No. 3

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
CENTRAIS ELETRICAS DE SANTA CATARINA S.A.

FEDERATIVE REPUBLIC OF BRAZIL

SALTO PILÃO HYDROELECTRIC POWER DEVELOPMENT PROJECT

FEASIBILITY STUDY REPORT

MAIN REPORT

MARCH 1994

NIPPON KOEI CO., LTD.
TOKYO, JAPAN

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
CENTRAIS ELETRICAS DE SANTA CATARINA S.A.

FEDERATIVE REPUBLIC OF BRAZIL

SALTO PILÃO HYDROELECTRIC POWER DEVELOPMENT PROJECT

FEASIBILITY STUDY REPORT

MAIN REPORT

MARCH 1994

NIPPON KOEI CO., LTD.
TOKYO, JAPAN

LIST OF REPORTS

1. EXECUTIVE SUMMARY
2. MAIN REPORT
3. SUPPORTING REPORT

PREFACE

In response to a request from the Government of the Federative Republic of Brazil, the Government of Japan decided to conduct a feasibility study on the Salto Pilão Hydroelectric Power Development Project and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Brazil a study team headed by Mr. Shigeo Ohnuma of Nippon Koei Co. Ltd., three times during the period from March 1993 to January 1994.

The team held discussions with officials concerned of the Government of the Federative Republic of Brazil and conducted field surveys at the study area and major studies in Florianópolis with assistance of Centrais Eletricas de Santa Catarina S.A.(CELESC); power company of the state of Santa Catarina.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Federative Republic of Brazil for their close cooperation to the team.

March 1994

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

March 1994

Mr. Kensuke Yanagiya
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Sir,

Letter of Transmittal

We are pleased to submit herewith the Final Report of Feasibility Study on Salto Pilão Hydroelectric Power Development Project in the Federative Republic of Brazil.

This Report deals with study on formulation and feasibility of a development plan for the Salto Pilão Hydroelectric Power Project to be developed by harnessing the head of more than 200 meters and river discharge in the middle stretch of the Itajai River in the state of Santa Catarina. In this state, about 95 percent of the power demand is dependent on supply from electric companies in other states and it is urged to develop the state's own electric power scheme in order to establish the stable power supply system. In line with this principle, the study has been carried out since March 1993, and development of a run-of-river type power scheme with an installed capacity of 142 MW is proposed in this Report.

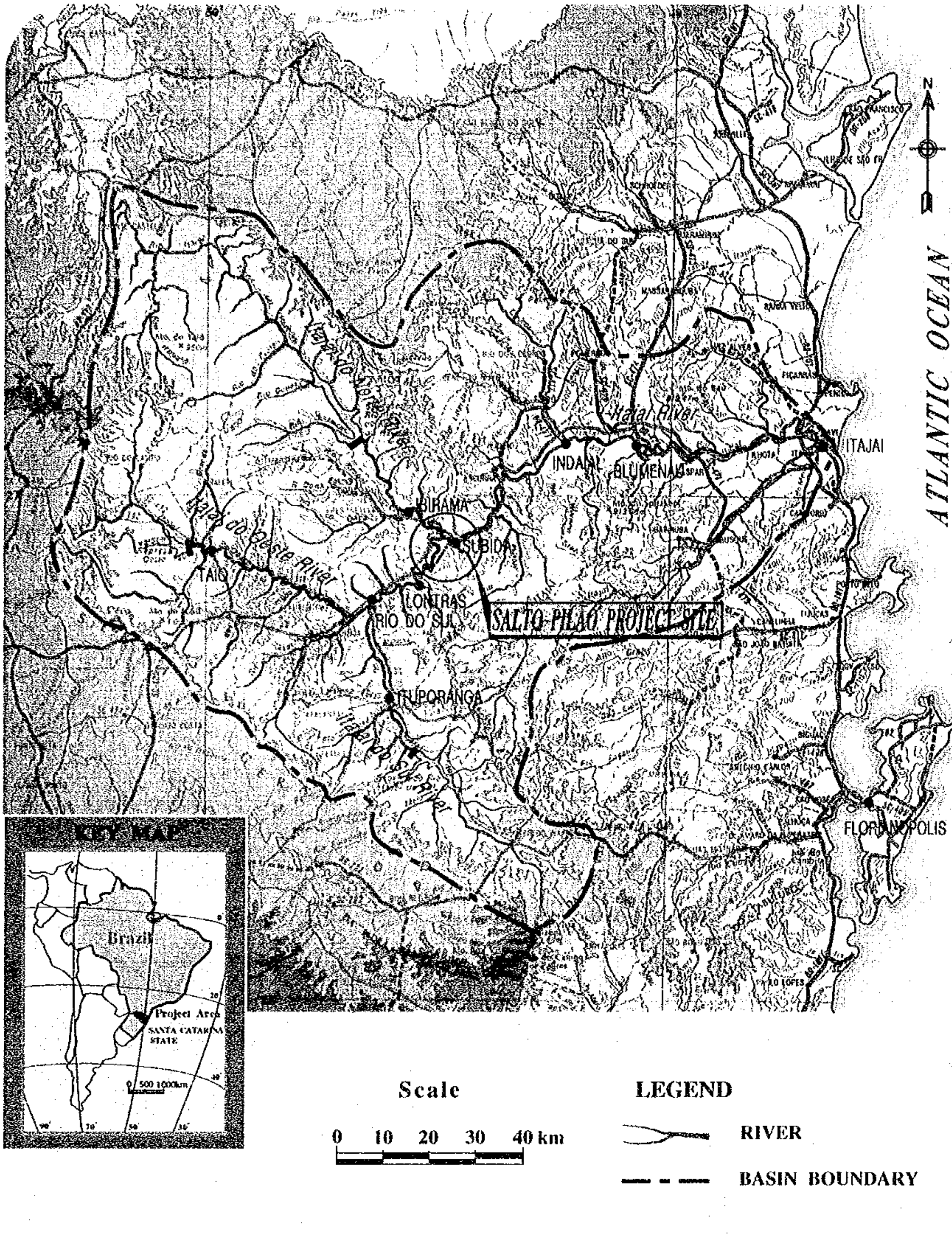
The Report consists of three volumes; Executive Summary, Main Report and Supporting Report. The Executive Summary presents main outputs of the study. The Main report covers all the studies including analyses of hydrology and geology, optimization of development scale, design, environmental study, cost estimate, evaluation of the proposed scheme and project implementation program. The Supporting Report presents back data for the studies, calculations of the studies and supporting parts of the Main Report.

We would like to express our grateful acknowledgment to all the officials concerned of JICA, Embassy of Japan in Brazil, the Government of Brazil and also of Centrais Eletricas de Santa Catarina S.A. for their assistance and advice rendered during the course of the study. We sincerely hope that the result of this study would contribute to the national and regional development of Brazil.

Yours sincerely,

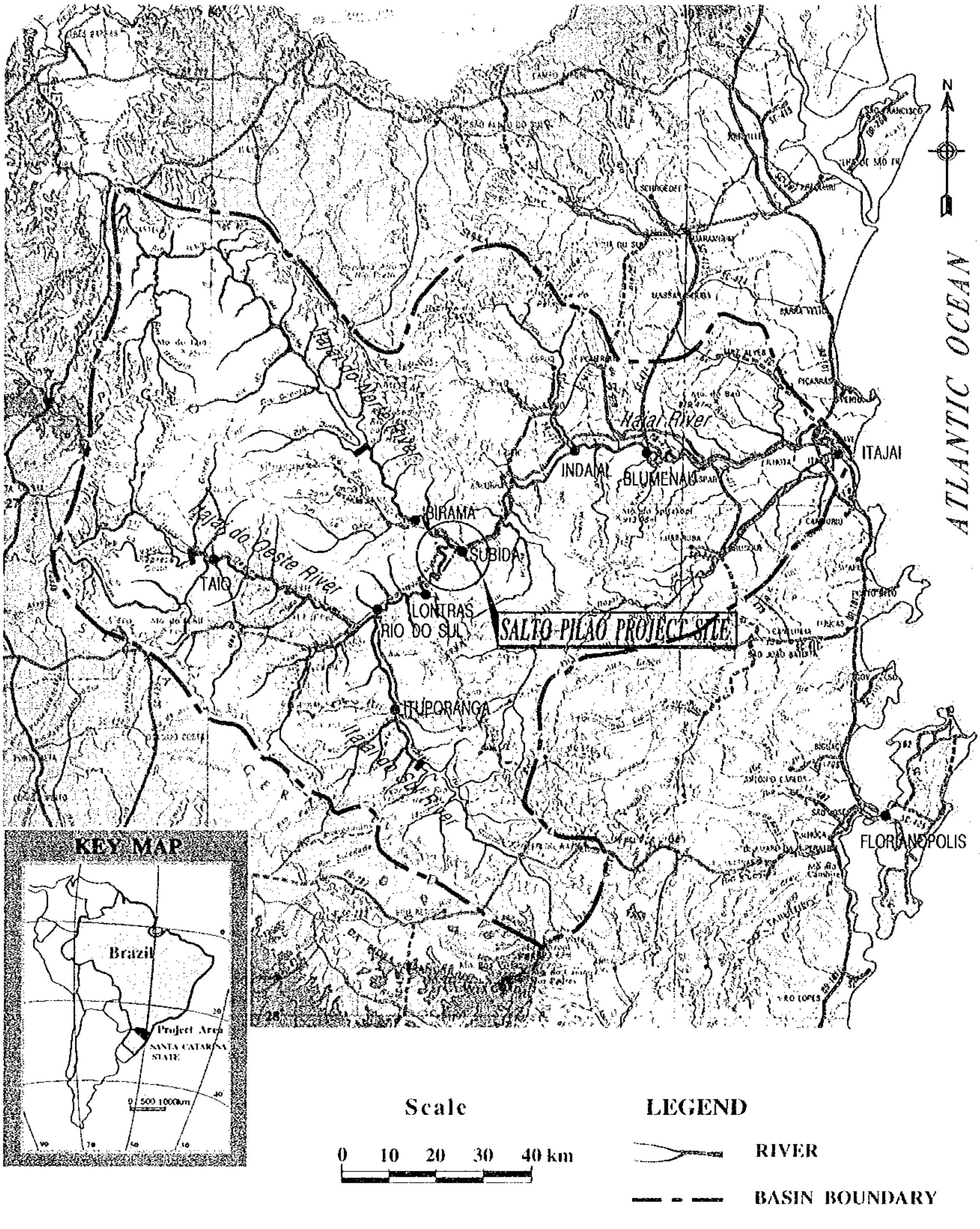
S. Ohnuma

Shigeo Ohnuma
Team Leader
Feasibility Study on Salto Pilão
Hydroelectric Power Development Project



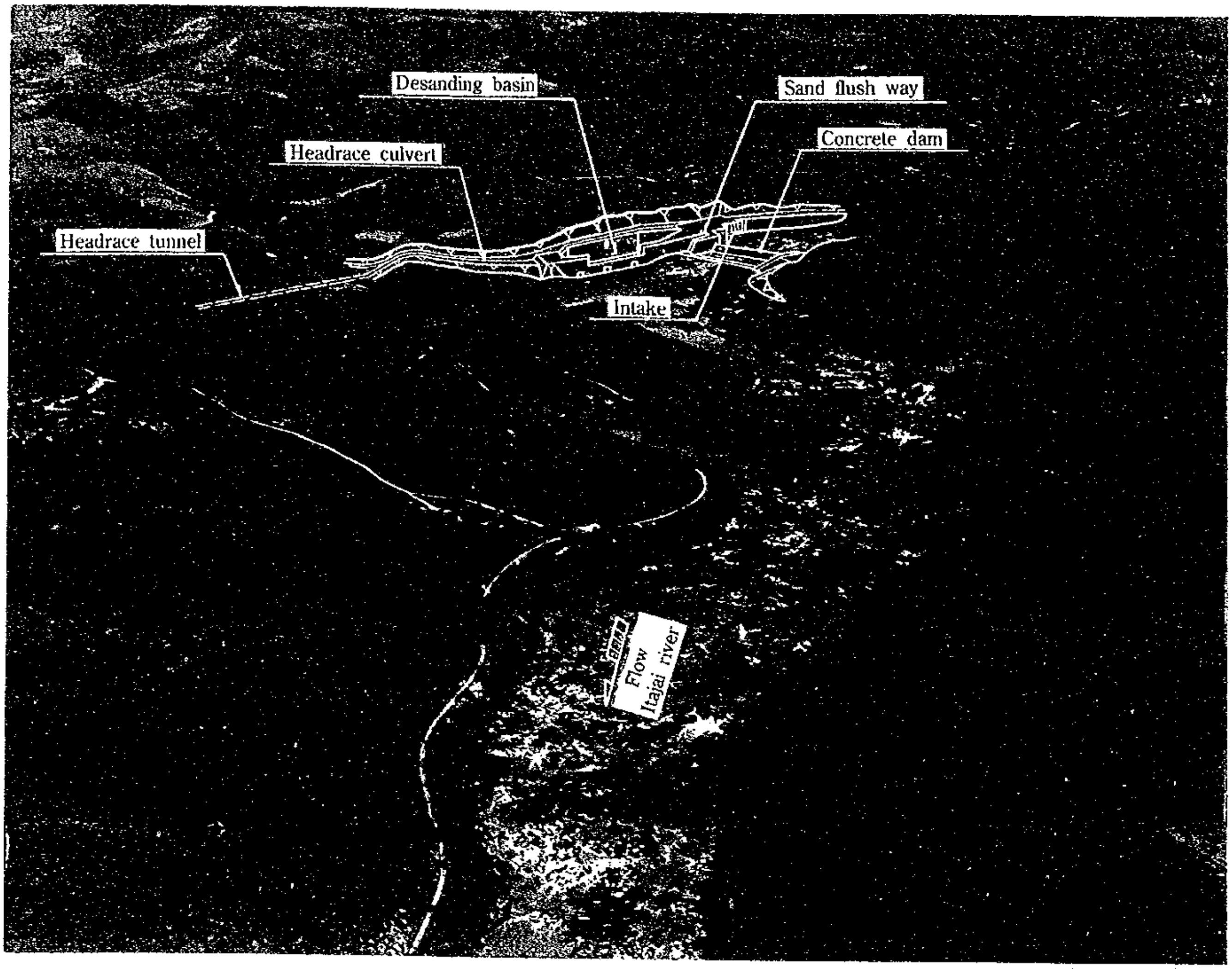
SALTO PILÃO HYDROELECTRIC DEVELOPMENT PROJECT

LOCATION MAP

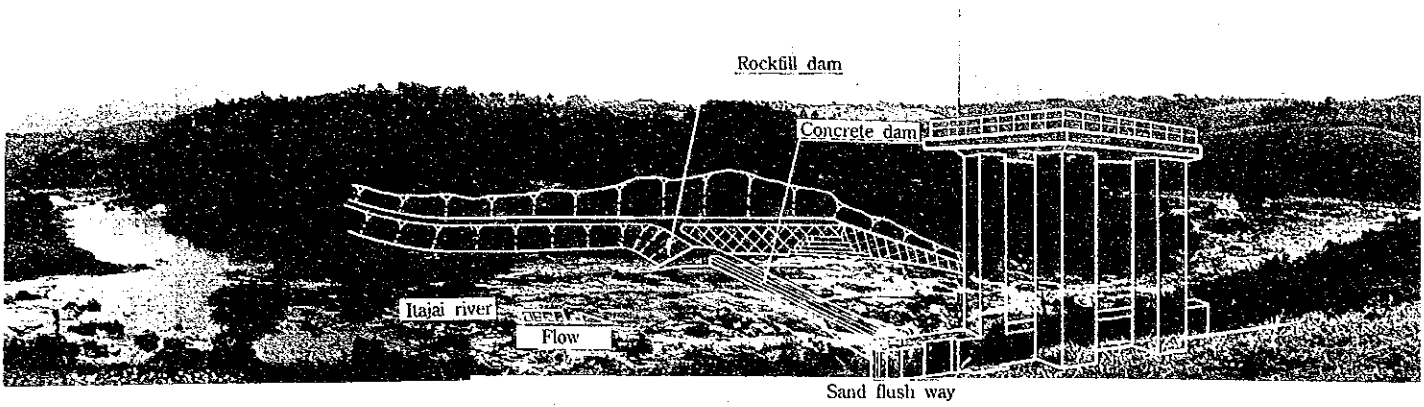


SALTO PILÃO HYDROELECTRIC DEVELOPMENT PROJECT

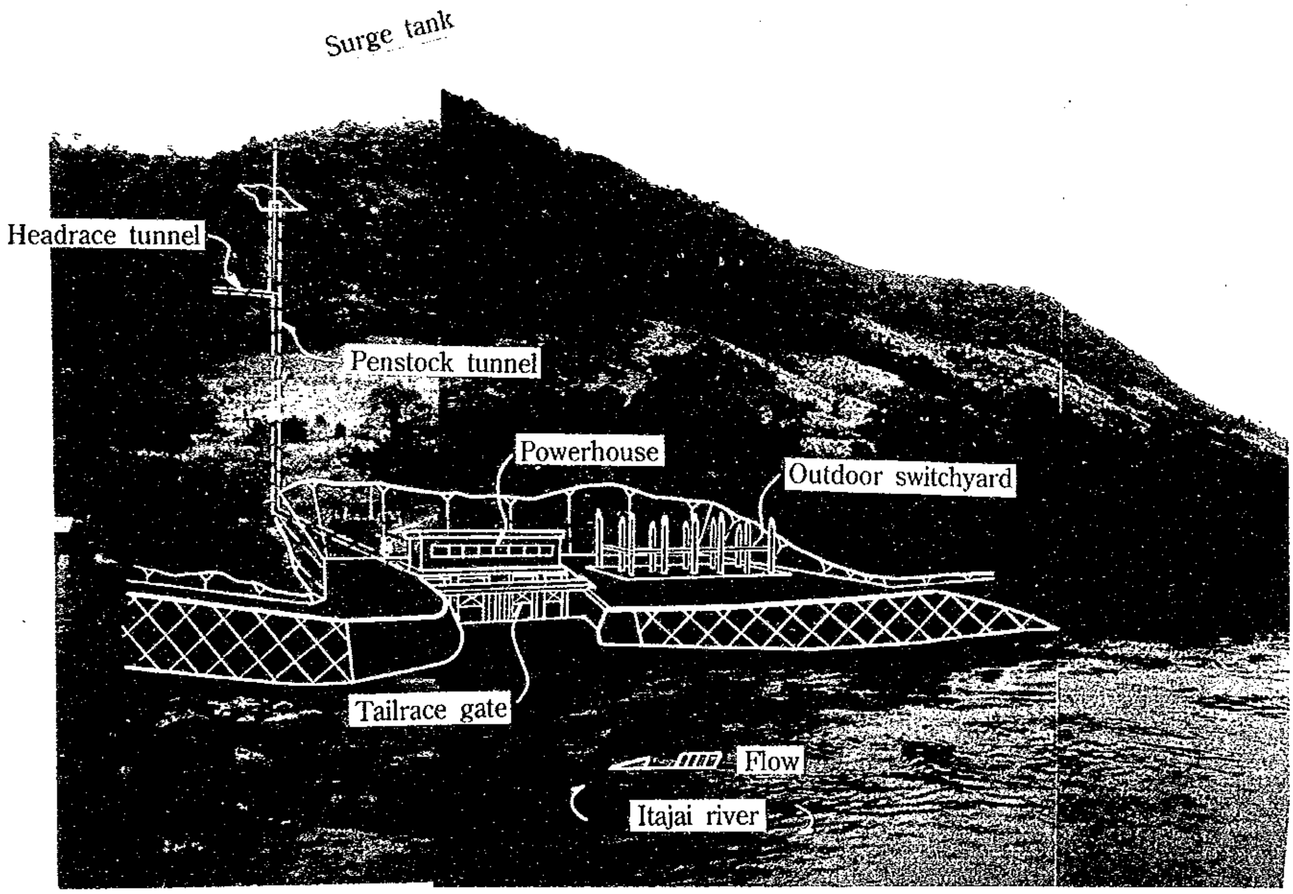
LOCATION MAP



1. Salto Pilão Dam Site
(Downstream View)



2. Dam Site (Looking from Right Abutment)



3. Powerhouse

SALTO PILÃO HYDROELECTRIC POWER DEVELOPMENT PROJECT

SALIENT FEATURES

(1) Location

River	Itajaí River
Latitude and longitude	27° 07' S and 49° 30' W
Municipalities	Lontras, Ibirama and Apiúna
State	Santa Catarina, Brazil

(2) Reservoir

Water level;	
Normal maximum	319.0 m
Flood W.L. (1000-year flood)	325.0 m
Area;	
Catchment area	5,597 km^2
Reservoir area at El. 319 m	0.16 km^2
Volume at El. 319 m	280,000 m^3
Daily regulation capacity	nil

(3) River Discharge at Damsite

Average in records	(1941/90)	108.2 m^3/sec
	(Apr.49/Nov.56)	86.3 m^3/sec
Minimum daily	(1941/90)	4.1 m^3/sec
Maximum daily	(1941/90)	2,499 m^3/sec
Minimum monthly mean (- do -)		9.0 m^3/sec
Dam design flood (1000-yr flood)		5,300 m^3/sec
Diversion flood (2-yr flood)		1,100 m^3/sec
Maximum discharge for generation use		90.0 m^3/sec

(4) River at Powerhouse Site

Catchment area	9,041 km^2
Average discharge	174.2 m^3/sec
Powerhouse design flood (10,000-yr flood)	12,000 m^3/sec
Water level;	
Full operation ($Qp=90m^3/s$)	111.5 m
Average load ($Qp=49m^3/s$)	111.2 m
Design flood	125.0 m

(5) Power Generation

Maximum plant discharge for 2 units	90.0 m^3/sec
Average plant discharge (1941/90)	56.3 m^3/sec
- do - (Apr.49/Nov.56)	49.0 m^3/sec
Gross static head	207.5 m
Maximum loss of head	28.2 m
Average loss head (Apr.49/Nov.56)	8.7 m
Effective head at Qp=90 m^3/s	179.3 m
Average effective head (Apr.49/Nov.56)	199.1 m
Total installed capacity	142 MW
Firm energy	70.46 MWy = 617.2 GWh/year
Secondary energy	11.08 MWy = 97.1 GWh/year

(6) Dam and Spillway

Type	Concrete dam with short embankment section and with ungated spillway
Total length	301.0 m
Lowest foundation level	307.0 m
Crest level, concrete	325.0 m
embankment	326.0 m
Maximum height	18 m
Spillway weir crest	319.0 m
Spillway overflow width	200 m
Spillway design outflow	5,300 m^3/s
Spillway chute	Concrete apron without dissipator
Sand flush way;	
Width	5.0 m
Bottom sill level	312.0
Gate, type	Double leaf steel roller gate
dimension (W x H)	5.0 m x 7.3 m x 1 nos.
Stoplog, dimension (W x H)	5.0 m x 1.8 m x 4 nos.
Type of river diversion during construction	Bypass channel type

(7) Intake

Type	Lateral flow intake
Inlet dimensions (L x H)	27.3 m x 10.0 m
Sill elevation	315.0 m
Top elevation	325.0 m

Trash rack (L x H x nos.)	5.7 m x 10.0 m x 4 nos.
Trash rake	Mechanical rake x 2 units

(8) Desanding Basin

Type	Trapezoidal section channel with side spillway
Number of bays	3
Dimension (H x W x L)	7.5 m x 52.9 m x 95.0 m
Inlet gate (W x H)	3.7 m x 4.4 m x 3 nos.
Stoplogs (W x H)	3.7 m x 1.5 m x 3 nos.
Outlet gate (W x H)	3.8 m x 4.8 m x 1 no.
Sand drain gate (W x H)	2.0 m x 1.0 m x 9 nos.

(9) Headrace

Total length (culvert + tunnel)	454 m + 5,638 m = 6,091 m
Culvert, type	Steel-lined concrete conduit
- do - , internal diameter	4.8 m (partially 5.8m)
Tunnel, type	Shotcrete-lined horseshoe section (partially concrete-lined circular section)
- do - , internal diameter	5.8 m

(10) Surge Tank

Type	Cylinder type with port
Diameter, cylinder	17.0 m
- do - , port	2.3 m
Height	42.9 m

(11) Penstock

Type	Concrete-lined vertical shaft and steel-lined horizontal tunnel
Length x diameter, concrete-lined	264.4 m x 4.8 m x 1 no.
, steel-lined	292 m x 4.3 m x 1 no.
, steel-lined	31.5 m x 2.5 m x 2 nos.

(12) Powerhouse

Type of building	Open-air type
Dimensions of building (W x L x H)	31.5 m x 57.5 m x 43 m

Ground level	125.0 m
Turbine setting level	107.2 m
Number of generating units	2 nos.
Inlet valve, diameter	2.5 m
Draft tube gate, type	Slide gate
Dimension (L x H)	3.4 m x 3.1 m x 2 nos.
Turbine, type	Vertical shaft Francis
rated output per unit	72.6 MW
rated head	179.3 m
rated rotation	327.3 rpm
Generator, type	Semi-umbrella, synchronous alternator
, rated output per unit	78.9 MVA
, power factor	0.9 (lagging)
, rated voltage	13.8kV
, Frequency	60 Hz
Station crane, span	17.0 m
, capacity	2 MN
Transformer, type	Oil-cooled, 3-phase, outdoor type
, voltage ratio	13.8/138kV
, rating x unit	80 MVA x 2 units

(13) Cost

Investment cost	US$ 215.5 million (Dec. 1992 price)
Unitary cost of installation	1,518 US$/kW
Unit cost of firm energy	34.7 US$/MWh

FEASIBILITY STUDY ON SALTO PILÃO
HYDROELECTRIC POWER DEVELOPMENT PROJECT

MAIN REPORT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

(1) Organizations and Agencies

JICA	:	Japan International Cooperation Agency
ACARESC	:	Associação de Crédito e Assistência Rural de Santa Catarina
CASAN	:	Companhia Catarinense de Águas e Saneamento
CEDEC	:	Coordenação Estadual de Defesa Civil
CELESC	:	Centrais Elétricas de Santa Catarina S.A.
CEPA	:	Instituto de Planejamento e Economia Agrícola de Santa Catarina
CIDASC	:	Companhia Integrada de Desenvolvimento Agrícola de Santa Catarina
CONAMA	:	Conselho Nacional do Meio Ambiente
DNAEE	:	Departamento Nacional de Águas e Energia Elétrica
DNER	:	Departamento Nacional de Estradas de Rodagem
DER	:	Departamento de Estradas de Rodagem
DNOS	:	Departamento Nacional de Obras de Saneamento
ELETROBRAS	:	Centrais Elétricas Brasileiras S.A.
ELETROSUL	:	Centrais Elétricas do Sul do Brasil S.A.
EMATER	:	Empresa de Assistência Técnica e Extensão Rural
EMBRAPA	:	Empresa Brasileira de Pesquisa Agropecuária
EMPASC	:	Empresa de Pesquisa Agropecuária de Santa Catarina
FATMA	:	Fundação de Amparo à Tecnologia e Meio Ambiente
FGV	:	Fundação Getúlio Vargas
FUNPIVI	:	Fundacão de Pscicultura Integrada do Vale do Itajai
FURB	:	Fundacão universida de Regional de Blumenau
GAPLAN	:	Gabinete de Planejamento e Coordenação Geral
GCPS	:	Grupo Coordenador de Planejamento dos Sistemas Elétricos
IBAMA	:	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais de Nova Veis
IBDF	:	Instituto Brasileiro de Desenvolvimento Florestal
IBGE	:	Instituto Brasileiro de Geografia e Estatística
IBRD	:	International Bank for Reconstruction and Development
ITAG	:	Instituto Técnico de Administracão e Gerência
MA	:	Ministério da Agricultura
MDUMA	:	Ministério do Desenvolvimento Urbano e Meio Ambiente
PORTOBRAS	:	Empresa Brasileira de Portos
SAMAE	:	Servico Autônomo Municipal de Água e Esgoto
SUDEPE	:	Superintendência do Desenvolvimento da Pesca
UFSC	:	Universidade Federal de Santa Catarina
ITAIPU BINATIONAL	:	Entity for hydropower development of Rio Paraná, which was established based on the treaty between Brazil and Paraguay

(2) **Abbreviations of Measurement**

Length

mm	:	milimeter
cm	:	Centimeter
m	:	meter
km	:	kilometer

Area

cm^2	:	square centimeter
m^2	:	square meter
ha	:	hectare
km^2	:	square kilometer

Volume

cm^3	:	cubic centimeter
l	:	liter
M^3	:	cubic meter
MCM	:	million cubic meter

Weight

g	:	gram
kb	:	kilogram
ton	:	metric ton

Derived Measure

m^3/sec	:	cubic meter per second

Money

Cr$	:	Cruzeiro
US$1	:	US dollar
¥	:	Japanese Yen

Time

s or sec	:	second
min	:	minute
hr	:	hour
yr	:	year

Electricity

Hz	:	Hertz
kV	:	Kilovolt
MVA	:	Megavolt Ampere
kVA	:	Kilovolt Ampere
MW	:	Megawatt
kW	:	Kilowatt
MWy	:	Megawatt year
GHh	:	Gigawatt hour
MWh	:	Megawatt hour
kWh	:	kilowatt hour
V	:	Volt
W	:	Watt

Others

%	:	percent
°C	:	degree centigrade
10^3	:	thousand
10^6	:	million
10^9	:	billion

(3) **Exchange Rate**

Official rate as of December 1992 : US$ 1 = Cr$ 11,163.33 = ¥ 120

(4) **Others**

GDP	:	Gross Domestic Product
GRDP	:	Gross Regional Domestic Product
GVA	:	Gross Value Added
VA	:	Value Added
PV	:	Production Value

(5) Previous Studies

Power Study - 1969	Power Study of South Brazil, Aug. 1969 - UNDP/Canambra
Itajai F/C Study - 1977	Master Plan on the Itajai River Basin Flood Control Project, Jan. 1988 - JICA
Lower Itajai F/C Study - 1990	Feasibility Study on the Flood Control Project in the Lower Itajai River Basin, Mar. 1990 - JICA
Hydro Inventory Study - 1991	Master Plan and Pre-feasibility Study on the Itajai River Basin Hydroelectric Power Potential inventory project, Oct. 1991 - JICA

Chapter 1 INTRODUCTION

1.1 Background of Water Resources Development in the Itajai River Basin

The Itajai river basin is characterized by its irregular river bed slope in the middle river stretch where the gentle river bed slope changes remarkably to steep river bed slope and a head of more than 200 m is created by this river bed slope variation. The study on the Salto Pilão Hydroelectric Power Development Project (the Project) by harnessing this head and river discharge in the main stream of the Itajai river was initiated in 1963 by Servix Engenharia S.A as the study on the Canoas Diversion. In 1966, the Project was restudied as a part of the power study of south central Brazil by Canambra Engineering Consultant Ltd. Based on the field surveys and studies performed through 1967 to 1968, a feasibility study on this Project was prepared in 1969 as a study on the Canoas Diversion project.

In order to mitigate the flood damages in the Itajai river basin, basin wide flood control study in the whole Itajai river basin and feasibility studies on the flood control project in Blumenau-Gasper areas and in the lower Itajai river basin were performed by JICA in the period from March 1986 to March 1990.

Overall hydroelectric power potential survey and study in the Itajai river basin were carried out in the period from June 1990 to October 1991 by JICA to identify the hydropower potential in the basin as a master plan and to study the most promising project on pre-feasibility level. In this JICA study, the Project was identified as the most promising project and pre-feasibility study was carried out in this survey period.

The Government of the Federative Republic of Brazil (hereinafter referred as the Government of Brazil) requested to the Government of Japan the technical assistance to promote the feasibility study on the Salto Pilão Hydroelectric Power Development (the Study). In response to the request of the Government of Brazil, the Government of Japan has decided to conduct the Study in accordance with the Basic Agreement of Technical Cooperation between the Government of Japan and the Government of Brazil signed in Brasília on September 22,1990. JICA, the official agency responsible for implementation of the technical cooperation programmes of the Government of Japan and CELESC, the executing agency responsible for implementation of the technical cooperation of the Study agreed the scope of works of the Study on December 15, 1992 in Florianópolis. The Study was carried out spanning 13 months from March 1993 by Study Team of JICA, in accordance with the determined scope of works.

1.2 Objective of the Study

The objective of the Study was to formulate feasibility study and design works related to the Project on the Itajaí river based on the result of pre-feasibility study which was completed in October 1991 and to transfer relevant technologies to Brazilian counterpart experts in the course of the Study.

1.3 Outline of Development

The Salto Pilão project site is located on the middle reach of the Itajai river which flows in eastern central part of the state of Santa Catarina in the South Region of Brazil as shown in Fig. 1.1.

It has been contemplated to develop the hydroelectric power potential by harnessing a head of about 210m between the downstream of Lontras and downstream of the confluence with the Itajaí river and the Norte river, one of the largest tributaries of the Itajaí river. In order to promote the hydroelectric power development, it was planned to construct a 18m high dam at 10km downstream of Lontras, to divert the river water of the Itajaí through a 6km long headrace tunnel to be provided in the right bank of the Itajaí river and to generate electric power of about 142MW at a power station proposed at Subida, about 5km downstream from the confluence with the Norte river.

1.4 Organization of the Study

The Study was carried out by dividing into three stages; i.e., the preliminary study stage, field investigation stage and feasibility study stage. Overall work flow is illustrated in Fig. 1.2.

In the preliminary study stage, preparatory works necessary for feasibility study and design were carried out. These are data collection and their review, confirmation of design criteria including collection and confirmation of design criteria necessary for planning and designing of this hydropower project through discussion with ELETROBRAS/DNAEE/CELESC's expert, preliminary environmental study including reconnaissance of the area likely to be affected by the Project and identification of properties to be affected and socio-economic study including collection of data related to socio and economic background of the Project and compilation of information necessary for hydroelectric power development.

In the field investigation stage, topographic survey, geotechnical investigation and sediment flow survey were performed. In the topographic survey, aero-photo mapping in the project area, topographic survey were carried out. For geotechnical investigation, exploratory drilling for dam site, waterway, powerhouse site and proposed quarry site and laboratory rock test were performed. For sediment flow survey, sampling and test work were carried out at the Itajaí river at about 4km upstream of the proposed damsite.

In the feasibility study stage, a series of feasibility study and design works were carried out. These are hydrological study, environmental study, power system and demand study, development plan formulation to determine optimum power development scale and to study principle structures, designing of main component of the Project, construction programming, cost estimation and project evaluation.

1.5 Field Survey Carried Out

To obtain the basis for feasibility study and design, topographic survey, geotechnical investigation and sediment flow survey were carried out. For topographic survey, aerial-photo mapping with acreage of 63 km^2, scale of 1:5,000 and contour interval of 2m, topographic survey at dam and powerhouse sites with a scale of 1:2,000 were performed by local contractors. For geological investigation, core boring of 300m in total length was carried out for damsite, headrace tunnel route, powerhouse site and quarry site. Laboratory rock test was made for the rock samples. The sediment flow survey was carried out 20 times in total at downstream of Lontras to estimate sediment yield in the Itajaí river.

1.6 Study Progress

The study was carried out by dividing into the preliminary study stage, field investigation stage and feasibility study stage. In the preliminary study stage of March 1993, the existing development schemes were reviewed. Brazilian criteria for planning and designing were discussed with staff of ELETROBRAS and CELESC, alternative frameworks of the Project were prepared and a detailed work plan was prepared based on the result of the collected data and their review and field reconnaissance. The field investigation of May to July 1993 was devoted to survey works including topographic survey, geotechnical investigation including geological core boring and laboratory rock test and hydrological observation of sediment loads. In the feasibility study stage from June

1993, a series of feasibility study including feasibility design, cost estimate, project evaluation and project implementation schedule was carried out based on the physical site conditions, results of hydrological study and environmental impact assessment. The work progress is illustrated in Fig. 1.3.

1.7 Content of Report

The report comprises three parts, namely, Executive Summary, Main Report and Supporting Report.

The Executive Summary states summary of the field surveys and feasibility study results. The Main Report `presents the project area including hydrology, geology and power demand and supply status and plan formulation to determine optimum scale of major project component, feasibility design of the optimal scale of project facilities, construction plan and costs, environmental impact assessment, economic and financial analyses and project implementation program. The Supporting Report comprises reports stating results of field investigation and basic studies and analyses necessary for feasibility study and design of the Project.

1.8 Acknowledgment

The study team wishes to express a sincere gratitude and appreciation to all the officials concerned and their staff for their substantial collaboration rendered during the course of the study. The study team acknowledges invaluable assistance received from CELESC which was the counterpart executing agency in this study.

Thanks are also extended to the cooperative responses accorded to the team's activities in the field by officials of the regional and provisional offices.

Chapter 2 SUMMARY AND CONCLUSION

2.1 Summary of the Study

Results of the study in respective fields are summarized as follows;

(1) Hydrology

(i) In the low flow analysis, a long-term daily mean discharge at the proposed damsite was estimated based on the ratio of the catchment area of the proposed damsite and Rio do Sul gauge which is located at about 20 km upstream of the proposed damsite. The estimated monthly mean discharge during the period from January 1941 to December 1990 was 108.2 m3/sec.

(ii) Flood flow analysis was made to estimate the probable peak flood discharges and their hydrographs with the selected return period by applying a mathematical simulation model and using rainfall data. The simulation model was established through calibration using rainfall and flood records for major floods in 1978, 1980, 1983 and 1984. The estimated flood peak discharges at the proposed damsite are as follows;

Return Period (year)	Peak Flood Discharge (m^3/sec)
2	1,600 (1,100)
10	2,600 (2,500)
100	3,600
1000	5,300
10000	7,400

Note : Figures in brackets show the flood peak discharge considering regulation effect by Sul and Oeste reservoirs.

(iii) In order to estimate the relationship between sediment loads including bed, suspended and wash loads and river flow discharge, sediment flow survey was carried out at Lontras bridge at about 4 km upstream of the proposed damsite for the period of 2 months from June to July in 1993. Based on this survey result, sediment rating formula was established. By applying a long-term daily mean discharge for 50 years to the established formula, annual average sediment loads was estimated at 247,000 m^3/year.

(2) Geology

In this study, core boring of 10 holes (300 m in total length) associated with in-situ water pressure test (Lugeon Test) was carried out for the proposed damsite, surge tank, penstock line, powerhouse and quarry sites. For headrace tunnel route, previously performed core boring data were referred. To confirm properties of rock, laboratory rock test was carried out.

(i) Three alternative dam axes were selected. These are named as axes B, C and D from upstream to downstream sites. The dam axis C coincides with the axis proposed in the previous Hydro Inventory Survey in 1991. The other axes B and D are located at about 500m upstream and downstream of the dam axis C respectively. The core boring was planned only to the axis C since the axis B was investigated in the previous studies and their data can be utilized and for the axis D, geological condition was expected to be similar to that of the axes B and C. Result of core boring for the axis C clarified that outcrop of granite scatters in the river bed but no rock outcrop appears on slopes of both banks, overburden including highly decomposed granite layer on both banks is deep and rock lies inclining towards inside of hills.

(ii) Length of tunnel is 5.5 to 5.9 km for the respective dam axes. Most part of the tunnel route passes granite mass zone except for downstream end portion of about 100 m which passes rhyolite zone. As far as the result of past drilling and geological reconnaissance is concerned, any sign of fault was not found along the lineaments except for rhyolite zone where many joints and cracks develop in the rock mass. Concrete lining for headrace tunnel may be omitted in the granite zone except in the portal, some portions crossing small valleys and rhyolite zone.

(iii) Result of core boring for the proposed powerhouse site in the upstream site shows that rhyolite is exposed on rock cliff just below the surge tank area and also on river side edge, depth of the soil overburden is about 25m at the maximum and generally becomes thinner towards the river side and the weathered rhyolite is about 10m in maximum and about 6m at the powerhouse site.

(iv) Natural deposit of sand and gravel mixture is scarce in and around the project area. Any deposits containing sand do not appear in the river bottom in 85 km long stretch up to Blumenau. Most practical way to obtain materials for concrete aggregate will be utilization of the proposed quarry near the construction site. The core boring was made for two alternative quarry sites located at 1 km upstream and 3 km downstream of the dam axis

B respectively. The available quantity of the rock materials for each of the quarry sites was estimated at 75,000 m^3 and 150,000m^3, respectively.

(3) Power Demand and Supply Status

(i) The power network formed by south and southeast power system and Itaipu power station which are interconnected each other is the biggest in Brazil. Total of the installed capacity of these systems was 45,000 MW and energy production was 198,900 GWh in 1992.

CELESC's transmission and distribution lines are linked with south/southeast transmission system through ELETROSUL's substations in the state. CELESC takes care 100 % of power demand of the state of Santa Catarina. The existing power supply facilities owned and operated by CELESC in 1992 comprise 12 power stations of run-of-river type hydropower plants with 73 MW in total capacity, transmission line of 3,454 km in total length. Electric energy required in CELESC system increased from 4,360 GWh in 1983 to 7,798 GWh in 1992 with average growth rate of 6.7%. However, amount of energy generated by CELESC itself unchanged.

(ii) The south system in which CELESC system is involved is one-fifth of the integrated south/southeast system in power market scale. Distribution of electric power to consumers in the south system is handled by four state power companies. The sold energy in 1990 - 1992 by these state companies was 31,850 GWh and the ratio of sold energy in each sector was 40 % for industry and 27 % for residential uses.

In the recent 10 years, number of consumers in CELESC system has rapidly increased especially in residential and industrial sectors, namely 1.8 times and 2.8 times respectively.

(iii) Monthly and hourly power demand in CELESC system for recent 22 years were investigated based on the available records. Result of this investigation shows that there are two load peaks every day, i.e., high peak in night time and low peak in day time, daily load factor varies between 65 and 81 % and in recent 10 years, monthly peak demand gradually increased and annual load factor was improved from 55 % in 1990 to 65 % in 1990.

(iv) On the basis of state-wide demand projection indicated in 10-year plan, annual power demand up to 2003 for south/southeast system has been calculated. The projected demand is 33,000 GWh in 1992 and 52,500 GWh in 2003 with annual average growth rate of 4.8%.

The power demand projection for CELESC system was calculated up to 2003. The projected demand is 1,360 GWh in 1982 and 2,220 GWh in 2003 with annual average growth rate of 4.5 %.

(v) Future balance of power and energy in the south/southeast system was studied based on power expansion program. According to this study, supply capacities of both peak power and energy seem to have sufficient reserve against demand for future 10 years if all the planned projects are implemented on schedule. However due to financial constraint and environmental problems, many of on-going projects in the south/southeast system are delaying in their completion. CELESC is continuously vulnerable to power shortage because its own generation is remarkably small and majority of its required electricity has to be purchased from other companies. In order to minimize possible future power shortage of CELESC due to retardation of power projects by federal utilities and to stabilize CELESC's power supply capacity, further input of CELESC's own generation plants is indispensable.

(4) Plan Formulation

The plan formulation for selection of the optimal development scale was studied on combination of alternatives in respect of the three items i.e., (1) selection of damsite, (2) dam scale including full supply level and (3) installed capacity of power plant.

(i) For selection of the dam axis, three alternative damsites were contemplated. The dam axis C has been selected in the Hydro Inventory Study in 1991. The dam axis B is located on the top of the rapid, at about 500m upstream of the dam axis C. The dam axis D is located at 500m downstream of the axis C. The selection of the optimal dam axis was studied from two cases, i.e., without and with regulation pond to cope with the daily peak power operation. The study on the selection of the dam axis and dam scale was made considering five parameters, namely (a) full supply level (FSL), (b) maximum plant discharge, (c) reservoir storage capacity, (d) reservoir sedimentation and (e) design flood flow. For setting FSL, 8 cases, namely, two cases for dam axis B and 3 cases for each of dam axes C and D were contemplated considering constraint of designed water level which does not exert any influence to the land of the existing resort complex located at about 1,000 m upstream of the dam axis B. For 8 cases set out, six cases of maximum plant discharge were contemplated assuming that the river flow of 7.2 m^3/sec is released to the downstream as river maintenance flow. For these combinations, 48 alternatives were studied. In this study, reservoir storage capacity considering 60 % of load factors for 3-hour peak operation, scale of non-gated spillway to discharge safely a half of 10,000 year flood and storage volume to accommodate the annual sediment deposit of 123,000 m^3 were contemplated.

(ii) For these 48 alternatives, construction cost and power benefit were calculated assuming that the headrace tunnel with shotcrete lined horse-shoe shaped section, single cylinder type surge tank and powerhouse with two generating units and plant discharge of 90 m^3/sec are adopted. In case with regulation pond, power energy is increased compared with the case without regulation pond since plant operation can be continued using stored water even through the reservoir inflow is lower than the restricted minimum plant discharge. The result of the comparative study showed that the lower dam is more economical for all dam axes, and the following 6 cases were selected for further study.

Dam Axis	Optimal F.S.L (m)	
	Without Regulation	With Regulation
B	319	324
C	310	315
D	305	310

(iii) For the selected 6 cases, mean cost of generation, which is one of the factors to evaluate viability of the power project, was estimated and it was clarified that the dam axis B is superior from the viewpoint of net benefit and mean cost of generation in either case of with and without regulation. The study on two cases with and without regulation for the dam axis B was made by means of firm energy, benefit, cost and mean cost of generation. Result of the study showed that the cost of power generation scheme with regulation is 12.8 % higher than that of the case without regulation, firm energy for the case with regulation increases by 5.8 % and consequently mean cost of generation for the case with regulation increases by 7.8 % compared with those for the case without regulation. This means that peak generation by regulating pond is not economical. Based on this result, pure base load power scheme without regulating pond was employed.

(iv) For the selected dam axis B for the case without regulating pond, comparative study to determine the optimum installed capacity was made for 6 cases of the maximum plant discharge. It was concluded from the result of study that the plant capacity of 142 MW is the most optimal scale since net benefit shows the largest value.

(5) Optimization and Design of Project Components

(i) Based on the result of plan formulation, optimization and feasibility design of the project components were carried out for civil works including dam and spillway, intake/desanding basin, headrace tunnel, surge tank, penstock and powerhouse, hydromechanical equipment and generating equipment.

(ii) For optimization study on the dam and spillway, two cases i.e., concrete dam with non-gated spillway and rock fill dam with gated spillway were studied, and concrete dam with non-gated spillway was selected from the economical and operational viewpoints. The designed concrete dam is 18 m in maximum height and 301 m in width including non-gated spillway section of 200 m.

(iii) The intake facilities comprise sandflushway, desanding inlet, desanding basin and intake. The designed sandflushway located on the right abutment of the dam has double leaf gate with 5 m wide and 7.3 m high. The desanding basin consists of three chambers with sand flush facilities. The chamber with 52.9 m wide and 190 m long is located on the right abutment immediately downstream of the dam axis. The intake facility with 3.8 m wide and 4.8 m high roller gate is located immediately downstream of the desanding chambers.

(iv) Two water conveyance methods, i.e, free flow tunnel and pressure tunnel are conceivable. Among these, pressure tunnel was selected from the economical viewpoint. There are two deep valleys downstream of the desanding basin. For crossing these valleys, culvert type waterway was adopted. The total length of the pressure tunnel is about 6100 m, and shotcrete lining for about 90 % of the total length and concrete lining for the remaining part were adopted. The determined optimum diameter is 4.8 m for the concrete lining part and 5.8 m for the shortcrete lining part.

(v) For the surge tank, cylindrical shaft type with orifice and diameter of 17 m was adopted. For the penstock, high pressure tunnel penstock with combination of 174 m long vertical shaft and 414 m long horizontal tunnel was employed. Length of the tunnel lined with steel liner is 324 m from the powerhouse and the other is the concrete lining section with 4.8 m in diameter. A bifurcation was set at 43 m upstream from the center of the generating unit. Diameter of the section with steel liner before the bifurcation is 4.3 m and 2.5 m in its downwards.

(vi) Number of the generating unit was studied based on the relationship among maximum plant discharge, combined efficiency, power loss due to planned stoppage, power loss due to unexpected stoppage, construction cost and duration of non-operation period.

Based on this study, two units installation was employed. For type of the powerhouse, open air type was selected based on the comparative study. Two alternative powerhouse sites are conceivable. One is the site proposed in the pre-feasibility stage and the other is located at 400 m downstream of the originally proposed site. The upstream site was selected mainly due to environmental reason. The designed powerhouse is 58.5 m in length, 31.5 m in width and 43.5 m in height.

(vii) A series of the generating equipment including hydraulic turbine, generator and main transformer were designed in accordance with general standard and result of the optimization study. The designed features of the generating equipment are as follows :

Hydraulic turbines ;	Two units of hydraulic turbine of vertical shift, single runner, single flow, Francis type. a rate output of 72,600 kW.
Generator ;	Two units of generator of three-phase, vertical shaft, semi-umbrella type synchronous alternator, rated at 78,900 KVA, 60 Hz, 0.9 power factor, 13.8 kV and 327.3 rpm.
Main transformer ;	Three-phase, two-windings, oil-immersed, OFAF cooling and outdoor use type with an off-circuit tap chamber.

Two circuits of 138 kV transmission lines will be introduced to this power station by means of T-branch of the double circuit transmission line between Blumenau and Rio do Sul substations. A part of the existing Blumenau - Rio do Sul line is still single circuit line as of 1993 but is scheduled by CELESC to be revised to double circuit line by end of 1994.

(6) Construction Plan and Cost Estimate

(i) Major construction works of this project comprise civil works including concrete dam, intake/desanding basin, headrace tunnel, surge tank, penstock line and power station and a series of hydromechanical works including gates, penstock and power generating equipment. The construction work of the concrete dam will be executed spanning two years diverting river water alternately by cofferdam and using concrete bucket and crane. About 6 km long horse-shoe shaped headrace tunnel will be executed by drill and blasting method and covering with shotcrete lining for majority of the tunnel length. The penstock line consists of about 174 m long vertical portion and 414 m long horizontal portion. The circular shaped penstock with inner diameter of 4.8 m in the vertical part will be executed using a raise climber and covering with concrete lining. Majority of the penstock in the horizontal part will be covered with steel lining. All the gates and penstock are scheduled to be manufactured at local factories and installed immediately after the completion of the civil works. The generating equipment will be procured through international tendering and majority of them will be erected after the powerhouse crane is available.

(ii) The project cost was estimated assuming that price level for cost estimate is December 1992, exchange rate is US$ 1 = Cr$ 11, 163.33 = Japanese Yen 120 and cost estimate is made based on the standard budget format of ELETROBRAS. The project cost estimated on the basis of these assumptions is US$ 215.5 million (or Cr$ 2,405,195 million). While, it was assumed that the project cost comprises the foreign currency portion and local currency portion. Based on the assumed ratio of the foreign and local currency components of the construction material and equipment, the project cost was divided into US$ 105.3 million of the foreign currency portion and US$ 110.2 million of the local currency portion.

(7) Environmental Impact Assessment

The environmental impact assessment was made to identify and predict the impact of the defined project features from viewpoints of natural and social environments and to propose mitigating measures for the effect to the project.

Identification of Signification Potential Impacts

(A) Physical environment by Project Activity

(i) Scenic Resources; It is expected that degradation of the landscape is of middle importance, due mainly to the effects caused by the construction of the surge tank, the possible exploitation of quarry A, and the effects of the river flow reduction on the island tourist resort located at about 8 km downstream of the damsite. The impoundment to be created is very small, and it will basically promote a modification of fast moving waters into slow moving waters in approximately 16 ha.

(ii) Topography and landscape; The proposed place for the project does not compose a typical scenery when compared with the traditional landscape of the Itajaí valley. There are several quarries over the hillside located in parallel with the river and these will cause degradation of the slope. The proposed reservoir will only have 0.16 km^2, and the extent of the impounded water level will only reach some 0.8 km upstream of the damsite. This impoundment is considered very small with a very fast turnover rate for the impounded water and only a few properties are to be submerged.

(iii) Soils; Most of the soils in the reservoir area are of hilly topography, restricting annual crops, with good aptitude for reforestation and pasture. It is estimated that there is no land suitable for annual crops. The potential impact on the soils of this area is considered to be no significant. The powerhouse area comprises majority the soils with aptitude of restrictions to annual crops, and the potential impact for the soils of the area due to the project activities are considered non significant. In the spoil bank areas, the soils are dedicated to pasture and grasses. The topography of the areas have a steep gradient, and no species of commercial or scientific interest and found or reported. Besides, these areas represent no significant subsistence of economic activities.

(iv) Water quality; During implementation of the project, the main effect on the water quality is the increase in the water turbidiness and the consequent effect to the river downstream. This effect is considered to be of medium importance, due to the fact that the turbidiness of the river is already adapted to this condition. No industrial activity or urban settlement exists in the stretch between the damsite and the Itajaí do Norte confluence. No water use for industry, agriculture or other human uses are detected, and no pollutant sewage, sanitary, agricultural or industrial are recorded or found to be released in the river.

(v) Mineral resources; No mineral resources are foreseen to be affected by the project activities. The mineral resources found in the area are only clay for ceramics, and kaolin for masonry stone, and these have low economic importance.

(vi) Roads; There are 18 access roads which may be utilized in the implementation of the project (AR-1 to AR-18). All of them except two (AR-1 and AR-17) are existing rural roads that must be reinforced and/or widened to accept the continuous traffic of vehicles, as well as the heavy weight of the materials to be transported. The actions of road improvement will not cause the negative impact on the environment, since these are existing road and no new areas will be opened through the construction of new roads. The exception are the roads leading to the surge tank (AR-1) and to penstock drainage adits (AR-17).

(B) Biological environment

(i) Flora; This project site is located in an area which is neither nucleus nor buffer zone of the Atlantic forest ecosystem. In the reservoir area, most of the arboreal vegetation has been already removed. All the vegetation in the directly affected area is secondary type vegetation in several stages of regeneration. The vegetation to be removed for reservoir exists only on the river banks and on the islands located in the reservoir. This impact is considered irreversible, but of little importance, due to the small area to be affected. The vegetation cover at the sides of the river in the stretch between the damsite and the Itajaí do Norte confluence has been highly degraded due to deforestation. In the powerhouse area, the slopes are very steep and rocky and the vegetation is secondary. In the surge tank area, the clearing of the vegetation is more conspicuous, since it is well preserved in this area. For probable area to be cleared consisting of 1.1 ha, including the access road, the impact is considered of middle importance and reversible. Vegetation in spoil banks is limited to grasses and bush and all the spoil banks chosen are degraded. The impacts on the flora are not considered significant. There is no aquatic flora of economic or scientific interest reported for the river stretch between the damsite and the Itajaí do Norte confluence.

(ii) Fauna; Only 800 m long stretch which is the longitudinal length of the created reservoir will be the extension of the transformation from fast moving to slow moving waters. There is no thermal stratification foreseen in the reservoir. The eutrophic conditions to be expected in the reservoir will not cause the deterioration of the water quality because of the absence of stratification and there is no evidence recorded as to infer that the fish species present in the river require migration to fulfill any of their vital functions. The bird species are common and usually found in degraded areas. Since the project will not affect the forest areas and the extent of the project area is relatively small, the impact on the avian fauna is considered to be no significant.

(iii) Endangered and protected species; Since the project area is located at outside of buffer and nucleus zones and has been highly degraded, no species in the category of endangered or protected species are found or reported in the project area.

(iv) Sensitive habitats; Due to the same situations mentioned in the above, no sensitive habitats are encountered in the proposed project area.

(v) Significative wildlands; Due to also the same situations in the above, there are no significant wild lands to be affected within the project area.

(vi) Species of commercial importance; The species of commercial importance found within the project area are fish species, which are an attraction for sport fishermen upstream of the damsite. It is foreseen that the creation of the reservoir will enhance the population of fish, and also increase the population of the sport fishermen. The impact created by the reservoir is considered positive.

(C) Socio-cultural environment

(i) Land; In the reservoir area, the areas to be submerged are minimal as being 4 ha, and do not involve important agricultural activities. No major impact in farming or agricultural activities is foreseen in the reservoir area. There is no farming activity along the river stretch between the damsite and the Itajaí do Norte confluence. CONAMA regulation requests to provide protection belts of 100 m horizontally measured from the highest level of the reservoir. In the reservoir area including 100 m wide buffer area along the reservoir margin, intake, desanding basin, borrow pits, spoil banks, surge tank and powerhouse, 25 houses are to be relocated and the areas to be compensated is about 100 ha in total. In the powerhouse site, the construction works will cause a disturbance in the economic basis of the community, and the permanent risk of accidents because of the increased traffic of vehicles, dislocation of rocks caused by blasting, along with noise and dust. The relocation of 10 nos of the houses will probably be the option to reduce these impacts. No touristic or recreational use of the river between the damsite and the Itajaí do Norte confluence exists except for the island tourist resort located at some 8 km downstream of the damsite. The potential impact expected is a reduction of the river flow. These effects will enhance the use of the river by the local tourists approaching the island.

(ii) Population; The job availability during construction phase will generate about 400 new jobs. This impact is considered non permanent and reversible in its consequences.

(iii) Historical-cultural patrimony sites; There are no patrimony except that represented by the stretch of railroad. It is desirable that the existing tunnel in the selected place for the quarry is maintained and this element will constitute the nucleus for a historical park of the region in question.

(iv) Water uses; The water use for agricultural purposes in the project area is incipient or non existing, but there is some uses for irrigation in the upstream sector of the damsite along the surroundings of the left bank. There is no farming activity along this river stretch between the damsite and the Itajaí do Norte confluence because of the steep slopes of the river banks with rocky areas and poor drainage. No impact is expected on the agricultural sector in the project area because of no water use. There are no populations in the vicinity of the river banks along the river stretch between the damsite and the Itajaí do Norte confluence. The few isolated houses in the upper portion of the slopes do not use the river water for their subsistence, and the potable water is extracted from water wells. In this project, the reservoir volume and surface are very small with a very fast turnover rate and so with a minimum stratification probability. Then the water quality in the reservoir is not expected to deteriorate. Because of these reasons, the water born diseases are not considered as a significant possibility and no major impact is expected in this area.

Consideration of Necessary Measures

(A) Physical environment

(i) Restoration program for degraded areas; The areas to be considered are those around the dam area, borrow pits, quarries, spoil banks, surge tank and powerhouse. The vegetation program shall be started after completion of the project works. Further study on the effects of the river flow reduction upon the landscape value of the Cotia island near Ibirama should be undertaken to evaluate and possibly mitigate this impact.

(ii) River maintenance flow; A river maintenance flow is needed for the maintenance of aquatic life in the river stretch between the damsite and the Itajaí do Norte confluence. The analysis offered that the flow discharge of 3 m^3/sec to be released from the dam will be enough for the aquatic life. However, the river maintenance flow was finally increased to 7.2 m^3/sec which corresponds to 80 % of the minimum monthly discharge at the damsite so as to satisfy the DNAEE's rule.

(iii) Geological impacts; A monitoring program of the geological impacts of the project works to control vibrations induced by blasting in the quarry, tunnel, powerhouse and damsite is advisable. The program will determine the effects of the blasts, and observe the stability of the hillsides.

(B) Biological environment

(i) Ecological station and protection zone for reservoir; CONAMA resolution requests the implementation of an ecological reserve area or station. For definition of this area, the protection areas of the Atlantic forest to maintain the environmental continuity should be contemplated. The budget estimated by law for the ecological station should be allowed for the restoration of the degraded slopes of the river stretch between the damsite and Itajaí do Norte confluence.

(ii) Conservation of Ichthyofauna resources; The conservation of the ichthyofauna resources is directly related to the river maintenance flow. Since scientific data on the existing populations is scarce, an ichthyological program designed to gain more knowledge of the existing species will contribute to establish depopulation programs in areas where this resource is being depleted. Water effluents caused by the concrete batching plant should be pre-settled to minimize the suspended solids, and the liquid effluent should be treated to reduce the PH to a range of 6-8, according to concrete batching plant regulations in Brazil.

(C) Socio-cultural environment

(i) Population resettlement; The community of Subida will probably require resettlement and reorganization of the physical standard of living of the community. The predisposition and expectations of the community should be evaluated, and committee of the local inhabitants should keep up with the relocation process. The decomposition of the productive basis and economic structure of the community should be determined by socio-economy study.

(ii) Public communication regarding flood stigma; The flood stigma associated with the dam construction is an important aspect to be considered, especially for the concerned groups of the communities of Lontras and Rio do Sul. In a lesser degree, community of Blumenau is important to obtain support in the question. A series of talks and explanations should be carried out with the organized groups of these communities such as municipal prefectures, environmental groups and municipal associations, with the purpose of clarifying the fact that the future dam will not have any detrimental effect on the occurrence of floods.

(iii) Manpower qualification program; Manpower qualification in the areas of Subida, Lontras and Ibirama will provide the conditions for the local inhabitants to take advantage of the job availability to be generated by the construction works of the project. The allocation of jobs for qualified people of the village of Subida is considered important. This action can be considered as an added value to the compensation of resettlement. The qualification and recruitment of the workers should entail interviews and data collection.

(iv) Public health control program; The implementation of actions for sanitary vigilance in the project area is essential. Basic sanitary precautions, epidemiological vigilance, permanent research on transmissible diseases. and public awareness thorough different information procedures are countermeasures to be considered. The sewage treatment originated by the construction of camp is highly advisable to avoid a focus of disease vector reproduction. The sewage system is to be constructed according to sound sanitary engineering criteria.

(v) Road signal and surface covering; The overload of the road net infrastructure, especially on the Lontras-Subida road and the village of Subida will require a well designed traffic signal system to minimize the accident probabilities and protection with asphalt to avoid dust during the dry season and muddy condition in the rainy season. The program could be designed by the local transportation department (DNER) by cooperation of CELESC, with a previous briefing of the expected situation by the second to the former.

(vi) Reservoir protection fence and establishment of buffer area; It is possible that visitors to the reservoir area will try to use it as a swimming place. This activity may cause accidents, and CELESC would be legally responsible for such happening. Consideration of countermeasures for this impact includes the expropriation of a buffer zone of 100 m around the reservoir area, and the fencing of this area to limit access. Proper signs of warning and transit prohibition will enhance this action and release CELESC from legal consequences.

Management and Monitoring Plan

(i) Environmental control actions of engineering works; It is prerequisite for implementation of the project to take measures of environmental control including construction process of the access roads, exploitation plan for the quarries, allocation of drainages for the spoil banks and adequate surface finishing and sewage treatment at the construction camp and the establishing of health care for periodic visits.

(ii) The following programs should be prepared and promoted under cooperation of the offices and agencies concerned;

Program	Purpose
- Reservoir cleaning program	Cleaning of the area to be submerged
- Monitoring program for geological impacts	Observation of stability of hillsides
- Restoration program for degraded area	Improvement of degraded area
- Implementation program for ecological area	Conservation of the selected ecological area
- Monitoring and conservation program for ichthyofauna	Conservation of ichthyofauna
- Climate condition observation plan	Observation of flood possibility
- Water quality control program	Evaluation of effect on project on water quality
- Public health control program	Sanitary and epidemiological vigilance
- Manpower qualification program	Project promotion
- Supporting program for municipalities	Project promotion
- Population transference program	Promotion of transference of population from Subida
- Monitoring of traffic regulation	Periodic vigilance of traffic law enforcement

(8) Project Evaluation

(i) The project evaluation to examine the economic and financial viability was made based on the estimated construction cost and the power energy to be generated by this power project. In addition, compitiveness of the project was also examined in terms of the unit cost of generation and loan repayability.

(ii) The economic cost was estimated at US$ 159.5 million by multiplying the economic conversion factors of 0.9 and the financial cost. The economic benefit was estimated based on the marginal cost of 51 US$/MWh which has been specified by ELETROBRAS for the year up to 2000, and also on cost of secondary energy of 11.92 US$/MWh. The estimated value was converted to the economic value using the conversion factor of 0.9. The estimated annual economic benefit is US$ 29.37 million. The economic evaluation of the project was made in terms of economic internal rate of return (EIRR) assuming the economic project life of 50 years. The estimated EIRR is 14.4 %. In order to examine the sensitivity of the evaluations, EIRR was further discussed for the case of cost overrun and benefit reduction. The results are as follows:

(Unit : %)

Reduction of Benefit		Cost Overrun 15 %	0 %
0 %	EIRR	12.7	-
15 %	EIRR	10.9	12.4

(iii) The financial viability of the project was assessed in terms of the financial internal rate of return (FIRR). The project expenditure comprises the investment cost excluding interest during construction, operation and maintenance cost and replacement cost of the major equipment. The estimated project expenditure is US$ 177.2 million. The project revenue is the earning by energy sale. Energy price at generating site was estimated based on CELESC's energy sale and sale income in 1992. The estimated annual project revenue is US$ 26.9 million. Based on the estimated project expenditure and revenue, FIRR was estimated at 12.1 %.

(iv) The loan repayability was examined assuming that 100 % of the project cost is financed with the condition of 10 % of interest and 20 year's loan period including 4 year's grace period. Result of the examination clarified that the project is sound in repayment capability since the accumulated balance becomes positive in 12 years after the loan is fully disbursed.

(v) Based on the financial cost and firm and secondary energies to be generated, mean cost of generation was estimated. The estimated value is 34.7 US$/MWh. While, ELETROBRAS specifies that the marginal cost of firm energy up to year 2000 in South region is 51 US$/MWh. It is concluded from these two values that this power project is worth developing.

(9) Project Implementation Program

(i) The implementation of the project works will be administrated by CELESC. The construction works at the site will be entrusted to and carried out by Salto Pilão Hydroelectric Project Management Office (S.P.M.O) which will be the execution agency and responsible for the construction and management of the project. SPMO has also responsibility on design and construction supervision. The construction of the project works will be entrusted to foreign/local contractors which will be selected by the international tendering under the supervision of SPMO assisted by the selected consultant.

(ii) The construction of the project works will be carried out during the period of 3.5 years. Since the critical path of the project works is the construction works of the 6 km long headrace tunnel and intake/desanding basin which include a huge amount of rock excavation and concrete works, these works will be carried out continuously immediately after the completion of the preparatory works and acquisition of lands. The construction work of about 18 m high dam will be executed spanning 2 years diverting the river water alternately by cofferdam. By about two months before the end of fourth year, all the construction works will be completed and river water will be impounded to accommodate test operation of the generating equipment. Commissioning and commercial operation will be made from the beginning of fifth year.

2.2 Conclusion

Study on future balance of power and energy in the south/southeast system clarifies that supply capacities of both peak power and energy seem to have sufficient reserve against demand for future 10 years if all the planned projects are implemented on schedule. However due to financial constraint and environmental problems, many of on-going projects in the south/southeast system are delaying in their completion. CELESC will be continuously vulnerable to power shortage because its own generation is remarkably small and majority of its required electricity has to be purchased from other companies. In order to minimize possible future power shortage of CELESC due to retardation of power projects by federal utilities and to stabilize CELESC's power supply capacity, further input of CELESC's own power generation plants is indispensable.

This Salto Pilão hydroelectric power development project had been identified by the master plan study performed for whole Itajai river basin as the most promising project. This project intends to develop the power by harnessing the head of about 210 m to be created by natural rapid between the downstream of Lontras and Subida and utilizing the river discharge in the Itajai main stream. It has been proposed to develop this project by pure run-of river type power scheme considering the topographic conditions of the project site and from the environmental aspects. At the proposed damsite, a hard rock consisting mainly of hard granite outrops and the granite zone extends to majority of the headrace tunnel route in the right bank of the Itajai river. Due to these favourable geological conditions, it is expected that no technical difficulties are encountered through the construction works of the project. Result of the environmental impact assessment indicates that only 25 houses (16 families consisting of 77 people) and the areas of 100 ha will be affected due to construction of 18 m high dam, the reservoir area of about 16 ha and related project facilities, and no serious impacts except the above properties are expected due to the project realizations. It has been proved that the project is technically sound and economically viable.

In order to realize the project, a huge amount of construction cost of about US$ 215.5 million is needed, and majority of this cost will have to be procured through an international financing agencies. It is recommended that CELESC will take necessary procedures including loan request and necessary technical assistance through the officials concerned of the Government of Brazil.

Chapter 3 BACKGROUND

3.1 Physical and Human Aspects of Brazil

3.1.1 Physical Ascpects of Brazil

Brazil has a land area of 8,511,965 km^2 which is about 22.5 times that of Japan. The largest dimensions are 4,160 km east-west and 4,190 km north-south. It is bounded by Guiana and Venezuela in the northwest, Colombia and Peru in the west, Bolivia and Paraguay in the southwest and Argentina and Uruguay in the south. To the north and east it faces the Altantic ocean. The geography of Brazil is divided into the flat Amazon region and the Brazilian highland in the eastern and southern regions. The Brazilian highlands gradually increase in elevation towards its eastern coast. The plain area along the eastern coast is very limited but many municipalities are located along this coast.

The general relief of Brazil is relatively low. About 41% of the country is below 250m in altitude, and only 3% is above 900m. Low erosional surfaces and pediplains between 200m and 300m occupy 17% of the territory.

Geomorphically, Brazil is devided into six units; (i) Guiana plateau, (ii) Amazonian plains and lowlands in the northern region (iii) Brazilian plateau in the central coastal and southern regions (iv) Pantanal plain in the western region (v) coastal plains and lowlands in the eastern region and (vi) Uruguay-South Rio Grande plateau in the southern region.

The large Brazilian plateau can be further divided into (i) Central plateau comprising large areas of crystalline plateau and sedimentary plateau (ii) Southern plateau with large areas of sedimentary and basaltic plateau (iii) Maranhão-Piauí plateau corresponding to the uplifted sedimentary Parnaiba basin, (iv) Northeastern plateau of crystalline shield rocks and isolated sedimentary chapadas and (v) Oriental and South-Oriental plateau which is more complex and mountainous part of the Brazilian plateau and comprises crystalline range.

Among the river basins in Brazil, the Amazon and São Francisco river basins in the northern regions are the largest. The Amazon and São Francisco river basins drain 56% and 8% respectively of the land. The famous Paulo Afonso Falls are a part of the São Francisco river. The Paraná river basin in the southern region drains 10% of the land and provides much of the hydraulic power of Brazil. The Brazilian hydraulic power potential is fourth in the world.

The annual mean temperature is 25.9°C in Rio de Janeiro in the southeastern zone and 19.5°C in Porto Alegre in the southern zone. The monthly mean maximum temperature is 26°C and 24°C respectively in Rio de Janeiro and Porto Alegre in January and 26.5°C in Belem in November. The monthly mean minimum temperatures are 20.8°C and 14.2°C respectively in Rio de Janeiro and Porto Alegre in July and 26.4°C in Belem in March. The annual rainfall is 2,770 mm in Belem, 1,074 mm in Rio de Janeiro and 1,313 mm in Porto Alegre.

3.1.2 Human Aspects of Brazil

The population in Brazil was estimated at about 146 million in 1991 and the annual average growth was 2.48% in 1970's and 2.08% in 1980's. The average population density is 17 persons per km^2. The population has been concentrated in the southeastern and northeastern zones. Centralization of population to big metropolitan cities such as São Paulo and Rio de Janeiro in the southeastern zone in particular has been accelerated continuously.

Total land of 8,511,965 km2 in Brazil is classified into 3,700,000 km2 (43,5%) of governmental reserve areas, 2,236,030 km2 (26.3 %) of agricultural lands, 1,006,700 km2 (11.9 %) of forest areas and 1,459,235 km2 (18.3 %) of other lands. The agricultural lands are further divided into 491,040 km^2 of cultivated land and 1,744,990 km2 of pasture.

The national economy of Brazil remarkably expanded in 70's. Its GDP anually grew at the real rate of 8.6% on average. Afterwards, its growth rate decreased to an average of about 2% per annum in the first half of the 80's. Although it recovered to about 8% per annum during '85 to '86, it paced down with negative growth rates in 1988 and 1990 due to world economic recession. In 1987, GDP per capita recorded the peak level of Cr$ 85 thousands at current price or equivalent to approximately US$ 2 thousand. Afteerwards, it gradually went down to approximately US$ 1.9 thousand till 1992. This was caused by economic recession over few years and by constantly increasing population in the country. The composition of major economic sectors, i.e., agriculture, industry and services, changed from 10.8%, 41.1% and 50.7% in 1985 to 9.6%, 33.2% and 53.2% in 1991, respectively. Their annual growth rates were 1.32%, 0.68% and 3.14% on average during six years. The industrial sector recorded the lowest growth. On the contrary, the role of services' sector comparatively increased its importance in the national economy. Incidentally, the GDP growth during the same period was 1.83% per annum on average.

The trade balance in 1991 was US$ 10.6 billion, which was broken down to US$ 31.6 billion of exports and US$ 21.0 billion of imports. The trade balance has been in red during the 70's, due to oil problems. Afterwards, it has turned into the black, owing to retrenching in finance and intensification of import restriction.

3.2 State of Santa Catarina

The state of Santa Catarina is located in the southern part of Brazil with a long triangular shape between the states of Parana and Rio Grande do Sul, facing to the Atlantic Ocean in the east and Argentina in the west.

The state has an area of 95,483 km2 or 1.12% of the national total and contains a coastal plain below 200m in altitude, coastal mountain ranges of altitude between 200 - 800m and western highland of altitude over 800m, in the ratios of 14%, 42% and 44% respectively. The mountains and highland are generally not so steep and rather flat on top so that they have been well developed for primary industry with a high efficiency of land use, namely 77.8% of the total area.

Majority of the rivers and tributaries originated in the western highland flow to west and south into the Uruguai river, those in the northern area drain to north into the Iguacu river and the remaining rivers in the eastern part flow to east into the Atlantic ocean.

The predominant climate is humid semi-tropical with the temperature ranging between 13 and 25^{o}C. The highlands have severe winters with temperature sometimes below freezing and snowfalls, while the coastal plains are rather temperate and variable in their temperatures due to the cold current along the Atlantic seaboard.

The administration of the state of Santa Catarina has been divided into 22 microregions which are further divided into 260 municipalities. The state government is located in Florianopolis, and is composed of 9 secretarias, 3 procuradorias and 7 special offices attached to the governor's cabinet.

The state of Santa Catarina has a population of 4,538 thousand or 3.1% of the national total population (146,154 thousand) in the census year 1991. The state population was 3,628 thousand in the previous 1980 census year. It increased at an average rate of 2.1% per annum during the two censuses.The population density of the state was 47.6 persons per km2 in 1991, 2.8 times of the national one (17.2 persons per km2). The most densely populated Micro-Region was "Foz do Rio Itajai", which was 174,9 persons per km2.

According to the 1980 census, Santa Catarina marked a higher growth in labor force and gainful workers than the national average. Of the total labor force of 1,336 thousand in 1980, 1,331 thousand or 98.1% was engaged in some jobs as gainful workers. They were distributed to 418 thousand or 30.8% of the total labor force in agricultural sector, 319 thousand or 31.6% in industrial sector and 484 thousand or 35.7% in service's sector.

Gross Regional Domestic product (GRDP) of Santa Catarina amounts to Cr$ 7,639 billion at current price in 1991. It accounted for 4.6% of GDP in 1991. GRDP grew at a real rate of 2.25% per annum on average between 1985 and 1991. This rate was larger than that of the country (1.83%). Per capita GRDP was Cr$ 1,683 thousand at current price (equivalent to approximately US$ 2.4 thousand) in 1991. In 1987, it was the largest among the recent seven years. Afterwards, it has gradually been going down because of nationwide economic recession. However, that of the state has still kept at about 24% higher position than that of the country.

Santa Catarina has three types of road network system, i.e., federal, state and municipal systems. The total length of these systems were 61,028 km as of December 1991 which comprises federal road of 2121 km, federal/state road of 914 km, state road of 4698km and municipal road of 53295 km. There are three major sea ports in Santa Catarina: Imbituba, Sao Francisco do Sul and Itajai. Sao Francisco do Sul is the most active as the main gateway to the northern industrial area of the state. Regarding cargo handling, it accounted for more than 60% amoung three ports. There is only an international airport in the state, Hercilio Luz Airport, in Florianopolis. It pays an important role for time saving in person trips and mail, in particular. Besides there are 26 airports in the state (Ref. H-09). Among them, six airports; Florianopolis, Joinville, Navegantes, Chapeco, Criciuma and Lages have regular flights.

No information regarding land use in the state is available as of 1993. The 1985 economic census of agricultural sector gave land utilization for agricultural purposes in the census report. The 1985's census states that agricultural land covers 74.1 thousand km2 in total, accounting for 78% of the state territory which comprises 21,933 km2 or 23% of the state area for crop production; 24,691 km2 or 26% for pasture and/or livestock yard; 19,094 km2 or 20% for forest; and 2,498 km2 or 3% for vacant land arable but not utilized.

Chapter 4 EXISTING DATA

The existing data including previous reports, documents and information necessary for study and planning of this Project was collected and reviewed to obtain the basis of further study and to set out necessary work items for additional investigation. The collected data for the respective fields are as follows;

(1) Topographic survey.

(i) Data of national ground control points established by IBGE and ground control points established by JICA Study Team.

(ii) Aerial photographs at a scale of 1:30,000 and those at a scale of 1:20,000 shot in 1993.

(iii) Aerial photo maps at a scale of 1:10,000 covering about 183 km^2 of the project area.

(2) Socio-economic study

(i) Population census in Brazil and Santa Catarina published by IBGE.

(ii) Economic statistics published by FGV.

(iii) Industrial and agricultural statistics in Brazil and Santa Catarina published by IBGE

(iv) World development report published by World Bank.

(3) Hydrology

(i) Climate data at Ituporanga and Blumenau published by EPAGRI.

(ii) Rainfall record at 12 gauges in the Itajaí river basin published by DNAEE.

(iii) Discharge record at 5 gauges in the Itajaí river and its tributaties published by DNAEE.

(iv) Discharge rating tables and measurement records at 5 gauges in the Itajaí river and its tributaries published by DNAEE.

(v) Hourly rainfall data at Taio published by DNAEE.

(vi) Flood analyses in the Itajai Flood Control Study - 1988 and Lower Itajai Flood Control Study - 1990 by JICA.

(4) Geology

(i) Core drilling data at 9 holes at the damsites proposed by UNDP in 1969.

(ii) Core drilling data at 3 holes at dam axis-C prepared by JICA in 1991.

(5) Power demand and supply status

(i) List of existing power stations in south/southeast system and CELESC system.

(ii) List of existing substations in CELESC system.

(iii) Power supply records published by CELESC/ELETROBRAS.

(iv) Hourly load variation and monthly peak demand records in CELESC system.

(v) List of generation expansion program in south/southeast system.

(vi) List of power demand forecast in south/southeast system and CELESC system.

(vii) Data for electric tariff in CELESC system.

(6) Plan formulation and feasibility design.

(i) Manual of electric power development prepared by ELETROBRAS.

(ii) Instruction for feasibility study on hydroelectric power development prepared by ELETROBRAS.

(iii) Energic dimensioning of hydroelectric scheme on feasibility level prepared by ELETROBRAS.

(7) Construction plan and cost estimate

(i) Standard of cost estimate prepared by ELETROBRAS.

(ii) List of unit prices for labor, materials and equipment prepared by ELETROSUL.

(iii) Instruction of cost estimate prepared by ELETROBRAS.

(8) Environmental impact study

(i) Manual of environmental investigation prepared by ELETROBRAS.

(ii) Environmental investigation report on Salto Pilão project prepared by local consultant.

Chapter 5 HYDROLOGY

5.1 Basin Description

The Itajai river with a catchment area of 15,220 km2 originates at an altitude of about 1,800 m in the mountainous area of the southern part of the basin, where the Itajai river is called as the Itajai do Sul river. The Itajai do Sul river flows northward and joins the Itajai do Oeste river at Rio do Sul and changes its name to the Itajai river. In the Itajai do Sul and Itajai do Oeste river basins, there exist the Sul and Oeste dams for flood control in the downstream reaches. After flowing northeastward through about 20 km long river stretch with a gentle riverbed slope of 1:7,000 along the city area of Rio do Sul, the Itajai river flows through about 10 km long cascades where the proposed damsite is located, and joins the Itajai do Norte river near Ibirama city. Then, it reaches to the proposed powerhouse site at about 5 km downstream of the confluence with the Itajai do Norte river. After passing the proposed powerhouse site, the Itajai river flows down along Apiúna, Ascurra, Indaial, Blumenau and Itajai cities joining the Benedito river at Indaial, the Itajai Mirim river at Itajai and finally it debouches into the Atlantic Ocean. Total length of the Itajai river is about 250 km.

The catchment areas of the proposed dam and powerhouse sites and the major tributaries in the project area are as follows:

a)	Itajai do Sul	:	2,166 km^2
b)	Itajai do Oeste	:	3,050 km^2
c)	Damsite	:	5,597 km^2
d)	Itajai do Norte	:	3,360 km^2
e)	Powerhouse site	:	9,041 km^2

5.2 Meteo-hydrological Conditions

According to the climatic records from 1985 to 1991 at Ituporanga which is located at about 40 km upstream of the proposed damsite, the annual mean temperature is 17.9°C and the recorded maximum and minimum temperatures are 30.9 °C and 5.5 °C respectively. The annual mean relative humidity is 81.9 % and the basin mean annual evaporation amount was around 1,500 mm corresponding to an evaporation rate of 4.1 mm/day.

The annual rainfall ranges from 1,400 mm to 1,500 mm in the center of the basin and from 1,500 mm to 1,800 mm in the mountainous area of the northern and southern parts of the basin. The basin mean annual rainfall was estimated at about 1,500 mm. The rainy days at Rio do Sul near the damsite is 145 days per year in an average for the latest decade from 1982 to 1991. Rainy days of heavy rainfall more than 30 mm is 15 days (4 %) in a normal year.

The monthly mean discharge at the Rio do Sul gauging station which is located at about 20 km upstream of the proposed damsite is 101.4 m^3/sec and the runoff coefficient is estimated at 0.4. The recorded maximum peak flood discharge is 2,560 m^3/sec in 1983 after the construction of the Sul and Oeste dams.

5.3 Low Flow Analysis

The low flow analysis was made to work out the long-term daily runoff for Salto Pilão hydroelectric power project and to establish flow duration curve based on the derived runoff.

In Rio do Sul gauging station, which has a catchment area of 5,230 km^2 and covers 93 % of that at the damsite, is located at about 20 km upstream of the proposed damsite and water level and discharge observation have been carried out for more than 50 years since 1940. Runoff data at Rio do Sul were reviewed by means of correlation and double mass curve analyses using runoff data at Apiúna gauging station at about 20 km downstream of the proposed damsite and basin mean rainfall at Rio do Sul. As a result, it was judged that runoff data at Rio do Sul are reliable and these are applicable for derivation of the long-term runoff at the proposed damsite.

The long-term daily mean discharge at the damsite was estimated by converting the daily mean discharges at Rio do Sul gauging station using basin mean annual rainfall and catchment area at these sites. The derived daily mean discharges are illustrated in Fig. 5.1 and the monthly mean discharges at the damsite estimated based on the derived daily discharges are given in Table 5.1.

Flow duration curve which is used for planning of run-of-river type scheme was established by arranging the daily mean discharge for the hydrologically critical period from April 1949 to November 1956, which was defined by ELETROBRAS. The established flow duration curve is illustrated in Fig. 5.2.

5.4 Flood Flow Analysis

Flood runoff analysis was made to review the previous study result and to estimate the probable peak flood discharges and their hydrograph with several return periods by applying a mathematical simulation model and using rainfall data in order to obtain the basis of design of flood diversion and spillway facilities. The return periods are designated at 2, 5, 10, 20, 50, 100, 200, 500, 1000 and 10000 years to cover design scale of the flood diversion and spillway facilities.

In order to estimate probable flood hydrograph at the proposed damsite, mathematical simulation model established by the Itajai river basin flood control project by JICA was applied. The model was resulted through calibration using rainfall and flood records during the major floods in 1978, 1980, 1983 and 1984 after the construction of Sul and Oeste dams. These floods were caused mainly by 4-day continuous rainfall. In this simulation model, probable rainfalls with the aforesaid return periods was estimated based on the basin mean daily rainfall worked out by Thiesen's method. Other parameters such as coefficients used for the basin model, runoff coefficient, average riverbed slope and base flow necessary for study on the simulation model were assessed based on the topographic and hydrological data. By adopting the parameters thus estimated to the simulation model, probable flood hydrographs at the damsite were estimated. The estimated flood hydrographs with the selected return periods are illustrated in Fig.5.3 and their peak flood discharges are summarized as follows:

Return Period (year)	Peak Flood Discharge (m^3/sec)
2	1,600 (1,100)
5	2,300 (2,000)
10	2,600 (2,500)
20	2,900
50	3,300
100	3,600
200	3,900
500	4,700
1000	5,300
10000	7,400

Note : Figures in brackets show the flood peak discharge considering regulation effect by Sul and Oeste reservoirs.

In order to cross-check the derived design peak flood discharge with 10,000-year return period, specific discharges of design flood applied to the dam projects in and around the Itajai river basin were compared employing the Creager's coefficient (C), which indicates the relationship between catchment area and peak flood discharge, as shown in Fig. 5.4. This figure indicates that the specific discharge of 1.32 (7,400 m^3/sec / 5,597 km^2) of the Salto Pilão project corresponds to flood discharge with C of about 50. While, the C of the Norte, Sul and Campos Novos dam projects, of which the catchment areas are in the similar order, are also about 50. Considering the scale of the design floods of the mentioned projects, it is judged that the design discharge of 7,400 m^3/sec is applicable to the Salto Pilão project.

While, ELETROSUL undertook review study on probable flood discharge with a return period of 10,000-year by means of frequency analysis using the annual maximum daily mean discharges for 52 years from 1940 to 1991 at Rio do Sul and by multiplying its result by the catchment area ratio of the damsite and Rio do Sul after the pre-feasibility study by JICA. Consequently, the probable peak flood discharge of 5,700 m^3/sec was worked out. This figure corresponds to C of about 35 and it is judged to be too small value compared with figures in other projects. Difference of peak discharge estimated by this study and ELETROSUL is caused by the difference of data, namely daily mean discharge employed by ELETROSUL and instantaneous flood peak discharge taking into account the comparatively small catchment area of the Salto Pilão project, which was applied by JICA.

In order to carry out flood analysis with high accuracy in the detailed design stage, accumulation of flood water level and discharge data during flood at Rio do Sul and at an automatic water level gauge to be newly installed at the proposed damsite are recommended.

5.5 Sediment Flow

A wash and suspended loads rating formula established by the previous flood control projects in the Itajai river basin was reviewed through the comparison of the sediment concentration and flow discharge data surveyed at Lontras suspension bridge site by the JICA study team for 2 months from June to July in 1993. Consequently, it was confirmed that the established rating formula is applicable to estimate sediment inflow volume into reservoir of the Salto Pilão project .

Based on the sediment rating formula and the long-term daily mean discharges for 50 years from 1941 to 1990 at Rio do Sul, annual average sediment load was estimated at 230 thousand m^3/year or 44 m^3/km^2/year assuming that 20 % of sum of the wash and suspended loads corresponds to bed load. Applying this specific sediment yield of 44 m^3/km^2/year, total sediment inflow discharge into the reservoir of the Salto Pilão project was derived at 247 thousand m^3/year.

5.6 Water Quality

According to the result of water quality analysis by DNAEE for the river water taken at Rio do Sul, the measured pH value, which is the indicator of acidity important for estimating the corrosion of such metal structures for hydropower schemes as steel gates in intakes and spillways, penstocks and generation equipment, was in the range of 5.5 to 7.6 in the Itajai river. This range is classified as neutral and it is judged that there will be no adverse effect on corrosion of metal structures.

Also, from the view point of utilization of river water for concrete works, oil and grease with a range from 3 ppm to 13 ppm were detected in the river water at Rio do Sul and therefore it is necessary to confirm the adaptability of the river water for construction purpose at the construction stage of the project.

5.7 River Maintenance Flow

5.7.1 General

Study on the river maintenance flow (R.M.F.) was made from two aspects, hydrology and environmental aspects. From hydrological aspect, river flow condition in the downstream stretch of the proposed weir site with and without project was studied. While for environment aspects, biological and anthropeic situations in the downstream stretch of the proposed weir site and expected effect on the river flow reduction were analyzed.

5.7.2 Hydrological Aspect

Based on the long-term daily mean discharge record for the period of 50 years from 1941 to 1990, relationship between drought year and minimum daily mean discharge was studied. Result of study shows that the minimum daily mean discharge varies from 4.1 m^3/sec in 1952 to 7.9 m^3/sec in 1944.

Duration of month in which no river water releases to the downstream stretch from the proposed damsite was examined assuming several maximum plant discharges. The result shows that the duration is 210 days for maximum plant discharge of 80m^3/sec and 130 days for 50m^3/sec

5.7.3 Environmental Aspect

Physical characteristics such as landscape and topography, river course, biological characteristics including aquatic fauna and flora and characteristics of anthropeic context such as land use and water use in the project area were investigated. Based on the result of these investigations, expected effects on flow reduction were examined for human environment and biological environment. It was clarified in this examination that no effects on flow reduction take place except for fish migration. For estimation of R.M.F., only acquatic fauna especially river water required for migrating fish in the envisaged river stretch of 10.2km between the proposed damsite and confluence with the Norte river was contemplated, assuming that the required water depth for migrating fish is 0.2m which is 2 times the maximum height of fish.

5.7.4 Recommendable R.M.F.

In order to determine appropriate R.M.F., the following two conditions should be satisfied;

(i) to ensure the river discharge for moving of fish, and

(ii) to ensure the river discharge to be needed for minimum exchange rate of 500% of the volume per day for keeping water quality and oxygenation condition of fish habitats.

Relationship between river flow discharge and water depth was studied referring the topographic characteristics of the river channel and 3 m^3/sec was proposed as the river RMF. However, RMF was finally decided at 7.2 m^3/sec from the viewpoint of possible tourism in future in overall Santa Catanina state.

5.8 Discharge Rating Curves at Dam and Powerhouse Sites

Water level observation was carried out at the proposed dam and powerhouse sites once a day from June to August in 1993. Based on the water levels observed and discharges estimated by converting from those at Rio do Sul and Apiúna, the stage-discharge rating curves were established for design of structures. Fig. 5.5 shows tailwater rating curve at powerhouse.

Chapter 6 GEOLOGY

6.1 Topographic Feature

The Itajaí river basin is located at eastern central part of the state of Santa Catarina. It is surrounded in its western/southwestern perimeters by high escarpment with altitude of 800 to 1,000 m asl which is called Serra Geral running southeast direction. The catchment area of the basin is 15,200 km².

Itajaí do Sul river and Itajaí do Oeste river; both originating from the southern mountain areas join at the city of Rio do Sul and change their names to the Itajaí river. The river level at this junction is around 330 m in elevation. In a 25 km stretch downstream of Rio do Sul to the village of Riachuelo, the Itajaí river flows at very flat gradient of about 1 in 13,000 normally having 80 to 100 m of flow width. About 2 km downstream of Riachuelo, the river begins to steeply descend in a series of rapids and cascades. In a 12 km stretch from Riachuelo to the point where Itajaí do Norte river joins, the river forms a gorge and falls about 197 m in total. Then, the river flows about 4 km along the Subida escarpment with flatter gradient and falls a further 19 m. At the end of the escarpment, a proposed powerhouse site is located. The total natural drop is thus about 216 m. The river flows further 145 km to its estuary. The total river length of the Itajaí is about 280 km. Fig. 6.1 shows longitudinal profile of the Itajaí river.

Between intake site near the village of Riachuelo and the Subida escarpment, land on the right of the river forms gently rolling hills with shallow valleys. Its general level is 400 to 450 m above sea level. It steeply drops about 340 m at the escarpment.

In the Inventory Study - 1991, topographic map of 1 to 10,000 was prepared, which covers project area between powerhouse site and lower parts of Itajaí do Sul and Itajaí do Oeste rivers. In the present investigation, two different scale maps have been prepared by photogrammetric survey; one is a 1 to 5,000 scale map covering the area between intake damsite and powerhouse site and the other is 1 to 2,000 maps separately covering dam area and powerhouse area. Covering area of those maps are shown in Fig. 6.2.

6.2 Previous Geological Investigation

The geological investigation for this project was initiated under UNDP by Canambra Engineering Consultants Ltd. (British India) and presented in their report "Power Study of South Brazil" dated August 1969. In their study, the Salto Pilão project was one of a multiple hydropower scheme in which water of the Canoas river regulated by reservoirs was to be diverted to the Itajaí river for power generation by the Salto Pilão and the other power stations. Geological survey carried out in the Salto Pilão project area consisted of:

- Core drilling : 9 holes with total length of 403.5m (4 holes at damsite, 3 holes along tunnel route and 2 holes on penstock route), including water pressure test in rock of each hole.
- Test pits : 6 places (4 at dam and 2 on tunnel route).
- Seismic survey : 7 points on tunnel route.
- Auger hole : 1 point on tunnel route.

The second investigation was carried out by JICA for the Hydro Inventory Study - 1991. In its study, the project was considered to be a single run-of-river type scheme and identified as the most promising one among 16 candidate projects in the Itajaí river basin. The geological survey carried out for the study included :

- Core drilling : 3 holes with total length of 110m (1 hole each for dam, tunnel and powerhouse), including water pressure test in each hole.

6.3. Basin Geology

Geological basement of the Itajaí river basin consists of old sedimentary rocks formed generally in the Pre-Cambrian and Paleozoic eras as shown in Fig. 6.3. On the steep slope of the Serra Geral escarpment along the basin's western perimeter, there appear many alternations of siltstone, shale and sandstone layers made by fluvial or marine deposits of the late Paleozoic Era. A western half of the basin below the escarpment is covered with siltstone and sandstone layers of the early Paleozoic era. An eastern half of the basin downstream from the Salto Pilão project area is covered with sandstone, siltstone and gneiss of the Pre-Cambrian age. Flat plains along river courses are covered with tertiary or quaternary alluvial deposits.

In the vicinity of the project area between Lontras and Subida, the land is formed by a large intrusive granite mass (Subida granite) made in the Cambrian age. On both sides of the Itajaí valley in downstream part of the Subida area, sedimentary rocks of Itajaí group lies. These two rock masses are separated by an intrusive rhyolitic rock appearing along the escarpment on the western side of the valley upstream of the powerhouse site in the Subida area.

Regarding the geological structure in the basin, tectonic lineament of two different directions are conspicuous, i.e. NE to SW and NW to SE. In the vicinity of the dam area, the lineamet of NE to SW traverses the right bank of the river. Another lineament of NE to SW traverses in the area of the headrace tunnel route.

6.4. Site Geology

6.4.1 Present Investigation

In this study, exploratory core drilling of 10 holes (300m in total length) associated with in-situ water pressure test (Lugeon test) was carried out in June - July 1993. To confirm properties of rock, thirteen samples taken from drilled cores and rock outcrop were tested at laboratory at São Paulo. Geological mapping was prepared and the results were plotted on the maps of 1 to 2,000 for damsite area and powerhouse area and the maps of 1 to 5,000 for overall project area including tunnel route. Fig. 6.4. shows location of the holes drilled at the present investigation and the previous investigations. The items of the present investigation works are listed in Table 6.1.

Three alternative dam axes were selected in this time, which were named the axes B, C and D. The axis C coincides to the axis proposed in the previous Hydro Inventory Study - 1991 (JICA). The other axes B and D were sited about 500 m upstream and downstream of the axis C respectively, based on field reconnaissance. The exploratory drilling was planned and made on the axis C only, since the axis B was investigated in the previous studies (by Canambra and JICA) and their data can be utilized, and as for the axis D, geological condition was expected to be similar to that of the axes B and C.

For the powerhouse area including penstock route, two alternative sites were selected at the preliminary planning after the field reconnaissance; one is located on the site proposed in the Inventory Study - 1991 and the other is located 200m downstream of the proposed site. As geological conditions of the upstream site have been surveyed in the previous investigations, the present exploratory drilling was planned for the downstream site.

As to the quarry area for rock material for constructin use, two sites were investigated; one is located 1 km upstream of the axis B and another is 3 km downstream of the axis B.

6.4.2 Rock Classifications

At present geological investigation, two standards of rock classification are contrasted, i.e., (1) Japanese Standard as summarized in Table 6.2 and (2) Brazilian Standard as tabulated in Table 6.3.

6.4.3 Geology in Each Site

(1) Whole Project Area

Intrusive granite appears in the hills between Lontras and top of Subida escarpment as well as in the Itajaí valley and its left bank hill between Lontras and the junction with the Itajaí do Norte river. The granite which extends from the damsite along the tunnel route to the surge tank site is a massive and hard rock, pink to gray in colour. Rhyolite appears along the face of Subida escarpment on right bank of the river between the junction of the Itajaí river and Itajaí do Norte river and Subida village. The proposed powerhouse is located at foot of the escarpment. Geological map of the project area is shown in Fig. 6.4. and geological section along the proposed tunnel route is shown in Fig. 6.5.

(2) Dam Area

Geological map of the dam area, which is based on result of the present investigation, is shown in Fig. 6.6. Geology of three alternative dam axes (B, C and D) is as follows :

Axis - B

Hard granite is exposed across the river bed where a waterfall with height of about 6 m is observed. This fall is supposed to be formed by erosion along vertical joint in the granite mass. Surface of the rock in the river bed shows open and interconnected joints, both horizontal and vertical, which apparently extends down to a depth of more than 5 m. In the cut slope of abandoned railway on the right bank, weathered granite is exposed but higher land is covered with thick overburden of sandy and clayey soil. There appears no rock outcrop on the left bank hill as well as on river side slope. The soil in the overburden gradually changes to soft decomposed granite with increase of depth. Total depth of the overburden including the decomposed granite is about 15 m on the right bank and 25 m on the left bank. Transition between the overburden and the hard bed rock is considerably thin. Surface of the sound rock on the left bank ascends gently towards inside of the hill though on the right bank it rises steeply. Accordingly, on the left bank, the rock surface higher than the dam crest level (approx. 325m) is expected to appear at 110 m in horizontal distance from the river side. Geological section along the dam axis is shown in Fig. 6.7.

One geotectonic lineament (GL-1) traverses the axis B with right angle at right side part of the river bed. At this position a cascade is formed. That lineament has a possibility of fault. It is conjectured, however, that there is no serious fracture zone along the lineament because its direction (NE to SW) is perpendicular to the waterfall's face line. In future detailed study, this lineament needs to be explored by inclined drilling.

Status of the granite rock in foundation is classified into the class A or B in the Japanese classification or the index H1F1A1S1 in the Brazilian classification. The rock has the compressive strength of over 140 MPa and the dynamic elasticity of more than 50 GPa as shown in Table 6.4. In-situ permeability of the rock is less than 1 Lugeon in general.

The clayey overburden on the right bank showed a relatively high permeability of 3 x 10^{-3} cm/sec at the in-situ test which was made at depth of 5 m from the surface. However, it is considered that deeper portion is less permeable and the permeability becomes the order of 10^{-4} cm/sec at portion deeper than 10 m. The overburden on both banks are deemed similar to each other in their physical properties.

Axis C

Left bank just upstream of the axis C is scored deeply into hill. Alluvial deposit spreads on the scored low area. Outcrops of granite scatters in the floor of valley. No rock outcrop appears on slopes of both banks. Overburden including highly decomposed granite layer on both banks is deep and the rock lies gently inclining towards inside of hills. Transition zone between the overburden and base granite is about 10 m in thickness on the left bank and about 5 m on the right bank. This zone consists of slightly weathered granite classified to CM or H3F2A3S3 and is deemed to be sufficient as foundation of low dam. Surface of this weathered rock is assumed to be 310 m in elevation on the right bank and 320 m in central part of the left bank ridge. Fresh granite below the transition zone is hard and massive, and classified as A-B or H1F1A1S1. Geological section along the dam axis is shown in Fig.6.7.