No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

DEPARTMENT OF POWER MINISTRY OF TRADE AND INDUSTRY
THE KINGDOM OF BHUTAN

FEASIBILITY STUDY ON THE DEVELOPMENT OF PUNATSANGCHHU HYDROPOWER PROJECT IN THE KINGDOM OF BHUTAN

FINAL REPORT

SUMMARY

FEBRUARY 2001

ELECTRIC POWER DEVELOPMENT CO.,LTD.

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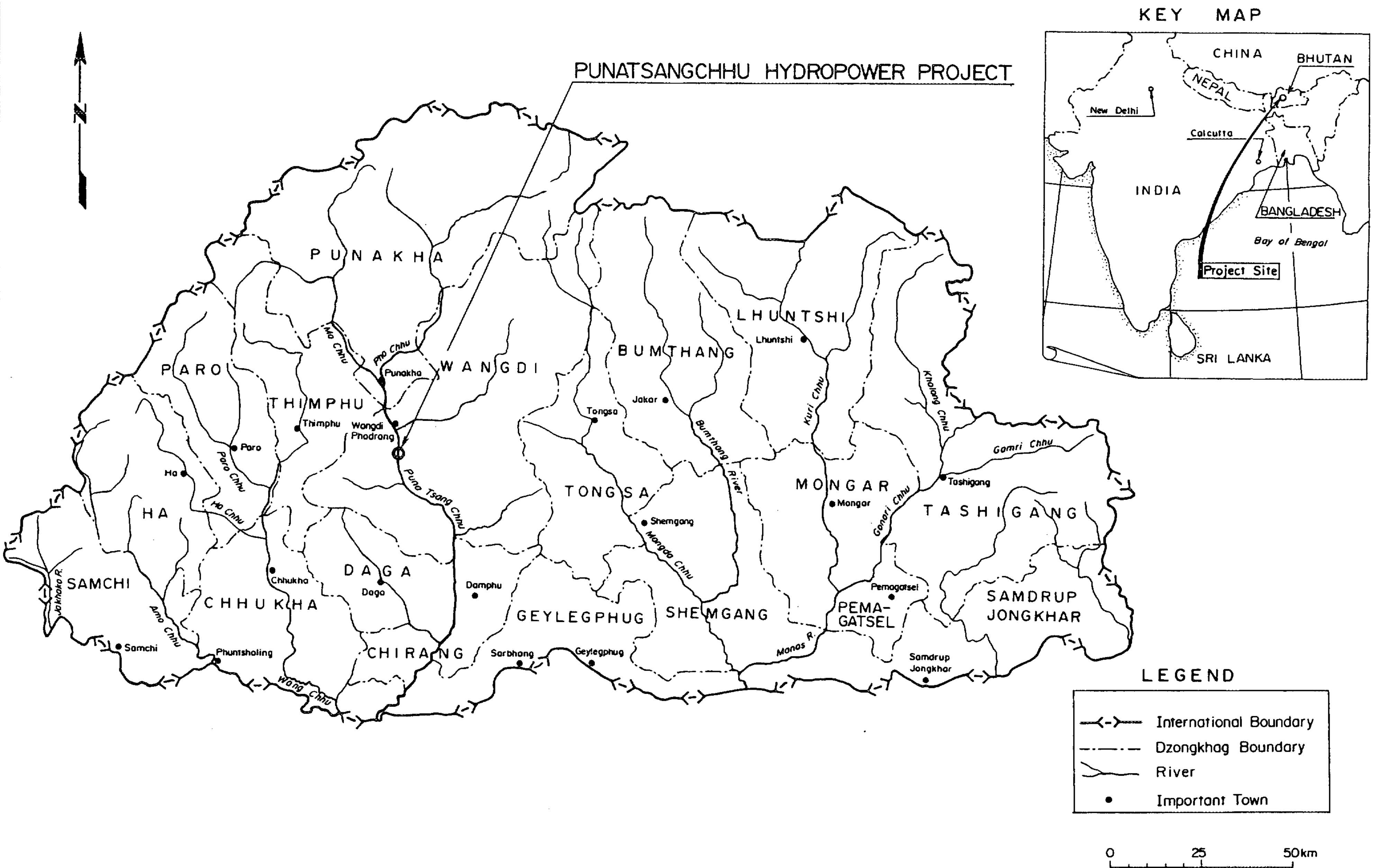
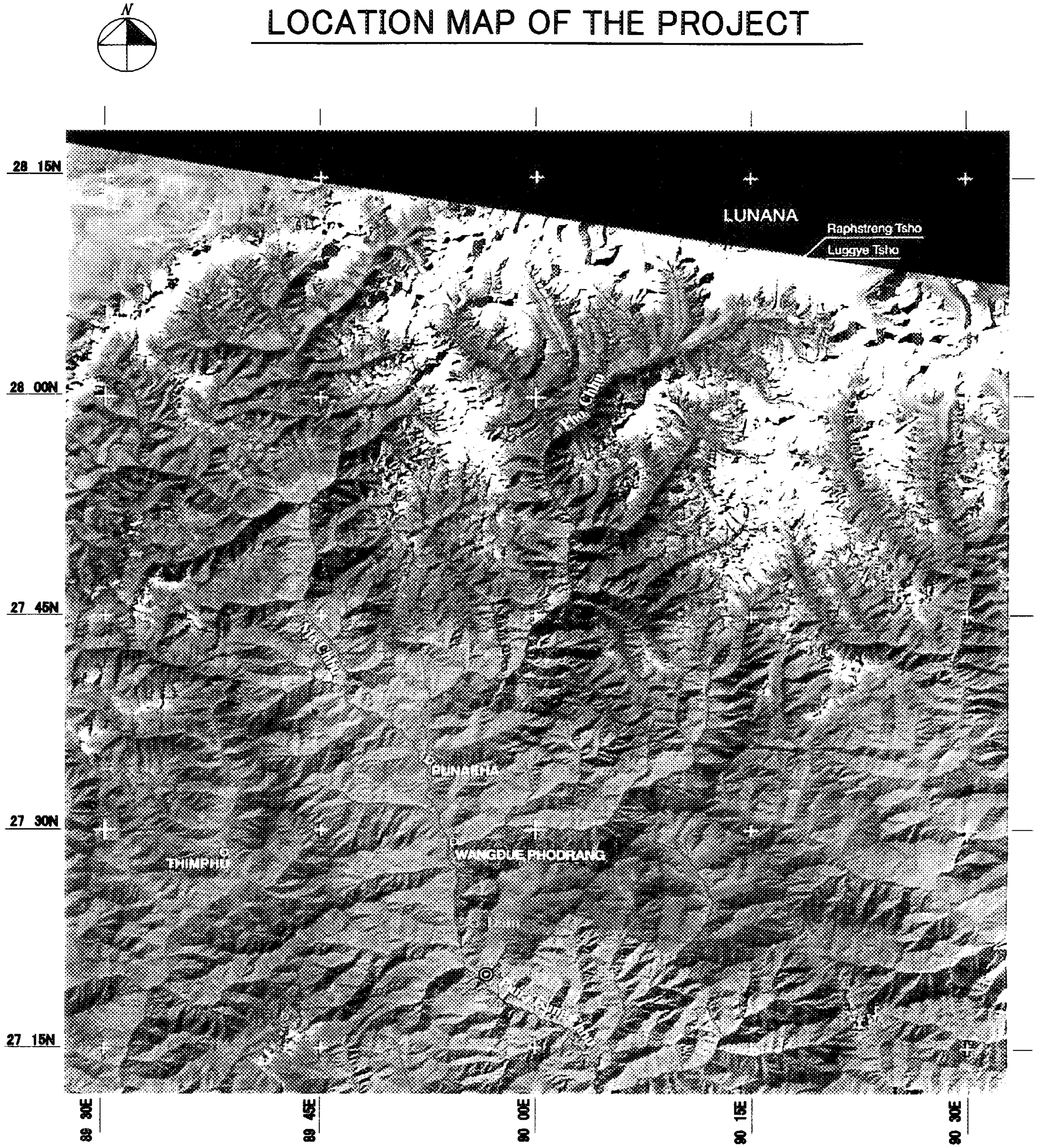


LOCATION MAP

LOCATION MAP OF THE PROJECT



1988 Glacier Lake
1988 & 1998 Glacier Lake
1998 Glacier Lake

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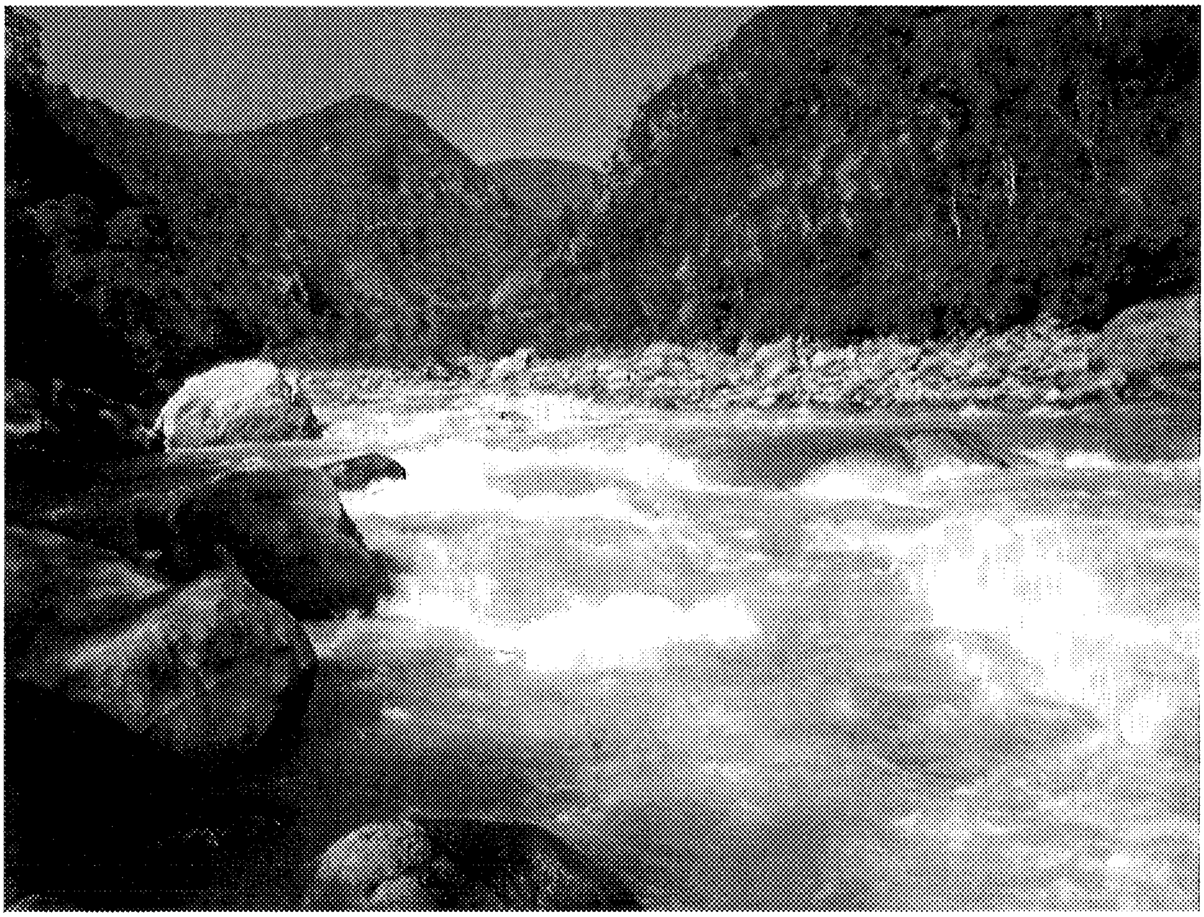
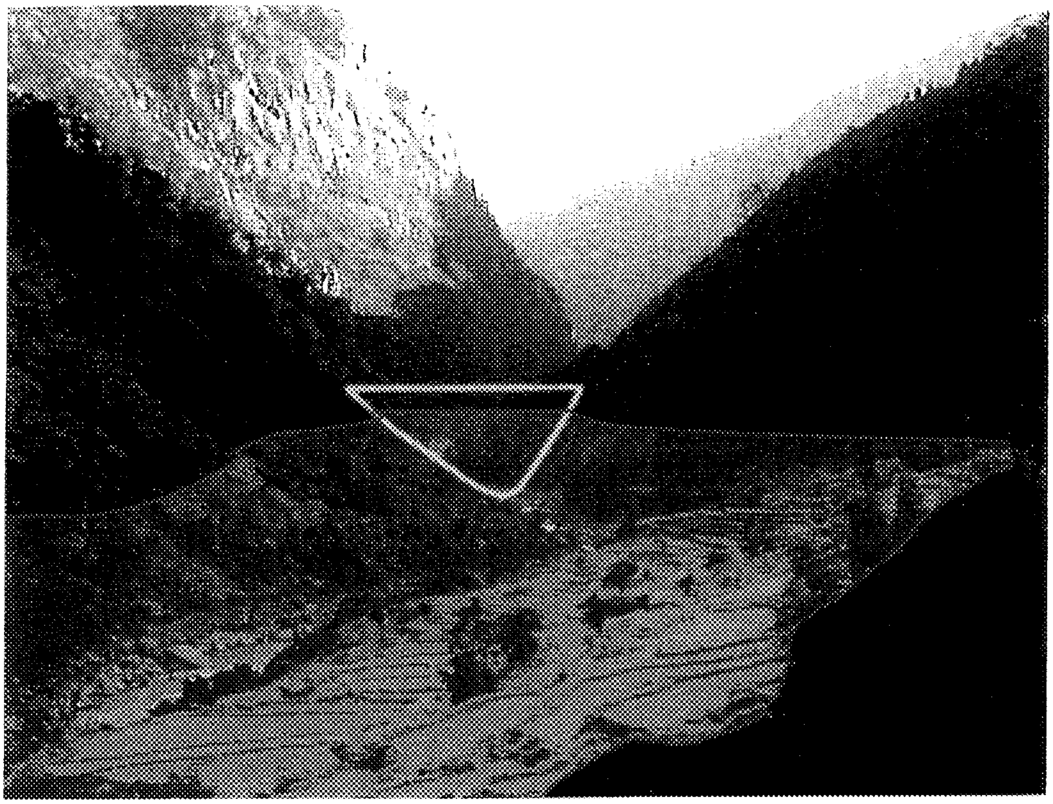
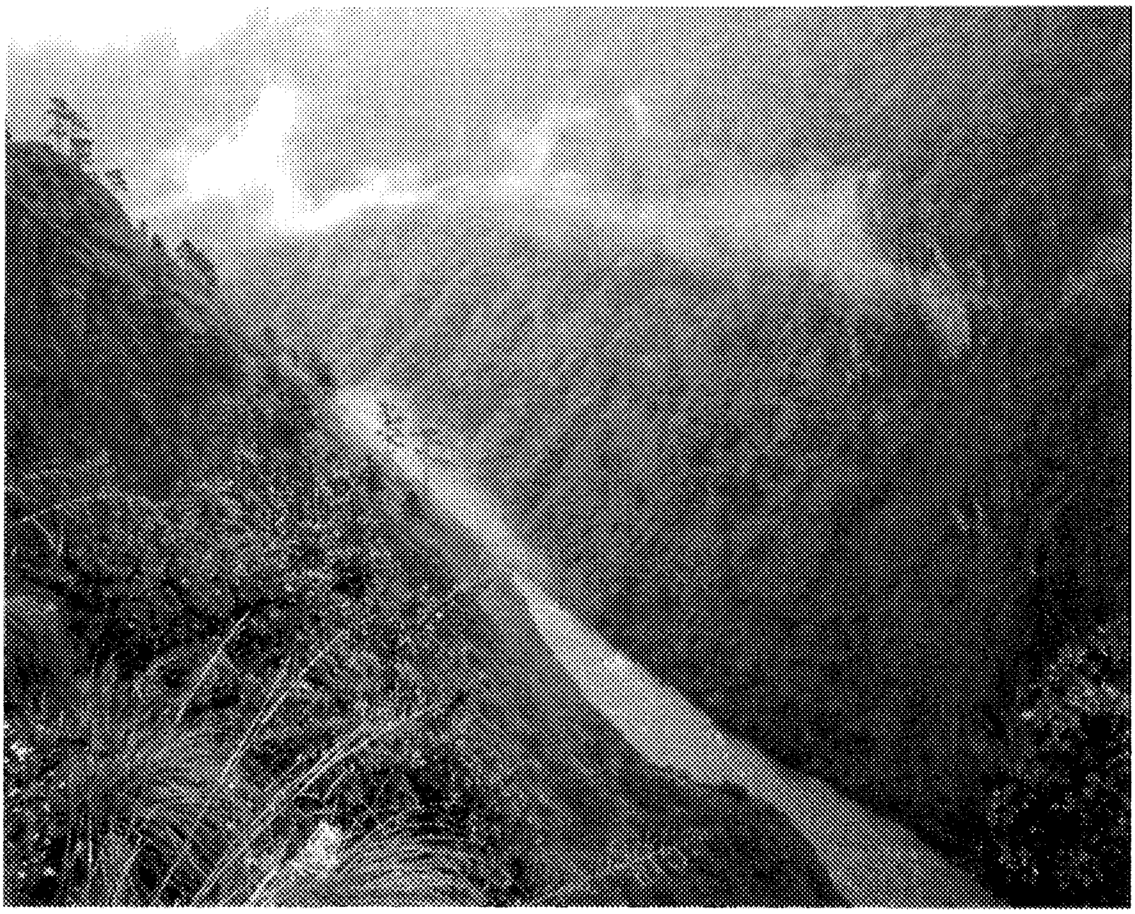


Upstream View from Dam Site (3.120)



Dam Site (3.120), View from Upstream

River Flow at Dam Site (3.120)



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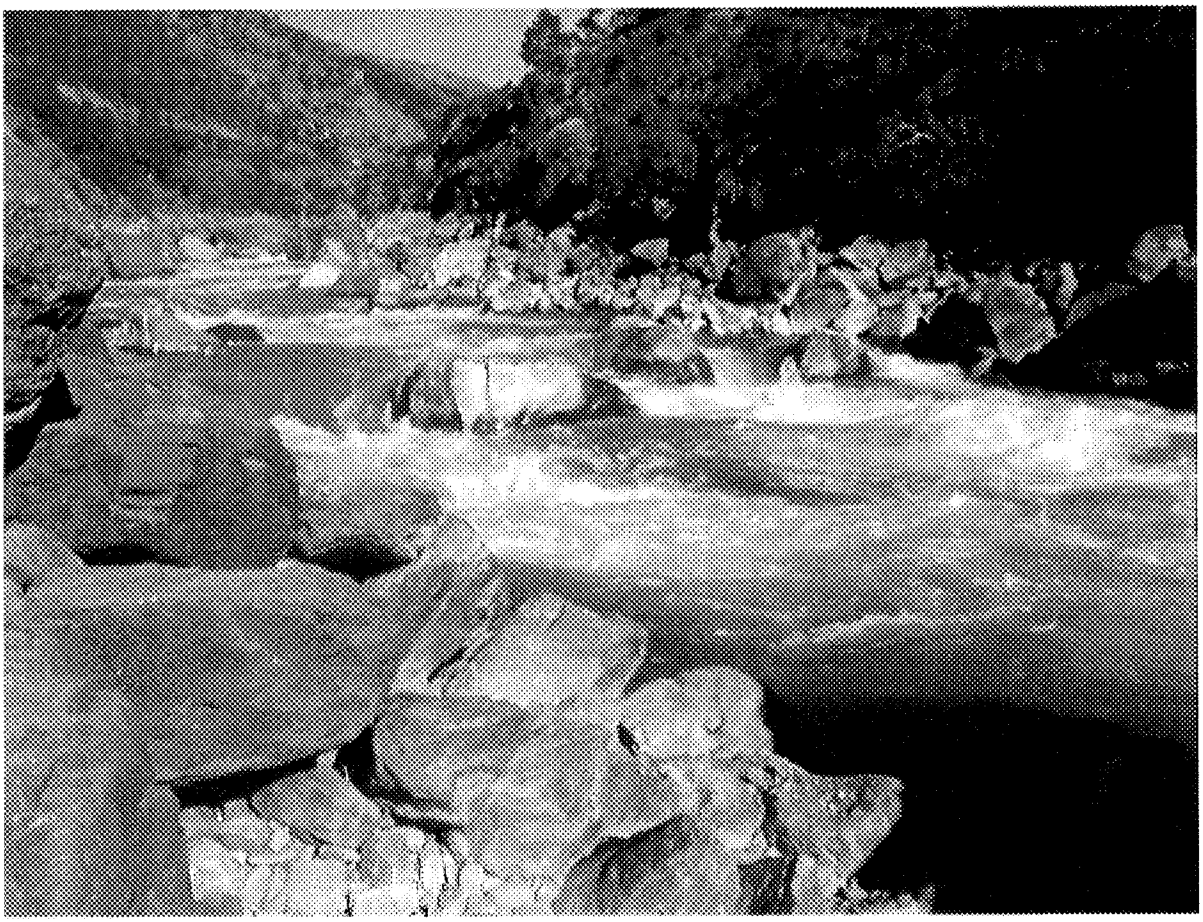

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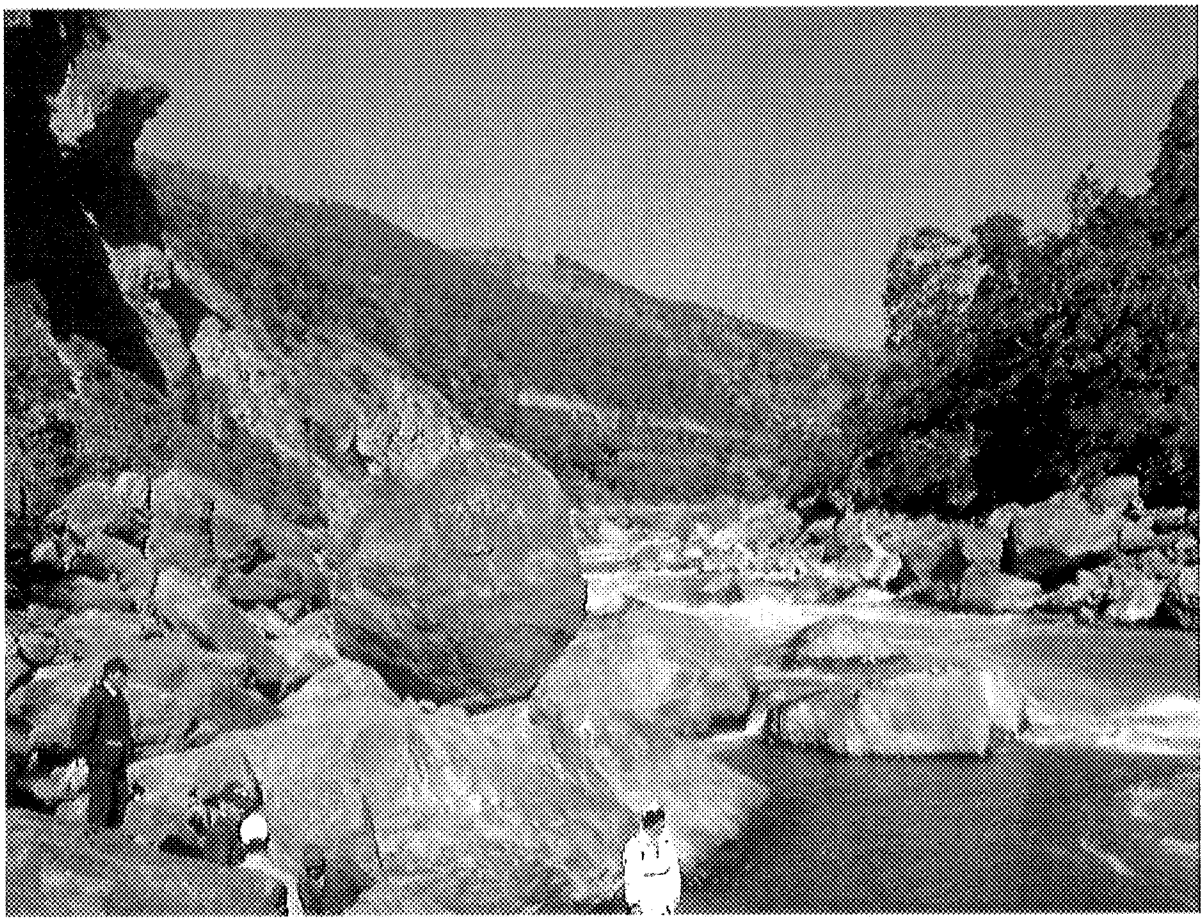

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ABBREVIATION

1. Country

Bhutan	The Kingdom of Bhutan

2. Domestic Organizations

RGB	The Royal Government of Bhutan
MoF	Ministry of Finance
NEC	National Environmental Commission
MTI	Ministry of Trade & Industry
DoP	Department of Power (ex-Division of Power)
GSB	Geological Survey of Bhutan
SoB	Survey of Bhutan
CHPC	Chhukha Hydro Power Corporation

3. International and Foreign Organizations

JICA	Japan International Cooperation Agency
JOCV	Japan Overseas Cooperation Volunteers
JBIC	Japan Bank for International Cooperation
IBRD	International Bank for Reconstruction and Development
ADB	Asian Development Bank
UNDP	United Nations Development Programme
NORAD	Norwegian Agency for Development Cooperation

4. Technical Terms

CA	Catchment area
PMF	Probable maximum flood
HWL	High water level
LWL	Low water level
IWL	Intake water level
TWL	Tailrace water level
EL	Elevation (m) above sea level
HPP	Hydropower plant (or project)
PS	Power station
GS	Gauging station
S/S	Sub station
T/G	Turbine and generator
T/L	Transmission line
D/L	Distribution line
AC	Alternating current
DC	Direct current

cct	Circuit
S/Y	Switchyard
GIS	Gas insulated switch gear
O&M	Operation and maintenance
Chhu	River
Tsho	Lake

5. Measurement

a) Length

mm	Millimeter
cm	Centimeter
m	Meter
km	Kilometer

b) Area

cm^2	Square centimeter
m^2	Square meter
ha	Hectare
km^2	Square kilometer

c) Volume

cm^3	Cubic centimeter
l	Liter
kl	Kiloliter
m^3	Cubic meter
MCM	Million cubic meter

d) Weight

g	Gram
kg	Kilogram
ton or t	Metric ton
tC	Carbon ton
gC	Carbon gram

e) Time

s	Second
min	Minute
h	Hour
d	Day
m	Month
yr	Year

f) Meteorology

C	Degree in centi-grade

K	Degree in Kelvin-grade
mb	Milibar

g) **Electrical Measures**

V	Volt
kV	Kilovolt
A	Ampere
Hz	Hertz (cycle)
W	Watt
kW	Kilowatt
MW	Megawatt
GW	Gigawatt
kWh	Kilowatt hour
MWh	Megawatt hour
GWh	Gigawatt hour
kVA	Kilovolt ampere

h) **Others**

Btu	British thermal unit
rpm	Revolutions per minute
%	Percentage
Lu	Lugeon

6. Economic Terms

GDP	Gross domestic product
B/C	Benefit cost ratio
B-C	Net benefit (Net present value)
EIRR	Economic internal rate of return
FIRR	Financial internal rate of return
DSCR	Debt service coverage ratio
LLRC	Loan life coverage ratio
FGC	Financial generation cost
IDC	Interest during construction
F/C	Foreign currency
L/C	Local currency
US$ or $	US dollar
M.US$	Million US dollar
USC or c	US cent
Rs.	Indian Rupee
Nu	Bhutanese Ngultrum
¥	Japanese Yen

CONCLUSION AND RECOMMENDATION

Conclusion

The conclusions described hereunder are based on all results of the Feasibility Study on the Punatsangchhu Hydropower Project, carried out from 1998 to 2001.

The Project is considered to be technically, economically, environmentally and financially feasible.

The Project is a power export-oriented development scheme to India utilizing the maximum potential of the mainstream of the Punatsangchhu so as to strengthen the financial foundation of the country by revenue of power export.

The Project could constantly supply qualified power, with peaking capacity, for the heightened power demand in the Eastern Region of India, represented by West Bengal State.

(Features of the Project)

The Project is a run-of-river type scheme with an installed capacity of 870MW for peak generation, providing annual energy production of 4,330MW, using a concrete gravity diversion dam 141 m in height from the rock foundation to create a reservoir of about 4.4 million m^3 active capacity, as well as twin tunnels of about 7 km in length and 7.40 m in diameter and an underground powerhouse.

Dimensions for major structures for the Project are shown in the Table (Punatsangchhu Hydropower Project).

(Project site)

The Project is located mid basin between the Punatsangchhu, one of major rivers flowing in the western region of the country, and the hydro power project identified as Project 3.120, then further studied at a pre-feasibility level in the Power System Master Plan in Bhutan (PSMP), funded with by a grant from UNDP and NORAD during the years 1990 to 1993.

The Project is a dam and waterway type scheme, and selected was a dam site 10 km downstream from Wangdue Phodrang, one of the major towns in the western region of the country. Also selected was a powerhouse site a further 8 km downstream from the dam site.

The Punatsangchhu has a steep river profile in mid basin where the Project is located, and suitable topographical conditions for the so-called dam and waterway type scheme. which obtains its available headrace primarily using waterway.

(Demand Forecast)

Demand forecast was studied for the power market of India, especially that of the Eastern Region of India, as well as for Bhutan, since the Project is a power export-oriented development scheme. The maximum power demand in Bhutan was 72 MW in 1996, whereas it is estimated to be 418 MW in 2020.

The maximum power and energy demand in the Eastern Region of India was 3,240 MW and 16,975 GWh, respectively, in 1996, whereas it is estimated to be 10,391 MW and 54,616 GWh, respectively, in 2020.

The power market of the Eastern Region may expect a power supply from Tala hydro power (1,020 MW) which is being constructed now and expects its commissioning within the next five years, and Punatsangchhu hydro power (870 MW), as part of its required power sources.

(The Optimum Power Generation Plan)

The studies of the optimum power generation plan were carried out with various powerhouse sites (Cases1 to 5 for downstream site, Cases6 to 10 for mid stream site, and Cases11 to 15 for upstream site), with altered maximum discharge for each case, as well as a common site and height for the dam and a 4-hour peaking duration.

As a result, Case 2, providing 870 MW installed capacity, was selected as the optimum power generation plan for the Project, aiming to utilize the maximum potential at mid basin in the river.

(Glacier Lake Outburst Flood, GLOF)

Glacier lake outburst flood (GLOF) is a distinctive hydraulic phenomenon where a glacier and glacier lake are in the upper reach of the basin.

Based on satellite image analyses and hydraulic simulation computation, with the presumption that two Glacier lakes, Luggye Thso and Raphstreng Thso, burst almost simultaneously, the peak discharge is presumed to be 4,600 m^3/s at the dam site.

This peak flood discharge is some 1/3 of the design flood at the dam site, therefore it could be released downstream safely without damaging the dam.

As a countermeasure to GLOF, it is essential that the reservoir water level be lowered by gate operation prior to the arrival of GLOF to the dam site; GLOF indicated by observation of the river water level and/or installation of a detective sensor in the upper basin.

(Construction Schedule and Project Cost)

Construction takes seven years in total, one year for preparatory works and six years for main civil works, electro-mechanical equipment and so on, from the beginning of preparatory works to commissioning the first unit.

The required project cost is US$813 million as of 2000, including direct costs such as preparatory works, main civil works, electro-mechanical equipment and so on, and indirect costs such as engineering and administration for the project, cost for land acquisition, physical contingency and so on.

The project cost covers construction of the A route transmission line (powerhouse site - Sarpang - Bongaigaon), which runs to the primary substation in India beyond the Bhutanese - Indian border.

(Environmental Impact Assessment)

Since the Project is a run-of-river type development with a relatively small-scaled reservoir, and located in a less populated area, submerged cultivated land and number of families to be resettled are limited. However, it is necessary that landowners and families to be resettled be granted proper compensation.

It is felt that major issues will not take place related to the natural environment, since the project area is located outside protected areas. It is required, however, that a mitigation plan, a proper monitoring system and management in the project area be implemented.

The required amount of water should be released in order to maintain the natural river condition between the dam and the powerhouse site where the natural river water decreases due to diversion of water for power generation.

The A route transmission line (powerhouse - Sarpang - Bongaigaon) of the Project crosses biological corridors linking protected areas on the way to the Bhutanese-Indian border. However, it is considered that environmental impact from the transmission line can be minimized by routing it along existing infrastructures such as roads, etc.

(Economic and Financial Evaluation)

Financial generating cost (FGC) of the Project is 2.59cent/kWh, when all financing is provided by equity with a discount rate of 10%. This FDC is competitive compared to average sale price in the power market of the Project i.e. the eastern states of India.

As regards economic evaluation of the Project, economic internal rate of return (EIRR) based on the revenue of power sale and value of alternative thermal power is 13.1% and 29.8%, respectively. This shows that the project is feasible from an economic point of view.

(Financing and Development Scenario)

Case studies on fund procurement for the Project were carried out with presumed schemes and conditions. Three scenarios are listed below:

-Existing finance scheme from India (scenario A)

-Financing under BOT scheme (scenario B)

-Region-oriented or regional ODA (scenario C)

According to the study results, every financing scenario would be possible, since DSCR is more than 1.5, which is the recommended level by international financial institutions.

Recommendation

The Punatsangchhu Hydropower Project is technically, economically and environmentally feasible, and should be implemented as a run-of-river type with a peak generating capacity to be value added, power export-oriented scheme.

Commissioning would be possible around 2010 or later, with necessary time scheduled for detailed design, financial procurement, construction and so on after taking the Feasibility Study into consideration. According to the demand forecast of 2010, power market circumstances in India, especially in the Eastern Region, are expected to be tightened. Therefore, the Project should be promoted to a next candidate hydro- power project, subsequent to those on-going now.

Layout and project cost of facilities shown in the report indicate a best alternative based on the Feasibility Study grade design. Detail design should be carried out and accuracy of the plan should be heightened further in order to implement the project without risk.

In this regard, appropriate additional geological investigation should be carried out as soon as possible at the riverbed, slope of right abutment of the dam site, along the tunnel route and at the powerhouse site to make the conditions there more clear.

Also, as regards the transmission line of the Project, a route was selected based on the results of the comparative study between A route (powerhouse-Sarpang -Bongaigaon) and B route (powerhouse-Kerabari-Coah Bihar) in terms of their construction cost, environmental impact and so on. A route was selected. However, final decision on this should be made based on the detailed study, which will be carried out from now on.

Mitigation measures plan (MMP) of GLOFs is now being studied so that it will be one of the basin control plans. The power generation plan is being studied, taking the study results of the Study Team, as well as the results of MMP, into consideration. If mitigation measures are implemented, the Project would be a more secure one.

Anticipated negative environmental effects during construction were studied by carrying out EIA as a grade of the feasibility study, i.e. muck transportation and disposal, drainage, turbidity, dust, noise, sewage water and so on during construction. These were confirmed settled, but countermeasures should be made clearer by formulating a detailed construction plan during the detailed design stage.

Bhutan should consolidate investment circumstances by reforming its organization in the power sector, as well as putting in order that sector's related laws, rules and codes, to guide loans of international financial institutions and capital of investors.

By this method, Bhutan should also select a scenario in which the country can implement a power export-oriented project in the most independent way possible.

PUNATSANGCHHU HYDROPOWER PROJECT

River		
	Name of River	Punatsangchhu
	Catchment Area	5,796 km^2
	Annual Inflow	9,398 × 10^6 m^3 (298 m^3/s)
Reservoir		
	High Water Level	1,161.50 m
	Low Water Level	1,147.00 m
	Available Drawdown	14.50 m
	Sedimentation Level	1,142.00 m
	Gross Storage Capacity	12.49 × 10^6 m^3
	Effective Storage Capacity	4.39 × 10^6 m^3
	Reservoir Area	0.53 km^2
Infrastructure		
	New road (highway)	400 m
	Bridge (permanent)	110 m
Dam		
	Type	Concrete Gravity Dam
	Elevation of Dam Crest	1,171.00 m
	Elevation of riverbed	1,090.00 m
	Height of Dam (from foundation)	141.00 m
	Length of Dam Crest	265 m
	Volume of Dam	830 × 10^3 m^3
Diversion Tunnel		
	Design Flood	1,470 m^3/s
	Type	Standard Horse Shoe, Pressure, Concrete Lining
	Number	Two
	Inner Diameter	7.80 m
	Length	822 m/932 m
Outlet Equipment		
	Type	Service: Jet Flow Gate
		Auxiliary: High Pressure Slide Gate

Spillway

Design Flood	13,900 m^3/s
Type	Shute with Gates
Elevation of Overflow Crest	1,142.00 m
Width of Overflow Crest	84.00 m (excluding pier width)
Energy Dissipator	Bucket Type
Type of Gate	Radial Gate
Number of Gate	Seven
Size of Gate	Width 12.00 m × Height 20.00 m

Emergency Spillway

Type	Flap Gate
Number	4
Size of Gate	Width 12.00 m × Height 5.00 m

Intake

Type	Horizontal
Number	Four
Elevation of Inlet Sill	1,144.00 m
Size	Width 10.50 m×Height 17.00 m
Type of Gate	Roller Gate
Number of Gate	Four
Size of Gate	Width 5.00 m×Height 5.00 m

Intake Tunnel

Type	Half Circle Half Rectangular, Concrete Lining
Number	Four Lines
Discharge Capacity	87.00 m^3/s per line × 4
Inner Diameter	5.00 m
Total Length	1,003 m

Settling Basin

Type	Underground, Concrete Lining
Number	Four
Size	Width 20.00 m × Height 37.00 ~ 41.00 m
Length	130.00 m

Headrace Tunnel

Type	Circular, Concrete Lining

	Number	Two Lines
	Max. Discharge	174.00 m^3/s per line × 2
	Inner Diameter	7.40 m
	Length	7,023 m/6,959 m
Surge Tank		
	Type	Orifice Type, Concrete Lining
	Number	Two
	Size	Diameter 15.00m×Height 63.00m
Penstock		
	Type	Steel Embedded
	Number	Four Lines
	Inner Diameter	7.40～3.20m
	Total length	1,037 m
Powerhouse		
	Type	Underground, Shotcrete･PS anchor
	Size	Width 20.00m×Height 38.00m×Length114.00 m
Access Tunnel		
	Type	Half Circle Half Rectangular, Concrete Lining
	Size	Width 6.00m×Height 6.00m×Length477m
Cable Tunnel		
	Type	Half Circle Half Rectangular, Concrete Lining
	Size	Width 4.00m×Height 4.00m×Length342m
Transformer House		
	Type	Underground, Shotcrete • PS anchor
	Size	Width 10.00m×Height 10.00m×Length 114.00m
Tailrace Tunnel		
	Type	Circular, Concrete Lining
	Number	Two Lines
	Max. Discharge	174.00 m^3/s per line × 2
	Inner Diameter	7.40 m
	Length	347 m/307 m
Development Plan		
	Normal Intake Water Level	1,154.30 m
	Normal Tail Water Level	845.00 m

	Gross Head	309.30 m
	Effective Head	286.30 m
	Maximum Discharge	348.00 m^3/s for 6 units
	Number of Unit	Six
	Installed Capacity	870 MW
	Firm Peak Power	859 MW
Turbine		
	Type	Vertical Shaft, Francis Turbine
	Number	Six
	Max. Discharge	58.00 m^3/s per unit
	Turbine Output	148,500 kW
	Revolving Speed	300 rpm
Generator		
	Type	Three phases Alternating Current Synchronous
	Number	Six
	Rated Output	161,700 kVA
	Revolving Speed	300 rpm
	Frequency	50 Hz
	Voltage	15 kV
	Power Factor	0.9 lag
Main Transformer		
	Type	Indoor special three phases, Forced-oil-forced-air Cooled type
	Number	Six(6)
	Capacity	161,700 kVA
	Voltage	(Primary) 15 kV (Secondary) 400 kV
Switchyard	Bus System	Double Buses with Bus Tie
	Bus Conductor Type	ACSR
	Number of Lines Connected	2 cct Transmission Line

	Voltage	400 kV	
	Conductor Type	ACSR	
Transmission Line	Length	140 km (80 km in Bhutan, 60 km in India)	
	Type of Transmission Tower	Steel lattice tower	
	Number of Circuit	Two(2), (Vertical configuration)	
	Voltage	400kV	
	Conductor Type	1,351.5 MCM ACSR (Martin)	
Annual Energy Production	Average Energy	4,330 GWh	
	Firm Energy	1,268 GWh	
Construction Period		6 years	
Project Cost		36.3×10^9 Nu (813×10^6 US$)	
Unit Construction Cost	Per kW	41,754 Nu/kW (934 US$/kW)	
Economic/Financial Evaluation	Financial Generation Cost	2.76 US cent/kWh	
	Economic/Financial Evaluation	Power Sale	Alternative thermal
	Benefit-Cost Ratio (Financial)	1.35	1.98
	EIRR	13.1%	29.8%
	FIRR	13.1%	---

1. INTRODUCTION

The Punatsangchhu Hydropower Project was carried out in Bhutan and Japan under a technical cooperation scheme by the Japan International Cooperation Agency (JICA), for the purpose of studying its technical, economical and environmental feasibility in the western region of Bhutan from November, 1998, to January, 2001.

Bhutan has aimed at establishing an export-oriented hydropower industry, with a view to strengthening the national economy, and utilizing abundant water resources and steep topography in the country. The Punatsangchhu Hydropower Project is one of the projects that will realize this strategy in the future.

The Project is a large-scaled and power export-oriented hydropower project to India, using a reservoir with a 4.4 million m^3 active capacity created by a diversion dam, conducting water downwards by means of a waterway of about 7 km and generating 4,330 GWh in annual energy production by an underground powerhouse of 870 MW.

The government of Bhutan requested that the government of Japan carry out a feasibility study of the Project. The government of Japan dispatched a JICA preparatory study team to Bhutan in July, 1998, to discuss the possibility of rendering a technical cooperation grant.

The JICA preparatory study team visited the project site, collected related data and prepared a Scope of Work (S/W) and Minutes of Meeting (M/M) after discussions with the Division of Power (DoP), which is the Counterpart under the Ministry of Trade and Industry (MTI). The JICA preparatory study team and DoP came to an agreement and finally signed the S/W and M/M on July 15, 1998.

For the purpose of implementation of the study, Electric Power Development Co., Ltd. (EPDC), Japan, was nominated as a consultant after the required document procedure, and a contract was drawn up.

Based on the above contract, EPDC dispatched the study team and started various activities for the Feasibility Study in November, 1998. The Study Team carried out the following studies: data collection, review of previous reports, hydrological study, geology study and material investigation, environmental study, power sector study in both Bhutan and India, aerial photography and mapping, ground survey, optimum power generation plan study, feasibility design of major structure and equipment, environmental impact assessment (EIA), construction planning and cost estimate, economic evaluation, financing study and so on.

The Study Team carried out site works in Bhutan with full cooperation from counterpart personnel of DoP, under the Ministry of Trade and Industry.

At the same time, the Study Team made technology transfers to the engineers and staff during these occasions of site works. The JICA also invited three engineers of DoP to Japan to carry out the Counterpart Training.

All activities of the Feasibility Study were completed in January, 2001.

2. GENERAL SITUATION IN THE KINGDOM OF BHUTAN

2.1 Introduction

The Bhutan is located in the Bhutan-Himalayas (Longitude 88.7°E, Latitude 26.7~28.4° N) in the eastern part of the Himalayas, having an area of 46,620 km^2 which is similar to that of Switzerland. The country is surrounded by the Tibet Autonomous Region of China to the north and by State of Arunachal Pradesh, Assam, and West Bengal of India along the northeast to the south and west, and stretches for 330 km east-west and 180 km north-south.

The climate of the country is categorized into three types, namely Alpine, Mid-montane, and Subtropical. Alpine is for the higher region above 3,500 m above sea level, Mid-montane is for the region between 1,800 m and 3,500 m above sea level, and Subtropical is for the region below 1,800 m ,which is from the foothills of the Himalayas to the mid- mountainous region.

The temperature of Punakha and Wangdue Phodrang, in the mid-basin of the Punatsangchhu, of which the project area is part, rises up over 30℃ in August and falls to 0℃ in January.

2.2 Economy and Energy Resources

According to the 43rd issue Statistical Yearbook published by the United Nations, the GDP of Bhutan in 1996 was U.S.$ 320 million, thus GDP per capita is U.S.$176. On the other hand, GDP in 1999 was U.S.$ 420 million based on the latest data, using an exchange rate of Nu.42.6/US$. Therefore GDP per capita, based on a population of 656,000, described in the same data, exceeds US$500.

The sector-wise share ratio of the GDP is 38.0% for the agricultural sector, 10.8% for the construction sector, and 10.9% for the community service sector. This indicates that national economy fundamentally relies on agriculture.

The primary energy production of the country is 150,000 oil equivalent metric tonnes (OMT) in 1996, of which electric power occupies 99.3% or 149,000 OMT, according to the 43rd issue Statistical Year Book published by the United Nations. 86.0% of the primary energy production, an equivalent of 129,000 OMT, is exported. The balance 0.7%, an equivalent of 1,000 OMT, consists of coal.

Hence it is essential that Bhutan promote the development of its hydropower resource and export electricity to strengthen the foundation of the national economy. Consequently, power stations such as Chhukha Hydro Power (336 MW), in operation since 1987 and owned by CHPC, and Tala Hydro Power (1,020 MW), under construction by THPA, to be commissioned by July 2006, have been developed for the purpose of exporting electricity. Middle capacity hydro power development, such as Basochhu Hydro Power (61 MW) and Kurichhu Hydro Power (60 MW), which is expected to be commissioned in 2001/02, have been under construction as well, for the purpose of regional or domestic consumption.

2.3 Transportation and Communication

The arterial roads extend about 700 km east-west and about 1,000 km north-south, hence 1,700 km in total and 3,400 km including roads other than arterial roads.

The only international airport of Bhutan, Paro airport, is located approximately 20 km west of Thimphu. Paro is connected with Bangkok, Delhi, Calcutta, Katmandu, Dhaka, and Yangon via aviation service owned by the Royal Government of Bhutan. The navigation distance and number of passengers on scheduled services in 1996 were1,000,000 km and 35,000 heads, respectively.

Although there are several ways to enter the country from India, the route from Phuentsholing is the most usual. It is about 800 km from Calcutta to Phuentsholing. From Phuentsholing, it is about 180 km to Thimphu via Chhukha and Simtokha.

3. OUTLINE OF PROJECT SITE AND SURROUNDINGS

3.1 Water Resource Development and the Current Situation

A Power System Master Plan (PSMP) for the whole country was set up during 1990~1993 with funds from UNDP and NORAD. The PSMP reported on 25 development projects in the country and indicated seven projects with a total potential generating capacity of 1,894 MW in the Punatsangchhu basin. A Pre-Feasibility Study carried out as a part of PSMP indicated two projects, Project 3.120 (Punatsangchhu, 760 MW) and Project 3.230B (650 MW).

The dam site for Project 3.120(Punatsangchhu) is located about 10 km downstream of Wangdue Phodrang, and the powerhouse is located a further 8 km downstream from the dam site. For Project 3.230B, the dam site is located further downstream, so that the two projects become a dam and waterway type cascade development on the main stream.

Basochhu Hydropower Project (61 MW) is being constructed as of November, 2000, on the right flank near the project area in the same basin. The electricity produced there is planned for the 66kV Western-grid connecting the power station to the Simtokha substation.

3.2 Natural and Social Environment of Project Area

(1) Natural Environment

Landscape

According to the land utilization map for Thimphu-Wangdue Phodrang Dzongkhags provided by the Department of Land Utilization Planning, Ministry of Agriculture, Thimphu-Wangdue Phodrang Dzongkhags , 92% of the region including the project area, equivalent to 63,206 ha, is covered with forest consisting of fir, mixed conifer and blue pine, etc.

Flora

The flora in the country is integrated and tangled within the small area because the climate consists of three quite distinctive types -- high Himalayas, cram monsoon and subtropical. Vegetation found in the country ranges from banana and citrus fruit orchards up to 1,300 m above sea level, rice and crop fields up to 2,400 m above sea level or higher, and forests of deciduous trees and alpine plants from the high land upwards.

Broad-leafed trees can be observed along both river banks near the riverbed around the project area. Chirpine or *pinus roxburghii* dominates in the mountain flanks above half way up. Fauna

According to the report by the Department of Forest of Bhutan, 15 kinds of mammalia, 3 kinds of reptilia, and 31 kinds of birds are known to inhabit the country. Out of these the fauna protected by the Forest and Nature Conservation Act (1995) are Barking Deer as endangered species, and Serow, Himalayan Black Bear, Leopard Cat, and Leopard under careful protection. However, this list was produced many years ago, and it is possible that it is not reflective of the current situation which would include the effect due to new arterial roads constructed after such investigation.

Water quality

The sewage water from residents' dwellings is disposed into the Punatsangchhu from Punakha and Wangdue Phodrang without treatment. However, the run-off in the Punatsangchhu is quite sufficient so that the river's self purification system can be relied upon and hence sewage does no harm. Also, the population around the project site is fairly sparse and no industries that are likely to cause water pollution are recognized so far. The water quality of the river can be considered good.

(2) Socioeconomic Environment

Population

The total population of Wangdue Phodrang in 1998 was approximately 28,800. The total number of households was 2,800, with an average number of people in each household of around 10.

Public facilities

One hospital, nine Basic Health Units (BHU), and 20 outreach clinics are facilitated in Wangdue Phodrang. There are a limited number of medical facilities in the area, and for most residents it is a few hours walk to the nearby BHS. Only 1,746 households, 63% of the total, are supplied a water system.

As for education facilities, there is one senior high school, three junior high schools, nine primary schools, and four community schools.

Transportation

Roads are constructed in such a way that they cross the Punatsangchhu basin longitudinally. Wangdue Phodrang is an important intersection that connects Punakha in the northern region, Thimphu in the western region, Trongsa and Mongar in the eastern and southern region. Those roads running north-south and east-west allow transition of large vehicles. The dam site is located about 10 km south of Wangdue Phodrang by arterial road, and the powerhouse site is located a further 8 km downstream on the same arterial road.

Industry

About 90% of the residents rely for their living on agriculture. They grow rice, flour, corn, buckwheat, barley, millets, potatoes, apples, oranges and mustard. There are 30 people who hold some kind of industrial license, and 180 people holding trading licenses in Wangdue Phodrang. There are 10 construction businesses, and also plants for such production as woodworking and paper..

Cultural preservation, recreation

It is unknown whether any cultural preservation or recreation facilities exist within the land required for the project that may stop the project.

4. POWER SECTOR SURVEY

4.1 Power Sector Survey in Bhutan

Within a single decade, between 1988 and 1998, real GDP increased approximately 1.7 times, from 1,993.6 millions Nu. to 3,541.3 millions Nu. (exchange rate : Bhutan 1 Nu. = 3.1 Yen as of October ,1998). With this increase in GDP, electric energy consumption also increased from 275.95 GWh in 1994/95 to 396.57 GWh in 1998/99 (total installed capacity was 56.67 MW), and the energy power sector contributed approximately 25% of the Governmental income in the middle of the 7th 5-year-plan.

Peak demand in Bhutan was rapidly increased, approximately 3.6 times, from 22 MW in 1990 to 80 MW in 1999. Bhutan has an important energy power sector which exports hydropower energy to India since completion of a large-scale power station in Chhukha in 1986/88.

4.2 Power Sector Survey in India

(1) Objective State for Power Sector Survey

The objective of the power sector survey is to grasp the situation of power demand and supply in both countries: Bhutan which exports power, and India which imports power, in order to reveal appropriateness and project position.

The objective States in this survey are West Bengal and Assam, because they are the nearest States in India to consume the imported power from Bhutan. Results of the survey revealed that the Eastern region including West Bengal State is more advantageous than the North-eastern region including Assam in the following points: 1) maximum consumption of Assam State being only 10% of that of West Bengal State in spite of the highest growth rate of demand forecast in the 11th plan than in other regions; 2) future plan for best energy mix: hydro and thermal power of the Eastern region including West Bengal state; and 3) advanced energy policy of import power in West Bengal state. Considering the above mentioned points, the export of hydropower energy of Bhutan to the Eastern region of India including West Bengal State is appropriate from the viewpoint of the power system.

(2) Power Sector in India

The most recent Electric Power Survey in India, conducted by the 15th Electric Power Survey Committee, constituted by the Government of India in March, 1994, was published in 1995. It reviewed the electricity demand projections in detail during the 9th plan period, up to 2001-02, and projected the perspective demand up to 2011-12 of the 11th plan.

The Planning Commission has considered a feasible addition to the generating capacity as 40,245 MW in the 9th plan (draft) in 1997-2002, keeping in view the status of on-going, approved and new projects, based on the 9th plan. They are to be required to develop 57,698 MW for the 10th plan and 58,047 MW for the 11th plan.

Out of the above capacity during 10th plan, development of 7,330 MW has been approved and 10,556 MW cleared by CEA so far. As well as the above, new projects of 39,812 MW have to be considered to meet the demand. In addition for the 11th plan, 9,086 MW have been cleared by CEA so far. On top of the above schemes, new projects of 48,961 MW have to be considered to meet the demand.

Especially, hydropower energy imported from other countries has been definitely planned:

(i) Eastern Region From Bhutan

Punatsangchhu Power Station : 870 MW

Tala Power Station : 1,020 MW

(ii) Northern Region from Nepal

Pancheswar Power Station : 6,480 MW

The 10th and 11th Development Plans by region and source of energy are listed below.

10th Five Year Plan(2002-07) (Unit: MW)

Region	Hydro	Thermal	Nuclear	Total
Northern	2,086	10,745	1,000	13,831
Western	2,250	17,744	1,000	20,994
Southern	1,711	6,321	2,880	10,912
Eastern	2,261	8,230	0	10,491
North Eastern	710	760	0	1,470
All India	9,018	43,800	4,880	57,698

CEA: Central Electric Authority

11th Five Year Plan(2007-12) Unit: MW

Region	Hydro	Thermal	Nuclear	Total
Northern	13,322*	3,300	1,000	17,332
Western	3,836	5,441	-	9,277
Southern	4,204	11,111	-	15,315
Eastern	5,852**	8,690	-	14,542
North Eastern	1,381	-	-	1,381
All India	28,505	28,542	1,000	58,047

* Including 6,480MW imports from Nepal.

** Including 1,785MW imports from Bhutan.

4.3 Power Sector Survey of West Bengal State

Dependable capacity of West Bengal was 3,792 MW as of 1997/98 (increased to 4,580 MW in 2000/March) and almost all are thermal power stations; only 4% are hydro power stations. On the other hand, there was a surplus of power capacity because peak demand was only 2,800 MW (increased to 3,217MW in 2000/March) in the power system. Energy available in the state of 19,166.29 GWh as of 1997/98, consisted of 13,192.4 GWh by state owned power stations and 5,974 GWh by power purchase from other states or countries (including 1,357GWh from Bhutan). Peak demand and energy consumption of West Bengal are shown in Fig. 4.1 to 4.2.

However, energy sold was 15,266.08 GWh, consumption within the state was 14,467.2 GWh, and power exchange to other states was 798.88 GWh from West Bengal including export of 4.5 GWh to Bhutan. The rest, 3,900 GWh, corresponded to losses of transmission and distribution lines (20.35 % of loss ratio).

POWERGRID is developing the interconnection line between the Eastern and Northern regions as a first priority project. It is greatly expected that a best mix of energy in the power system will be carried out within both regions, especially that surplus power at off peak of the Eastern region including West Bengal will be supplied to the Northern region. From the point of view of the whole power system, it is enough to reveal propriety of imported hydro power from Bhutan because of the advantage of system load variation and a quick response of start/stop for the power stations; furthermore, the effect of CO_2 reduction.

4.4 Power Sector Survey of Assam State

Dependable capacity of Assam was 1,217 MW as of 2000/March. It consisted of 20% of hydro power stations and 80% thermal power stations. On the other hand, peak demand was approx. 565 MW and balanced with the capacity in the power system. Energy available in the state of 2,582. 6 GWh as of 1997/98 consisted of 936 GWh by state owned power stations and 1,464.3 GWh of power purchase from other states. Energy sold was 1,877 GWh, and 705 GWh (27.3% of total) was loss of transmission and distribution lines. Furthermore, 5.38 GWh was exported from Assam to other states, including export of 2.7 GWh to Bhutan. The power exchange is active between state and state in the regions.

Five REBs (Regional Electricity Boards) manage and operate the power exchange on the regional level as a power pool system using POWERGRID interconnection line. Therefore, Assam purchases about 50% of power from others despite enough dependable capacity of their own power stations. It was because purchased power from other states was cheaper than self-generated power. As for the financial aspect, the development program for new projects has been established, but is behind schedule compared to the growth of demand.

Technical losses were high due to transferring power through long distance transmission lines as well as commercial losses by un-metering and imperfect levy of electric charge, etc.

As well, it is important to increase the load factor performance of thermal power stations taking into consideration technical and financial aspects, because of low efficiency or stoppage of power plants without maintenance (average P.L.F was 40.6% in thermal power stations of the state).

4.5 Power Purchase Business in India

Gross energy generation by public electric utilities in 1997/98 in India was 421,747.28 GWh, and 394,989.25 GWh was the available supply energy of all India excepting 30,684.2 GWh (7.28 %) for power station services use. 391,063.08 GWh (92.72 %) was a net energy generation at bus-bar, 2,541.51 GWh (0.74 %) was purchased from non-utilities, and 1,384.66 GWh (0.42 %) was imported from Bhutan. On the other hand, total energy sold was 296,748.92 GWh (75.13 %) and the remaining 321.43 GWh (0.08 %) was sold to other countries (Bhutan and Nepal) with 97,918.9 GWh (24.79 %) for commercial and technical losses in the power system. Details are shown in Tables 4.52 to 4.54.

Imported energy region-wise was only the Eastern region (West Bengal state) and 1,384.66 GWh (0.42 %) was imported from Bhutan. Percentage of power exchange for each region from other states is shown in Fig.4.3.

Fig. 4.1 Peak Demand and Power Supply Position from 1997-98 to 1999-2000, WEST BENGAL STATE

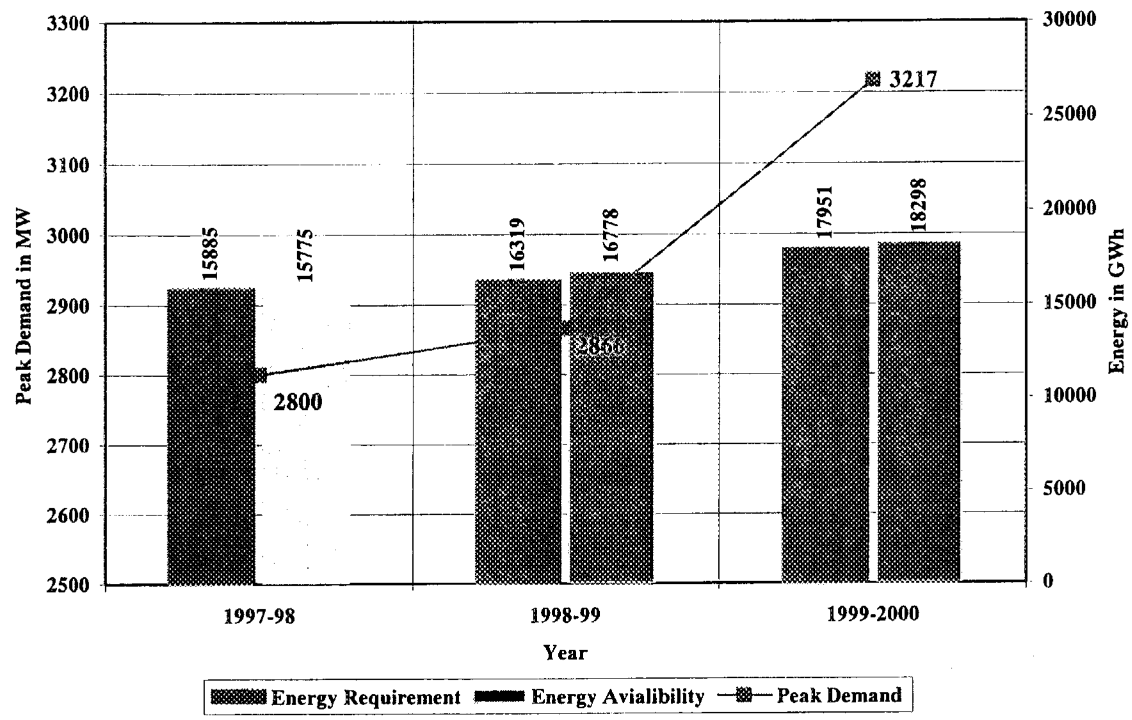
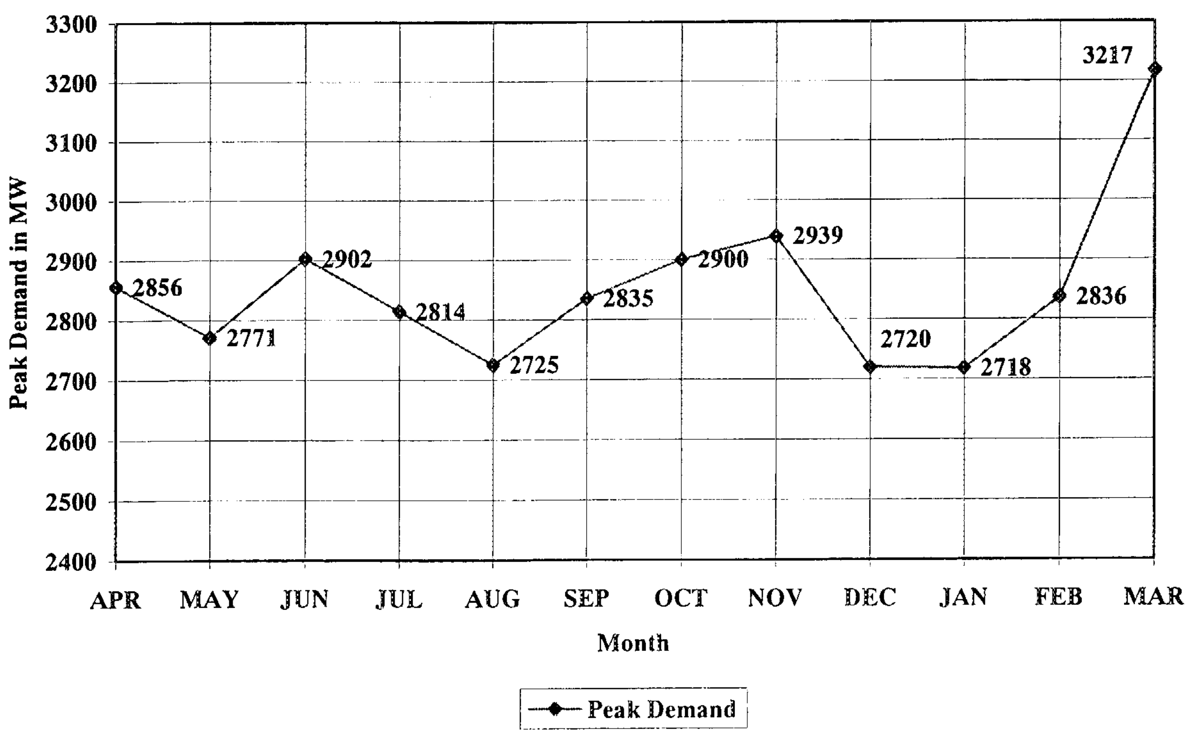


Fig. 4.2 Monthly Peak Demand for the Year 1999-2000 WEST BENGAL STATE



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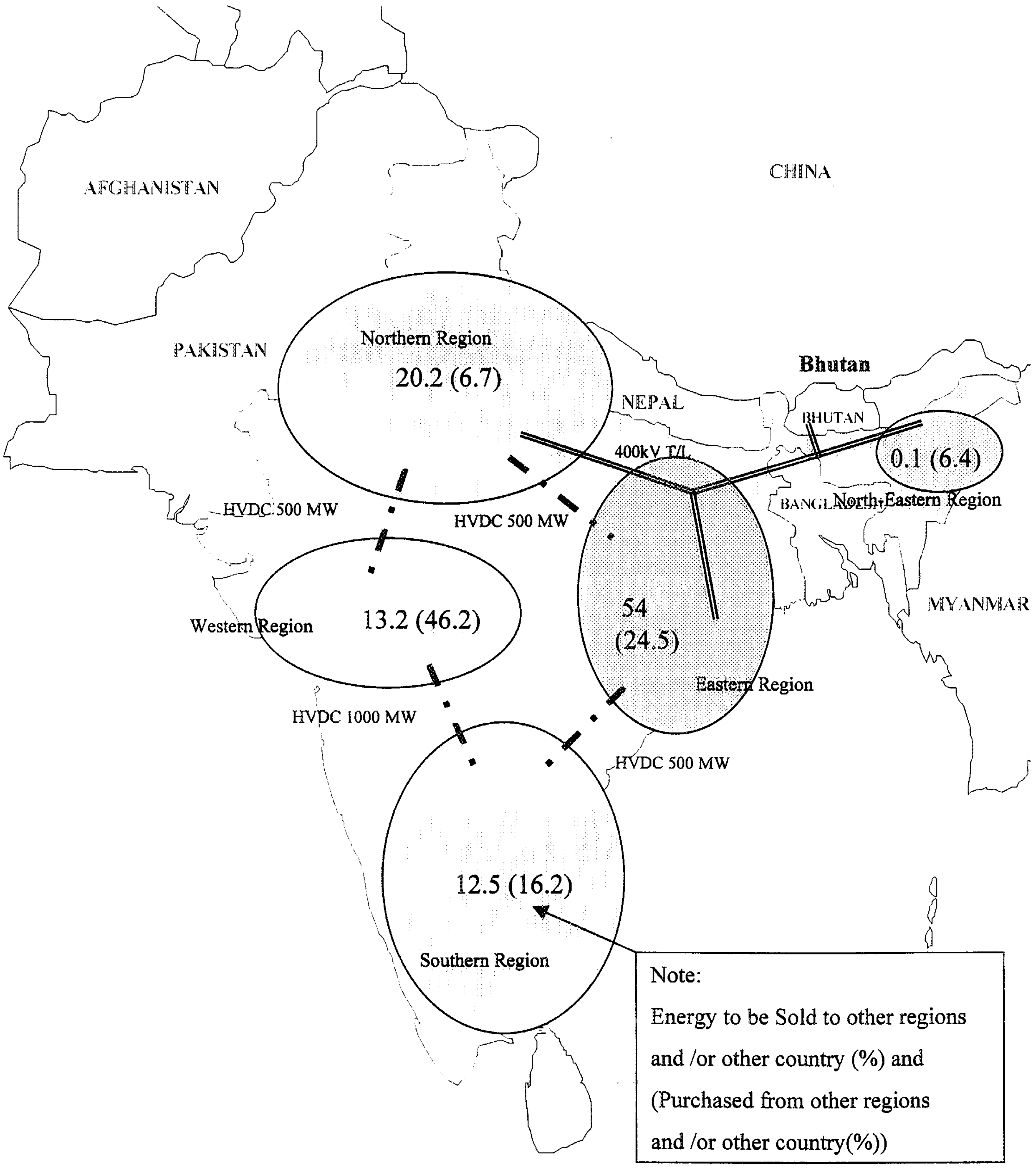

Fig.4.3 Percentage of Power Sold and Purchased in Region Wise, India in 1997/98

5. POWER DEMAND FORECAST AND SUPPLY

5.1 Power Demand

Power demand forecasts up to 2020 revealed that the peak power of 72 MW in 1996 will increase to 418 MW (515 MW at high scenario) in 2020, and annual energy consumption from 412 GWh to 2342 GWh. An annual average growth rate over the 24 years is 6.4 ~ 6.5%. On the other hand, in West Bengal State, the peak power of 3,240 MW in 1996 will increase to 10,391 MW in 2020, and annual energy consumption from 16,975 GWh to 54,616 GWh. An annual average growth rate over the 24 years is around 5.0%.

5.2 Power Supply

It is possible to fill an increasing power demand in Bhutan between 2000 and 2020 by drawing gradually the generated energy of Chhukha (336 MW) exporting to West Bengal State and of the planned Basochu (61 MW) and Kurichu (60 MW) plants. On the other hand, West Bengal State has to develop new thermal power plants with 5,250 MW in capacity and 27,590 GWh in generating energy with a plant factor of 60%, under the condition that it import the surplus energy of Chhukha (CHP), Basochu and Kurichu plants from Bhutan.

If Tala (1,020 MW) and Bunakha (18 0MW) projects, which are planned in Bhutan to take the place of a new power plant in West Bengal State, will be commissioned by 2008, Punatsangchhu project (870 MW) will need to be commissioned in around 2009~10 for West Bengal State.

5.3 Commissioning Year of the Big Projects in Bhutan

The big projects, Tala, Bunakha and Punatsangchhu, should be commissioned in steps to meet the energy demand and supply balance in West Bengal State. The latest DOP plan shows that Tala is scheduled to be commissioned in 2006, and Bunakha is under the 9FYP (2003 to 2007). After both projects are developed in steps, Punatsangchhu will have to be commissioned in two steps for the balance of energy. That is, to commission three units (145 W × 3 = 435 MW) in 2010 as the first step and the other three units (145 MW × 3 units = 435 MW) in 2011 as the second step. In the case that West Bengal State develops new power plants or is expected to purchase the required energy from other states, it will allow delay of the commissioning years of these projects in view of the demand and supply balance.

6. METEOROLOGY AND HYDROLOGY

6.1 Summary

The Punatsangchhu originates in the Himalayas of northwestern Bhutan and flows south. The river is formed by the Mochhu and the Phochhu, which join at Punakha and flow into the Brahmaputra river at Assam State in India. The Punatsangchhu is called the "Sankosh River" in India, and the total length is approximately 320 km.

The rainy season affected by monsoons is four months long, ranging from June to September in the basin. The highest temperature is over 30°C in August as compared to the lowest, approximately 0°C in January, in the midstream area including the project site near Wangdue Phodrang. The largest discharge is approximately 1,200 m^3/s in the rainy season as compared to the smallest, 60 m^3/s in the dry season at the project site.

6.2 Meteorological and Hydrological Stations

Meteorological observation has been carried out by DoP in the Punatsangchhu basin. Data from 10 meteorological stations, Gasa, Punakha, Shelgana, Wangdi, Gaselo, Basochhu, Tashithang, Damphu, Sonkosh, Drujeygang is available. Locations of these stations are shown in Fig. 6.1. Table 6.1 shows the period and kind of data of each station.

Discharge measurement has been carried out by DoP at six hydrological stations in the Punatsangchhu basin as shown in Fig. 6.1. There are four stations, Yebesa, Wangdi Rapids, Dubani and Kerabari, on the main stream and two stations, Maza Fall and Toshiding, on the tributaries.

6.3 Discharge at the Project Site

As shown in Fig. 6.1 Wangdi Rapids GS (Gauging Station) is located about 9 km upstream and nearest the damsite. Therefore, discharge at the damsite was to be converted from its data. The catchment areas and average discharges are as follows.

	Wangdi Rapids GS	Damsite
Catchment Area : A (km^2)	5,640	5,796
Average Discharge : Q (m^3/s)	290	298

Firm discharge (95%) at the damsite was calculated to be 64.0 m^3/s.

6.4 Flood Discharge at the Project Site

(1) Probable Flood

Based on maximum daily discharge for 8 years,1992-1999, frequency analysis was carried out using the Gumbel distribution. The results are summarized in the table below.

Probable Flood

Return Period (year)	5	10	20	50	100	200	1,000
Flood Discharge (m^3/s)	1,469	1,630	1,784	1,984	2,134	2,283	2,628

(2) Probable Maximum Flood (PMF)

As it is considered that this project will play a very important role in the economic and social development of Bhutan, it will be appropriate to adopt the Probable Maximum Flood (PMF) in the design of the Punatsangchhu dam. PMF is defined as the flood that may be caused under the theoretical combination of the most severe meteorological and hydrological conditions.

PMF discharge at the damsite was calculated to be 13,900 m^3/s as shown in the flood hydrograph. (Fig. 6.2)

(3) Glacier Lake Outburst Flood (GLOF)

The occurrence of Glacier Lake Outburst Flood (GLOF) is often reported in areas where rivers have their origins in glacial ranges. The result of simulation of GLOF using the Luggye and Raphstreng Lake (Fig. 6.3) outbursts is shown in Fig. 6.4. The peak discharge of these two lakes was calculated to be 4,600 m^3/s as shown in this hydrograph.

In order to cope with GLOF in the Punatsangchhu basin, it is thought that one of the most effective measures is to lower the water level of glacier lakes. On the other hand, the important element in protecting river constructions like dams from damages by GLOF is to first provide gauging stations, sensors, etc. in the upstream basin and then to directly connect these facilities with the gate operation system for data transmission, so that the reservoir water level can be lowered prior to the arrival of GLOF surge. Further, considering the possibility of malfunction of the control system for spillway gates or mistakes in operation, the dam should be designed to permit overtopping.

6.5 Sedimentation

Annual average suspended load over 8 years (1992-1999) is 1,354,569 m^3/year at the Wangdi Rapids gauging station. The bed load and total load are calculated to be 338,642 m^3/year and 1,693,211 m^3/year respectively, on the assumption that the bed load equals 25% of the suspended load. The specific total load is 300 m^3/year/km^2 in the project area.

The shape of the deposit in the reservoir was simulated by a computer program (EPDC/KCC FLOW 500 MODEL). According to the result of the simulation as shown in Fig. 6.5, it is considered that the front of the deposit will reach the damsite in 20 years. Since spillway gates (sill level of spillway gate: EL 1,142m) equipped at the dam will be operated throughout the period of wet seasons, it is considered that the surface of the deposit will keep equilibrium at the dotted line shown in the figure.

However, the sediment load due to GLOF is not considered in this analysis. There is a possibility that the deposit will progress faster than calculated in the simulation due to the deposit of GLOF. Therefore it is necessary to pay attention to this point when designing the structures.

6.6 Calculation of Backwater during Flood

Backwater at the upstream area of the damsite during a flood was to be calculated based on the simulation of the deposit shape. GLOF with estimated peak discharge of 4,600 m^3/s was adopted for the target flood for this calculation. Two cases for backwater calculation, for conditions on the river before and after the dam construction were carried out, respectively.

According to the result of the calculation, water surfaces before and after the dam construction begin to approach each other at 4 km upstream from the damsite and are closer further upstream. As well, the difference between the water levels is about 1-2 m at about 8 km upstream from the damsite. This shows that there is little difference in scales of inundated areas due to dam existence.

Table 6.1 Availability of Data

Meteorological Station

Station Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Data
Gasa											-			-		**R,T,H**
Punakha				-												**R,T,H**
Shelgana																**R,T,H**
Wangdi	-	-	-	-	-											**R,T,H,W,E,S,D**
Gaselo	-								-	-	-					**R,T,H**
Basochhu	-	-	-	-	-											**R,T,H**
Tashithang									-							**R,T,H**
Sonkosh													-			**R,T,H**
Drujeygang																**R,T,H**
Damphu	-	-	-	-	-	-	-	-	-	-	-					**R,T,H,W,E,S,D**

LEGEND **R** : Rainfall, **T** : Temperature, **H** : Humidity, **W** : Wind Speed/Direction, **E** : Evapolation, **S** : Soi l Temperature, **D** : Duration of Sunshine

Hydrological Station

Station Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Data
Yebesa																Discharge, Suspended Load
Wangdi Rapids																Discharge, Suspended Load
Dubani							-									Discharge, Suspended Load
Maza Fall																Discharge

LEGEND [shaded] : Available [-] : No Data

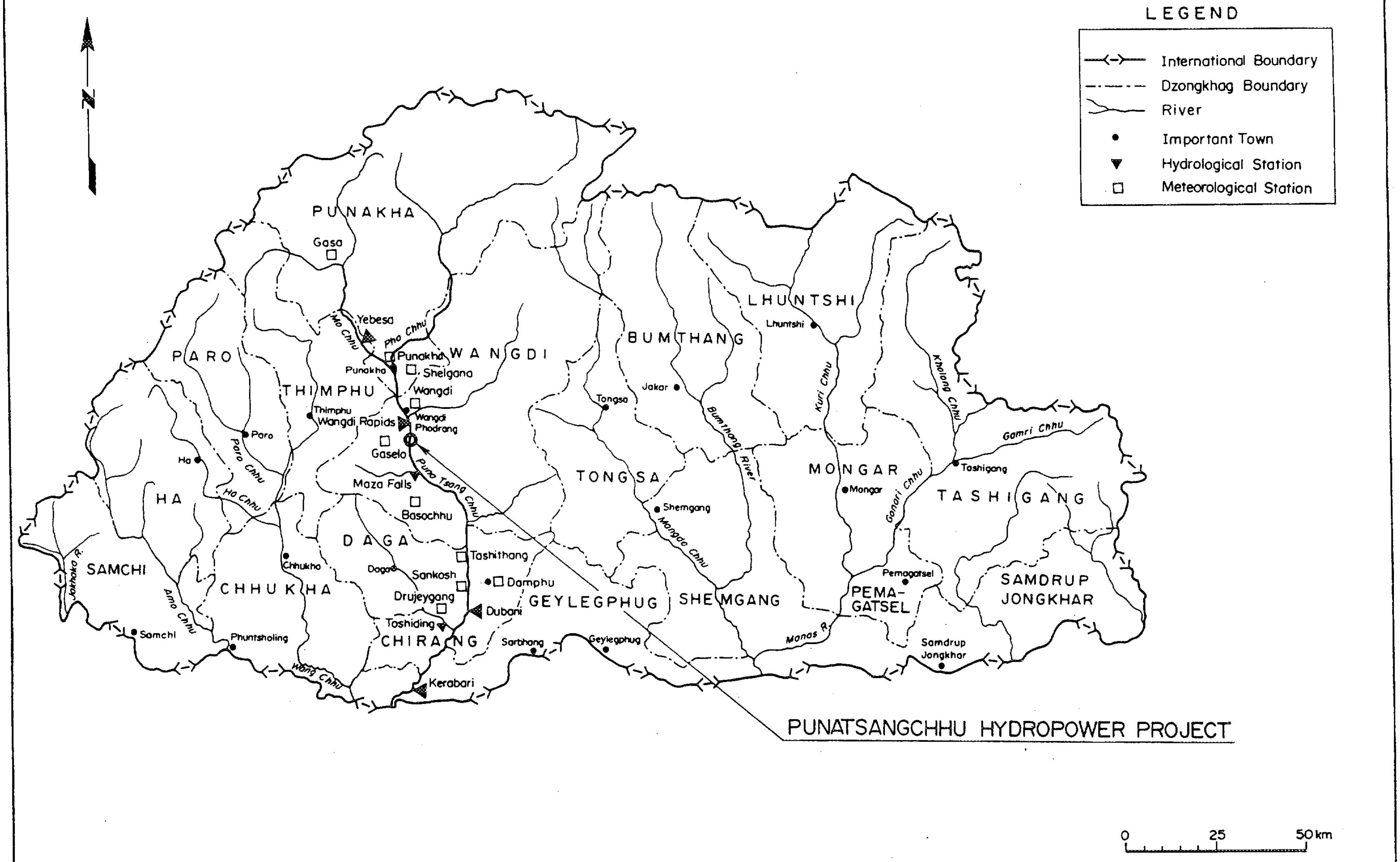

Fig. 6.1 Location Map of Hydrological and Meteorological Stations

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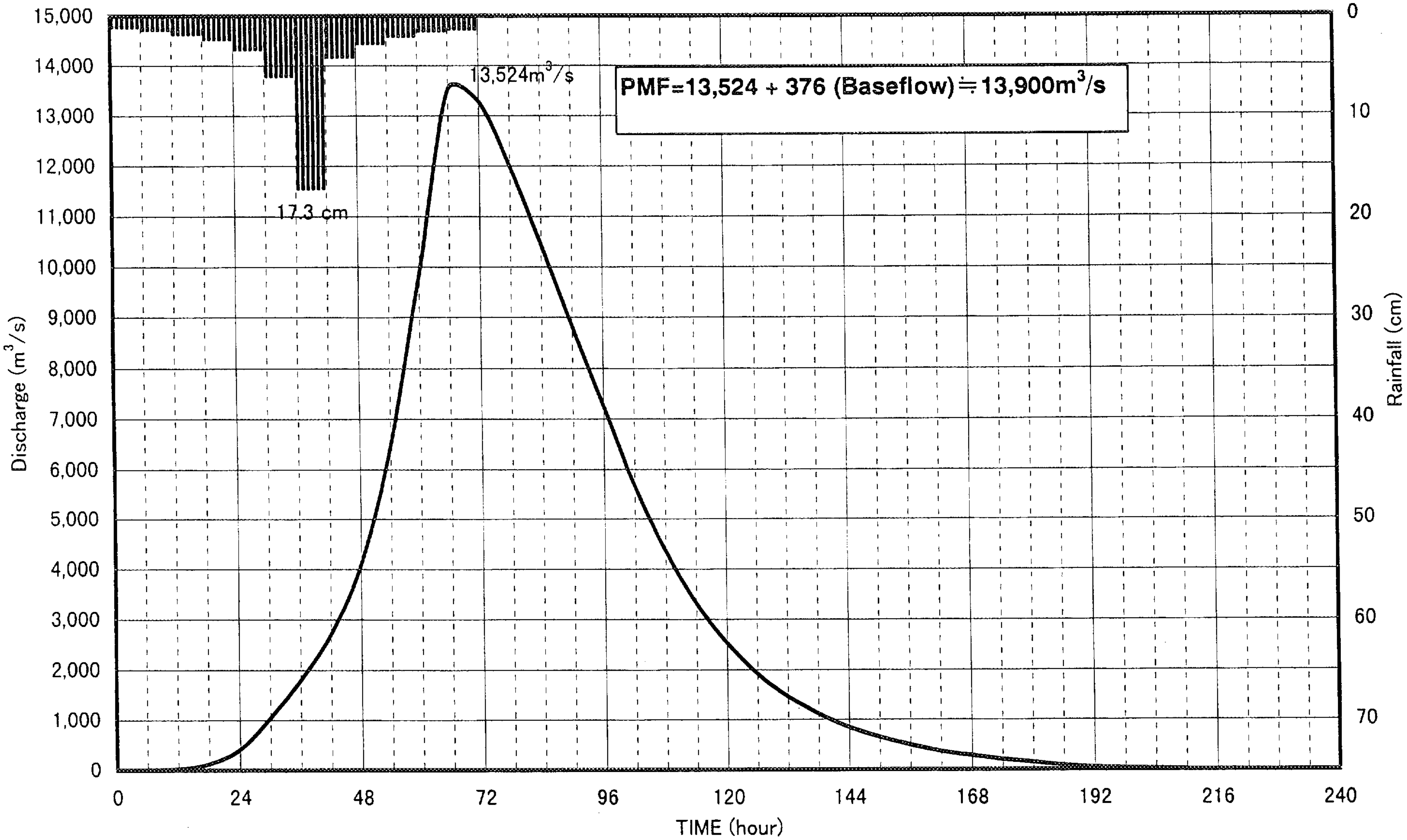

Fig. 6.2 Hydrograph of PMF

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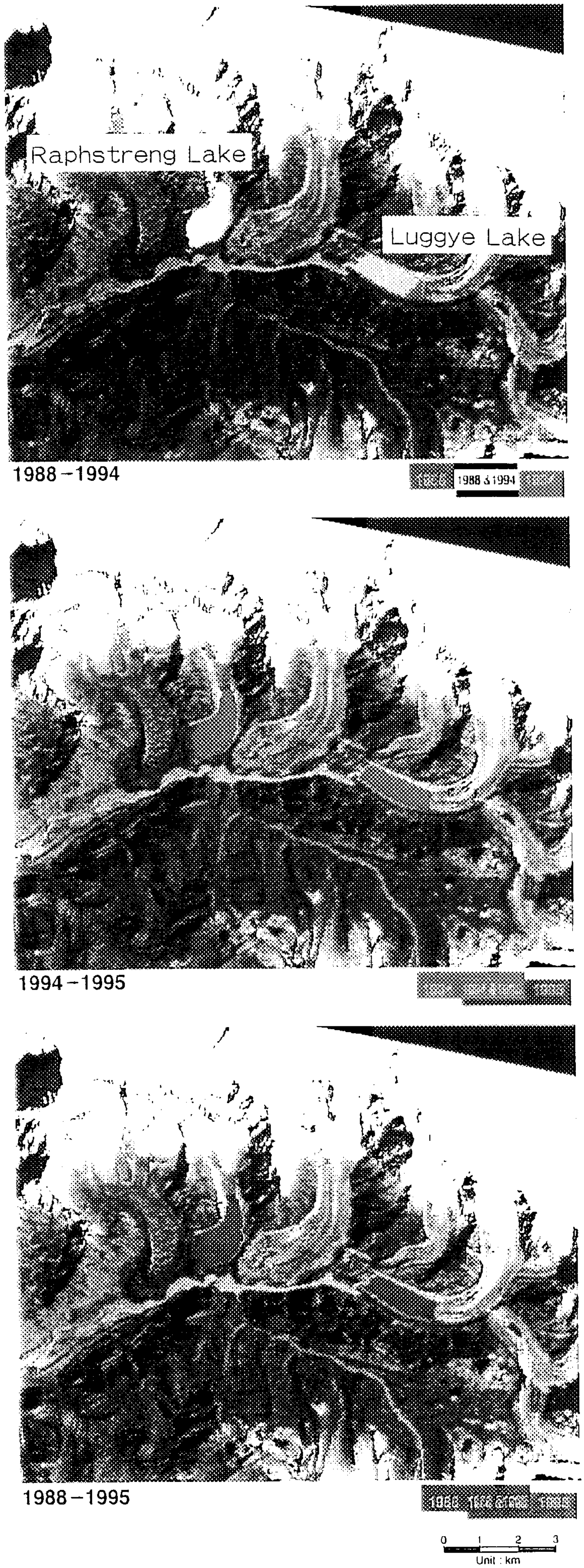

Fig. 6.3 Glacier Lakes in Punatsangchhu Basin

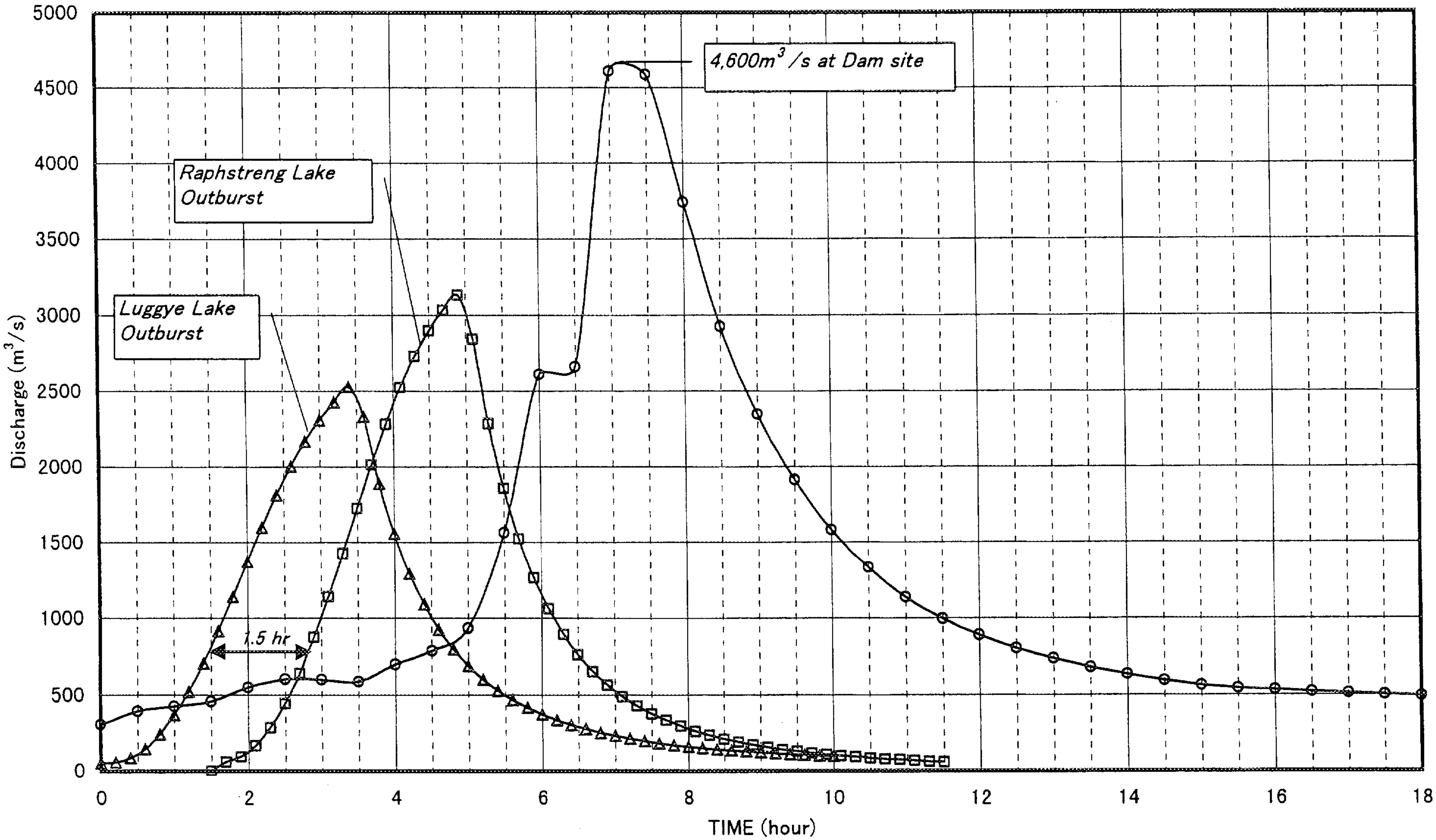

Fig. 6.4 Simulation of Glof from Luggye and Raphstreng Lake

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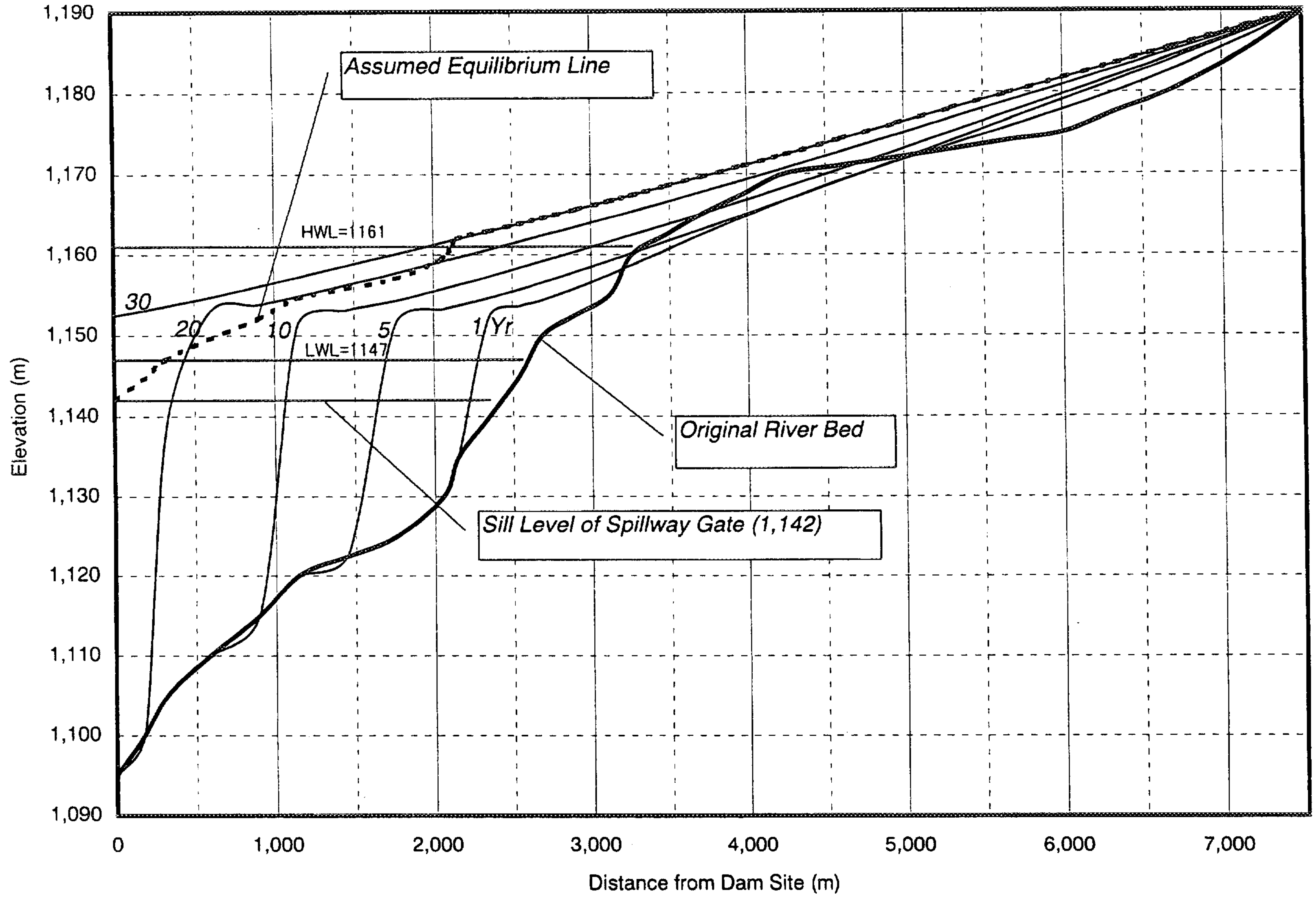


Fig. 6.5 Simulation of Sedimentation

7. GEOLOGY

7.1 Topography

(1) The area about 22 km long from Punakha to the dam site via Wangdue Phodrang

The river topography of this area shows one of the old stage characterized by the gentle river gradient (1/368) and by the thick alluvium (about 35m thick at the Wangdue Phodrang Bridge).

Moreover, on the left bank in this area, because the gneissosity of the bedrock dips towards the mountain, the topography of the banks is stable and gentle as a whole.

(2) The river about 8 km from the dam site to the powerhouse site

The river in this area shows the topography of the maturity stage characterized by the steep river gradient (1/8~1/78) and many rapids.

Accordingly, the topography on the left bank where the gneissosity dips against the mountain slopes forms many cliffs dipping more than 45° and many gorges. However, at the right bankwhere gneissosity dips along the slopes of the river bank, colluvium containing many large to huge boulders are found in many places.

7.2 Geology

The bedrock distributed in the project area (reservoir, dam, headrace tunnel and powerhouse areas) consists mainly of gneiss. Gneissosity of bedrock in the project area trends N30°E to N50°E and dips 30 to 40°SE. Judging from the tendency of gneissosity at the project area, the bedrock of the project area seems to be located at the eastern wing of the large scale anticlinal structure. Concerning the fault, it cannot be found on outcrops along the road.

7.3 Site Geology

(1) Geology of Reservoir

1) Slope Stability

- No large landslide active at present was found in the reservoir nor in its surrounding areas, and the slopes around the reservoir are gentle. Therefore, there is a low possibility that a large landslide will occur which would hinder the functions of the reservoir.

2) Water Tightness

No soluble rock, such as limestone, is distributed in the reservoir area. Furthermore, the mountain bodies of both banks are thick. Therefore, no leakage from the reservoir to the neighboring basin is predicted. As mentioned above, the water-tightness of the reservoir is evaluated to be sufficient from geotechnical viewpoints.

(2) Geology at Dam Site

1) Foundation Treatment

- Permeability of the bedrock on the left bank is less than 10 Lu, therefore, improvement by grouting is considered to be highly possible.
- At the lower elevations on the right bank (drill hole DD-4), permeability of the bedrock is 10 to 13 Lu from the bedrock surface to a depth of 14.4 m, and less than 10 Lu in the deeper section. Therefore, improvement by grouting is considered to be highly possible.
- On the right abutment, it is necessary to pay careful attention to the foundation improvement of the bedrock within the section showing a seismic velocity of 1.8 to 2.2km/sec (18.9 to 47m below the ground surface). The bedrock 47m below the ground surface or deeper shows a seismic velocity of more than 4.0km/sec, so the bedrock is considered to be compact and relatively impermeable.
- Groundwater level in the right bank may become lower towards the river, because of the existence of probable discontinuity. Therefore, it is necessary to take care of the groundwater level in considering the foundation treatment.
- In general, the permeability of the bedrock at the dam site is evaluated as highly improvable.

2) Excavation of Dam Foundation

Based on the results of geologic logging of the drilled cores, assumption on the depth of foundation excavation at the dam site is summarized in Table 3.16 from geotechnical viewpoints by each drill hole.

Good rock occurs below the bedrock surface in the area covered by alluvium at the lower elevation of the dam. Therefore, dam foundation excavation below an elevation of 1,100m is considered to be the removal of alluvium and the trimming of rock surface. However, it is noted that the thickness of alluvium is inferred to be about 70m, and the alluvium includes boulders of 6m in diameter. Furthermore, primary wave velocity in the section deeper than 8 m below the ground surface is more than 1.8km/sec, and this fact indicates that alluvium there is compact.

On the abutment of the left bank, the foundation excavation is considered to be the removal of alluvium and the trimming of rock surface. The depth of foundation excavation below the ground surface is inferred to range from 9.8 to 12.6 m at the place near drill hole DD-1 and DD-2.

Slope instability of the right bank above the dam abutment may occur during the foundation excavation, because the slopes there are covered by thick colluvium (28.3m in DD-8) and the shallower part of the bedrock is loosened by movement along gneissosity.

(3) Geology at Surge Tank, Penstock and Powerhouse Sites

1) Powerhouse

The bedrock at the powerhouse site is evaluated as follows from the engineering geological point of view.

- The apparent dip of the gneissosity at the powerhouse site is 20° and inclined to the main river. However, this apparent dip is calculated using the assumption that the strike is N70°E. Therefore, this dip might be a little steeper than the real dip. The apparent dip depends on the strike.
- There are F-1, F-2 and their sheared zones at the powerhouse site. The deepest part of the F-2 sheared zone is 142.80 m from the surface (elevation 918.2 m). The drilling core, which was caught deeper than 143 m, is fresh but has many cracks along the gneissosity till the depth of 155 m (RQD between depth of 142.8m and 155m is 0%.). Average RQD between depths of 155 m and the bottom of the hole (depth of 180 m, elevation 881m) is only about 50%. The reason for this poor RQD is estimated to be the influence of F-1 and F-2. The bedrock between the bottom of the hole (elevation 881 m) and the arch of the powerhouse (elevation 861m) might be very fresh and compact without fail. However, the dip of gneissosity is comparatively gentle and the bedrock near the site often has an intercalation of biotite and typical gneissic structure. Therefore, these geologic conditions must be carefully taken into account for the civil design of the powerhouse.
- There is a possibility that water may spring at the time of excavation. However, it is thought that not so much water will spring that will make the excavation very difficult.

2) Surge Tank

The bedrock at the surge tank site is evaluated as follows from geotechnical viewpoints.

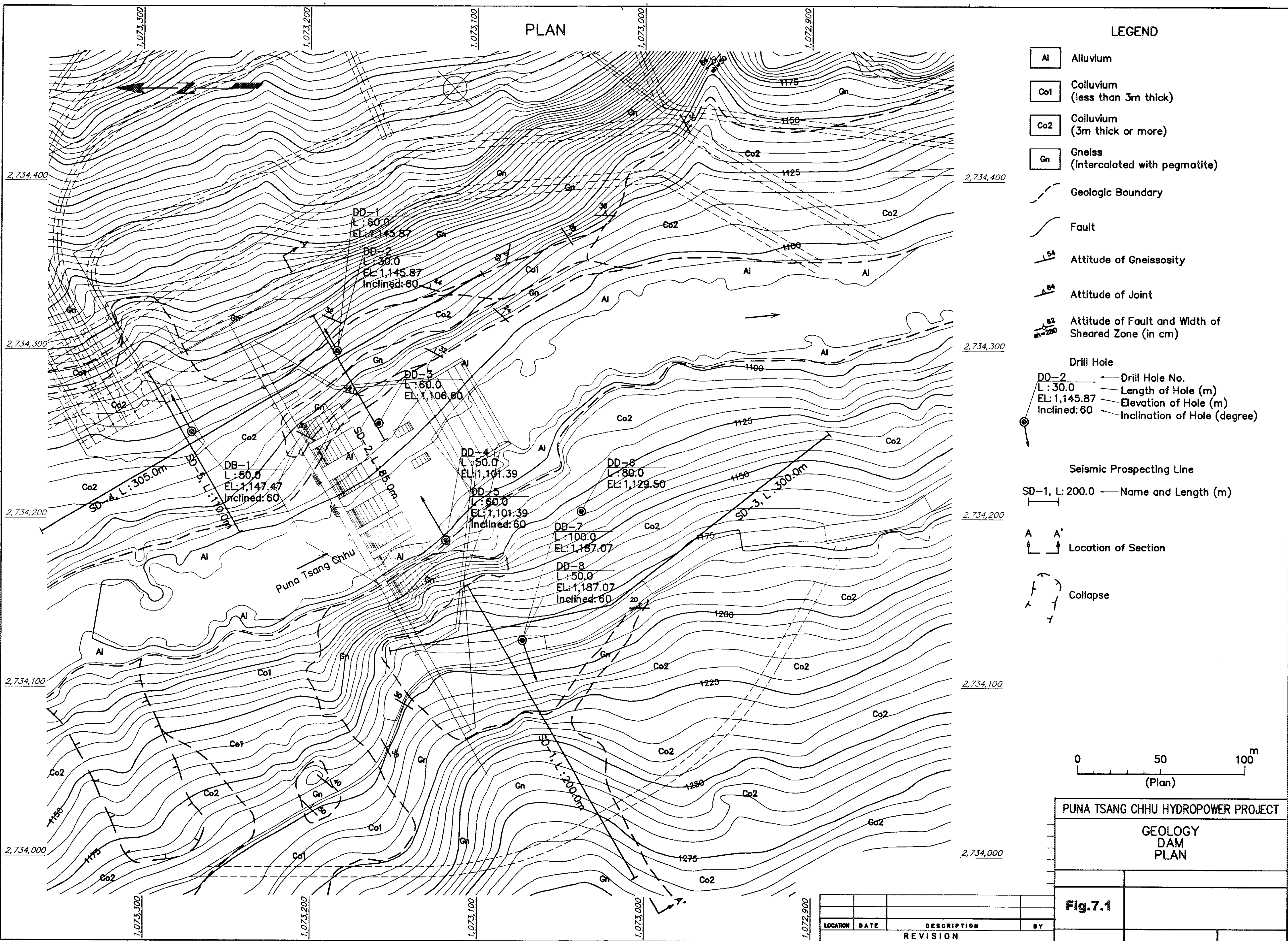
- The bedrock here is gneiss. The apparent dip of the gneissosity here is about 20° and inclined to the main river as at the powerhouse site.

- There might be the extended part of F-1, F-2 and their sheared zones at the surge tank site because the size of these zones is quite big. The F-1 and its sheared zone is estimated to be located at a depth of between 100~120 m from the surface (elevation 1,080 to 1,060 m).
- The sheared zone along the gneissic structure is predicted to be distributed at some part of the surge tank excavation. However, the apparent dip of the gneissosity here is about 20° and gentle. Therefore, this geologic structure will not interfere with the excavation of the vertical shaft.
- Near the surface, the bedrock is estimated to be exfoliated along the gneissosity and joints and appear as huge boulders.
- The vertical shaft is located above the water level. Therefore, it is considered almost impossible that water may spring at the time of excavation.

3) Penstock

The bedrock at the penstock site is evaluated as follows from geotechnical viewpoints.

- At the section between about 50m and 200m from the upstream end of the penstock, the bedrock is predicted to be very bad, because the section might be crossed by F-1, F-2 and their sheared zones.
- It is impossible to predict the quantity of water that may spring during the excavation. It is thought to be highly possible that water may spring constantly at the time of excavation.



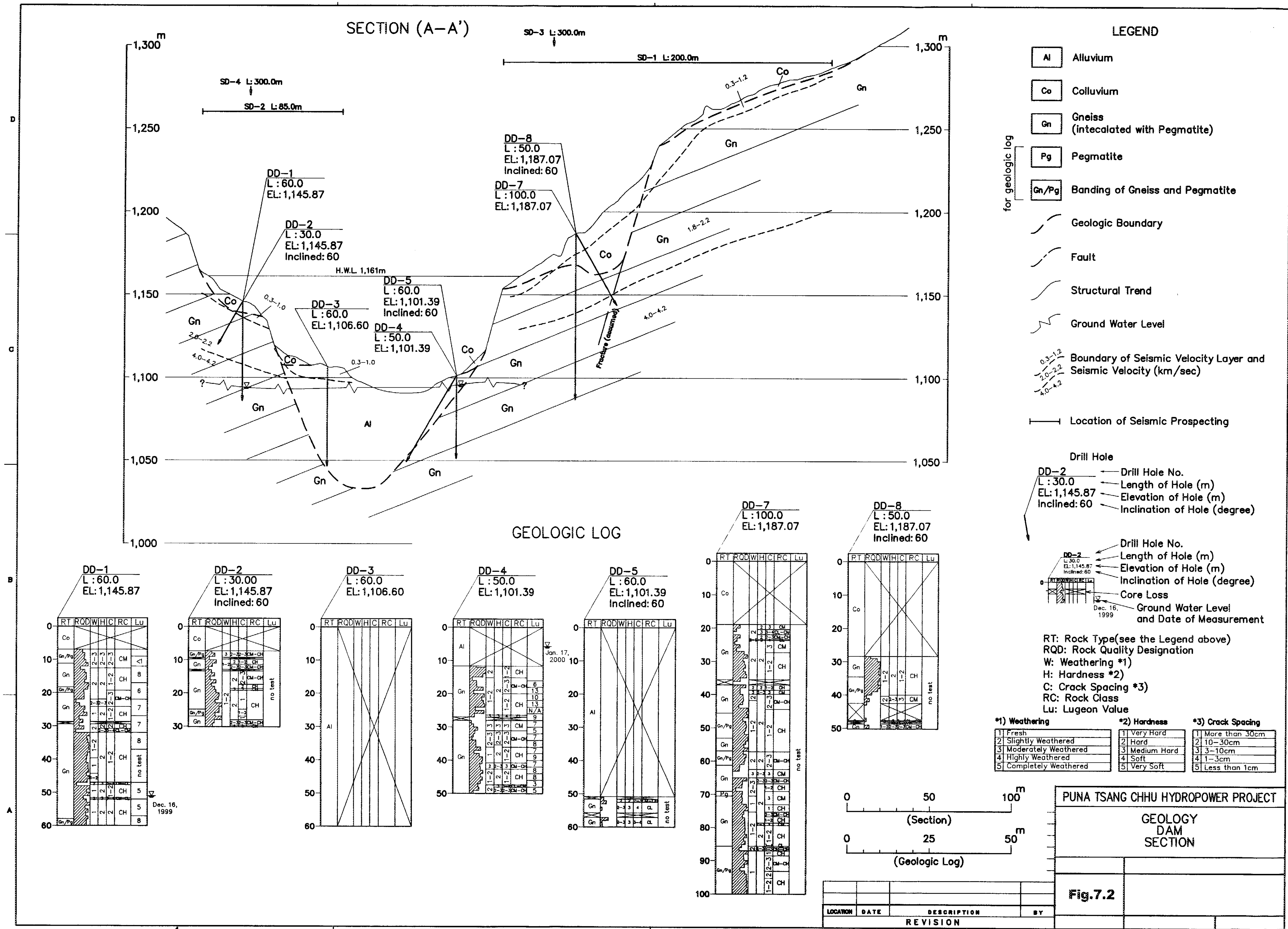
PUNA TSANG CHHU HYDROPOWER PROJECT

GEOLOGY
DAM
PLAN

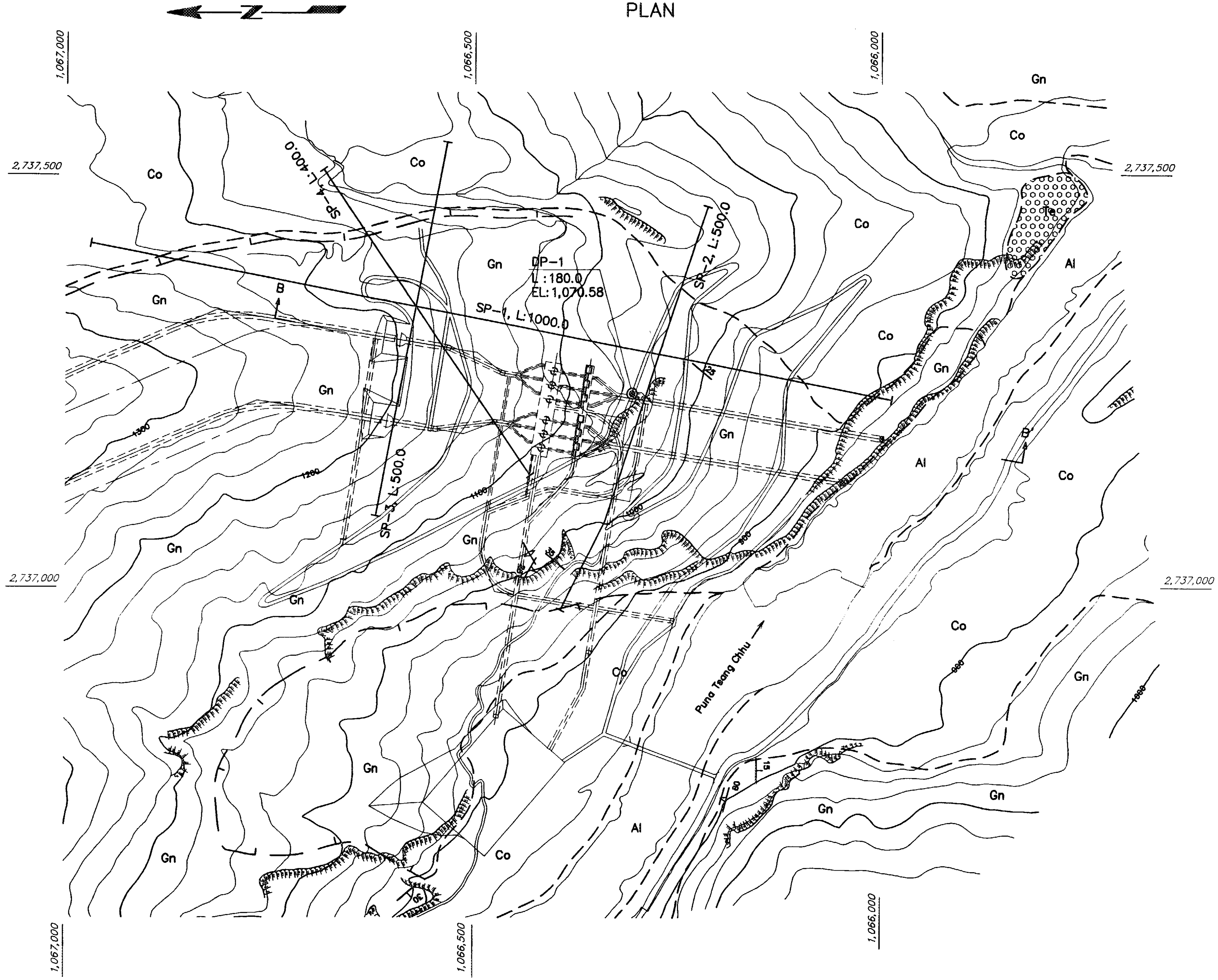
Fig.7.1

LOCATION	DATE	DESCRIPTION	BY
REVISION			

SHEET NO. OF


SECTION (A-A')
GEOLOGIC LOG
LEGEND
Al Alluvium
Co Colluvium
Gn Gneiss (intecalated with Pegmatite)
Pg Pegmatite
Gn/Pg Banding of Gneiss and Pegmatite
for geologic log
Geologic Boundary
Fault
Structural Trend
Ground Water Level
Boundary of Seismic Velocity Layer and Seismic Velocity (km/sec)
Location of Seismic Prospecting
Drill Hole
DD-2 Drill Hole No.
L : 30.0 Length of Hole (m)
EL: 1,145.87 Elevation of Hole (m)
Inclined: 60 Inclination of Hole (degree)
Core Loss
Ground Water Level and Date of Measurement
RT: Rock Type(see the Legend above)
RQD: Rock Quality Designation
W: Weathering *1)
H: Hardness *2)
C: Crack Spacing *3)
RC: Rock Class
Lu: Lugeon Value
*1) Weathering
1 Fresh
2 Slightly Weathered
3 Moderately Weathered
4 Highly Weathered
5 Completely Weathered
*2) Hardness
1 Very Hard
2 Hard
3 Medium Hard
4 Soft
5 Very Soft
*3) Crack Spacing
1 More than 30cm
2 10–30cm
3 3–10cm
4 1–3cm
5 Less than 1cm
SD-4 L: 300.0m
SD-2 L: 85.0m
SD-3 L: 300.0m
SD-1 L: 200.0m
H.W.L. 1,161m
DD-1 L : 60.0 EL: 1,145.87
DD-2 L : 30.0 EL: 1,145.87 Inclined: 60
DD-3 L : 60.0 EL: 1,106.60
DD-4 L : 50.0 EL: 1,101.39
DD-5 L : 60.0 EL: 1,101.39 Inclined: 60
DD-7 L : 100.0 EL: 1,187.07
DD-8 L : 50.0 EL: 1,187.07 Inclined: 60
Fracture (assumed)
Dec. 16, 1999
Jan. 17, 2000
no test
0 50 100m (Section)
0 25 50m (Geologic Log)
PUNA TSANG CHHU HYDROPOWER PROJECT
GEOLOGY DAM SECTION
Fig.7.2
LOCATION DATE DESCRIPTION BY
REVISION
SHEET NO. OF

PLAN



LEGEND

- Al — Alluvium
- Co — Colluvium
- Terrace Deposit
- Gn — Gneiss
- Geologic Boundary
- Landslide Scarp
- Attitude of Bedding Plane
- Attitude of Joint
- Attitude of Fault and Width of Sheared Zone

Drill Hole

DP-1 — Drill Hole No.
L :180.0 — Length of Hole (m)
EL:1,070.58 — Elevation of Hole (m)

Seismic Prospecting Line

SP-1, L:1000.0 — Name and Length (m)

B B' Location of Section

0 — 250 m (Plan)

PUNA TSANG CHHU HYDROPOWER PROJECT

GEOLOGY
POWERHOUSE
PLAN

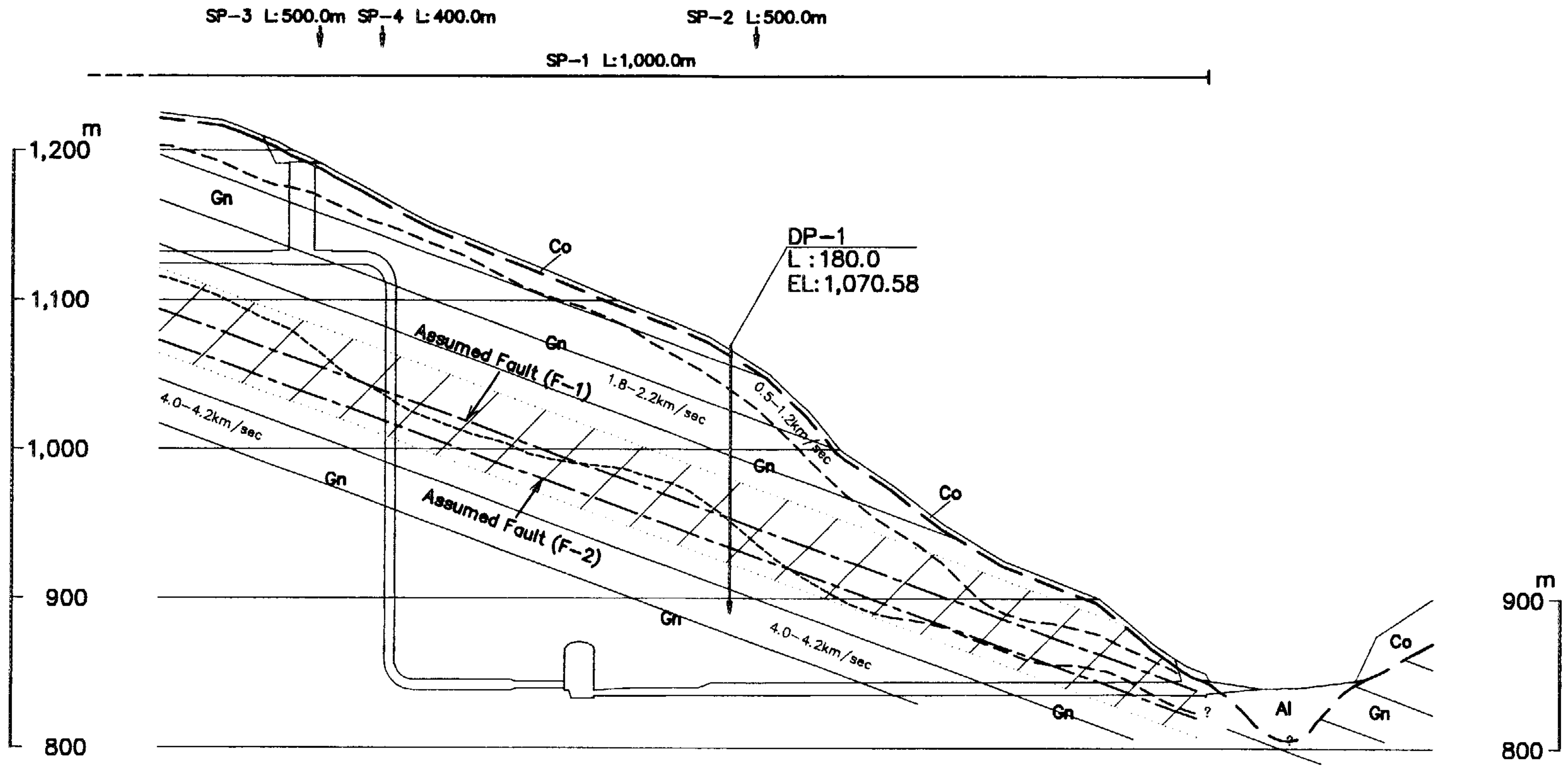
Fig.7.3

LOCATION	DATE	DESCRIPTION	BY
REVISION			

SHEET NO. OF

24-3

PROFILE (B–B')



LEGEND FOR PROFILE

- Al — Alluvium
- Co — Colluvium
- Gn — Gneiss (intecalated with Pegmatite)
- Sheared Zone
- Geologic Boundary
- Fault
- Structural Trend

Drill Hole

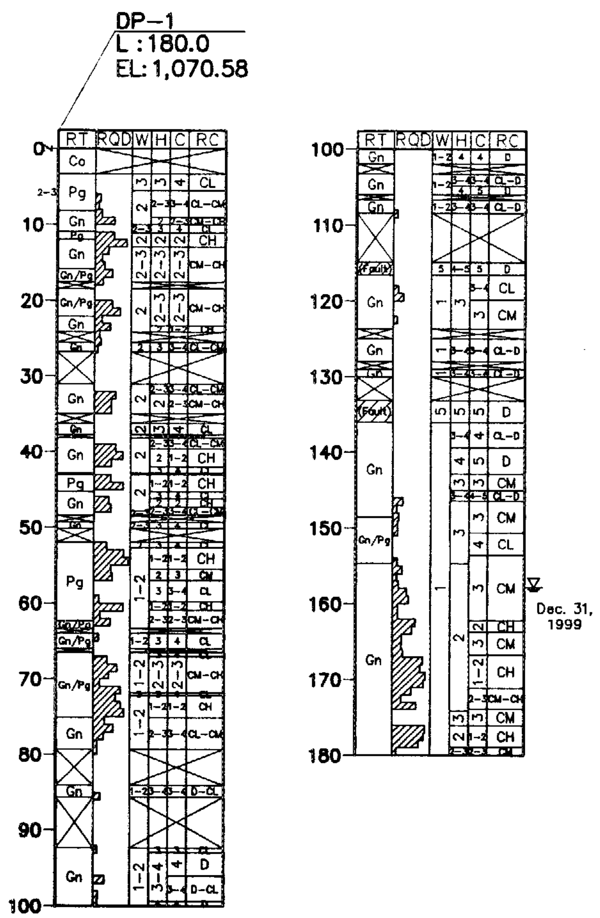
DP–1 — Drill Hole No.
L :180.0 — Length of Hole (m)
EL:1,070.58 — Elevation of Hole (m)

Seismic Prospecting

SP–3 L:500.0m — Location of Seismic Prospecting and Line No.

0.3–1.2, 2.0–2.2, 4.0–4.2 — Boundary of Seismic Velocity Layer and Seismic Velocity (km/sec)

GEOLOGIC LOG



LEGEND FOR GEOLOGIC LOG

- Co — Colluvium
- Gn — Gneiss
- Pg — Pegmatite
- Gn/Pg — Banding of Gneiss and Pegmatite
- (Fault) — Fault

Drill Hole No.
Length of Hole (m)
Elevation of Hole (m)
Core Loss
Ground Water Level and Date of Measurement (Dec. 16, 1999)

RT: Rock Type(see the Legend above)
RQD: Rock Quality Designation
W: Weathering *1)
H: Hardness *2)
C: Crack Spacing *3)
RC: Rock Class

*1) Weathering

1	Fresh
2	Slightly Weathered
3	Moderately Weathered
4	Highly Weathered
5	Completely Weathered

*2) Hardness

1	Very Hard
2	Hard
3	Medium Hard
4	Soft
5	Very Soft

*3) Crack Spacing

1	More than 30cm
2	10–30cm
3	3–10cm
4	1–3cm
5	Less than 1cm

0 — 250 m (Profile)

0 — 50 m (Geologic Log)

PUNA TSANG CHHU HYDROPOWER PROJECT

GEOLOGY POWERHOUSE PROFILE

Fig.7.4

LOCATION	DATE	DESCRIPTION	BY

REVISION

SHEET NO. OF

24 / 1 / 4