in the Republic of Colombia" under the control of Instituto Colombiano de Energia Electrica (ICEL).

This Report is the feasibility study report concerning the rehabilitation of 12 small – scale power plants (thermal power : 1 and hydroelectric power : 11) selected through consultation with ICEL on the basis of the Pre – Feasibility Study Report submitted in June 1988.

The feasibility study was conducted for the duration of 17 months starting from the site survey in November, 1988 upto the preparation of the draft final report in March, 1990. Upon submission of the draft final report to your Agency, the sutdy team visited the Republic of Colombia during January 29, 1990 – February 19, 1990 for consultation with ICEL upon such report. All the findings and comments obtained in the discussions were fully incorporated in the Final Report.

The only thermal power plant discussed in the Report is Termopaipa Plant (rated output : 173 MW) in Boyaca Prefecture under the control of EBSA. The rehabilitation programmes are classified into (1) remodelling the existing # 2 unit constructed in 1975 (present output : 66 MW) mainly for increasing the output by 8 MW by replacing its turbine, and (2) transforming the cooling water system newly equipped with a cooling tower. Approximately estimated construction costs as of September 1989 show ¥ 1.69 billion (¥ 1.08 billion for foreign currency portion) for remodelling # 2 unit and ¥ 2.08 billion (¥ 1.23 billion for foreign currency portion) for transforming the cooling water system, totalling ¥3.77 billion (¥2.31 billion for foreign currency).

For rehabilitation of hydroelectric power plants, we recommended 4 plants, Municipal, Intermedia, San Cancio and Julio Bravo among 11 candidates for being highly practicable and easy for early commencement of construction. For such recommendation, we made a careful selection including needs for local electrification besides the economic indices of power programmes and the results obtained from cost – benefit analysis. Rehabilitation of these 4 plants will increase the power output by 8,850 KW and also expected is the annual electric energy increase of 84.8 GWh. Approximately estimated construction cost as of September 1989 shows ¥2.16 billion (¥1.2 billion for foreign currency portion). Although this feasibility study is limited to the rehabilitation programmes, we also suggested that much possibility was found in terms of redevelopment of potential hydro – energy in many existing small – scale power plants.

We earnestly wish that the rehabilitation of the candidate plants selected in this Report will be realized and that the transfer of technology to ICEL engineers be fruitful.

In submitting this Final Report, we wish to express our sincere gratitude to your Agency, Japanese Embassy in Colombia, and ICEL groups for much assistance and cooperation extended to us through the whole period of our site survey and works in Japan.

For and on behalf of
Feasibility Study Team on the
Small – Scale Power Plants
Rehabilitation Project
in the Republic of Colombia

Masami Ono

Masami Ono, Team Leader

CONTENTS

ABBREVIATIONS

CAMBSA	Compañia del Acueducto Metropolitano de Bucaramanga S.A.
CAR	Corporación Autónoma Regional de la Sabana de Bogotá y de los Valles de Ubaté y Chiquinquirá
CEDELCA	Centrales Electricas del Cauca S.A.
CEDENAR	Centrales Electricas de Nariño S.A.
CELGAC	Compañia de Electricidad y Gas Cundinamarca
CHEC	Central Hidroelectrica de Caldas S.A.
CIF	Cost, Insurance and Freight
CRQ	Corporacion Autonoma Regional del Quindio
CRAMSA	Corporacion Regional Autonoma Manizales Salamina Aranzazu
CVC	Corporacion Autonoma Regional del Valle del Cauca
DANE	Departamento Administrativo Nacional de Estadistica
E.	Electrificadora de
EBSA	Electrificadora de Boyaca S.A.
E.P.	Empresas Publicas
E/P	Electric Precipitator
EADE	Empresa Antioqueña de Energia S.A.
EDEQ	Empresa de Energia del Quindio
EEASA	Empresa de Energia del Amazonas S.A.
EEB	Empresa de Energia de Bogota
ELECTRAGUAS	Instituto de Aprovechamiento de Aguas y Fomento Electrico
ELECTROLIMA	Erectrificadora del Tolima S.A.
EPM	Empress Publicas de Medellin
EPP	Empress Publicas de Pereira
ESSA	Electrificadora de Santander S.A.
F/S	Feasibility Study
FOB	Free on Board
HIMAT	Instituto Colombiano de Hidrologia, Meteorologia y Adecuacion de Tierras
HP	High Pressure
ICEL	Instituto Colombiano de Energia Electrica
IGAC	Instituto Geografico 'Agustin Codazzi'
ISA	Interconexion Electrica S.A.
JICA	Japan International Cooperation Agency
P/P	Power Plant
S.A.	Sociedad Anonima
WHO	World Health Organization

SUMMARY OF THE STUDY

CONTENTS

1. Background and Objective of the Study

The increase in power demand in Colombia in the 1970s was 15-20%. The Government of Colombia forecasts a favorable increase for the future and has promoted the power development plan mainly consisting of large-scale hydroelectric power plant in order to cope with the increasing power demand. However, the increase in power demand in the 1980s stopped. The annual growth rate in power demand for the latest years was 4-5%.

For this, excessive investment was made in positive construction for power development. Electric power industries fell into a serious financial condition. The Government of Colombia has decided not to start the new large-scale power development by the year 1990.

Under these circumstances, the Government of Colombia promoted 1) the small-scale power development for rehabilitation and power-optimization of the existing small-scale generating facilities (that were left behind in power development) and for rural-electrification, 2) the construction of transmission lines.

The Government of Colombia has requested in March 1987 that the Government of Japan conducts the study to formulate the rehabilitation plan for 82 small-scale power plants (thermal: 3, hydroelectric: 62, diesel: 17) operated by 15 public electric power companies under the jurisdiction of Instituto Colombiano de Energia Electrica (ICEL).

Japan International Cooperation Agency (JICA) conducted the study by dividing into two stages; pre-feasibility study (FS) (1987) and FS (1988-89). In the pre-FS, JICA study team selected candidate power plant sites for FS from among 82 power plants. Based on the results of the pre-FS, and after discussion with the Colombian side, 12 power plants (thermal: 1, hydroelectric: 11, diesel: 0) were selected for the FS.

2. Study Plan

The F/S was conducted in accordance with the Scope of Work (S/W) agreed in July 1988 between JICA and ICEL.

2.1 Power Plants for F/S

Twelve power plants selected for the F/S are listed below. Locations of power plants are shown in Fig. 1 and these power plants are widely distributed over eight departments.

Termopaipa Thermal Power Plant	Boyaca Department
Puente Guillermo Run-of-River Type Hydroelectric Power Plant	Boyaca Department
Caracoli Run-of-River Type Hydroelectric Power Plant	Antioquia Department
San Cancio Run-of-River Type Hydroelectric Power Plant	Caldas Department
Intermedia Run-of-River Type Hydroelectric Power Plant	Caldas Department
Municipal Run-of-River Type Hydroelectric Power Plant	Caldas Department
Silvia Run-of-River Type Hydroelectric Power Plant	Cauca Department
Ovejas Run-of-River Type Hydroelectric Power Plant	Cauca Department
La Vuelta Run-of-River Type Hydroelectric Power Plant	Choco Department
Julio Bravo Run-of-River Type Hydroelectric Power Plant	Nariño Department
Zaragoza Run-of-River Type Hydroelectric Power Plant	Santander Department
Lagunilla Run-of-River Type Hydroelectric Power Plant	Tolima Department

Eleven small-scale power plants are the run-of-river type. The present condition of these power plants is summarized in Table 1. Total installed capacity of these power plants was approximately 17 MW, while the total present output was 8.8 MW; power drop of about 50%.

Fig-1 Power Plant Location Map

- Thermal Power Plant

Code No	No	Name of Power Plant
101	1	Termopaipa Thermal Power Plant

- Hydroelectric Power Plants

Code No	No	Name of Power Plant
201	2	Caracoli Hydroelectric Power Plant
210	3	P.Guillermo Hydroelectric Power Plant
211	4	San Cancio Hydroelectric Power Plant
212	5	Intermedia Hydroelectric Power Plant
213	6	Municipal Hydroelectric Power Plant
227	7	Silvia Hydroelectric Power Plant
228	8	Ovejas Hydroelectric Power Plant
233	9	La Vuelta Hydroelectric Power Plant
248	10	Julio Bravo Hydroelectric Power Plant
251	11	Zaragoza Hydroelectric Power Plant
261	12	Lagunilla Hydroelectric Power Plant

Location of Power Plant Installed

Department	Power Plant		Total
	Thermal	Hydroelectric	
Antioquia	0	1	1
Boyaca	1	1	2
Caldas	0	3	3
Cauca	0	2	2
Choco	0	1	1
Nariño	0	1	1
Santander	0	1	1
Tolima	0	1	1
Total	1	11	12

Table 1 Present Status of Run-of-River Type Hydroelectric Power Plants Selected for Rehabilitation Plan

JICA Dode No.	Power Plant	Electric Power Company	Dept.	Available Discharge Q (m^3/s)	Head H (m)	Rated Output		Present Operating Status			Remarks
						Type* x No.	Po (kW)	Service Year**	Available Output Pe (kW)	Pe/Po (%)	
201	Caracoli	EADE	Antioquia	5.0	86.0	Px1 Fx1	1,600 1,600	55 27	1,150 1,150	72 72	
210	P. Guillermo	EBSA	Boyaca	2.6	58.0	Fx2	640 640	30 40	0 0	0 0	Not operated since 1984 because of damage to penstocks
211	San Cancio	CHEC	Caldas	5.6	59.8	Fx1 Px1	1,350 970	43 61	1,000 750	74 77	Large variance between the rated output and theoretical one
212	Intermedia	CHEC	Caldas	5.6	59.0	Px1	1,120	43	900	80	
213	Municipal	CHEC	Caldas	5.6	80.6	Px2	1,056x2	45	700x2	66	
227	Silvia	CEDELCA	Cauca	1.5	31.0	Fx1 Fx1	500 104	36 30	0 100	0 96	Not operated since1972 because of breakdown
228	Ovejas	CEDELCA	Cauca	7.0	24.5	Fx1	900	51	650	72	
233	La Vuelta	E. CHOCO	Choco	54.0	4.8	Fx1 Fx1	1,000 1,000	75 60	300 200	30 20	
248	Julio Bravo	CEDENAR	Nariño	2.0	120.0	Px3	500x3	48	0	0	Not operated since 1983 because of damage to penstocks
251	Zaragoza	ESSA	Santander	6.5	30.0	Fx1 Fx1 Fx1	520 520 520	40 58 53	400 400 400	77 77 77	
261	Lagunilla	ELECTROLIMA	Tolima	0.5	120.0	Px1 Px1	240 152	50 50	0 0	0 0	Not operated since 1972 because of equipment failure

Note: * P : Pelton Type F : Francis Type
** Service year is computed starting from the year in which generating equipment was manufactured.

2.2 Organization of the Study Team

JICA F/S Study Team is composed of the same team leader and team members who participated in the Pre-F/S, in addition to experts such as a hydroelectric power generation planner (civil engineer), hydroelectric generation equipment planner (mechanical engineer), a hydrologist, geologists and an economist as listed below.

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

The Organization of the ICEL Counterpart

The following are the engineers appointed by ICEL as counterparts of the JICA F/S Team and their area of work:

Name	Field	Position
Juvenal Peñaloza Rosas	Civil Engineering	Head of Central Eng. Div.
Jairo E. Gonzalez Morales	Civil Engineering	Central Engineering Div.
Rafael Torres Mariño	Civil Engineering	Central Engineering Div.
Mario Gutierrez Ospina	Civil Engineering	Central Engineering Div.
Rafael Gomez Florez	Civil Engineering	Central Engineering Div.
Jorge E. Hurtado Muñoz	Civil Engineering	Central Engineering Div.
Augusto Sanabria Diaz	Mechanical Engineering	Central Engineering Div.
Luis E. Becerra P.	Mechanical Engineering	Central Engineering Div.
Ramiro Velasco	Electrical Engineering	Central Engineering Div.

Supporting Technical Staff of the Respective Public Electric Power Corporation

The JICA F/S Team obtained the cooperation and support of the technical staff of the following public electric power corporations when executing the field work and the data collection at the sites of the power plants which are being evaluated for the rehabilitation.

Corporation	Name	Position
EADE	Humberto Alonso Cadavid A.	Manager of Planning Department
	David Aguilar	Manager of Substation and Plants
	Walter Leon Ospina Ortiz	Planning Engineer
EBSA	Edgar Olante Reyes	President
	Francisco Duque	Vice President
	Enoc Guerrero	Chief of Planning Dept.
	Hector Pulido	Chief of Termopaipa
	Jorge Hernan Ramirez S.	Chief of Service Engineer
	Pedros Lesmes	Service Engineer

(continued)

Corporation	Name	Position
EBSA	Avelino Cely	Service Engineer
	Fernando Crus F.	Chief of Electrical Engineer
	Jose de Los Santos Cardenas	Electrical Engineer
	Alvaro Delgado O.	Production Engineer
	Fabio Abril G.	Mechanical Engineer
	Reinaldo Avelia	Operation Engineer
	Flaviano A. Gonzalez	Civil Engineer
CHEC	Alberto Naranjo A.	Director of MIEL Project
	Hernando Duque Vargas	Manager of Small Plants
	Jorge H. Garcia C.	Member of MIEL Project
	Claudia M. Agudelo	Member of MIEL Project
E. CHOCO	Juan B. Hinestroza C.	President
	Jose Wilson Guerrero	Chief of Planning Office
	Jose Antonio Correa H.	Engineer
	Luz Elba Gonzalez	Engineer
	Carlos Osorio Molina	Manager of "Metales Preciosos del CHOCO"
	Juan Ramon Gilabert	Chief of La Vuelta Power Plant
CEDELCA	Fernando Iragorri Cajiao	President
	Jose Morales M.	Vice President
	Larry Guzman	Civil Engineer
CEDENAR	Hernando Carreño Pilonieta	President
	Enrique Moreno B.	Vice President
	Diego Delgado Ruiz	Director of Power Generation/Transmission Program
	Juan Carlos Salazar	Civil Engineer

(continued)

Corporation	Name	Position
CEDENAR	Alvaro E. Martines	Civil Engineer
ESSA	Hernando Uribe Niño	President
	Ruben Gelves Diaz	Vice President
ELECTROLIMA	Ivan Nichols N.	President
	Hugo Neira S.	Chief of Planning Division
	Francisco Corrales	Chief of Small Power Plants

2.3 Study Items

The feasibility study (F/S) was conducted during 17 months starting from the site survey in November, 1988 up to the preparation of the final report in March, 1990.

The F/S was conducted by dividing into the field work in Colombia and home work in Japan according to the study items defined in the S/W, as shown in Table 2.

Table 2 Time Schedule of FS

Working item	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																		
	(2) Procurement procedure																		
	(3) Ground survey																		
	(4) Photogrammetric mapping																		
	(5) Geological investigation																		
	(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

3. Rehabilitation Plan of Termopaipa Thermal Power Plant

There are three items to be investigated at Termopaipa thermal power plant (Rated output: 173 MW). Out of the three items, two items are the investigation for the improvement plan, i.e., the solution of malfunction that the existing No. 2 unit (available output: 66 MW) is confronted with, and the improvement of reliability in operation, maintenance and inspection rather than the investigation of the rehabilitation, as detailed below.

- Investigation Item (1):
  No. 2 Turbine Output Increasing Plan (66 MW → 74 MW)

- Investigation Item (2):
  No. 2 Unit Instrumentation System Modification plan

The remaining one item relates to the F/S for improvement of cooling system for cooling water which is used for Termopaipa power plant.

- Investigation Item (3):
  Cooling System Modification Plan

3.1 Renovation Plan of Existing No. 2 Unit

3.1.1 Turbine Output Increasing Plan (66 MW → 74 MW)

In No. 2 unit of turbine constructed in 1975, the rated output of generator is 74 MW, while the rated output of turbine is 66 MW. There is 8 MW difference between the rated output of generator and turbine. Old turbine parts (turbine rotors, blades, nozzles, diaphragms, etc.), that were installed 15 years ago, and feed water heater will be replaced with new ones to improve for increasing turbine output from 66 MW to 74 MW.

- Replacement work plan of No. 2 unit

Manufacturing and installation costs	US$6.34 x 10^6
(foreign currency portion)	US$4.06 x 10^6
(local currency portion)	US$2.28 x 10^6

- Construction period

Preparatory work	7 months
Manufacturing	14 months
Installation, tests	4 months
Total	25 months

- Economic indices

Construction cost per kW	US$790/kW
Generating cost per kWh	20 mills/kWh

- Items to be noted for implementation

If the turbine output is increased to 8 MW, the required steam consumption is 285.85 T/H. Since the amount of steam generation of the existing #2 boiler is 300 T/H during the peak period, and 284 T/H for maximum continuous capacity, it is short by a steam volume of 1.85 T/H in the case of the maximum continuous capacity. Accordingly, detailed discussions with the boiler manufacturer on the boiler performance need to be made for the implementation of this plan.

3.1.2 Instrumentation Improvement Plan

The objective of the improvement plan is 1) the change from the pneumatic instrumentation plan to the electrical instrumentation system, 2) the simplicity of the proper operation, smooth maintenance and inspection, and 3) the improvement of monitoring and control.

Boiler supervised and controlled by the central supervisory panel, and the instrumentation unit for turbine will be replaced with electrical instrumentation system controlled by a computer.

Main improvement items are as follows:

	Control Item	Details of Plan
(1)	Boiler facilities	
	1) Automatic boiler control	Replacement with automatic boiler digital control unit (DDC).
	2) Automatic main boiler control	Coal feeder speed shall be feeded back as coal flow
	3) Heavy oil flow control	Heavy oil flow meter shall be installed and a new boiler master circuit shall be installed at DDC.
	4) Main steam pressure control	New cascade control of outlet steam temperature shall be installed at DDC.
	5) Start-up feed water control	DDC control circuit shall be installed so that drum and level control at the time of start-up, can be made at the start-up feed water control valve.
(2)	Condenser and deaerator level control	
	1) Mechanical governor	Replacement with electrical governor (DEH) for automatic follow-up of accelerator, frequency, stress, valve switchover, runback, load and governor
	2) Condenser and deaerator level control	Replacement with DDC-based remote control system

- Improvement plan of No. 2 unit instrumentation system

Manufacturing and installation costs	US$5.75 x 10^6
(foreign currency portion)	US$3.68 x 10^6
(local currency portion)	US$2.07 x 10^6

- Construction period

Preparatory work	10 months
Manufacturing	12 months
Installation and tests	5 months
Total	27 months

- Economic indices

  Increase in generating cost 1.9 mills/kWh

- Items to be noted for implementation

  Measured points and their locations of the existing instrumentation system shall be clearly indicated on the drawing, which is necessary for improvement of the instrumentation system. In addition, the coordination of the instrumentation system for No. 3 unit shall be considered.

  If the boiler control system is replaced with DDC, feed water flow control system needs to be changed.

3.2 Improvement Plan of Cooling System for Cooling Water

In the present cooling system, water that cools condenser and bearings for auxiliary equipment has been discharged into the Chicamocha River on the upstream side from the intake. The cooling system confronts the following problems. To solve these problems and improve the cooling efficiency, a new cooling tower will be constructed and the cooling system for circulating the cooling water will be improved.

- Problems in the present cooling system

  1) A cooling pond with a wide area for natural cooling is required.

  2) The temperature increase that occurs while cooling water is drawn lowers the cooling efficiency.

  3) Because of natural cooling using the cooling pond, the cooling efficiency is influenced by weather conditions.

  4) Temperature rise in the cooling pond accelerates propagation of aquatic plants and aggravates water circulation. Bearing the cost of removing aquatic plants can not be ignored.

  There are various types of cooling tower. However, a mechanical-draft cooling tower was selected. Design conditions of circulation type cooling system using the mechanical draft cooling tower are as follows:

- The circulating cooling system's design condition

  - Cooling tower capacity

For the No. 1 unit	7,000 m^3/H
For the No. 2 unit	13,000 m^3/H
For the No. 3 unit	13,000 m^3/H

  - *Cooling tower temperature* — *Entrance of the cooling tower: 35°C*
    Exit of the cooling tower: 27°C

  - Ambient temperature (wet-bulb temperature) — 13°C

  - Cooling water boosting pump specification outline

	(capacity) x (lift)
For the No. 1 unit	7,000 m^3/H x 20 m
For the No. 2 unit	13,000 m^3/H x 20 m
For the No. 3 unit	13,000 m^3/H x 20 m

  - Chemical liquid pouring equipment will be installed in order to improve the water quality of the circulating cooling water.

- Estimated amount and construction period

Estimated amount (unit: US$$10^6$)

	Foreign currency portion	Local currency portion	Total
Equipment cost	8.76	-	8.76
Installation cost	-	4.94	4.94
Civil construction cost	-	1.17	1.17
Total	8.76	6.11	14.87

Construction period

Preparatory work	13 months
Machine/equipment manufacturing	10 months
Transportation	2 months
Installation and testing	9 months
Total	34 months*

* inclusive of seven-month civil construction period

- Economic indices

  Increase in generating cost 4.9 mills/kWh

- Items to be noted for implementation

Since the candidate site for cooling tower is close to the Chicamocha River, the soil survey shall be conducted to confirm the bearing capacity at the site.

Investigation shall be made to confirm the presence of underground pipes, cables, etc. If underground pipes, cables, etc. are present, the studies for reconstruction of existing facilities or design change in the newly constructed facilities shall be made.

3.3 Recommendations on Environmental Problems

Factors adversely affecting the environment, that Termopaipa power plant is confronted with, are soot and smoke caused by unequipped electrostatic precipitator, and flow-out of coal ash into the Chicamocha River. Since the latter one greatly affects cities located downstream, it is desirable to urgently work out countermeasures, including the execution of revetment work of the existing ash disposal site and the selection of new ash disposal site.

There is no sufficient space near the existing boiler for installing new electrostatic precipitator which prevents soot and smoke from No. 1 unit, the large-scale reconstruction work, e.g., the removal of the existing smokestack is necessary. Thus, this plan's feasibility is low.

The following general methods for prevention of flow-out of coal ash from the existing and the presently used ash disposal sites are considered.

(1) Walls for prevention of ash flow-out shall be erected on the both banks of the Chicamocha River.

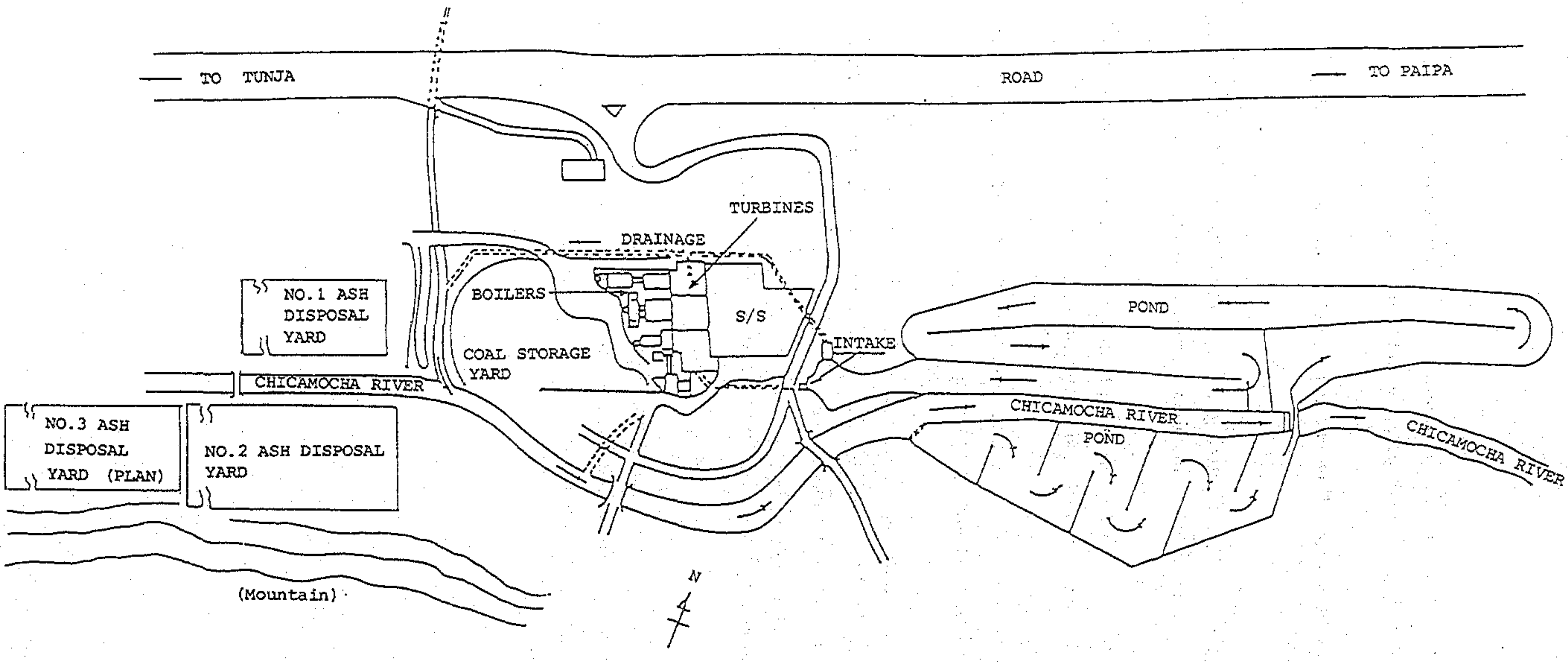
(2) Rainwater, after filtered at filtering and settling tanks installed at the ash disposal site, shall be discharge into the Chicamocha River.

(3) Channel for draining rainwater flowing from a mountain shall be constructed between No. 2 ash disposal site and the mountain.

(4) Coal ash shall be covered with soil or sand, and turf and trees shall be planted to prevent coal ash from splattering by wind.

On the other hand, the following are pointed out as environmental problems in the future. More specifically, as No. 1 unit (33,000 kW) has deteriorated, power demand in Boyaca Department has increased. For the future expansion, proper countermeasures, e.g., land acquisition of ash disposal site, environmental prevention of ash flow-out, environmental protection in the surrounding area shall be worked out.

Accordingly, the existing open cycle cooling water system (using the cooling pond) shall be reconstructed to a closed cycle cooling water (using the cooling tower). As a result, the freed area from the cooling pond occupying a wide area can be effectively used. (Refer to Fig. 2.)



SPACE OF ASH DISPOSAL YARD

NO.1 : 100m x 600m (full)

NO.2 : 300m x 1,500m (about 80% is ocupied)

NO.3 : (250m x 2,000m) (plan)

AREA OF POND = 580,000m^2 (Average depth:3m)

Fig.2 GENERAL LAYOUT IN TERMOPAIPA POWER PLANT

4. Optimum Rehabilitation Plan for Hydroelectric Power Plant

For 11 small-scale hydroelectric power plants that were nominated for the F/S of rehabilitation plan, P. Guillermo hydroelectric power plant in Boyaca Department is excluded from the object of selection, because the rehabilitation plan will be made if the reconstruction works of head tank and penstock are executed.

For 10 small-scale hydroelectric power plants that were nominated for the FS of rehabilitation plan, the outline of the plans which were evaluated as the optimum ones among the comparative alternatives (for each power plant), is shown in Table 3.

4.1 Evaluation by the Criterion

Construction cost per kW and generating cost per kWh greatly fluctuate in the optimum rehabilitation plans are shown in Table 3 for the remaining 10 power plants. To evaluate the superiority of the rehabilitation plans for these power plants, the following three standard values are applied.

Criterion ① : Recovered or increased output is more than 1,000 kW

Criterion ② : Construction cost per kW is less than US$2,000 kW

Criterion ③ : Generating cost per kWh is less than 30 mills/kWh

Evaluation for Generation Plan of Respective Power Plants

Power plant	Economic indices of generation plan					
	Output increase ΔP (kW)		Rehabilitation cost per ΔP (US$/kW)		Generating cost per ΔE (power increase) (mills/kWh)	
Caracoli	4,400	o	1,600	o	18	o
San Cancio	650	x	5,035	x	33	x
Intermedia	1,600	o	2,310	x	23	o
Municipal	3,100	o	1,350	o	15	o
Silvia	240	x	2,800	x	33	x
Ovejas	2,450	o	3,300	x	33	x
La Vuelta	7,200	o	2,800	x	32	x
Julio Bravo	3,500	o	1,220	o	15	o
Zaragoza	1,400	o	2,900	x	35	x
Lagunilla	5,000	o	1,400	o	16	o

Note: o = satisfies the value of selection criteria
x = does not satisfy the value of selection criteria

Table-3 General Statement of the Optimum Rehabilitation Plan for Hydroelectric Power Plants

Group	Power Plant	(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)	(29)	(30)	(31)
		Max. available discharge Qo (m³/s)	Net head Ho (m)	Rated output Po (kW)	(14) Output Pe (kW)	(15) Generated energy Ee (GWh)	Max. available discharge Q1 (m³/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)
1	Caracoli (ALT-1)	5.0	86.0	3,200	2,300	18.81	10.0	82.9	8,124	0.835	6,700	57.0	96	4,400	38.1
	Municipal (ALT-2)	5.6	79.6	2,112	1,400	5.94	7.0	79.6	5,460	0.835	4,500	34.8	88	3,100	28.9
	Julio Bravo (ALT-1)	2.0	120.0	1,500	0	0	3.0	143.0	4,204	0.835	3,500	29.4	97	3,500	29.4
	Lagunilla (ALT-3-1)	0.5	120.0	392	0	0	2.0	309.0	6,056	0.830	5,000	43.2	99	5,000	43.2
2	Intermedia	5.6	56.8	1,120	900	3.33	5.6	56.8	3,117	0.830	2,500	19.7	88	1,600	16.4
	San Cancio	5.6	53.8	2,320	1,750	8.44	5.6	53.8	2,952	0.830	2,400	18.5	88	650	10.1
	La Vuelta (ALT-2)	54.0	4.8	2,000	500	6.25	100.0	9.65	9,457	0.823	7,700	65.7	96	7,200	59.4
3	Silvia Total	1.5	31.0	604	100	0.82	1.1	31.0	334	0.740	240	2.1	98	240	2.1
	Silvia No.1 Unit	1.1		500	0	0									
	Ovejas (ALT-2)	7.0	24.5	900	650	2.97	15.0	26.0	3,822	0.830	3,100	26.2	94	2,450	23.2
	Zaragoza (ALT-1)	6.5	30.0	1,560	1,200	6.29	10.0	32.8	3,214	0.830	2,600	18.4	78	1,400	12.1

Group	Power Plant	(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)	
		(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 Clf	(42) Local currency portion Clℓ	(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
1	Caracoli (ALT-1)	2,900	1,200	4,100	2,900	7,000	1,600	1,050	26.8	305	329	634	661	12	18
	Municipal (ALT-2)	2,450	1,000	3,450	750	4,200	1,350	950	18.0	255	140	395	413	13	15
	Julio Bravo (ALT-1)	2,300	950	3,250	1.050	4,300	1,220	1,220	14.0	242	158	400	414	15	15
	Lagunilla (ALT-3-1)	3,800	1,500	5,300	1,600	6,900	1,400	1,400	20.0	401	252	653	673	16	16
2	Intermedia	1,900	750	2,650	1,050	3,700	2,310	1,500	10.0	197	145	342	352	19	23
	San Cancio	1,900	750	2,650	600	3,250	5,035	1,350	9.6	197	111	308	318	18	33
	La Vuelta (ALT-2)	7,400	2,950	10,350	9,770	20,120	2,800	2,600	30.8	772	1,026	1,798	1,829	29	32
3	Silvia No.1 Unit	458	184	642	34	676	2,800	2,800	1.0	48	18	66	67	33	33
	Ovejas (ALT-2)	2,650	1,050	3,700	4,300	8,000	3,300	2,600	12.4	277	433	710	722	29	33
	Zaragoza (ALT-1)	2,250	900	3,150	1,000	4,150	2,900	1,600	10.4	236	154	390	400	23	35

- Power Plants Whose Repairing Plans are Feasible (Group 1)

The following four power plants satisfy the standard values described above.

1) Caracoli Run-of-of-river Type Hydroelectric Power Plant
(Antioquia Dept. Owner: EADE, Rated output 3,200 kW)

Present output: 2,300 kW → Post-rehabilitation output: 6,700 kW

2) Municipal Run-of-river Type Hydroelectric Power Plant
(Caldas Dept. Owner: CHEC, Rated output: 2,112 kW)

Present output: 1,400 kW → Post-rehabilitation output: 4,500 kW

3) Julio Bravo Run-of-river Type Hydroelectric Power Plant
(Nariño Dept. Owner: CEDENAR, Rated output: 1,500 kW)

Present output: 0 kW → Post-rehabilitation output: 3,500 kW

4) Lagunilla Run-of-river Type Hydroelectric Power Plant
(Tolima Dept. Owner: ELECTROLIMA, Rated output: 392 kW)

Present output: 0 kW → Post-rehabilitation output: 5,000 kW

- Power Plants Required to Consider the Located Condition or Regional Characteristic (Group 2)

There are the following three power plants which do not satisfy all of the three standard values, but which are required to consider not only the economic indices of generation plan but also the located condition or regional characteristic.

1) Intermedia Run-of-river Type Hydroelectric Power Plant
(Caldas Dept. Owner: CHEC, Rated output: 1,120 kW)

Present output: 900 kW → Post-rehabilitation output: 2,500 kW

2) San Cancio Run-of-river Type Hydroelectric Power Plant
(Caldas Dept. Owner: CHEC, Rated output: 2,320 kW)

Present output: 1,750 kW → Post-rehabilitation output: 2,400 kW

3) La Vuelta Run-of-river Type Hydroelectric Power Plant
(Choco Dept. Owner: CHOCO, Rated output: 2,000 kW)

Present output: 500 kW → Post-rehabilitation output: 7,700 kW

- Intermedia and San Cancio Power Plants (Caldas Dept. Owner: CHEC) are nominated as Group 2 for the following reasons:

  A group of these three power plants are located along the Chinchina River; the tailrace for San Cancio P/P is connected to the intake for Intermedia P/P. Similarly, the tailrace for Intermedia P/P is connected to the intake for Municipal P/P. Accordingly, the planned available discharge at respective P/Ps is controlled by the maximum available discharge ($Q=5.6\ m^3/s$) at San Cancio P/P, located most upstream. Since there is no great difference in the standard net head for respective power plants, the coordination of the optimum machine types, the standardization of the administration, operation and maintenance, or the interchangeability of parts should be considered for the rehabilitation of these three power plants.

- La Vuelta Hydroelectric Power Plant (Choco Dept. Owner: Metales Preciosos del Choco) is nominated as Group 2 for the following reasons:

  There is a background that adoption of rehabilitation or improvement plan cannot be decided merely by economic indices of generation plan.

  Social, economical and other considerations, including ripple effects by the development of this area, are deemed to be requested.

In the rehabilitation plan of La Vuelta Hydroelectric Power Plant, the plan in which the Torincho type diversion weir will be reconstructed into a concrete dam, is selected.

The following basic data is insufficient.

- Geological survey data for dam foundation
- Geographical survey data of submerged extent
- Investigation data of compensation for submerged items, etc.

- Power Plants for which Rehabilitation is Infeasible (Group 3)

Rehabilitation of the following three power plants is infeasible.

1) Silvia Run-of-river Type Hydroelectric Power Plant
(Cauca Dept. Owner: CEDELCA, Rated output: 604 kW)

Present output: 100 kW → Post-rehabilitation output: 340 kW

2) Ovejas Run-of-river Type Hydroelectric Power Plant
(Cauca Dept. Owner: CEDELCA, Rated output: 900 kW)

Present output: 650 kW → Post-rehabilitation output: 3,100 kW

3) Zaragoza Run-of-river Type Hydroelectric Power Plant
(Santander Dept. Owner: ESSA, Rated output: 1,560 kW)

Present output: 1,200 kW → Post-rehabilitation output: 2,600 kW

4.2 Economic and Financial Analyses

A cost-benefit analysis is adopted to evaluate the profitability of the rehabilitation plans. Assumptions for this cost-benefit analysis are summarized below.

- Preconditions for Cost-benefit Analysis

  1) Adoption of incremental cost-benefit analysis

     The difference between the revenue after the existing facilities are rehabilitated and the revenue when the existing facilities are not rehabilitated is regarded as the profitability of the investment.

     If the existing facilities are not changed, the residual life of the existing power plant is estimated to be five years after the installation of new equipment. (Refer to Fig. 3.)

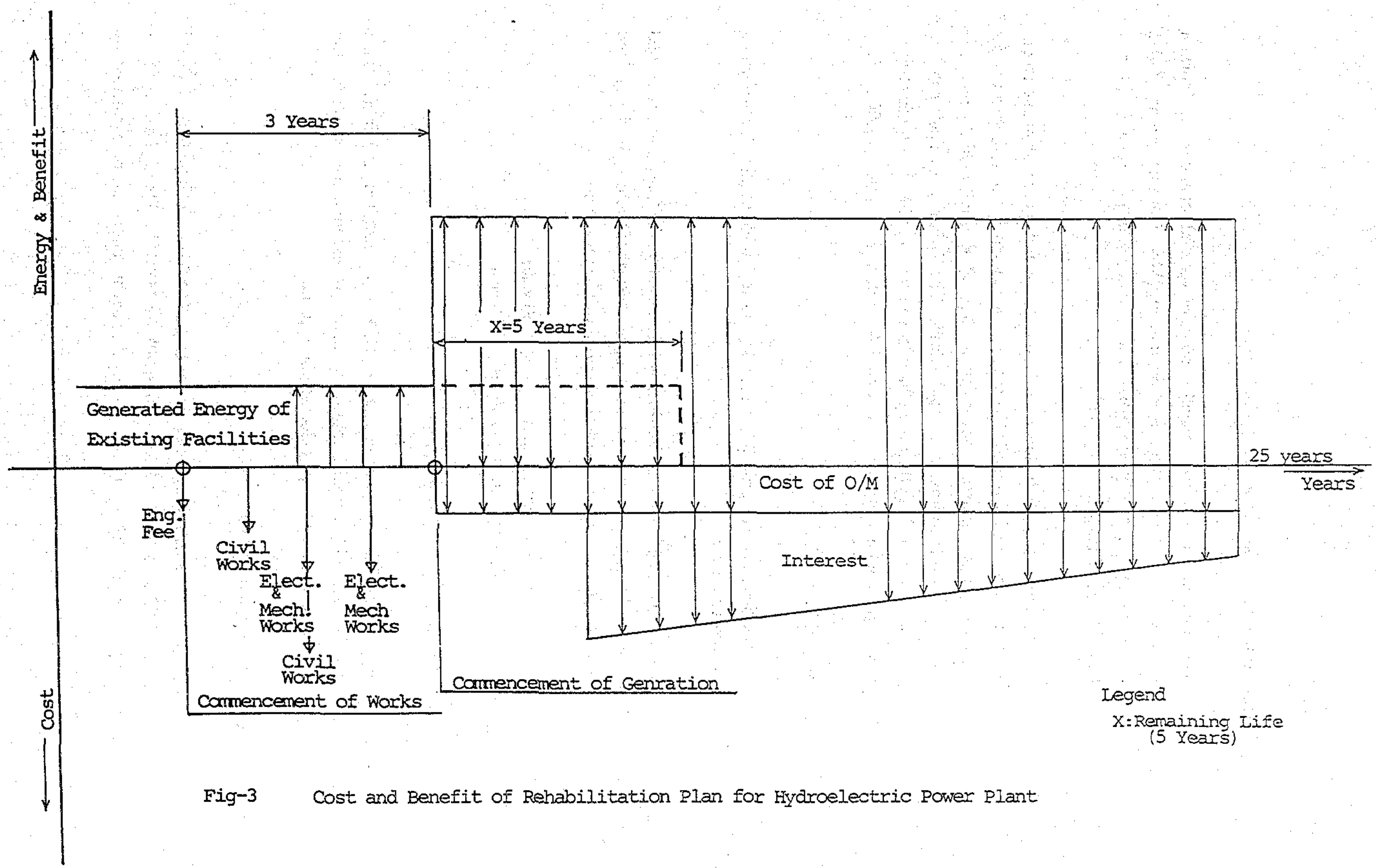


Fig-3 Cost and Benefit of Rehabilitation Plan for Hydroelectric Power Plant

(2) Estimation of construction cost

The construction cost is estimated in both foreign and local currency portion according to the market price as of September, 1989. Currency exchange rate between foreign currency (US$) and local currency (Col.$) is set at US$1.00 = Col.$369.4, as determined by DNP.

The construction cost includes the contingency and technical management expense. The land acquisition cost is not accounted because the plan is for rehabilitating the existing power plant. The FOB price of the generating facilities is taken from Japanese market price. The CIF price is calculated in the ratio of CIF price to FOB price which ISA usually applies to a hydroelectric power generation project. The ratio of CIF price to FOB price is 1.00 : 1.12.

(3) Service life

The service life of the project is set to 25 years after rehabilitation for evaluating the profitability.

The annual depreciation of facilities will be based on the fixed amount method adopted by ICEL. The service life, as described below, is determined according to the facility. The residual price will be set at zero.

1) Service life of civil structure : 50 years
2) Service life of generating facilities : 25 years

(4) Operation and maintenance costs

This study adopts the average cost, i.e., US$4.0 per installed capacity (kW) per year, which ISA usually applies to make an estimate of operation and maintenance costs of a hydroelectric power plant.

(5) Estimation of revenue

ICEL's electricity selling unit price of US$13.36/MWh (Col.$4,936.18/MWh) and US$2,942.36/MW (Col.$1,086,909.69/MW) in December, 1988 is adopted as the financial unit price. Annual revenue can be estimated by multiplying the rated capacity with the annual supplied power at the generating terminal.

(6) Conditions for borrowing capital on investment

The loan conditions for borrowing capital in foreign and local currency are as follows:

1) Loan conditions of foreign currency

- Annual interest : 10%
- Period for principal repayment : 25 years (including a 4-year grace period)
- Terms of payment : Repayment of the principle in equal, annual amounts

2) Loan conditions of local currency

- Annual interest : 21%
- Period for principal repayment : 8 years (including a 1-year grace period)
- Terms of payment : Repayment of the principal in equal, annual amounts

(7) Discount rate

The discount rate which is used to calculate the net present value (NPV) and the cost-benefit ratio (C/B Ratio) is set to 7.6% per year. It is determined by the real interest rate in Colombia.

4.2.1 Cost-Benefit Analysis for Hydroelectric Power Plants in Group-1

The results of the cost-benefit analysis for hydroelectric power plants having a high possibility of implementation that were assigned to Group-1, are shown below.

Evaluation Index of Rehabilitation Plan of
Hydroelectric Power Plants in Group-1

Power Plant	Evaluation Index of Generation Plan			Cost-Benefit Analysis		
	Incremental Output ΔP (kW)	Construction Cost per ΔP (US$/kW)	Generating cost per Energy Increment ΔE (mill/kWh)	C/B	NPV (US$1,000)	FIRR (%)
Caracoli	4,400	1,600	18	0.99	53	7.7
Municipal	3,100	1,350	15	0.86	366	9.2
Julio Bravo	3,500	1,220	15	0.96	100	8.1
Lagunilla	5,000	1,400	16	1.06	-202	7.0

4.2.2 Cost-Benefit Analysis for Hydroelectric Power Plants in Group-2.

San Cancio, Intermedia and Municipal power plants in Caldas Department are grouped into one rehabilitation plan because they are all located at the Chinchina River and owned by CHEC. The result of the cost-benefit analysis for this rehabilitation plan is shown below.

Evaluation Index of Rehabilitation Plan for Hydroelectric Power Plants Located at Chinchina River

Power Plant Package*	Evaluation Index of Generation Plan			Cost-Benefit Analysis		
	Incremental Output ΔP (kW)	Construction Cost per ΔP (US$/kW)	Generating cost per Energy Increment ΔE (mill/kWh)	C/B	NPV (US$1,000)	FIRR (%)
Package ①	4,700	1,680	18	1.01	-177	7.5
Package ②	5,350	2,100	21	1.07	-384	6.8

*Package ①: Combination of Municipal and Intermedia
Package ②: Combination of Municipal, Intermedia and San Cancio

The results of the cost-benefit analysis for La Vuelta Hydroelectric Power Plant, owned by Metales Preciosos del Choco in Choco Department listed in Group-2 are as follows.

Evaluation Index of Rehabilitation Plan for La Vuelta Hydroelectric Power Plant

Power Plant	Evaluation Index of Generation Plan			Cost-Benefit Analysis		
	Incremental Output ΔP (kW)	Construction Cost per ΔP (US$/kW)	Generating cost per Energy Increment ΔE (mill/kWh)	C/B	NPV (US$1,000)	FIRR (%)
La Vuelta	7,200	2,800	32	2.29	-6,398	0.5

4.2.3 Cost-Benefit Analysis for Hydroelectric Power Plants in Group-3

The results of the cost-benefit analysis of rehabilitation plan for Silvia and Ovejas hydroelectric power plants owned by CEDELCA in Cauca Department and Zaragoza Hydroelectric Power Plant owned by ESSA in Santander Department show a very low profitability and low possibility of materialization. The evaluation index of generation plan for each hydroelectric power plant, measured by the construction cost per kW and generating cost per KWh, and the results of the cost-benefit analysis are shown below.

Evaluation of Rehabilitation Plan for
Hydroelectric Power Plants

Group	Rehabilitation Plans	Economic Index of Generation Plan			Cost-benefit Analysis			
		Incremental output ΔP (kW)	Construction cost per ΔP (US$/kW)	Generating cost per energy incremental ΔE (mills/kWh)	C/B	NPV (US$1,000)	FIRR (%)	EIRR (%)
Group-1	Caracoli ALT-1	4,400	1,600	18	0.99	53	7.7	11.2
	Municipal ALT-2	3,100	1,350	15	0.86	366	9.2	11.5
	Julio Bravo ALT-1	3,500	1,220	15	0.96	100	8.1	10.5
	Lagunilla ALT-3-1	5,000	1,400	16	1.06	-202	7.0	10.4
Group-2	Intermedia	1,600	2,310	23	1.37	-538	4.6	5.8
	San Cancio	650	5,035	33	1.40	-491	4.6	6.9
	La Vuelta ALT-2	7,200	2,800	32	2.29	-6,398	0.5	2.4
Group-3	Silvia REH	240	2,800	33	2.02	-173	1.1	3.4
	Ovejas ALT-2	2,450	3,300	33	2.63	-3,226	-0.4	1.5
	Zaragoza ALT-1	1,400	2,900	35	1.74	-936	2.7	5.0

4.3 Rehabilitation Plan of Hydroelectric Generating Equipment

The JICA Study Team recommended the following four power plants as possible candidates for rehabilitation, after hearings with the electric power companies and evaluation of the respective hydroelectric power plants, as described in Section 4.2.

1) Municipal run-of-river type hydroelectric power plant
   Owner: CHEC

   Present rated output: 2,112 kW → Post-rehabilitation output: 4,500 kW

2) Intermedia run-of-river type hydroelectric power plant
   Owner: CHEC

   Present rated output: 1,120 kW → Post-rehabilitation output: 2,500 kW

3) San Cancio run-of-river type hydroelectric power plant
   Owner: CHEC

   Present rated output: 2,320 kW → Post-rehabilitation output: 2,400 kW

4) Julio Bravo run-of-river type hydroelectric power plant
   Owner: CEDENAR

   Present rated output: 1,500 kW → Post-rehabilitation output: 3,500 kW

4.3.1 Municipal, Intermedia and San Cancio Hydroelectric Power Plants

San Cancio, Municipal and Intermedia power plants, owned by CHEC, are located along the Chinchina River in Caldas Department. Compared individually, the rehabilitation plan for Municipal Power Plant is deemed best. However, these three power plants should be grouped into one generation plan with rehabilitation made in the order of Municipal, Intermedia and San Cancio power plants.

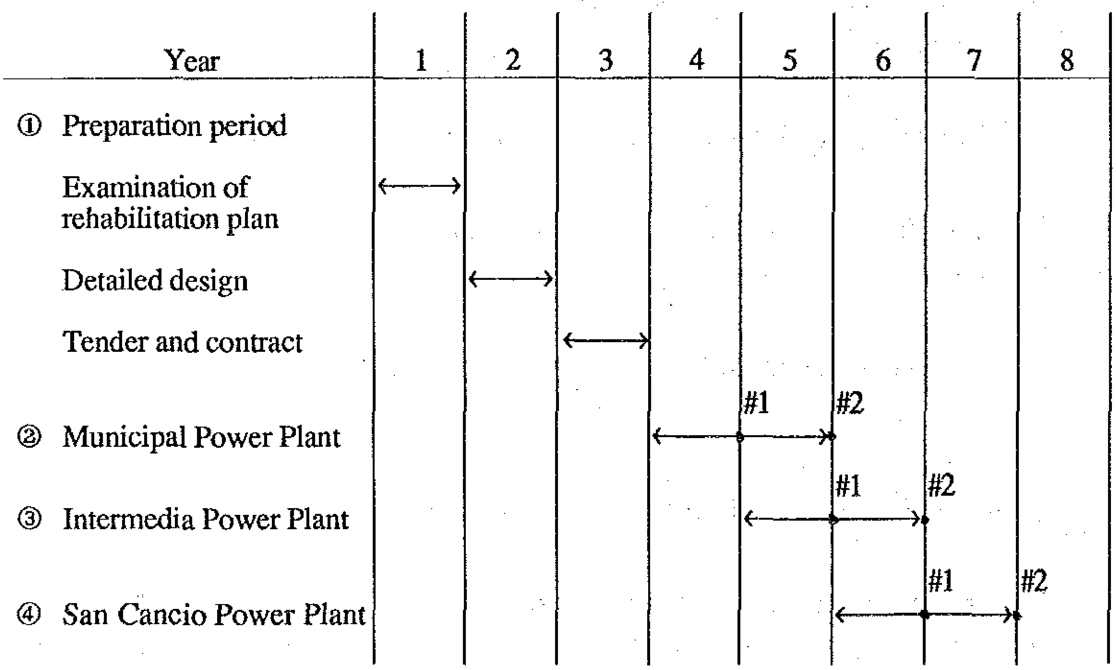
- Plan for rehabilitation work
  The cost for rehabilitation work is estimated at US$11,150,000 (foreign currency apportionment: US$6,250,000; local currency apportionment: US$4,900,000)

according to September, 1989 market price. The ration of foreign currency to local currency is 0.56 : 0.44.

(unit: US$$10^3$)

Power Plant	Foreign currency apportionment	Local currency apportionment	Total
Municipal	2,450	1,750	4,200
Intermedia	1,900	1,800	3,700
San Cancio	1,900	1,350	3,250
Total	6,250	4,900	11,150

If the rehabilitation work is executed in the order of Municipal, Intermedia and San Cancio power plants, the construction is estimated to take 48 months.



- The economic index of these three power plants grouped into one rehabilitation plan is as follows.

Increased output ΔP (kW):	5,350
Annual potential power generation increment ΔE (MWh):	55,400
Construction cost per ΔP (US$/kW):	2,100

Generating cost per ΔE (mills/kWh):	21
C/B ratio:	1.07
Net present value (NPV) (US$$10^3$):	- 384
Internal rate of return (IRR) (%):	6.8

Items to be recorded for implementation

The ICEL group should record data on the following items at an early date for implementing the rehabilitation of the three power plants.

① Discharge capacity of the existing conduction channel
② Discharge at the remaining waterbasin at the intake site of Municipal power plant
③ Water quality of the Chinchina River

4.3.2 Julio Bravo Hydroelectric Power Plant

Data for some items is needed for the implementing the rehabilitation of Julio Bravo power plant, which has a high possibility of implementation.

- Plan for rehabilitation work
  The cost for rehabilitation work is estimated at US$4,300,000 according to September, 1989 market price. The ration of foreign currency to local currency is 0.54 : 0.46.

(unit: US$$10^3$)

Power Plant	Foreign currency apportionment	Local currency apportionment	Total
Julio Bravo	2,300	2,000	4,300

The rehabilitation work period is estimated at 36 months, and preparation period at 48 months.

Year	1	2	3	4	5	6	7	8
Preparation period								
Examination of rehabilitation plan	←→							
Detailed design		←—	—→					
Tender and contract				←→				
Civil construction					←—	—→		
Equipment manufacturing					←—	—→		
Equipment installation						←—	#1 —→	#2

- Economic index of this rehabilitation plan is as follows.

Increased output ΔP (kW):	3,500
Annual potential power generation increment ΔE (MWh):	29,400
Construction cost per ΔP (US$/kW):	1,220
Generating cost per ΔE (mills/kWh):	15
C/B ratio:	0.96
Net present value (NPV) (US$$10^3$):	100
Internal rate of return (IRR) (%):	8.1

Items to be recorded for implementation

The ICEL group should record data on the following two items at an early date for implementing the rehabilitation of Julio Bravo power plants.

① Hydrological regime at the existing diversion weir
② Year-to-year transition of water quality at the intake site

4.3.3 Power plants excluded from consideration

Caracoli Power Plant in Antioquia Department (owned by EADE), and Lagunilla Power Plant in Tolima Department (owned by ELECTROLIMA) were excluded from consideration since work cannot commence at an early date.

- Caracoli Power Plant
  The reconstruction plan for doubling the available discharge is considered more advantageous than the rehabilitation plan. The inspection for worn pipes and the identification of residual life must precede the execution of either plan. For the reconstruction plan, the existing penstock (diameter: 1,350 mm, length: 1,300 m) needs to be replaced, even though it appears to be well maintained.

- Lagunilla Power Plant
  The hydrological gauging station which was located at Lagunilla River was washed away during the volcanic eruption of Nevado del Ruiz in November, 1985. However, debris flow has changed the hydrological regime at the river basin, so a two-year record of discharge data recorded at Lagunilla River is needed.

4.4 Recommendations on Rehabilitation of Small-scale Hydroelectric Power Plants

Sixty-two small-scale hydroelectric power plants were nominated by ICEL for pre-F/S in November, 1987. This F/S concluded that the four power plants described in Section 4.3 have the highest probability of implementation, from the present total output of 8,850 kW to a post-rehabilitation output of 12,900 kW. These results are within the study scope limits of the rehabilitation of the existing generating facilities of this S/W. However, an examination of the other power plants outside of the study scope limits suggests that other measures can be implemented for improvement, as suggested by the following examples.

1) Investigate the water utilization coefficient at power plants with low hydroelectric power
   Inza Hydroelectric Power Plant (Cauca Department)
   Rio Recio Hydroelectric Power Plant (Tolima Department)

2) Power plants located along the same river should be developed as a group
Bayona, Campestre and La Union hydroelectric power plants, along the Quindio River in Quindio Department

3) Existing diesel power plants to be substituted with hydroelectric power plants
Rio Napia Hydroelectric Power Plant (Cauca Department)

CHAPTER 1 CONTENTS OF THE REPORT

This report summarizes the results of the Feasibility Study (hereinafter referred to as the F/S) for the rehabilitation plan of 12 power plants (thermal: 1, hydroelectric: 11), which have been selected from 82 small-scale power plants (thermal: 3, hydroelectric: 62, diesel: 17) managed by 13 public electric power companies under the Instituto Colombiano de Energia Electrica (ICEL).

The F/S was performed in accordance with the Scope of Work (S/W) which was agreed and signed in July 1988 between the Japan International Cooperation Agency (JICA) and ICEL.

The names and locations of the power plants selected for the F/S are as follows:

Termopaipa Thermal Power Plant .... Boyaca Department
Puente Guillermo Run-of-River Type Hydroelectric Power Plant .... Boyaca Department
Caracoli Run-of-River Type Hydroelectric Power Plant .... Antioquia Department
San Cancio Run-of-River Type Hydroelectric Power Plant ..... Caldas Department
Intermedia Run-of-River Type Hydroelectric Power Plant ...... Caldas Department
Municipal Run-of-River Type Hydroelectric Power Plant ...... Caldas Department
Silvia Run-of-River Type Hydroelectric Power Plant .... Cauca Department
Ovejas Run-of-River Type Hydroelectric Power Plant .... Cauca Department
La Vuelta Run-of-River Type Hydroelectric Power Plant .... Choco Department
Julio Bravo Run-of-River Type Hydroelectric Power Plant .... Nariño Department
Zaragoza Run-of-River Type Hydroelectric Power Plant .... Santander Department
Lagunilla Run-of-River Type Hydroelectric Power Plant .... Tolima Department

The detailed study results of the respective 12 power plants are enclosed in separate volumes (refer to Appendix-1) of this report.

In the case of the Puente Guillermo Hydroelectric Power Plant in Boyaca Department, the rehabilitation plan is fulfilled by implementing the penstock reconstruction work.

The rehabilitation plan of the remaining 10 hydroelectric power plants is divided into the following three groups according to selection criteria established during the pre-F/S (from November 1987 to June 1988):

- a promising feasible group
- relatively infeasible group
- an intermediate group considering site locations and local conditions

The rehabilitation plan was prepared in accordance with power development standard (Plan de expansion en generacion published in June 1987 by Interconexion Electrica S.A. (ISA). However, since the above standard was established for development plan of large-scale hydroelectric power plants, it was not completely applied to the rehabilitation plan.

CHAPTER 2 STUDY PLAN

The ICEL requested the government of Japan in February 1987 to execute a study for a rehabilitation plan for the 82 small-scale power plants (thermal: 3, hydroelectric: 62, diesel: 17) owned by 15 public electric power companies under the ICEL, for the purpose of utilizing them more effectively.

The above 82 power plants are distributed extensively in 13 departments and 1 direct control district all over the country, as described in Appendix-2, attached to this report. JICA decided to execute this F/S in two stages of Pre-feasibility study (pre-F/S) and F/S. JICA conducted the pre-F/S in 8 months between November 1987 and June 1988, in order to grasp the current situation of these power plants, as well as select the power plants which have relatively high potential for realizing efficient rehabilitation.

The F/S was executed by JICA during 17 months between November 1988 and March 1990, based on the pre-F/S study results, on the 12 power plants (thermal: 1, hydroelectric: 11) which have been selected by JICA and ICEL, in order to formulate the optimum rehabilitation plan. Study Plan for the F/S is described hereafter.

2.1 Locations of Study Area

As described earlier, this F/S includes only 1 thermal power plant at Termopaipa. All other 11 power plants are run-of-river hydroelectric power plants.

As shown in the following table, those power plants are distributed over eight departments of Antioquia, Boyaca, Caldas, Cauca, Choco, Nariño, Santander, and Tolima.

Distribution of the Study Locations

Department	Power Plant		Total
	Thermal	Hydroelectric	
Antioquia	0	1	1
Boyaca	1	1	2
Caldas	0	3	3
Cauca	0	2	2
Choco	0	1	1
Nariño	0	1	1
Santander	0	1	1
Tolima	0	1	1
Total	1	11	12

(1) Termopaipa Power Plat Rehabilitation Plan

The F/S covered three rehabilitation items, two of which are for the No. 2 unit as follows.

1) Increase of the turbine output of the No. 2 unit (66-74 MW)

2) Changing the No. 2 unit's air type instrumentation system to the electric type instrumentation system

3) Change to the closed cycle system of cooling water system by installing a new cooling tower.

(2) Hydroelectric Power Plants Rehabilitation Plan

Table 2.1, describes the current status of the names and locations of the 11 run-of-river hydroelectric power plants, which were selected of the F/S. The total installed power generation capacity of these 11 power plants is 16,988 kW, while their total available output is 8,000 kW, indicating approximately 50% output reduction.

Table 2.1 Present Status of Run-of-River Type Hydroelectric Power Plants Selected for Rehabilitation Plan

JICA Dode No.	Power Plant	Electric Power Company	Dept.	Available Discharge Q (m^3/s)	Head H (m)	Rated Output		Present Operating Status			Remarks
						Type* x No.	Po (kW)	Service Year**	Available Output Pe (kW)	Pe/Po (%)	
201	Caracoli	EADE	Antioquia	5.0	86.0	Px1 Fx1	1,600 1,600	55 27	1,150 1,150	72 72	
210	P. Guillermo	EBSA	Boyaca	2.6	58.0	Fx2	640 640	30 40	0 0	0 0	Not operated since 1984 because of damage to penstocks
211	San Cancio	CHEC	Caldas	5.6	59.8	Fx1 Px1	1,350 970	43 61	1,000 750	74 77	Large variance between the rated output and theoretical one
212	Intermedia	CHEC	Caldas	5.6	59.0	Px1	1,120	43	900	80	
213	Municipal	CHEC	Caldas	5.6	80.6	Px2	1,056x2	45	700x2	66	
227	Silvia	CEDELCA	Cauca	1.5	31.0	Fx1 Fx1	500 104	36 30	0 100	0 96	Not operated since1972 because of breakdown
228	Ovejas	CEDELCA	Cauca	7.0	24.5	Fx1	900	51	650	72	
233	La Vuelta	E. CHOCO	Choco	54.0	4.8	Fx1 Fx1	1,000 1,000	75 60	300 200	30 20	
248	Julio Bravo	CEDENAR	Nariño	2.0	120.0	Px3	500x3	48	0	0	Not operated since 1983 because of damage to penstocks
250	Zaragoza	ESSA	Santander	6.5	30.0	Fx1 Fx1 Fx1	520 520 520	40 58 53	400 400 400	77 77 77	
261	Lagunilla	ELECTROLIMA	Tolima	0.5	120.0	Px1 Px1	240 152	50 50	0 0	0 0	Not operated since 1972 because of equipment failure

Note: * P : Pelton Type F : Francis Type
** Service year is computed starting from the year in which generating equipment was manufactured.

2.2 Organization of the Study Team

2.2.1 JICA F/S Study Team

JICA F/S Study Team is composed of the same team leader and team members who participated in the Pre-F/S, in addition to experts such as hydroelectric power generation planners (civil engineer), a hydroelectric generation equipment planner (mechanical engineer), a hydrologist, geologists and an economist as listed below.

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

2.2.2 The Organization of the ICEL Counterpart

The following are the engineers appointed by ICEL as counterparts of the JICA F/S Team and their area of work:

Name	Field	Position
Juvenal Peñaloza Rosas	Civil Engineering	Head of Central Eng. Div.
Jairo E. Gonzalez Morales	Civil Engineering	Central Engineering Div.
Rafael Torres Mariño	Civil Engineering	Central Engineering Div.
Mario Gutierrez Ospina	Civil Engineering	Central Engineering Div.
Rafael Gomez Florez	Civil Engineering	Central Engineering Div.
Jorge E. Hurtado Muñoz	Civil Engineering	Central Engineering Div.
Augusto Sanabria Diaz	Mechanical Engineering	Central Engineering Div.
Luis E. Becerra P.	Mechanical Engineering	Central Engineering Div.
Ramiro Velasco	Electrical Engineering	Central Engineering Div.

2.2.3 Supporting Technical Staff of the Respective Public Electric Power Corporation

The JICA F/S Team obtained the cooperation and support of the technical staff of the following public electric power corporations when executing the field work and the data collection at the sites of the power plants which are being evaluated for the rehabilitation.

Corporation	Name	Position
EADE	Humberto Alonso Cadavid A.	Manager of Planning Department
	David Aguilar	Manager of Substation and Plants
	Walter Leon Ospina Ortiz	Planning Engineer
EBSA	Edgar Olante Reyes	President
	Francisco Duque	Vice President
	Enoc Guerrero	Chief of Planning Dept.
	Hector Pulido	Chief of Termopaipa
	Jorge Hernan Ramirez S.	Chief of Service Engineer
	Pedro Lesmes	Service Engineer
	Avelino Cely	Service Engineer
	Fernando Cruz F.	Chief of Electrical Engineer
	Jose de Los Santos Cardenas	Electrical Engineer
	Alvaro Delgado O.	Production Engineer

(continued)

Corporation	Name	Position
EBSA	Fabio Abril G.	Mechanical Engineer
	Reinaldo Avelia	Operation Engineer
	Falaviano A. Gonzalez	Civil Engineer
CHEC	Alberto Naranjo A.	Director of MIEL Project
	Hernando Duque Vargas	Manager of Small Plants
	Jorge H. Garcia C.	Member of MIEL Project
	Claudia M. Agudelo	Member of MIEL Project
E. Choco	Juan B. Hinestroza C.	President
	Jose Wilson Guerrero	Chief of Planning Office
	Jose Antonio Correra H.	Engineer
	Luz Elba Gonzalez	Engineer
	Juan Ramon Gilabert	Chief of La Vuelta Power Plant
	Carlos Osorio Monila	Manager of "Metales Preciosos del Choco"
CEDELCA	Fernando Iragorri Cajiao	President
	Jose Morales M.	Vice President
	Larry Guzman M.	Civil Engineer
CEDENAR	Hernando Carreño Pilonieta	President
	Enrique Moreno B.	Vice President
	Diego Delgado Ruiz	Director of Power Generation/Transmission Program
	Juan Carlos Salazar	Civil Engineer
	Alavaro E. Martinez	Civil Engineer
ESSA	Hernan Uribe Niño	President
	Ruben Gelves Diaz	Vice President
ELECTROLIMA	Ivan Nicholls N.	President
	Hugo Neira S.	Chief of Planning Division
	Francisco Corrales	Chief of Small Power Plants

2.3 Study Items

The following are the items which were covered by the F/S and defined in the Scope of work agreed and signed between JICA and ICEL in July 1988.

(1) Review of the existing data

(2) Site reconnaissance

(3) Field work
  1) Topographic survey
  2) Photogrammetric mapping (when necessary)
  3) Geological investigation
  4) Hydrometeorological study
  5) Data collection for the above studies and site confirmation

(4) Power survey (power demand forecast and analysis and discussion of the supply plan)

(5) Discussion of the alternative rehabilitation plan proposals and selection of the optimum rehabilitation plan

(6) Designing the feasibility grade

(7) Stability analysis of the main facility

(8) Implementation plan

(9) Construction costs for rehabilitation plan

(10) Economic and financial analyses

(11) Compilation of the maintenance and management manual

2.4 Study Work Flow and Implementation Plan

Fig. 2.1 indicates the contents of the F/S, work flow and study processes.

As Table 2.2 shows, the site work and work performed in Japan were implemented separately during the 17 month period between November 1988, the start of the site reconnaissance, and March 1990, the time of submitting the final report.

Table 2-1 Flow chart of Entire Study Process

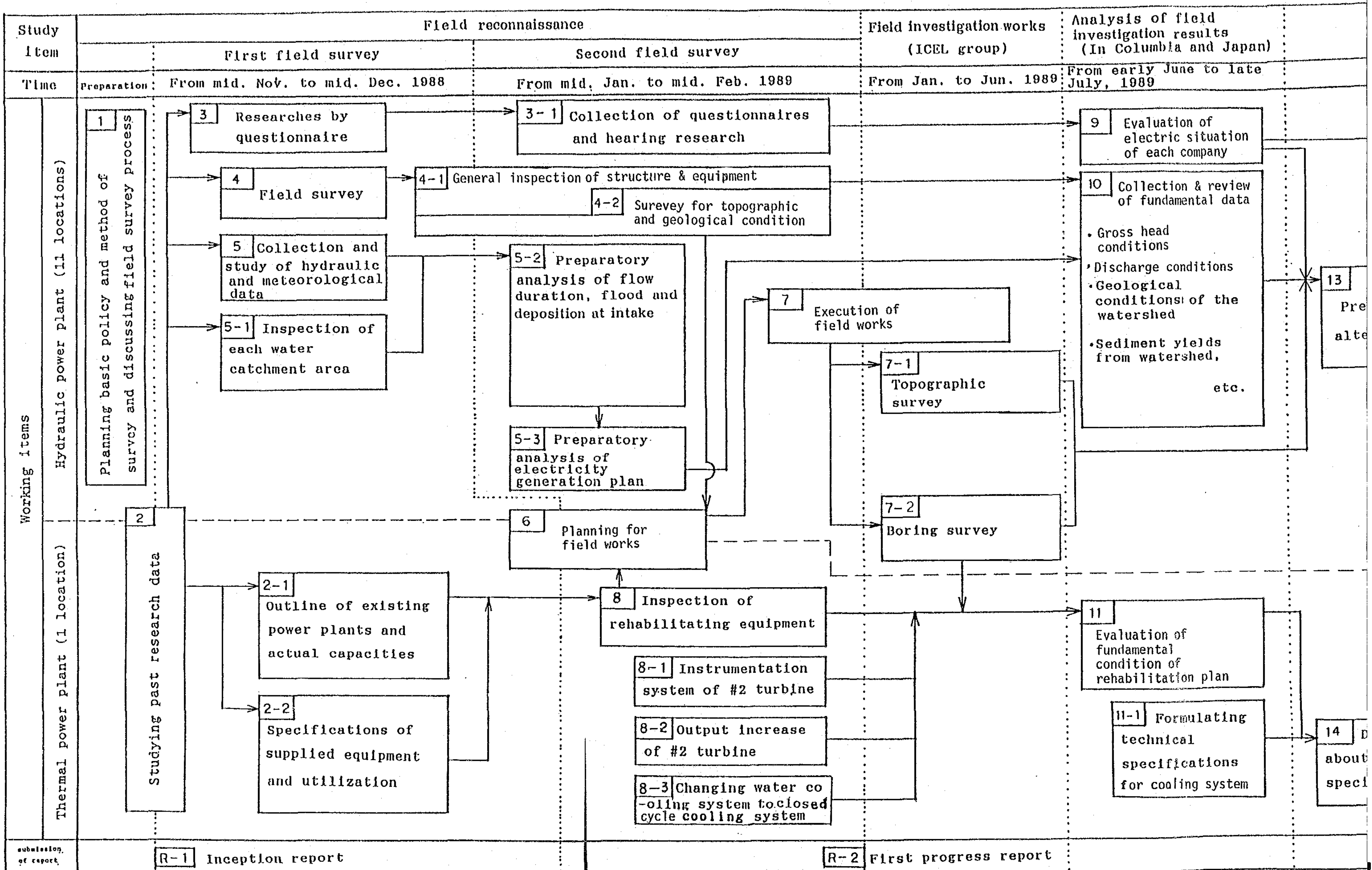
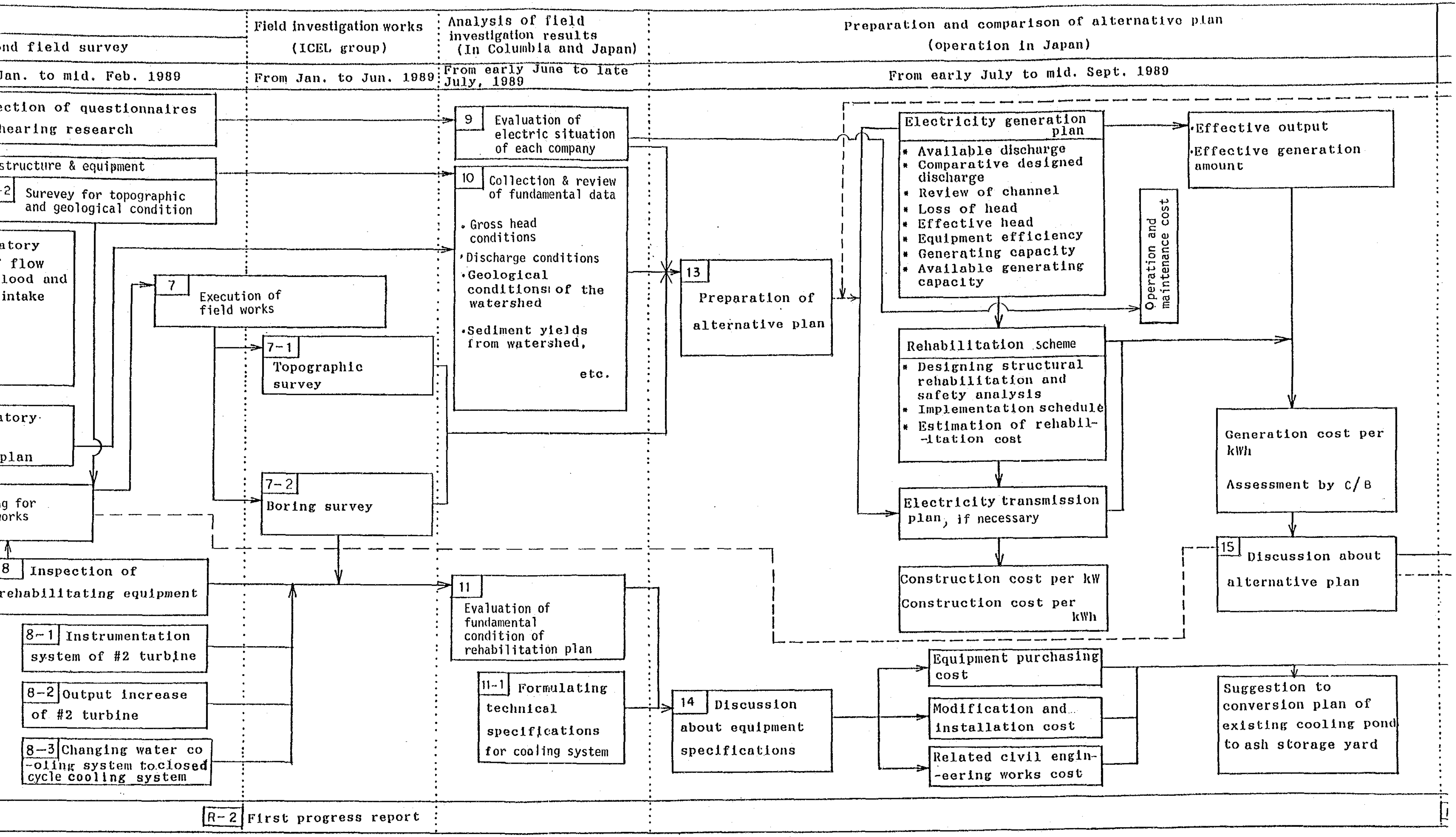
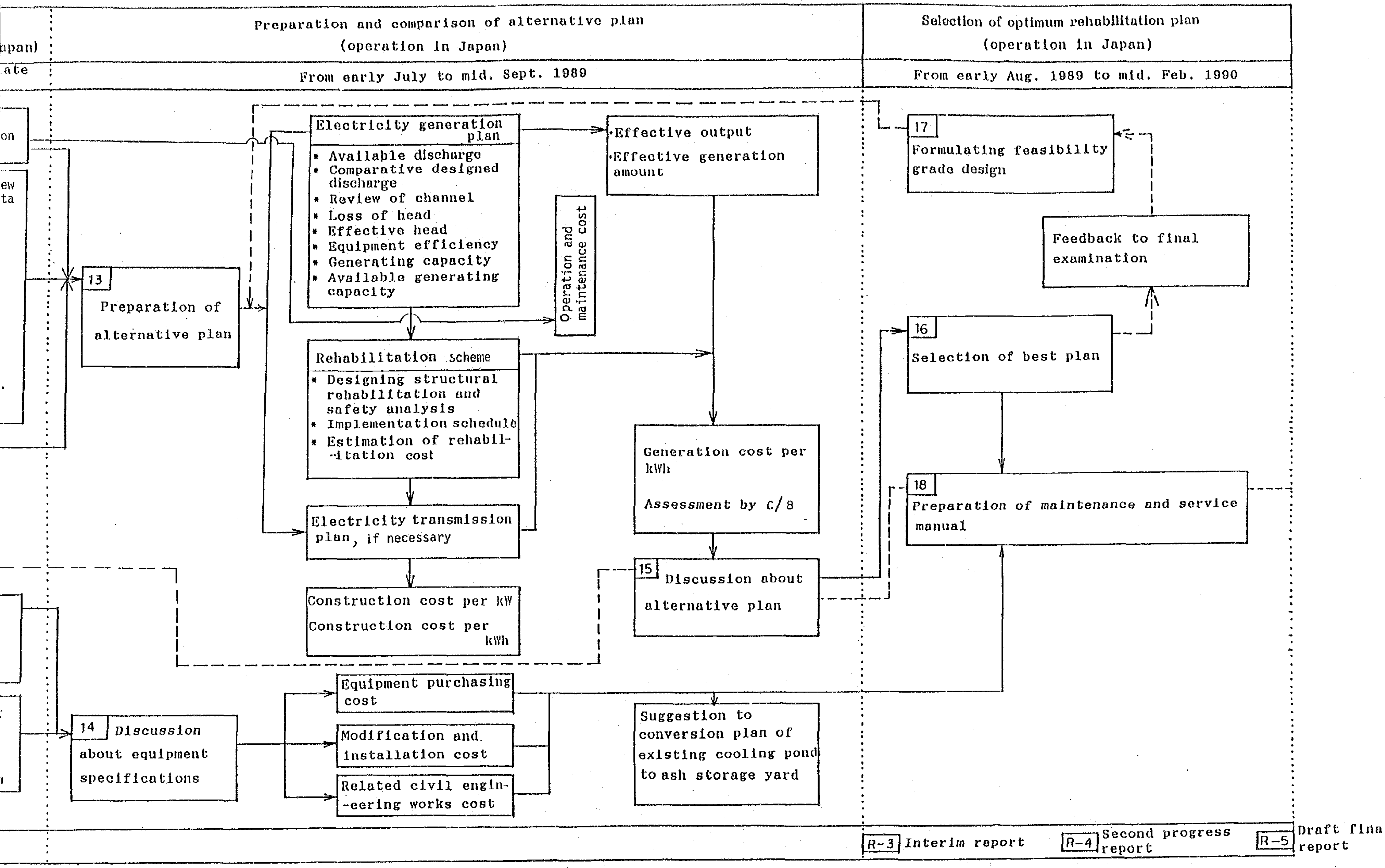


Table 2-1 Flow chart of Entire Study Process





apan)
ate
Preparation and comparison of alternative plan
(operation in Japan)
From early July to mid. Sept. 1989
Selection of optimum rehabilitation plan
(operation in Japan)
From early Aug. 1989 to mid. Feb. 1990
on
ew
ta
13 Preparation of alternative plan
Electricity generation plan
* Available discharge
* Comparative designed discharge
* Review of channel
* Loss of head
* Effective head
* Equipment efficiency
* Generating capacity
* Available generating capacity
Operation and maintenance cost
·Effective output
·Effective generation amount
Rehabilitation scheme
* Designing structural rehabilitation and safety analysis
* Implementation schedule
* Estimation of rehabilitation cost
Electricity transmission plan, if necessary
Construction cost per kW
Construction cost per kWh
Generation cost per kWh
Assessment by C/B
15 Discussion about alternative plan
14 Discussion about equipment specifications
Equipment purchasing cost
Modification and installation cost
Related civil engineering works cost
Suggestion to conversion plan of existing cooling pond to ash storage yard
17 Formulating feasibility grade design
Feedback to final examination
16 Selection of best plan
18 Preparation of maintenance and service manual
R-3 Interim report
R-4 Second progress report
R-5 Draft final report

Table 2.2 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

CHAPTER 3 POWER CONDITIONS IN ICEL GROUP

ICEL group consists of ICEL itself as well as public electric power companies existing in the following 14 departments and 1 direct control district.

The positioning of the ICEL group in power sector of Colombia is shown in Appendix-3.

Table 3.1 Departments where Public Electric Power Companies of ICEL Group are located

No.	Abbreviation of Electric Power Companies	Department	Remarks
1	EADE	Antioquia	except EPM
2	EBSA	Boyaca	
3	CHEC	Caldas	
4	E. Caqueta	Caqueta	
5	CEDELCA	Cauca	
6	CELGAC	Cundinamarca	except EEB
7	E. Choco	Choco	
8	E. Huila	Huila	
9	EMSA	Meta	
10	CEDENAR	Nariño	
11	CENS	Norte de Santander	
12	EDEQ	Quindio	
13	ESSA	Santander	
14	ELECTROLIMA	Tolima	
15	EEASA	Comisario del Amazonas	

The electric demand can be grasped through the two main factors of 'electric energy' and 'peak demand'. For the ICEL group the average annual increase rate in electric energy was 6.2% during 10 years from 1980 to 1989. This figure exceeds the average annual increase in the whole Colombia.

For the ICEL group the electric energy was 6,277 GWh and for the whole Colombia it was 32,386 GWh in 1989.

The peak demand in 1989 was 1,185 MW, while the installed capacity of the generating facilities owned by the ICEL group was 1,884 MW. On that total the installed capacity of ICEL itself was 852 MW (45%).

It is supplied by ICEL's isolated power sources to meet demand in 1989, and a deficiency is covered by electricity bought from the country-wide network. The whole area of Colombia has sufficient installed capacities to cover the country's demand.

Among the generating facilities belonging to ICEL group, a number of isolated power sources (diesel and hydroelectric) with small capacity and not connected to the national grid, have been found. The large majority of isolated power sources are maintained and operated by a self-governing body. Power demand in the whole area of Colombia and ICEL group is shown in Table 3.2.

Table 3.2 Energy demand, Whole Colombia and ICEL Group

Whole Colombia			ICEL Group				
Year	Demand		Demand		Installed Capacity (MW)		
	(GWh)	(MW)	(GWh)	(MW)	Proper	ISA**	Total
1980	19,481	3,568	3,650	698	577	99	676
1981	19,519	3,404	3,677	657	577	136	713
1982	21,549	3,855	4,125	757	672	279	951
1983	23,073	4,040	4,313	830	702	279	981
1984	24,588	4,230	4,651	861	702	440	1,142
1985	25,739	4,436	5,055	920	852	468	1,320
1986	27,551	4,838	5,284	976	852	468	1,320
1987	29,493	5,150	5,675	1,086	852	985	1,837
1988	31,148	5,443	6,017	1,116	852	1,032	1,884
1989	32,386	5,698	6,277	1,185*	852	1,032	1,884

* Confirmed data
** Power plants owned by ISA, but capacities are included in ICEL group.

CHAPTER 4 BASIC DATA COLLECTION AND REVIEW

Through the cooperation of the ICEL counterparts, the JICA Study Team was able to successfully collect much valuable data necessary for the F/S especially data such as meteorological, hydrological, topographical, geological, construction price, and other related data, which are necessary for the hydroelectric power generation planning.

The list of the collected reference documents and the result of the documents' review and analysis etc. are described in the separate F/S report for the respective power plants. Therefore, this report limits its description to their summary.

4.1 Hydrological Data

Table 4.1 indicates the names of the hydrological gauging stations where the river discharge data was collected for the rehabilitation plan study for the power plants in 11 locations. The only hydrological gauging station where discharge is measured in the ICEL group is the Bocatoma hydrological gauging station at the San Cancio Hydroelectric Power Plant in CHEC. Other hydrological gauging stations are controlled by HIMAT, CAR, and CVC. Only at the following 3 locations, of those hydrological stations described in Table 4.1, suspended sediment is measured.

Caracoli, the Caramanta Hydrological Gauging Station at the Nus River
La Vuelta, the Aguasal Hydrological Gauging Station of the Andagueda River
Zaragoza, the Cafe Madrid Hydrological Gauging Station of the Surata River

The water quality analysis is executed at the following hydrological gauging station:

Julio Bravo, the Universidad Gauging Station of the Pasto River

Table 4.1 Hydrological Gauging Stations where Discharge Data was Collected

Name of the plant	Hydrological gauging station					Period of the discharge gate observation	Distance from the intake gate
	Name of the river	Number	Name	Service years	Controller		
Caracoli	Nus	2308-716	Caramanta	73-07	HIMAT	75-85	Upstream 5 km
P. Guillermo	Suarez	3-60ILMG	Garavito	Unconfirmed	CAR	77-86	Upstream 5 km
San Cancio	Chinchina	6-939	Bocatoma	79-12	CHEC	79-87	Intake gate
Intermedia	Chinchina	6-939	Bocatoma	79-12	CHEC	79-87	Upstream 25. km
Municipal	Chinchina	6-939	Bocatoma	79-12	CHEC	79-87	Upstream 5.5 km
Silvia	Piendamo	2602-709	Cortijo El	61-05	HIMAT	77-87	Downstream 1.5 km
	Piendamo	2602-710	Pte. Carretera	63-12	HIMAT	75-85	Downstream 19 km
Ovejas	Ovejas	2602-711	Abajo Tarabita	64-09	CVC	64-87	Upstream 10 km
	Ovejas	2602-728	Los Cambulos	81-07	CVC	82-86	Upstream 1 km
La Vuelta	Andagueda	1107-701	Aguasal	76-05	HIMAT	77-85	Downstream 3 km
Julio Bravo	Pasto	5204-701	Universidad	70-08	HIMAT	72-86	Upstream 6 km
Zaragoza	Lebrija	2319-729	Cafe Madrid	68-12	HIMAT	75-85	Downstream 8 km
	Surata	-	-	Unconfirmed	CAMB S.A.	82-87	Downstream 1.9 km
Lagunilla	Lagunilla	4-132	El Bosque	56-02	HIMAT	57-64	Upstream 0.5 km
	Lagunilla	2125-708	Quinta Cobra	72-04	ELCTRAGUAS	74-75	Downstream 27 km

4.1.1 Discharge Data Collection

The JICA Team collected the data assuming that at least the data for the past 10 years is available regarding the discharge data at the respective hydroelectric power plants. However, as Table 4.2 shows, only at the following 6 locations the complete discharge data for the past 10 years was available:

Caramanta Hydrological Gauging Station for the Caracoli Power Plant
Garavito Hydrological Gauging Station for the P. Guillermo Power Plant
Cortijo El and Pte. Carretera Hydrological Gauging Station for the Silvia Power Plant
Abajo Tarabita Hydrological Gauging Station for the Ovejas Power Plant
Universidad Hydrological Gauging Station for the Julio Bravo Power Plant
Cafe Madrid Hydrological Gauging Station for the Zaragoza Power Plant

The Bocatoma Hydrological Gauging Station for the San Cancio Power Plant on the Chinchina River was built in December 1979 and the observation data is available for 8 years up to 1987. However, in 1984 there were many days in which observations were not recorded and therefore the data available in actually for 7 years only.

The Aguasal Hydrological Gauging Station for the La Vuelta Power Plant was built in June 1976. Although the discharge observation records for 10 years up to 1986 were collected during the period of 1980 to 1984 observations were not recorded on many days, and so the continuous data actually covers only 5 years.

The Quinta Cobla Hydrological Gauging Station for the Lagunilla Power Plant was built in 1972 but abolished in 1975. The observation record during these years is incomplete. Therefore, this study adopted the data collected at the El Bosque Hydrological Gauging Station (built in February 1956), which was under the control of ELECTRAGUAS which is the former name of the HIMAT, between 1957 and 1964, although it is old.

Table-4.2 Hydrological Gauging Station And Term of Observation Recods Collected

No	Hydroelectric P.P	Code No	River	Name of Gauging Station	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Caracoli	2308-716	Nus	Caramanta																		07*		O	O	O	O	O	O	O	O	O	O	O					
2	P.Guillermo	3-60IIMG	Suarez	Garavito																						O	O	O	O	O	O	O	O	O	O				
3	San Cancio	6-939	Chinchina	Bocatoma																								12*+	O	O	O	O	+	O	O	O			
4	Intermedia	6-939	Chinchina	Bocatoma																								12*+	O	O	O	O	+	O	O	O			
5	Municipal	6-939	Chinchina	Bocatoma																								12*+	O	O	O	O	+	O	O	O			
6	Silvia	2602-709	Piendamo	Cortijo El						05*															O	O	O	O	O	O	O	O	O	O	O	O			
		2602-710	Piendamo	Pte Carretera								12*												O	O	O	O	O	O	O	O	O	O	O	O				
7	Ovejas	2602-711	Ovejas	Abajo Tarabita									09*+	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O			
		2602-728	Ovejas	Comblos Los																										07*	+	O	O	O	O				
8	La Vuelta	1101-701	Andagueda	Aguasal																					05*	O	O	O	+	+	+	+	+	O	O				
9	Julio Bravo	5204-701	Pasto	Universidad															08*		+	O	O	O	O	O	O	+	+	+	O	O	O	O	O				
10	Zaragoza	2319-729	Lebrija	Cafe Madrid													12*							O	O	O	O	O	O	O	O	O	O	O	O				
		---------	Surata	Zaragoza																											+	+	+	+	+	O	O		
11	Lagunilla	2325-708	Lagunilla	Quinta Cobra																	04*		+	+															
		4-132	Lagunilla	El Bosque	02*	+	O	O	O	O	O	O	O																										

Note * : Indicates The Instllation Date of Gauging Station.
+ : Indicates Years in Which Many Times of Observation Lack are Recognized.

The register of the HIMAT Hydrological Gauging Station, in the river basin of the Surata River, in which the Zaragoza Power Plant is located, shows that the Dep Vidrio Hydrological Gauging Station (No. 2319-747, built in May 1981) is registered. But it was not possible to obtain its discharge data from the HIMAT. Instead, the team was able to collect the discharge data at the Cafe Madrid Hydrological Gauging Station along the Lebrija River located downstream from the point where the Surata River joins.

On the other hand, the JICA Team obtained the discharge data (7 years of 1982-1988) from the observations measured at the intake gate of the Bucaramanga water treatment plant, which is directly downstream the outlet of the Zaragoza Power Plant, through ESSA. In this case also, due to so many days of no observation, only 2 years equivalent data is available for throughout the year.

4.1.2 Flow-Duration at the Respective Hydrological Gauging Stations

(1) Formulation of the 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 averaged 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-day 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.

In this study, the representative flow-duration curve at the hydrological gauging point was formulated by using the most popular (a) Parallel method. In the process of the formulation of the flow-duration curve, the years in which there are many days without observation were excluded. In the flow-duration curve diagram, the horizontal axis indicates the number of days by %, while the vertical axis indicates the daily average discharge (m^3/s).

(2) The Flow-Duration Curve at the Respective Hydrological Gauging Stations

The following represent the flow-duration curves which are drawn based on the yearly observed discharge data at the respective hydrological gauging stations described in Table 4.1.

1) Caramanta Hydrological Gauging Station for the Caracoli Power Plant

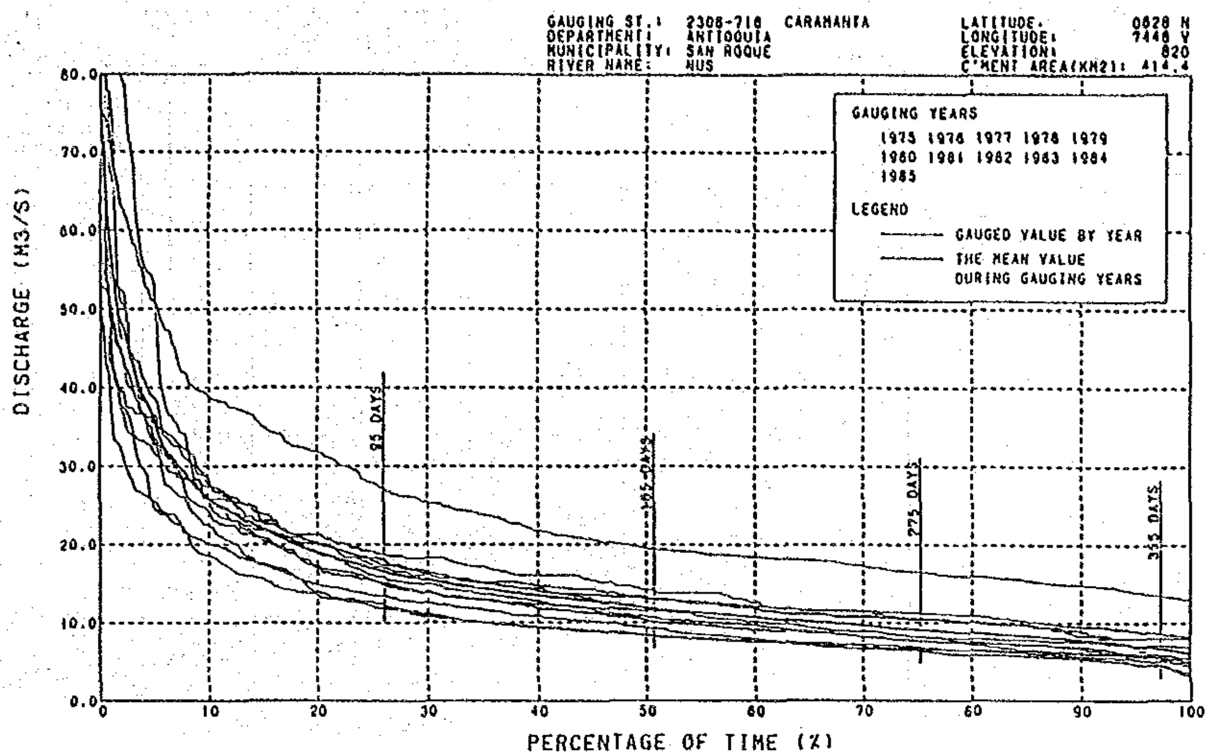
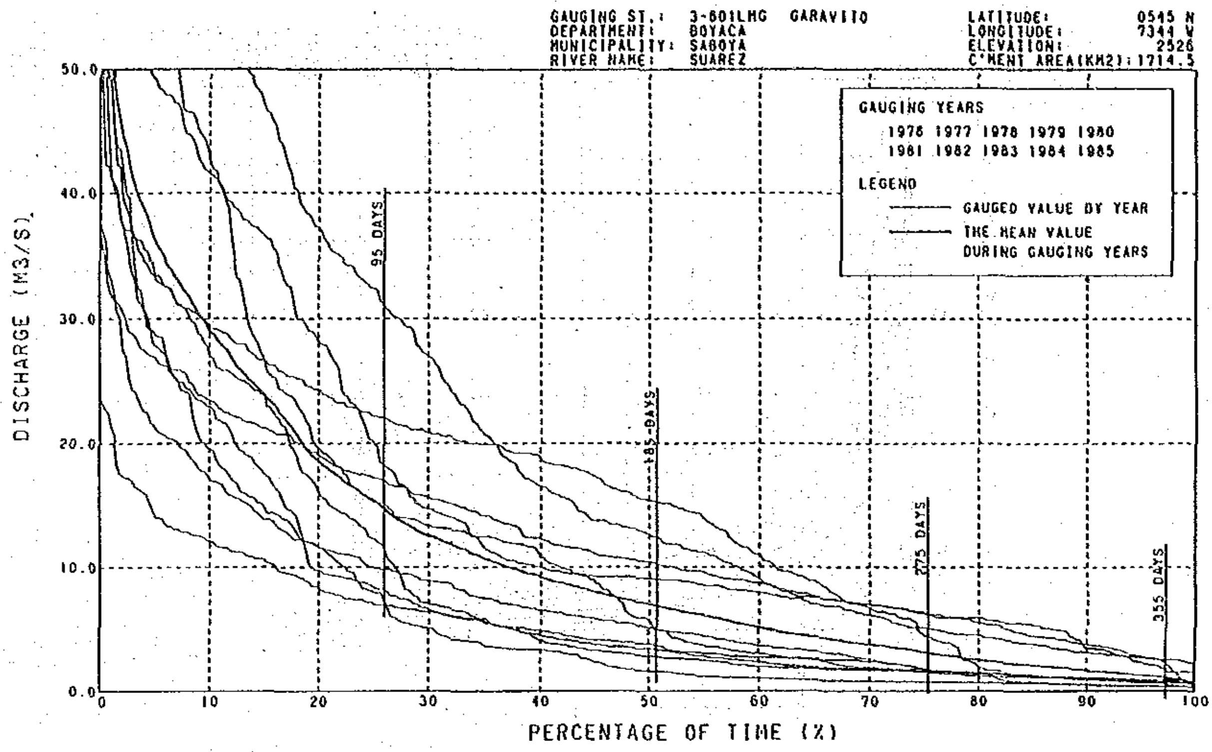


Fig. 4.1-(1) The Flow-Duration Curve at the Respective Hydrological Gauging Station

2) Garavito Hydrological Gauging Station for the Pte. Guillermo Power Plant



3) Bocatoma (San Cancio) Hydrological Gauging Station for the San Cancio, Intermedia and Municipal Power Plants

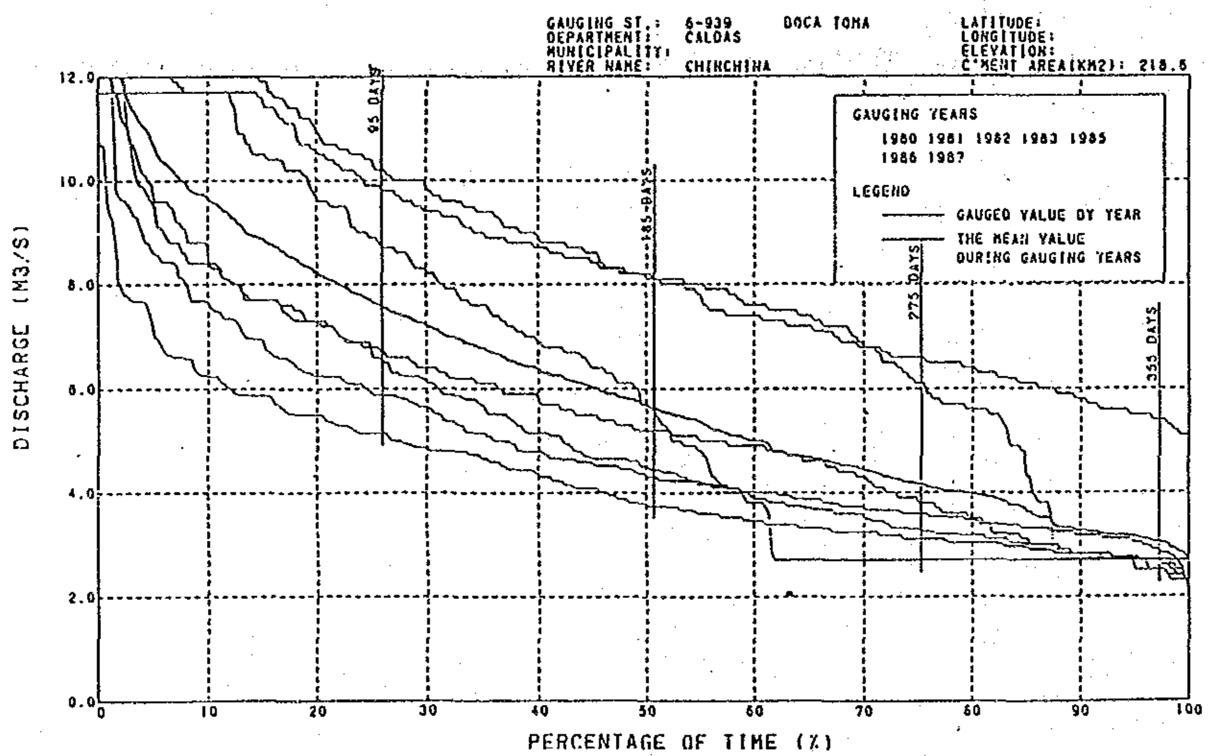
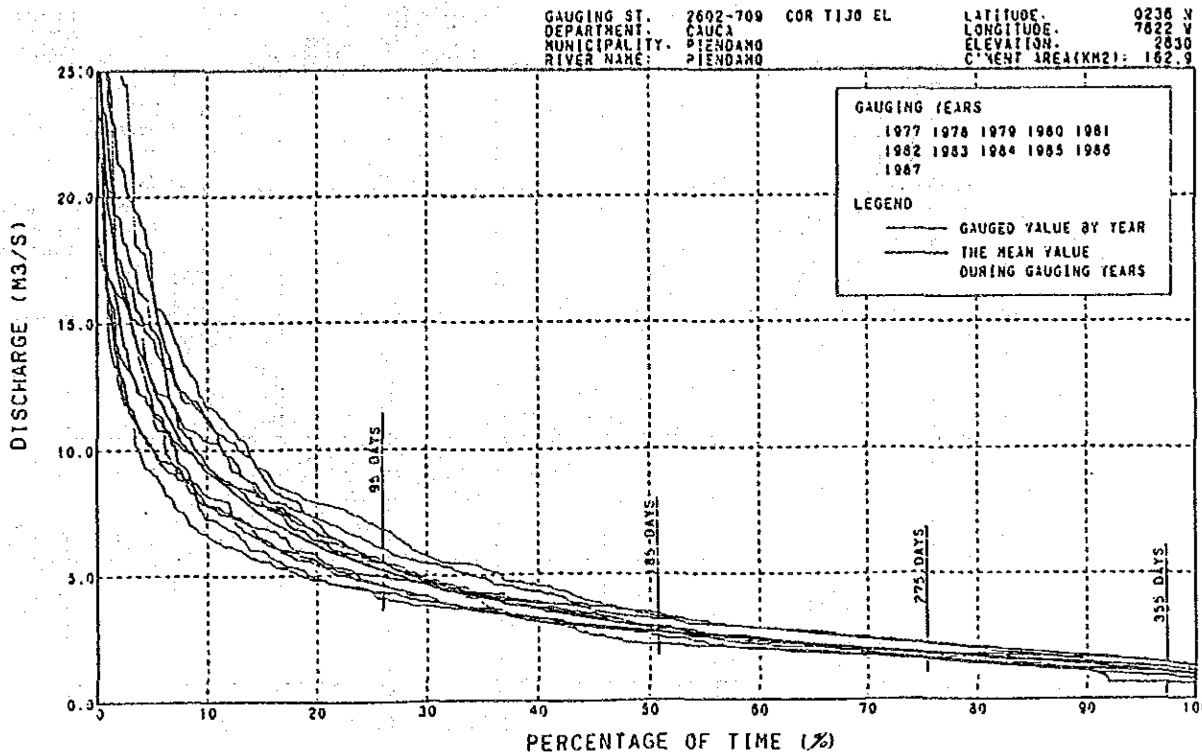


Fig. 4.1-(2) The Flow-Duration Curve at the Respective Hydrological Gauging Station

4) Cortijo El Hydrological Gauging Station for the Silvia Power Plant



5) Abajo Tarabita Hydrological Gauging Station for the Ovejas Power Plant

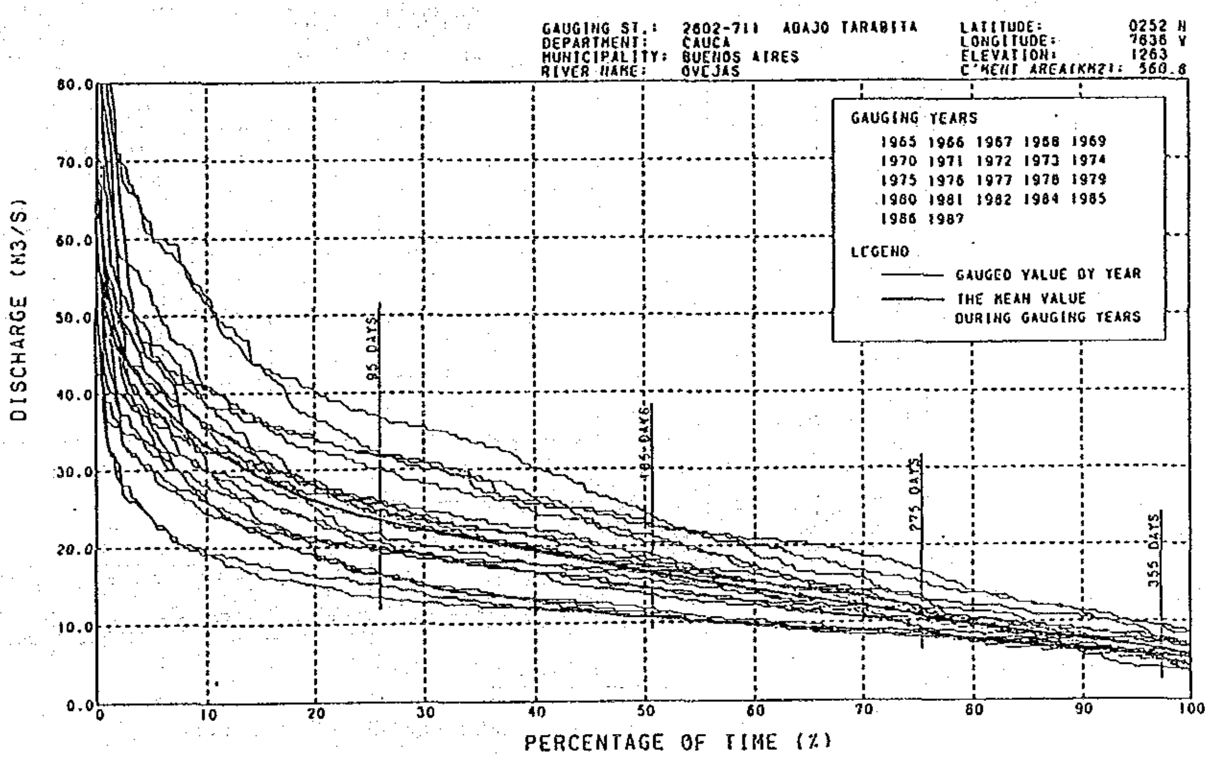
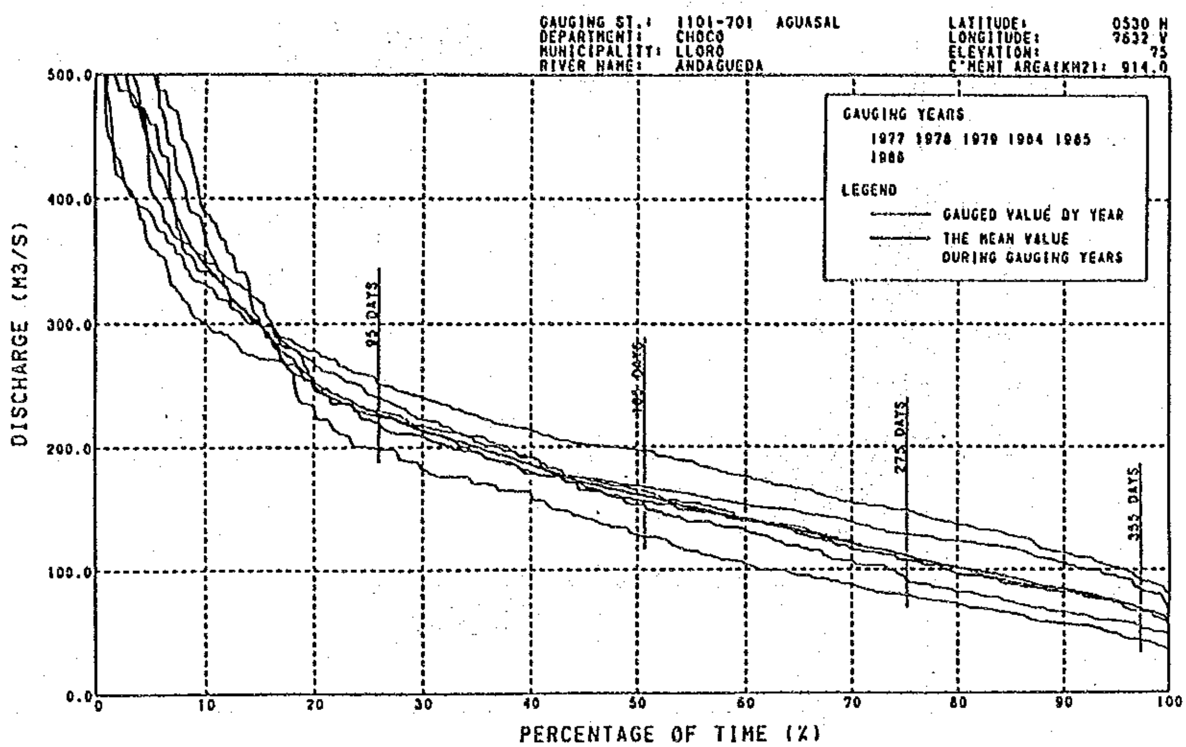


Fig. 4.1-(3) The Flow-Duration Curve at the Respective Hydrological Gauging Station

6) Aguasal Hydrological Gauging Station for the La Vuelta Power Plant



7) Universidad Hydrological Gauging Station for the Julio Bravo Power Plant

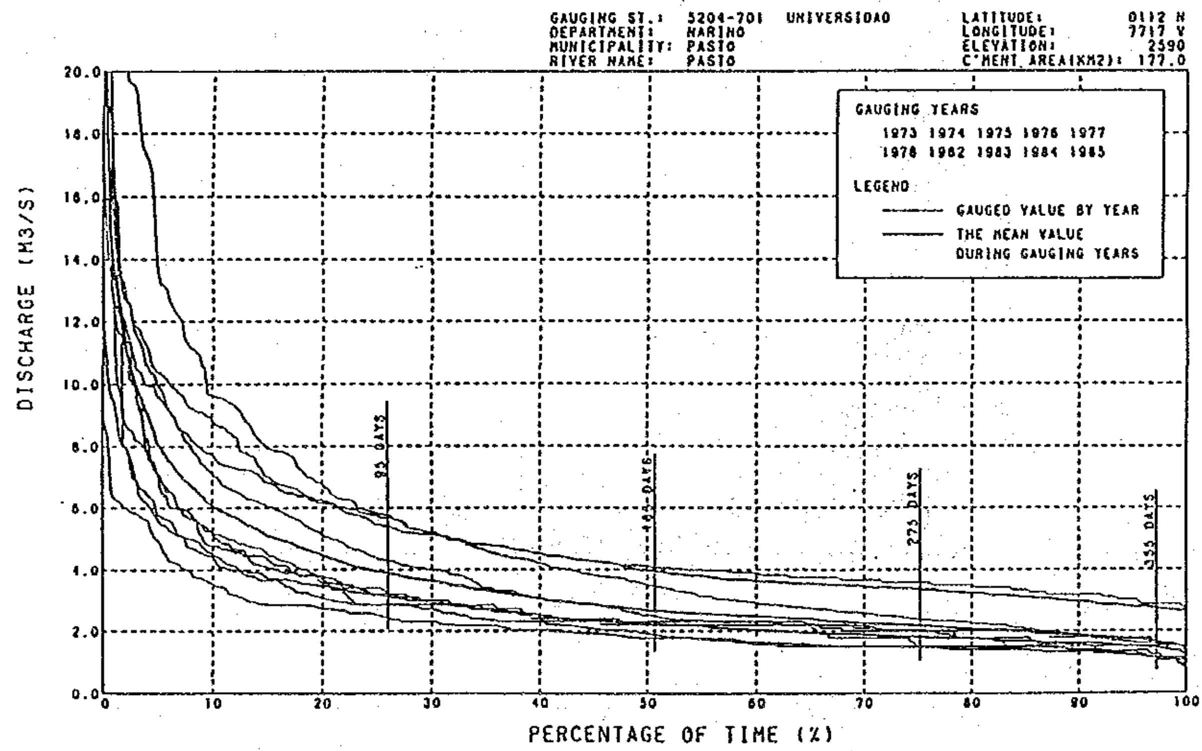
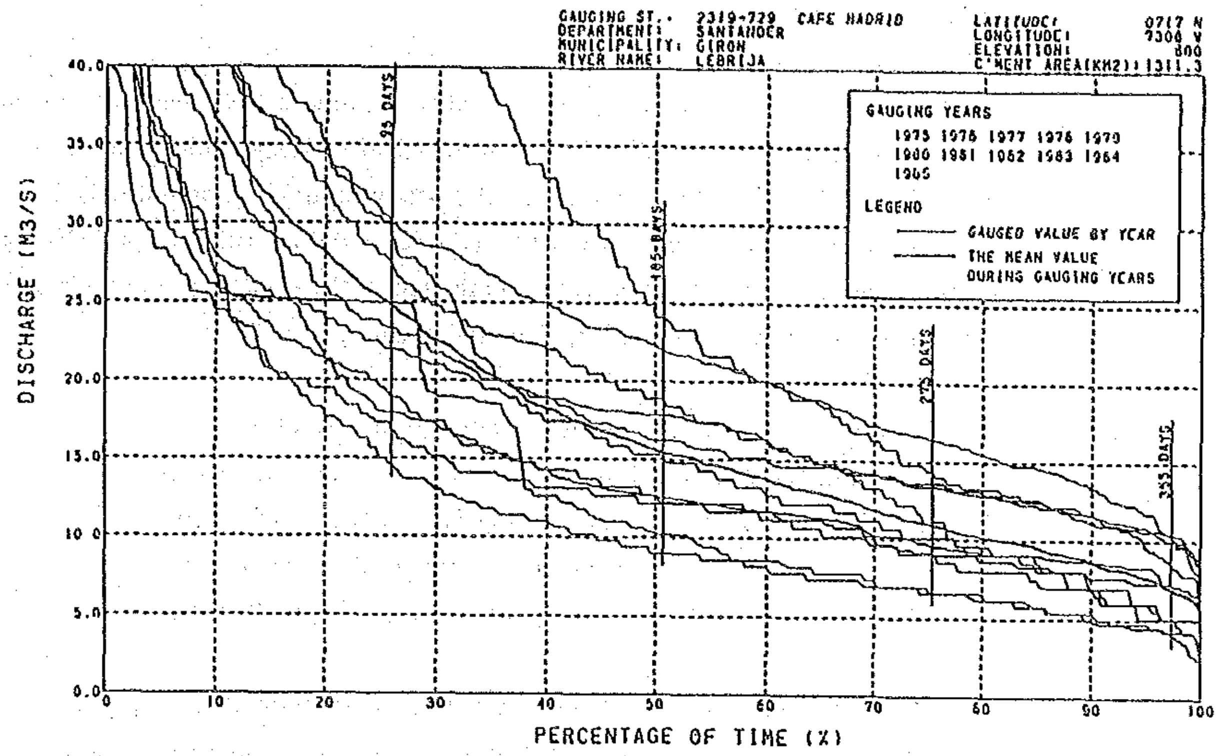


Fig. 4.1-(4) The Flow-Duration Curve at the Respective Hydrological Gauging Station

8) Cafe Madrid Hydrological Gauging Station for the Zaragoza Power Plant



9) El Bosque Hydrological Gauging Station for the Lagunilla Power Plant

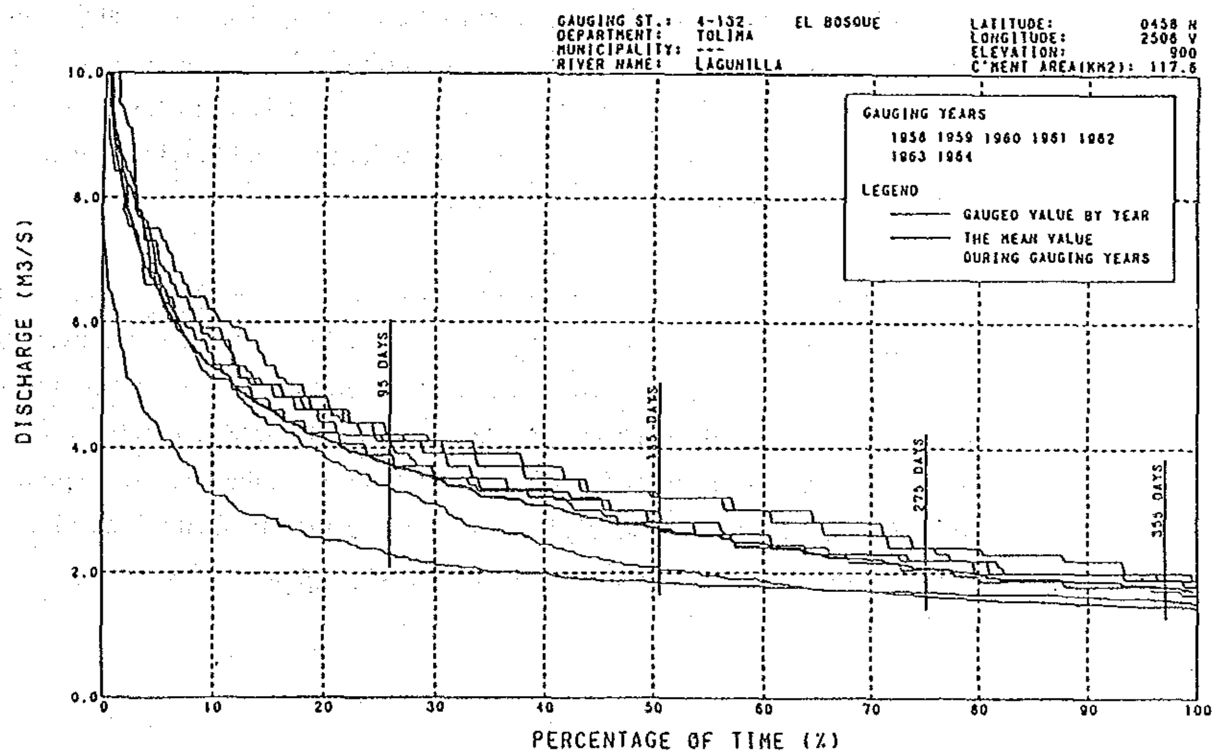


Fig. 4.1-(5) The Flow-Duration Curve at the Respective Hydrological Gauging Station

4.1.3 Comparison Regarding the Location and Catchment Area of the Respective Hydrological Gauging Stations

The JICA Study Team discovered significant errors in terms of locations, especially latitude, in the case of the following 5 hydrological gauging stations, when the F/S team plotted the respective stations on the topographical maps published by the Instituto Geografico "Agustin Codazzi" (IGAC) (scale 1:100,000 or 1:400,000), using the latitude and longitude values indicated in the register at the hydrological gauging stations, in order to confirm their actual current positions.

Caramanta Hydrological Gauging Station of the Nus River
Cortijo El Hydrological Gauging Station of the Piendamo River
Los Combulos Hydrological Gauging Station of the Ovejas River
Universidad Hydrological Gauging Station of the Pasto River
El Bosque Hydrological Gauging Station of the Lagunilla River

The F/S team performed the collation by using the topographical map published by the IGAC, since there was a concern that great error were occurring in terms of the catchment area size for the respective hydrological gauging stations. Table 4.3 shows the results where in the case of Caramanta and El Bosque Hydrological Gauging Stations there was a great difference between the size of the catchment area recorded in the register of the respective hydrological gauging stations and data measured by the JICA Study Team. At the Andagueda River in Choco department, although there was no great error in terms of the latitude and longitude, there was a great error in terms of the catchment area size.

On the other hand, since there are no officially approved values available for the intake areas around the intake gate points of the 11 hydroelectric power plants selected for rehabilitation, the JICA Study Team measured each area by using the topographical map published by IGAC. Since the data must be internally coherent, in order to calculate the discharge and flow-duration curve at the intake-gate point also, the JICA Study Team decided to adopt the data measured by themselves with regard to the catchment area of the respective hydrological gauging station.

Table 4.3 Comparison of Catchment Area

No.	River	Gauging Station		Catchment Area (km^2)			
		No.	Name	**A Original	B Measured	Scale of Topographic Map	Difference A - B
*1	Nus	2308716	Caramanta	320	414.4	1:100,000	-94.4
*2	Piendamo	2602709	Cortijo El	180	162.9	1:400,000	17.1
*3	Ovejas	2602728	Cambulos	No Info.	851.9	1:400,000	-
*4	Andagueda	1101701	Aguasal	1030	914.0	1:500,000	-116.0
*5	Pasto	5204701	Universidad	177	178.8	1:100,000	-11.8
*6	Lagunilla	4-132	El Bosque	155	117.6	1:100,000	-37.4

** Original data supplied by HIMAT, CHEC, CVC, CAR

* There is no discrepancy between the existing spot and the point shown in latitude and longitude.

4.2 Topographical and Geological Data

The source of topographical and geological data concerning the Power Plants locations can mainly be divided into (1) aerial photographs and topographical maps prepared or published by IGAC, (2) as-built drawings and measurement drawings for rehabilitation works belonging to the respective electric power companies, and (3) results of the topographical survey and boring geological study implemented for this study.

Table 4.4 indicates the availability of topographical and geological reference materials by respective power plant site, collected through the cooperation of the ICEL counterparts.

4.2.1 Topographical Data

Aerial photographs and survey drawings on a scale of 1/2500 are available for the 3 power plants at San Cancio, Intermedia and Municipal in the Chinchina river system in Caldas department and with a scale of 1/5000 for the Lagunilla Power Plant along the Lagunilla River in Tolima department.

Table 4.4 Topographical and Geological Reference Materials by the Respective F/S Locations

Power Plant	Data	Aerial phototgraph	Aerial photograph measurement diagram	Topographical map published by IGAC			Already available design document		Site study work implemented for this F/S	
				S = 1:100,000	S = 1:25,000	S = 1:10,000	Drawing at completion	Drawing for completion	Topograpical measurement diagram = 1:200	Boring study results
Ther-mal	Termopaipa	Δ	X	Δ	O	Δ	O	O	X	X
HYDROELECTRIC	Caracoli	O	X	O	O	Δ	O	X	O	3 holes, total length 27 m
	P.Guillermo	O	X	O	O	Δ	O	X	O	3 holes, total length 38.5 m
	San Cancio	O	O	O	O	Δ	O	O	O	Pit 6 holes, total length 9 m
	Intermedia	O	O	O	O	Δ	O	O	O	Pit 2 holes, total length 3.1 m
	Municipal	O	O	O	O	Δ	X	O	O	Pit 2 holes, total length 5 m
	Silvia	O	X	O	O	Δ	X	O	O	4 holes, total length 49 m
	Ovejas	O	X	O	O	Δ	X	O	O	4 holes, total length 40 m
	La Vuelta	O	X	O	O	Δ	O	X	O	X
	Julio Bravo	O	X	O	O	Δ	X	O	O	4 holes, total length 44 m
	Zaragoza	O	X	O	O	Δ	X	O	O	4 holes, total length 36.5 m
	Lagunilla	O	O	O	O	O	X	X	O	4 holes, total length 55 m

Legend
O: Already corrected
Δ: Not yet collected
X: No data available

The majority of the documents made at the time of the completion of the construction work on the P. Guillermo Power Plant owned by EBSA and La Vuelta Power Plant controlled by preciosos del Choco S.A., a precious metal company, in Choco department were made available to the Study Team. However, in many cases the coordinates and standard altitude in the drawings at the time of completion or rehabilitation plan drawings are decided, thus it is difficult to establish consistency with the current situation.

In the topographical survey executed in this F/S, the topography surrounding the structure was not sufficiently covered in some locations, since the measurement range was reduced to the minimum due to the restraints of the work period and the need for saving the costs. However, the greatest defect in the measurement this time is that it was possible to use common technical specifications since the site engineer was absent.

4.2.2 Geological Data

Geological boring surveys were executed by the respective public electric power companies under their own supervision and a report was complied, except in the case of Termopaipa and La Vuelta power plants.

The following are the geological survey reports submitted to and reviewed by the Study Team during this Study.

Caracoli Power Plant:

Perforaciones planta electrica Municipio de Caracoli, 1989, Tecnisuelos.

P. Guillermo Power Plant:

Estudio de suelos microcentral hidroelectrica Puente Guillermo, 1988, Lopez Hermanos Ltda.

Silvia and Ovejas Power Plants:

Informe de resultados de perforaciones y ensayos de suelos para las Pequenas centrales hidroelectricas de Silvia y Ovejas, 1989, Estudio De Suelos Ltda.

Julio Bravo Power Plant:

Informe de resultadoes de perforaciones y ensayos de suelos para la pequena central hidroelectrica de Julio Bravo en Past, 1989, Estudio De Suelos Ltda.

Zaragaoza Power Plant:

Optimizacion planta de Zaragoza de laelectrificadora de Santander, 1989, Ingenieria de Suelos Ltda.

Lagunilla Power Plant:

Estudio de geologia nueva planta Lagunilla perforacions explorations, 1989, Consultoria Colombiana S.A.

4.3 Construction Price 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 Colombiana 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 by the respective public electric power companies (refer to Table 4.5).

Table 4.5 Unit Price List

	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. EARTHWORK (EARTH)	p/m^3	2,400	2,925	700	800	2,950	990	2,500	1,100
2. EARTHWORK (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	1,10,000	1,100,000	480,000
7. SCREEN	p/t	1,682,000	500,000	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. POWERHOUSE (REPAIR)	p/m^2	–	10,000	–	–	–	–	–	–
10.POWERHOUSE (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 5
REHABILITATION PLAN FOR TERMOPAIPA THERMAL POWER PLANT

The results of the rehabilitation plan study for Termopaipa Power Plant executed based on the data collected during the pre-F/S and the F/S and confirmed by the site reconnaissance are summarized hereafter.

5.1 No.2 Turbine Output Upgrading Plan (66 MW → 74 MW)

By replacing parts of the turbine main unit (turbine rotor, blade, nozzle, diaphragm etc.) and water supply heater (No. 1 LP, No. 2 LP, and No. 4 HP) by new parts the turbine output will increase from 66 MW to 74 MW.

For actually implementing this plan, before the work is started it is necessary for the makers of the already installed turbine and E. Boyaca to closely coordinate their actions, in accordance with the newest data on the current turbine such as its running record and maintenance record etc.

The peak steam quantity generated by the currently installed No. 2 boiler is 300 T/H and its continuous maximum quantity is 284 T/H.

Since the quantity of steam necessary to increase the turbine output by 8 MW is 285.85 T/H, the boiler peak capacity can satisfy the necessary steam quantity.

However, it is not possible to increase the turbine output by 8 MW in the case of continuous operation since the steam is insufficient by 1.85 T/H even when the maximum continuous capacity is applied. Therefore, before the actual rehabilitation work is implemented, it is necessary for the markers of the currently used boiler and EBSA to discuss the boiler performance, using the newest data such as the running records of the boiler main unit and accessories as well as their maintenance records.

The estimated rehabilitation cost in September, 1989 is ¥885 million (US\$6.3 x 10^6, ¥140/US\$ exchange rate). The cost of the work for increasing the output by 1 kW is estimated as ¥111,000 (US\$790), while the power generation cost is 20 mills/kWh.

5.2 No. 2 Unit Instrumentation System Modification Plan

According to this rehabilitation plan, in order to improve the reliability and secure the ease of the operation/maintenance of the No. 2 unit, its air system instrumentation shall be partially changed to electric system using a computer.

In the selection of the maker, it is necessary to discuss whether to select the same maker as in the case of the already installed No. 3 unit's instrumentation system, while considering the parts' compatibility, reliability, handling method and maintenance etc.

Furthermore, it is necessary to prepare all the drawings clearly describing the respective measuring positions for the currently used No. 2 unit.

The cost for the above in September, 1989 is estimated at ¥805 million (US$5.8 x 10^6). With the condition that the operation cost can be maintained at the current level, this portion will create a burden of ¥0.28/kWh (1.9 mills/kWh) on the power generation cost.

5.3 Cooling System Modification Plan

The cooling efficiency can be improved by installing a cooling tower and changing the cooling system to one with circulating the cooling water.

Modification plan of the cooling system for No. 1 unit through No. 3 unit is studied.

The circulating cooling system's design conditions are as follows:

Cooling tower capacity	
For the No. 1 unit	7,000 m^3/H
For the No. 2 unit	13,000 m^3/H
For the No. 3 unit	13,000 m^3/H
Cooling water temperature	
Entrance of the cooling tower:	35°C
Exit of the cooling tower:	27°C

Ambient temperature (wet-bulb temperature): 13°C

Cooling water boosting pump specification outline

	(Capacity)	x	(Lift)
For the No. 1 unit	7,000 m^3/H	x	20 m
For the No. 2 unit	13,000 m^3/H	x	20 m
For the No. 2 unit	13,000 m^3/H	x	20 m

Chemical liquid pouring equipment will be installed in order to improve the water quality of the circulating cooling water.

For realizing the plan of changing the cooling system, the following confirmation and study will be necessary:

(1) Since the space planned for installing the cooling tower is near the Chicamocha River, a boring survey is necessary before the installation in order to check if bearing capacity is sufficient.

(2) It is necessary to survey and confirm the already installed infrastructures. If the existence of any infrastructure is confirmed it is necessary either to change the location of that infrastructure or to modify the design.

The following is an estimate of the cost for the cooling system change. The total cost in September, 1989 is ¥2,071 million (US$14.8 x 10^6) and it will create a burden of ¥0.7/kWh (4.9 mills/kWh) on the power generation cost.

Cost for the cooling system change (unit: US$$10^6$)

Equipment		Civil Work	Total
Foreign Currency	Local Currency	Local Currency	
8.8	4.9	1.1	14.8

5.4 Environmental Problems and Countermeasures

The power plant will adversely affect the surrounding environment by smoke emission due to the fact that there is no electrostatic precipitator in the No. 1 unit as well as by coal ash flowing out into the Chicamocha River.

In order to install an electrostatic precipitator for preventing the smoke emission in the No. 1 unit, work of large scale is necessary including the removal of the currently used stack and construction of a new one, due to the problem of space availability around the currently used boiler. Thus, there is very little possibility of actually implementing the work.

Since the flowing out of coal ash adversely affect the cities located downstream, the revetment work of ash disposal site and land acquisition of new ash disposal site are required urgently.

In order to prevent the ash from flowing out of the already used and currently used disposal sites, it is possible to consider the following proposals which are very commonly used methods:

(1) Construct walls on both banks of the Chicamocha River for preventing the ash from flowing out.

(2) Filter the rain water inside the ash disposal ground by filtering and sedimentation tanks and then drained into the Chicamocha River.

(3) Install an appropriate drainage route etc. in the space between the No. 2 ash disposal site and the mountain in order to treat the rain water from the mountain side.

(4) In order to prevent the ash from flying and spreading from the ash disposal ground, cover the ash by soil or sand and plan a lawn or trees on top of it in.

CHAPTER 6
REHABILITATION PLAN FOR THE HYDROELECTRIC POWER PLANTS

The power plants selected by this F/S for the rehabilitation plan are mostly those which have been in use for more than 40 years. So the generation equipment are old and deteriorated with a greatly reduced output even if it were still in operation. Therefore, those power generating equipment which have broken down and been left unrepaired, as well as those with greatly reduced operation efficiency due to long years of use and deterioration have been replaced by new equipment in the rehabilitation plan. Where Pelton and Francis type turbines are installed in the same power plant, the most appropriate type should be selected. Since these run-of-river hydroelectric power plants have a low utilization factor of river water, partly due to its old age, in many locations it is possible to increase the power capacity by increasing the design discharge. Therefore, the JICA Study Team has prepared the optimal power generation plan, as a comparative alternative to the rehabilitation plan.

6.1 Comparison of Rehabilitation Plans

The contents and the process of study on the rehabilitation plans for the respective power plants have been reported in separate volumes, as indicated in Appendix 1. The main results of the comparison between alternative proposals are described here.

The basic issues commonly adopted in the respective proposals in the process of the comparison of alternatives are as follows:

(1) Calculation of the generated output and generated energy

The annual generated energy is calculated by the following formula using a representative flow-duration curve around the intake:

Generated output $P = 9.8 \times Q \times He \times \eta$ (kW)

Annual generated energy $E = P \times 8760 \times \varepsilon$ (kWh)

Where, η = resultant efficiency of the turbine and generator

ε = yearly operation rate of the generating equipment expressed by discharge

$$\varepsilon = \frac{\text{Discharge passing through the turbine per year}}{\text{Maximum available discharge} \times 8760} \times 100\%$$

(2) Rehabilitation and Reform of the existing civil structures

Only those structures which are functionally or structurally incomplete or unstable will be rehabilitated or reformed. The life of those structures after the rehabilitation or reform work is set to be 50 years, while the depreciation period for the rehabilitation and reform work cost is 25 years.

Those structures which are not to be rehabilitated or reformed will be limited to those with a guaranteed life of 25 years from now under normal use and maintenance conditions. The existing conduction channels and penstocks will be maintained at current levels as much as possible.

(3) Generating equipment

The generating equipment after the rehabilitation work are the 2 unit system.
The life of the new generating equipment is 25 years and its total cost will be depreciated over the same period.

The FOB price of the new generating equipment adopted is equivalent to 90% of the lower of the two price estimates submitted by two Japanese manufacturers.

The following are the price structure of the generating equipment based on the FOB cost:

Item	Foreign currency	Local currency	Total
(1) FOB price	1.00	-	1.00
(2) CIF + Tax	0.343	-	0.343
(3) Value added tax	0.134	-	0.134
(4) (1) + (2)	1.343	-	1.343
(5) Domestic transport and insurance	-	0.06	0.06
(6) Installation	-	0.10	0.10
(7) Test and trial operation	-	0.06	0.06
(8) (5) + (6) + (7)	-	0.22	0.22
(9) (4) + (8)	1.343	0.22	1.563

(4) Contingency costs and engineering fees

The contingency costs and engineering fees in the feasibility stage are calculated as follows:

- Civil construction costs
  Contingency costs are 15% of the direct total costs.
  Engineering fees are 10% of the total of the direct costs plus contingency costs.
- Generating equipment costs
  Contingency costs are 10% of the direct total cost.
  Engineering fees are 8% of the total of the direct costs plus contingency costs.

(5) Interest

The interest rate is divided into foreign currency and local currency apportionments under the following conditions.

- The foreign currency portion is based on the annual interest rate of 10% (four-year grace period), 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% (one-year grace period), with repayment of the principal in equal, annual amounts over 8 years.

(6) Benefit calculation

The benefit unit prices in relation to the kW and kWh are to be set as follows by adopting the electric power sales unit price of ICEL in December 1988.

Benefit cost per MW	:	1,086,909.69 pesos/MW
Benefit cost per MWh	:	4,936.18 pesos/MWh

The initial investment amount in the rehabilitation costs during the construction period is to be set as follows:

The initial amount of investment for rehabilitation work cost during the construction is as follows.

Timing	Civil construction	Electrical/mechanical facilities cost
Commencement of work	40%	10%
After one year	60%	45%
After two years (operation of #1 unit scheduled)	-	45%
After three years	-	-

(7) Currency exchange rates

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

6.1.1 Caracoli Hydroelectric Power plant

The Caracoli Hydroelectric Power plant is located on the Nus River in Autioquia Department. It is a run-of-river type hydroelectric power plant with a rated output of 3,200 kW, managed by EADE.

As of February 1989, the maximum output was 2,300 kW, having declined by approximately 900 kW (28%) from the original capacity. Also, the annual generated energy in 1988 was recorded as 18,285.9 MWh.

(1) Current status of the power plant and problems

This hydroelectric power plant connects the head between the upper and lower streams by a short cut using an iron penstock. In the already installed power generating facility, the diversion weir, intake gate, and desilting basin/head tank are either damaged or have deteriorated with aging. However, the headrace structure consisting of an 80-meter length of rock piled embedded pressure tunnel part and the penstock (diameter: 1,350 mm, length: 1,300 m) are still strong.

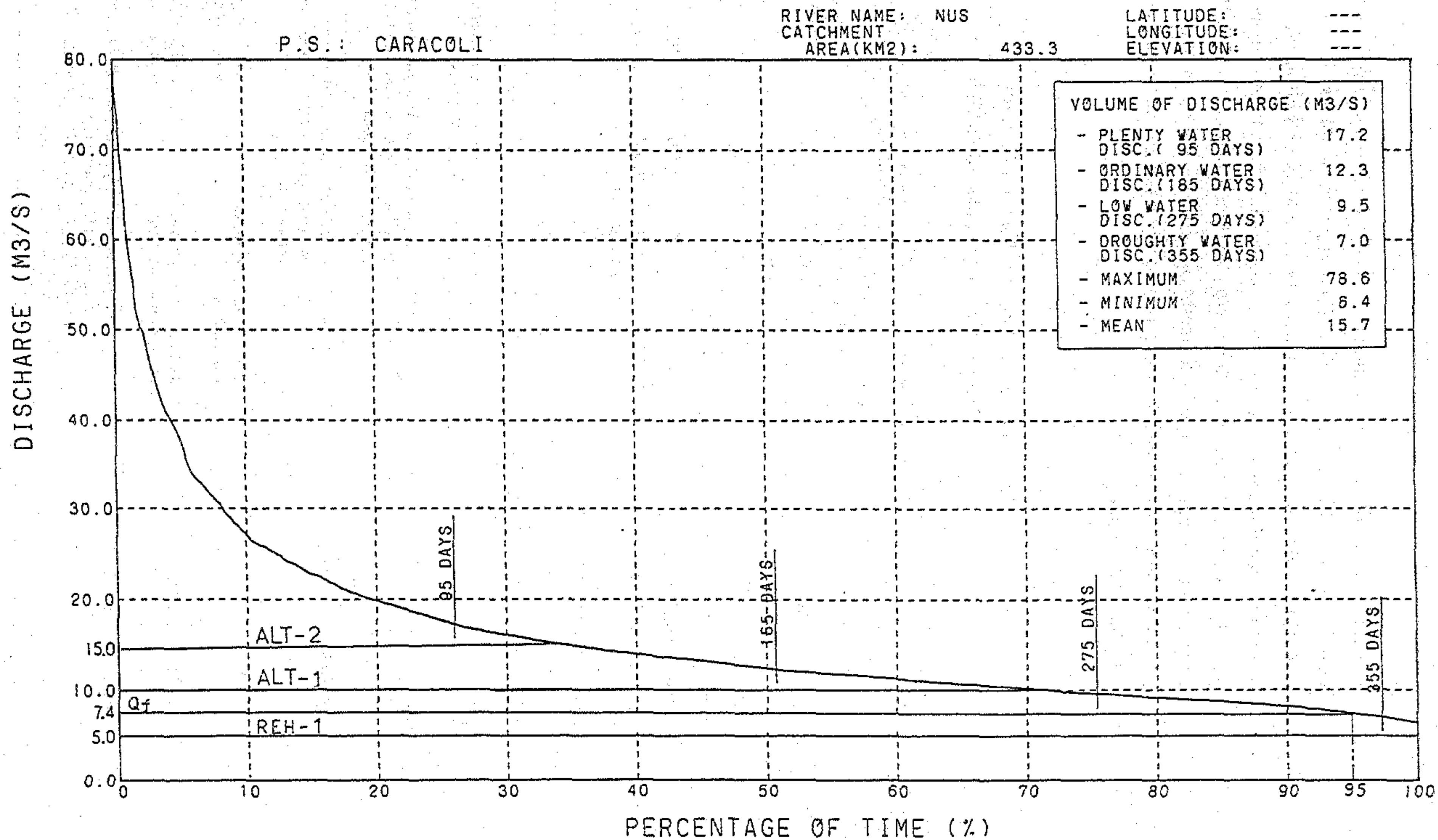
The generating equipment consists of both a Pelton type turbine (rated output : 1600 kW), manufactured in 1935 and a horizontal shaft Francis type turbine (rated output 1600 kW), manufactured in 1963. Their service years have exceeded 55 years and 27 years respectively. The current maximum output is 1150 kW for both machines, maintaining a capacity of approximately 72% of the rated output.

The lack of either discharge observation equipment at the power plant or a hydrological gauging station along the river hindered the study to establish the rehabilitation plan. In this study, the data used was collected from the discharge data taken at the observation records kept at the #2308-716 Caramanta hydrological gauging station at HIMAT, which is located approximately 5 km upstream from the intake of this power plant. There was a 94.4 km^2 difference between the value of the catchment area (320 km^2) recorded at this gauging station and the measured value of the catchment area (414.4 km^2).

(2) Alternative proposals of the rehabilitation plan

As the flow-duration curve (Figure 6.1) for the intake gate point, which was estimated from the discharge data at the Caramanta hydrological gauging station in HIMAT, indicates the maximum available discharge at the current power plant Q=5.0 m^3/s is too small from the viewpoint of water utilization.
Accordingly, comparative studies were made for the generation-optimizing plan, as well as the rehabilitation plan of the existing generating facilities. Three plans for power generation were considered, with the maximum available discharge set at 5.0 m^3/s (current maximum available discharge), 10.0 m^3/s and 15.0 m^3/s respectively.

Fig-6.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



The three rehabilitation plans shown in Table 6.1, consist of the current status rehabilitation plan (REH-10), as well as 2 power generation plans (ALT-1 and ALT-2). The REH-1 plan proposes to replace only the old No.1 Pelton type turbine and generator, manufactured in 1935, with a horizontal shaft Francis type turbine and generator, which is the same model as No. 2 turbine (manufactured in 1963). Since the generating equipment capacity increases by more than double in ALT-1 and ALT-2, a 2-unit system is formulated by using two new horizontal shaft Francis type turbines with the same output.

Table 6.1 Alternative Plans for Caracoli Hydroelectric Power plant Rehabilitation

Item	Alternative				
	Rehabilitation of the existing facilities			Increase of power output	
	REH-1			ALT-1	ALT-2
	Unit No.1	Unit No.2	Total		
Discharge, Q (m^3/s)	2.5	2.5	5.0	10.0	15.0
Max. output, P (kW)	1,700	1,100 (present output)	2,800	6,700	10,200
Facility utilization factor (%)		100		96	80

Rehabilitation and improvement plan:		
Diversion weir	Because of damage to this weir, a new sandtrap will be built (common to all plans).	
Intake	Will be reconstructed into the horizontal intake type in parallel with the diversion weir modification. Screen and gate will be replaced.	
Desilting basin/head tank	Will be reconstructed to match the intake layout to prevent vortexes from developing. (Common to all plans)	
Penstocks	The existing penstocks will be used.	Will be replaced with new one.
Generating equipment	#1 Pelton turbine will be replaced with new one.	Will be replaced with new one.
Powerhouse building	The existing buildings and the overhead crane will be used after partial repair. The base of the generating equipment will be remodeled.	

(3) Selection of optimum plan

The study results of the alternative plans indicates that there is little significant difference between ALT-1 and ALT-2, since both are are advantageous, as shown in Table 6.2. Detailed studies of the maximum design available discharge from 10 m^3/s to 15 m^3/s are required for the rehabilitation. In this report, ALT-1 (10 m^3/s) is selected as the optimum plan. The basic design for ALT-1 conducted during the FS is detailed in a separate report.

Table-6.2 Comparison of Rehabilitation Plan for the Caracoli 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 Q_1 (m^3/s)	Standard net head H_1 (m)	Theoretical output =9.8x(20) x(21) (kW)	Resultant efficiency η	Output =(22)x(23) P_1 (kW)	Annual probable generated energy E_1 (GWh)	Facility utilization factor ε (%)	Output =(24) - (14) ΔP (kW)	Annual probable generated energy (25) - (15) ΔE (GWh)
REH-1 Pelton	2.5	86.0	1,600	1,200	9.17	2.5	82.9	2,031	0.835	1,700	14.9	100	500	5.7
REH-1 Francis	2.5	86.0	1,600	1,100	9.64	2.5	82.9	2,031	0.542	1,100	9.6	100	0	0
REH-1 Total	5.0	86.0	3,200	2,300	18.81	5.0	82.9	4,062	------	2,800	24.5	100	500	5.7
ALT-1						10.0	82.9	8,124	0.835	6,700	57.0	96	4,400	38.1
ALT-2						15.0	82.9	12,186	0.845	10,200	72.3	80	7,900	53.5

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 C_{1f}	(42) Local currency portion $C_{1\ell}$	(43) (41)+(42) C_1	Civil work cost C_2	(43)+(44) C	Cost per ΔP =(45)/(30) C/ΔP	Cost per P_1 =(45)/(24) C/P_1	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 E_1 =(65)/(25) ÷0.95	per ΔE =(65)/(31) ÷0.95	C/B	Priority order
REH-1 Pelton	1,000	400	1,400	900	2,300	4,700	1,400	6.8	107	106	213	220	16	41	1.51	3
REH-1 Francis																
REH-1 Total																
ALT-1	2,900	1,200	4,100	2,900	7,000	1,600	1,050	26.8	305	329	634	661	12	18	0.99	1
ALT-2	3,600	1,450	5,050	3,750	8,800	1,100	860	40.8	376	420	796	837	12	16	0.96	1

(Notes)

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

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

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

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

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

(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

6.1.2 Puente Guillermo Hydroelectric Power plant

This power plant is a run-of-river type hydroelectric power plant with a rated output of 1280 kW. It is owned by EBSA and located along the Suarez River in Boyoca Department. Since the anchor block base of the penstock sunk and the penstock was damaged, operation has been stopped since 1985 for repairs. Therefore, the main task in the rehabilitation of this power plant is the repair of the penstock.

Although the civil structures, such as the diversion weir, intake gate, the 372 m extension of the open channel and head tank are still sound, the attached gates, valves and screens, especially the components of the tank have greatly deteriorated or been damaged with age.

The generating equipment consists of 2 units of horizontal shaft Francis type turbine (rated output 640 kW for each), which were manufactured in 1950 and 1960 respectively. The service years of both exceeded 30 years. Also, since the plant has not been in operation for over 5 years due to the penstock breakdown, careful inspections are necessary for restarting the operation.

(1) Observation on the cause of penstock accident

The soil of the area from the tank to the power plant through the penstock consists of alternating layers of sandstone and slate. The head is secured utilizing a steep cliff in the sandstone layer part in this area. The following is a summary of the geological observation on the accident which occurred in the penstock section.

Leaks in the steel pipes caused the ground water level to rise in the talus deposit, which was the base of the penstocks, leading to a small-scale landslide.

(2) Tank and penstocks rehabilitation plan

In conducting the rehabilitation design of the head tank and penstock, the following design standards for civil structures are implemented.

- The maximum available discharge will be set at 2.60 m^3/s, which is the same as present.
- The head tank will be reconstructed to match the layout of the penstock. The storage capacity of the reconstructed head tank will be equivalent to a two-minute capacity of the maximum available discharge.
- Penstocks in two rows (diameter: 800 mm) will be laid, which is the same as the existing one. The foundation of the anchor block will be built 4 m into the ground.

6.1.3 San Cancio, Intermedia and Municipal Hydroelectric Power plants

San Cancio (rated output 2,320 kW), Intermedia (rated output 1,120 kW) and Municipal (rated output 2,112 kW) power plants are a series of run-of-river type hydroelectric power plants, located upstream of the Chinchina River in Caldas Department . The plants are owned and operated by CHEC.

The current maximum output as of February 1989 and the generated energy in 1988 of the respective power plants are as follows.

Power plant	Manufacturing date of generating equipment	Max. output as of Feb., 1989 (kW)	Output drop rate (%)	Annual generated energy in 1988 (MWh)
San Cancio	#1 1929	750	▲26	6,175
	#2 1947	1000	▲23	
Intermedia	1947	900	▲20	3,279
Municipal	1945	1400	▲34	5,448

(1) Current situation of the power plant facilities and problems

The tailrace of San Cancio Power plant is directly connected with the conduction channel of the Intermedia Power plant with a maximum available discharge is 5.6 m^3/s. The Municipal Power plant's maximum available discharge is recorded as 5.6 m^3/s, the same as the official maximum available discharge at the San Cancio and Intermedia power plants, although the former has a facility capable also intaking the remaining