REPUBLIC OF CHINA

PRE-FEASIBILITY REPORT
ON
LI-WU CHI HYDROELECTRIC POWER DEVELOPMENT PROJECT

SEPTEMBER 1968

OVERSEAS TECHNICAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

REPUBLIC OF CHINA

PRE-FEASIBILITY REPORT
ON
LI-WU CHI HYDROELECTRIC POWER DEVELOPMENT PROJECT

SEPTEMBER 1968

OVERSEAS TECHNICAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

PREFACE

The Japanese Government, in response to the request from the Government of the Republic of China, entrusted the Overseas Technical Cooperation Agency to conduct a pre-feasibility study on the Li-Wu Chi Hydroelectric Power Project in Hualien Hsien.

The Overseas Technical Cooperation Agency, considering the present situation of electric demand and supply and the benefit of the Project to the economic development of the Republic, organized an investigation team consisting of four engineers of the Electric Power Development Company and a staff of the Overseas Technical Cooperation Agency. The Team headed by Mr. Y. Takaishi, Chief of the Civil Engineering Laboratory of the Electric Power Development Company conducted field investigations, and studies on the Project in Japan.

The Team visited the Republic of China and stayed at the site from February 15 to March 20, 1968 to conduct field investigations and to collect relevant information and data, and after return to Japan, it completed this report on the basis of the data collected in the field.

This report gives the economic soundness of the Li-Wu Chi Hydroelectric Power Development Project, and recommends the construction of Kuyuan and Chipan Power Stations. Before implementing the Project, it is recommended that further detailed investigations be carried out.

Nothing would be more gratifying to the Agency if this report could be of use in harnessing the Li-Wu Chi to contribute to the economic development of the Republic, and also in promoting closer friendly relationship between the Republic of China and Japan.

The Agency takes this opportunity to express its sincere thanks for the kind cooperation and assistance extended to the Team by the Government of the Republic of China and the Taiwan Power Company in conducting the pre-feasibility studies, and especially for the earnest cooperation of the engineers dispatched from the Taiwan Power Company to Japan to participate in the studies and compilation of the report.

S. Shibusawa

Shinichi Shibusawa
Director General
Overseas Technical Cooperation Agency

Letter of Transmittal

Mr. Shinichi Shibusawa, Director General
Overseas Technical Cooperation Agency

Dear Sir:

This is a report on the pre-feasibility studies prepared by the survey team for the Li-Wu Chi Hydroelectric Power Development Project Planned by the Taiwan Power Company in the Republic of China.

A survey team headed by Yasushi Takaishi were in Taiwan from February 15 to March 20, 1968 and in cooperation with the Taiwan Power Company engineers, conducted a field survey of the Project Area as well as investigations of related areas. Information and data on topography, geology, hydrology, electric power supply and demand, construction costs, etc. were collected, and meetings were held to exchange opinions regarding the project between the survey team and the Taiwan Power Company. Additional data required to prepare the report were forwarded to Japan by Taiwan Power Company after the team returned home.

Upon returning to Japan, the survey team, on the basis of information and data gathered in Taiwan under the direction of the leader of the survey team, prepared this report with the assistance of the engineering staff of the Electric Power Development Company and with the cooperation of the four Taiwan Power Company engineers who visited the Electric Power Development Company as trainees under the sponsorship of the Overseas Technical Cooperation Agency.

The project consists of constructing two power stations, Kuyuan and Chipan, on the Li-Wu Chi to obtain a total output of 240 MW and annual energy production of 1,035 x 10^6 KWh. Power will be transmitted to the switchyard of Tachien Power Station, and then to load centers.

For excution of this project, a construction period of approximately 3.5 years and a capital of approximately NT$2,410,430,000 will be necessary. With completion of the project, a saving of approximately NT$103,820,000 can be anticipated, and it is estimated that low-cost-power NT$0.197 will be obtained In view of the remarkably increasing demand for electricity, it is considered necessary to implement a feasibility study following this survey in order that the

Project may get under way at an early date.

We take this opportunity to express our sincers appreciation to the staff of the Taiwan Power Company, as well as all others with whom the team came into contact with in the course of our stay in Taiwan and also the four trainees who worked with us in Japan, for their generous assistance and kind cooperation.

September, 1968.

Y. Takaishi

Yasushi Takaishi
Leader, Japanese Survey Team
for Li-Wu Chi Hydroelectric
Power Development Project
(Civil Engineer, Electric
Power Development Company)

PREFACE

LETTER OF TRANSMITTAL

* * * * * * * * * * *

CONTENTS

KEY AND LOCATION MAP

CHAPTER 1. INTRODUCTION 1

1.1 Authorization 1
1.2 Purpose and Scope of Report 2
1.3 Investigation and Studies 2
1.4 Basic Data 3
1.5 Organization of Survey Team 3

CHAPTER 2. SUMMARIZATION AND RECOMMENDATIONS 5

2.1 General 5
2.2 Power Generation Scheme 5
2.3 Transmission Scheme 8
2.4 Power Demand and Supply Program 8
2.5 Timing and Order of Development 9
2.6 Economic Evaluation of Project 10
2.7 Recommendations 10

CHAPTER 3. LOAD FORECAST AND POWER DEMANDS AND SUPPLY PROGRAM 13

3.1 Description of Supply Territory 13
3.2 General Description of Taiwan Power Company 21
3.3 Load Forecast 25
3.4 Power Supply and Demand 34

CHAPTER 4. HYDROLOGY 49

4.1 Run-off Gaging Stations and Meteorological Observatories 49
4.2 Precipitation 49
4.3 Typhoons 52

4.4 Run-off 52
4.5 Flood Discharge 68
4.6 Temperature, Water Temperature, Humidity and Evaporation 73
4.7 Sedimentation 74

CHAPTER 5. GEOLOGY 79

5.1 Topography and Geology of the Project Area 79
5.2 General Problems of Design and Construction 84
5.3 Geology of Sites of Structures 86
5.4 Aggregates 101
5.5 Earthquakes 102

CHAPTER 6. DEVELOPMENT SCHEME 105

6.1 Alternative Schemes of Development 105
6.2 Basic Condition in Study of Alternative Schemes 105
6.3 Study of Alternative Schemes and Selection of the Scheme 120
6.4 Determination of Scale of Development 125
6.5 Energy Production 132
6.6 Transmission System 135
6.7 Telecommunications System 140

CHAPTER 7. DESCRIPTION OF STRUCTURES AND EQUIPMENT 143

7.1 Structures 143
7.2 Generating Facilities 147
7.3 Transmission Line 151

CHAPTER 8. CONSTRUCTION SCHEDULE AND PROCEDURE 153

8.1 Basic Construction Schedule 153
8.2 Local Conditions and Relevant Matters 153
8.3 Construction Procedure of Major Structures 160

CHAPTER 9. COST ESTIMATE 165

- 9.1 Basic Conditions 165
- 9.2 Summary of Estimated Construction Costs 169

CHAPTER 10. ECONOMIC EVALUATION 179

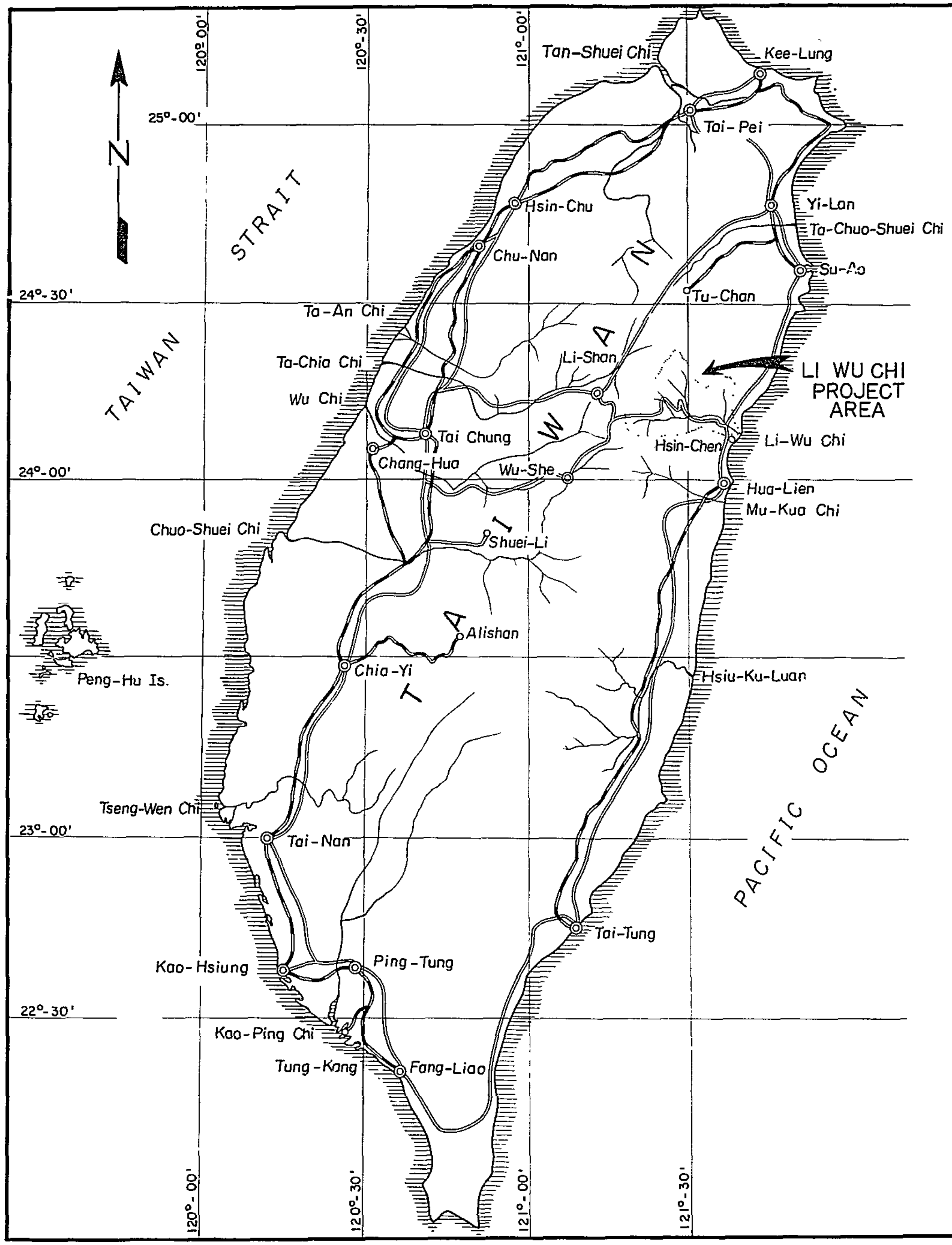
- 10.1 Saleable Energy 179
- 10.2 Annual Cost and Energy Cost 179
- 10.3 Annual Benefit 181
- 10.4 Benefit-Cost Ratio 187

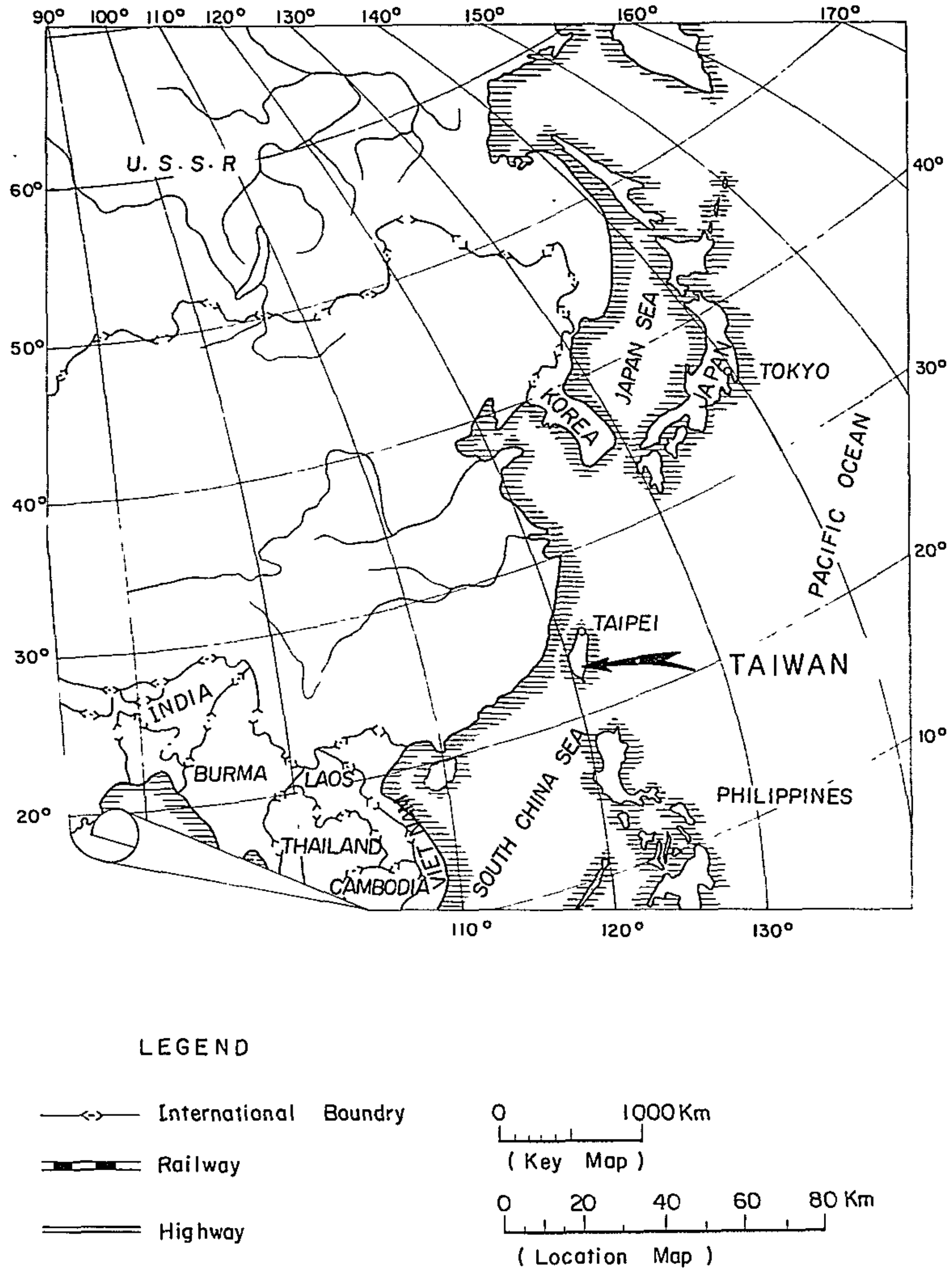
CHAPTER 11. INVESTIGATION REQUIRMENTS FOR FEASIBILITY STUDY 191

- 11.1 Hydrological Survey and Study 191
- 11.2 Preparation of Topographical Map 191
- 11.3 Geological Survey 193
- 11.4 Aggregate Survey 195

APPENDIX

- A-1 Drawings 199
- A-2 Evaluation of Hydroelectric Power 255
- A-3 Hydrological Data 263
- A-4 List of Basic Data 287





OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

KEY AND LOCATION MAP

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN

DATE: AUG 1968

CHAPTER 1

INTRODUCTION

CHAPTER 1.

INTRODUCTION

1.1 Authorization

The Taiwan Power Company (hereinafter called "Taipower") is planning a hydroelectric power development on the Li-Wu Chi as a part of its program to meet the rapidly increasing power demand with which Taiwan has been faced in recent years.

The Li-Wu Chi located in the northern part of Hualien Hsien on the east coast of Taiwan has a catchment area of approximately 610 km^2. The river, approximately 53 km long has a gradient of 1/15 to 1/50, and the annual run-off is approximately $1,000 \times 10^6 m^3$. It has long been noted for its huge hydroelectric potential.

However, since this area is isolated by a steep terrain which makes transportation difficult, hydroelectric power development has been retarded. The only existing plant is the 32,000 KW Li-Wu Power Station built in December 1951 at the lowermost reaches of the river.

Upon completion of the East-West Cross Island Highway in 1962, transportation to the hinterland has been greatly facilitated. Therefore, "Taipower", contemplating hydroelectric power development in the upstream reaches of this river, conducted a series of surveys and investigation studies and prepared an elementary scheme for development of the Li-Wu Chi in 1965.

In order to make further studies of this scheme, the Republic of China Government requested the technical cooperation of the Japanese Government in 1966. In compliance with the request, the Japanese Government agreed to send a group of experts consisting of four engineers from the Electric Power Development Company (hereinafter called "EPDC") for six months in May 1966 to cooperate with "Taipower". These experts, in cooperation with "Taipower", conducted a reexamination of the Elementary Li-Wu Chi Development Scheme and prepared a report of the Hydroelectric Power Development Projects on the Li-Wu Chi in November 1966.

Following this, in 1967, the Republic of China Government requested the Japanese Government to conduct a pre-feasibility study of the Li-Wu Chi Hydroelectric Power Development Project. The Japanese Government commissioned the Overseas Technical Cooperation Agency (hereinafter called "OTCA") to carry out the study. OTCA formed a six member team comprising team leader, Yasushi Takaishi, who is a senior civil engineer of EPDC, four EPDC engineers and an OTCA staff member. The team was send to Taiwan in February 1968 to perform field studies in connection with the requested pre-feasibility study.

1.2 Purpose and Scope of Report

The purpose of this report is to study various schemes for hydroelectric power development of the Li-Wu Chi, establish and propose the particular scheme which would be the most advantageous, and carry out a preliminary study on technical and economical soundness of the selected scheme. It also defines and recommends items of investigation and study which shall be implemented in a subsequent feasibility study.

The scope of the study covers possible power station sites in the area upstream of the existing Li-Wu Chi Power Station, as well as the transmission facilities between the switchyard at Tachien Power Station which is under construction and the power stations proposed in the study.

1.3 Investigations and Studies

1.3.1 Field Surveys

In cooperation with the Taipower engineers, the survey team, from February 15 to March 20, 1968 conducted surveys of the Project Area and related areas, collecting necessary data.

Following this, the survey team exchnaged opinions and held discussions with "Taipower" engineers at the head office of "Taipower".

1.3.2 Work Executed in Japan

After return of the survey team to Japan, the studies on the item listed below were made between March 21 and August 31, 1968 on the basis of information and data collected in the field for the preparation of the pre-feasibility report.

a. Load Forecast
b. Hydrologic Analysis
c. Geological Considerations and Evaluations
d. Studies of Various Development Schemes
e. Selection of Most Favorable Development Schemes and Determination of Scale
f. Calculation of Energy Production using IBM
g. Preliminary Design and Cost Estimation
h. Evaluation of Hydroelectric Power

1.4 Basic Data

Basic data for the study of the project such as meteorological records, hydrological records, topographical maps, geological maps, records and information on power demand and supply, and construction cost estimates were either furnished or loaned to the survey team by "Taipower". These are given in the List of Basic Data included in the Appendix-4.

1.5 Organization of Survey Team

The survey team organized for undertaking the field survey was consisted of members stated below:

	Name of the Member
Team Leader	Mr. YASUSHI TAKAISHI Civil Engineer, chief of laboratory, Electric Power Development Co., Ltd.
Member	Mr. MAMORU TAKAICHI Civil Engineer, Assistant chief Engineering Section, Foreign Activities Dept. Electric Power Development Co., Ltd.
Member	Mr. YOSHITAKA HORI Electrical Engineer, Assistant chief Demand and Supply Planning Sect. Sales Dept. Electric Power Development Co., Ltd.
Member	Mr. HIDEHARU KASHIWAGI Geologist, Kuzuryu-Gawa Construction Office Electric Power Development Co., Ltd.

Memer	Mr. SHOZO IMAI Civil Engineer, Design Section, Water power Construction Dept. Electric Power Development Co., Ltd.
Member Liason Officer	Mr. SHOICHI INAGAKI Counsilor, Development Survey Div. Overseas Technical Cooperation Agency.

CHAPTER 2

SUMMARIZATION AND RECOMMENDATIONS

CHAPTER 2

SUMMARIZATION AND RECOMMENDATIONS

2.1 General

For the Li-Wu Chi Hydroelectric Power Development Project planned by "Taipower", field surveys and investigation of related areas were conducted on the basis of the data supplied or loaned by "Taipower", and as a result of the studies made in Tokyo, it was possible to command a general outlook on the basic conception of the development plan and its economic soundness. Details are described in Chapter 3 and subsequent chapters.

However, it is unfortunate that the data made available was inadequate for the present study to form a development plan. Especially data concerning geology was extremely poor and the survey team was obliged to depend on the results of a surface survey. Nevertheless, from the present outlook, it is believed that the project appears promising and exceedingly economical so that necessary procedures and preparation work should be carried out to proceed for a feasibility study.

2.2 Power Generation Scheme

As rainfall is abundant in the Li-Wu Chi basin and the rivers and streams have steep gradients, it is believed that the hydroelectric potential is extremely great. Most of the rainfall is concentrated in the period from May to September. In this respect it would be desirable to develop power stations with reservoirs, but since the river valleys are narrow and steep, there are no sites suitable for reservoirs.

In consideration of the future power demand trend in the "Taipower" system, hydroelectric resources should preferably be developed to meet peak demands corresponding to load conditions.

Consequently, it is considered that the optimum method of development on the Li-Wu Chi is run-off-river schemes with regulating ponds.

The unified plan proposed here is intended for an overall utilization of the Li-Wu Chi running east from the central mountain range, as well as its medium to smaller tributaries. For this purpose the river water will be diverted to Chipan from Tuo-Po-Kuo Chi in the west, and Taosai Chi in the east. The diversion is approximately 47 km in length. Two regulating ponds will be con-

Table 2-1-1 Outline of Li -Wu Chi Hydro-Electric Project

Item	Unit	Ku-Yuan Powerstation	Chi-Pan Powerstation	Total
Generating System		Regulating Pondage System	Regulating Pondage System	
Catchment Area	km^2	254.95	412.00	
Pondage		Tuo-Po-Kuo	Ku-Yuan	
Annual Runoff	m^3/s	17.80	28.70	
High Water Level	m	1,255.00	682.50	
Gross Storage	10^3m^3	500.00	440.00	
Effective Storage	"	380.00	290.00	
Drawdown	m	12.00	9.00	
Dam				
Hight x Crest Length	m	35 x 44	36 x 60.5	
Volume	m^3	13,000.00	19,000.00	
Design Flood	m^3/s	2,100.00	3,380.00	
Water Way				
Pressure Tunnel (Dia x Length)	m	3.3 x 10,100 3.4 x 2,400	4.15 x 10,700	
Non-Pressure Tunnel(")	m	2.0-2.8 x 14,650	2.0-2.8 x 9,350	
Tailrace (")	m	3.3x160	4.2x130	
Power Generation				
Mean Water Level	m	1,249.00	678.00	
Tailrace Water Level	m	685.50	162.65	
Rated Head	m	527.09	480.60	
Discharge				
Maximum	m^3/s	20.80	36.30	
Average	"	11.70	19.40	
Average for ten days of June, 1963	"	3.63	5.86	
Output				
Maximum	MW	92.00	148.00	240.00
Average	"	51.70	79.10	130.80
Average for Ten Days of June, 1963	"	16.05	23.94	39.99
Annual Possible Energy Production	10^6KWh	455.20	694.50	1,149.70

structed along the way. A head of approximately 1,092 m is obtainable between the high water level of EL. 1,255 m of the uppermost regulating pond and that of EL. 163 m of the existing regulating pond at the Li-Wu Power Station. Two power stations are proposed at Kuyuan and Chipan to make use of this head and obtain a total output of 240 MW and a possible annual energy production of approximately 1,149.70 x 10^6 KWh. The total construction cost of the power stations is estimated to be approximately NT$2,266.36 million.

The salient features of the Kuyuan and Chipan Power Stations are shown in Table 2-1-1 and 2-1-2.

Table 2-1-2 Outline of Li-Wu Chi Hydro-Electric Project

Item	Unit	Ku-Yuan Powerstation	Chi-Pan Powerstation	Total
Construction Cost (Interest rate = 6%)				
Generating Facility	10^6NT$	1,160.770	1,070.250	2,231.020
Domestic Currency	"	831.852	725.070	1,556.922
Foreign Currency	"	238.918	345.180	674.098
Transmission Facility	"	-	-	143.050
Domestic Currency	"	-	-	73.770
Foreign Currency	"	-	-	69.280
Total Construction Cost	"	1,160.770	1,070.250	2,374.070
Domestic Currency	"	831.852	725.070	1,630.692
Foreign Currency	"	328.918	345.180	743.378
Construction Cost (Interest rate = 7%)				
Generating Facility	10^6NT$	1,179.160	1,087.200	2,266.360
Domestic Currency	"	845.026	736.550	1,581.576
Foreign Currency	"	334.134	350.650	684.784
Transmission Facility	"			144.070
Domestic Currency	"	-	-	74.290
Foreign Currency	"	-	-	69.780
Total Construction Cost	"	1,179.160	1,087.200	2,410.430
Domestic Currency	"	845.026	736.550	1,655.866
Foreign Currency	"	334.134	350.650	754.564

2.3 Transmission Scheme

In view of the geographical locations of the Kuyuan and Chipan Power Stations, the maximum output of 240 MW of these two stations can be transmitted to the load center of either the eastern or western part of Taiwan.

However, since the present supply capacity in the eastern part far exceeds the demand and there is a plan to develop the Mukua Chi River System in the future, it is preferable to transfer the power obtainable at the stations to the western area. Power from the stations to the western area can be transmitted by interconnection with either the Tachien or Chuoshuei Chi Transmission System. However, in view of the capacity of the proposed transmission line and the capacity of the existing transmission system, it would be more advantageous to interconnect with the Tachia Chi System at the switchyard of Tachien Power Station.

The outline of the transmission plan to the switchyard of the Tachien Power Station from the Kuyuan and Chipan Power Stations is given below.

Chipan Power Station – Kuyuan Power Station

Distance:	Approx. 12 km
Capacity:	172 MVA
Voltage:	154 KV
Number of circuits:	1 cct
Frequency:	60 cycle
Conductor:	ACSR 477 MCM (240 mm^2)

Kuyuan Power Station – Tachien Power Station (under construction)

Distance:	Approx. 39 km
Capacity:	211 MVA
Voltage:	154 KV
Number of circuits:	2 cct
Frequency:	60 cycle
Conductor:	ACSR 636 MCM (330 mm^2)

2.4 Power Demand and Supply Program

With progress in industrialization and improvement in living standards due to the remarkable development of the national economy, power demand has increased steadily, and recently, the rate of growth has approached a level as high as 15% annually.

It is believed that in the future the growth of national economy will gradually become more stabilized and the annual rate of increase of demand will be around 10%.

According to the results of the load forecast, the peak power demand in 1976, when the Li-Wu Chi Development Project is to be put in operation, will be 3,000 MW and 4,800 MW in 1981.

On the other hand the composition of power supply sources has been changing greatly in recent years. In other words, construction of large capacity thermal power stations has been increased and the ratio of supply of thermal power has risen in the entire supply capacity. Consequently, thermal power has come to supply a larger part of base loads and hydro power has been used to supply peak loads. At present, in the "Taipower" power system thermal power has completely surpassed hydro power in supply capability.

This trend is also expected to continue in future development of power resources. The Linkou and Talin Thermal Power Plants as well as a 500 MW unit nuclear power plant and peak hydro - large-capacity reservoir type power stations - such as the Tachien (234 MW) and Lower Tachien Power Station are being proposed or are already under construction.

According to the results of calculations of power supply capacity including the Li-Wu Chi Development Project, the combined hydro and thermal supply capacity will reach 3,700 MW in December 1976, and the system reserve capacity will be slightly upward of 20%. The optimum requirement for reserve capacity is calculated on a detailed study of the dependability of supply, the composition of supply sources and other factors. A tentative calculation of the reserve capacity requirements in the "Taipower" System indicates a requirement of 16 to 19% of maximum peak load. Therefore, the reserve capacity in 1976 will slightly exceed the requirement. However, considering that the annual rate of growth of power demand around that time is expected to be about 300 MW it is desirable to push the Li-Wu Chi Development Project ahead so that it may start operation in 1976.

2.5 Timing and Order of Development

It is believed desirable that the Li-Wu Chi Project comprising the construction of the Kuyuan and Chipan Power Stations and the transmission lines from these power stations to the switchyard of Tachien Power Station be put into operation around 1976. Therefore, since the main construction work will require approximately 3.5 years for completion, the feasibility, definite studies and all other preparatory work should be completed by around 1972.

Although it is preferable to complete the Kuyuan and Chipan Power Stations simultaneously, the Chipan Power Station which is relatively more accessible may be built first, followed by construction the Kuyuan Power Station. In this case the access road to the latter should be completed during construction of the former.

2.6 Economic Evaluation of Project

Costs and benefits of the Project calculated at interest rates of 6% and 7% per annum are given in Table 2-2.

2.7 Recommendations

In the present study, the project is evaluated as being sound from an economic point of view, but further surveys and studies leading to a feasibility study should be commenced and implemented as early as possible. The surveys and studies required include the following.

(1) It is necessary to continue with hydrological surveys, preparation of topographical maps, and geological and material surveys as described in Chapter 11, in order to obtain complete and satisfactory basic data for the feasibility study.

(2) Should the unified project consisting of the Kuyuan and Chipan Power Stations proposed as Alternative Scheme III be considered unfavourable as a result of geological surveys, it will be necessary to examine Alternative Scheme I comprising the Tienhsiang and Chipan Power Stations.

(3) It is necessary to make studies and collect data for establishing future supply and demand forecasts. The studies include estimation of future load curves of representative months in the power system.

(4) A basic study of an interconnection with power systems of the eastern and western areas should be made in relation to the development of the Li-Wu Chi.

(5) It is necessary to prepare and compile various data required for to study of the financial schedule for the project.

Table 2-2 Energy Cost and Annual Benefit

Item	Unit	Ku-Yuan Powerstation	Chi-Pan Powerstation	Total
Installed Capacity	MW	92.000	148.00	240.00
Annual Energy Production at Generating End	10^6KWh	409.680	625.05	1,034.73
Annual Energy Production at Transmission Line End	"	399.850	610.05	1,009.90
Interest Rate-6%				
Construction Cost				
Generating End	$10^6\text{NT\$}$	1,160.770	1,070.250	2,231.020
Per Kilowatt	NT\$	12,617.000	7,231.000	9,296.000
Per Kilowatt hour	"	2.830	1.71	2.160
Transmission End	$10^6\text{NT\$}$	-	-	2,374.070
Per Kilowatt Hour	NT\$	-	-	2.350
Annual Cost (C)	$10^6\text{NT\$}$	88.180	87.020	175.200
Per Kilowatt hour	NT\$	0.221	0.143	0.173
Annual Benefit (B)	$10^6\text{NT\$}$	116.460	175.84	292.300
Surplus Benefit (B-C)	"	28.280	88.82	117.100
Benefit-Cost Ratio (B/C)	"	1.321	2.021	1.668
Interest Rate-7%				
Construction Cost				
Generating End	$10^6\text{NT\$}$	1,179.160	1,087.200	2,266.360
Per Kilowatt	NT\$	12,817.000	7,346.000	9,443.000
Per Kilowatt hour	"	2.880	1.740	2.190
Transmission Line End	$10^6\text{NT\$}$	-	-	2,410.430
Per Kilowatt Hour	NT\$	-	-	2.390
Annual Cost (C)	$10^6\text{NT\$}$	100.530	98.750	199.280
Per Kilowatt hour	NT\$	0.251	0.162	0.197
Annual Benefit (B)	$10^6\text{NT\$}$	120.800	182.300	303.100
Surplus Benefit (B-C)	"	20.270	83.550	103.820
Benefit-Cost Ratio (B/C)	"	1.202	1.846	1.521

CHAPTER 3

LOAD FORECAST AND POWER DEMANDS AND SUPPLY PROGRAM

CHAPTER 3.

LOAD FORECAST AND POWER DEMAND AND SUPPLY PROGRAM

3.1 Description of Supply Territory

3.1.1 Natural Conditions and Population of Taiwan

Taiwan, The Republic of China, is an island located 150 km east of Main Land, 400 km north to south and 140 km east to west and with an area of 36,000 km^2. Of the total area, 65% is mountainous, and the Central Mountain Range with a series of peaks over 3,000 m in height runs north to south slightly east of the middle of the island. West of the Mountain Range, there is a wide, relatively flat plain, while on the eastern side, the topography is rugged with very little flat area.

The Tropic of Cancer passes through the middle of the island and because of the sub-tropical climate, the agricultural products are plenty and annual precipitation reaches 2,000 mm. The northern part of the island generally has abundant precipitation with a short dry season coming around November. The southern part normally has less precipitation which is, moreover, concentrated in the summer months, and between October and April following year there is very little rainfall. Also, since Taiwan is located in the path of typhoons it is often struck by these storms between June and October.

The population of Taiwan is presently close to 13,500,000 and the annual population growth rate is 2.5%. Seventy percent of the population is concentrated in cities and agricultural areas where water is conveniently available. The agricultural population rate is 50% of the employed, but this ratio is decreasing yearly, as the industrial and commercial population rate is increasing.

3.1.2 Economic Condition

Since 1953, when the First Four-Year Economic Development Plan was launched, the economy of Taiwan has made remarkable progress at an annual rate of 8% to date, and the per capita income has increased by 4% annually. Growth of production in mining and industry is 13% annually, while 6% in agriculture, forestry and fisheries, which indicates rapid industrialization of Taiwan.

At present, the Fourth Economic Development Plan (1965 - 1968) is under way and during the period from the First Plan to the Fourth Plan, industrial achievements in Taiwan have made rapid strides. In recent years, the chemical, machinery, electrical and metal industries have been extremely marked. Ninety percent of exports in 1953 was agricultural products including processed agricultural products such as sugar, rice, etc., but now it is under 60%, as textile products, machinery, metal products, chemical products, cement, paper, pulp, etc. have been increased. In the case of imports, capital items such as machines and tools which were about 15% of the volume in 1953 have recently advanced to 30%.

As stated above, industrialization since 1953 has been extremely remarkable, especially so in the past several years, showing without any doubt that the economic structure of Taiwan is being greatly changed.

Table 3-1 Economic Growth

	Gross National Production			Net National Income			Production Index			
							(1)		(2)	
	10^9NT$	Index	Increased Rate(%)	10^3NT$	Index	Increased Rate(%)	Index	Increased Rate (%)	Index	Increased Rate(%)
1952	40	100	-	4.1	100	-	100	-	100	-
1953	45	111	10.5	4.3	106	5.7	114	14.2	124	24.1
1954	49	120	8.8	4.4	108	2.3	117	2.0	133	7.2
1955	51	125	4.1	4.4	108	0.1	119	2.4	148	11.1
1956	53	130	4.0	4.4	108	0.1	127	6.5	155	5.1
1957	57	140	7.6	4.5	110	1.7	140	10.5	177	13.6
1958	60	149	6.0	4.6	113	2.7	152	8.2	190	7.6
1959	65	162	8.9	4.9	121	6.6	155	2.2	215	13.1
1960	69	171	5.5	5.0	124	2.9	155	-0.5	245	13.8
1961	75	185	8.2	5.3	130	4.8	171	10.6	270	10.5
1962	81	199	8.0	5.4	133	2.7	173	1.3	305	12.8
1963	90	222	11.3	5.9	146	9.2	179	3.6	336	10.1
1964	102	254	14.2	6.7	165	13.5	198	10.3	427	27.1
1965	111	276	8.7	6.9	170	2.8	215	8.7	497	16.5
1966	120	296	7.3	7.1	177	3.9	227	5.9	565	13.7
1953 - 1966			8.1			4.1		6.1		13.2

at 1964 prices

Note: (1) forestry and fishery
(2) mining and manufacturing

Table 3-2 Change of Composition Ratio of Industries in Export and Import

	Export				Import		
	1/(%)	2/(%)	3/(%)	4/(%)	5/(%)	6/(%)	7/(%)
1952	26.9	68.3	3.6	1.2	13.1	74.2	12.7
1953	13.1	79.6	6.4	0.9	17.3	68.6	14.1
1954	14.8	77 3	6.8	1.1	19.3	69.1	11.6
1955	29.7	62 6	6 1	1.6	18.6	71.2	10.2
1956	15 0	71.7	11.9	1.4	24.1	68.0	7.9
1957	16.6	74.7	7.2	1.5	26.4	65.8	7 8
1958	23.8	63.1	11.3	1.8	25.9	62.9	11.2
1959	24.0	53 6	20 9	1.5	31.1	61.2	7.7
1960	11.7	55.9	30.4	2.0	27.5	63.0	9.5
1961	15.3	42.7	39.7	2.3	28.4	59.7	11.9
1962	13.8	36.0	47.2	3.0	25.7	64.6	9.7
1963	14.3	43.1	39.5	3.1	24.6	67.0	8.4
1964	16.0	40.4	39.9	3.7	25.0	64.5	10.5
1965	27.4	27.2	41 3	4.1	29.5	62.7	7.8
1966	23.2	22.7	49.2	4.9	29.6	62.4	8.0

Note: 1/ Agricultural products
2/ Processed agricultural products
3/ Manufactured products
4/ Others
5/ Capital
6/ Agricultural and manufactured products
7/ Consumable goods

Since, in the establishment of an industrial area, geographical conditions generally play an important role, the Taipei-Keelung District and the Kaohsiung District which have good ports have been growing as large industrial areas. It is assumed that this trend will not be changed in the future.

In Taiwan, coal is the most important resources, being 50% of the total energy consumption. Production has been increased yearly, although recently the rate of increase has been slow so that annual production is now 5 million tons. The production area is the northern region from Keelung to Hsinchu with the reserves of presumably 200 million tons, but this coal is not economical and it will be difficult for coal to maintain a superiority over petroleum. Since petroleum or natural gas resources are not abundant in Taiwan, if petroleum is to be used in great quantities as a fuel for power generation, it will have to be imported.

Abundant mineral resources in Taiwan is limestone, 2 million tons of which are produced annually, and large quantities are used as raw materials for cement and chemicals.

Since Taiwan is rich in rainfall, water resources are abundant. Due to the great seasonal variation and the steep terrain, however, there are various difficulties involved in the utilization of water. Nevertheless, progressive investments have recently been started towards effective water utilization. Agricultural water, industrial water, hydroelectric power generation, and drinking water can be listed as the aims of water utilization. The greatest quantities are being used presently for irrigation and hydroelectric power generation in Taiwan. Irrigation is mostly being used in the coastal plain in the southwestern part of Taiwan. This district has 60% of the total irrigated area of the island, and the production of agricultural products, the greatest being rice, is increasing.

Looking at the water resources of Taiwan from the aspect of hydroelectric power generation, the salient features are the large quantities of rainfall and the steep gradients of rivers and streams which readily provide high heads so that the conditions are exceedingly favorable for this industry. Therefore, hydroelectric power generation has been developed for a long time with the aim of effective utilization of water resources, but with the raising of industrial levels and improvement of living standards, the increase in power demand has also been extremely marked with a growth rate of 13% annually. Since there is a limit to the extent that hydro power alone can be depended on, the ratio of thermal power generation has recently increased to a point where more than 60% of the energy quantity is met by thermal power. At present, hydroelectric power potentials which can be developed economically are estimated at 2. 5 to 3 million KW and it will still be of importance from the standpoint of the national economy to continue developing the remaining water resources as sources of energy in harmony with other forms of water utilization.

In 1966, the Taiwanese economy, due to expanded foreign trade and increased domestic investiment, reached a level of NT\$124, 500 x10^{6} (U. S. \$3, 100 x 10^{6}) in gross national product which corresponded to a real growth of 7. 3% over the previous year. The per capita income reached NT\$7, 559 (U. S. \$189) which was a 3. 9% real growth over the previous year. The agriculture, forestry and fishery grew 5. 9% overall, and particularly, the marine and livestock industries showed large gains of more than 10%. The mining and industrial production showed a growth of 13. 7%, of which the machinery industry, the electrical equipment and appliance industry, and building construction registered growths of more than 30%.

The production of coal was 5 million tons, which was almost the same as in the previous year, while petroleum and natural gas were greatly advanced over the previous year through development of new sources. However, only 36,000 kl of petroleum and 440 x 10^6m^3 of natural gas were produced, and it is not expected that even in the future production will be increased enough to occupy an important position in energy consumption.

The economy of Taiwan, as mentioned above, has progressed immensely, and in the future with increased agricultural production capacity, raising of educational standards and strengthening of social capital such as roads, ports and harbors, railroads and communications as a basis, the industrial levels will be raised even further and concentration of population in the cities will become more advanced so that it is thought that economic growth will continue at a rate which will not be lower than that of up to the present.

Table 3-3 Gross National Product of Taiwan, 1965 - 1966

Item	1966 (estimated)	1965(revised)
At Current Prices		
Amount (NT$ million)	124,489	113,112
Annual Growth Rate(%)	10.1	10.4
At 1964 Prices		
Before Adjustment of Trading Gain or Loss		
Amount (NT$ million)	124,527	115,228
Annual Growth Rate (%)	8.1	12.4
After Adjustment of Trading Gain or Loss		
Amount (NT$ million)	119,627	111,444
Annual Growth Rate (%)	7.3	8.7

Source: DGBAS

Table 3-4 National Income and Per Capita Income of Taiwan, 1965 - 1966

Item	1966 (estimated)	1965(revised)
I. National Income		
At Current Prices		
Amount (NT$ million)	100,867	91,891
Annual Growth Rate (%)	9.8	8.5
At 1964 Prices		
Amount (NT$ million)	95,707	89,613
Annual Growth Rate (%)	6.8	5.8
II. Per Capita Income		
At Current Prices		
Amount (NT$)	7,559	7,078
Annual Growth Rate (%)	6.8	5.4
At 1964 Prices		
Amount (NT$)*	7,172	6,903
Annual Growth Rate (%)	3.9	2.8

* After adjustment of trade gain or loss.
Source: DGBAS

Table 3-5 Distribution of Aggregate Supply and Demand, 1964 - 1965

Item	1965 (%)	1964 (%)
1. Gross National Product	82.2	84.5
2. Total Imports	17.8	15.5
Aggregate Supply	100.0	100.0
3. Private Consumption	51.9	54.1
4. Government Consumption	14.0	14.1
5. Gross Domestic Capital Formation	18.5	15.9
6. Total Exports	15.1	15.8
7. Factor Income from Abroad and Statistical Discrepancy	0.4	0.1
Aggregate demand	100.0	100.0
Net Exports (6 minus 2)	(-) 2.7	0.3

Source: DGBAS

Table 3-6 Production of Major Agricultural Products, 1965 - 1966

Unit: Metric ton

Item	1966	1965	Percentage Change
Food Crops			
Rice	2,379,661	2,348,041	1.3
Sweet Potatoes	3,459,811	3,131,103	10.5
Wheat	28,498	23,492	21.3
Peanuts	115,038	125,817	(-) 8.6
Soybeans	63,335	65,709	(-) 3.6
Corn	51,408	41,079	25.1
Special Crops (1)			
Sugarcane (2)	8,818,306	9,489,770	(-) 7.1
Bananas	530,886	452,210	17.4
Mushrooms	38,454	32,430	18.6
Pineapple	270,531	231,005	17.1
Citrus Fruits	136,782	114,434	19.5
Tea	21,507	20,730	3.7
Tobacco	15,054	16,301	(-) 7.6
Jute	14,339	17,228	(-) 16.8
Flax	12,941	12,460	(-) 3.9
Citronella	107,005	132,437	(-) 19.2

Notes: (1) Compiled from provincial department of agriculture & forestry data.
(2) Crop year.

Source: MOEA

Table 3-7 Index Numbers of Industrial Production, 1965 - 1966

Base period: 1961=100

Item	1966	1965	Percentage Change
General Index	209.1	183.9	13.7
Mining	136.2	129.7	5.0
Manufacturing	212.6	188.3	12.9
Food	129.5	135.8	(-) 4.6
Textiles	153.7	145.9	5.3
Lumber & Lumber Products	321.0	270.3	18.8
Paper & Paper Products	182.8	172.8	5.8
Chemicals & Chemical Products	361.1	312.7	15.5
Non-metalic Mineral Products	179.4	151.8	18.2
Basic Metals	185.0	156.9	17.9
Machinery	228.1	176.0	29.6
Electrical Machinery and Appliances	544.2	401.2	35.6
Transport Equipment	377.9	333.6	13.3
Building Construction	836.9	532.6	57.1
Public Utilities	175.4	154.6	13.5

Source: MOEA

Table 3-8 Production of Major Mineral Products, 1965 - 1966

Item	Unit	1966	1965	Percentage Change
Coal	m.t.	5,014,533	5,054,463	(-) 0.8
Crude Petroleum	k.l.	35,906	20,835	72.3
Natural Gas	1,000m^3	439,168	309,6 6	41.8
Electrolytic Copper	m.5.	2,319	1,885	23.0
Pyrite	m.t.	42,005	39,260	7.0
Sulphur	m.t.	6,970	6,881	1.3
Marble	m.t.	1,121,877	899,480	24.7
Dolomite	m.t.	51,578	50,577	2.0
Salt	1,000m.t.	411	560	(-) 26.6

Source: MOEA

Table 3-9 Production of Major Manufactured Products, 1965 - 1966

Item	Unit	1966	1965	Percentage Change
Canned Mushrooms	1,000 standard boxes	1,488	1,828	(-) 18.6
Canned Pineapple	1,000 Boxes	5,016	4,306	16.5
Canned Asparagus	1,000 boxes	1,746	712	145.2
Sugar (raw value)	1,000 m.t.	927	968	(-) 4.2
Cigarettes	million pcs.	13,845	13,664	1.3
Alcoholic Beverages	1,000 hl.	1,008	1,024	(-) 1.6
Monosodium Glutamate	m.t.	7,964	11,747	(-) 32.2
Cotton Yarn	m.t.	59,059	54,936	7.5
Synthetic Yarn	m.t.	15,960	14,324	11.4
PVC Powder	m.t.	44,175	25,305	74.6
Paper	1,000 m.t.	145	139	4.3
Fuel Oil	1,000 kl.	1,179	931	26.6
Gasoline	1,000 kl.	436	357	22.1
Kerosene	1,000 kl.	34	30	13.3
Diesel Oil	1,000 kl.	374	344	8.7
Calcium Cyanamide	m.t.	11,624	26,689	(-) 56.4
Ammonium Sulphate	m.t.	277,417	279,941	(-) 0.9
Nitrochalk	m.t.	43.062	48,611	(-) 11.4
Urea	m.t.	189,282	185,012	2.3
Calcium Superphosphate	m.t.	212,000	195,850	8.2
Caustic Soda	m.t.	74,915	57,435	30.4
Soda Ash	m.t.	28,168	16,851	67.2
Cement	1,000 m.t.	3,112	2,444	27.3
Plate Glass	1,000 standard boxes.	832	704	18.2
Reinforcing Bars	1,000 m.t.	326	260	25.4
Aluminum Ingot	m.t.	17,217	18,912	(-) 9.0
Aluminum Foil	m.t.	1,055	1,197	(-) 11.9
Electric Fans	unit	247,512	186,817	32.5
Household Refrigerators	unit	43,056	38,123	12.9
Fluorescent Lamps	1,000 pieces	6,004	4,111	46.0
Plywood	1,000 m^2	98,178	78,762	24.7
Trucks, Buses & Autos	set	4,524	3,261	38.7
Sewing Machines	1,000 unit	154	79	94.9
Machine Tools	unit	11,512	6,476	77.8
General Machinery & Parts	m.t.	108,924	82,466	32.1

Source: MOEA

Table 3-10 Construction of Building, 1965 - 1966

Item	Unit	1966	1965	Percentage Change
Brick Building	m^2	1,771,160	1,039,386	70.4
Reinforced Concrete Building	m^2	1,017,431	698,326	45.7
Wooden Construction	m^2	50,820	42,698	19.0
Others	m^2	27,588	14,899	85.2
Total	m^2	2,886,999	1,795,309	59.7

Source: MOEA

3.2 General Description of Taiwan Power Company

The Taiwan Power Company (Taipower) is a joint-stock corporation which carries out integrated power supply from the development of power resources, power generation, power transmission and power transforming to power distribution for all of Taiwan and Penhu Island. The majority of the shares are held by the Central Government, and the company is operated under the s pervision of the Ministry of Economic Affairs.

The power systems of Taipower are completely interconnected with the exception of Penhu Island, and the installed capacity at the end of 1966 was 1,475 MW of which 757 MW was thermal and 718 MW hydro. The ratio of hydro to thermal was 49:51 and the thermal component exceeded 50% for the first time. The transmission system consists of 154 KV trunk line systems under which there are 69 KV and 34.5 KV systems, and 12 KV and 3.45 KV distribution systems.

The transitions in peak load and energy output are shown in Fis's. 2 and 3 indicating that in 1966, peak load reached 1,240 MW and an energy output 7,300 GWh. Trends in energy sales are given in Fig. 4 showing that in 1966 sales reached 6,500 GWh. The breakdown given in Table 3-11 indicates the growth in residential demand. The regional distribution of energy sales given in Table 3-12 shows the great increases in the Taipei Hsien and the Kaohsiung Hsien with extremely little growth in the Eastern Area.

Since it is thought that the steady growth in power demand following the advancement of the Taiwanese economy will continue in the future, it should be said that the mission of Taipower as the nucleus of the economic development is of great importance.

Table 3-11 Salable Energy by Consuming End

Class of Service	Number of Customers	% Increases over Last Year	Million KWh Sold	Percentage of Total	% Increase over Last Year
Industrial	66,410	12.5	5,189	80.1	13.9
Commercial	205,610	6.8	184	2.8	8.1
Residential	1,471,920	6.1	1,108	17.1	17.1
Total	1,743,940	6.4	6,481	100.0	14.3

Table 3-12 Salable Energy by District

District	% Increase (Decrease) Over 1965		% of Total	
	Lighting	Power	Lighting	Power
Taipei	15.1	15.3	33.5	21.4
Keelung	12.3	8.5	4.3	9.9
Ilan	12.2	19.9	2.1	5.1
Taoyuan	22.7	14.7	4.4	3.0
Hsinchu	12.6	41.4	5.7	10.5
Taichung	17.3	25.4	10.3	6.6
Changhua	14.5	8.4	4.6	2.1
Chiayi	14.4	18.5	7.3	3.5
Tainan	15.7	9.7	8.9	5.5
Kaohsiung	19.8	9.8	11.3	27.1
Pingtung	14.4	(3.9)	4.3	1.3
Hualien	9.9	(15.2)	1.7	3.7
Taitung	17.5	20.7	1.0	0.1
Penghu	23.2	14.7	0.6	0.2
Total	15.8%	13.9%	100%	100%

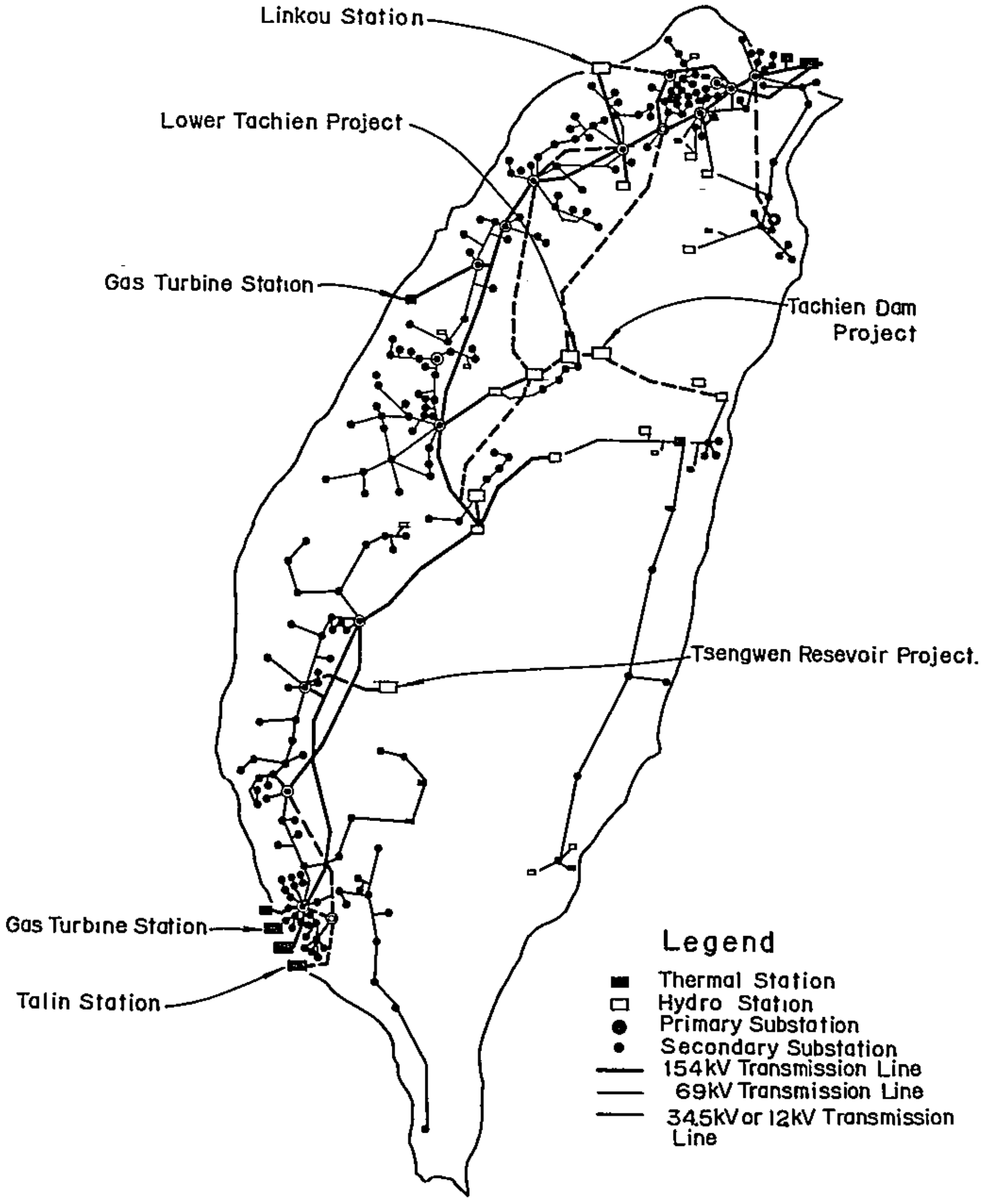


Fig 3-1 Transmission Line System.

Fig 3-2 Installed Capacity and Peak Load.

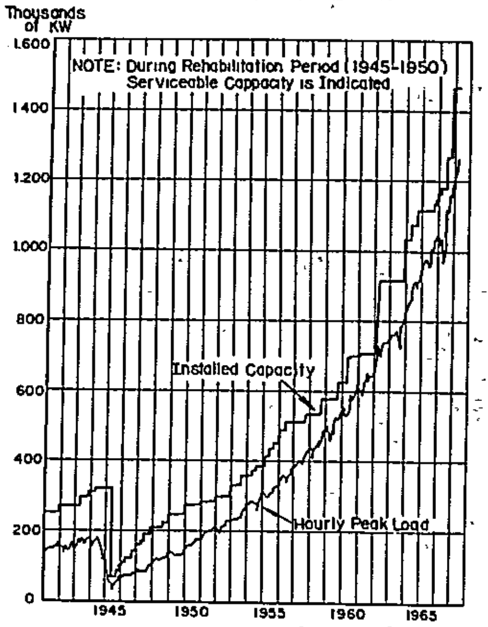


Fig 3-3 Energy Output.

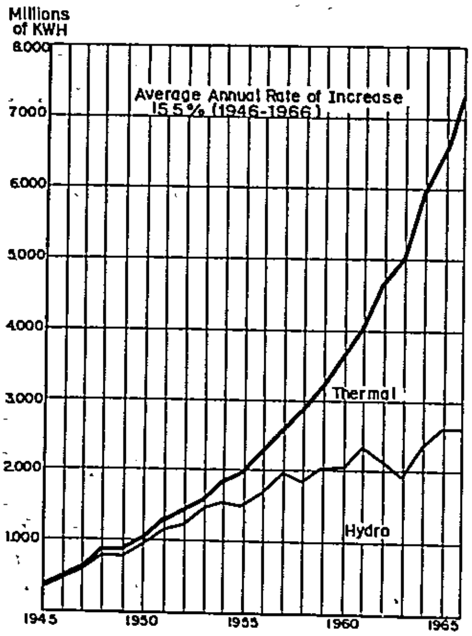
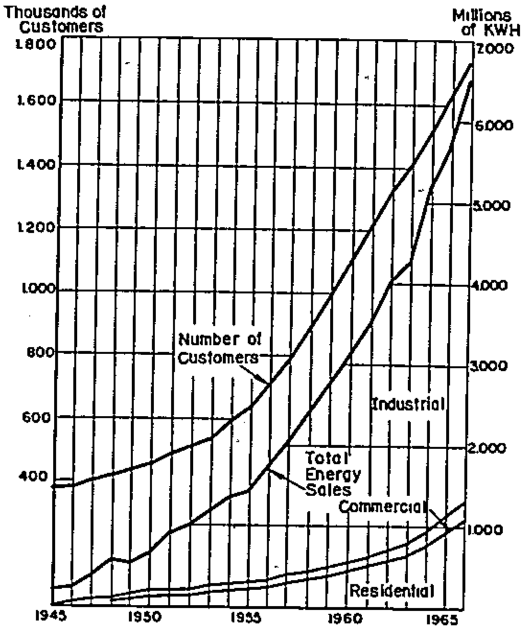


Fig 3-4 Customers and Sales



3.3 Load Forecast

3.3.1 Outline of Power Demand

In 1966, the power demand showed a growth of 14% over the previous year and the total demand during the year was 6,500 GWh with per capita consumption being 500 KWh. In this demand, 20% was for lighting for residential and commercial demand while the remaining 80% was for industrial use.

Household electrification has caused the lighting demand to increase from around 1964 at a high growth rate of 17%, and since there will be even more household electrification and commercial demand with the increase in buildings in the future, a steady growth of this type will continue.

Table 3-13 Dissemination of Electrical Appliance

Electrical Appliance	Number of Units per 100 Households		
	Dec. 1966	Oct. 1962	Percentage Increase
Radio	47.4	38.2	24
Electric Fan	66.8	43.6	53
Electric Iron	13.4	10.5	28
Rice Cooker	24.6	3.1	694
Refrigerator	3.4	1.1	209
Television Set	1.3	0.1	1,200
Washing Machine	0.9	0.3	200
Air Conditioner	0.9	0.4	125

On the other hand, the growth rate of industrial demand has been comparatively stable since entering the sixties, and in 1966 the power demand ratio of each industry as shown in Table 3-14 indicates the rate of the fertilizer industry to be the highest followed by chemicals, steel, cement, ceramics, textiles and foodstuffs. Compared to the preceding year, the growth rate of the chemical, cement, ceramic, machinery, textile, paper and pulp industries are the highest being above the 14% in the entire industrial demand. It is estimated that with the rise in industrial levels, the growth rates for machinery and chemical industries will become high.

Table 3-14 Demand Increase by Industries

Industry	% Increase (decrease) over Last Year	% of Total
Fertilizer	(3.1)*	13.8
Alkali	11.6	5.5
Paper and Pulp	16.6	6.2
Other Chemicals	49.3	10.1
Cement and Ceramics	33.2	8.1
Iron and Steel	9.5	9.6
Aluminum	(4.1)*	6.9
Other Metals	14.8	2.0
Textile	20.5	7.4
Machinery	22.9	2.5
Food Processing	8.8	7.0
Coal & Mining	14.1	6.5
Irrigation and Agriculture	2.6	3.3
Other	20.1	11.1
Total	13.9%	100%

* Due to power restriction in the first part of 1966

Peak load takes place in December, reaching 1,240 MW in 1966. This was a growth of 16.5% over the previous year. In the future, due to the climatic conditions of Taiwan and the increase in demand from buildings caused by urbanization, it is thought that the summer demand will greatly outgrow the winter demand so that the peak load during the year will be in the summer season.

3.3.2 Load Forecast

In forecasting the long-term power demands over the periods of 10 to 20 years, it is necessary to grasp the future shifts numerically in economical indexes which are closely related to power demand, such as gross national product, population, industrial structure and living standards. In connection with this study, since it was difficult to obtain sufficient data on the various indexes of the future economic situation, it is impossible to make a detailed forecast of power demand, but it is adequate enough for judging general trends.

The method of forecast was to separate power demands into lighting demand and industrial demand, forecasting the former from the correlation with GNP and the latter from the correlation with IIP.

(1) Population

The transition in the population of Taiwan is shown in Table 3-15 indicating that the 8,100 x 10^3 persons in 1952 has been increased to 13,000 x 10^3 persons in 1966. This growth rate is 3.5% annually. Recently, this population growth rate has slowed down considerably to 2.5% annually. According to the data of the Taiwan Population Research Center, the future population trend is forecasted as in Table 3-15, with the population in 1976 estimated to reach 16,400 x 10^3 persons and the annual growth rate lowered to 2%.

If it is assumed the population will grow thereafter at this rate, it will reach 18,000 x 10^3 persons in 1981.

(2) Gross National Product (GNP)

The index of gross national product with 1952 as the base is as shown in Table 3-15. The growth rate up to 1966 was 8% with the total amount being NT $124,500 x 10^6. According to the Government's long-term economic development program, it is estimated that the future economic growth rate will be 7%. The per capita GNP in 1966 accounted for 185.6% of that in 1952 which is an annual increase of as much as 4.4%.

Assuming that the GNP will increase in the future at 7% annually, the per capita GNP will grow at a rate close to 5% annually, and it is calculated that it will be 289% in 1976 and 367% in 1981.

(3) Index of Industrial Production (IIP)

IIP with 1952 as 100 is shown in Table 3-15 with the growth up to 1966 being 13% annually and the elasticity value for GNP, 1.62.

Assuming that the IIP of a future year is estimated by the correlation with GNP, the following equation is obtained from the data covering the period from 1952 to 1966 and IIP is calculated by this equation.

$$\text{Log } Y = -1.0870 + 1.5500 \text{ Log } X$$

where

Y : IIP
X : GNP (index)
Y, X : 100 in 1952

Calculating IIP for 1976 and 1981 from the above equation, the results are 1,580 and 2,669, respectively.

(4) Lighting Demand

The lighting demand which grew at a rate of 11% annually up to 1963 was increased greatly to 17% from 1964 by household electrification accompanying improved living standards with the annual demand in 1966 reaching 1,300 GWh. The advances in household electrification are shown in Table 3-13, in which ownership of television sets and rice cookers are especially marked.

The lighting demand of a future year in terms of per capita demand is calculated from the correlation with per capita GNP. Obtaining the equation below from data for the period between 1952 and 1966, the future demand was calculated.

$$\text{Log. } Y \doteq -2.084 + 1.7987 \text{ Log. } X$$

where

Y : Per capita lighting demand (KWh/person)
X : Per capita GNP (index)
X : 100 in 1952

Calculating per capita lighting demands in 1976 and 1981 by the above equation, they are 219 KWh/person and 338 KWh/person, respectively, or 3,600 GWh and 6,100 GWh in total demand.

(5) Industrial Power Demand

In the fifties the growth rate of industrial power demand varied greatly between 10 and 20% annually. From the 1960's, the growth rate has not varied as greatly being stabilized at 10 to 13% annually. In 1966 the demand including the demand restricted, reached 5,400 GWh and as shown in Table 3-14 the growing demand for power of the chemical, cement, machinery and textile industries was so great as to exceed 20% annually in growth rate. The IIP with 1952 as 100 was 565 in 1966.

The industrial power demand was divided broadly into "small power" and "large power" demands, in order to forecast the future, and each of these was esti estimated by its correlation with IIP. For small power, an equation was obtained from data of the period from 1956, while for large power, since the elasticity value for IIP has become considerably small after 1959, data of the period from 1959 on were used to obtain an equation to calculate future demands.

(i) Small Power

$$\text{Log } Y = 1.0079 + 0.7803 \text{ Log } X$$

where Y : Smaller power (GWh)
X : IIP (index)
X : 100 in 1952

(ii) Large Power

$$\text{Log } Y = 1.3574 + 0.8141 \text{ Log. } X$$

where Y : Large power (GWh)
X : IIP (index)
X : 100 in 1952

From the above equations, the industrial power demands for 1976 and 1981 are calculated as follows :

Unit : GWh

	Small Power	Large Power	Total
1976	3,192	9,191	15,970
1981	4,807	14,098	25,018

(6) System Losses

The ratio of system losses was greater than 20% in 1952, but after that, due to system improvements such as adoption of higher voltage in distribution systems, and also due to the increase in the ratio of thermal power, this loss ratio has been considerably lowered. Entering the 1960's, the ratio has fallen below 15% and presently it is lowered to 12%, but recently, this lowering of the loss ratio appears to have reached a limit.

As for system loss rate in the future, since they depend on the structure of the system, location of power sources and other conditions, it is difficult to make an accurate estimate unless the future power source locations, system structure, regional load distribution, etc. are definitely known. However, as detailed study to that extent is not necessary for judgment of the general situation, the losses have been assumed to be 12% in this study, taking into consideration the past actual loss ratios in the Taipower System and from experiences obtained by electric power companies in Japan.

(7) Energy at Transmitting End

From the above forecasts, the energy at the consumer's end in 1976 and 1981 will be 15,970 GWh and 25,018 GWh respectively, and the energy at the transmitting end in 1976 and 1981 will reach 18,147 GWh and 28,429 GWh respectively.

Table 3-15-1 Load Forecast

(1) Year	(2) Populations	(3) Growth Rate	(4) GNP	(5) GNP Growth Rate	(6) GNP per Capita	(7) Growth Rate per Capita GNP	(8) IIP	(9) Growth Rate	(10) IIP Elasticity per GNP	(11) Lighting Demand	(12) Growth Rate	(13) Lighting Demand per Capita	(14) Growth Rate	(15) Elasticity (13) per (6)	Industrial Power Energy (GWh) (including curtailment)		
	(10^3man)	(%)	(Index)	(%)	(Index)	(%)	(Index)	(%)		(GWh)	(%)	(GWh/man)	(%)		Small Power	Large Power	Total
1952	8,128	-	100	-	100	-	100	-	-	259	-	32	-		-	-	838
1953	8,438	3.8	111	10.5	107	6.5	124	24.1	2,30	301	16.2	36	12.0		-	-	924
1954	8,749	3.7	120	8.9	112	5.0	133	7.2	0.81	324	7.6	37	3.5		-	-	1,123
1955	9,078	3.8	125	4.1	112	0.3	148	11.1	2.71	341	5.2	38	1.6		-		1,229
1956	9,390	3.4	130	4.0	113	0.5	155	5.1	1.28	381	11.7	41	8.0		513	876	1,389
1957	9,690	3.2	140	7.7	118	4.3	177	13.6	1.77	434	13.9	45	10.3		580	1,073	1,653
1958	10,039	3.6	149	6.0	120	2.3	190	7.6	1.27	479	10.4	48	6.5		615	1,373	1,988
52～58				(7.0)		(3.0)		(11.3)	(1.61)		(10.9)		(6.5)	(2.16)			
1959	10,431	3.9	162	8.9	126	4.8	215	13.1	1.47	533	11.3	51	7.1		685	1,729	2,414
1960	10,792	3.5	171	5.5	129	1.9	245	13.8	2.51	5.91	10.9	55	7.2		728	2,004	2,732
1961	11,149	3.3	185	8.1	135	4.7	270	10.5	1.30	662	12.0	59	8.4		784	2,216	3,000
1962	11,512	3.3	199	8.0	141	4.6	305	12.8	1.60	737	11.3	64	7.7		901	2,429	3,330
1963	11,884	3.2	222	11.3	152	7.9	336	10.1	0.89	805	9.2	68	5.8		1,021	2,721	3,742
1964	12,257	3.1	254	14.2	168	10.7	427	27.0	1.90	949	17.9	77	14.3		1,102	3,142	4,244
1965	12,628	3.0	276	8.7	177	5.5	497	16.5	1.90	1,115	17.5	88	14.1		1,264	3,451	4,715
1966	12,993	2.9	296	7.4	186	4.7	565	13.7	1.85	1,291	15.9	99	12.6		1,455	3,966	5,421
58～66				(9.0)		(5.5)		(14.5)	(1.61)		(13.1)		(9.7)	(1.76)			
52～66				(8.0)		(4.4)		(13.0)	(1.61)		(12.0)		(8.3)				
1967	13,338	2.7	317	7.0	193	4.1	614			1,413		106			1,528	4,248	5,776
1968	13,689	2.6	339	7.0	201	4.3	682			1,560		114			1,659	4,626	6,285
1969	14,038	2.6	363	7.0	210	4.3	758			1,726		123			1,800	5,043	6,843
1970	14,385	2.5	388	7.0	219	4.4	842			1,913		133			1,954	5,495	7,449
1971	14,729	2.4	415	7.0	229	4.5	935			2,120		144			2,120	5,990	8,110
1972	15,069	2.3	444	7.0	240	4.6	1,038			2,350		156			2,301	6,522	8,823
1973	15,405	2.2	475	7.0	251	4.7	1,153			2,618		170			2,498	7,106	9,604
1974	15,736	2.2	508	7.0	263	4.7	1,281			2,911		185			2,710	7,743	10,453
1975	16,062	2.1	544	7.0	275	4.8	1,422			3,228		201			2,941	8,429	11,370
1976	16,383	2.0	582	7.0	289	4.9	1,580			3,587		219			3,192	9,191	12,383
66～76		(2.3)		(7.0)		(4.5)		(10.9)	(1.55)		(10.9)		(8.1)	(1.80)			
1977	16,711	2.0	623	7.0	303	4.9	1,754			3,993		239			3,464	10,008	13,472
1978	17,045	2.0	666	7.0	318	4.9	1,948			4,448		261			3,760	10,901	14,661
1979	17,386	2.0	713	7.0	333	4.9	2,164			4,937		284			4,081	11,875	15,956
1980	17,733	2.0	763	7.0	350	4.9	2,403			5,497		310			4,429	12,940	17,369
1981	18,088	2.0	816	7.0	367	4.9	2,669			6,113		338			4,807	14,098	18,905
76 ～ 86		(2.0)		(7.0)		(4.9)		(10.9)	(1.55)		(11.1)		(8.8)	(1.80)			

Table 3-15-2 Load Forecast

Year	Growth Rate of Industrial Power (%)			Elasticity of Industrial Power Per IIP		Total Load	Growth Rate of Total Load	Composition of Total Load (%)		Transmission Loss	Energy at Sending End	Average Output	Annual Load Factor	Maximum Output
	Small Power	Large Power	Total	Small Power	Large Power	(GWh)	(%)	L.D	I.D.	(%)	(GWh)	(MW)	(%)	(MW)
1952	-	-	-	-	-	1,097	-	23.6	76.4	-	1,420	157	67.7	232
1953	-	-	10.3	-	-	1,225	11.7	24.6	75.4	-	1,564	179	66.0	271
1954	-	-	21.5	-	-	1,447	18.1	22.4	77.6	-	1,805	206	65.2	317
1955	-	-	9.4	-	-	1,570	8.5	21,8	78.2	-	1,966	224	66.7	336
1956	-	-	13.0	-	-	1,770	12.7	21.5	78.5	21.3	2,250	256	66.4	385
1957	13.1	22.4	19.0	0.96	1.65	2,087	17.9	20.8	79.2	18.4	2,555	292	65.9	443
1958	6.0	28.0	20.3	0.79	3.69	2,467	18.2	19.4	80.6	16.1	2,880	329	64.9	507
52~58			(15.4)											
1959	11.4	26.0	21.4	0.87	1.99	2,947	19.5	18.1	81.9	13.8	3,213	367	65.3	562
1960	6.3	16.0	13.2	0.46	1.16	3,323	12,8	17.8	82.2	13.6	3,628	413	65.0	635
1961	7.7	10.7	9.8	0.73	1.02	3,662	10.2	19.1	80.1	13.6	4,084	466	64.8	719
1962	14.9	9.9	11.0	1.16	0.77	4,067	11.1	19.1	80.1	13.4	4,693	536	69.6	770
1963	13.3	12.0	12.4	1.32	1.19	4,547	11.8	17.7	82.3	13.0	5,019	573	66.9	857
1964	7.9	15.5	13.4	0.29	0.57	5,193	14.2	18.3	81.7	12.3	5,914	673	68.2	986
1965	14.7	10.0	11.1	0.89	0.61	5,830	12.3	19.1	80.9	12.1	6,455	737	69.1	1,066
1966	15.1	15.0	15.0	1.10	1.10	6,712	15.1	19.2	80.8	11.7	7,340	838	67.4	1,243
58~66	(11.2)	(12.5)	(12.0)	(0.77)	(0.86)									
1967						7,189		19.7	80.3	12.0	8,051	932	68.0	1,370
1968						7,845		19.9	80.1	12.0	8,786	1,017	68.0	1,495
1969						8,569		20.2	79.8	12.0	9,597	1,111	68.0	1,633
1970						9,362		20.4	79.6	12.0	10,485	1,214	68.0	1,785
1971						10,230		20.7	79.3	12.0	11,457	1,327	68.0	1,951
1972						11,173		21.0	79.0	12.0	12,513	1,449	68.0	2,130
1973						12,222		21.4	78.6	12.0	13,688	1,585	68.0	2,330
1974						13,364		21.8	78.4	12.0	14,967	1,733	68.0	2,548
1975						14,598		22.1	77.9	12.0	16,349	1,893	68.0	2,783
1976						15,970		22.5	77.5	12.0	17,886	2,071	68.0	3,045
66~76	(8.5)	(8.9)		(0.78)	(0.81)		(9.0)							
1977						17,465		22.8	77.2	12.0	19,560	2,265	68.0	3,330
1978						19,109		23.2	76.8	12.0	21,402	2,478	68.0	3,644
1979						20,893		23.6	76.4	12.0	23,400	2,710	68.0	3,985
1980						22,866		24.0	76.0	12.0	25,609	2,966	68.0	4,361
1981						25,018		24.4	75.6	12.0	28,020	3,245	68.0	4,772
76~81	(8.5)	(8.9)		(0.78)	(0.81)		(9.2)							

L.D = Lightning Demand
I.D = Industrial Demand

Fig. 3-5 Correlation Between IIP and GNP

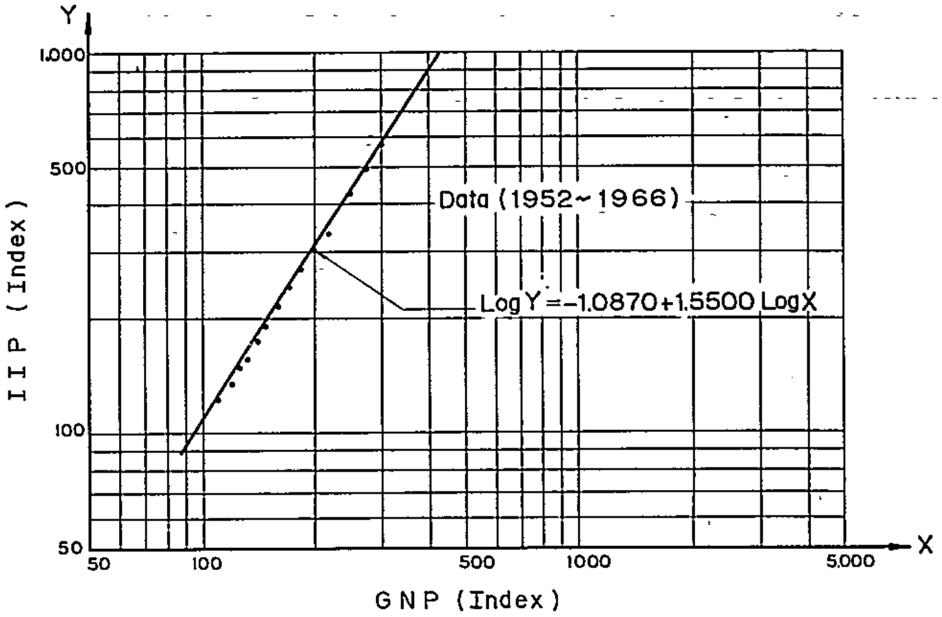


Fig 3-6 Correlation Between Per Capita Lighting Consumption and Per Capita GNP

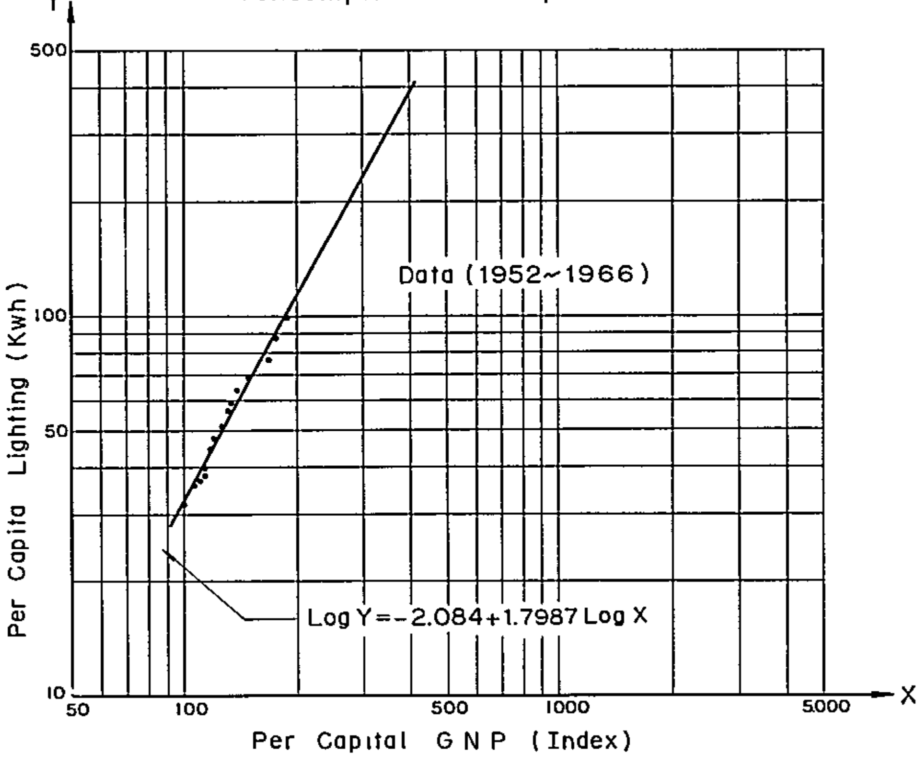


Fig 3-7 Correlation Between Small Power and IIP

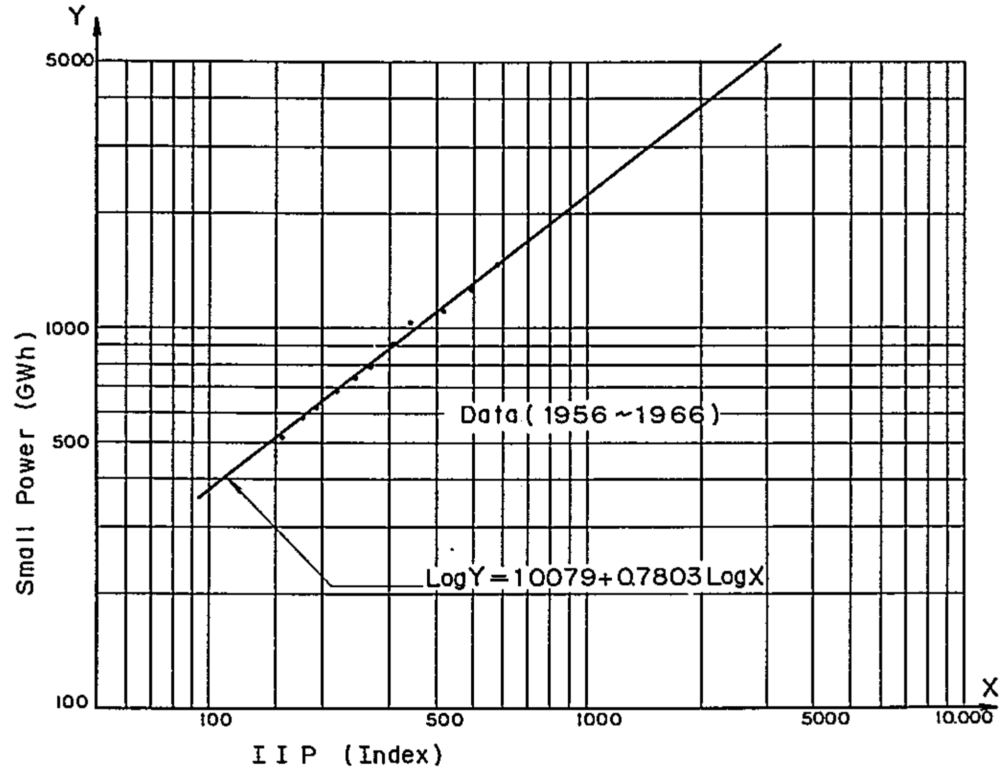


Fig 3-8 Correlation Between Large Power and IIP

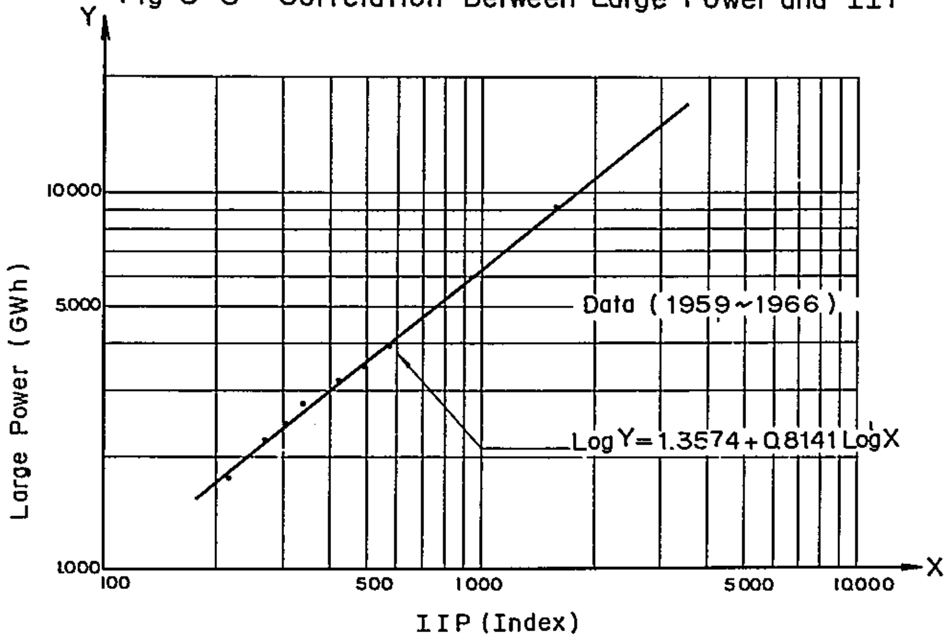
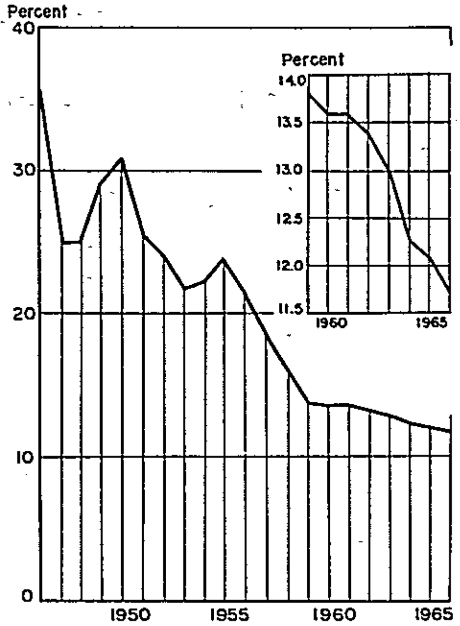


Fig 3-9 Line Losses



3.4 Power Supply and Demand

3.4.1 Outline of Power Supply and Demand

The energy production in 1966 was 7,300 GWh, of which 36% was hydro and 64% was thermal. Hydro energy production which was 1,200 GWh in 1952 grew to 2,700 GWh by 1966 while thermal energy production which was only 190 GWh in 1952 grew to 4,700 GWh by 1966. From the standpoint of energy production, thermal power exceeded hydro power for the first time in 1962, and since then the ratio of thermal power to hydro power has been increasingly raised, and in the near future nuclear power should emerge as another base load supply source.

Annual peak load which was 230 MW in 1952 increased to 1,240 MW by 1966. With the transition in the supply pattern of hydro and thermal power, hydro power has come to serve the purpose of meeting peak load and the annual load factor had been lowered from 54% in 1952 to 43% in 1966. On the other hand, thermal power has gradually come to be used more for base load, and the annual load factor of 37% in 1952 was increased to 77% in 1966.

It is thought that power plants to be developed in the future will consist mainly of large capacity thermal or nuclear plants for base load and hydro plants for peak load. The trend of thermal being the main source and hydro the subordinate will continue to prevail.

Load curves of peak load days in the months of August and December of the Taipower System for the 5 years from 1963 to 1967 are illustrated in Fig's. 3-10 and 3-11 and it can be explained roughly as follows.

(1) Peak load occurs at 18:00 hrs in December and 20:00 hrs in August.

(2) Morning peak occurs between 11:00 hrs and 12:00 hrs for both December and August. The ratio of morning peak to daily peak has recently increased from 80% around 1963 to 85% for December and from 85% around 1963 to 90% for August.

(3) The daily load factors are roughly 73% in December and 78% in August.

Table 3-16 Trend of Supply Capability

	Installed Capacity (MW)			Max. Output (MW)	Energy Production		
	Hydro	Thermal	Total		Hydro	Thermal	Total(10^6KWh)
1952	277	55	332	232	1,231	189	1,420
1953	303	60	363	271	1,466	98	1,564
1954	330	62	392	317	1,565	240	1,805
1955	351	142	493	346	1,531	435	1,966
1956	378	143	521	385	1,653	597	2,250
1957	399	143	542	442	1,938	617	2,550
1958	399	183	582	507	1,859	1,021	2,880
1959	448	185	633	562	2,011	1,202	3,213
1960	448	261	709	635	2,065	1,563	3,628
1961	538	385	923	719	2,339	1,745	4,084
1962	538	385	923	770	2,161	2,532	4,693
1963	538	502	1,040	857	1,931	3,088	5,019
1964	628	502	1,130	986	2,359	3,555	5,914
1965	628	558	1,186	1,066	2,585	3,870	6,455
1966	718	757	1,475	1,242	2,660	4,680	7,340

(4) The duration of peak hours as indicated in Fig. 3-12 shows little change over the years for December, lasting 3 to 4 hours for 20% of the daily peak load. However, for August there is a definite change in the peak hours. The 3.5 hours around 1963 have recently become about 6 hours. In April, there is some change noticed but this is not pronounced, being an increase to 4.5 hours from 3 hours around 1963.

3.4.2 Power Supply and Demand

The purpose of establishing a long-term supply and demand program is to provide a stable supply of power and to economically develop power facilities to meet future power demand.

First it is necessary to secure the balance between demand and supply capacity. Power facilities are constantly faced with the danger of forced outage. Also, in the case of hydro plants, the power output varies with the amount of river run-off, while thermal plants normally require 30-day overhauls every year. On the other hand, miscalculations in demand are possible. Therefore, it is far from easy to maintain a demand-supply balance by merely possessing generating facilities corresponding to the forecasted peak load; it is necessary to have reserve facilities.

In this study, supply capacity is expressed in terms of maximum power supply capability, and reserve capacity is defined as the difference between maximum power supply capability and demand. The reserve capacity is then examined to see whether or not it satisfies the required quantity.

(1) Peak Load

In estimating annual peak load, either annual energy according to use is arranged by month and day to assume daily load curves which are added up in making the calculation, or annual load factor is assumed according to use in the calculations. Needless to say, the first is the better method of estimation. But in this study, since it was difficult to obtain sufficient data and in practice it is somewhat unreasonable to apply the cumulative method for long-term forecasts, it has been decided to make the estimate by annual load factor.

The annual load factor of the Taipower System is as given in Table 3-15. Taking into account annual load factor records of various other countries, the future annual load factor is estimated at 68%. According to the estimates, annual peak load will be 3,045 MW in 1976 and 4,772 MW in 1981.

(2) Load Curve

It is quite important to exactly forecast future load curves in order to study how the hydro power development in the Taipower System should be carried out.

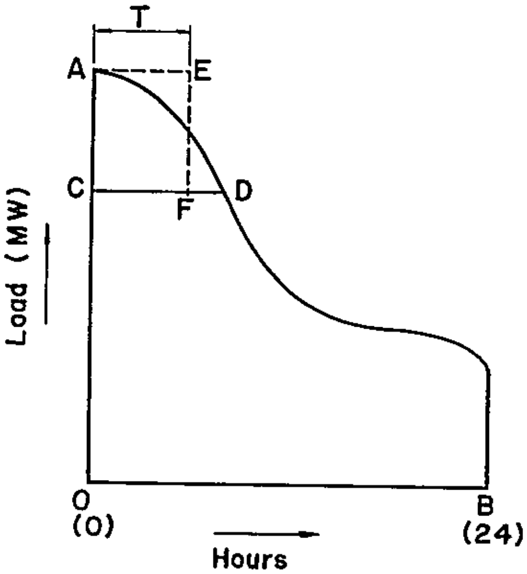
With variation of usage or type of industry and of the structural ratio of electric energy consumption, the future load curve would vary accordingly. Therefore, in estimating the load curve, it is necessary to estimate the standard load curve and power demand ratio by usage, and to compose a combined load curve from standard load curves by usage and power demand ratio. Judging from the past records of Taipower and those in Japan, the following generalizations on the load curve can be made.

(i) The ratio of industrial demand to total demand is as high as 80% in terms of power (kw), but the overall load curve of industrial demand shows little variation according to season and the load factor is extremely high at 87%. In comparing the actually recorded load curves of Taipower with those of the Japanese electric power industry, it is found that there are very great similarities, and in viewing the records in Japan from the past to the present, not much variation can be noted. Therefore, although in the future industrial demand it is anticipated that there will be great growth in the machinery industry with a relatively low load factor and in the chemical industry with a relatively high load factor, it is permissible to apply the present load curve to the forecast of future load curve without substantial adjustment.

(ii) The ratio of lighting demand to total demand is small at 20%, but since the load curve varies considerably by season and the load factor is around 50%, it has a great influence on the combined load curve. Especially, this demand has the nature of greatly affecting the duration of peak load. Therefore, the result of this load curve estimation is decisive in forming the peak load portion of the load duration curve and has a great influence on the hydroelectric power development plan. It is necessary that further detailed studies should be made of the lighting load curve. However, data necessary for the studies could not be obtained in sufficient quantity, and a rough estimate has been made according to the present Taipower records referring to records in Japan.

(iii) The combined load curves are estimated by combining the industrial load curve and the lighting load curve. Estimated combined load curves for December, the representative winter month, and for August, the representative summer month, are shown in Fig's. 3-13 and 3-14.

Peak durations of the estimated load curves for December and August are shown in Table 3-17. Reading at 20% on the load curve, a 5.5 hour and 7.0 hour durations are found for December and August respectively.



Note) Equivalent peak hours

First, the duration curve of the daily load is described as shown in the figure drawn below. The section between Point A and Point O indicates the maximum load (MW).

Second, Point C is placed so that the section between Point A and Point C occupies 20% of the maximum load.

Third, if a straight line is drawn from Point C to Point D horizontally, the duration curve will be divided into two parts; ACD and CDBO.

Fourth, Area ACFE is made equivalent to the rectangular area of ACD. Thus, if energy (MWh) equivalent to Area ACD with peak output equivalent to the section (MW) from A to C is generated, it will be possible to continuously generate energy for T hours indicated with the dotted line of AE. In this case, T hours can be defined as "equivalent peak hours".

Table 3-17 Continuous Peaking Hour

Peaking Part	December	August
15%	3.5	5.0
20%	5.5	7.0
25%	7.5	9.0

(3) Supply Capacity

The supply capability of Taipower at the end of 1966 was 718 MW in hydro and 757 MW in thermal, on a total of 1,475 MW. In response to the steady growth in power demand as described previously, construction of both hydro and thermal plants have been advanced at a high tempo, and among major power stations in operation or scheduled to be put in operation are the gas turbines in Southern Taiwan (101.7 MW) in 1967, Tunghsiao Gas Thermal (60.64 MW) and Linkou Thermal No. 1 (300 MW) in 1968, Talin Thermal No. 1 (300 MW) in 1969, Talin Thermal No. 2 (300 MW) and Lower Tachien Hydro (180 MW) in 1970, Linkou Thermal No. 2 (300 MW) in 1971, the expansion of Lower Tachien Hydro (180 MW) and Tachien Hydro (156 MW) in 1973, and the expansion of Tachien Hydro (78 MW) and a nuclear power plant (500 MW) in 1974.

As a result, it is planned for the total installed capacity at the end of 1975 to reach approximately 4,000 MW, of which hydro being approximately 1,400 MW and thermal and nuclear approximately 2,600 MW. The ratio of hydro and thermal installations is 35% to 65%.

As described above, the structure of supply capacity of the Taipower System will be greatly changed in the next 10 years, and the features of this change are : (i) Large capacity oil thermal plants will be constructed in a rapid succession and the trend of thermal as the main power source and hydro as the subordinate will continue. (ii) The Tachien Hydro Power Station will be developed, and along with the various downstream plants, a large reservoir-type hydro power source will be completed and a large peak capability will be provided. (iii) Nuclear power will be introduced as a base load plant.

(4) KW Balance

(i) Hydro Power Supply Capacity

Broadly dividing hydro power stations into the 3 groups consisting of the river run-off, pond and reservoir types, the transmitting end supply capacity of the driest day of each month is calculated. The driest day in this case is the day which has a daily inflow averaged over the 10 driest days of each month. Supply capacity is calculated as described below

a) River Run-off Type

Average output determined by inflow of the driest day.

b) Pond Type

Output consisting of the average output determined by inflow of the driest day plus regulating capability. This regulating capability is calculated from the effective capacity of pondage and the peak duration hours required by the system load.

c) Reservoir Type

The reservoir type is a power station having a reservoir with regulating capacity of at least one month and is capable of supplying power at maximum output when necessary; therefore, the supply capacity is taken as the maximum output.

(ii) Thermal Power Supply Capacity

Thermal power stations, because of the nature of the facilities, require one month-overhaul every year. When the ratio of thermal power in the entire supply capacity becomes high, the effect of the loss in output due to the overhaul on the supply and demand program, especially on the KW balance, is exceedingly great.

Overhaul of thermal power stations is usually carried out in the wet season when hydro supply capacity is increased or between the winter and

In the Taipower System, it is assumed that February, March, April and May are the months in which demand is relatively small, but so far as could be seen from the records of monthly peak load it was judged premature to arrive at a conclusion. Therefore, thermal capacity during scheduled inspection and repair (MW/month) is based on only monthly fluctuation of hydro power supply capacity due to run-off, and not upon fluctuation in demand. This capacity during scheduled inspection and repair deducted from the total (hydro and thermal) installed capacity indicates the thermal supply capacity at the transmitting end.

(iii) Demand

Monthly peak load will be used.

(iv) Necessary Reserve Capacity

With the great change in the structure of the supply capacity of the Taipower System, or the increase in the ratio of thermal power in the installed capacity, the number of thermal units will be increased to a point where it will be unrealistic to consider the maximum of only 1 unit being out of order. In other words, it will be possible that at one time several thermal units will not be capable of generating full power. In order to cope with this, the number of days of outage in the supply capacity will be estimated by probability calculations, whereupon the necessary reserve capacity for maintaining the required reliability level would be sought.

In determining the necessary over-all reserve capacity and in future studies it is important to keep in mind the influence of run-off conditions on hydro supply capacity, as well as the possibility of under estimating future load.

Since in this study such a detailed examination as described above could not be made, the required reserve capacity is boldly estimated at 16% to 19% of peak load (transmitting end).

(v) KW Balance

As it is assumed that the annual peak load will occur in December, the KW balance for this month is calculated. The results are shown in Table 3-18 with a reserve capacity of 22% in 1976 being slightly above the required amount.

The short peaking hydro capability in 1976 of the pond type including the Kuyuan and Chipan Power Stations will be approximately 330 MW. When the reservoir type Tachien and Lower Tachien Power Stations are also considered as short peaking hydro plants, the total peaking capability will reach approximately 900 MW. Peak duration required of this peaking capability will be about 8.5 hours for December, according to the estimated load duration curve. Therefore, it is estimated that approximately 60% of the dependable capability calculated for a peak duration of 5 hours will be the true dependable capability at the time of start-up. In this case, the B/C of the Li-Wu Chi Project at the time of start-up is calculated as given below.

Initial year benefit = $143.03 \times 10^6 \times 0.6 + 160.07 \times 10^6$
= NT\$$245.89 \times 10^6$

Annual cost	NT\$$199.28 \times 10^6$
Surplus benefit	NT\$ 46.61×10^6

In other words, even when the dependable capability is latent in the initial year, it is seen that the economics of the Project will be adequate. Depending on the method of operation of the reservoir type hydro plant at Tachia Chi, it will be possible to utilize the peaking capability of the power stations in this project even more effectively, while from 1981, regardless of the operation of Tachia Chi, it will be possible to effectively utilize the peaking capability of the power stations of this Project. Therefore, it is thought that the Project will be economical even when developed in 1976 as scheduled.

(5) KWh Balance

Hydro energy supply is taken as the electric energy for a normal water year. Deducting this hydro energy supply from the annual power demand at the transmitting end, the balance is considered as the thermal and nuclear energy supply needed to obtain a simplified KWh balance. The calculation results are as given in Table 3-18. Since the thermal ratio is high, as well as a considerable allowance can be seen in the thermal supply capacity, it may be considered that an ample balance exists in regard to KWh.

Table 3-18 System Load Balance

	1975 (December)	1976 (December)	1977 (December)
Installed Capacity			
Hydro (MW)	1,415.17	1,813.87	1,813.87
Run-of-River	76.17	148.37	148.37
Pondage	131.30	371.30	371.30
Reservoir	1,207.70	1,294.20	1,294.20
Thermal (MW)	2,069.07	2,069.07	2,519.07
Nuclear (MW)	500.00	500.00	500.00
Total (MW)	2,984.87	4,382.94	4,832.94
Dependable Peaking Capability			
Hydro (MW)	1,240.90	1,534.70	1,534.70
Run-of-River	35.60	46.00	46.00
Pondage	125.90	336.30	336.30
Reservoir	1,079.40	1,152.40	1,152.40
Thermal (MW)	2,016.40	2,016.40	2,489.40
Nuclear (MW)	475.00	475.00	475.00
Sub-total (MW)	3,732.30	4,026.10	4,499.10
Maintenance of T. & N. (MW)	-310.90	-310.50	-361.00
Total (MW)	3,421.40	3,715.60	4,138.10
Peak Load Demand (MW)	2,783.00	3,045.00	3,330.00
System Gross Reserve (MW)	638.40	670.60	808.10
System Gross Reserve (%)	22.90	22.00	24.20
Annual Power Generation			
Hydro (GWh)	4,433.60	5,640.70	5,640.70
Run-of-River	422.30	525.80	525.80
Pondage	765.70	1,869.30	1,869.30
Reservoir	3,245.60	3,245.60	3,245.60
Thermal & Nuclear (GWh)	11,915.40	12,245.30	13,919.30
Total (GWh)	16,349.00	17,886.00	19,560.00
Annual Power Demand (GWh)	16,349.00	17,886.00	19,560.00

Fig. 3-10 Actual Load Curve (August)

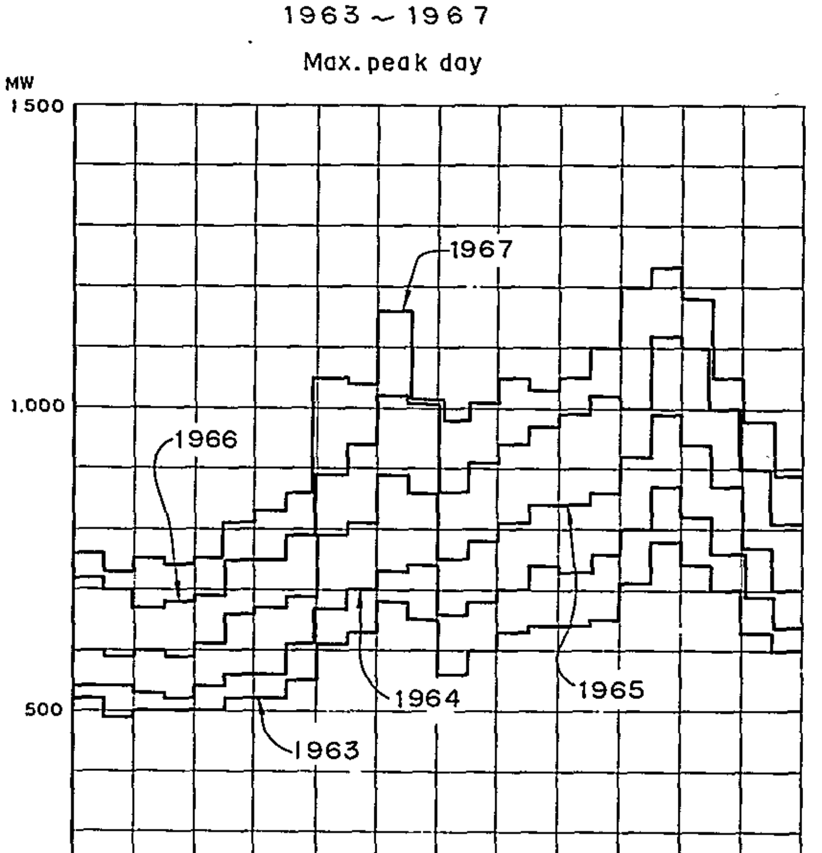


Fig. 3-11 Actual Load Curve (December)

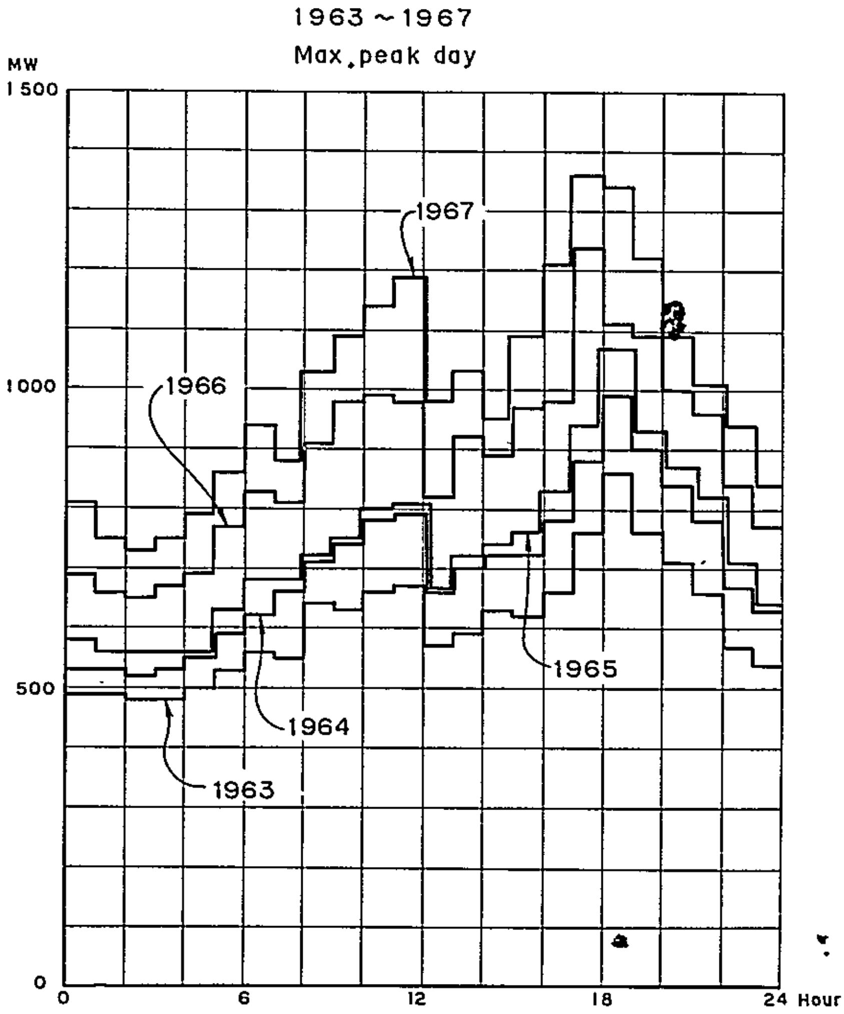


Fig. 3-12 Equivalent Peaking Hours

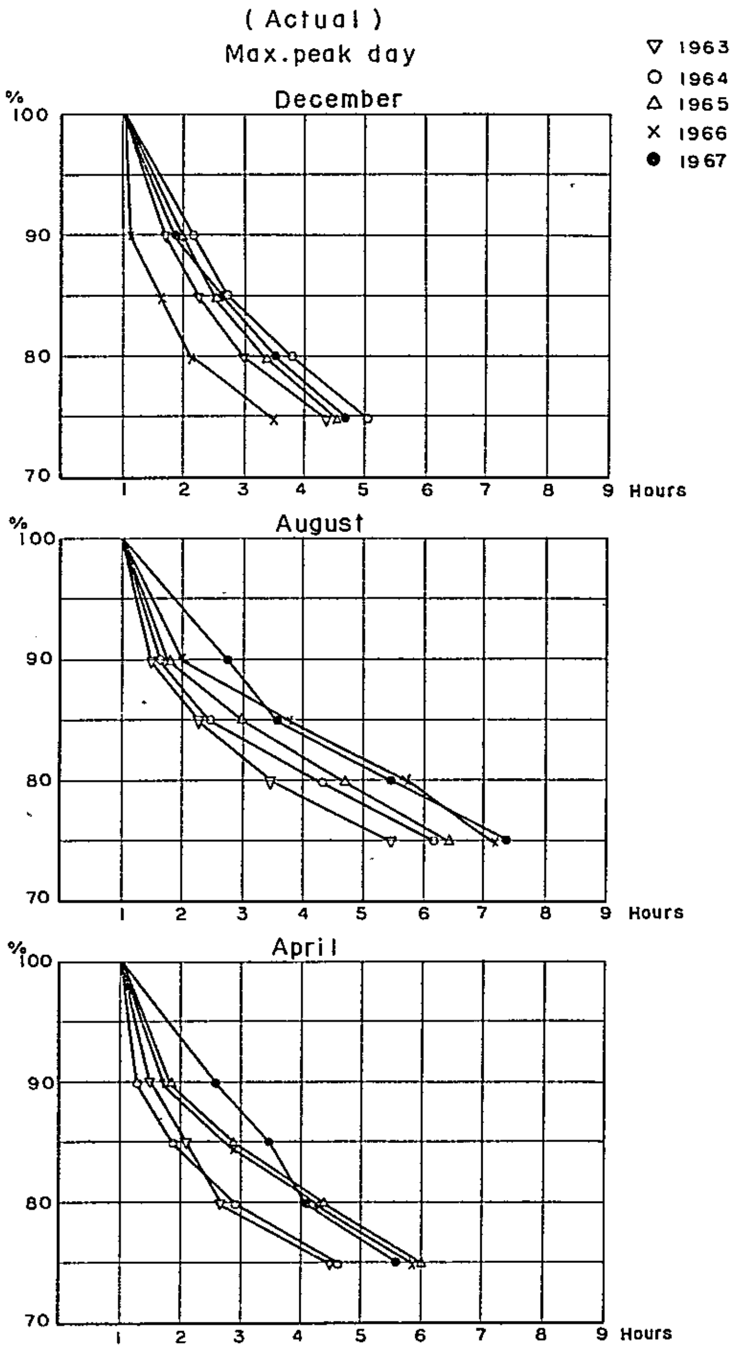


Fig. 3-13 Total Load (1976)
Winter

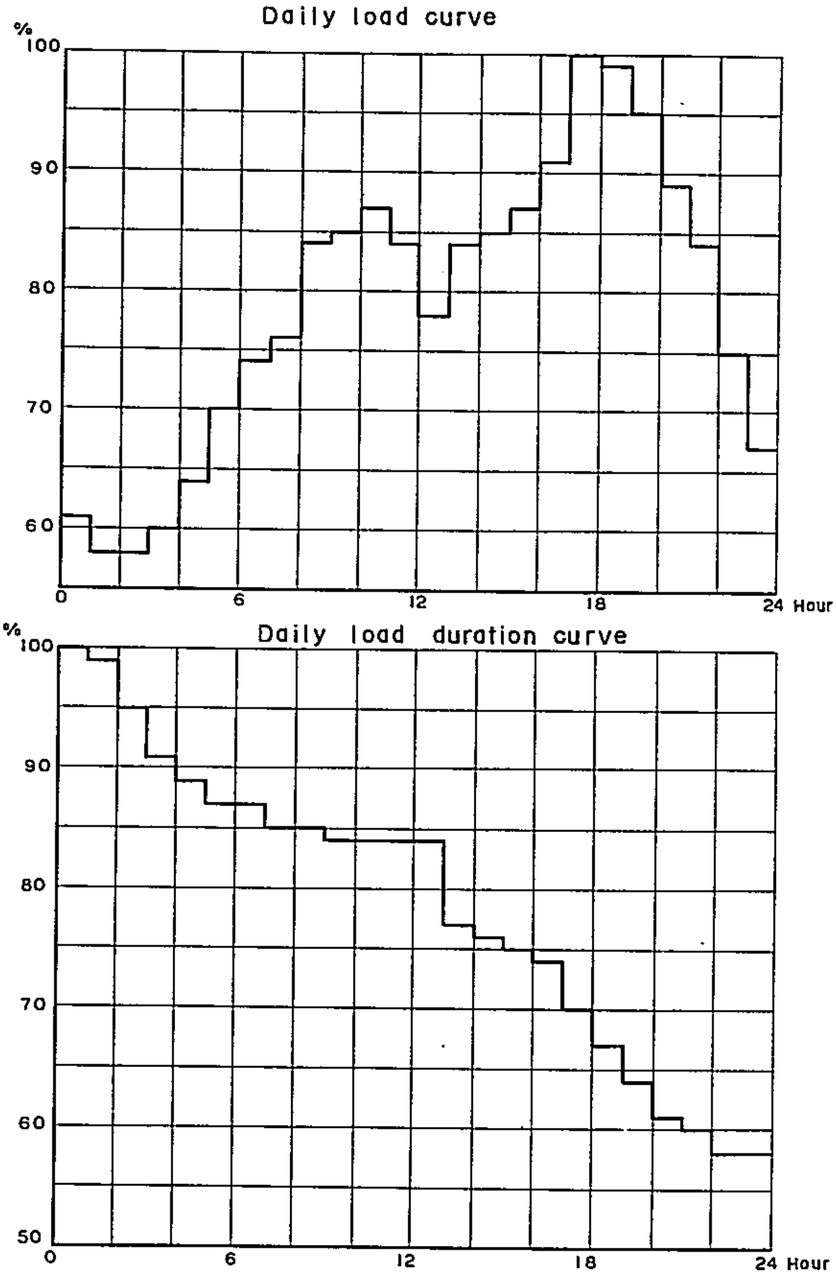
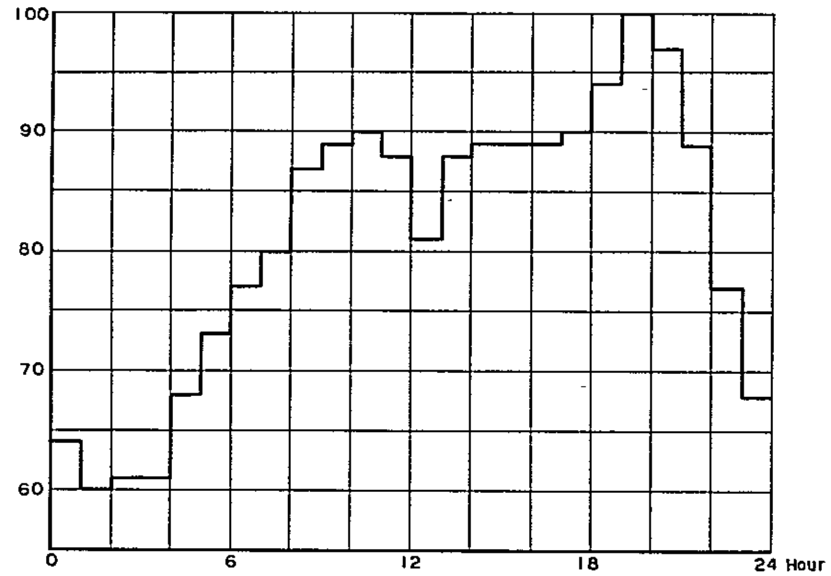
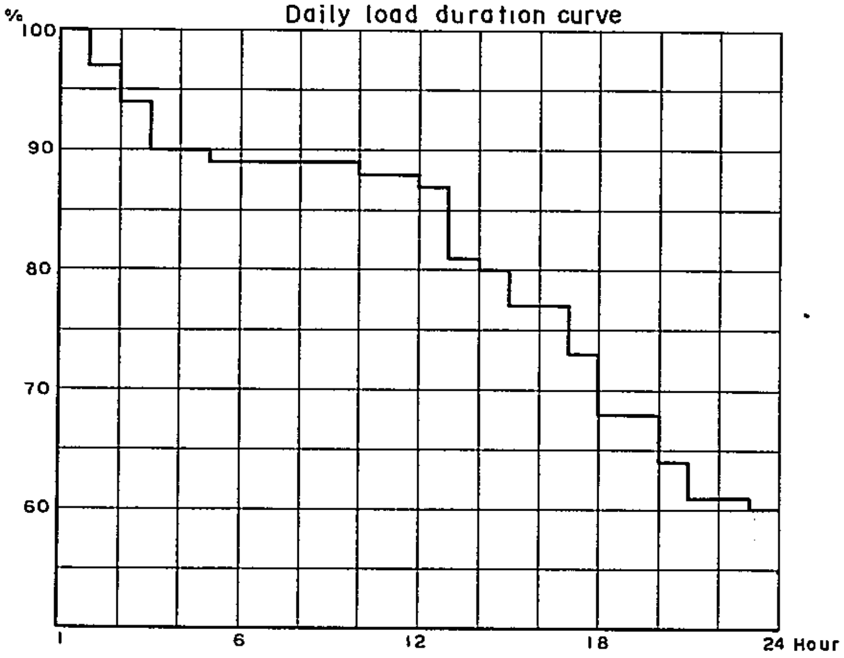


Fig 3-14 Total Load (1976)
Summer

Daily load curve



Daily load duration curve



CHAPTER 4

HYDROLOGY

CHAPTER 4.

HYDROLOGY

4.1 Run-off Gaging Stations and Meteorological Observatories.

The locations and outlines of the run-off gaging stations and meteorological observatories in the Li-Wu Chi Basin are shown in Fig. 4-1 and Table 4-1.

The recording period of the run-off gaging stations and meteorological observatories is short except at the Lushuei Site, and they are located near the East-West Cross Island Highway considering the convenience of transportation.

As shown in Table 4-1, there are 10 run-off gaging stations in operation and they are located near the respective proposed intake sites. However, most of the stations rely on automatic water level recorder for observation because of the unfavorable topography and inconvenient road conditions. Flood water observation is rarely made except at the Lushuei Gaging Station. Daily run-off observation was started in 1957, and the records are available for 11 years up to the present. Other gaging stations have daily run-off records as shown in Table 4-1.

4-2. Precipitation

The precipitation in the Li-Wu Chi Basin is concentrated between the months of April and September by rain fronts and typhoons, and it accounts for approximately 70% of the annual precipitation. Table 4-2 gives monthly average rainfalls and monthly rainy days in the Li-Wu Chi Basin. However the rainfall distribution is varied at each observatory, and it indicates complicated precipitation conditions peculiar to mountanious areas, according to elevation, wind direction and wind velocities.

There are 15 most rainy days on an average in April and May influenced by seasonal rain fronts. Nextly, there are about 13 days a month by typhoons in August and September and there are less than 10 fewest days a month in the winter.

The topography of the Li-Wu Chi Basin is rugged in general, and weathering of paleozoic strata, and landslides and dislocations caused by the geological structure occor at places, so that the growth of trees is not so good. Therefore, the water retention capacity in the basin is poor and the run-off coefficient is

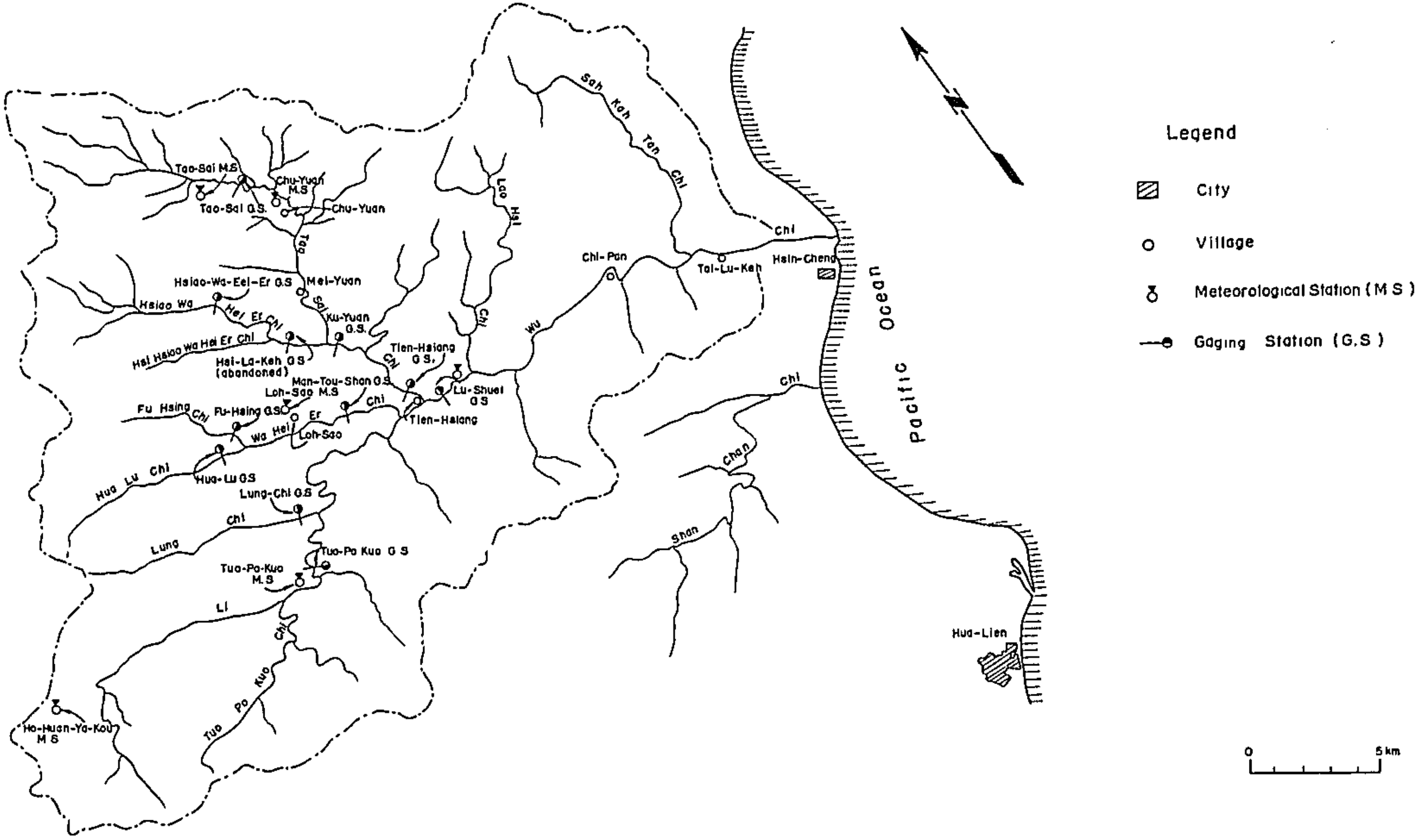
Table 4-1 Run-off Gaging Stations and Meteorological Stations of Li-Wu Chi

Run-off Gaging Stations

Name	Elevation (m)	Drainage Area (km^2)	Date Gaging Began	Basic Data	Remark
Chi-Pan Intake	169	510.1	1955 - 1	Daily Discharge	1959-12 abandoned Calculated from Li-Wu P.S. Discharge
Chi-Pan Upstream	169	509.3	1955 - 8	"	1960-4 Abandoned
Lu-Shuei	379	434.6	1956 - 2	Daily Discharge Flood Discharge	
Tien-Hsiang	425	175.8	1964 - 2	Daily Discharge	
Ku-Yuan	643	152.1	1964 - 9	"	
Tao-Sai	1,233	37.8	1964 - 9	"	
Hsi-La-Keh	826	51.4	1964 - 9	"	
Fu-Hsing	1,205	12.0	1964 - 3	"	
Hua-Lu	1,273	27.1	1964 - 3	"	
Man-Tou Shan	721	51.8	1964 - 9	"	
Chih-En	1,244	18.6	1964 - 3	"	
Tuo-Po-Kuo	1,130	115.2	1964 - 9	"	

Meteorological Stations

Name	Elevation(m)	Date Observation Began	Annual Rainfall	Average (mm)	Basic Data	Remark
Chi-Pan	200	1952 - 1	2,094.9			
Lu-Shuei	430	1956 - 2	2,030.3			
Ho-Huan-Ya-Kou	2,550	1958 - 7	1,943.2			
Chu-Yuan	1,200	1962 - 8	1,731.4			
Chin-En	1,995	1963 - 3	1,737.4			
Loh-Sao	1,110	1962 - 6	1,822.6			
Ku-Pei-Yang	1,250	1965 - 3	2,005.9			
Tuo-Po-Kuo	1,255	1965 - 3	1,803.3			
Tao-Sai	1,500	1968 - 4	-			



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO-JAPAN

TAIWAN POWER COMPANY, TAIWAN REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

LOCATION OF
GAGING STATION

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E.P.D. Consultants) TOKYO JAPAN

FIG 4-1 DATE: AUG 1968

thought to be about 85% to 95%.

4.3 Typhoons

Taiwan is frequently struck by typhoons in summer and the heavy rainfalls accompanied by them are the major cause of floods.

Fig. 4-2 indicates the paths of typhoons obtained by statistical methods. It is distinct that a great number of typhoons land on the east coast of Taiwan, or even if they do not land, many of them pass close by to bring heavy rainfalls.

Since the majority of the typhoons hit the east coast as stated above, the Eastern Area is frequently damaged by them. In these cases, the entire Li-Wu Chi Basin is always in a heavy rainfall area. Table 4-3 gives the rainfall records of the Li-Wu Chi Basin caused by the recent major typhoons.

Table 4-4 gives the monthly probability of typhoons striking Taiwan and according to this the typhoon season is from April to December with the greatest frequency in July to September. The annual average number of typhoons striking Taiwan is 3.7.

Regarding wind velocities during typhoons, the maximum recorded velocity is said to have been 45 m/sec at Hualien according to the reports of the Meteorological Agency, but as the various sites of the Li-Wu Chi Project are all in mountainous areas protected by high peaks, it is thought that wind velocities are comparatively small.

4.4 Run-off

4.4.1 Method of Dealing Run-off

As described in 4.1, there are 10 run-off gaging stations including the Lushuei Gaging Station in the Li-Wu Chi Basin, but recording periods are extremely short with the exception of the Lushuei Gaging Station.

The period of observation at the Lushuei Gaging Station covers 13 years from 1955 to 1967, and daily run-off records are available for the 11 years from 1957 to 1967. However, as for the other gaging stations, the periods in which daily run-off have been recorded are only the recent 2 to 4 years. Moreover, because of rugged topographical conditions, few of these stations are favorably located for run-off gaging, and in addition, some amount of error in gaging records

Table 4-2 Monthly Record of Rainfall

Location: Lu-Shuei (EL. 430 m)

Monthly Record of Rainfall

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	164.0	134.6	142.2	148.0	643.3	725.1	1,968.5	989.3	1,705.5	651.7	814.3	91.9
Min.	5.9	6.5	11.8	3.5	19.0	12.4	23.2	23.2	25.3	3.5	3.9	3.7
Ave.	40.0	60.3	58.2	44.0	133.2	205.0	333.0	335.7	470.2	168.9	133.2	34.5

Monthly Record of Rainfall Frequency (in day)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	20	15	13	16	18	24	13	21	16	18	16	14
Min.	2	6	5	3	4	6	5	6	6	1	3	3
Ave.	8.2	10.3	10.0	9.1	14.2	14.7	9.0	10.8	10.8	7.8	8.6	8.8

Location: Chu-Yuan (EL. 1,200 m)

Monthly Record of Rainfall (in mm)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	216.1	112.7	73.9	111.1	184.9	895.5	901.3	958.4	683.0	490.2	710.9	94.8
Min.	12.6	40.5	19.2	25.3	48.5	169.6	73.6	43.2	74.9	30.2	27.9	21.5
Ave.	69.8	71.7	48.0	58.4	123.0	237.3	295.2	343.4	268.0	234.5	177.0	44.0

Monthly Record of Rainfall Frequency (in day)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	16	10	18	17	18	22	12	20	14	22	16	14
Min.	6	10	4	6	6	10	5	9	9	5	4	6
Ave.	10	10	10	8	14.4	15.6	8.4	13.8	11.7	11.2	11.2	10.8

Location: Loh-Sao (EL. 1,110 m)

Monthly Record of Rainfall (in mm)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	79.8	141.4	100.7	120.2	183.8	470.3	940.8	204.5	167.3	439.7	611.4	118.8
Min.	18.1	61.3	72.3	39.6	89.1	142.6	54.5	35.2	43.3	18.4	23.3	21.1
Ave.	44.8	90.9	83.4	78.9	140.7	282.4	335.4	188.7	108.0	276.6	200.9	56.4

Monthly Record of Rainfall Frequency (in day)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	20	20	18	20	20	24	13	17	17	24	19	21
Min.	11	12	9	13	16	11	7	9	10	8	15	9
Ave.	14.7	15	14	16.3	18	16.7	10	10.5	13.3	15.4	17.3	15

Location: Ho-Huan-Ya-Kou (EL. 2,550 m)

Monthly Record of Rainfall (in mm)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	488.1	310.7	666.0	264.6	317.8	625.7	796.4	761.1	522.9	306.2	457.8	154.6
Min.	32.8	92.2	33.0	11.3	24.4	96.8	71.9	96.4	81.4	9.0	16.7	6.0
Ave.	101.7	136.1	181.8	125.1	174.4	290.3	310.1	311.3	281.4	126.8	126.6	50.1

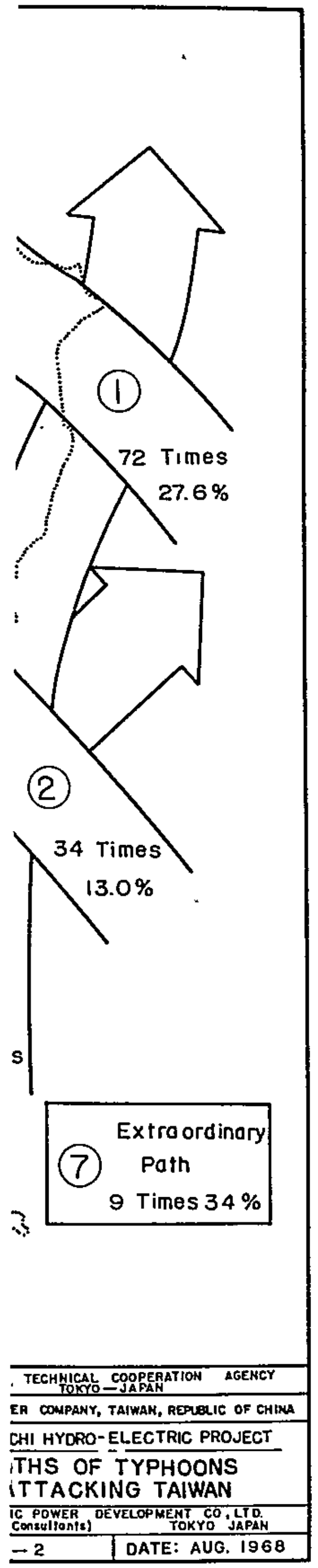
Monthly Reocrd of Rainfall Frequency (in day)

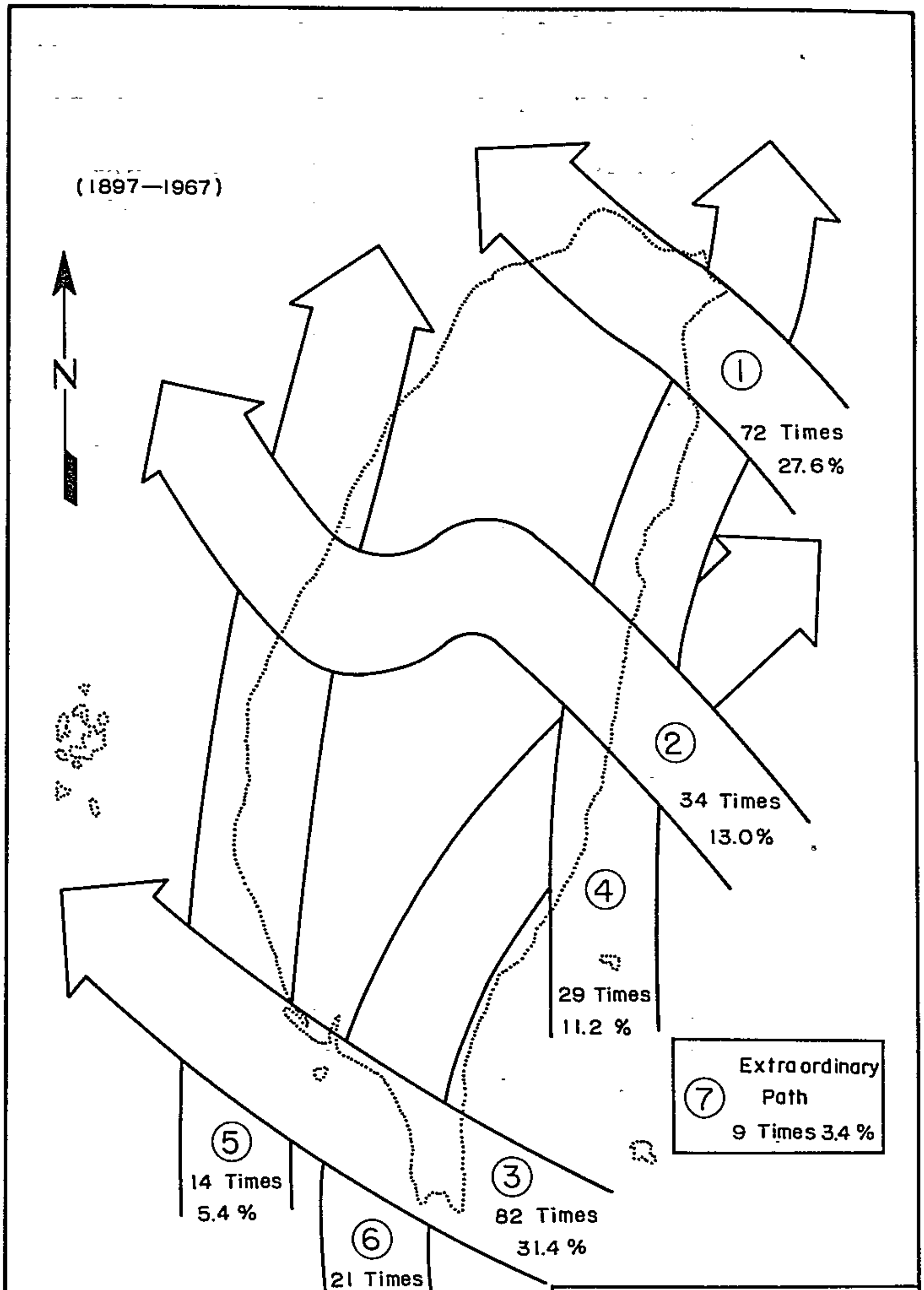
Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	15	19	17	15	21	23	22	22	20	19	16	15
Min.	0	0	6	3	0	11	11	11	6	5	5	4
Ave.	9.9	9.8	10.1	1.1	14.1	18	15.7	16.1	12.6	10.9	10.3	8.1

Location: Chih-En (EL. 1,244m)

Monthly Record of Rainfall (in mm)

Item \ Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Max.	314.6	73.0	104.7	111.0	316.0	729.3	368.0	379.8	403.9	422.4	397.6	77.4
Min.	21.2	26.8	27.3	33.8	29.9	119.0	80.5	51.9	38.9	2.8	9.7	11.8
Ave.	97.2	56.6	68.1	69.8	139.8	298.6	262.0	162.9	185.7	154.9	159.7	44.0





OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO—JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

PATHS OF TYPHOONS
ATTACKING TAIWAN

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN

FIG.: 4—2 DATE: AUG 1968

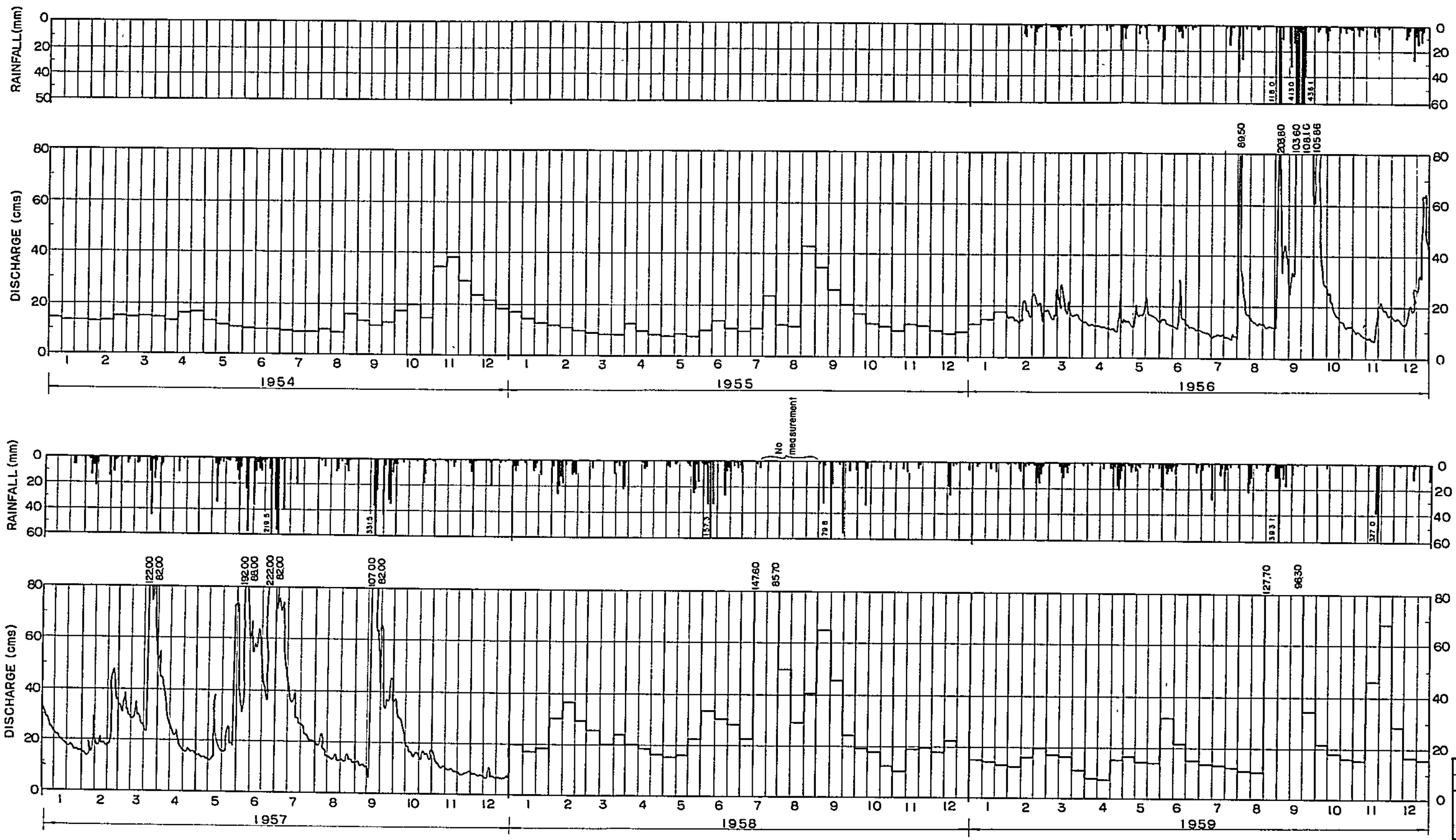
Table 4-3 The Major Rainstorm Recorded at the Meteorological Stations of Li-Wu Chi Drainage

Unit: mm

Gauging Station / Rainy Days / Date	Lu-Shuei 1	Lu-Shuei 2	Lu-Shuei 3	Chi-Pan 1	Chi-Pan 2	Chi-Pan 3	Chu-Yuan 1	Chu-Yuan 2	Chu-Yuan 3	Ho-Huan-Ya-Kou 1	Ho-Huan-Ya-Kou 2	Ho-Huan-Ya-Kou 3
1950- 5-26	423.0	516.0	529.6	475.2	587.4	596.8	-	-	-	96.4	103.3	137.4
1950- 9-11	299.7	481.6	-	365.5	414.5	-	-	-	-	173.8	243.5	-
1951- 9-23	401.2	506.2	507.4	-	-	-	-	-	-	113.8	199.5	200.0
1951- 8-30	451.7	785.8	793.6	316.8	587.9	595.3	345.3	612.7	626.1	264.6	366.3	380.0
1951- 9- 5	289.0	451.3	465.9	327.5	502.0	534.5	325.4	544.2	553.4	219.3	326.3	268.0
1951-10- 3	305.2	586.1	588.8	253.1	361.1	-	335.4	432.1	437.4	192.8	284.9	288.9
1952- 7-16	208.5	291.0	291.7	153.6	306.6	-	156.8	267.1	-	199.3	256.2	270.1
1952- 9-11	68.9	82.3	89.5	144.0	158.4	162.8	157.4	201.1	240.3	165.2	286.6	350.6
1954- 7-14	796.7	904.1	943.1	392.0	462.0	500.0	273.8	315.8	352.2	141.9	227.6	232.7
1954- 7-25	693.1	981.8	983.1	-	-	-	283.5	524.5	525.0	165.2	227.7	227.8
1956-10-18	223.9	445.3	497.1	170.0	295.0	375.0	176.0	258.6	325.1	170.8	254.5	299.7
1956-11-18	511.6	704.1	706.1	350.0	605.0	630.0	371.0	600.3	621.6	166.7	272.9	286.9
Maximal Record	796.7	981.8	983.1	475.2	605.0	630.0	371.0	612.7	626.1	264.6	366.3	380.0

Table 4-4 Statistic Record of Typhoon in Taiwan

Year / Month	1916 ~ 1967 Frequency	Percentage	Annual Frequency
Jan.	0	0	0
Feb.	0	0	0
Mar.	0	0	0
April	2	0.8	0.03
May	11	4.2	0.15
June	16	6.2	0.23
July	63	24.2	0.89
Aug.	82	31.5	1.15
Sept.	59	22.7	0.83
Oct.	20	7.7	0.28
Nov.	7	2.7	0.10
Dec.	0	0	0
Total	260	100	3.66



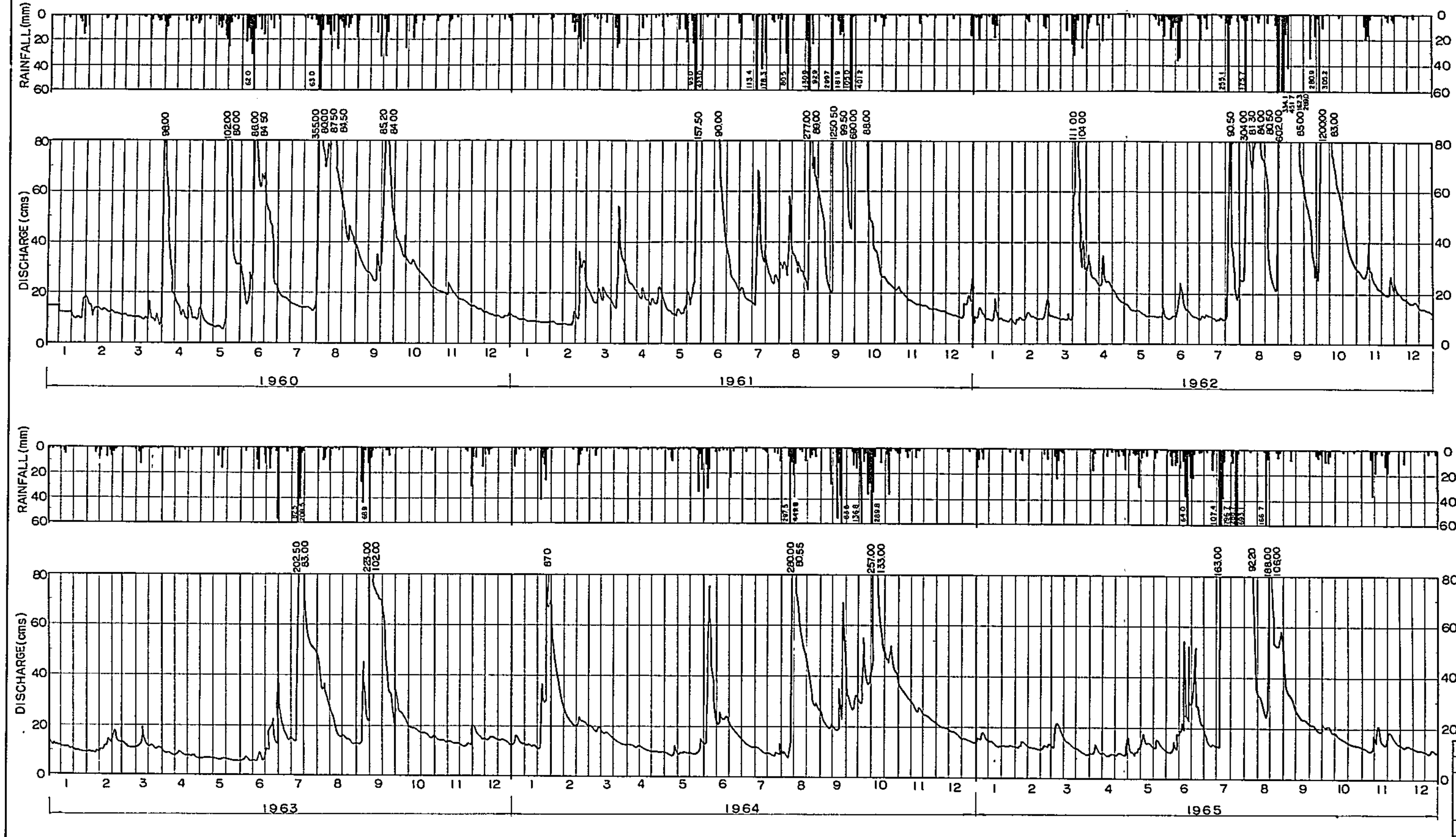
OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO—JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI-WU CHI HYDRO-ELECTRIC PROJECT
DAILY RAINFALL AND DISCHARGE
HYDROGAPH
LU-SHUEI GAGING STATION

ELECTRIC POWER DEVELOPMENT CO., LTD
(E P D Consultants) TOKYO JAPAN

FIG 4-3-1 DATE. AUG 1968



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO—JAPAN

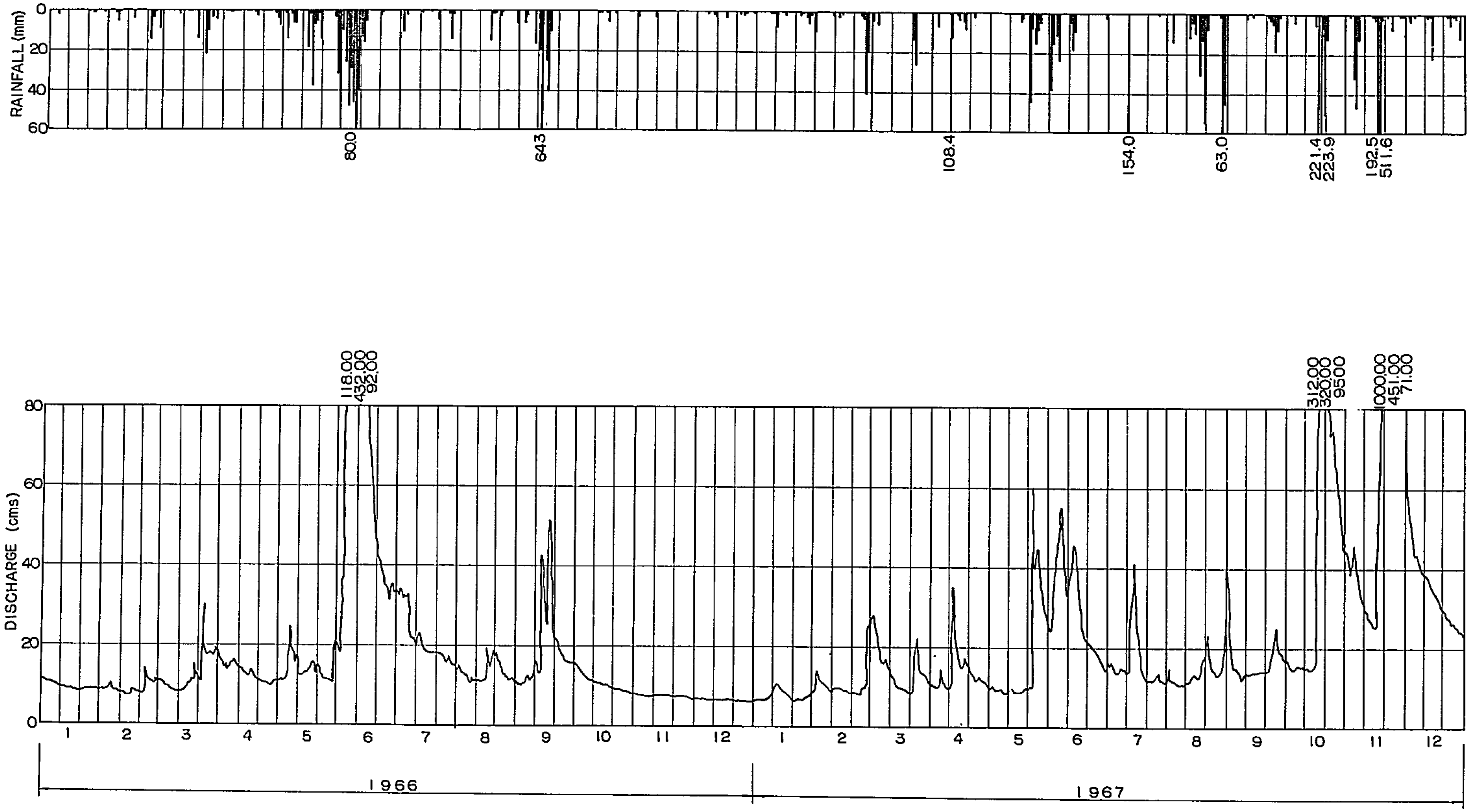
TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI-WU CHI HYDRO-ELECTRIC PROJECT

DAILY RAINFALL AND DISCHARGE HYDROGRAPH
LU-SHUEI GAGING STATION

ELECTRIC POWER DEVELOPMENT CO., LTD
(E P D Consultants) TOKYO JAPAN

FIG. 4—3—2 DATE. AUG. 1968



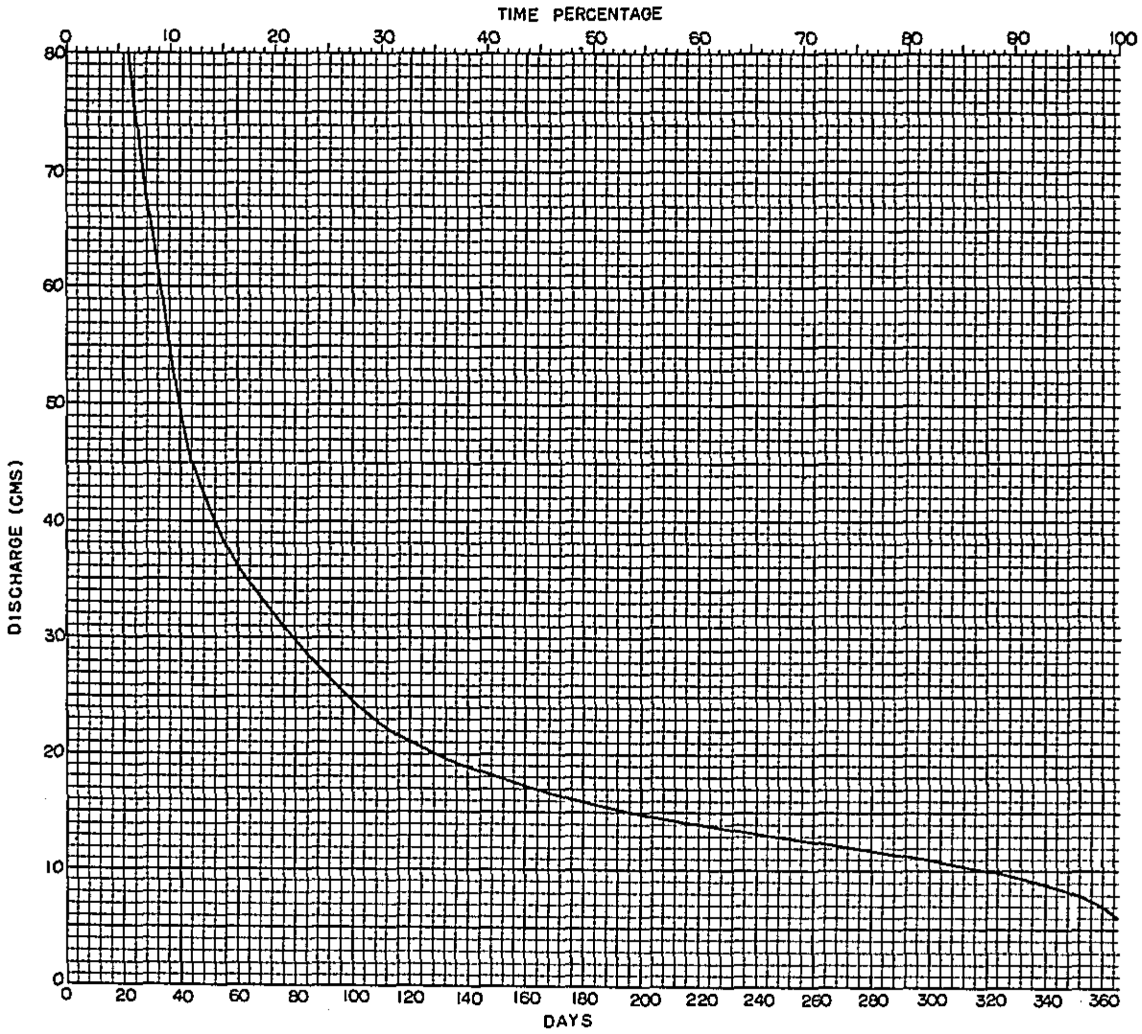
OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO — JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI-WU CHI HYDRO-ELECTRIC PROJECT
DAILY RAINFALL AND DISCHARGE
HYDROGAPH
LU-SHUEI GAGING STATION

ELECTRIC POWER DEVELOPMENT CO., LTD
(E P D Consultants) TOKYO JAPAN

FIG.: 4-3-3 DATE: AUG. 1968



RECORD PERIOD 1954-1967

OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO-JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

DISCHARGE DURATION CURVE
LU-SHUEI GAGING STATION

ELECTRIC POWER DEVELOPMENT CO., LTD
(E P D Consultants) TOKYO JAPAN

FIG 4-4
DATE. AUG 1968

is inevitable due to inconvenient access road condition.

However, the topography and river conditions of the Lushuei Gaging Station are good and Taipower observers are stationed permanently here for run-off gaging. Besides, the measurements using automatic recording apparatus and observations during flood are made, and also considering its central location in the Li-Wu Chi Basin, the Lushuei Gaging Station is designated as the standard gaging station for this Project.

Concerning records observed at the Lushuei Gaging Station (434.6 km^2 of catchment area), there are the periods for which records are missing because of the damage of gaging equipment caused by floods or due to interference by construction work for the East-West Cross Island Highway, but the run-off measurements of simultaneous run-off gaging were made in the neighborhood with extremely good correlations so that the missing parts of the Lushuei Gaging Station can be replenished with these records.

Fig. 4-3 shows the daily run-off and daily rainfall records of the standard Lushuei Gaging Station while Fig. 4-4 gives the series duration curve of this station obtained from 10-day average run-off.

4.4.2 Run-off at Each Intake Site

As stated in 4.4.1, the run-off at each intake site will be determined based on the run-off at the standard Lushuei Gaging Station.

Each intake site at the Kuyuan Power Station is all located on the main stream and tributaries branching in a fan shape considerably upstream of the Lushuei Gaging Station, and each catchment area is different in the topography, flora and precipitation conditions. Therefore, it would be appropriate to use run-off calculated using correlations between the records of these gaging stations established near the individual intake site and Lushuei upon improvement of accuracy and supplementing of records of the former. However, there is a disadvantage in this method of obtaining run-off from a equation when the number of specimens is small as there will be a considerable variation depending on the data to be supplemented.

Table 4-5 shows the equation calculated in the Review Report of 1966 between the gaging stations near the various dam sites and Lushuei Gaging Station, the equation calculated with supplemented data by this Survey Team, and the catchment area ratios to the Lushuei Gaging Station. As seen from this table, the

Table 4-5 Correlation Between Run-off at Individual Gaging Station and Lu-Shuei Gaging Station

Name of Gaging Station	Correlation Formula		Ratio of Drainage Area	Remark
	Proposed	In Review Report		
Tao-Sai Chi	$y = 0.0808x + 0.1836$	$y = 0.100x + 0.03$	0.0867	y = Discharge of individual gaging station,
Hsiao-Wa-Hei-Er Chi	$y = 0.1083x - 0.0130$	$y = 0.105x - 0.173$	0.1183	
Fu-Hsin Chi	$y = 0.0196x + 0.0974$	$y = 0.027x + 0.000$	0.0276	x = Discharge of Lu-Shuei Gaging Station
Hua-Lu Chi	$y = 0.0424x + 0.2668$	$y = 0.063x - 0.160$	0.0624	
Lung Chi	$y = 0.0441x - 0.2443$	$y = 0.033x - 0.017$	0.0428	
Tuo-Po-Kuo Chi	$y = 0.2870x + 0.0177$	$y = 0.196x + 0.313$	0.2651	
Ku-Yuan	$y = 0.3072x + 0.2603$	$y = 0.322x - 0.146$	0.3499	
Man-Tou Shan	$y = 0.082x + 0.4825$	$y = 0.110x - 0.250$	0.1192	

number of specimens are still small at the present and the equations show a considerable amount of variation.

Of the equation determined by the Survey Team, those of the Tuo-Po-Kuo and Man-Tou-Shan sites which were obtained using observation value by run-off gages are $y = 0.338x - 0.959$ and $y = 0.0945x - 0.105$ respectively, and are greatly different from $y = 0.196x + 0.313$ and $y = 0.110x - 0.250$ in the Review Report or $y = 0.2651x$ and $y = 0.1192x$ based on catchment area ratios. Therefore, equations are reobtained using daily run-off records for the two sites. The results, as given in Table 4-5, are good correlation for the Tuo-Po-Kuo Site, but in the case of Man-Tou-Shan, $y = 0.151x - 1.2050$ has been obtained indicating an even more excessively small run-off, and therefore, conversions of the catchment area are made from the correlative formulas of the Hualu and Fuhsing Gaging Stations.

Next, the studies are made on the annual inflow using the equation in Table 4-5. Fig. 4-5 shows the total inflow into the Tuo-Po-Kuo Regulating Pond.

As seen from this, the inflow of the Kuyuan Power Station, especially in the dry season, turn to be great accounting for approximately 20% more than the run-off according to the equation of the 1966 Review Report and approximately 10% more than the run-off obtained by the conversion from the catchment area ratio with the Lushuei Gaging Station. Therefore, since the effective output would be greater in the dry season at the Kuyuan Power Station, for the present, the run-offs of the various intake sites have been determined by conversion from the catchment area ratio with the Lushuei Gaging Station,standing on the more conservative side.

Making the similar study of the various intake sites for the Chipan Power Station, the results is in reverse to the Kuyuan Power Station indicating the smaller amount of inflow obtained by conversions from catchment area ratio. Considering the run-off at the Lushuei Gaging Station the result is that there is an exceedingly great amount of rainfall and outflow in the field of approximately 30 km^2 of catchment area remaining between the Kuyuan Dam and Lushuei Gaging Station. However, the direct catchment areas of the various intake sites of the Chipan Power Station are 412 km^2 in total and it is a difference of only 5% compared with the 434.6 km^2 of catchment are of the standard Lushuei Gaging Station. As there is not much difference in elevation and location, it has been decided that the run-offs of the various intake sites would be calculated by conversion from the catchment area ratio with the Lushuei Gaging Station for the present.

Therefore, the run-off at the intake dam sites for the Kuyuan and Chipan Power Stations is obtained by converting catchment area ratio with the Lushuei Gaging Station at the present, but for a more accurate grasp of the run-offs at the various intake sites, it is necessary to add more records of run-off to the previous records and determine the equation formulaes of run-off with the above additional records.

Fig. 4-5 CORRELATION BETWEEN RUN OFF AT TUO-PO-KUO DAM AND LU-SHUEI GAGING STATION

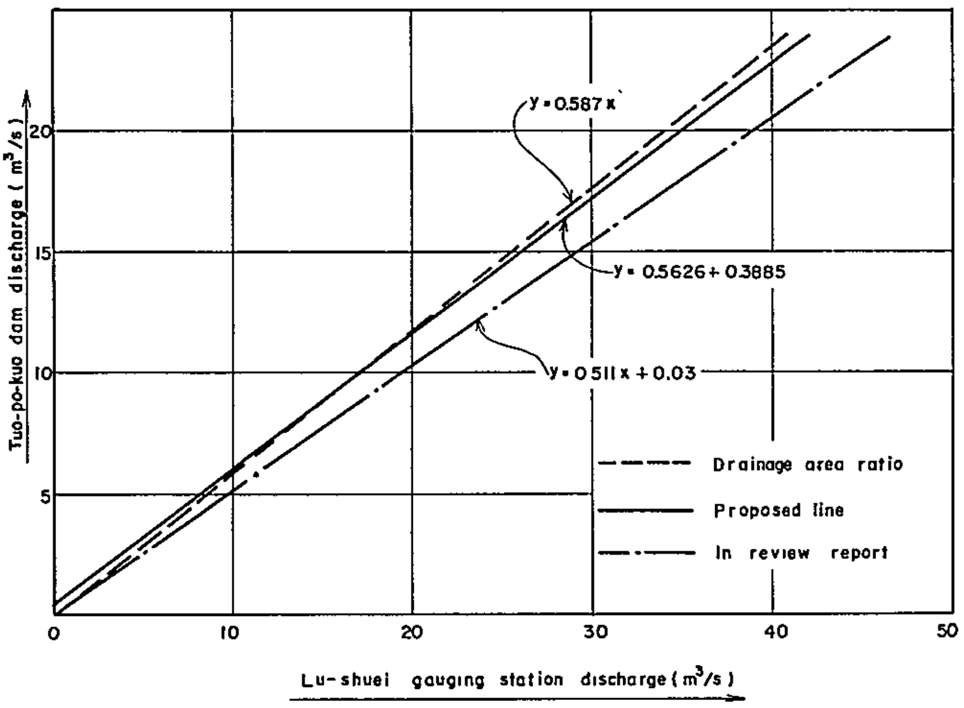


Table 4-6 Yearly Maximum Discharge at Lu-Shuei

Order	Yearly Maximum Discharge (m^3/s)	Date
1	4,120	1967-9-18
2	2,960	1962-9- 5
3	2,470	1965-7-26
4	1,550	1961-9-26
5	1,260	1956-9-23
6	1,030	1959-9- 4
7	700	1958-7-16
8	595	1963-7-16
9	586	1966-6- 8
10	460	1960-8- 1
11	380	1957-6-25
12	350	1964-8- 8

4.5 Flood Discharge

4.5.1 Determination of Flood Discharge

The estimated flood discharge at each intake site will be determined by handling the rainfall at meteorological observatories and the flood discharge measurement values obtained at the Lushuei Gaging Station by a statistical method and computing the 100-year probable flood discharge by probability calculations. Table 4-6 shows the yearly maximum flood discharge at the Lushuei Gaging Station and the maximum flood disxharge was 4,120 m^3/sec (specific run-off : 9.5 m^3 /sec/km^2) of November 18, 1967. The 50-year flood discharge and the 100-year flood discharge at the Lushuei Gaging Station calculated by the Harzen's Method or the Gumbel's Method using the 12 records of the abovementioned table are shown in Table 4-7.

As mentioned previously, since the information is extremely limited under the circumstances where the flood discharge measurement in the Li-Wu Chi Basin has not been performed except at the Lushuei Gaging Station, it has been decided to obtain the 100 - year probable flood discharge at the various dam sites from the daily maximum rainfall records of the last 5 to 9 years.

Table 4-7 Design Flood at Lu-Shuei

Probably Year / Method	50 years	100 years	100 years (Specific Flood)
Harzen's Method	5,300 m^3/s	6,500 m^3/s	15.0 $m^3/s/km^2$
Gumbel's Method	5,300 m^3/s	6,100 m^3/s	14.1 $m^3/s/km^2$

Table 4-8 tabulates the daily maximum rainfalls of each year in the order of quantity. From these values the 100-year probable daily maximum rainfall of each meteorological observatory is obtained according to statistical method (Harzen's Method), and the 100-year flood specific run-off, Q $m^3/sec/km^2$, of each dam site has been obtained considering other elements, such as topography, catchment area, etc. Table 4-9 and Fig. 4-6 show the results of these calculations.

Table 4-8 Maximum Daily Rainfall

(Unit: mm)

(1) Loh-Sai		(2) Chu-Yuan		(3) Chih-En		(4) Lu-Shuei		(5) Ho-Huan-Ya-Kou	
Order	Rainfall	Order	Rainfall	Order	Rainfall	Order	Rainfall	Order	Rainfall
1	345.5	1	371.0	1	270.9	1	511.6	1	321.9
2	326.0	2	345.3	2	223.4	2	449.8	2	264.6
3	250.0	3	283.5	3	214.3	3	436.0	3	199.3
4	186.8	4	242.5	4	175.3	4	423.0	4	196.2
5	90.0	5	157.4	5	122.3	5	393.1	5	173.8
		6	98.9			6	331.5	6	170.8
						7	208.5	7	165.2
						8	183.3	8	138.7
						9	157.3		

Fig. 4-6 PROBABILITY OF DAILY RAINFALL
(Hazen's method)

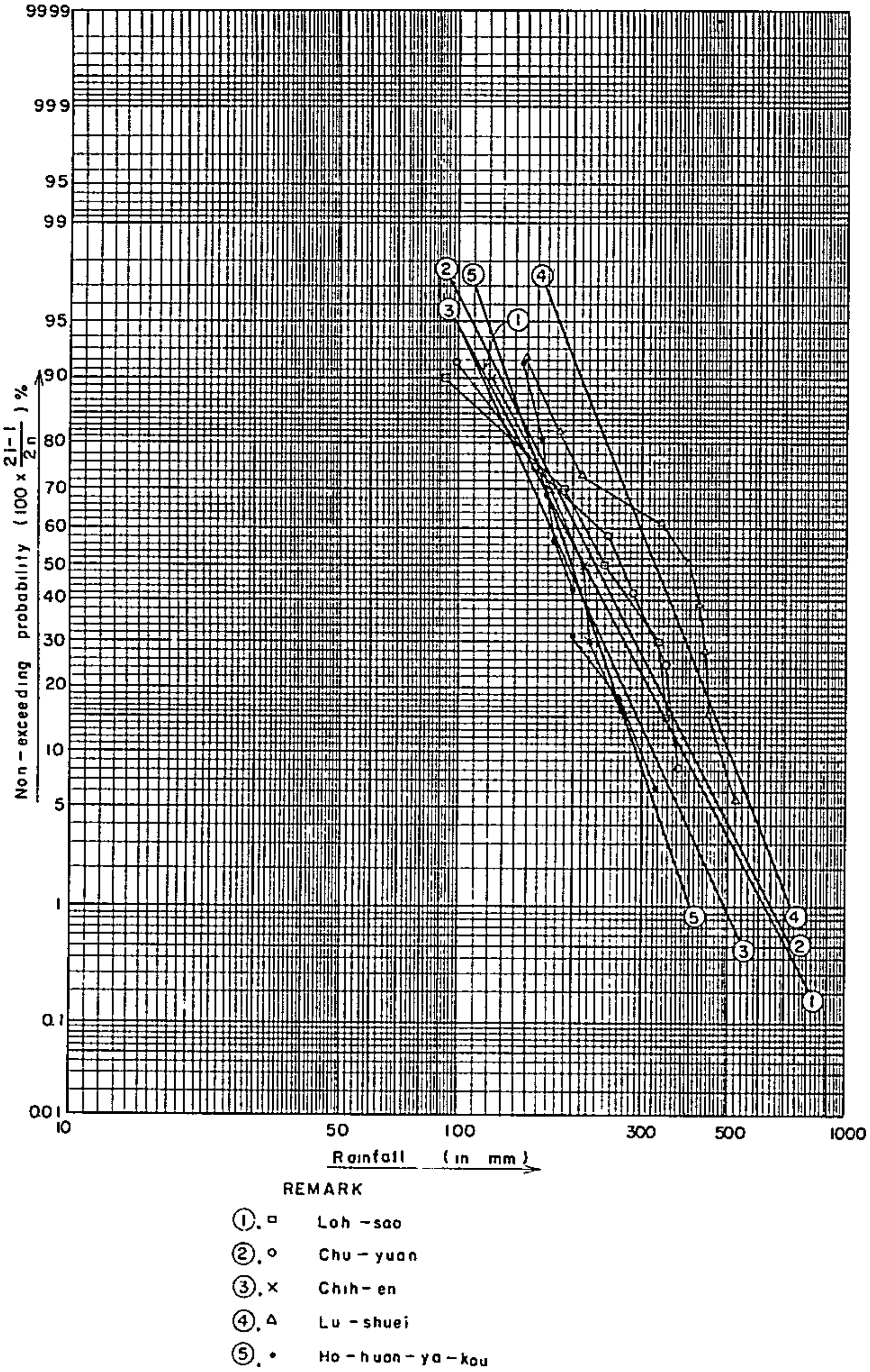


Table 4-9 Calculation of Specific Flood Discharge at Each Dam Site

Location of Damsite	Available Observation Station	Drainage Area (km^2) A	Probable Maximum Daily Rainfall (in mm.) R_{24}	Cofficient of Runoff f	Arrival Time					Intensity of Average Rainfall $r=\frac{R_{24}}{24}\cdot(\frac{24}{t})^{1/2}$ (mm/hr)	Specific Flood Discharge $Q/A=\frac{f.r}{3.6}$ (m^3/s/k^{2}m)
					L (m)	$H_{(m)}$	$\frac{H}{L}$	$\frac{L}{72(\frac{H}{L})^{0.6}}$ (hr)	$t_{(hr)}$		
a Tao-Sai	(2) x 0.8 + (5) x 0.2	53.59	592	0.95	8,000	1,500	0.1875	0.34	1.00	120.80	31.8
b Hsiao-Wa-Hei-Er	same above	39.50	592	0.95	7,000	1,400	0.2000	0.28	1.00	120.80	31.8
c Fu-Hsin	(1) x 0.4 + (3) x 0.4 + (5) x 0.2	12.13	520	0.95	5,500	1,300	0.2364	0.20	1.00	106.14	27.9
d Hua-Lu	same above	27.73	520	0.95	8,500	1,900	0.2235	0.32	1.00	106.10	27.9
e Lung-Chi	(3)	19.29	480	0.95	9,000	1,650	0.1833	0.39	1.00	98.00	25.8
f Tuo-Po-Kuo	(3) x 0.7 + (5) x 0.3	103.40	456	0.95	15,000	1,300	0.0867	1.06	1.06	90.00	23.7
g Ku-Yuan	(1) x 0.3 + (5) x 0.3 + (2) x 0.4	175.60	538	0.90	13,500	2,000	0.1481	0.67	1.00	109.80	27.4
h Wa-Hei-Er	(1) x 0.75 + (5) x 0.25	55.61	565	0.90	13,500	2,500	0.1852	0.58	1.00	115.30	28.8
i Ku-Pei-Yang	(3) x 0.8 + (5) x 0.2	165.49	464	0.90.	24,000	2,800	0.1167	1.40	1.40	80.00	20.0
j Tien-Hsiang	(1) x 0.3 + (2) x 0.2 + (3) x 0.3 + (4) x 0.1 + (5) x 0.1	424.00	571	0.90	31,000	2,100	0.0677	2.59	2.59	72.40	18.1

Note:
(1) Loh-Sao
(2) Chu-Yuan
(3) Chih-En
(4) Lu-Shuei
(5) Ho-Huan-Ya-Kou

The design flood discharge at the Lushuei Site obtained from Table 4-9 is 7,870 m^3/sec. This flood discharge of the Lushuei site obtained from rainfall is found to be approximately 15% greater than the flood discharge obtained by the Harzen's Method which produces a large volume in discharges using probability calculations based on records of flood discharge measurement. The flood discharge measurement at the Lushuei Gaging Station is available for 12 years and much reliable than the probability calculations based on scarce rainfall data.

Therefore, the values of the specific flood discharge obtained from rainfall and decreased by 15% are determined to be the design specific flood discharge of the various regulating pond dam and intake dam sites.

Table 4-10 shows the design flood discharge (the 100-year probable flood discharge) of each dam site.

Table 4-10 Design Flood Discharge Based on Rainfall Data

Name of Dam	Drainage Area (km^2)	Design Flood Discharge Ratio Obtained from the Rainfall (m^3/s/km^2)	Design Flood Discharge of Individual Dam (m^3/s)	Name of River
For Ku-Yuan Power Station				
East Tung Tao-Sai Dam	2.73	27	80	Tung Tao-Sai
Middle Tung Tao-Sai Dam	3.12	27	90	"
West Tung Tao-Sai Dam	3.06	27	60	"
Chung Tao-Sai Dam	6.41	27	180	Chung Tao-Sai
Tao-Sai Dam	37.00	27	1,000	Tao-Sai
Hsiao-Wa-Hei-Er Dam	32.30	27	900	Hsiao-Wa Hei-Er
Hsi-Hsiao-Wa-Hei-Er Dam	7.20	27	200	Hsi-Hsiao-Wa-Hei-Er
Fu-Hsing Dam	12.13	24	300	Fu-Hsing
Hua-Lu Dam	27.73	24	900	Hua-Lu
Lung Chi Dam	18.60	22	400	Lung Chi
Tuo-Po-Kuo Dam	103.40	20	2,100	Li-Wu Tuo-Po-Kuo
For Chi-Pan Power Station				
Lao-Hsi-Chi Dam	20.00	23	460	Lao-Hsi-Chi
Hsiu-Tu Dam	15.00	23	350	Hsiu-Tu
Ku-Yuan Dam	148.01	23	3,400	Tao-Sai Hsiao-Wa-Hei-Er
Man-Ton Shan Dam	53.00	24	1,300	Wa-Hei-Er
Ku-Pei-Yang Dam	159.00	17	2,700	Li-Wu
Hsi-To-Po-Kuo Dam	16.17	17	280	Li-Wu
Tien-Hsiang Dam	424.00	15.5	6,600	Li-Wu

4.6 Temperature, Water Temperature, Humidity and Evaporation

The temperature in the Li-Wu Chi Basin is generally high and the annual mean temperature is around 20°C. However, there is snowfall near the peaks of the central mountain range in winter, and the East-West Cross Island Highway is often closed to traffic. The Highway is also shut down by landslide which takes place along the river when it rains heavily. Therefore, appropriate attention should be paid in this regard during construction work. The records of temperature, water temperature, evaporation and relative humidity of each month near the project site are shown in Table 4-11.

4.7 Sedimentation

There are rockslides and landslides at many places in the Li-Wu Chi Basin because of the topograhical and geological features, and a great quantity of sand and gravel is transported to downstream during the flood. Much of the sediment is considered to be caused by rockslides, and that would not be any direct correlation between sediment volume and run-off.

Fig. 4-7 shows the results of sediment volume measured at the Lushuei Gaging Station. According to this figure, the annual sedimentation at the Lushuei Site is estimated to be approximately 6,000,000 m^3 per year. Therefore, it is necessary to consider that sediment may be deposited to the crests of sand flush sluiceway or spillways immediately after the completion of the dams.

In flushing out the sediment into the regulating ponds or sand sedimentation ponds, it is most effective to operate the sand flush gates for several days when the run-off has been comparatively decreased after a flood in order to avoid sedimentation during the course.

Table 4-11 Meteorological Records at Major Stations

Lu-Shuei Station

Item	Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature (in °C)	Max.	30.0	29.6	35.2	35.5	33.4	36.2	38.0	36.5	37.0	32.6	32.0	29.0
	Min.	2.0	5.8	6.2	9.0	12.4	13.0	16.8	17.6	13.5	9.8	6.5	4.4
	Ave.	13.3	14.6	17.9	21.6	24.6	25.9	27.4	26.8	25.4	23.1	19.8	14.9
Relative Humidity (in %)	Max.	100	100	100	98	97	98	100	96	100	98	100	100
	Min.	47	62	51	55	47	47	41	50	51	47	38	65
	Ave.	88.3	86.5	81.4	76.5	74.4	76.8	73.5	74.7	76.9	74.2	80.7	87.4
Evaporation (in mm)	Max.	62.2	80.3	118.6	193.3	188.4	208.6	255.1	240.4	166.2	154.6	89.4	65.0
	Min.	36.5	30.9	51.8	79.2	54.7	87.6	95.8	92.9	96.8	83.3	58.8	40.8
	Ave.	47.6	55.5	91.9	125.7	120.9	133.6	187.9	169.5	137.9	114.1	67.9	51.1
Water Temperature (in °C)	Max.	16.0	16.5	19.0	21.5	23.2	23.6	24.0	23.2	23.0	21.0	20.0	18.3
	Min.	7.5	9.5	10.5	12.3	13.0	13.0	17.2	17.8	15.0	14.5	12.5	9.6
	Ave.	12.6	13.4	14.7	17.4	17.1	19.7	20.8	20.9	17.9	18.1	16.3	14.1

Chu-Yuan Station

Item	Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature (in °C)	Max.	26.0	26.0	32.0	30.0	31.0	32.0	34.0	35.0	34.0	29.0	29.0	27.0
	Min.	0	5.0	3.0	9.0	8.0	14.0	13.0	14.0	9.0	7.0	5.0	3.0
	Ave.	10.8	12.2	14.5	18.8	21.3	22.9	24.6	24.4	21.8	18.9	16.7	12.1
Relative Humidity (in %)	Max.	100	89	90	90	90	91	91	91	100	94	95	93
	Min.	50	52	44	55	50	46	45	46	51	31	50	44
	Ave.	79.3	77.7	74.7	75.3	71.3	71.3	64.7	65.3	69.3	74.3	77.5	80.0
Evaporation (in mm)	Max.	70.4	81.0	106.7	114.3	123.2	139.1	203.8	187.8	137.3	116.6	83.6	62.7
	Min.	48.7	60.7	76.4	91.6	114.2	89.1	164.5	138.1	117.0	76.5	57.6	43.4
	Ave.	61.2	72.8	96.5	104.8	118.2	114.8	179.3	169.4	128.6	98.6	74.2	56.7
Water Temperature (in°C)	Max.												
	Min.												
	Ave.												

Loh-Sao Station

Item	Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature (in °C)	Max.	26.0	25.8	32.5	28.5	28.5	32.0	34.0	36.5	32.5	31.5	29.0	25.0
	Min.	1.0	4.5	3.5	9.0	9.0	13.0	10.5	14.0	9.0	6.0	5.5	2.0
	Ave.	11.3	12.5	14.9	18.7	20.6	22.8	24.7	24.4	22.0	19.6	16.9	12.5
Relative Humidity (in %)	Max.	100	100	100	99	100	100	100	98	98	100	100	100
	Min.	56	64	48	61	45	48	51	49	50	46	63	59
	Ave.	87.3	85.0	81.7	81.0	78.3	76.3	69.7	72.3	74.3	80.3	83.5	86.0
Evaporation (in mm)	Max.	74.4	64.8	95.0	114.1	113.9	130.4	182.5	196.6	141.2	97.8	72.1	75.3
	Min.	37.0	46.2	79.7	83.8	98.2	81.8	138.4	142.3	112.0	89.2	66.2	34.0
	Ave.	58.9	57.8	86.3	96.5	98.8	105.9	162.8	165.2	123.6	93.2	69.3	53.8
Water Temperature (in °C)	Max.												
	Min.												
	Ave.												

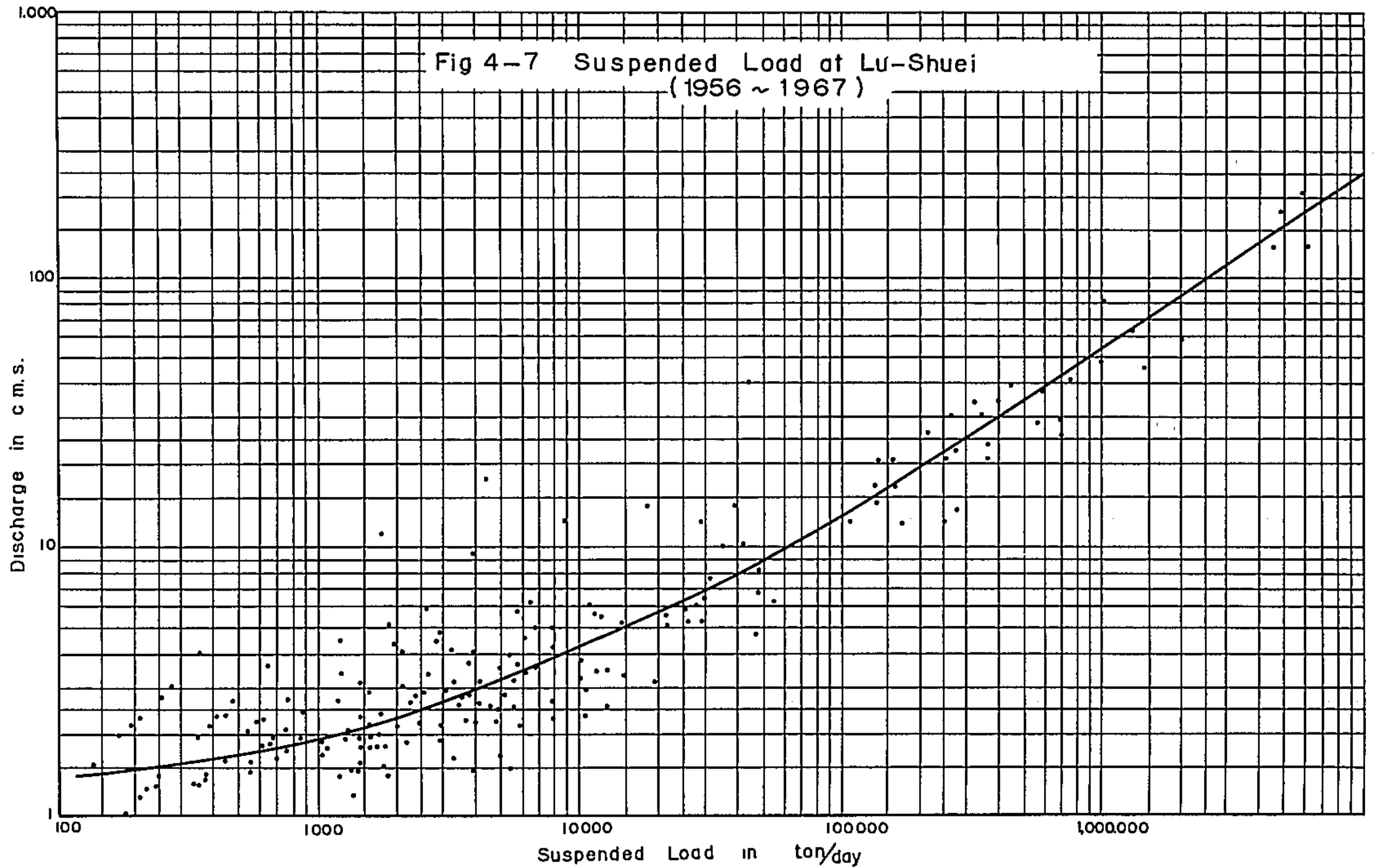


Fig 4-7 Suspended Load at Lu-Shuei (1956 ~ 1967)

CHAPTER 5

GEOLOGY

CHAPTER 5.

GEOLOGY

5.1 Topography and Geology of the Project Area

5.1.1 Topography

Except a part near the estuary, the entire basin of the Li-Wu Chi is of a typical mature stage topography with prominent undulations, and especially, the midstream crystalline limestone area is a magnificent gorge, Tai-Lu-Kuo Gorge, which is rarely seen anywhere in the world where steep vertical cliffs as high as 1,000 m continue for a distance of approximately 17 km. Covering the whole area, prominent upheaval is marked and accompanying it the erosion by the river is severe forming V-shaped river channels for a long distance. Upheaval is seen intermittently and there are many places in the basin where numbers of river terrace indicate eras when upheaval interrupted so that the flat surfaces of the upper terrace can be seen attached to the steep mountain slopes. There are some cases of terrace located in a difference of 500 m in elecation with the present river bed and some terrace deposits are as thick as 200 m. The grade of the river bed is generally very steep being approximately 1/20 on the average, but in the Project Area upstream of Tienhsiang the grade is roughly 1/13. Below Tienhsiang down to Chipan the grade is 1/240. From the estuary to Tienhsiang, there are few large tributaries, but upstream from Tienhsiang, many tributaries are spread out in the dendritic form and the vicinity of Tienhsiang holds the position of the pivot of a fan.

5.1.2 Outline of Geology

The rocks distributed in the Li-Wu Chi Basin are of various crystalline schists formed by dynamic metamorphism and crystalline limestone formed by metamorphism of limestone. These metamorphic rocks are called Ta-Nan-Ao schist and the period of their formation is said to be from the late paleozoic era to the early mesozoic era. In addition, gneiss which was originated later than the said crystalline schists is found in the downstream area.

Black schists are distributed widely upstream of Lushuei in rough alternations with green schist as described below. That is, these black schists and green shcists are mainly distributed at some parts on the Tienhsiang Dam site in

Alternative Scheme I and also parts to the west of this location. These rocks of which the original rocks were mudstone, shale and fine grained sandstone are composed of mica-graphite-quartz schist, graphite-mica schist and graphite schist. Intrusions of quartz vein are frequently found in these rocks, presenting a white and banded appearance. These rocks, when fresh, are sound and hard and offer no problems as foundations for structures, but are susceptible to weathering deterioration. They are also readily changed by faulting and many parts have been altered to graphitic rock.

Green schists are metamorphic rocks such as chlorite schist and chlorite-quartz schist composed of basic volcanic extrusive material and plutonic rock or ultra-basic rock as the original rock, and although there are some massive parts, schistosity is generally well developed. The above metamorphic rocks are all sound and hard, and particularly, the chlorite-quartz schist is sound and hard like siliceous schist. These rocks also become soft and weak when weathered, but in general they have high resistivity against weathering and offer no special problems as foundations for structures.

Siliceous schists are distributed in the vicinity of Hoh-Zan-Ting upstream of Chihmu Bridge and parts of the Hualu Chi. These rocks are composed of siliceous sandstone, chert, siliceous rock and quartz veinlet which have changed into quartzite and quartz schist through metamorphism and have frequently been subjected to later intrusions of quartz veinlets and silicification. These rocks always have interbeds of thin black schist, green schist and crystalline limestone. The rock quality is extremely hard, but schistosity and joint are developed and there are some open cracks..

Crystalline limestones are distributed from the vicinity of Chinheng Bridge to the vicinity of Lushuei on the East-West Cross Island Highway and forms the spectacle of the so-called Tai-Lu-Ko Gorge. Near Chipan, there are intrusions of gneiss to be described later, but there is no marked contact metamorphism. They are white to dark gray and hard, dense and massive. Large solution cavity cannot be seen. Frequently, there are thin layers of siliceous schist, black schist and green schist, but their boundaries are well bonded and cause no trouble. This rock, besides the abovementioned wide area, is also between other schists. The limestone layers in green schist are mostly less than 50 m thick but in the mid-stream area of the Wa-Hei-Er Chi there are about 1 km thick and some lenticular limestones. Gneiss is distributed in the area around Chipan. This is equalgranular, grayish white or grayish brown in color, and frequently has layers of crystalline limestone. The original rocks are, quartz feldspar sandstone to arkose sandstone, and granodiorite. Schistose structure is not very prominent and many parts are massive. Cross joints which are roughly orthogonal to the schistosity are fairly well developed, and whether schistosity or cross joints would be of greater significance from the civil engineering point of view should be observed directly by exploratory adit.

Diabase is a dark green rock which is dense and hard only rarely intruded roughly along schistosities in veinlets of less than 1 m width. However, upstream of the Tuo-Po-Kuo Dam Site there is fairly wide distribution. When this country rock is black schist the contact surface is lightly weakened, but not so in the case of other schists.

Because of the rugged topography and steep river bed grades, the bed rock near the river bed is generally very fresh. Horwever, since the slope of the mountainside is steep, creep phenomena preluding rockslides can be seen in many places.

Of the black schists, graphite schist is easily weathered and altered and is deteriorated into small particles without large blocks and then altered into black clay. The green schists are far more durable against weathering than black schists, but where there has been faulting they have easily been weathered into the clay state. Siliceous schists and gneiss are extremely resistant to weathering and tend to be broken into large blocks instead of becoming clay. Crystalline limestone is also exceedingly durable to weathering and although there are small-scale unconnected solution cavities, there are none of a scale large enough to be of significance from the civil engineering standpoint. There were many places with considerably large amount of water springing from the faces of slopes along the East-West Cross Island Highway, especially between Tienhsiang and Kuyuan. This is probably because the last field survey was carried out at the time of unusual heavy rainfall. These springs are emerged from the irregular cracks in the bed rock. In the Li-Wu Chi Project, since there will be exceedingly great length of extension of tunnels it will be necessary to consider the possibility of encountering sudden springs during tunnelling even where the bed rock is good. As seen from the locations of springs along the highway, the water comes from extremely irregular cracks. Therefore, it is very difficult to presume in advance where spring will be met during tunnelling.

A hot-spring is found at a river bed of the Taosai Chi in Wenshan upstream of Tienhsiang, but since hot water is small in volume and the location is at a considerable distance from the Project Area, it would not be any effect on construction work.

The major geologic structure of the Li-Wu Chi Basin corresponds to the crossing point of the Luhson Arc stretching south-southwest and the Ryukyu Arc stretching north-east, the strike of the strata bends widely from NNE-SSW in the southern part of the basin to NE-SW in its northern part. As the Li-Wu Chi channel crosses this geologic structure, it cuts through almost all layers of the Ta-Nan-Ao schist from the estuary to the Central Mountain Range. Besides the large-scale structure folding from the Luhson Arc to the Ryukyu Arc, there are other well developed minor foldings and interformational foldings.

Near Lohsao there is a synclinal axis running NE-SW, which is called the Lohsao Syncline. Also, there are the Lushuei Fault passing near Lushuei downstream of Tienhsiang and the Shan-Chui-Shan Fault passing near Chiu-Chu-Tan, and they comprise the main structural line within the Li-Wu-Chi Project Area. The Lushuei Fault is located at the downstream portal of the first tunnel below Tienhsiang with a strike roughly N-S and a dip of approximately 50° to the west and is a thrust fault accompanied by a fractured zone of approximately 7 to 15 m. In the middle of February 1968, an approach to the tunnel collapsed due to this fault, and the transportation was stopped on the East-West Cross Island Highway for about a month. The extension of this fault continues to the tunnel of the Chipan Project. The San-Chui-Shan Fault runs to the northeast near the point approximately 300 m downstream of Chiu-Chu-Tan and continues to San-Chui-Shan. This fault strikes N20° E and dips 80° NW or stands vertically. The stratification of the crystalline limestone on the eastern side of this fault dips southeast, but on the western side it dips to the northwest. The thickness of the major fault is approximately 10 m. This fault contains gouge and breccia and is accompanied by fractured zones and minor faults. Including these minor faults, the thickness along the Cross Island Highway is as much as 150 m. There are some of vertical cliffs in outcrops of this fault at the East-West Cross Island Highway with the fault material well compacted and stable. As this fault continues on to the headrace tunnel of the Chipan Project, caution will be necessary in excavating the tunnel.

5.1.3 Deposits

Since the topography of the Project Area is rugged and the rainfall is great, the topsoil is generally thin.

There are several steps of terrace deposits at various places in the Li-Wu Chi Basin and seen flat planes on the top surface of the terrace. At places, there are differences in elevation of approximately 500 m between the highest terrace and the present river bed. The bed rock of the terrace deposits is roughly horizontal in most cases although there are some deposits which have accumulated in V-shaped valleys.

The materials comprising the deposits are flat round pebbles or subangular pebbles of various schists distributed in the Li-Wu Chi Basin enveloped in the matrix of sand and clay. Diameters are almost all between 10 to 20 cm although there are at times some of 1 to 2 m. The deposits are generally well compacted and as seen along the East-West Cross Island Highway, even the faces of almost vertical slopes are stable.

The peiod in which terraces were deposited was at a time when upheaval phenomena of the Li-Wu Chi Basin temporarily stopped and the river meandered over deposited sand and gravel. The present is a period of upheaval with the river bed being eroded and deposits are not being formed. At the period when deposits are being formed, even when the weathering of the bed rock progresses, it is protected by the deposits from being stripped and the bases of river terrace deposits generally remain weathered layers to a considerable depth.

The river bed grade of the Li-Wu Chi is extremely steep and the velocity of the flow is great so that sediment is rapidly transported down to the Pacific Ocean. From the midstream to upstream reaches of the Project Area, the river bed deposits are generally thin, but here and there, where the river is wider, there are fair amount of deposits. From the midstream to upstream stretches of the Li-Wu Chi, pebbles of 20 to 30 cm in diameter are most abundant generally being of uneven particle distribution with little sand while there are a considerable number of large boulders of several meters in diameter. The various schists, other than black schist, crystalline limestone and gneiss tend to form large boulders. Since the rocks distributed in the Li-Wu-Chi Basin are various schists, crystalline limestone and gneiss, the larger stones are massive, but smaller ones are flat and round or sub-angular. In the uppermost reaches, rocks of the Tertiary System from near the Central Mountain Range can be seen.

There are many slides in the Li-Wu Chi Basin of which some are extremely great magnitude. These slides are overwhelmingly numerous at the slope of the Central Mountain Range in the upper reaches whereas at middle reaches they tend to be more numerous in the black schist area. Besides sliding of the bed rock, there are also large scale slides of terrace deposits which are scattered over a wide area.

5.2 General Problems of Design and Construction

The quantity of sediments of the Li-Wu Chi is extremely great and water is muddied dark green by even light rainfall. As previously pointed out, the bed rock underneath terrace deposits is weathered deeply and the terrace deposit and the bed rock underneath slide together. There are many landslides and rockfalls throughout the Basin. Therefore, attention must be paid to design of sand flushing facilities for various structures.

Terrace deposits and degraded deposits change at times to a fluid condition when saturated with water and earthquake force is added. If a great earthquake should occur at a time of heavy rainfall, an incident similar to the case of the Mukua Chi in which an enormous quantity of sediment was carried down and raised the level of the river bed to unusual height can be expected. In 1951, at the time of the great Hualien Earthquake, there were formed more than four naturally dammed lakes in Li-Wu Chi by slides. It is reported that the largest of these dams was as high as 73 m. In view of such examples, in design of various structures it will be necessary to pay attention to damage from floods and sediments transported by them and earthquakes. Especially, the approaches to various tunnels connecting to underground powerhouses should be located as much as practicable at higher elevation than the present river bed.

In the Li-Wu Chi Basin, there are various crystalline schists, gneiss and crystalline limestone. Except the black schist, they have the property of moving into large blocks. When the moving quantities are large, it can plainly be seen that boulders are moving, but when they are small, they are easily mistaken for bed rock. Sometimes it is difficult to discern large boulders from bed rock by boring so that caution will be required.

The rock of schistose structure are anisotropic in the physical and mechanical properties and caution is needed in regard to the relation between the direction in which the structure is installed and the schistose structure. When the rock has been altered and weakened by weathering or faulting, the significance of schistose structure is great. On the other hand, when the rock is fresh, rather than the schistose structure, orthogonal cross joints are at times of greater significance. These points should be confirmed with exploratory adits as it is difficult to estimate the condition from the ground surface.

As briefly mentioned previously, black schist is readily weathered and its nature is easily changed by faulting action and other influences. The altered rock becomes graphitic and swells and moreover tends to slide along schistosity. Although there would be little problem in driving tunnels of small cross section, there would be extremely serious problems in excavation of a large section such as of an underground powerhouse. Therefore, areas of black schist should be avoided in constructing underground powerhouses. They should also be avoided as locations for surge tank.

The strikes of the various schists of the Li-Wu Chi Basin are roughly parallel to the central mountain range in the south , but change to a northeast direction in the north. The headrace tunnel of the Chipan Power Station crosses roughly perpendicular to these strikes, but out of the headrace tunnels of the Kuyuan Power Station, the tunnel to the Lohsao combined tank is roughly parallel to the strikes. Accordingly, in the excavation of the tunnel, the same kind of rock would continue for a long distance and there would be black schist which was mentioned as having problem to continue for a great length. Therefore, it will be desirable for the tunnel to avoid this black schist and go through neighboring green-schist or siliceous schist.

In the Li-Wu Chi Development Project, the extension of tunnels is very long in all of the alternative schemes. Moreover, the topography of the routes are exceedingly rugged. Therefore, it will be extremely difficult to conduct surface geological survey of the entire routes along tunnel center lines. Even should seismic prospecting be carried out along the center lines, the irregularities of the topography are so great that errors in analysis would be increased and reliability would be poor. It is thought that the geological survey by aerophotography is the only way by which the entire routes can be surveyed.

Since sand and gravel deposited along the Li-Wu Chi consist almost all of crystalline schists, the shape of smaller particles are flat. When these deposited sand and gravel are to be used as concrete aggregates, appropriate attention must be paid to this flat shape. The same thing can be said if aggregate is to be quarried and acceptability should be confirmed through aggregate tests. However, the greater part on the station side of the headrace tunnel of the Chipan Power Station is comprised of crystalline limestone and gneiss which are dynamic metamorphic rocks and tend to be more or less flat, but not as much as crystalline schist, and having the hardness, they are thought to be usable for concrete aggregate.

5.3 Geology of Sites of Structures

The geology of the foundation for each structure in Alternative Scheme I to Alternative Scheme V is described below.

5.3.1 Alternative Scheme I, Tienhsiang Upper River System

Alternative Scheme I is a project combining the Tienhsiang Upstream and Downstream Systems and the Chipan Project.

5.3.1-A Tuo-Po-Kuo Dam

(a) Topography

The width of the valley bottom (EL. approx. 1,227 m) is approximately 14 m with the width of the valley at design high water level (EL. 1,251 m) 17.5 m, the valley walls being roughly vertical. The river bed grade in this vicinity is approximately 1/10.

(b) Geology

From the left bank to an elevation of approximately 1,240 m on the right bank is limestone. Higher than this is black schist. The limestone is fresh, massive, hard and sound, but the surface of black schist is slightly loosened. Bedding is generally parallel to the dam axis and the dip is 70° to 90° toward the downstream direction. The crystalline limestone on the left bank and on the lower part of the right bank and the black schist on the upper part of the right bank are contemporaneous heteropic facies, and the boundary is tight so that this is not a fault. This boundary is roughly parallel to the river channel and inclined approximately 50° towards the mountain. There are few joints in the crystalline limestone, but a great many are found in the black schist and the surface is lightly loosened. Upstream of the dam site, there are several faults which are fairly wide, but none exactly at the dam site. The fractured zones of these faults are well compacted. River bed deposits are fairly widely spread at parts upstream and downstream of the dam site where the river is broadened, but only fill the narrow gorge at the dam site to a thickness estimated at 6 to 7 m.

In the project area for the dam, the originally proposed location is the best site because downstream on the right bank there is thick talus while upstream of the sharp bend in the river channel above this site, the left bank above about EL. 1, 240 m is not in good condition due to occurrence of creep. The geology of the river bed at the dam site is not clear due to sand and gravel deposits and requires investigation. The open crack on the left bank side pointed out in the Taipower Review Report (1966) is thought to be a fractured zone of a fault which has been eroded. As the direction of the crack is roughly parallel to the dam axis it is unlikely that it continues on in the downstream direction.

5. 3. 1-B Lung Chi Dam

(a) Topography

The width of the valley bottom at the dam site is approximately 23 m with the valley walls on both sides being close to vertical. The river bed grade upstream of the dam axis is comparatively gentle being about 1/20, but downstream it is about 1/10.

(b) Geology

The left bank is comprised of crystalline limestone, the right bank of green schist and the boundary is at the middle of the river bed. Outcrops on both left and right banks show boundaries to be tightly bonded. The strike of the strata is in the direction corssing the river channel and the dip is 75° in the downstream direction or vertical. The dam axis is running slightly slopewise to the strikes of strata. The rock facies of the crystalline limestone on the right bank are changed to black schistose rock or silliçeous shistose rock extremely rich in lime. In both cases, the bed rocks are fresh, sound and hard and there are few cracks. The thickness of deposits at the river bed is estimated to be 5 to 6 m, but very large boulders are seen and investigations will be necessary.

5.3.1-C Hualu Dam

(a) Topography

The dam site is located approximately 25 m downstream of a waterfall about 10 m high and the river bed is deeply eroded down in a V-shape. The left bank slope is steeply inclined at about 70° while the right bank is gently sloped at approximately 30°. The river bed grade at the dam site is gentle.

(b) Geology

Black schist in good condition is exposed at the left bank, but the right bank is widely covered by talus with the bed rock assumed to be the same black schist as the left bank. The strike of the black schist is approximately N20°E in the direction crossing the river and dips approximately 30° to 50°SE, in other words, toward the downstream direction. There is a fractured zone of approximately 5 m wide from the left bank continuing to the river bed portion and reaching the right bank. At the river bed portion this is narrowed to about 1 m and the fractured zone material is consolidated. As the dam is of small scale, it is thought to be not necessary to treat this fractured zone, but a thorough observation should be made after excavation of the talus.

5.3.1-D Fuhsing Dam

(a) Topography

The lower part of the left bank slope is gently inclined, but from about the proposed dam crest they are a steep walls of approximately 75°. The slope on the right bank is approximately 45°.

(b) Geology

The bed rock is fresh, sound and hard green schist and the strata cross the river flow slantingly N30° E and dip 60° in the downstream direction. There is a fault from the right bank approximately 10 m downstream of the dam axis which crosses the river flow and then runs along the left bank. The strike is N30°E to N15°W and the dip 50° to 60° towards the left bank. The fractured zone of this fault is 0.5 to 1 m wide and is generally consolidated, but some treatment may be necessary depending on conditions found after excavation. The left bank side of the river bed is covered by thin deposits, but the bed rock is exposed on the right bank side for about 10 m from the valley bottom.

5.3.1-E Hsi-Hsiao-Wa-Hei-Er Dam

(a) Topography

The valley bottom at the dam site is very narrow being approximately 4m. The valley wall on the right bank is extremely steep, but on the left bank it is relatively gently sloped. Approximately 35 m upstream of the dam axis there is a waterfall about 10 m high while 2 m downstream of the dam axis there is another waterfall approximately 6 m high. The river bed gradient is steep both above and below the dam site.

(b) Geology

On both banks the river bottom is extremely fresh and sound siliceous schist, but downstream of the dam axis the rock is siliceous green schist. Bed rock is exposed at the river bed and both banks, and there is extremely little deposited material. The strike and dip of the strata are N 60°E and 60°SE respectively. On the right bank the boundary between the green schist and the siliceous schist forms a small fault which has a fractured zone of approximately 15 cm wide.

5.3.1-F Hsiao-Wa-Hei-Er Dam

(a) Topography

The valley bottom (EL. approx. 1,270 m) is approximately 20 m wide with the slope of the valley walls on both left and right banks roughly same at about 60° to 70°. The river bed gradient is gentle upstream of the dam site, but downstream it is comparatively steep. Upstream of the dam site, the river bed is widened.

(b) Geology

On the right bank there are fresh, sound siliceous schist and green schist while on the left bank there is grayish black schist with some surface deterioration. In the deeper parts, however, it is thought to be massive and sound. On the left bank of the river bed there is a thin deposit which is estimated to be approximately 2 to 3 m thick. The strike of the strata is N30°E in a direction crossing the river flow and the dip is about 70° towards the downstream direction. About 50 m upstream of the dam site on the left bank there is a small-scale landslide with talus deposited to the river bed of the same bank.

5.3.1-G Taosai Dam

(a) Topography

The width of the valley bottom is approximately 60 m and the slopes of the left and right banks are approximately 50° and 70° respectively to form a "boat-bottom" - shaped valley and the river bed grade is approximately 1/10.

(b) Geology

The bed rock is black schist with bed rock exposed at the right bank. The left bank is covered with thin topsoil. The strata are roughly parallel to the dam axis and are inclined 35° to 60° in the downstream direction. On the left bank there is a strike fault of N35°E strike and 50°SE dip. The width of the fractured zone is 50 to 80 cm and slightly loosened. River deposits are thick over a fairly wide area. It is necessary to confirm this thickness and the condition of the bed rock.

In the recent Taipower Review Report (1966), a comparison site was selected at a location approximately 100 m downstream of this dam site where the width of the river is narrowed, but there are some doubt that the bed rock of black schist protruding on the left bank may have moved slightly in mass form. In order to confirm this, the topsoil behind the rock mass should be removed to make an examination. Further, on the right bank side at the parts of high elevation, there is a fear that the weathering of the bed rock may be deep. Because of the above, there is some concern that weathering may be deep at the points of high elevation on the upstream side, but the geology of the left and right banks is better than that of the downstream site.

5.3.1-H Tienhsiang Underground Powerhouse and Tailrace

In the vicinity of the underground powerhouse and the various surrounding structures, river terrace deposits are widely distributed and the thickness of the deposits is very great. It is desirable for the river terrace deposits to be unrelated to the various structures and thorough attention has been paid in this regard in preparing Alternative Scheme I. It is undesirable for the foundations of the various structures to be directly on the terraces with the possible exception of substation sites, and at the same time the locations should not be where sliding of terrace deposits may affect the structures. In general these terrace deposits are well compacted and even the cliffs along highways stand up almost vertically. As previously mentioned, if the deposits were water-saturated and a severe earthquake should occur, the possibility of the deposits becoming fluid must also be considered.

The area surrounding the underground powerhouse is estimated to consist of green schist. Green schist is a sound rock into which veinlets of quartz and calcite have been intruded and as the powerhouse is deep underground, the rock is thought to be more fresh and sound. The green schist has also thin layers of siliceous schist, but the latter is even more sound and the bondaries are also tight. The strike of the strata is roughly N40° to 50°E and the dip 40° to 50°NW.

According to the survey data obtained up to the present, there are no large faults passing the vicinity of the power station so that there are no problems in construction of an underground powerhouse. However, since there are schistosities seen in this green schist, in Alternative Scheme I the direction of the main chamber has been determined so that it will be stable against sliding of the schistosity planes. As mentioned before, cross joints will sometime be of significance and thorough studies should be made by means of exploratory adits.

The tailrace on the powerhouse side to roughly the center is mainly green schist while from the center to the tailrace outlet is black schist. The green schist on the powerhouse side has thin layers of crystalline limestone of not more than 10 m in thickness, and since few phyllitic portions are found, the green schist is generally fresh and sound. The black schist distributed on the tailrace outlet side has a fair amount of phyllitic material, expecially near the outlet. A considerable amount of strike fault are also seen in this portion, most of which have widths of not more than 1 m and the fractured zones are generally well compacted. The strike of the strata crosses the tailrace route perpendicularly or slantingly and is N40° to 60°E while the dip is 50° to 60° towards the upstream side forming a regular monoclinal structure. The section crossing the Taosai Chi does not appear to have any geological weakness, but adequate caution is required in excavation of the black schist area.

5.3.1-I Waterway Tunnel

(a) Section between Hualu and Fuhsing

The length of the tunnel in this section is approximately 1,100 m. Generally, the bed rock is mainly black schist, but besides this, from the upstream side, there are siliceous schist of 40 m, green schist of 100 m and the alternations of crystalline limestone and green schist of 100 m in width. As the strikes of these strata are roughly north-south, they form angles roughly of 40° to 50° with the center of the tunnel.

The surface portion of the black schist is brittle and weak and there are many slides while the deeper underground portion, although fresh is thought to be weaker than other rocks. The siliceous schist is massive, green schist calcareous and massive, while the alternations of crystalline limestone and green schist are schistose and frequently have thin layers of black schist. Except the black schist, all of these rocks are generally sound. Most faults are well compacted, but the fault approximately 170 m downstream of Hualu is approximately 10 m wide and soft and weakened.

(b) Section between Fuhsing and Surge Tank

From Fuhsing to the valley running northeast to southeast about 1 km east of Lohsao there is mainly green schist, and from here to the surge tank black schist is mainly distributed. However, the green schist has thin layers of crystalline limestone, black schist and siliceous schist, and in the black schist, there are thin layers of green schist, crystalline limestone and siliceous schist. The green schist and siliceous schist are generally sound, but the black schist is weak in many cases.

There is an anticlinal axis running NNE-SSW through Lohsao and approximately 800 m to the west there is a synclinal axis running parallel. The rocks in the vicinities of these structural lines have been weakened by folding. The strikes of the strata are parallel to these structural lines and cross roughly orthogonal to the center of the tunnel. Faults in this section rarely have fractured zones more than 1 m in width, and moreover, these zones are all well compacted.

The strata and faults of black schist on the surge tank side cross the center of the tunnel almost perpendicularly and form a monoclinal structure inclining about 50° to the west, but there are parts around faults which have been upset due to the effects of this structure. A major fault dividing the green schist and black schist zones is not distrinct as it is covered by talus, but it is assumed to be of a considerable magnitude. Also, about 350 m east of this, a fault is assumed to exist where each stratum is reciprocally inclined in the reverse direction. The fault is also covered by talus so that the size is unknown although it seems to be of significant size. There are fractured zones which are wider than 5 m, but most of them are not more than 1 m and well compacted with few clay.

(c) Summary of Geology of Waterway Tunnel

1. The route from Hualu to the surge tank is roughly parallel to the East-West Cross Island Highway and the center of the tunnels are close to the highway so that the geological features of the tunnels can be estimated to a fair degree by the investigations of the outcrops along the tunnels. However, as the topography is rugged, it is extremely difficult to carry out the investigations along the center lines of the tunnels. Regarding the tunnel on the Tuo-Po-Kuo side farther upstream from Hualu and the tunnels related to the Hsiao-Wa-Hei-Er Chi and the Taosai Chi, it was again impossible to carry out surveys and neither are there survey data up to the present. This is because there are no roads existing parallel to the routes of these tunnels and the topography is extremely steep.

2. As the tunnels of the East-West Cross Island Highway are almost all unlined, the pressure tunnels which are deeper in the rock than these tunnels seem to require less lining, but it seems to be considerable rock pressures in black schist zones and at faults.

3. Between Hoh-Zan-Ting and Hualu, no prominent water springs are found along the East-West Cross Island Highway. However, between Tienhsiang and Hoh-Zan-Ting, there are a great number of springs. This is probably because the difference in elevation between the river bed and the East-West Cross Island Highway is far greater west of Hoh-Zan-Ting than beyween Tienhsiang and Hoh-Zan-Ting. This is probably because the groundwater table is at a shallow depth in the case of the former whereas it is deeper down in the case of the latter. As the tunnels are located deep in the bed rock and thus below the groundwater table, it is assumable that springing of water inside the tunnels may be about the same as that along the highway between Tienhsiang and Hoh-Zan-Ting.

5.3.1-J Surge Tank and Penstock

The center of the surge tank is at an elevation of approximately 1,350 m on the ridge of Hoh-Zan-Ting and the bottom is at an elevation of 1,251 m. This ridge is very narrow, but is covered with thick topsoil and talus. The rare outcrops of bed rock are loosened. However, as the bottom of the surge tank is at the point approximately 100 m vertically down from the surface, it is assumed that a fresh bed rock exists at this depth, and at least from the surface geological surveys, no geological defects as a surge tank site can be recognized.

Although the ground surface of the penstock route is loose or covered with thick talus at places, since the penstock is in a depth, it is assumed that a fresh bed rock may be found and it is thought there will be no speciall problems. The strata consist of green schist, black schist, siliceous schist and crystalline limestone with the strike roughly paralled to the center of the penstock and the dip 45° to 70°NW. Therefore, the penstock and the strata are roughly orthogonal.

5.3.2 Alternative Scheme I, Lower River System.

5.3.2-A Ku-Pei-Yang Dam

(a) Topography

The width of the river bed is approximately 30 m with the slope of the left bank approximately 60° while the right bank is roughly vertical up to about high water level above which a gentle slope of approximately 30° is formed. The river bed gradient is gentle being about 1/200.

(b) Geology

The bed rock is green schist with numerous veinlets of quartz and is fresh and sound. The strata strike N30°E and dip 80° to vertical in the upstream direction. Large faults cannot be seen, but the valley wall on the left bank is loosened to the height of 5 m and there are open joints. The river deposits are about 10 m thick, but this requires further confirmation.

5.3.2-B Man-Tou-Shan Dam

(a) Topography

The gorge of about 8 to 12 m in width with both banks standing vertically continues for about 110 m near the dam site. The dam is located near the upstream end of this gorge. The river bed gradient of the gorge is about 1/25.

(b) Geology

The bed rock is a white crystalline limestone and massive and extremely fresh and sound. This rock contacts green schist approximately 40 m upstream of the dam site. The boundary running N30°E is almost parallel to the dam axis and inclined approximately 60° to the upstream side. The surface of the boundary is generally tight, but on the left bank side there is some springing of water from this surface. There is a fault about 15 m downstream of the dam axis with strike of N25°E and dip of 60° NW and fractured zone from about 10 to 150 cm wide, but since the fault is fairly well compacted and at some distance from the dam, there probably is no direct effect on the dam. The thickness of river deposits is thought to be extremely small.

5.3.2-C Kuyuan Dam

(a) Topography

The width of the valley in the vicinity of the dam site is 15 to 20 m with the left bank slope of approximately 60° and the right bank close to vertical.

(b) Geology

The base rock at the river bed portion and the left bank is green schist while at the right bank it is calcareous green schist with a thin layer of crystalline limestone of about 4 m in thickness. Fresh, sound bed rock are widely exposed over the entire dam site, and here and there are thin top-soil layers or river deposits. The ground strata cross the dam axis slantingly with the strike N20° to 30°E and the dip 80° or more to the upstream side. The boundaries with the crystalline limestone are generally tight, but the boundary of the foot-wall is a fractured zone of 10 to 30 cm wide. However, this is also well compacted and offers no problem. There should be no problems regarding the foundation even if the elevation of the dam should be as high as about 700 m. Since the slope on the right bank is unstable, there may be danger of sliding in the rainy season. Therefore, it is desirable for the location of the dam to be as upstream as possible like the site originally proposed or even farther upstream.

5.3.2-D Lower River System Power Station and Headrace of Alternative Scheme I

The power station is used in common with the Upper River System and has already been described. The surge tank and the penstock are located in schist mainly consisting of green schist and the strike of the strata and the center line of the penstock are roughly orthogonal. The geology is similar in general to that of the Upper River System.

Survey has not been completed regarding the headrace tunnel, but according to the geological map on the scale of 1 : 50,000 which was drawn by 'Taipower, there are green schist, black schist, crystalline limestone and silliceous schist along the tunnel route. Green schists are found predominating among them. The center of the tunnel and the strata cross at about 30° to 60°. Therefore, the conditions are favorable, differing from the strata to the combined tank of the Tienhsiang Upper River System.

5.3.3 Chipan Power Station of Alternative Scheme I

5.3.3-A Tienhsiang Dam

(a) Topography

The width of the valley bottom is approximately 50 m and the valley wall on the left bank side slopes gently up to the East-West Cross Island Highway above which the inclination is increased to approximately 60°. The right bank is a steep cliff of about 80°. The river bed gradient is approximately 1/16 and the flow channel snakes around huge boulders over the river deposits.

(b) Geology

The bed rock is black schist with quartz veinlets and schistosity is well developed. The strike is roughly N40°E and the dip is approximately 40° in the upstream direction. There are 2 faults on the left bank side with fractured zones of 10 to 30 cm width. These faults are joined on the face of the slope at 10 m of the East-West Cross Island Highway and continue together upstream. On the right bank about 5 m upstream of the dam axis, there is the fault which has a fractured zone approximately 1 m wide, with the strike of N50°E and dip of 80° NW and the boundary is formed between black schist on the downstream side and the alternations of green schist and black schist on the upperstream side. This fault cuts across another fault about 20 to 50 cm wide which has a N-S strike parallel to the river channel and the dip of approximately 40° into the mountain. The abovementioned fault forming the boundary between the black schist and the alternations of green schist, and black schist has a cavity near the river bed for the reason that fault material has been gouged out, but it seems that the deeper parts are filled. However, depending on the conditions after the excavation, some treatment may be necessary. The thickness of the river deposits is thought to be from 5 to 6 m, but caution should be exercised not to mistake boulders for bed rock. Further, the geology of the bed rock underneath the deposits must be confirmed in the future.

5.3.3-B Pressure Tunnel

(a) Section between Intake and Vicinity of IP-1 (See Dwgs. 18 and 19).

Black schist is distributed over the greatest length, but there is green schist near the intake and siliceous schist is distributed in the section of approximately 150 to 850 m downstream of the intake. The strike of the strata and the center line of the tunnel cross at angles of 45° to 80° and the dip is 40° to 60° in the upstream direction. Microfolding is developed in the black schist which shows strong characteristics of exfoliation and is brittle and weak. There are numerous strike faults parallel to the strata which therefore cross roughly perpendicularly with the center of the tunnel. The most prominent of these faults is the one called the Lushuei Fault which forms the boundary between black schist and siliceous schist at the downstream portal of the tunnel between Luhsuei and Tienhsiang. The strike of this fault is N-S and the dip 50° to the west. The width of the fractured zone is approximately 10 m and sliding is readily caused by rainfall.

(b) Section between Vicinity of IP-1 and Point 800 M Downstream of IP-3 (See Dwgs. 18 and 19)

Although there are some green schist or black schist found locally, the rock is mainly massive crystalline limestone which is exceedingly fresh and sound. There is a slight schistose structure and the strike is roughly NE-SW and the dip NW, but approximately 1 km downstream of Chihmu Bridge, there is an anticlinal axis in the NNE-SSW direction, and the strike of the strata further downstream or to the eastern side is N-S or almost at a right angle with the tunnel center while the inclination is to the downstream side. The largest fault is the Shan-Chui-Shan Fault and its major fault is approximately 1 km upstream of Chihmu Bridge. This major fault strikes NNE-SSW, dips approximately 80° in the upstream direction, and crosses with the tunnel. There are fractured zones 5 to 10 m wide on the hanging wall side and another approximately 6 m wide on the foot-wall side, and in between, there are two lines each of approximately 5m wide fractured zones and 5 to 25 cm wide fault clay. These comprise a broad fault zone 60 to 100 m wide. However, as can be seen at the face of the slope of the East-West Cross Island Highway, the zone is generally well compacted and rainfall does not easily cause it to slide. Between this major fault and the downstream Chihmu Bridge, there are what are thought to be minor faults. The strike is roughly N60°E and the dip 50° to 70°NW and, like the major fault, this also crosses with the tunnel. Fractured zones of 1 to 3 m in width are found at 20 to 50 m spacings and the rock between the small faults is phyllitic and is disturbed. These minor faults also comprise a broad fault zone which is 70 to 150 m wide. However, similar to the major fault, these are well compacted and the slope along the highway has not slided.

(c) Section between Point 800 M Downstream of IP-3 and Chipan Underground Powerhouse Further Downstream (See Dwgs. 18 and 19)

The rock in this section is almost all gneiss, but there is a layer of crystalline limestone about 100 m wide in the middle. The gneiss shows a slight banded structure but is generally massive and sound. There are joints parallel to the bands and others which are orthoronal, and which are predominent depending on the location. Locally, there are also places about 20 cm thick which are extremely schistose. The crystalline limestone is stratified in approximately 10 cm thickness and is sound and hard. As the gneiss is an intrusive rock body, the contact surface with the crystalline limestone is tightly bonded and sound.

5.3.3-C Surge Tank and Penstock

Detailed surveys are incomplete, but according to the geological map on the scale of 1 : 50,000 prepared by Taipower, the rock is gneiss.

5.3.3-D Chipan Underground Powerhouse

The exploratory adit has been excavated by Taipower at the location approximately 500 m upstream of the existing Chipan Dam for the purpose of investigating the geology. According to this, approximately 40 m of the surface portion is talus and deeper inside to 60 m gneiss of not very good quality while further inside good gneiss, but at around 95 m there is a fractured zone. The site proposed for the powerhouse is estimated to be good gneiss, but as the surface portion is not satisfactory because of the thick talus, another exploratory adit is now being driven approximately 400 m upstream of Chipan Dam for comparison which, as of May 1968 has reached the depth of 55 m. According to the informations from Taipower up to about 25 m there is slightly cracked gneiss, but deeper inside very sound gneiss in good conditions. Judging from this second adit, it appears that the geology of the location now being excavated is better than the beforementioned upstream location as a powerhouse site, but it is necessary to proceed with excavation of the second adit to the powerhouse site for actual examination and confirmation. In this case, although faults are of course important, schistosity and cross joints traversing the schistosity must be given close attention.

5.3.4 Alternative Scheme II

This scheme corresponds to Alternative Scheme I from which the Tienhsiang Lower River System has been excluded and there are no structures which require an additional description.

5.3.5 Alternative Scheme III

This scheme proposes to conduct the waters of the Tienhsiang Upper River System of Alternative Scheme I to Kuyuan Underground Powerhouse to generate power and also to conduct the waters of the Tienhsiang Lower River System of Alternative Scheme I to Kuyuan Regulating Pond and upon combining the water, conduct it to Chipan Power Station for power generation.

Regarding Kuyuan Underground Powerhouse, although topographical maps were available for Kuyuan Dam and the reservoir, there was none for the vicinity of the powerhouse location and a geological survey was made by foot measurements utilizing the topographical map of the reservoir. At the point approximately 350 m on the Hsiao-Wa-Hei-Er Chi from its junction with the Taosai Chi, there is a boundary between black schist and green schist. The strike is N45°

E and the dip 50°W. As previously described, black schist is not satisfactory for an underground powerhouse and green schist nearer Kuyuan Dam is better. The strike and the dip of the schistorsity of this green schist are N35°E and 70°W respectively, but the rock is sound with few cracks and the schistose structure is not very prominent. Crystalline limestone layers about 4 to 5 m thick are sandwiched in this green schist and the boundaries with the green schist are sometimes disturbed in fault-like manner. The form of the crystalline limestone is also irregular. The results of the surface geological exploration reveal no basic problems for an underground powerhouse in this green schist zone and the conditions are satisfactory. However due to considerations of the boundaries with the crystalline limestone, joints and schistosity, a final decision on the location and the direction of the underground powerhouse should rest upon data obtained from the exploratory adit.

The location of the tunnel line from Loh-Sao Combined Tank to the surge tank is slightly different from that of the tunnel line described in Alternative Scheme I. However, it is believed that no notable difference with the geology proposed in Alternative Scheme I is found because the said center line intersects at the same angle as that of the center line in Alternative Scheme I. The boundary between black schist and green schist was assumed according to data obtained from geological surveys, and it was decided for the surge tank to be located inside green schist. Since the ground surface of the surge tank might be covered with terrace deposit, it is recommended that adit exploratory survey be made in addition to the geological investigation of the terrace deposit. Although in a plane, the center line of the penstock is roughly parallel to the strata, the penstock can be inclined slightly slantwise with the strike of strata. It is also expected to almost penetrate into green schist, but some portions of crystalline limestone might be found locally.

5.3.6 Alternative Scheme IV

This scheme consists of the combination of conduction of the waters of the Tienhsiang Upper River System in Alternative Scheme I along the right bank of the Li-Wu Chi to the underground powerhouse for power generation and the Chipan Project of Alternative Scheme I, and two intake sites on the right bank side of the Li-Wu Chi are added to the intake sites of the Tienhsiang Upper River System of Alternative Scheme I.

Surveys of the intake sites are incomplete, but according to the geological map on the scale of 1 : 50,000 prepared by Taipower, the intake sites on the Tuo-

Po-Kuo side are in green schist while those on the powerhouse side are in siliceous schist. Tge underground powerhouse site is also in siliceous schist. According to surface reconnainssance and the above information, it is considered that there is no basic problems of geology regarding the under ground powerhouse.

5.3.7 Alternative Scheme V

This scheme is a combination of conduction of the waters of the Tienhsiang Upper River System of Alternative Scheme I to farther south than the Taosai tributary, adding water from 6 intake sites to generate power at Chipan and the Chipan Project of Alternative Scheme I. Of the various structures, the additions to those of the Tienhsiang Upper River System of Alternative Scheme I are the six intake dams and the extension of the tunnel. Although there are geological maps on the scale of 1 : 50,000 as survey information, they are not much useful regarding it. Inferring from the geological map, the half of the tunnel near the Taosai side mainly comprises of black schist and green schist. The center line of the tunnel is roughly perpendicular to strata. The remaining half on the powerhouse side is composed of crystalline limestone and gneiss. Consequently, there exists no remarkable difference with the geology of the tunnel between the Tienhsiang Dam and proposed Chipan Powerhouse.

5.4 Aggregates

(1) Junction of Taosai Chi Tributary

Deposits are widely distributed and the thickness is estimated to be 4 to 5 m. As the rocks are various schists distributed upstream of this location, smaller particles are mostly flat. The diameters are unevenly and there is little fine sand.

(2) Upstream of Tuo-Po-Kuo

The deposits are on the left bank of the main stream approximately 1 km upstream of the dam site. The thickness is estimated to be 3 to 5 m and the surface is covered with shrubs and trees. The rocks are consisted of various schists distributed upstream with most smaller particles being flat or spindle-shaped, but there is a considerable amount of sub-angular pebbles. Diameters are mostly 15 to 20 cm, but the particle-size is irregular and there is little sand.

(3) Estuary

Near the estuary of the Li-Wu Chi there are great quantities of sand and gravel with a considerable amount of pebbles and high content of sand. The rocks are consisted of various schist groups, crystalline limestone and gneiss distributed along the Li-Wu Chi. As in the case of the other sites, a great deal of the smaller particles are flat.

(4) Excavated Material from Tunnels and Underground Powerhouses

The rock at Chipan Underground Powerhouse is gneiss which is satisfactory as both coarse and fine aggregate for concrete. On the intake side of the tunnel, crystalline limestone is distributed over a considerable length and this is also satisfactory as coarse aggregate. However, in manufacturing fine aggregate, there is a tendency for finely powdered material to be produced so that caution is required. The excavated material from Tienhsiang Underground Powerhouse is mostly green schist and partly siliceous schist, and although these rocks are sound they have the property of becoming flat and it is desirable to carry out tests on material excavated from exploratory adits.

(5) Heh-Shau-Chu Quarry

The rock is comprised of fresh green schist and crystalline limestone and the topsoil is thin. However, regarding the green schist, there is the previously mentioned characteristic of becoming flat while the crystalline limestone tends to produce finely divided powder and it is necessary to carry out investigations and tests in advance.

5.5 Earthquakes

From a broad viewpoint, Taiwan is situated in the Circum-Pacific Earthquake Belt. This is more finely divided into the Eastern Earthquake Belt, the Transverse Earthquake Belt and the Western Earthquake Belt. The sea east of the Li-Wu Chi is in the Eastern Earthquake Belt and is the area of Taiwan most frequently subjected to earthquakes. According to the records for the entire island of Taiwan from 1930 to 1961, out of an average 1,315.7 earthquakes per year there were 515.5 or approximately 39% in the Hualien District. Of these, the felt earthquakes were 280.5 on average per year, of which 123.2 or approximately 44% were in the Hualien District. Of the earthquakes of all of Taiwan of magnitude 4.8 or greater, the peak of 70 or more on the average annual frequency curve is in the Pacific Ocean off Li-Wu Chi. Although the Li-Wu Chi Basin is slightly apart from this peak area, an epicenter of some great earthquake causing heavy damage has been in this basin. In the Great Hualien Earthquake of 1951, it is reported that more than 4 dammed lakes were formed on the Li-Wu Chi of which the largest was the dam 73 m high storing a total quantity of 5,000,000 m^3 of water, but on April 8 of the following year, the dam disintegrated from natural causes and the lake disappeared.

Table 5-6-1 Frequency of Sensible Earthquake

District / Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Monthly Average	Percentage
Northern District	3.8	3.1	3.4	3.8	3.4	2.8	3.5	4.5	12.1	5.4	5.0	3.8	54.6	4.5	19.2
Taichung	2.0	1.4	1.1	1.3	1.0	1.2	3.3	1.4	1.3	1.3	1.8	0.7	17.8	1.6	6.8
Hualien	10.0	8.6	11.7	8.0	8.3	16.5	5.9	7.0	8.5	16.7	14.6	7.4	123.2	10.3	44.0
Tainan	4.2	2.4	2.4	2.6	2.0	2.6	1.5	2.3	2.8	2.5	1.7	6.8	33.8	2.8	12.0
Hengchun	0.4	0.4	0.6	1.2	0.6	0.3	0.4	1.0	0.4	0.4	0.4	0.4	6.5	0.5	2.2
Taitung	4.3	2.6	3.0	3.2	2.7	4.0	2.7	4.0	4.0	3.3	3.9	6.9	44.6	3.7	15.8
Total	24.7	18.5	22.2	20.1	18.0	27.4	17.3	20.2	29.1	29.6	27.4	26.0	280.5	23.4	100.0

Table 5-6-2 Frequency of Insensible Earthquake

District / Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Monthly Average	Percentage
Northern District	12.8	11.3	10.2	13.4	15.1	13.1	14.9	20.0	29.5	21.1	12.9	12.8	187.1	15.6	18.1
Taichung;	3.9	3.8	3.8	4.6	3.7	4.0	4.2	3.6	6.5	5.4	3.8	3.7	51.0	4.2	4.9
Hualien	24.0	40.6	31.2	26.1	25.6	23.7	19.8	22.1	35.9	67.9	46.8	28.6	392.3	32.7	37.9
Tainan	18.6	7.5	7.4	9.3	4.2	3.2	3.2	4.5	5.7	3.8	5.4	16.5	89.3	7.4	8.6
Hengchun	4.2	6.6	7.1	9.0	7.5	5.2	9.2	13.6	11.3	7.0	6.0	5.6	88.6	7.4	8.6
Taitung	15.0	15.3	14.9	14.9	17.5	15.1	15.3	19.1	19.4	17.4	21.3	41.8	277.0	18.9	21.9
Total	78.5	85.1	74.6	77.3	73.6	64.3	60.6	82.9	108.3	112.6	96.2	109.2	1,035.2	86.3	100.0

CHAPTER 6

DEVELOPMENT SCHEME

CHAPTER 6

DEVELOPMENT SCHEME

6.1 Alternative Schemes of Development

In order to determine what manner of development would be the most advantageous, a total of 5 alternative schemes have been examined, including the schemes already studied and annew scheme proposed upon field reconnaissance by the Survey Team. (cf. Review Report 1966, Li-Wu Chi Hydro Electric Development Alternative Schemes, 1967)

These 5 alternative schemes are shown in Figs. 6-1 through 6-5, and the outlines are given in Table 6-1.

Since the Li-Wu Chi Project Area is in an extremely rugged mountain area where gorges are narrow, river grades steep and sedimentation extremely great because of landslides and falling rocks, reservoir construction is difficult. Consequently, the five alternative schemes have become river run-off type with daily regulating ponds of small scale.

There are few suitable and economical sites for regulating ponds in this Project Area except at Tuo-Po-Kuo which is at the confluence of the main river and tributaries at Tienhsiang and Kuyuan which is at a confluence of tributaries. Therefore, the above alternative schemes are all inevitably based on provision of these regulating ponds.

6.2. Basic Conditions in Study of Alternative Schemes

The examination of the Schemes has been carried out in accordance with the basic conditions described below.

6.2.1 Topographical Maps Used

The topographical maps used are 1 : 500, 1 : 1,000 and 1 : 2,500 survey maps and 1:25,000 and 1:50,000 aerophotographic maps provided by Taipower. The survey maps cover localities of the proposed sites for structures in the Li-Wu Chi Project, and the aerophotographic maps are used for waterways, access roads and temporary construction facilities.

6.2.2 Handling of Run-off Records and Generation

The studies of the alternative schemes have been made with run-off information from the run-off records of 1955 to 1965 contained in the Review Report of Li-Wu Chi Hydroelectric Project (1966). However, for the sites of the Kuyuan, Man-Tou-Shan and Ku-Pei-Yang Dams, for the reasons described in 4.4, the records of Lushuei Gaging Station are used according to the calculation of the catchment area ratio.

Therefore, the dependable outputs and energy productions of Tienshiang Power Station and Kuyuan Power Station, which comprise the Upper River System Development are based on the run-off data obtained from the correlation between Lushuei Gaging Station and the respective intake dam sites of the Upper River Development. The dependable outputs and energy productions of Chipan Power Station which are Lower River System Development Project and the Lower River System Tienhsiang Power Station in the alternative scheme I are obtained by conversions based on the catchment area ratio between Lushuei Gaging Station and each intake site of the downstream development system. However, in the case of flood discharge, since the past maximum discharge was recorded at Lushuei Gaging Station in 1967, the quantity has been determined based on flood discharge and rainfall data between 1955 and 1967.

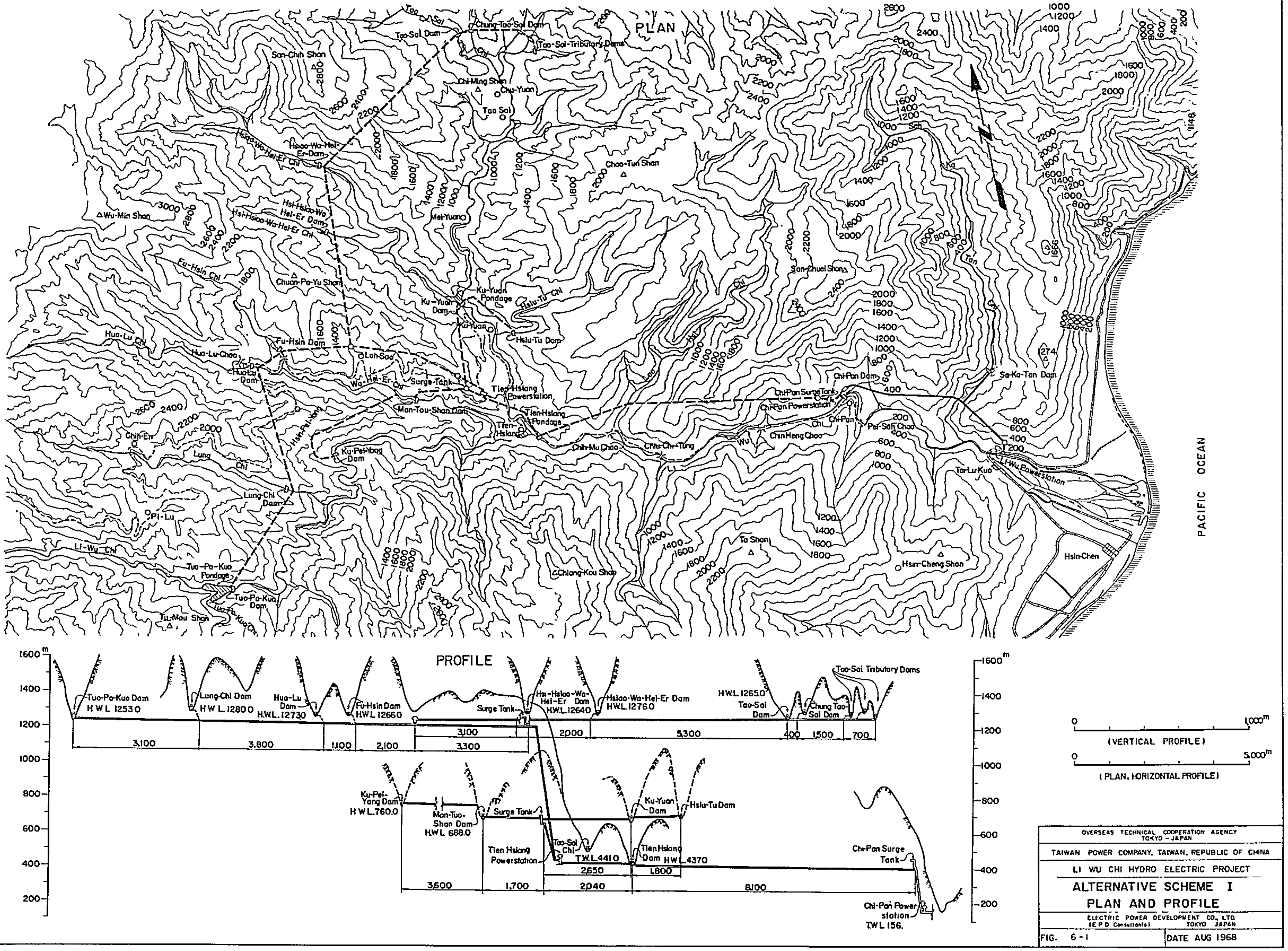
6.2.3 Intake Water Levels and Tailwater Levels

Studies made in the Elementary Scheme for development of Li-Wu Chi (Taipower, 1965) and the Review Report (Taipower, 1966) are reviewed to determine the proposed levels of intake water and tailwater. As the design flood discharges are increased comparing to the figures used in the Review Report (1966) in order to spill the flood and secure effective regulating capacities, the high water levels of Tuo-Po-Kuo, Kuyuan, and Tienhsiang Regulating Ponds have been raised slightly higher than in the Review Report to 1,253.1 m, 679.0 m and 437.0 m respectively.

The tailwater levels in the case of discharge into regulating pond are determined after calculating the backwater at the time of flood. The tailwater level of Chipan Power Station which is a scheme of the downstream development is determined using the intake water level of the existing Li-Wu Power Station as a basis.

Table 6-1 Outline of Alternative Schemes

Scheme / Item	Alternative Scheme I			Alternative Scheme II		Alternative Scheme III		Alternative Scheme IV		Alternative Scheme V	
	Tien-Hsiang High System	Tien-Hsiang Low System	Chi-Pan	Tien-Hsiang High System	Chi-Pan	Ku-Yuan	Chi-Pan	Tien-Hsiang High System	Chi-Pan	Chi-Pan Left	Chi-Pan
Pondage Name	Tuo-Po-Kuo	Ku-Yuan	Tien-Hsiang	Tuo-Po-Kuo	Tien-Hsiang	Tuo-Po-Kuo	Ku-Yuan	Tuo-Po-Kuo	Tien-Hsiang	Tuo-Po-Kuo	Tien-Hsiang
Catchment Area (km^2)	255.50	141.10	424.00	255.50	424.00	255.50	392.00	278.10	424.00	296.30	127.70
Pondage											
Annual Inflow (m^3/s)	15.37	9.48	28.51	15.37	28.51	15.37	26.35	16.54	28.51	18.54	8.58
High Water Level (m)	1,253.10	679.00	437.00	1,253.10	437.00	1,253.10	679.00	1,253.10	437.00	1,253.10	437.00
Low Water Level (m)	1,246.00	674.00	431.50	1,246.00	431.50	1,246.00	675.00	1,245.30	431.50	1,244.00	435.00
Effective Storage (m^3)	230,000.00	143,000.00	430,000.00	230,000.00	430,000.00	230,000.00	125,000.00	245,000.00	430,000.00	270,000.00	143,000.00
Drawdown (m)	7.10	5.00	5.50	7.10	5.50	7.10	4.00	7.80	5.50	9.10	2.00
Type of Dam	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity	Concrete Gravity
Height x Length of Crest (mxm)	33x44	32x55	36x90	33x44	36x90	33x44	32x55	33x44	36x90	33x44	36x90
Volume (m^3)	11,000.00	16,000.00	38,000.00	11,000.00	38,000.00	11,000.00	16,000.00	11,000.000	38,000.00	11,000.00	38,000.00
Spillway											
Design Flood Discharge (m^3/s)	2,100.00	3,400.00	6,600.00	2,100.00	6,600.00	2,100.00	3,400.00	2, 100.00	6,600.00	2,100.00	6,600.00
Waterway											
Pressure Tunnel (m)	3.0x10,100 3.1x 3,300	2.2x2,650	3.95x8,100	3.0x10,100 3.1x 3,300	3.95x8,100	3.0x10,100 3.1x 2,400	3.8x10,700	3.2x9,000	3.95x8,100	3.0x34,900	2.6x8,100
Non-Pressure Tunnel (m)	13,000.00	9,350.00	-	13,000.00	-	13,000.00	9,350.00	24,350.00	-	-	-
Tailrace Tunnel (m)	1,750.00	-	570.00	1,750.00	570.00	160.00	130.00	800.00	570.00	570.00	570.00
Generation											
Mean Water Level (m)	1,249.55	676.50	434.25	1,249.55	434.25	1,249.55	677.00	1,249.20	434.25	1,248.55	436.00
Tailrace Water Level (m)	441.00	443.00	156.60	441.00	156.60	682.00	156.60	440.00	156.60	156.60	156.60
Effective Head (m)	767.30	226.50	263.25	767.30	263.25	534.55	480.10	769.20	263.25	1,001.45	265.50
Maximum Discharge (m^3/s)	16.00	7.00	29.00	16.00	29.00	16.00	27.00	17.00	29.00	19.00	10.00
$\eta = 9.8 \times \eta t \times \eta g$	8.40	8.50	8.50	8.40	8.50	8.40	8.50	8.40	8.50	8.40	8.50
Maximum Output (MW)	103.10	13.40	65.00	103.10	65.00	71.80	110.00	109.80	65.00	159.80	22.50
Dependable Peaking (MW)	100.80	13.40	64.80	100.80	64.80	70.20	109.30	108.80	64.80	159.40	22.50
Annual Energy $(10^{6}\mathrm{KW})$	578.40	111.00	372.10	578.40	372.10	403.00	627.50	621.00	372.10	908.20	131.60
Construction Cost $(10^{3}\mathrm{NT\$})$	1,084,016.00	226,758.40	654,207.90	1,064,585.00	654,207.90	910,327.20	830,565.10	1,202,784.80	654,207.90	1,888,017.40	410,359.90
Construction Cost/K W (NT$)	10,514.20	16,922.30	10,064.70	10,325.80	10,064.70	12,768.70	7,543.70	10,954.30	10,064.70	11,814.90	18,238.20
Construction Cost/KWh (NT$)	1.874	2.043	1.758	1.841	1.758	2.259	1.324	1.937	1.758	2.079	3,118
B-C $(10^{6}\mathrm{NT\$})$	65.50	7.50	45.50	67.00	45.50	33.20	9.86	67.50	45.50	88.60	1.50
Combined Construction Cost $(10^{3}\mathrm{NT\$})$	1,964,982.30			1,718,392.90		1,740,892.30		1,856,992.70		2,298,377.30	
Combined Construction Cost/KW	10,826.30			10,222.40		9,570,60		10,623.50		12,607.70	
Combined Construction Cost/KWh	1.851			1.808		1.689		1.870		2.210	
B-C $(10^{6}\mathrm{NT\$})$	118.60			112.60		131.90		113.10		90.20	



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO - JAPAN

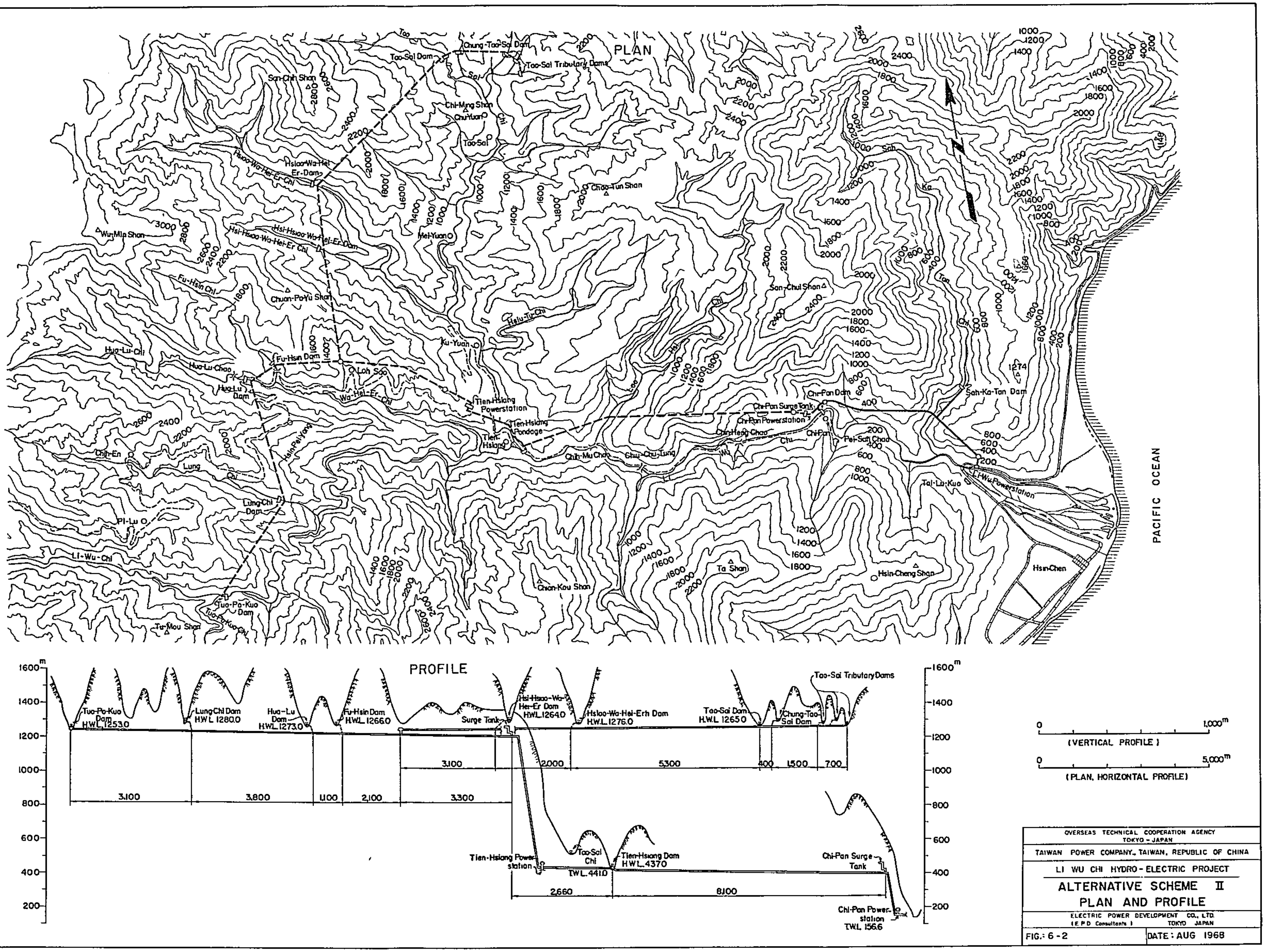
TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO ELECTRIC PROJECT

ALTERNATIVE SCHEME I
PLAN AND PROFILE

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN

FIG. 6-1 DATE AUG 1968



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO – JAPAN

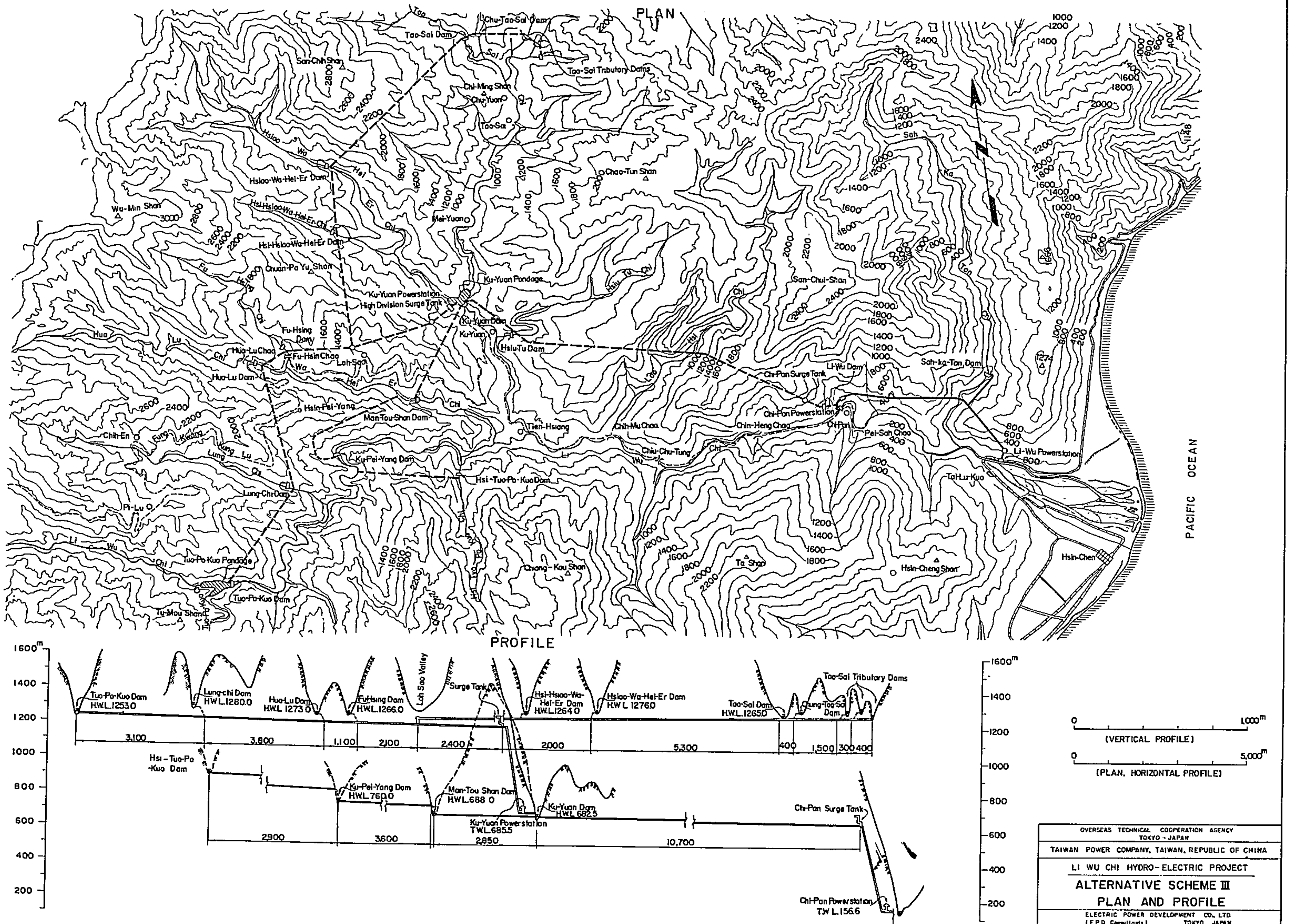
TAIWAN POWER COMPANY., TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

ALTERNATIVE SCHEME II
PLAN AND PROFILE

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN

FIG.: 6-2 DATE: AUG 1968



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO - JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

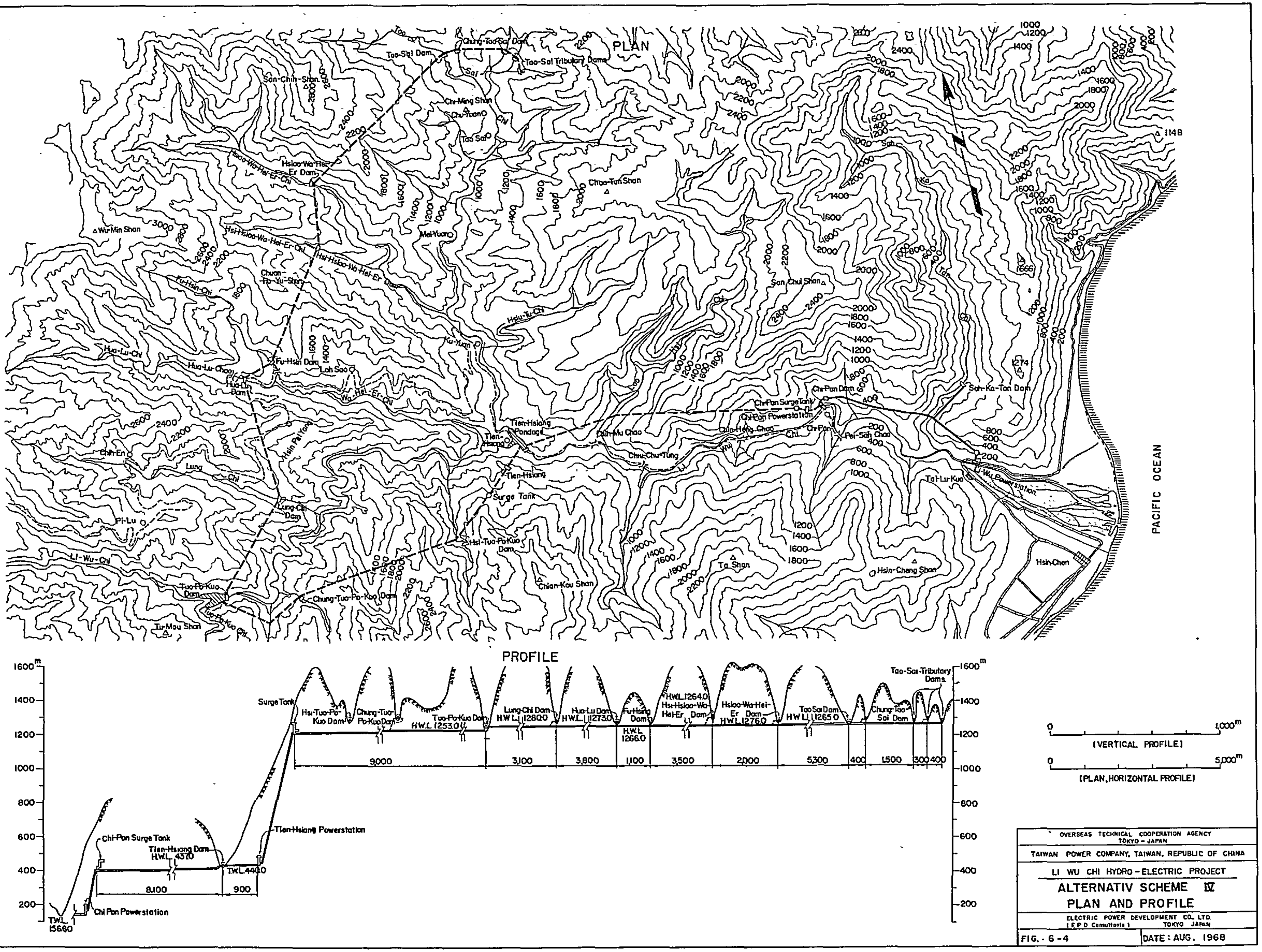
LI WU CHI HYDRO-ELECTRIC PROJECT

ALTERNATIVE SCHEME III
PLAN AND PROFILE

ELECTRIC POWER DEVELOPMENT CO., LTD
(E P D Consultants) TOKYO JAPAN

FIG 6-3

DATE: AUG 1968



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO – JAPAN

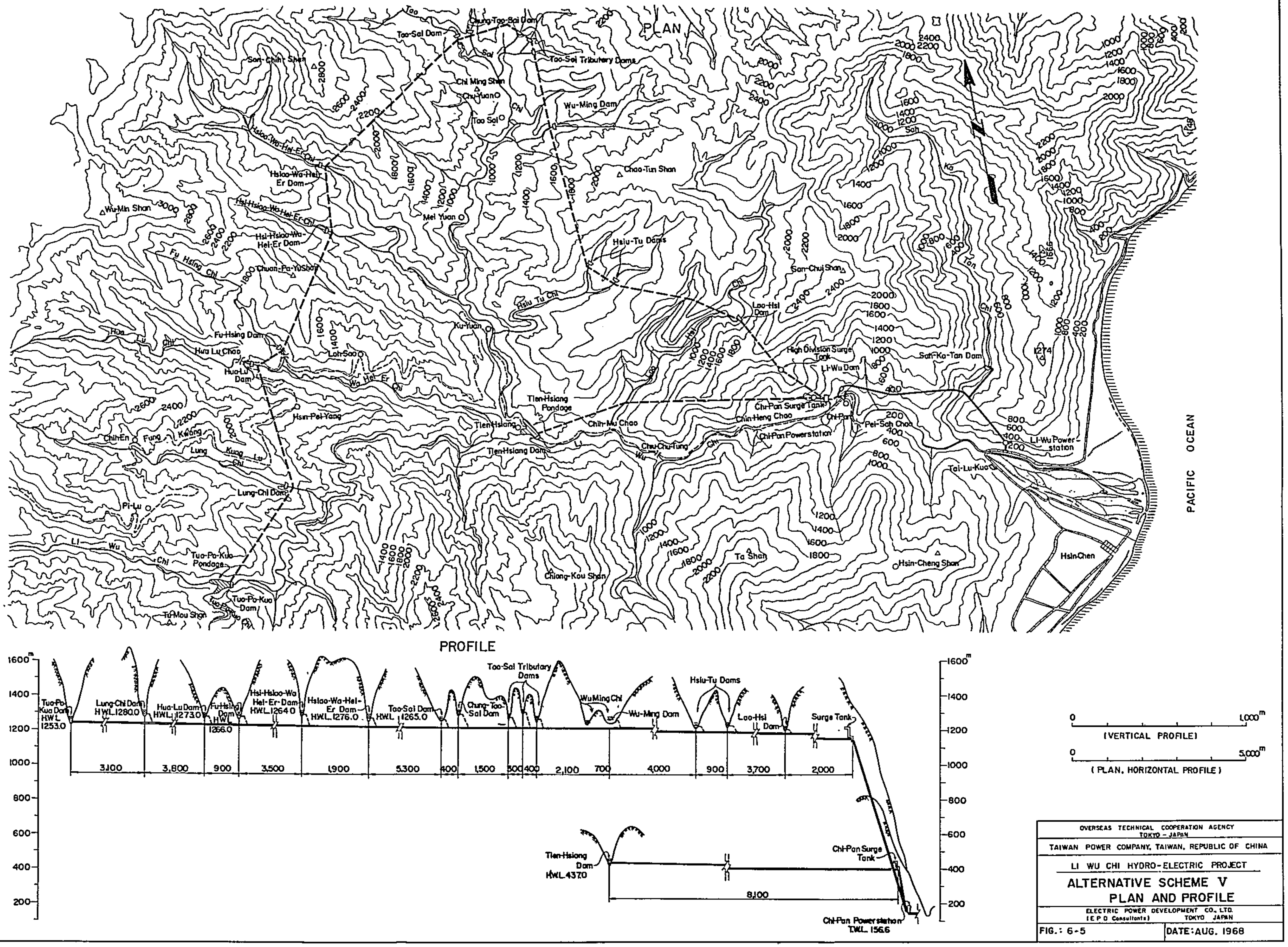
TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

ALTERNATIV SCHEME Ⅳ
PLAN AND PROFILE

ELECTRIC POWER DEVELOPMENT CO. LTD.
(E P D Consultants) TOKYO JAPAN

FIG. - 6 - 4 DATE : AUG. 1968



OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO – JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

ALTERNATIVE SCHEME V
PLAN AND PROFILE

ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN

FIG.: 6-5 DATE: AUG. 1968

6. 2. 4 Effective Capacities of Regulating Ponds

Taipower, in it's Taipower Planning Standard, prescribes that calculation of dependable peaking capacity of a hydroelectric power station should be based on the average run-off of the first 10 days of June 1963 as the dry-water quantity of the System, and that the dependable peaking time should be 5 hours. Therefore, at the stage of examing the alternative schemes, these prescriptions are employed to derive the effective capacities of regulating ponds, and the following formula is used for the calculation.

where: $Ve = (Q - q)\ 5 \times 3,600$

q = The average run-off in the first 10 days of June 1963 in m^3/s

Q = Available water during the dependable peaking hours in m^3/s

Ve = Effective capacity required in m^3

6. 2. 5 Determinations of Cross Sections of Pressure Tunnels and Steel Penstocks

Cross sections of pressure tunnels and steel penstocks are determined by applying the economical cross section determining method in which the sum of the annual annual benefit losses due to head losses and the annual expenses of the works concerned would be the minimum. In calculation of energy losses in pressure tunnels, it was assumed the concrete lining would be laid using steel forms to obtain a coefficient of roughness of $n = 0.013$, while the coefficient of the steel penstocks is $n = 0.012$. The benefit losses are calculated at the rate of NT$0. 4 per KWh.

6. 2. 6 Construction Costs

The unit cost in the Review Report (1965) is applied to calculated the construction costs with the indirect cost assumed to be 40% of the direct construction cost, and contingencies are 20% for civil engineering works, 10% for electrical machinery and equipment, and 15% for indirect costs.

The interest during construction is calculated for a construction period of three years at the rate of 6% per annum.

6. 2. 7 Economical Calculations

The benefit calculation for comparison of the various alternative schemes are obtained using the Talin Thermal Power Station (300,000 kw x 2 exclusively heavy-oil-burning thermal) as the standard thermal and the kw benefit of NT$ 566.21 and kwh benefit of NT$0.1596 calculated by Taipower. Besides this, an additional 5% is included in the kw value because of the advantage of hydro power in accordance with the Taipower Planning Standard.

Annual cost is calculated at a ratio of 8% of the total construction cost:

The economics are studied according to surplus benefit (B-C), but benefit-cost ratio has been also obtained for the reference.

6.3 Study of the Alternative Schemes and Selection of the Scheme

Comparisions have been made of the 5 alternative schemes in accordance with the basic conditions described in 6.2. The results are shown in Table 6-2.

According to this, the most favorable scheme is the Alternative Scheme III followed by the Alternative Scheme I. In comparing Scheme III and Schem I, the former is more advantageous in suplus benefit (B-C) by approximately NT$ 13 x 10^6. Converting in term of construction cost, this is approximately NT$160 x 10^6. As can be seen from the outlines of the construction works, both schemes have their various structures arranged along the East-West Cross Island Highway with no great difference in tunnel work which will have the most significant effect on the construction period and construction cost. At this stage, in regard to other works, there seem to be no factors which could arise to cause a great increase in construction cost for only one of the schemes.

Therefore, according to the present surveys, examination of available information, and the fact that the construction cost of the Alternative Scheme I is approximately NT$160 x 10^6 greater, the development plan has been limited to one scheme, and the Alternative Scheme III proposed by the present Survey Team has been selected as the best scheme.

Alternative Scheme III is a proposal of two-step development for the Li-Wu Chi catchment area with Kuyuan Power Station as the Upper River System Development and Chipan Power Station as the Lower River System Development. As clearly seen in Table 6-1, the development scale of this scheme is not inferior in comparison to the other 4 schemes, and it meets the requirement that this should be an effective and large scale development as important peaking stations to cope with the increasing power demand of Taiwan.

Table 6-2-1 Cost and Benefit of Alternative Schemes

Unit: 1,000 NT$

Scheme / Item	Alternative Scheme I			Alternative Scheme II	
	Tien-Hsiang High System	Tien-Hsiang Low System	Chi-Pan	Tien-Hsiang Low System	Chi-Pan
Direct Cost					
Dam, Intake	49,378.2	35,288.3	55,389.6	49,378.2	55,389.6
Waterway	227,447.8	48,194.2	129,875.3	227,447.8	129,875.3
Surge Chamber	9,633.2	9,956.1	9,476.9	9,633.2	9,476.9
Penstock	63,435.3	2,377.2	23,580.0	63,435.3	23,580.0
Powerhouse	52,833.5	6,258.7	33,117.5	52,833.5	33,117.5
Tailrace	23,708.6	376.1	12,346.4	17,921.6	12,346.4
Equipment	131,040.6	24,338.0	94,378.0	131,040.6	94,378.0
Access Road	49,519.4	-	9,082.4	44,567.5	9,082.4
Subtotal Costs	606,996.6	126,788.6	367,246.1	596,257.7	367,246.1
Indirect Costs	242,798.6	50,715.4	146,898.4	238,503.0	146,898.4
Contingencies	144,714.9	30,531.2	86,046.2	141,922.8	86,046.2
Construction Cost	994,510.1	208,035.2	600,190.7	976,683.5	600,190.7
Interest during Construction	89,505.9	18,723.2	54,017.2	87,901.5	54,017.2
Total Cost	1,084,016.0	226,758.4	6454,207.9	1,064,585.0	654,207.9
Sum of Project Cost	1,084,016.0	226,758.4	1,964,982.3	1,064,585.0	1,718,392.9

	Unit	Tien-Hsiang High System	Tien-Hsiang Low System	Chi-Pan	Total	Tien-Hsiang High System	Chi-Pan	Total
Net Project Cost	NT$1,000	1,084,016.0	226,758.4	654,207.9	1,964,982.3	1,064,585.0	654,207.9	1,718,392.9
Annual Cost (C)	"	86,721.2	18,140.6	52,336.6	157,198.4	85,166.8	52,336.6	137,503.4
Dependable Peaking	10^3KW	100.8	13.4	64.8	179.0	100.8	64.8	165.6
Average Annual Energy	10^6KWh	578.4	111.0	372.1	1,061.5	578.4	372.1	950.5
Capacity Value	NT$1,000	57,073.9	7,587.2	36,690.4	101,351.5	57,073.9	36,690.4	93,764.3
Energy Value	"	92,312.6	17,715.6	59,387.1	169,415.3	92,312.6	59,387.1	151,699.7
Hydro Advantage of Hydro Capacity Value (5%)	"	2,853.7	379.3	1,834.5	5,067.5	2,853.7	1,834.5	4,688.2
Annual Benefit (B)	"	152,240.2	25,682.1	97,912.0	275,834.3	152,240.2	93,912.0	250,152.2
Surplus Benefit (B-C)	"	65,519.0	7,541.5	45,575.4	118,635.9	67,073.4	45,575.4	112,648.8
Benefit Cost Ratio (B/C)	'	1,755.0	1,415.0	1,870.0	1,754.0	1,787.0	1,870.0	1,819.0
Construction Cost/KW	NT$	10,514.2	16,922.3	10,064.7	10,826.3	10,325.8	10,064.7	10,222.4
Construction Cost/KWh	NT$	1,874.0	2,043.0	1,758.0	.1,851.0	1,841.0	1,758.0	1,808.0

Table 6-2-2 Cost and Benefit of Alternative Schemes

Unit: 1,000 NT$

Scheme / Item	Alternative Scheme III		Alternative Scheme IV		Alternative Scheme V	
	Ku-Yuan	Chi-Pan	Tien-Hsiang High System	Chi-Pan	Chi-Pan Left	Chi-Pan
Direct Costs						
Dam, Intake	49,378.2	54,125.4	37,408.6	55,389.6	79,444.0	55,389.6
Waterway	216,111.5	225,771.7	189,788.7	129,875.3	420,427.9	81,659.1
Surge Chamber	7,634.0	9,630.0	11,356.3	9,476.9	10,631.0	6,600.0
Penstock	37,117.8	66,221.3	42,828.7	23,580.0	111,640.0	11,000.0
Powerhouse	33,934.5	56,269.9	43,499.5	33,117.5	63,262.0	17,000.0
Tailrace	4,225.9	7,792.0	11,069.1	12,346.4	4,553.8	6,400.0
Equipment	111,931.7	135,902.8	117,126.0	94,378.0	169,777.5	42,210.0
Access Road	49,519.4	117,216.3	13,006.9	9,082.4	193,938.9	9,082.4
Subtotal	509,853.0	672,929.4	466,083.8	367,246.1	1,053,677.1	229,341.1
Indirect Costs	203,941.2	269,171.7	186,433.5	146,898.4	421,470.8	91,736.4
Contingencies	121,368.4	161,371.2	109,469.1	86,046.2	256,978.2	55,407.7
Construction Cost	835,162.6	1,103,472.3	761,986.4	600,190.7	1,732,126.1	376,485.2
Interest during Construction	75,164.6	99,312,5	68,578.7	54,017.2	155,891.3	33,874.7
Total Costs	910,327.2	1,202,784.8	830,565.1	654,207.9	1,888,017.4	410,359.9
Sum of Project Cost	910,327.2	1,740,892.3	1,202,784.8	1,856,992.7	1,888,017.4	2,298.377.3

	Unit	Ku-Yuan	Chi-Pan	Total	Tien-Hsiang High System	Chi-Pan	Total	Chi-Pan Left	Chi-Pan	Total
Net Project Cost	NT$1,000	910,327.2	830,565.1	1,740,892.3	1,202,784.8	654,207.9	1,856,992.7	1,888,017.4	410,359.9	2,298,377.3
Annual Cost (C)	"	72,826.1	66,445.2	139,271.3	96,222.7	52,336.6	148,559.3	151,041.3	32,828.7	183,870.0
Dependable Peaking	10^3KW	70.2	109.3	179.5	108.8	64.8	173.6	159.4	22.5	181.9
Average Annual Output	10^6KWh	403.0	627.5	1,030.5	621.0	372.1	993.1	908.2	131.6	1,039.8
Capacity Value	NT$1,000	39,747.9	61,886.7	101,634.6	61,603.6	36,690.4	98,294.0	90,253.8	12,739.7	102,993.5
Energy Value	"	64,318.8	100,149.0	164,467.8	99,116.6	59,387.1	158,498.7	144,948.7	21,003.3	165,952.0
Advantage of Hydro Capacity Value (5%)	"	1,987.4	3,094.3	5,081.7	3,080.1	1,834.5	4,914.6	4,512.7	636.9	5,149.6
Annual Benefit (B)	"	106,054.1	165,130.0	271,184.1	163,800.3	97,912.0	261,712.3	239,715.2	34,379.9	274,095.1
Surplus Benefit (B-C)	"	33,228.0	98,684.8	131,912.8	67,577.6	45,575.4	113,153.0	88,671.9	1,551.2	90,225.1
Benefit-Cost Ratio(B/C)		1,456	2,485	1,947	1,700	1,870	1,761	1,587	1,047	1,490
Construction Cost/KW	NT$	12,768.7	7,543.7	9,570.6	10,954.3	10,064.7	10,623.5	11,814.9	18,238.2	12,607.7
Construction Cost/KWh	NT$	2,259	1,324	1,689	1,937	1,758	1,870	2,079	3,118	2,210

In Proposed Scheme III, since the regulating capacity of Kuyuan Dam which should comprise the regulating pond for Chipan Power Station cannot be made of a size to regulate the inflow of the entire catchment area due to topographical and geological conditions, it has been decided that Kuyuan and Chipan Power Stations would be operated simultaneously. For this reason a demerit, that when one generator is out of order at Kuyuan Power Station, the output at Chipan Power Station would be lowered, and that the other alternative schemes do not possess, will be created.

The benefit loss for this case will be examined for reference. In general, it is estimated in Japan that the outage of a hydroelectric power station will be 0.5 % per unit annually. Therefore, the probability of the output drop at Chipan Power Station due to the hindrance at Kuyuan Power Station would be 1.0% annually. As an extreme case, if Chipan Power Station were to operate with one unit, the total annual benefit in Alternative Scheme III would be NT$269,532.8 x 10^3, the surplus benefit (B-C) NT$30,261.5 x 10^3 and the benefit cost ratio (B/C) 1.935, which demonstrate that the advantage of the Alternative Scheme III remain unchanged.

Further, in case of such accident, Chipan Power Station would be operated at the peak with two units even for a short period, while for the rest of the time the operation would be by one unit avoiding overflow of water from Kuyuan Regulating pond. Therefore, the actual benefit loss would be very small.

6.4 Determination of Scale of Development

6.4.1 Basic Conditions for Determination of Scale

As described in 6.3, the proposed development scheme is Alternative Scheme III, and Kuyuan Power Station is selected for upstream development and Chipan Power Station for downstream development. Different Scale of these power stations have been studied to determine the most economical scales. In order to improve the accuracy in carrying out this study, among the fundamental items used in the comparison of the alternative projects in 6.2, handling of run-off records, effective capacities of regulating ponds, construction costs and economical calculation are treated in slightly different manner.

(1) Handling of Run-off Record and Generation

In determining scales of development, run-off volume obtained by catchment area ratio conversions based on daily run-off records at Lushuel Gaging Station for 1957 to 1967 are used for both power stations.

The effective capacities of regulating ponds, intake water levels and tailwater levels of the two power stations will be determined on this run-off volume.

The effective outputs, based on the abovementioned run-off records, are obtained using the average inflow of the run-off of the 10 driest days in each month in consideration of future increases in thermal power facilities as described in the detail in Appendix - 2. Energy production is calculated from the catchment area ratio conversions obtained from a series duration curve based on the average 10 day run-off at Lushuei Gaging Station between the years 1965 - 1967 as indicated in Fig. 4-4.

Furthermore, in determining the scale of development, the diversion from Lao-Hsi Chi to Chipan Power Station has been taken into consideration.

(2) Effective Capacities of Regulating Ponds

The effective capacities of regulating ponds are obtained for each peaking hour according to run-off data described in (1), the peaking hours determined in Appendix - 2 and the maximum water consumption. And the necessary maximum capacities are determined to be the effective capacities for each regulating pond.

(3) Layout

The total length of the non-pressure intake tunnel from Taosai Dam to Hsiao-Hei-Er Dam is designed to be 5,300 m in determining the project and its scale is as shown in Fig. 6-3. However, since the cross section is small and the tunnel is long, in pre-designing the development scale, the layout has been changed as shown in Dwg. No. 22 in order to add a work adit in the middle of the tunnel to facilitate the construction and to shorten the period. Thus the construction cost has been calculated.

(4) Construction Costs

Construction costs are calculated by adding the unit costs obtained by the method described in detail in Chapter 9. However, indirect costs, contingencies, interest during construction, and the construction periods are calculated as in the same method as described in 6.1.6.

Table 6-3 Outline of Alternatives Scheme for Determination of Scale

Item \ Name of Power Station	Ku-Yuan Power Station	Chi-Pan Power Station	Ku-Yuan Power Station	Chi-Pan Power Station	Ku-Yuan Power Station	Chi-Pan Power Station	Ku-Yuan Power Station	Chi-Pan Power Station
Pondage Name	Tuo-Po-Kuo	Ku-Yuan	Tuo-Po-Kuo	Ku-Yuan	Tuo-Po-Kuo	Ku-Yuan	Tuo-Po-Kuo	Ku-Yuan
Catchment Area (km^2)	254.95	412.00	254.95	412.00	254.95	412.00	254.95	412.0
Pondage								
High Water Level (m)	1,253.10	679.00	1,255.00	682.50	1,256.00	683.50	1,257.00	684.00
Gross Storage (10^3m^3)	480.00	400.00	500.00	440.00	540.00	480.00	560.00	500.00
Effective Storage (10^3m^3)	230.00	130.00	380.00	290.00	420 00	330.00	440.00	350.00
Drowdown (m)	7.10	4.00	12.00	9.00	13.00	10.00	14.00	11.00
Dam								
Height, Length of Crest (m)	35 x 44	36x60.5	35 x 44	36 x 60.5	35 x 44	36 x 60.5	35 x 44	36 x 60.5
Volume (m^3)	9,800	16,000	13,000	19,000	15,000	21,000	16,000	22,000
Spillwat								
Design Flood Discharge (m^3/s)	2,100.00	3,400.00	2,100.00	3,400.00	2,100.00	3,400.00	2,100.00	3,400.00
Water Way								
Pressure Tunnel (m)	3.0 x 10,100 3.1 x 2,400	3.8 x 10,700	3.2 x 10,100 3.3 x 2,400	4.2 x 10,700	3.55 x 10,100 3.65 x 2,400	4.4 x 10,700	3.65 x 10,100 3.75 x 2,400	4.6 x 10,700
Non-Pressure Tunnel(m)	13,000.00	9,350.00	13,000.00	9,350.00	13,000.00	9,350.00	13,000.00	9,350.00
Tailrace Tunnel (m)	160.00	130.00	160.00	130.00	160.00	130.00	160.00	130.00
Generation								
Mean Water level (m)	1,249.55	677.00	1,249.00	678.00	1,249.50	678.50	1,250.00	679.00
Tailrace Water Level (m)	682.00	156.60	685.50	162.65	686.50	162.65	685.50	162.65
Effective Head (m)	533.00	478.00	533.00	473.00	533.00	473.00	533.00	473.00
Maximum Discharge (m^3/s)	16.00	28.50	19.70	34.60	23.00	38.00	26.00	43.00
Maximum Output (MW)	71.60	115.70	88.20	140.50	102.90	154.30	116.40	174.70
Annual Energy (10^6KWh)	420.80	617.10	442.80	642.40	461.20	669.50	476.50	691.30
Construction Cost $(10^6NT\$)$	946.30	871.40	1,042.00	1,025.00	1,127.90	1,115.80	1,197.60	1,232.30
Combined Construction Cost $(10^6NT\$)$	1,817.70		2,067.00		2,243.70		2,429.90	
Benefit								
Dependable Peaking (KW)	69,400.00	110,500.00	81,900.00	123,430.00	86,400.00	125,840.00	86,800.00	126,240.00
Annual Energy (10^6KWh)	420.80	617.10	442.80	642.40	461.20	669.50	476.50	691.30
Capacity Benefit $(10^3NT\$)$	33,477.00	53,303.00	39,506.00	59,540.00	41,677.00	60,702.00	41,870.00	60,895.00
Advantage of Hydro Capacity B $(10^3NT\$)$	10,043.00	15,991.00	11,851.00	17,862.00	12,503.00	18,210.00	12,561.00	18,268.00
Energy Benefit $(10^3NT\$)$	66,696.00	97,810.00	70,183.00	101,820.00	73,100.00	106,115.00	75,525.00	109,571.00
Total Annual Benefit $(10^3NT\$)$	110,216.00	167,104.00	121,540.00	179,222.00	127,280.00	185,027.00	129,956.00	188,734.00
Construction Cost/KW (NT$/KW)	13,216.40	7,531.50	11,814.00	7,295.30	10,961.10	7,231.30	10,288.60	7,053.80
Construction Cost/KWh (NT$/KWh)	2,249.00	1,412.00	2,353.00	1,596.00	2,446.00	1,667.00	2,513.00	1,783.00
Combined Output (MW)	187.30		228.70		257.20		291.10	
Combined Energy (10^6KWh)	1,037.90		1,085.20		1,130.70		1,167.80	
Combined Construction Cost/KW (NT$)	9,704.70		9,038.00		8,723.50		8,347.30	
Combined Construction Cost/KWh (NT$)	1,751.00		1,905.00		1,984.00		2,081.00	

Fig. 6-6 ANNUAL BENEFIT AND ANNUAL COST OF KU-YUAN AND CHI-PAN Power Stasion

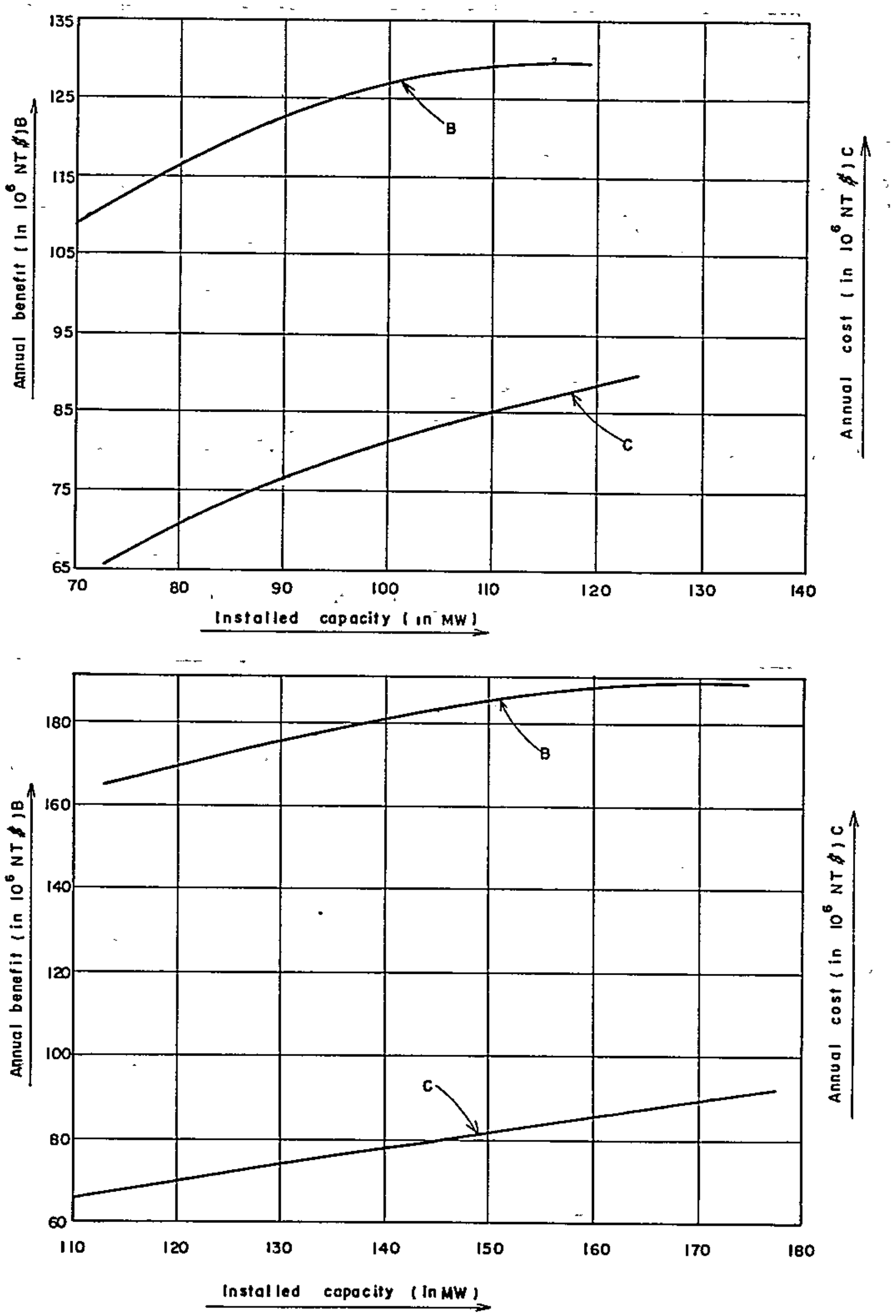


Fig. 6-7 SURPLUS BENEFIT AND BENEFIT-COST RATIO OF KU-YUAN AND CHI-PAN Power Station

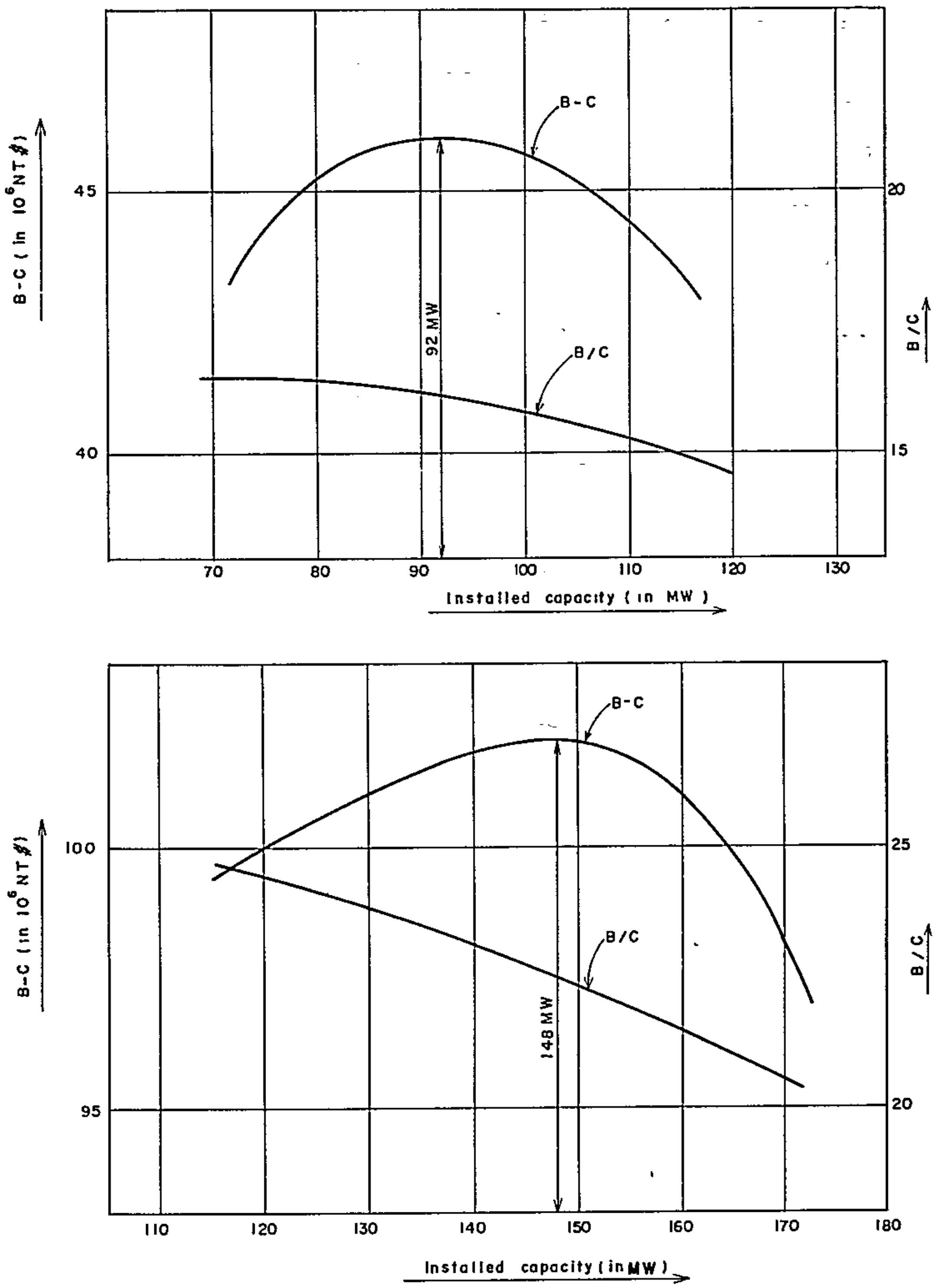


Table 6-4 Outline of Proposed Scheme

Name of Power Station Item	Ku-Yuan Power Station	Chi-Pan Power Station
Pondage Name	Tuo-Po-Kuo	Ku-Yuan
Catchment Area (km^2)	254.95	412.0
Pondage		
High Water Level (m)	1,255.0	682.5
Gross Storage (10^3m^3)	500	440
Effective Storage (10^3m^3)	380	290
Draw Down (m)	12.0	9.0
Type of Dam	Concrete Gravity	Concrete Gravity
Height, Length of Crest (m)	35 x 44.0	36 x 60.5
Volume (m^3)	13,000	19,000
Spillway		
Design Flood Discharge (m^3/s)	2,200.0	3,430.0
Waterway		
Pressure Tunnel (m)	3.3 x 10,100 3.4 x 2,400	4.15 x 10,700
Non-Pressure Tunnel (m)	2.0~2.8 x 14,650	2.0~2.8 x 9,350
Tailrace Tunnel (m)	160.0	130.0
Generation		
Mean Water Level (m)	1,249.0	678.0
Tailrace Water Level (m)	685.5	162.65
Effective Head (m)	527.09	480.60
Maximum Discharge (m^3/s)	20.8	36.3
Maximum Output (MW)	92.0	148.0
Annual Energy (10^6 KWh)	409.68	625.05
Construction Cost (10^6NT$)	* 1,161 ** 1,179	* 1,070 ** 1,087
Constructiln Cost/KW (NT$/KW)	12,617 12,817	7,231 7,346
Construction Cost/KWh (NT$/KWh)	2.83 2.88	1.71 1.74
Combined Output(MW)	240.0	
Combined Energy (10^6KWh)	1,034.73	
Combined Construction Cost/KW (NT$/KW)	* 9,296 ** 9,443	
Combined Construction Cost/KWh (NT$/KWh)	* 2.16 ** 2.19	

Note: * Interest rates = 6%
** Interest rates = 7%

(5) Economical Calculations

The calculation of benefit to determine the scale of the proposed scheme has been made using the benefits of NT$467.14 per kw and NT$ 0.1585 per kwh which are the results of studies described in detail in Chapter 10, having Talin thermal power as the standard (300,000 kw x 2 and exclusively heavy oil burning thermal power). As the advantage of hydro power described in Chapter 10, an increase of 30% is added to the kw value. The above values are based on the interest rate of 6%, so annual cost is determined based on 6.654% amortization (Ref. Ch. 10) obtained at the interest rate of 6% to the total construction cost, and from the average operation and maintenance cost obtained from actual figures of operation and maintenance cost of hydroelectric power stations of Taipower (Ref. Taipower Planning Standards).

6.4.2 Determination of the Optimum Scale

The outline of the various facilities examined in determining the development scale is shown in Table 6-3.

The annual cost and annual benefit of these facilities calculated by the methods in 6.4.1 are shown in Fig. 6-6, and the surplus benefits (B-C) and benefit-cost ratio (B/C) using the values in Fig. 6-6 are given in Fig. 6-7. According to this, the development scale of the Li-Wu Chi Hydroelectric Project has been determined at 92,000 kw for Kuyuan Power Station and 148,000 kw for Chipan Power Station, or a total of 240,000 kw. The outline of these two power stations are shown in Table 6-4.

6.5 Energy Production

The output and annual energy production of the proposed development scheme are calculated by an electronic computer using daily run-off record obtained from Taipower. As stated in 4.4 "Run-off", the run-off at each intake dam site on the Li-Wu Chi is determined by the correlation and according to this, the output and energy production are determined. However, since there are too few dependable samples for obtaining an equation and the various correlation coefficients fluctuate greatly, these are not used at the present time.

Table 6-5 gives the results of calculations of energy production at the Kuyuan and Chipan Power Stations based on the catchment area ratio conversions obtained from daily run-off records at Lushuei Gaging Station.

Table 6-5 Annual Energy Production of Proposed Scheme

Ku-Yuan Power Station

Unit: 10^3KWh

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1957	41,533	37,670	60,601	43,628	35,019	65,870	57,746	29,074	47,097	38,701	18,038	14,115	489,092
1958	35,882	53,449	44,433	34,276	34,158	53,706	56,310	64,072	58,942	32,143	30,523	39,321	537,215
1959	48,920	45,500	51,065	47,764	40,335	53,003	41,946	40,475	58,283	36,749	30,794	26,788	521,622
1960	37,191	25,018	21,711	35,742	34,321	56,788	31,984	68,510	58,557	58,172	35,219	23,631	486,844
1961	17,731	23,900	42,967	37,168	36,131	60,540	47,986	60,909	62,185	60,738	32,169	26,442	508,866
1962	21,074	18,637	37,327	45,233	24,599	24,335	30,945	62,246	65,374	67,007	46,194	32,062	475,033
1963	21,059	20,806	22,979	15,782	13,008	17,359	52,548	42,597	55,530	39,505	25,931	29,569	356,673
1964	36,024	46,573	32,450	21,204	19,814	44,505	22,418	54,170	50,142	67,436	51,974	33,978	480,688
1965	27,576	21,999	26,624	19,291	25,701	41,881	50,877	65,305	47,312	32,033	27,380	22,243	408,222
1966	17,844	15,833	24,693	23,030	27,547	63,652	41,090	25,153	36,058	20,758	14,229	13,437	323,324
1967	15,126	17,991	25,341	24,292	31,658	50,724	29,726	27,321	28,927	47,371	61,872	59,711	420,060
Average	29,087	29,761	35,472	31,583	29,299	48,397	42,143	49,076	51,673	45,510	34,029	29,029	455,239

Chi-Pan Power Station

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1957	61,918	57,364	92,725	66,356	53,003	105,239	89,318	43,348	73,659	57,835	26,909	21,055	748,729
1958	53,502	81,583	66,519	51,116	50,928	81,259	88,184	100,840	92,624	47,935	45,520	58,629	818,639
1959	72,942	67,837	76,139	71,223	60,490	81,910	62,550	60,877	90,858	54,788	46,710	39,949	786,273
1960	57,560	37,306	32,366	54,746	52,755	89,157	47,692	110,329	90,216	88,208	52,522	35,232	748,089
1961	26,426	35,707	64,767	55,399	55,459	95,542	72,532	93,719	99,053	94,895	47,956	39,425	780,880
1962	31,425	27,787	57,897	67,474	36,695	36,298	47,180	98,089	104,412	106,181	69,142	47,803	730,383
1963	31,399	31,018	34,254	23,531	19,411	25,889	82,840	64,221	87,281	58,903	38,668	44,095	541,510
1964	55,279	70,543	48,387	31,615	29,548	67,570	33,428	84,725	75,877	107,442	77,600	50,668	732,682
1965	41,107	32,789	39,699	28,764	38,324	63,338	80,603	103,338	70,871	47,746	40,813	33,163	620,555
1966	26,606	23,599	36,817	34,346	41,083	100,320	61,270	37,509	54,694	30,950	21,213	20,029	488,436
1967	22,566	26,831	37,785	36,207	48,797	78,270	44,598	41,006	43,153	74,326	97,792	92,311	643,642
Average	43,703	44,760	53,396	47,343	44,227	74,981	64,563	76,182	80,245	69,928	51,350	43,851	694,529

Table 6-6 Annual Energy Production of Ku-Yuan Power Station Based on Correlation Run-off

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1957	41,141	37,544	59,876	43,349	35,027	65,774	57,319	29,175	47,166	38,478	18,578	14,822	488,249
1958	35,710	52,843	43,986	34,144	34,059	53,025	56,102	63,823	58,669	32,134	30,545	39,021	534,061
1959	48,262	44,832	50,296	47,107	40,103	52,649	41,568	40,224	57,897	36,552	30,948	26,987	517,425
1960	37,342	25,208	22,109	35,821	34,493	56,551	31,969	68,510	58,014	57,407	35,053	23,962	486,439
1961	18,297	24,137	42,671	36,911	36,251	60,296	47,527	60,262	62,066	60,409	32,113	26,667	507,607
1962	21,525	19,084	37,558	44,685	24,879	24,609	31,178	61,977	65,268	66,785	45,647	32,037	475,232
1963	21,487	21,125	23,337	16,382	13,776	17,894	52,530	42,339	55,352	39,200	26,136	29,666	359,224
1964	36,147	46,136	33,038	21,582	20,254	44,270	22,834	53,999	50,400	67,743	54,035	33,903	484,341
1965	26,918	18,544	25,914	19,456	31,424	48,321	55,660	67,939	37,897	24,610	24,896	19,512	401,091
1966	15,303	14,771	24,040	23,046	28,641	63,602	44,908	25,443	40,806	25,522	16,851	14,381	337,314
1967	16,381	18,918	31,487	27,568	32,101	55,742	31,973	28,798	33,461	48,483	62,664	59,504	447,080
Average	28,956	29,377	35,847	31,823	30,092	49,339	43,052	49,317	51,545	45,211	34,315	29,133	458,007

According to this, the energy production will be 455.2×10^6 kwh at Kuyuan Power Station and 694.5×10^6 kwh at Chipan Power Station totalling $1{,}149.7 \times 10^6$ kwh. The average output will be 51.7 MW at Kuyuan Power Station and 79.1 MW at Chipan Powerhouse giving a total of 130.8 MW

As a reference, the energy production at Kuyuan Power Station is obtained from daily run-off of the each intake site and from run-off data supplemented by correlation coefficient determined by the Survey Team for the period that the records are not available. The results are given in Table 6-6. Comparing the results with the energy production obtained by the catchment area ratio conversion method mentioned above, there is a fairly good agreement, but the result based on the correlation coefficient shows a large energy production in dry seasons or dry years, and on the contrary, the energy production decreases in wet seasons or wet years. As a total, the energy production is slightly greater. Therefore, according to examination also, output and energy production calculated by the catchment area ratio conversion method which produces the safer result are used in making the economic evaluation of Chapter 10.

Energy at the generating end is estimated at a utilization rate of 90% considering the reduction in energy production due to the ineffective inflow for the flushing of large amount of sediment, leakage, outage, etc.

6.6 Transmission System

6.6.1 Outline of Existing System

In 1967, when the Li-Wu Chi Power Stations are scheduled to be in service, the outline of the major transmission system of Taipower Will be as described below. (Fig. 6-8)

(1) A 345 kv trunk transmission line of extra high voltage starting from the Taipei Area in the Northern Taiwan which is a major demand center and at the same time a great power source with neclear and thermal stations, extends about 120 km toward the south to connect with a 154-kv system at Tienlung Power Station, which is the center of the large capacity hydroelectric power source of the Tachia Chi in the Central Taiwan, and then extends approximately 210 km to the further south to the Kaohsiung Area, which is the major demand area and also large-capacity thermal power source in the Southern Taiwan, forming a North-South Interconnecting System.

(2) Power supply to the major sub-stations and transmission from the major hydro and thermal power sources are almost entirely carried out by 154-kv lines.

(3) The trunk line system in the east coast area of Taiwan is comprised of 66-kv lines and the interconnection with the west coast area is operated at all times by a 66-kv East-West connecting line between Wanta Power Station of the Chuoshuei Chi and Lungchien Power Station of the Mukua Chi in the east.

6.6.2 Transmission Voltage and Number of Circuits

In considering transmission from Kuyuan and Chipan Power Staion, the first question to arise is whether to transmit the power to the Eastern Area of the Western Area. The power demand of the Eastern Area is presently about 50 mw, and considering the natural conditions of this area, the rapid growth in demand cannot be expected. Moreover the supply capacity of the area exceeds the demand greatly and considering that there is a program of future development of several tens of thousand kw on the Mukua Chi, the power of both Kuyuan and Chipan Stations will not be required to be transmitted to the Eastern Area, and it would be desirable for the entire quantity to be transmitted across the central mountain range to the western coast. It will be appropriate for the transmission voltage to be 154 kv in view of the relationship with the existing system voltage and of the scale of development of this Project. The line can be connected into the switchyard of either Tachien Power Station or Wanta Power Station. (Fig. 6-9)

The distance of transmission will be approximately 40 km from either Tachien Power Station or Wanta Power Station. Since the section between Wanta and Chukon of the line from Wanta Power Station to the primary substation in the Western Coast area is HDCC 125 mm^2 circuits the transmission line capacity will be about 250 mw even at the maximum safe current capacity. Besides the maximum output of 35.9 mw of Wanta Power Station, the power transmitted from the east to the west via the East-West Connecting Line will be superimposed. And the power flow will exceed 100 mw. It will be impossible to transmit the 240 mw of the presently planned hydro electric-power of Li-Wu Chi System unless the transmission lone of this section are greatly improved.

When Tachien is the terminal of the transmission line, double circuits of ACSR 636 MCM are proposed between Tachien and Kukuan of which the safe current capacity of one circuit is 422 MVA, and 2 circuits of ACSR 636 MCM and double circuit of ACSR 795 MCM, a total of 4 circuits are proposed between Kukuan and Tienlung. Further, between Kukuan and Hsinchu, two-circuits of ACSR 477 MCM dual-conductor are also planned, and they will be connected with the 345-KV extra high-voltage trunk line at Tienlung Power Station so that the system will be greatly strengthened. Therefore, the Tachien Power Station will be the most suitable terminal for transmission of the hydroelectric power of Li-Wu Chi System. If Tachien Power Station is the terminal point for power transmission, since the distance between Kuyuan Power Station and Kukuan Power Station is approximately 55 km, there is no need to take the transient stability and steady-state stability into account, and it will be enough to consider the capacity determined by the cross section area of conductor.

Therefore, the number of circuits may be considered only from the standpoint of an influence upon the system in case of outage by an accident regarding the section between Chipan and Kuyuan, as the maximum output of Chipan Power Station is 148 MW, the ratio to the system capacity (around 1976) at the time of starting the operation is around 4.5% which is less than 5% and will continue to decrease over the year; moreover, since the length of this section is extremely short, only 12 km, one circuit will be sufficient for this section. Between Kuyuan and Tachien, since the total maximum output capacity of both Kuyuan and Chipan Power Station is 240 MW, the distance is 39 km, and the line crosses the central mountain range, 2 circuits will be provided for this section. Taking into account the minimum conductor size for the line operation, transmission losses and the increase in construction costs an ACSR 477 MCM with a safe current capacity of 172 MVA has been selected as the conductor for the Chipan-Kuyuan section. For the section between Kuyuan and Tachine, taking into consideration the need to withstand overloading for short periods when one circuit is out of service and the need to operate one circuit for long hours on one circuit because of continued trouble, an ACSR 636 MCM with a safe current capacity of 211 MVA will be employed.

As for the various transmission lines west of Tachien, both technically and economically, it is unnecessary for the present project to be altered because of the interconnection of the Li-Wu Chi hydroelectric power stations to the system.

Fig 6-8 Transmission Line System (1976)

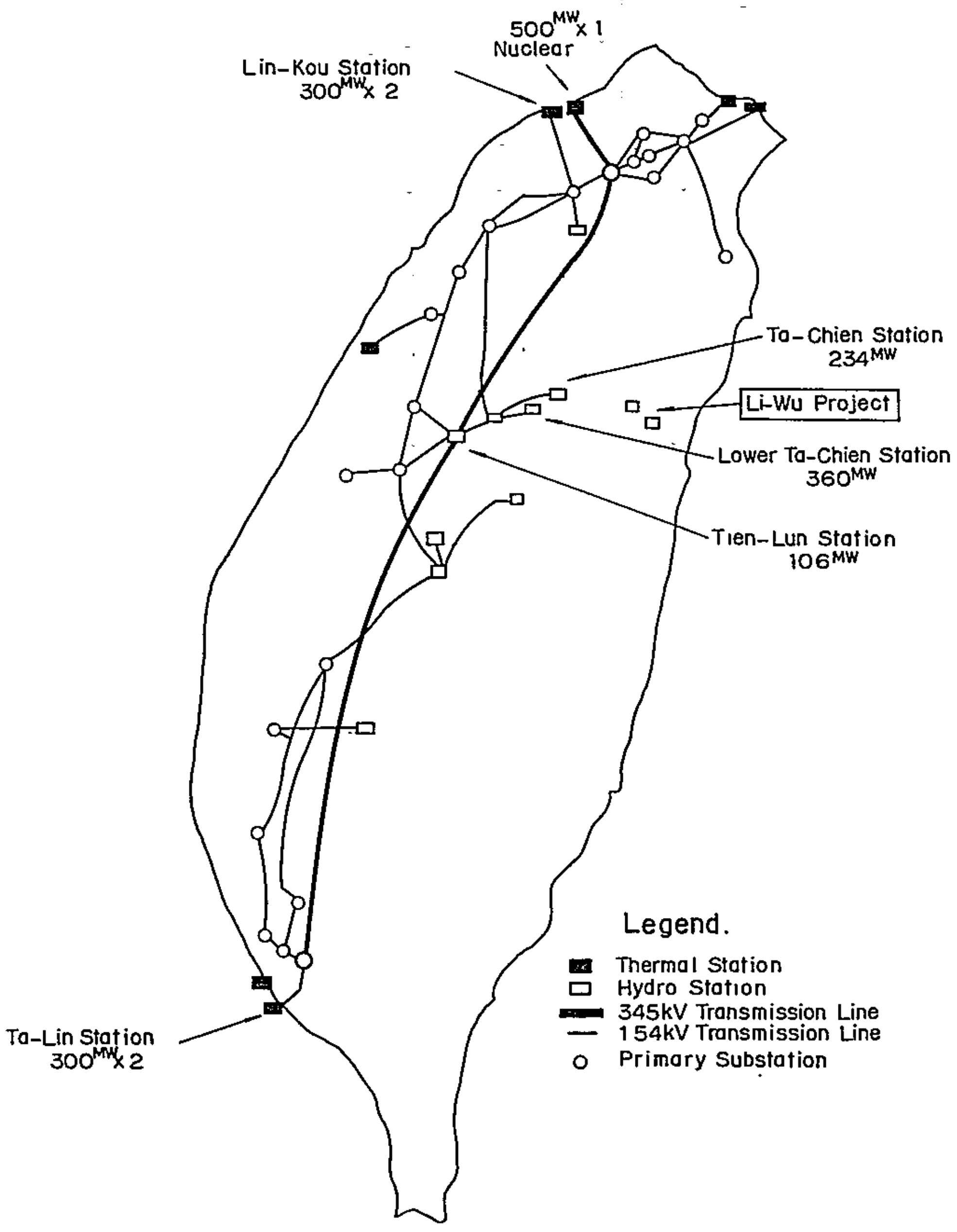
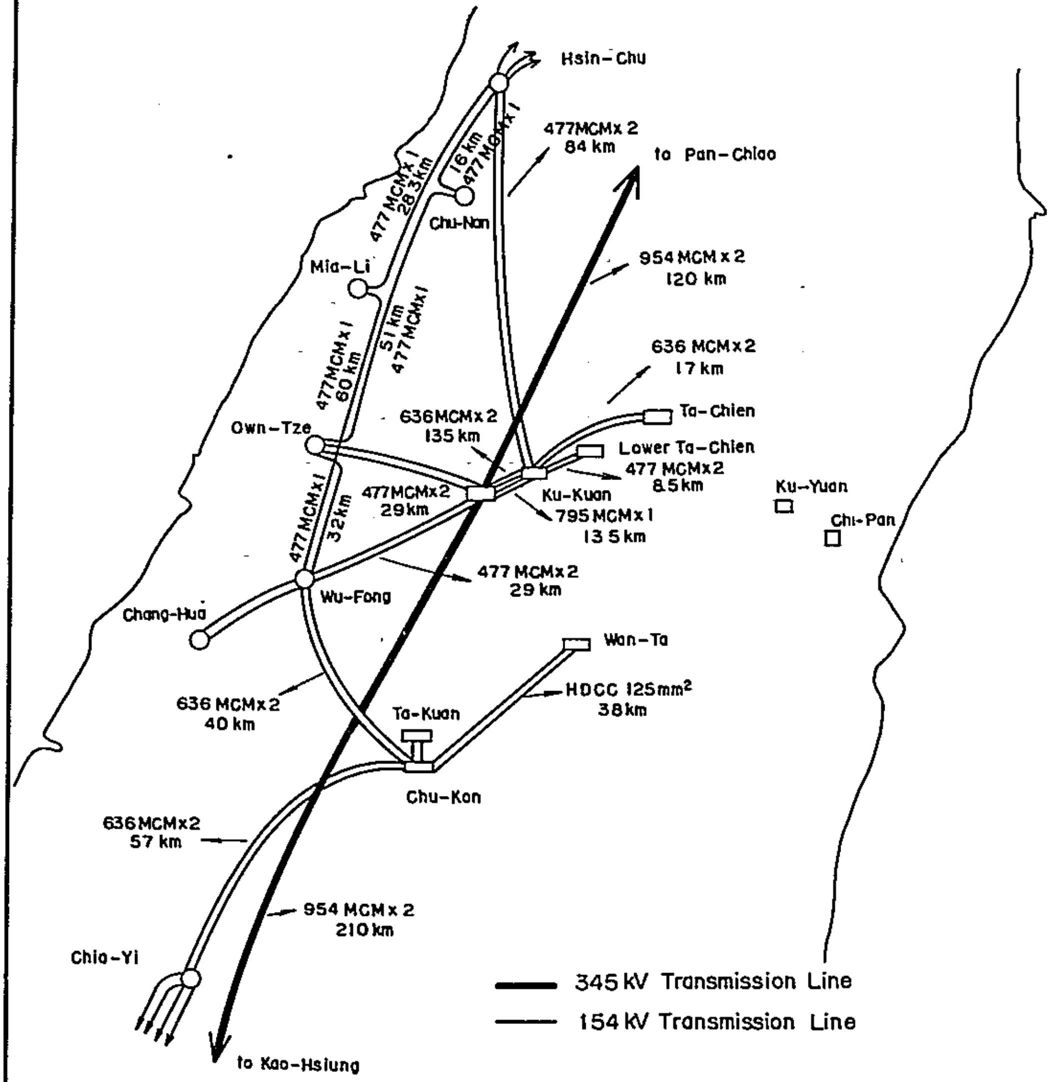


Fig 6-9 General Map of Major Transmission Line System in Central Area (1976)



Ku-Yuan ~ Ta-Chien
Ku-Yuan ~ Wan-Ta } ------ About 40km

6.7 Telecommunication System

6.7.1 Basic Conditions

The basic conditions of the telecommunication plan are as described below.

(1) The central load-dispatching office is in Taipei head office, and load-dispatching orders to the power stations of this project will be issued from Taipei.

(2) Between the Taipower head office and Tachien Power Station, there is already a microwave channel and the connection between the existing channel and the new channel will be made by a base group (60 to 108 kc, 12 ch.) of a sub-carrier wave as recommended by CCITT.

(3) The telecommunication channel between Tachien, Kuyuan, Chipan Power Stations is determined to facilitate connection with the existing microwave channel and the future increase of channels.

(4) As for the maintenance of the transmission line between Tachien, Kuyuan and Chipan Power Stations bordering the watershed between Tachien Power Station and Kuyuan Power Station, the western side will be administered by Tachien Power Station and the eastern side will be administered by Kuyuan Power Station.

6.7.2 Outline of Plan

1. Microwave Radio Telephone (Communication Channels for Load-Dispatching and Maintenance)

Between Tachien, Kuyuan and Chipan Power Stations microwave channels of 7,000 MH_z will be provided as a multipurpose communication system for load-dispatching, maintenance, telemetering carrier relay, fault locater, etc.

2. VHF Radio Telephone (Channels for Line Maintenance and Plant Maintenance)

(1) VHF relay units will be provided in the various hills near Tachien Power Station and Kuyuan Power Station as channels for line maintenance. And through these VHF relay units individual VHF channels for line maintenance will be provided for communication between Tachien Power Station and VHF mobile units in the western area from the watershed, and between Kuyuan Power Station and the eastern area from the watershed.

Communication for line maintenance between Tachien and Kuyuan Power Stations the microwave channel between the two stations will be used.

(2) As a dam maintenance communication system between Power Station Tuo-Po-Kuo Dam and Taosai Dam, a telephone channel through the VHF relay unit will be provided and it will be set at the same site as the VHF relay unit for line maintenance. And between Chipan Power Station and Kuyuan Dam, telephone channels for dam maintenance will be formed through a microwave channels between Kuyuan Powerhouse and Chipan Powerhouse and VHF radio telephone between Kuyuan Powerhouse and Kuyuan Dam.

Furthermore, at Tuo-Po-Kuo and Kuyuan Dams, water level gages will be installed and through common use of the dam maintenance VHF channel, the water levels at Tuo-Po-Kuo Dam and Kuyuan Dam will be telemetered to Kuyuan Power Station and Chipan Power Station respectively.

3. Power Line Carrier Telephone Channel

As reserve channels to the microwave circuit, power line carrier telephone channels will be provided between Tachien Power Station and Kuyuan Power Station and also between Kuyuan Power Station and Chipan Power Station.

CHAPTER 7

DESCRIPTION OF STRUCTURES AND EQUIPMENT

CHAPTER 7

DESCRIPTION OF STRUCTURES AND EQUIPMENT

7.1 Structures

The major civil engineering structures of Kuyuan Power Station and Chipan Power Station are shown in Dwgs. 22, 23 and 24.

7.1.1 Regulating Dams and Intake Dams

The regulating ponds of Kuyuan Power Station and Chipan Power Station are selected to be at the Tuo-Po-Kuo and Kuyuan sites respectively.

In selecting the dam sites, the topography, geology, design flood discharge, regulating capacity and appurtenant structures of each dam and power station have been taken into consideration. As both power stations are run-off-river type with daily regulating ponds the heights of the dams are determined based on the two conditions, that is, the necessary regulating capacities would be secured and design flood discharge released. The type of the dams, in view of the flood characteristics, flood discharge, topography and geology of the dam sites, is selected to be the concrete gravity type.

The design flood discharge of Tuo-Po-Kuo Dam and Kuyuan Dam are calculated to be 2,100 m^3/sec at Tuo-Po-Kuo Dam and 3,400 m^3/sec. at Kuyuan Dam.

The effective capacities of the regulating pond are selected based on peaking hours and average run-off of dry 10 days of each month determined in Appendix 2. As a result, the effective capacities of Tuo-Po-Kuo Regulating Pond and Kuyuan Regulating Pond are 360,000 m^3 and 290,000 m^3, respectively.

The spillway of Tuo-Po-Kuo Dam will be provided with a tainter gate 10.0 m wide and 19.0 m high and a roller gate 5.0 m wide and 7.0 m high which will be used for both spilling and sand-flushing. The spillway of Kuyuan Dam will be provided with two tainter gates 10.0 m wide and 19.0 m high and a roller gate 3.0 m wide and 4.0 m high for design flood discharge. It is considered that at the times of small-scale flood the roller gates installed at each dam would be operated, in order to avoid the operation of the larger tainter gates as much as possible.

The spillway gates will have the same widths for both regulating pond dams and the stop-logs, which also have the same width so that they can be used in common will be installed in front of these gates for maintenance of the gates.

In selecting each dam site the topography and geology are taken into consideration to lower the height of the dam as low as possible. Among the intake dams for Kuyuan Power Station, Lungchi, Hualu and Fuhsing Dams have been selected at the sites where the minimum falling height can be obtained so that entraining of air could be avoided as the intaken water flows down the pressure tunnels directly.

The stream on which Hsi-Tuo-Po-Kuo Dam, one of the intake dams for Chipan Power Station, is to be constructed, joins the main stream in the form of waterfall, therefore the intake will be performed upstream of the waterfall. As for Ku-Pei-Yang Intake Dam, the site has been chosen at the upstream of the landslide area on the left bank to avoid the landslide area.

As for Laohsi Chi Intake Dam, the water will be taken directly into the pressure tunnel. Therefore, the structure should be designed to prevent entraining of air and inflowing of sediment as much as possible.

7.1.2 Pressure Tunnel

Pressure tunnels will be as shown in Dwg. 22. The pressure tunnel of Kuyuan Power Station is 12,500 m long from Tuo-Po-Kuo Intake to the surge tank, and the cross section is designed to convey the maximum discharge of 20.8 m^3/sec. As a result, the shape is determined to be circular. Although there will be dry season inflows from the Lungchi, Hualu and Fuhsing intake sites, since their quantities are small, the inner diameter from Tuo-Po-Kuo Intake to the Lohsao Combining Tank will be 3.30 m, while from Lohsao Combining Tank to the surge tank the inner diameter will be 3.40 m in consideration of inflow from the Taosai System.

The pressure tunnel of Chipan Power Station will be 10,700 m long from the Kuyuan Regulating Pond Intake to the surge tank with the maximum discharge of 36.3 m^3/sec. The design will be circular with an inner diameter of 4.15 m.

The pressure tunnels of both power stations will be lined with concrete for the entire sections and reinforced with steel bars wherever necessary. Grouting will be performed around the tunnels for the entire sections and at each section of faults which exist in several places, temporary linings will be performed prior to the final linings.

7.1.3 Non-Pressure Tunnels

The design discharge capacities of the non-pressure tunnels for Kuyuan and Chipan Power Stations are shown in Table 7-1. The design discharge has been obtained based on the ratio between the maximum discharge of each power station and the catchment area at each intake site. For the discharge of not more than 4 m^3/sec, tunnels will not be lined except the invert sections, while for the greater discharge, the tunnels will be lined of the inverts and the side walls.

The grade of the tunnels will be 1/1,000 to 1/800, and it is assumed that fully lined tunnel sections will cover 30% of the total length. Roughness coefficients used in the calculation of discharge are $n = 0.014$ for concrete lining and $n = 0.035$ for rock surface.

7.1.4 Combining Tank and Shaft

The combining tank for Kuyuan Power Station will be provided near Lohsao. In order to prevent the pressure caused in Taosai Non-Pressure Tunnel at the time of shutting down the turbine, syphons will be provided for inflow of water from Non-Pressure Tunnel and the structure will be such that entraining of air will be prevented.

To divert flows from Lungchi, Hualu and Fuhsing dams to Kuyuan Power Station inclined shafts will be constructed to lead water into the pressure tunnel excavated underneath the rivers. The same method will be employed for the diversion of water from Hsiutu Chi and Laohsi Chi dams to Chipan Power Station. The shafts will be designed to prevent air from entering into the tunnels.

Table 7-1 Maximum Discharge of Non-pressure Tunnels

	Catchment Area (km^2)	Length of Tunnel (m)	Discharge (m^3/s)
(Ku-Yuan Power Station)			
Tao-Sai Tributary ~ Tao-Sai Dam	14.32	2,600	1.4
Tao-Sai ~ Hsiao-Wa-Hei-Er	38.73	6,950	4.5
Hsiao-Wa-Hei-Er ~ Hsi-Hsiao-Wa-Hei-Er	32.30	2,000	7.2
Hsi-Hsiao-Wa-Hei-Er ~ Combined Tank	7.20	3,100	7.8

	Catchment Area(km^2)	Length of Tunnel (m)	Discharge (m^3/s)
(Chi-Pan Power Station)			
Upper Tien-Hsiang~Ku-Pei-Yang	16.00	2,900	1.6
Ku-Pei-Yang~Man-Tou Shan	13.14	3,600	3.0
Man-Tou Shan~Ku-Yuan	37.00	2,850	6.8

7.1.5 Surge Tank

The surge tanks of Kuyuan Power Station and Chipan Power Station will be the water chamber type in consideration of draw-down of regulating ponds, lengths of pressure tunnels, heads, locations of powerhouses, etc.

The determination of cross sections and lengths of the surge tanks are based on the following particulars :

The maximum discharge would be 20.8 m^3/sec and 36.3 m^3/sec, respectively with surging calculations based on upsurging at shut-down of turbine under normal high water level and down surging by sudden load increase from 50% to 100% under low water level.

Sand flushes will be provided near the surge tanks for both power stations to flush sediment in the tunnels together with water before inspection of the pressure tunnels.

7.1.6 Penstocks

For both Kuyuan and Chipan Power Stations, penstocks will be provided in inclined shafts excavated underground. After placing the penstock in the shafts, void around the penstock pipe will be filled with concrete. In calculating the weight of the pipe the penstock is expected to support 100% of the design pressure. At the high pressure zones, high tension steel is to be used.

The lengths of penstocks will be approximately 818 m at Kuyuan and 773 m at Chipan and each pipe is branched out at the bottom to conduct water into two turbines at each powerhouse.

7.1.7 Powerhouse

The powerhouses, considering topography and geology, conditions within the catchment areas and relations between pressure tunnels and regulating ponds, will be selected to be underground type at both Kuyuan and Chipan Power Stations.

The number of generating units will be two 46,000 KW units for Kuyuan Power Station and two 74,000 KW units for Chipan Power Station in consideration of the conditions of operation, stability at the times of accident and for economy.

As both power stations are located in rugged mountainous areas and the powerhouses will be constructed inside the bed rock, the arrangements of equipment are determined to be as compact as possible. Further, the main transformers will be placed underground and the power will be conducted to outdoor switchyards by using cable ducts.

The access tunnels connecting to the existing East-West Cross Island Highway will be graded at 1:10 to 1:11. For ventilation of the underground powerhouses, large capacity ventilation facilities will be installed with suction through cable shafts and exhaust through the access tunnels.

7.1.8 Tailrace

The tailrace of Kuyuan Power Station will be a 160 m long gravity tunnel with the design discharge of 20.8 m^3/sec. The shape will be horseshoe-shape with the inner diameter of 3.3 m, and the entire length will be lined with concrete.

The tailrace of Chipan Power Station is designed to be 130 m long pressure tunnel, with the discharge of 36.3 m^3/sec. The inner diameter will be 4.20 m with the entire length lined with concrete and reinforced with steel bars. A tailrace gate will be installed for each turbine and will be controlled from a gate chamber.

As the water discharged from Chipan Power Station will exceed the discharge of Li-Wu Power Station, the tailrace cannot be connected directly to the headrace tunnel of Li-Wu Power Station. Therefore, it will be discharged directly into Chipan Regulating Pond.

7.2 Generating Facilities

7.2.1 Kuyuan Power Station

(1) Turbines and Generators

The hydraulic conditions of Kuyuan Power Station, 527.1 m in head and 10.4 m^3/sec in per unit discharge, are beyond the economical limit to adopt Francis turbines. Although technically possible, it is very rare in the world and will involve various technical problems to install a Francis turbine for such a high head. Therefore, for Kuyuan Power Station, Pelton turbines are considered as the most suitable ones since the head is over 500 m.

Of the Pelton turbines, horizontal shaft 2-jet type or vertical shaft 4-jet type are conceivable. In the case of Kuyuan Power Station, the vertical shaft 4-jet is advantageous since it will save excavation of the underground powerhouse and a higher revolving speed can be obtained with 4-jet with a smaller unit.

The generators will be of an enclosed-hood air-circulation type, and the voltage will be 13.2 KV, which will be the most economical for this range of capacity. Control system of turbines and generators will be one-man control system, as well as at Chipan.

(2) Transformers and Appurtenant Equipment

The power stations of the Li-Wu Chi System are expected to play an important role in the power system in the future as peak load stations. Therefore, taking the reliability, large capacity and problems of transportation into consideration the unit system will be adopted for the main transformers.

As the power stations will be built underground because of the topography, it will be difficult for outdoor switchyard of suitable size to be provided in the vicinities of the power stations. For this reason transformer rooms will be provided underground. The transformers will be 3 phase, oil-immersed, water-cooled type. The output of the transformers will be conducted above ground through cable ducts using 154-KV cables, and from here it will be conducted by overhead lines to outdoor switchyard located at a considerable distance from the powerhouse.

Because of these peculiar conditions due to topography, the generators of high-pressure synchronized system are adopted and parallel circuit breakers will be installed at the outdoor switchyard.

Further, in order to protect the main transformers and 154-KV cables from lightning strokes which may hit the 154-KV overhead lines between the outdoor switchyards and the entrances of the cable ducts, lightning arrestors will be provided at the ends of cable ducts.

In order to hold down the lengths of the enclosed bus lines between the generators and main transformers as much as possible from a civil engineering standpoint, the distances between powerhouses and transformer rooms will be made as short as permissible. As for transformer rooms, they will be at the same elevations as the assembly rooms of the powerhouses so that overhead travelling cranes for assembly of turbines and generators can be utilized for assembly of the main transformers.

(3) Design Data

a) Hydraulic Turbine

Type	Vertical Shaft, Pelton Type
Number of Units	2 sets
Output	47,500 KW per unit
Effective Head	527.1 m
Maximum Discharge	10.4 m^3/sec per unit
Revolving Speed	450 rpm

b) Generator

Type	Vertical Shaft, Enclosed Hood, Air Circulation Type
Number of Units	2 sets
Output	51,000 KVA per unit
Voltage	13.2 KV
Frequency	60 c/s
Power Factor	0.9

c) Main Transformer

Type	Indoor, Three-phase, oil-immersed Water-cooled Type
Number of Units	2 sets
Capacity	51,000 KVA per unit
Voltage	13.2/154 KV

d) Outdoor Switchyard

Bus Line Voltage	154 KV

Number of Outgoing Circuits	3
Number of Circuit Breaker	5 sets

7. 2. 2 Chipan Power Station

(1) Turbines and Generators

For the hydraulic conditions that the effective head is 480. 6 m and the maximum discharge is 18. 15 m^3/sec per unit, either Pelton Turbine or Francis Turbine would be applicable. However, in consideration of the various conditions listed below, the Francis type would be advantageous for Chipon Power Station.

1) Comparing the two types from the aspect of turbine efficiency, the maximum efficiency is higher for the Francis type, but at low loads the Pelton type is of greater advantage.

Chipan Power Station being a peak load station, the Francis type with better efficiency under heavy loads will be advantageous.

2) In the case of Francis Turbine, the elevation of the turbine center can be set below the water level of existing Chipan Dam so that the effective head can be utilized to a greater advantage in comparison with the Pelton type.

3) In the case of Francis Turbine, the revolving speed of the turbine and generator can be selected at a high level and the equipment can be minimized to an economy size.

4) The structure of the equipment is simple in the case of Francis Turbine and the maintenance is easily performed.

5) Although there are a few examples of Francis Turbines in the world under a high head exceeding 450 m, there has recently been a high-head, large-capacity Francis Turbine made and installed in Japan for 465 m and 66 MW so it is not thought that there will be much problem technically in this regard. The generators will be of an enclosed-hood, air-circulation, 3-phase, synchronized type and the voltage will be 16. 5 KV in view of the large capacity. Control of turbines and generators will be achieved by the one-man control system.

(2) Transformers and Appurtenant Equipment

The design of facilities has based on the same concept as for Kuyuan Power Station.

(3) Design Data

a) Hydraulic Turbine

Type	Vertical Shaft, Francis Type
Number of Units	2 sets
Output	76,500 KW x 2
Effective Head	480.6 m
Maximum Discharge	18.15 m^3/sec x 2
Revolving Speed	600 rpm

b) Generator

Type	Vertical Shaft, Enclosed Hood, Air Circulation Type
Number of Units	2 sets
Capacity	82,000 KVA x 2
Voltage	16.5 KV
Frequency	60 c/s
Power Factor	0.9

c) Main Transformer

Type	Indoor, three-phase, oil-immersed water-cooled type
Number of Units	2 sets
Capacity	82,000 KVA x 2
Voltage	16.5/154 KV

d) Outdoor Switchyard

Bus Line Voltage	154 KV
Number of Outgoing Circuit	1
Number of Circuit Breakers	3 sets

7.3 Transmission Line

The routes of the transmission lines are selected as shown in Dwg. 25. Since the topography of this area is extremely rugged and a tall mountain range must be crossed, in planning the mechanical design of supporting structures and dielectric design of insulators special attentions have been given. Supporting structures will be steel towers (Dwg. 26) while insulators will be 250 mm suspension insulators with various number on a string as necessary. The outlines of the facilities are given below.

Section	Chinpan - Kuyuan	Kuyuan - Tachien
Distance	12 km	39 km
Voltage	154 KV	154 KV
Number of Circuits	1 cct	2 cct
Support	Steel Tower	Steel Tower
Insulator	250 mm Standard Suspension Insulator x 10 discs	250 mm Standard Suspension Insulator x 14 discs
Frequency	60 c.p.s.	60 c.p.s.
Conductor	477 MCM ACSR	636 MCM ACSR
Overhead Ground Wire	1 line of 90 mm^2GSC	1 line of 90 mm^2GSC

CHAPTER 8

CONSTRUCTION SCHEDULE AND PROCEDURE

CHAPTER 8

CONSTRUCTION SCHEDULE AND PROCEDURE

8.1 Basic Construction Schedule

The structures to be constructed in the Li-Wu Chi Development Project, as described in Chapter 7, consist of 2 dams with regulating ponds, 15 small-scale dams, non-pressure tunnels of 24 km in total length, large and small pressure tunnels of 23 km in total length, 2 underground powerhouses, penstocks of these powerhouses embedded in inclined shafts, surge tanks and tailrace tunnels.

Of these structures, the only outdoor works are the dams, and the greater part of the work will be underground. Since none of the dams is of a large scale, it is thought that at present there will be no special difficulties so long as care-of-river is duly excercised. Of the underground works, the tunnel construction for a total length of 47 km will have an overwhelming influence on the construction period and construction cost of this Project.

The Project Area is extremely rugged all over there being rockslides everywhere, and it is thought that the construction of access roads for delivery of materials and access and agress of personnel to work sites other than those places immediately along the East-West Cross Island Highway will have a great influence on the entire construction schedule.

The construction period required for completion of this Project is thought to be at least 42 months taking account of the overall work procedure, the sizes of construction machinery to be used, the various related matters described in the following sections and the construction plans.

The construction schedules of major works are indicated in Table 8 -1.

8.2 Local Conditions and Relevant Matters

8.2.1 Meteorological Conditions

According to the information so far obtained, as outlined below, there will not be the period that the construction works become impossible merely because of meteorological conditions, except when the transportation of construction materials is held up by heavy rains or typhoons.

The temperature averages about 20°C annually and even at the intake dam sites of the Kuyuan Power Generation Project the temperature rarely drops below 0°C. The highest temperature in the summer is about 38°C.

The annual precipitation is about 2,000 mm, and the number of rainy days is about 130 days a year. The rainy season is generally for six months between May and October. In July, August and September, rain is especially heavy. Although there is the record of 800 mm in the past in daily maximum rainfall, considering frequency of occurrence, about 500 mm of daily rainfall should be considered in planning the construction works.

8.2.2 Transportation

(1) Transportation Routes

Transportation routes to Hualien City which will be the base of the operations for this development project consist of air, land and sea routes.

a) Air Route

There are daily scheduled flights from Taipei to Hualien Airport. The time required is 40 minutes.

b) Land Route

As overland routes there are the Suhua Highway from the railroad terminal Suao in Northern Taiwan to Hualien and the East-West Cross Island Highway from Taichung City in Western Taiwan which joints the Suhua Highway at Li-Wu Power Station. Descriptions of the two highways will be given later.

c) Sea Route

Hualien Port which has been opened as an international port for only a short while is a dredged harbor with approximately 400 m of berths for vessles of maximum draught of 7.2 m (total berth length of approximately 800 m) where lumber, cement, grains and fertilizer are loaded and coal, oils and fats are unloaded. The port is well equipped with landing places and warehouses and there are cranes for unloading cargoes so that not only the imported equipment and materials, but the construction materials from the sourthern or northern parts of Taiwan can be landed at this port.

(2) Transportation Routes to Construction Sites and Their Conditions

The transportation routes to the construction sites are the Seaside Route from Hualien City to Tai-Lu-Kuo along the Suhua Highway for 25.5 km from Tai-Lu-Kuo along the East-West Cross Island Highway to Tienhsiang for 19.4 km, and the 173 km long Mountain Route from Taichung City over the East-West Cross Island Highway to Tienhsiang.

Table 8-1 Construction Schedule

Item	Specification	1st year				2nd year				3rd year				4th year			
Preparation Works																	
Electric Power for Construction	Lump-Sum	■	■	■	■												
Base Camp & Other Building	Lump-Sum	■	■	■													
Ku-Yuan Power Station																in service	
Access Road	46,000 m	■	■	■	■	■	■	■	■								
Dam & Intake	Lump-Sum					■	■	■	■	■	■	■	■	■	■		
Pressure Tunnel	3.3 m x 10,100 m 3.4 m x 2,400m Max. L = 2,400 m			■	■	■	■	■	■	■	■	■	■	■	■		
Non-Pressure Tunnel	2.0~2.8 x 14,650 m Max. L = 3,100 m			■	■	■	■	■	■	■	■	■	■	■	■		
Surge Tank	Lump-Sum			■	■				■	■	■	■	■	■	■		
Penstock	"					■	■	■	■	■	■	■	■	■	■		
Powerhouse	"			■	■	■	■	■	■	■	■	■	■	■	■		
Electrical Equipment	46,000KW x 2									■	■	■	■	■	■		
Tailrace	Lump-Sum			■	■					■	■	■	■	■	■		
Chi-Pan Power Station																	
Access Road	13,500 m	■	■	■													
Dam & Intake	Lump-Sum							■	■	■	■	■	■	■	■		
Pressure Tunnel	4.15 m x 10,700 m Max. L = 3,300			■	■	■	■	■	■	■	■	■	■	■	■		
Non-Pressure Tunnel	2.0~2.8 m x 9,350 m Max. L = 3,600 m			■	■	■	■	■	■	■	■	■	■	■	■		
Surge Tank	Lump-Sum			■	■				■	■	■	■	■	■	■		
Penstock	"					■	■	■	■	■	■	■	■	■	■		
Powerhouse	"			■	■	■	■	■	■	■	■	■	■	■	■		
Electrical Equipment	74,000 KW x 2									■	■	■	■	■	■		
Tailrace	Lump-Sum					■	■					■	■	■	■		
Transmission Line	51 km									■	■	■	■	■	■		

The conditions of these transportation routes such as width, maximum grade, minimum turning radius, etc. are given in Table 8-2.

There are the total of 39 tunnels between Tienhsiang and Tai-Lu-Kuo of which the longest is 183 m. The cumulative total length of 6 tunnels of 100 m or longer is 1,889 m. There are 8 tunnels with width of not more than 5 m totalling the length of 440 m. Two tunnels less than 4.5 m wide comprise the length of 55 m. There are 4 tunnels totalling 96 m in length which are of less than 5 m in height.

Table 8-2 Condition of Transportation Road

Section	Length (km)	Width (m)	Min. Turning Radius (m)	Grade (%)	Condition of Road Surface	Limited Load of Bridge
(1) Su-Hua Highway						
Su-Ao ~ Tai-Lu-Kuo	93.0	4	15	10	Gravel	H-20
Tai-Lu-Kuo ~ Hua-Lien	25.5	10	30	-	Asphalt	H-20
(2) E-W Cross Island Highway						
Tai-Lu-Kuo ~ Tien-Hsiang	19.4	4.5	20	10	Asphalt	H-20
Tien-Hsiang ~ Loh-Sao	16.1	4	15	15	Asphalt	H-20
Loh-Sao ~ Ta-Yu-Lien	42.8	3	14	15	Gravel	H-20
Ta-Yu-Lien ~ Tai-Chung	145.0	-			Gravel	

Note: From Review Report 1966 - Taipower

8.2.3 Highway Transportation

The construction materials which can be purchased in Eastern Taiwan are cement and lumber and all other materials must be transported from Southern or Northern Taiwan. The highways to the Eastern Area are the beforementioned Suhua Highway and East-West Cross Island Highway on which, under the present conditions, the traffic is closed for considerable periods in a year because of typhoons or heavy rainfalls.

The standard domestic freight charge in the case of overland transportation according to the regulations of the Highway Bureau is NT$1.6 per ton kilometer. At this rate, the charge between Taichung and Tienhsiang would be NT$340/ton. On the other hand, according to the Regular Line Freight Tariff established on June 1, 1966, the charge by sea is NT$55/ton between Cheelung and Hualien and NT$100/ton between Kaohsiung and Hualien and even if stevedoring and overland freight from Hualien to Tienhsiang is added, the sea route is clearly cheaper.

From the above, it is thought that even domestic materials will be transported by sea and landed at Hualien Port. Therefore, a material depot will be provided at Hualien Port and using this depot as a base, the transportation to construction sites will be made by truck.

8.2.4 Access Roads

The conditions to be met by access roads to the various tunnel portals and other construction sites are thought to be as follows:

(1) All materials, not only construction materials, but also foodstuffs, other necessary materials, machinery and equipment must be transported safely and with reliability.

(2) After completion of construction, maintenance and operation of structures should not be hindered.

(3) During the construction works, rapid transportation must be possible at all times.

(4) At the same time that construction costs should not harm the economics of the Project, the transportation costs should be low.

8.2.5 Construction Materials

(1) Domestic Materials and Imported Materials

Construction materials such as large-sized section steel, pits, rods, steel frames and the accessories, air-entering agents and welding rods will be required to be imported, but other materials such as cement, reinforcing steel, lumber, fuel, oil and fat, and explosives can all be purchased domestically without using the foreign currency.

(2) Cement

Normal portland cement in 50-kg bags produced at the nearby Hualien Plant of the Taiwan Cement Company will be available.

(3) Reinforcing Steel, Lumber, Explosives, Oil and Fat and Other Domestic Materials

Differently shaped steel bars of about 9 to 25 mm in diameters are being manufactured in the southern part of Taiwan to meet the demand of the entire country.

Timbers and Lumbers are available at Hualien.

Explosives consisting of dynamite, detonators and fuses are all produced in the Northern Taiwan.

Regarding steel, small-sized section steel up to 75 mm can be produced domestically, but concerning section steel large than 75 mm and thick steel plates, the domestic production is still only at the stage of preparation.

Various materials other than the imported materials previously mentioned can be purchased in the domestic market.

8.2.6 Aggregates

(1) Sand and Gravel Deposits

The sand and gravel deposits of the Project Area are mainly at three locations: approximately 1 km upstream of Tuo-Po-Kuo Dam, the upstream river bed of Meiyuan on the Taosai Chi, and downstream of the existing Li-Wu Power Station Chipan Dam on the mainstream of the Li-Wu Chi.

(2) Other Aggregate Sources

As sources of aggregate other than sand and gravel deposits, it is conceivable that tunnel excavation muck can be crushed or rock from slides can be used.

8.2.7 Power for Construction

In this Project Area, the supply of power for general demand is being made only to meet the demand of the Tienhsiang Area.

For power required for the construction it is conceivable to use diesel generators or to receive power from elsewhere by transmission lines. It is thought to be appropriate to use the both for this Project.

8.3 Construction Procedure of Major Structures

8.3.1 Kuyuan Power Station Structures

(1) Tuo-Po-Kuo Regulating Pond Dam

Excavation of the temporary diversion tunnel and the abutments on both banks will be carried out in the rainy season, and with the start of the dry season in October the river flow will be switched to the temporary diversion tunnel and excavation of the river bed will be performed. Following this, concrete will be placed in the river bed during the dry season up to at least the original level of the river bed so that overflow of flood during the rainy season will not obstruct construction work.

(2) Intake Dams

The topographical conditions of all locations of the intake dams are bad, but as the flood discharges are not great, it should be possible for the dams to be constructed within one dry period by coffering one half of the river after another.

(3) Pressure Tunnels

As the total length of the pressure tunnels is 12.5 km, adits for excavation will be provided at Tuo-Po-Kuo, Lung Chi, at a point between the above two, Fushing Chi, Losao, at a point between the above two, and near the surge tank for excavation from both ends. The excavation will be full-section mechanical excavation. The excavation muck will be loaded on trolleys by shovel loaders of about 3 m^3 capacity and will be hauled out using diesel engine cars.

After completing excavation, concrete will be conveyed by mixers and placed by pumps.

(4) Non-Pressure Tunnels

All the waterway tunnels from Taosai Chi to the pressure tunnel will be non-pressure tunnel.

The excavation will be mechanical full-section excavation. Concrete will be hauled in using pan-type trolleys and diesel engine cars, and placed mannually.

The tunnel lengths from the East Taosai to the Taosai Tributary Intake Dams will be comparatively short and of the minimum cross section so that jumboes and diesel engine cars will not be used. For loading of excavation muck, bucket loaders will be used. It should be possible to carry out construction without any other special mechization.

(5) Surge Tank

Excavation of the upper chamber will be performed utilizing air exhaust shafts from which excavation muck will also be hauled out. The excavation of the vertical shaft and lower chamber will be performed utilizing an inclined shaft provided between the lower chamber and the work adit to be used in common to carry the excavation muck out and to bring in the penstock pipe. The excavation will be completed before delivery of pipe. After completion of the excavation, concrete placement will be made utilizing the air exhaust shafts and work adits.

(6) Penstock

The excavation of the inclined shaft for the penstock will be carried out after digging a pilot shaft, then the shaft will be expanded from the upper part.

Three adits will be provided in the intermediate section.

The excavation muck will first be placed in bins from which it will be loaded on trolleys to be pushed outside manually. After completion of the expansion of the shaft, the penstock pipe will be hauled in through the work adit at the bottom part of the surge tank. After installation of the penstock concrete will be placed to fill void around the penstock.

(7) Powerhouse

On starting the construction of the powerhouse, the construction of the cable duct and access tunnel will be hurried simultaneously and after the excavation and placement of concrete for arch of ceilling the powerhouse are performed the main equipment room will be excavated. The excavation of the main equipment room will be done by bench cut to the level of the access tunnel with tractor shovels or vertical shaft muck bins used to load the muck on dump-trucks for hauling to the outside through the access tunnel. Below the level of the access tunnel, the tailrace tunnel will be utilized for hauling out the muck. After completion of the excavation, the overhead travelling crane will be installed followed by installation of turbines and generators.

(8) Tailrace Tunnel

The tailrace tunnel will be utilized as a route for hauling out the excavation muck of the lower part of the powerhouse. After the hauling out, concrete will be placed.

8.3.2 Chipan Power Station Structures

(1) Kuyuan Regulating Dam

Care of river for the construction of Kuyuan Dam will be by a temporary diversion tunnel. As in the case of Tuo-Po-Kuo Dam, the excavation of the river bed portion and concrete placement up to the original level of the river bed will be performed in one dry season.

(2) Non-Pressure Tunnels

All waterway tunnels totalling 9.35 km in length will be non-pressure tunnels and the work will be performed by the same method as for the Kuyuan Non-Pressure tunnels.

(3) Pressure Tunnel

The total length of the pressure tunnel will be 10.7 km. Work adits for excavation will be provided at Hsiutu Chi, Laohsi Chi, Yen-Tzu-Kou and the surge tank. The construction method will be roughly the same as that described for the Kuyuan Power Station pressure tunnel.

(4) Surge Tank

The method of constructing the surge tank will be roughly identical to the method of the surge tank for Kuyuan Power Station.

(5) Penstock

Excavation of the inclined shaft for the penstock will be made by digging a pilot shaft and then expending from the upper part. Three adits will be provided in the intermediate section. Excavation muck will be loaded onto trolleys from muck bins and hauled outside manually. After expansion of the shaft, penstock pipe will be hauled in from the work adit at the bottom part of the surge tank and upon installation of the pipe, concrete will be placed.

(6) Powerhouse and Tailrace

The construction of the powerhouse will follow roughly the same method as the powerhouse of Kuyuan Power Station.

The tailrace will connect to the regulating pond of the existing Li-Wu Chi Power Station.

CHAPTER 9

COST ESTIMATE

CHAPTER 9.

COST ESTIMATE

9.1 Basic Conditions

In consideration of the natural conditions of the Project Sites, regional conditions, scale of the construction, technological levels presently conceivable, data of past construction works in Taiwan and the available data of similar works in Japan, the construction cost is estimated on the basis of prices of commodities as of March, 1968.

The basic conditions for construction cost estimate are as follows;

9.1.1 Scope of Cost Estimates

The scope of construction cost estimate covers the construction of the Kuyuan and Chipan Power Stations and also of the transmission line connecting these power stations with the switchyard of the Tachien Power Station.

9.1.2 Cost of Civil Works

(1) The quantities of construction has been based on the preliminary design drawings attached to this Report and, whenever necessary, supplementary drawings.

The length of the tunnels are based on topographic maps on the scale of 1 : 50,000.

(2) The unit price of materials and the labor wage procured in Taiwan are based on prices as of March, 1968.

The unit price of various types of labor wages on the basis of 8 net working hours per day is as follows:

The unit price of the materials is on the basis of delivered prices at Haulien on the east coast of Taiwan, and all imported materials are assumed to be imported from Japan.
Insert Table 9-2

(3) The unit price of construction works has been estimated based on the records in Taiwan and also on the data obtained from the same type of work in Japan, taking the local conditions and construction schedule into

consideration.

The unit prices used in the "Review Report of Hydroelectric Development Projects on Li-Wu Chi River (Dec. 1966)" are amended by applying prices of commodities as of March, 1968.

(4) Custom duties on imported construction materials and machinery are included in the unit price.

(5) Contingencies are included in the amount equivalent to 20% of the costs of civil works.

Table 9-1 Unit Labour Wage

Class	Unit Cost (NT$)
Foreman	110
Equipment Operator	110
Helper	90
Driver	90
Driller, Underground Work	110
Driller, Open Excavation	90
Mechanic, Electrician	90
Skilled Laborers	90
Common Laborers	60

Table 9-2 Unit Cost of Imported Material

Material	Unit	C.I.F. US$	Tax NT$	Total NT$
Large Formed Steel	ton	124	1,000	6,000
Steel Plate	"	127	1,400	6,500
Steel Supporter	"	168	1,400	8,100
Boring Bit	p.c.s	6.1	36	280
Boring Rod	kg	1.75	10	80

Table 9-3 Unit Cost of Material Available in Taiwan

Material	Unit	Specification	Unit Cost
Cement	ton	50kg Sack	857
Fly Ash	"	40kg Sack	80
Reinforcement Bar	"	ϕ 9 - 25 mm	4,500
Timber	m^3	Sawed	3,500
Timber	"	Materials	1,600
Small Formed Steel	ton	below 75 mm	4,900
Steel Frame	"		4,900
Steel Plate	"	3 mm～25 mm	5,500
Nail	kg	-	7
Iron Wire	ton	-	6,100
Gasoline Oil	liter	-	5.4
Light Oil	"	-	4.0
Gear Oil	"	-	9.0
Mobile Oil	"	-	6.5
Grease	kg	-	29.7
Dynamite	"	-	18.5
Detonator	piece	-	1.4
Fuse	m	-	1.6

9.1.3 Cost of Equipment

(1) The principal equipment including gates, penstock pipes, turbines generators, etc. are assumed to be imported from Japan.

(2) The costs of equipment are estimated by adding ocean freight, marine insurance, import duties, cost of inland transportation in Taiwan and installation costs at the construction site to the FOB prices at a Japanese port.

(3) Contingencies are included in the amount equivalent to 10% of the costs of equipment.

9.1.4 Various Taxes and the Levy

(1) The import duty is calculated by the CIF price plus 10 percent and multiplying by the rate described in the Taipower Planning Standard.

(2) The harbor taxes are estimated at the rate of 3.75% of CIF price plus 10%.

(3) Additional taxes are estimated at the rate of 20% of the import duties.

9.1.5 Overhead Cost

Power for construction works, supervision expenses for design and construction works and administration expenses, etc. are estimated as overhead cost.

Contingencies equivalent to 15% of the overhead cost are included in the amount.

9.1.6 Land Acquisition Cost

The Project Area is comprised mostly of the state-owned land and partly private property. However, as indemnification for such privately-owned land is assumed to be so small that it can be financed under the item of contigencies, therefore no independent item for indemnification for property purchase is listed in the cost estimate.

9..1.7 Interest During Construction

The interest during construction has been estimated in accordance with the construction period and the average annual expenditure coefficient described in Chapter 8.

The same interest rate has been assumed on both domestic and foreign currencies, and the rate of interest is assumed at 6.0 and 7.0 per cent per annum.

9.1.8 Classification of Domestic and Foreign Currencies

The construction costs are estimated by breaking them down into domestic and foreign currency requirements. Those to be covered by the domestic currency include wages for local labor, expenses at site for foreign engineers, costs of

Table 9-4 Summary of Estimated Construction Cost

Unit: 10^6NT$

Item	Interest Rate-6%			Interest Rate-7%		
	Total	F.C.	D.C.	Total	F.C.	D.C.
Generating Facility						
Ku-Yuan Powerstation	1,160.77	328.918	831.852	1,179.16	334.134	845.026
Chi-Pan Powerstation	1,070.25	345.180	725.070	1,087.20	350.650	736.550
Total	2,231.02	674.098	1,556.922	2,266.36	684.784	1,581.576
Transmission Facility						
Transmission Line	95.89	41.77	54.12	96.57	42.07	54.50
Telecommunication	47.16	27.51	19.65	47.50	27.71	19.79
Total	143.05	69.28	73.77	144.07	69.78	74.29
Grand Total	2,374.07	743.378	1,630.692	2,410.43	754.564	1,655.866

Note: F.C. = Foreign Currency

D.C. = Domestic Currency

materials procured in Taiwan, custom duties and taxes charged on imported materials and equipments and inland freight charges, etc.

All other costs are included in foreign currency requirements.

The exchange rate used in the calculation is one U.S. dollar = 40.1 N.T. dollars = 360 yen.

9.2 Summary of Estimated Construction Costs

The total construction costs of the Project estimated at the interest rates of 6 and 7% per annum are equivalent to N.T.$2,374,070,000 and N.T.$ 2,410,430,000, respectively.

The results of the estimated construction costs are itemized in the following Table 9-4, Table 9-5 and Table 9-6.

Table 9-5 Summary of Estimated Construction Cost of Ku-Yuan Power Station

Item	Total	F.C.	D.C.
	NT$	NT$	NT$
Civil Work	458,467,600	105,212,400	353,255,200
Access Road	66,663,800	23,983,800	42,680,000
Dam, Intake	57,404,000	9,826,000	47,578,000
Waterway	262,968,700	56,990,500	205,978,200
Surge Chamber	8,289,900	1,543,900	6,746,000
Penstocks	9,385,100	2,033,100	7,352,000
Powerhouse	50,562,100	10,041,100	40,521,000
Tailrace	3,194,000	794,000	2,400,000
Equipment	174,307,000	133,825,000	40,482,000
Penstocks	29,152,000	22,841,000	6,311,000
Generator, Turbine, Transformer etc.	145,155,000	110,984,000	34,171,000
Indirect Cost	268,323,100	21,044,500	247,278,600
Contingencies	149,372,700	37,581,700	111,791,000
Subtotal	1,050,470,400	297,663,600	752,806,800
Interest Rate-6%			
Interest during Construction	110,299,600	31,254,400	79,045,200
Total Construction Cost	1,160,770,000	328,918,000	831,852,000
Interest Rate-7%			
Interest during Construction	128,689,600	36,470,400	92,219,200
Total Construction Cost	1,179,160,000	334,134,000	845,026,000

Table 9-6 Summary of Estimated Construction Cost of Chi-Pan Power Station

Item	Total	F.C.	D.C.
	NT$	US$	NT$
Civil Work	407,425,800	104,950,000	302,475,800
Access Road	46,488,600	19,488,600	27,000,000
Dam, Intake	44,421,600	11,653,200	32,768,400
Waterway	230,121,500	52,711,400	177,410,100
Surge Cnamber	17,342,100	6,829,000	10,513,100
Penstocks	9,323,200	1,836,600	7,486,600
Powerhouse	54,662,300	11,472,800	43,189,500
Tailrace	5,066,500	958,400	4,108,100
Equipment	192,734,400	147,551,400	45,183,000
Penstocks	34,423,400	27,007,400	7,416,000
Generator, Turbine	158,311,000	120,544,000	37,767,000
Indirect Cost	232,721,400	20,988,300	211,733,100
Contingencies	135,663,400	38,890,000	96,773,400
Subtotal	968,545,000	312,379,700	656,165,300
Interest Rate-6%			
Interest during Construction	101,705,000	32,800,300	68,904,700
Total Construction Cost	1,070,250,000	345,180,000	725,070,000
Interest Rate-7%			
Interest during Construction	118,655,000	38,270,300	80,384,700
Total Construction Cost	1,087,200,000	350,650,000	736,550,000

Table 9-7 Breakdown of Construction Cost of Ku-Yuan Power Station

Unit : 1,000 US$
1,000 NT$

Item	Civil Work			Installation Cost		Import Taxes	Equipment	Total
	(US$)	(NT$)	Total (NT$)	(US$)	(NT$)	(NT$)	(US$)	(NT$)
Pondage Dam	59.7	14,718.0	17,111.9	4.5	414	763	99.3	22,448.8
Dam	40.2	10,410.0	12,022.0	4.1	380	700	91.9	16,950.2
Care-of-River	2.9	704.0	820.3					820.3
Diversion Tunnel	5.2	1,306.0	1,514.5					1,514.5
Intake	11.4	2,298.0	2,755.1	0.4	34	63	7.4	3,133.8
Intake Dam	81.6	31,683.0	34,955.2					34,955.2
Lung-Chi	12.7	3,822.0	4,331.3					4,331.3
Hua-Lu	11.7	3,281.0	3,750.2					3,750.2
Fu-Hsing	9.6	2,866.0	3,251.0					3,251.0
Tong-Tao-Sai 1 ~ 3	8.2	4,714.0	5,042.8					5,042.8
Chung-Tao-Sai	3.3	1,916.0	2,048.3					2,048.3
Tao-Sai	23.4	8,851.0	9,789.3					9,789.3
Hsiao-Wa-Hei-Er	7.4	3,614.0	3,910.7					3,910.7
Hsi-Hsiao-Wa-Hei-Er	5.3	2,619.0	2,831.6					2,831.6
Pressure Tunnel	976.7	139,178.2	178,344.0					178,344.0
Dia = 3.30 m	736.6	107,040.0	136,577.7					136,577.7
Dia = 3.40 m	206.6	29,350.0	37,634.7					37,634.7
Adit	33.5	2,788.2	4,131.6					4,131.6
Non-Pressure Tunnel	444.5	66,800.0	84,624.7					84,624.7
Tong-Tao-Sai ~ Tao-Sai	49.7	8,090.0	10,083.0					10,083.0
Tao-Sai ~ Hsiao-Wa-Hei-Er	113.6	16,710.0	21,265.4					21,265.4
Hsiao-Wa-Hei-Er ~ Hsi-Hsiao-Wa-Hei-Er	78.8	11,670.0	14,830.0					14,830.0
Hsi-Hsiao-Wa-Hei-Er ~ Combined Tank	178.5	26,380.0	33,537.9					33,537.9
Combined Tank	6.8	2,314.0	2,586.7					2,586.7
Adit	17.1	1,636.0	2,321.7					2,321.7
Surge Tank	38.5	6,746.0	8,289.9					8,289.9
Upper Chamber	17.7	3,840.0	4,549.8					4,549.8
Shaft	2.4	636.0	732.2					732.2
Lower Chamber	3.6	640.0	784.4					784.4
Sand Flush	14.8	1,630.0	2,223.5					2,223.5

Penstock	50.7	7,352	9,385.1	26.4	2,471	3,840	543.2	38,537.4
Civil Works	27.6	5,350	6,456.8					6,456.8
Steel Penstock	-	-	-	26.4	2,471	3,840	543.2	29,152.3
Adit	23.1	2,002	2,928.3					2,928.3
Powerhouse	250.4	40,521	50,562.1					50,562.1
Civil Works	83.1	14,591	17,923.3					17,923.3
Architecture	91.4	12,000	15,665.1					15,665.1
Transformer Chamber	14.6	3,350	3,935.5					3,935.5
Gate Chamber	4.7	1,100	1,288.5					1,288.5
Gallery	23.5	3,850	4,792.4					4,792.4
Cable Duct	13.1	2,230	2,755.3					2,755.3
Switchyard	20.0	3,400	4,202.0					4,202.0
Tailrace	14.5	2,330	2,911.5	0.2	21	40	5.3	3,194.0
Tailrace Tunnel	10.5	1,930	2,351.1					2,351.1
Outlet	4.0	400	560.4					560.4
Draft Gate	-	-	-	0.2	21	40	5.3	282.5
Access	598.1	42,680	66,663.8					66,663.8
Tao-Sai	398.2	26,410	42,377.8					42,377.8
Tuo-Po-Kuo	167.4	12,960	19,672.7					19,672.7
Loh-Sao	2.5	380	480.3					480.3
Surge Tank	30.0	2,930	4,133.0					4,133.0
Electric Equipment				127.9	10,989	23,182	2,639.8	145,155.0

Table 9-8 Breakdown of Construction Cost of Chi-Pan Power Station

Unit: 1,000 US$
1,000 NT$

Item	Civil Work			Installation Cost		Import Taxes	Equipment	Total
	(US$)	(NT$)	Total (NT$)	(US$)	(NT$)	(NT$)	(US$)	(US$)
Pondage Dam	80.9	21,857.5	25,101.6	7.5	711.4	1,355	184.3	34,864.5
Dam	61.8	16,420.0	18,898.2	6.7	631.0	1,200	157.5	27,313.9
Care of River (including Diversion Tunnel)	7.8	1,800.0	2,112.8					2,112.8
Intake	11.3	3,637.5	4,090.6	0.8	80.4	155	26.8	5,837.8
Intake Dam	17.8	8,843.9	9,557.7					9,557.1
Hsi-Tuo-Po-Kuo	2.6	1,645.4	1,749.7					1,749.7
Ku-Pei-Yang	5.2	2,606.4	2,814.9					2,814.9
Man-Tou Shan	1.4	803.8	859.9					859.9
Hsin-Tu	4.8	1,951.2	2,143.7					2,143.7
Lao-Hsi Chi	3.8	1,837.1	1,989.5					1,989.5
Pressure Tunnel	1,070.2	139,550.1	182,465.1					182,465.1
Pressure Tunnel	1,022.2	136,030.1	177,020.3					177.020.3
Adit	48	3,520.0	5,444.8					5,444.8
Non-Pressure Tunnel	244.3	37,860.0	47,656.4					47,656.4
Hsi-Tuo-Po-Kuo ~ Ku-Pei-Yang	55.4	10,640.0	12,861.5					12,861.5
Ku-Pei-Yang ~ Man-Tou Shan	69.1	11,260.0	14,030.9					14,030.9
Man-Tou Shan ~ Ku-Yuan	95.8	14,200.0	18,041.6					18,041.6
Adit	24.0	1,760.0	2,722.4					2,722.4
Surge Tank	170.3	10,513.1	17,342.1					17,342.1
Surge Chamber	46.3	7,708.3	9,564.9					9,564.9
Sand Flash	124.0	2,804.8	7,777.2					7,777.2
Penstock	45.8	7,486.6	9,323.2	30.0	2,797.0	4,619	643.5	43,746.6
Civil Works	32.0	6,290.6	7,573.8					7,573.8
Steel Penstocks	-	-	-	30.0	2,797.0	4,619	643.5	34,423.4
Adit	13.8	1,196.0	1,749.4					1,749.4
Powerhouse	286.1	43,189.5	54,662.3					54,662.3
Civil Works	86.6	15,956.1	19,428.8					19,428.8
Architecture	95.3	13,084.0	16,905.5					16,905.5
Transformer Chamber	16.7	3,977.4	4,646.1					4,647.1
Bus Tunnel	0.7	133.0	161.1					161.1
Cable Duct	2.6	534.8	639.1					639.1
Access Tunnel, Bridge	63.6	5,258,1	7,808.5					7,808.5
Switchyard	11.7	2,168.1	2,637.3					2,637.3
Gate Chamber	8.9	2,078.0	2,434.9					2,434.9
Tailrace	15.5	3,996.1	4,617.7	0.4	32.0	64	8.4	5,066.5
Tunnel	15.5	3,996.1	4,617.7					4,617.7
Gate	-	-	-	0.4	32.0	64	8.4	448.8

Access	13,500 m	486 .0	27,000.0	46,488.6					46,488.6
Powerhouse~Surge Tank	5,500 m								
Lu-Shuei ~ Lao-Hsi Chi	5,000 m								
Lung-Chi ~ Ku-Pei-Yang	3,000 m								
Electric-Equipment					149.6	12,491.0	25,276	2,856.5	158,311.0

Table 9-9 Summary of Estimated Construction Cost of Transmission Line

Item	Chi-Pan from Ku-Yuan		Ku-Yuan from Ta-Chien		Total		
	F.C US$	D.C 1,000 NT$	F.C US$	D.C 1,000 NT$	F.C 1,000 NT$	D.C 1,000 NT$	Total 1,000 NT$
Materials (CIF)	134,200	-	771,900	-	36,330	-	-
Import Tax		1,290		7,410	-	8,700	8,700
Transportation		340		1,730	-	2,070	2,070
Installation Cost		4,000		21,000	-	25,000	25,000
Indirect Cost		1,650		9,170	-	10,820	10,820
Contingency	13,420	810	77,190	4,390	3,640	5,200	8,840
Sub-Total	147,620	8,090	849,090	43,700	39,970	51,790	91,760
Interest Rate-6%							
Interest during Construction	6,640	360	38,210	1,970	1,800	2,330	4,130
Total Construction Cost	154,260	8,450	887,300	45,670	41,770	54,120	95,890
Interest Rate-7%							
Interest during Construction	7,750	420	44,580	2,290	2,100	2,710	4,810
Total Construction Cost	155,370	8,510	893,670	45,990	42,070	54,500	96,570

Table 9-10 Summary Estimated Construction Cost of Telecommunication System

Item	F.C. US$	D.C. 1,000 NT$	Total 1,000 NT$
Materials (C.I.F)	531,000	-	21,290
Import Tax	-	5,320	5,320
Transportation	-	60	60
Installation Cost	66,000	6,150	8,800
Indirect Cost	-	5,320	5,320
Contingency	59,700	1,950	4,340
Subtotal	656,700	18,800	45,130
Interest Rate-6%			
Interest during Construction	29,550	850	2,030
Total Construction Cost	686,250	19,650	47,160
Interest Rate-7%			
Interest during Construction	34,480	990	2,370
Total Construction Cost	691,180	19,790	47,500

CHAPTER 10

ECONOMIC EVALUATION

CHAPTER 10

ECONOMIC EVALUATION

10.1 Saleable Energy

As already described in Chapter 6, the annual energy production at the Kuyuan and Chipan Power Stations totals 1,149.70 x 10^6 KWh, and the power from these stations will be effectively used immediately after they are put into operation.

The rates of transmission loss in KW and KWh between these stations and the switchyard of the Tachien Power Station and outage of the stations are estimated at 2.8%, 2.4% and 10.0%, respectively. This outage is estimated in consideration of the losses caused by ineffective discharge for flushing sediment and by leakage, etc. Therefore, the saleable energy at the switchyard of Tachien Power Station will be 1,009.90 x 10^6 KWh.

10.2 Annual Cost and Energy Cost

10.2.1 Annual Cost

As described in Chapter 9, the total estimated construction costs of Kuyuan and Chipan Power Stations and of the transmission lines connecting the power stations with the switchyard of the Tachien Power Station computed at interest rates of 6 and 7% per annum are NT$2,374,070,000 and NT$2,410,430,000, respectively.

The estimated construction costs and serviceable years for each facility are shown in Table 10-1.

Table 10-1 Construction Cost and Productive Years

Unit : 10^6NT$

Item	Average Productive year	Construction Cost Rate-6%	 Rate-7%
Generating Facility			
Ku-Yuan Power Station	50	1,160.77	1,179.16
Chi-Pan Powet Station	50	1,070.25	1,087.20
Subtotal		2,231.02	2,266.36

Unit : 10^6NT$

Item	Average Productive year	Construction Cost Rate-6%	 Rate-7%
Transmission Facility			
Transmission Line	35	95.89	96.57
Telecommunication System		47.16	47.50
Subtotal		143.05	144.07
Grand Total		2,374.07	2,410.43

The annual cost is estimated on the basis of the following conditions:

(1) Two estimations are made at interest rates of 6 and 7% and the same interest rates are applied to both domestic and foreign currencies.

(2) The interest rates and depreciation are estimated in accordance with the sinking fund method throughout the average productive years of the Project.

(3) The operation and maintenance costs are estimated from the actual figures available at the existing power stations of Taipower.

(4) Replacements, taxes and levies and insurances are estimated in compliance with the Taipower Planning Standards.

The equalized annual cost factors of this Project estimated based on the above conditions are shown in Table 10-2.

The annual cost of this Project estimated in accordance with the above equalized annual cost factors is NT$175, 200, 000 in case of an interest rate of 6% per annum and NT$199, 280, 000 in case of 7%.

The breakdown of the annual cost is shown in Table 10-3.

10. 2. 2 Energy Cost

By dividing the total annual cost derived in 10. 2. 1 by the salable energy determined in 10. 1, the energy costs per KWh, at the sending end of Kuyuan and

Table 10-2 Equalized Annual Cost Factor

Item	Unit	Generating Facility		Transmission Facility	
		Rate-6%	Rate-7%	Rate-6%	Rate-7%
(1) Fixed Charge		6.654	7.556	8.527	9.353
Interest	%	6.000	7.000	6.000	7.000
Depreciation	"	0.344	0.246	0.897	0.723
Replacement	"	0.200	0.200	0.100	0.100
Taxes	"	0.010	0.010	1.530	1.530
Insurance	"	0.100	0.100	-	-
(2) Operation and Maintenance	NT$	variable	variable	including in taxes	including in taxes
(3) Total		(1) + (2)	(1) + (2)	8.527	9.353

Chipan Power Stations, and at the switchyard of the Tachien Power Station, can be obtained.

The energy costs per KWh estimated at the interest rates of 6 and 7% are shown in Table 10-4, respectively.

10.3 Annual Benefit

10.3.1 Fundamental Economic Evaluation

The economic evaluation of hydro power was made in comparison with a certain standard thermal power plant.

10.3.2 Selection of Standard Thermal Power Plant

As a standard thermal power plant, the Talin Thermal Power Plant is selected considering the favorable situations that its size is reasonable from the standpoint of magnitude of power demand, growth rate and structure of supply

Table 10-3 Annual Cost

Unit: 10^6NT$

Item	Interest Rate-6%	Interest Rate-7%	Note
Generating Facility			
Ku-Yuan Power Station			
Fixed Charge	77.240	89.100	
Operation and Maintenance	6.260	6.260	
Subtotal	83.500	95.360	
Chi-Pan Power Station			
Fixed Charge	71.210	82.150	
Operation and Maintenance	8.290	8.290	
Subtotal	79.500	90.440	
Total	163.000	185.800	
Transmission Facility			
Fixed Charge	12.200	13.480	
Operation and Maintenance	-	-	including fixed charge
Total	12.200	13.480	
Total Annual Cost	175.200	199.280	
1/ Ku-Yuan Power Station	88.180	100.530	
2/ Chi-Pan Power Station	87.020	98.750	

Note: Transmission cost is allocated to Ku-Yuan and Chi-Pan power stations according to the ratio of each installed capacity.
The figures include the transmission costs by the following calculations.

1/ = Transmission Cost = $\frac{92}{240} \times 12.20 \times 10^6 = 4.68 \times 10^6$ NT$

" = $\frac{92}{240} \times 13.48 \times 10^6 = 5.17 \times 10^6$ "

2/ = Transmission Cost = $\frac{148}{240} \times 12.20 \times 10^6 = 7.52 \times 10^6$ "

" $\frac{148}{240} \times 13.48 \times 10^6 = 8.31 \times 10^6$ "

Table 10-4 Energy Cost

Item	Unit	Interest Rate-6%	Interest Rate-7%
Generating End			
Annual Energy Production			
Ku-Yuan Power Station	10^6KWh	409.680	409.680
Chi-Pan Power Station	"	625.050	625.050
Subtotal	"	1,034.730	1,034.730
Annual Cost			
Ku-Yuan Power Station	10^6 KWh	83.500	95.360
Chi-Pan Power Station	"	79.500	90.440
Subtotal	"	163.000	185.800
Per kilowatt Hour			
Ku-Yuan Power Station	NT$	0.204	0.233
Chi-Pan Power Station	"	0.127	0.145
Combined	"	0.158	0.180
Transmission End			
Annual Energy Production			
Ku-Yuan Power Station	10^6KWh	399.850	399.850
Chi-Pan Power Station	"	610.050	610.050
Subtotal	"	1,009.900	1,009.900
Annual Cost			
Ku-Yuan Power Station	10^6NT$	88.180	100.530
Chi-Pan Power Station	"	87.020	98.750
Subtotal	"	175.200	199.280
Per Kilowatt Hour			
Ku-Yuan Power Station	NT$	0.221	0.251
Chi-Pan Power Station	"	0.143	0.162
Combined	"	0.173	0.197

capacity in the Taipower System, and that it is a modern date thermal power plant.

The Talin Thermal Power Plant will have two 300 MW units for a total plant capacity of 600 MW in the first stage.

The construction costs and general features of this standard thermal power plant are shown in Table 10-5.

Table 10-5 Construction Cost and General Features of Standard Thermal Power Plant

Item	Unit	Value
Installed Capacity	MW	6,000.0
Unit Capacity x Number of Unit	MW x Unit	300 x 2
Annual Capacity Factor	%	70.0
Thermal Efficiency at Generating End	%	37.4
Annual Energy Production	MKWh	3,600.0
Station Service Loss	%	5.0
Unit Cost of Fuel	NT$/$10^6$BTU	16.6
Construction Cost	Million NT$	3,060.0
Life Year	Year	30

10.3.3 Annual Cost of Standard Thermal Power Plant

The construction cost of the standard thermal power plant is estimated at NT$3,060 x 10^6 as shown in Table 10-5.

In estimating the annual cost of this standard thermal power plant, the interest rates of 6 and 7 % per annum have been used and the same interest rates are applied to both domestic and foreign currencies. The annual cost factors as shown in Table 10-6 are employed.

The annual cost of the standard thermal power plant estimated by using the annual cost factors shown in Table 10-6 are classified into fixed costs and variable costs as shown in Table 10-7 as obtained at the interest rates of 6 and 7% respectively.

The fixed costs per KW estimated at the interest rates of 6 and 7% are NT $482.38 and NT$520.94, respectively, while the variable costs per kWh are NT$ 0.1585 at both interest rates.

Table 10-6 Annual Cost Factor of Standard Thermal Power Plant

Item	Unit	Interest Rate-6%	Interest Rate-7%
(1) Fixed Charge	%	8.285	9.079
Interest	"	6.000	7.000
Depreciation	"	1.265	1.059
Replacement	"	0.350	0.350
Taxes	"	0.300	0.300
Insurance	"	0.370	0.370
(2) Operation and Maintenance	NT$	variable	variable
(3) Total		(1) + (2)	(1) + (2)

In this estimation, however, the same plant rating is assumed to have an allowance of 10% of overload in accordance with the Taipower Planning Standards and the remainder after deducting 5% station loss is assumed to be the net peaking capability.

10.3.4 Unit Cost of Benefit

The annual benefit of a hydroelectric power station can be derived from the benefit per KW and benefit per KWh.

The benefit per KW is the annual fixed costs per KW of the standard thermal power plant.

As described in Appendix 2 in detail, the outage factor due to accidents and scheduled inspection and maintenance in a thermal power plant is higher than that of a hydroelectric power plant. Therefore, when a thermal power plant is integrated in a power supply system, an additional supply capacity is required, in order to supply power at the same dependability as in the case of a hydroelectric power. This additional capacity required in the case of a thermal power plant is to be regarded as a benefit of a hydroelectric power, and a KW adjustment factor of 1.30 is calculated in consideration of the above additional capacity.

The benefit per KWh is the annual variable cost per KWh of the standard thermal power plant.

Consequently, the benefit per KW and the benefit per KWh will be respectively as follows:

	at 6% Interest Rate	at 7% Interest Rate
Benefit per KW	NT$627.09	NT$677.22
Benefit per KWh	NT$ 0.1585	NT$ 0.1585

Table 10-7 Annual Cost of Standard Thermal Plant

Item		Unit	Interest Rate-6%	Interest Rate-7%
(1) Capacity				
Name Plant Rating		MW	300 x 2	300 x 2
Net Peaking Capability		"	315 x 2	315 x 2
(2) Investment	1/	NT$/KW	5,100.00	5,100.00
(3) Annual Capacity Cost		NT$/KW	482.38	520.94
Fixed Charge		"	422.53	463.03
Fixed O & M	2/	"	68.17	68.17
Total at Name Plant		"	490.70	531.20
Total at Net Peaking	3/	"	467.14	505.70
Transmission Line Cost		"	12.43	12.43
Transmission Line Loss		"	2.81	2.81
Total at Load Center		"	482.38	520.94
(4) Energy Cost		NT$/KWh	0.1585	0.1585
Energy Fuel	4/	"	0.1524	0.1524
Variable O & M	5/	"	0.0057	0.0057
Transmission Line Loss		"	0.0004	0.0004
Total at Load Center		"	0.1585	0.1585

Note: 1/; Per name plant KW

2/; 65% of the total operation and maintenance cost

3/; 95.2% of name plant

4/; Fuel Cost = 16.60 NT$/$10^6$ BTU

5/; 35% of the total operation and maintenance cost

10.3.5 Annual Benefit

The salable energy available from this Project is 1,009.90 x 10^6 KWh as already described in 10.1.

The dependable peaking capability of the two power stations of this Project is 211,197 KW as shown in Table 10-8 and Table 10-9.

When the unit cost of benefit, described in 10.3.4 is applied to the above, the annual benefit of this Project is expected to be NT$292.30 x 10^6 at the interest rate of 6% per annum or NT$303.10 x 10^6 at the rate of 7% as shown in Table 10-10.

10.4 Benefit-Cost Ratio

The annual cost and annual benefit of this Project are shown in Table 10-3 and Table 10-10 respectively.

The annual surplus benefit and benefit-cost ratio are shown in Table 10-11.

Table 10-8 Dependable Peaking Capability of Ku-Yuan Power Station

Month	Date	Peaking Hour	Average Output KW	Dependable Peaking KW
1	'67 Jan. 1 - 10	5	18,838	90,422
2	'66 Feb. 11 - 20	6	20,929	83,716
3	'66 Mar. 1 - 10	6	23,221	92,884
4	'63 Apr. 21 - 30	6	20,058	80,232
5	'63 May 21 - 31	6	16,271	65,084
6	'63 Jun. 1 - 10	7	16,050	55,052
7	'64 Jul. 21 - 31	7	26,513	90,940
8	'67 Aug. 1 - 10	7	29,513	102,715
9	'57 Sept. 1 - 10	7	29,033	99,583
10	'66 Oct. 21 - 31	5	22,821	109,541
11	'66 Nov. 21 - 30	5	18,846	90,461
12	'66 Dec. 11 - 20	5	17,929	86,059
	Average		21,705	87,224
	Dependable Peak			84,782

Table 10-9 Dependable Peaking Capability of Chi-Pan Power Station

Month	Date	Peaking Hour	Average Output KW	Dependable Peaking KW
1	'67 Jan. 1 - 10	5	28,088	134,822
2	'66 Feb. 11 - 20	6	31,175	124,700
3	'66 Mar. 1 - 10	6	34,621	138,484
4	'63 Apr. 21 - 30	6	29,921	119,684
5	'63 May 21 - 31	6	24,263	97,052
6	'63 Jun. 1 - 10	7	23,942	82,121
7	'64 Jul. 21 - 31	7	39,529	135,584
8	'67 Aug. 1 - 10	7	44,646	153,136
9	'57 Sept. 1 - 10	7	43,296	148,505
10	'66 Oct. 21 - 31	5	34,008	163,238
11	'66 Nov. 21 - 30	5	28,138	135,062
12	'66 Dec. 11 - 20	5	26,729	128,299
	Average		32,363	130,057
	Dependable Peak			126,415

Table 10-10 Annual Benefit

Item	Unit	Interest Rate-6%	Interest Rate-7%
Unit Benefit			
KW Value	NT$	627.0900	677.2200
KWh Value	"	0.1585	0.1585
Annual Benefit			
Ku-Yuan Power Station			
Dependable Peak	KW	84,782.00	84,782.00
Energy Production	10^6KWh	399.85	399.85
KW Benefit	10^6NT$	53.08	57.42
KWh Benefit	"	63.38	63.38
Combined Benefit	"	116.46	120.80
Chi-Pan Power Station			
Dependable Peak	KW	126,415.00	126,415.00
Energy Production	10^6KWh	610.05	610.05
KW Benefit	10^6NT$	79.15	85.61
KWh Benefit	"	96.69	96.69
Combined Benefit	"	175.84	182.30
Combined			
Dependable Peak	KW	211,197.00	211,197.00
Energy Production	10^6KWh	1,009.90	1,009.90
KW Benefit	10^6NT$	132.23	143.03
KWh Benefit	"	160.07	160.07
Combined Benefit	"	292.30	303.10

Table 10-11 Benefit-Cost Ratio

Item	Unit	Interest Rate-6%	Interest Rate-7%
Ku-Yuan Power Station			
Annual Cost (C)	10^6NT$	88.180	100.530
Annual Benefit (B)	"	116.460	120.800
Surplus Benefit (B-C)	"	28.280	20.270
Benefit-Cost Ratio (B/C)	"	1.321	1.202
Chi-Pan Power Station			
Annual Cost (C)	10^6NT$	87.020	98.750
Annual Benefit (B)	"	175.840	182.300
Surplus Benefit (B-C)	"	88.820	83.550
Benefit-Cost Ratio (B/C)	"	2.021	1.846
Combined			
Annual Cost (C)	10^6NT$	175.200	199.280
Annual Benefit (B)	."	292.300	303.100
Surplus Benefit (B-C)	"	117.100	103.820
Benefit-Cost Ratio (B/C)	"	1.668	1.521

CHAPTER 11

INVESTIGATION REQUIREMENTS FOR FEASIBILITY STUDY

CHAPTER 11

INVESTIGATION REQUIREMENTS FOR FEASIBILITY STUDY

11.1 Hydrological Survey and Study

There are 10 gaging stations in the Li-Wu Chi Basin, including the Lushuei Gaging Station which started run-off gaging in February, 1956.

The 9 gaging stations located upstream of the Lushuei Gaging Station started run-off gaging in 1964. Therefore, in order to enhance the accuracy of correlation between the run-off records at these 9 stations and that of the Lushuei Station which is regarded as the standard gaging station, further examination of the correlation should be made between the above mentioned gaging stations, in improving the facilities at the stations and carefully continuing the gaging works.

With respect to flood gaging, particularly careful observation at the Tuo-Po-Kuo, Kuyuan and Lushuei Gaging Stations are required in order to improve the accuracy of run-off gaging.

There are 6 precipitation observatories including Chipan observatory in the basin. It is advisable to carry on gaging at these observatories to grasp the distribution of precipitation in the basin.

11.2 Preparation of Topographical Maps

11.2.1 Topographical Map Needed for Overall Project

In the Li-Wu Chi Basin, it is necessary to complete topographical maps on the scale of 1 : 5,000 and contour interval of 5 m by aerophotography for the area of about 400 km^2 upstream of Chipan up to the elevation of 1,600 m. However, if it is considered difficult to compile topographical maps on the scale of 1 : 5,000 due to budgetary plight and in consideration of construction schedules, a map on the scale of 1 : 10,000 will serve the purpose although it lacks the accuracy to some degree for formulation of development schemes.

11.2.2 Detailed Topographical Maps

As shown in Fig. 11-1, for most of the proposed sites of regulating ponds, intake dams, powerhouse, tailraces, etc. of the proposed development scheme of the Li-Wu Chi, fairly detailed topographical maps are already prepared.

However, the sites and areas for which more detailed topographical maps are required are shown in Fig. 11-1. The requirements are as follows:

(1) Preparation of topographical maps for the proposed intake dam sites (4 sites) on the tributary of the Taosai Chi.

The areas to be covered would extend about 50 m both upstream and downstream of the axis lines of the intake dams on both banks and up to the elevation of about 1,400 m.

Scale : 1 : 500 Contour interval : 1 to 2 m

(2) Preparation of topographical maps for the area near the proposed site of the Kuyuan Power House.

The area to be covered it that extending on the right bank from 100 m upstream of the Hsiao-Wa-Hei-Er Chi Suspension Bridge to the vicinity of the curve on the East West Cross Island Highway downstream of the Kuyuan Dam site for elevations ranging from 700 m to 1,400 m.

The tableland near the curve on the East-West Cross Island Highway is expected to be the site of the switchyard, and therefore, this tableland should be included in the topographical map.

Scale : 1 : 500 to 1 : 1,000 Contour interval : 2 to 5 m

(3) Preparation of a topographical map for the area including the proposed site of the Hsutu Chi Intake Dam.

The area to be covered is that extending on both banks 100 m both upstream and downstream of the axis line of the intake dam and up to the elevation of about 700 m.

Scale : 1 : 500 to 1 : 1,000 Contour interval : 2 to 5 m

(4) Preparation of a topographical map for the area including the proposed site of the Laohsi Chi Intake Dam.

The area to be covered would extend on both banks from the confluence of the Laohsi Chi and its tributary to 350 m downstream and up to the elevation of about 750 m.

Scale : 1 : 500 to 1 : 1,000 Contour interval : 2 to 5 m

(5) Preparation of a topographical map for the area including the proposed site of the Chipan Powerhouse.

With respect to the left bank, the area to be added to the available topographical map on the scale of 1 : 1,000 is the area up to about 500 m upstream and to the elevation of about 750 m.

As for the right bank, the area to be added to the available topographical map is the area extending from about 500 m upstream of the stream end on the available map to about 500 m downstream of the existing Li-Wu Intake Dam and up to the elevation of about 400 m.

Scale : 1 : 1,000 Contour interval : 2 to 5 m

(6) Preparation of a topographical map for the area including the combining tank proposed at the site about 500 m north of Lohsao.

The area to be covered is a 200 m square including the proposed site of the combining tank for elevations ranging from 1,200 m to 1,300 m.

Scale : 1 : 500 to 1 : 1,000 Contour interval : 2 to 5 m

(7) Preparation of a topographical map for the are including the proposed site of the Hsi-Tuo-Po-Kuo Chi Intake Dam.

Scale : 1 500 to 1 : 1,000 Contour interval : 2 to 5 m

11.3 Geological Survey

(1) Tuo-Po-Kuo Dam Site

As the gorge is covered with river deposit, the geology of the foundation rock is unidentified. Therefore, surveys for the foundation rock by inclined boring is required.

(2) Lung Chi Dam Site

The river bed is fairly thickly covered with river deposit and boring is required to determine the thickness of the deposit.

(3) Taosai Dam Site

The river bed is widely and thickly covered with deposit and the survey by boring is required to determine the thickness of the deposit.

As the survey at each intake site on the Taosai Tributaries is not yet completed, a surface geological survey will be necessary after completion of the topographical survey work.

(4) Kuyuan Powerhouse Site

The survey is not yet completed because topographical maps are not available. After completion of the topographical survey, a surface geological survey will be required for the area from the surge tank site to the tailrace site. Exploratory adits for survey of the surge tank site and the site for the main equipment room of the power plant are also required.

(5) Tienhsiang Powerhouse Site

The Tienhsiang Power Station is a part of Alternative Scheme I, and Alternative Scheme I will be adopted in case a decisive defect is discovered in the proposed Kuyuan Power Station. If and when such a defect is found in the project as a result of survey by the exploratory adit for Kuyuan Station, a survey of the alternative Tienhsiang Power Station by an adit will be desirable. In such an event, if the adit is excavated along the cable tunnel, it will be useful in the construction work that may follow.

(6) Laohsi Chi Intake Dam Site

The survey is not yet completed due to unavailability of a topographical map. Therefore, after completion of the topographical survey, a surface geological survey will be required. If deposit on the river bed is thick, the investigation by boring will be desirable.

(7) Tienhsiang Dam Site.

In case Kuyuan Power Station in Alternative Scheme III has a decisive defect, a survey by inclined boring to determine the thickness of the deposit on the river bed and the conditions of the foundation rock will be required at the Tienhsiang Dam Site in Alternative Scheme I. The number of borings should be two and the boring sites should be as close as possible to each bank. It will be possible to determine the thickness of the gravel and at the same time to determine the property of the foundation rock if the borings are drilled toward the stream center parallel to the dam axis.

(8) With respect to the tunnel on the side of Tuo-Po-Kuo from Hualu, the survey along the East-West Cross Island Highway is required, since it has not yet been completed. However, the survey would cover an area 1 km towards the mountain pass from Yangming Tunnel, and any survey for an area beyond this point would not be of any help in determining the geology of the tunnel.

(9) Geological survey data along the East-West Cross Island Highway are available for the section between Chipan and Tienhsiang of the tunnel connecting Kuyuan Regulating Pond and the Chipan Power Station. However, for the section of the tunnel between Tienhsiang and Kuyuan, the survey

data along the river banks of the Taosai Chi are more helpful than those along the East-West Cross Island Highway. Consequently, a surface geological survey along the river banks of the Taosai Chi is required for the section between Tienhsiang and Kuyuan.

(10) Chipan Powerhouse Site

The exploratory adit for this site was under excavation as of the end of June, 1968, and the information so far obtained from Taipower reveals that the geology consists of gneiss and is in very good conditions. However, it is advisable to excavate the scheduled length of 150 m, since the adit has not yet reached the proposed site of the main equipment room of the power station.

(11) Since geological survey along the center line of the tunnel passing the Li-Wu Chi Basin is impracticable due to the steep topography, it is insufficient to assume the geology of the tunnel according to the geological survey data along the East-West Cross Island Highway or the river banks, since both are so far from the area where the tunnel runs through.

However, with the aid of a geological survey method of aerophotography, a survey along the center line of the tunnel will be preferable. Therefore, it is desirable to make a geological survey for the overall Project Area by aerophotography.

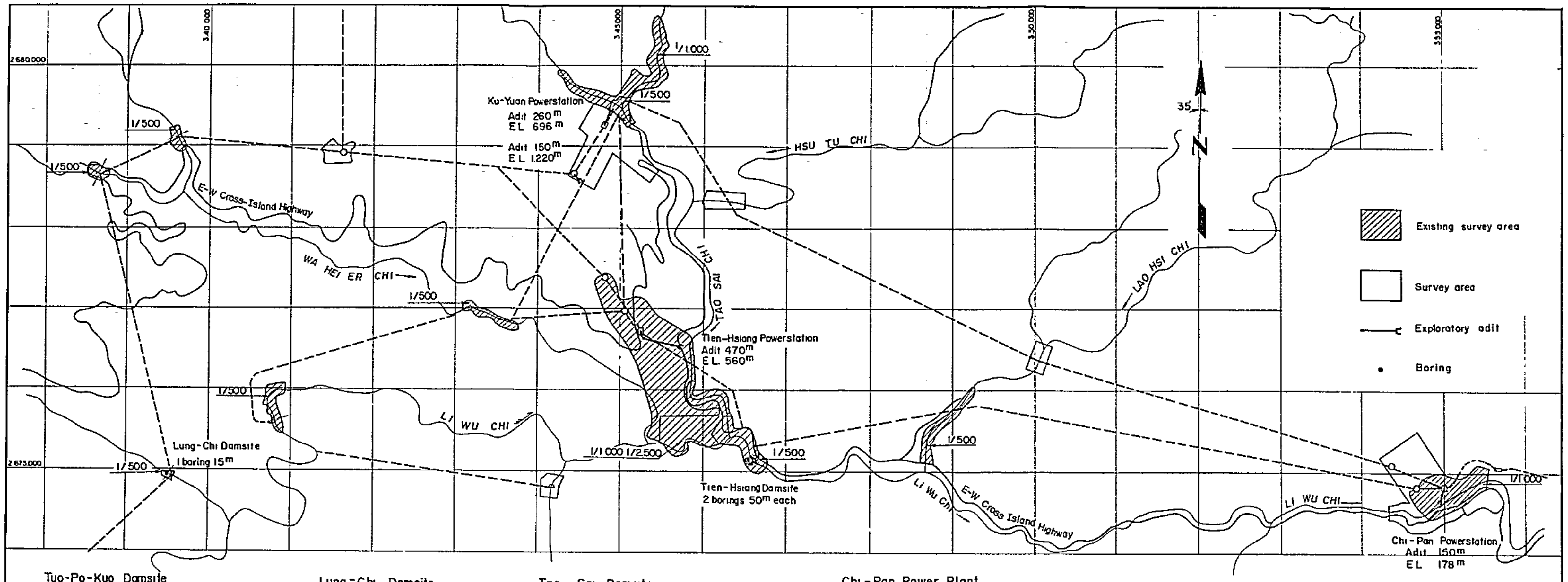
(12) Material surveys for the quarry are not yet completed. Since flatness peculiar to crystalline schist is anticipated, it is desirable to perform material tests on the specimens taken from adit excavation.

The locations, areas and quantity of the above surface geological surveys and geological survey constructions are shown in Fig. 11-1.

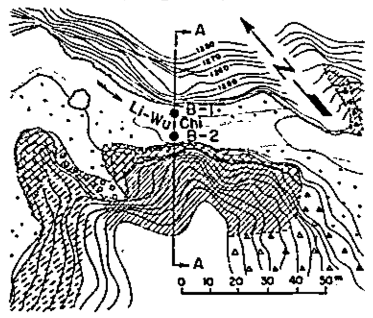
11.4 Aggregate Survey

(1) For the deposited gravel at the proposed aggregate sites at the Taosai Chi, Tuo-Po-Kuo and the estuary of the Li-Wu Chi, it is required to make a survey of the volumes of the deposit available as concrete aggregate and to determine suitability as aggregate material, gradation, and conduct crushing tests and concrete tests.

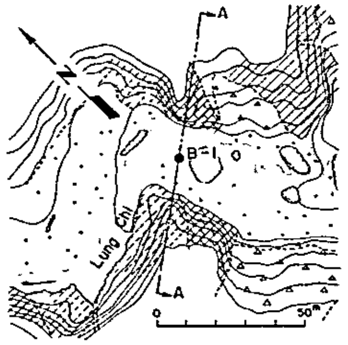
(2) It is also necessary to conduct similar tests as described in (1) above to determine suitability as concrete aggregate on the material excavated from the adits for geological surveys.



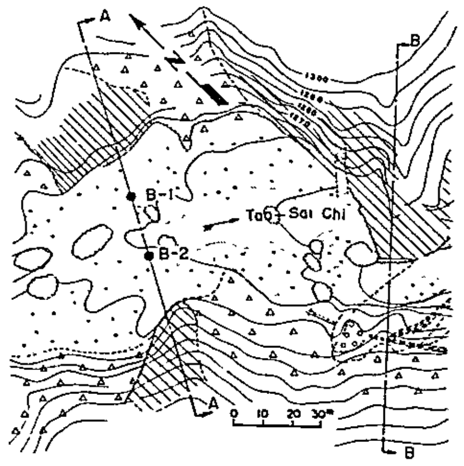
Tuo-Po-Kuo Damsite



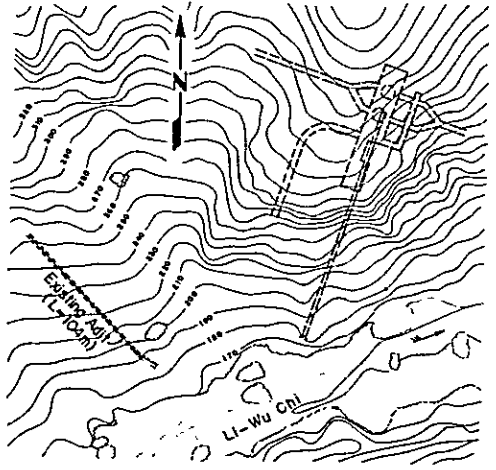
Lung-Chi Damsite



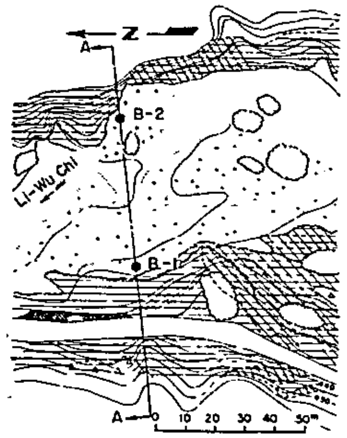
Tao-Sai Damsite



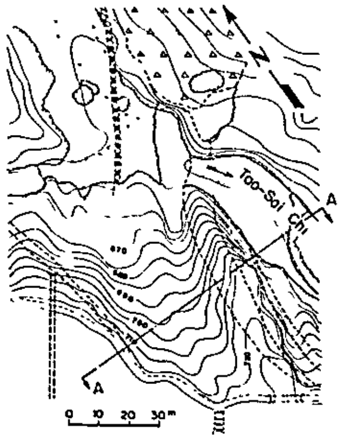
Chi-Pan Power Plant



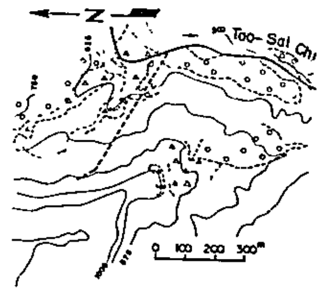
Tien-Hsiang Damsite



Ku-Yuan Power Plant



Tien-Hsiang Power Plant



Boring

Location	No	Depth	Bearing	Inclination	Remark
Tuo-Po-Kuo Damsite	1 1	20(m) 20	Along dam axis	45° toward river center	Holes are as close to the bank as possible
Lung-Chi Damsite	1	15	—	Vertical	—
Tao-Sai Damsite	1 1	15 15	—	Vertical	—
Tien-Hsiang Damsite	1 1	50 50	Along dam axis	35° toward river center	Holes are as close to the bank as possible

Exploratory adit

Location	No.	Length	Remark
Ku-Yuan Power House	1 1	260(m) 150	S 36°W, EL 696 m N 42°W, EL 1220 m
Tien-Hsiang Power House	1	470	Along main cable tunnel
Chi-Pan Power House	—	150	Under excavation

Surface geological investigation

Location	Area	Remark
Lao-Chi Chi	Damsite	———
E-W Cross Island Highway	From Hua-Lu bridge to Yang-Ming tunnel + 1 km	Along E-W Cross Island Highway
Tao-Sai tributaries	Damsites	———
Ku-Yuan Power House	From surge tank to tailrace	Including access tunnel
Tao-Sai-Chi river bed	From Tien-Hsiang to Ku-Yuan Damsite	———

0 3 km

OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO – JAPAN

TAIWAN POWER COMPANY, TAIWAN, REPUBLIC OF CHINA

LI WU CHI HYDRO-ELECTRIC PROJECT

PROPOSED LOCATIONS OF BORINGS, ADITS, AND SURVEY AREA FOR THE FEASIBILITY STUDY

ELECTRIC POWER DEVELOPMENT CO., LTD
(EPD Consultants) TOKYO JAPAN

FIG. II-1 DATE AUG 1968