EMPRESA NACIONAL DE ELECTRICIDAD S. A.

REPUBLICA DE BOLIVIA

FEASIBILITY REPORT

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MARCH 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

EMPRESA NACIONAL DE ELECTRICIDAD S. A.

REPUBLICA DE BOLIVIA

FEASIBILITY REPORT ON PILAYA HYDRO-ELECTRIC POWER PROJECT

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PREFACE

In response to the request of the Government of the Republic of Bolivia, the Government of Japan decided to conduct a survey on the PILAYA RIVER HYDRO-ELECTRIC POWER DEVELOPMENT Project and entrusted the survey to the Japan International Cooperation Agency (JICA). The JICA sent to Bolivia a survey team headed by Mr. Toshio ENAMI.

The team had discussion on the project with the officials concerned of the Government of Bolivia and conducted a field survey in the southern area of Bolivia. After the team returned to Japan, further studies were made and the present report has been prepared.

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

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

Tokyo, March, 1982

Keisuke Arita
President
Japan International Cooperation Agency

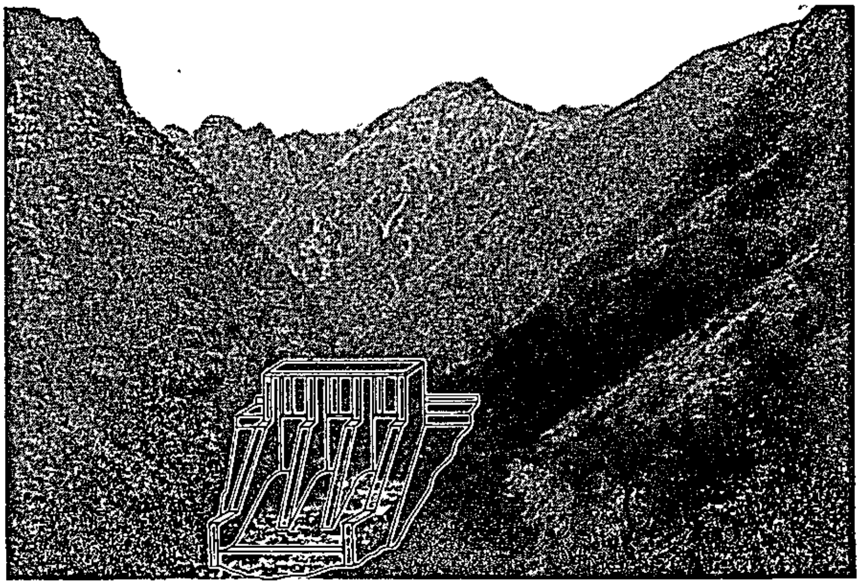
CONTENTS

ABBREVIATIONS OF THE PRINCIPAL AUTHORITIES CONCERNED AND COMPANIES

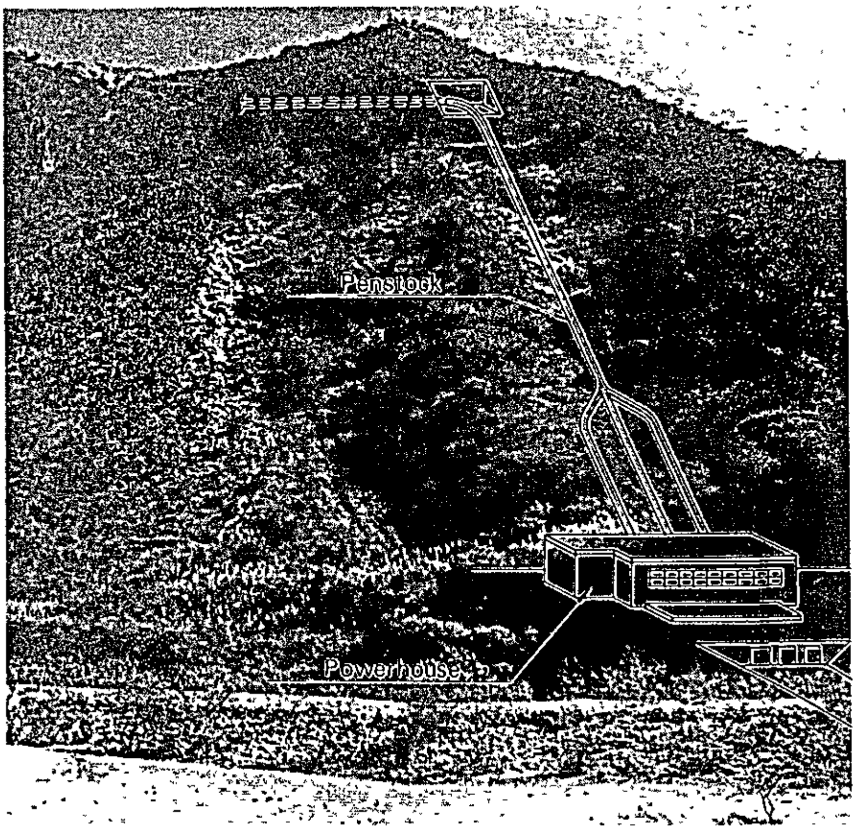
JICA	:	Japan International Cooperation Agency
ENDE	:	Empresa Nacional de Electricidad S.A.
BPC	:	Bolivian Power Company
CESSA	:	Cooperativa Eléctrica Sucre S.A.
ELFEC	:	Empresa de Luz y Fuerza Eléctrica Cochabamba S.A.
ELFEO	:	Empresa de Luz y Fuerza Eléctrica de Oruro S.A.
SEPSA	:	Servicios Eléctricos Potosí S.A.
SETAR	:	Servicios Eléctricos de Tarija
COMIBOL	:	Corporación Minera de Bolivia
DINE	:	Dirección Nacional de Electricidad
CRE	:	Cooperativa Rural de Electrificación
YPFB	:	Yacimientos Petrolíferos Fiscales Bolivianos
UN	:	United Nations
IBRD	:	International Bank for Reconstruction and Development (World Bank)

ABBREVIATIONS OF THE PRINCIPAL UNITS AND OTHERS

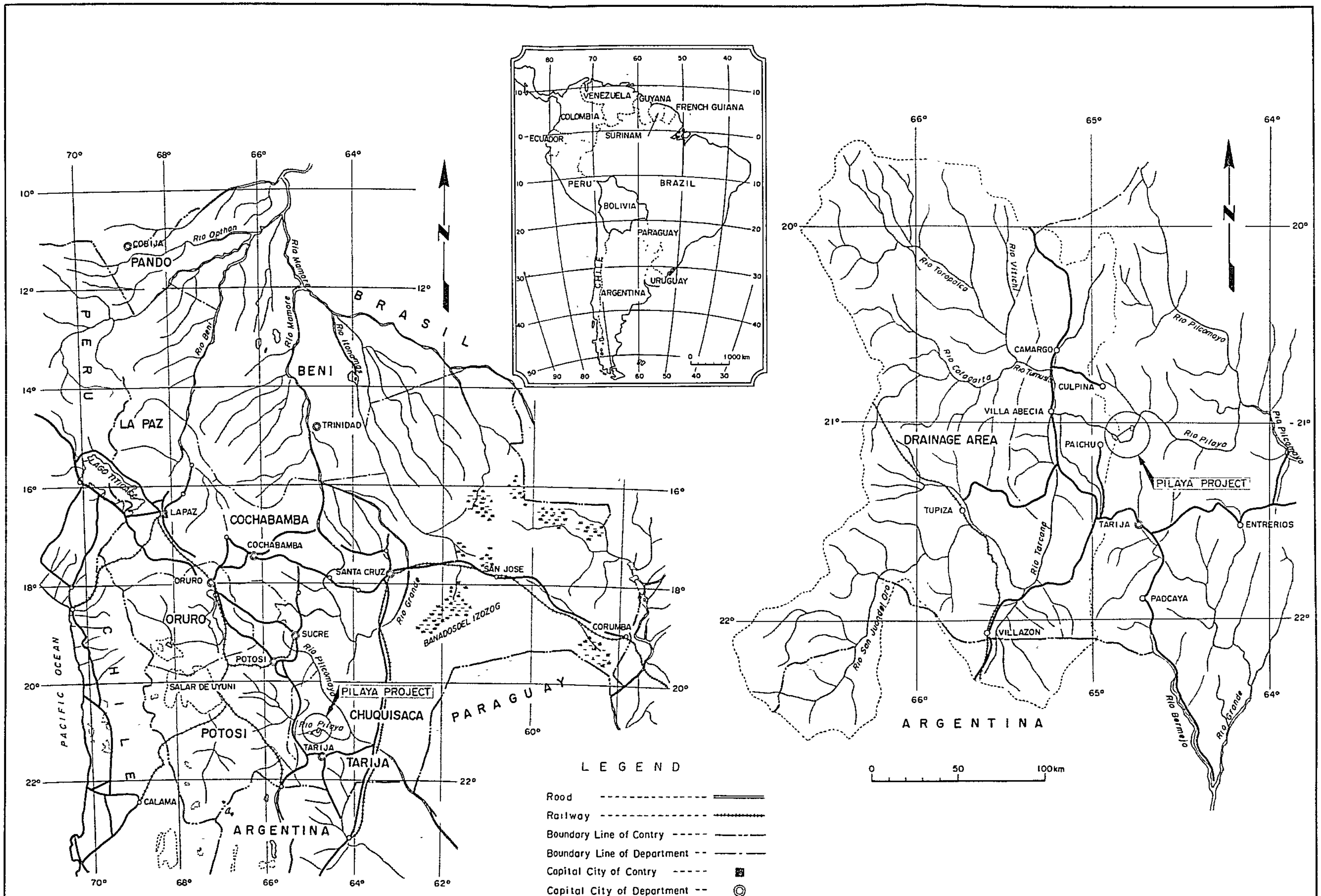
BTU	:	British thermal unit = 0.252 kcal
CIF	:	Cost Insurance Freight
FOB	:	Free on board
ft^3	:	Cubic feet = 0.0283 m^3
kW	:	Kilowatt
MW	:	Megawatt = 1,000 kW
kWh	:	Kilowatt hour
GWh	:	Gigawatt hour = 1,000,000 kWh
kV	:	Kilovolt
MVA	:	Megavoltampere
m	:	Meter
km	:	Kilometer
km^2	:	Square kilometer
m^3	:	Cubic meter
rpm	:	Revolution per minute
Hz	:	Herz
mm	:	Millimeter
cm	:	Centimeter
m^2	:	Square meter
cm/s	:	Centimeter per second
m/s	:	Meter per second
m^3/s	:	Cubic meter per second
m^3/s-d	:	Cubic meter per second-day
sec	:	Second
min	:	Minute
°C	:	Degree celsius
T.B.M.	:	Tunnel boring machine
EL.	:	Elevation
KPH	:	Kilometers per hour
bbl	:	Barrel = 159 liter



Pilaya Dam Site Viewed from the Downstream



Pilaya Powerhouse Site Viewed from the Rio Pilaya



KEY AND LOCATION MAP

CHAPTER 1

INTRODUCTION

CHAPTER 1 INTRODUCTION

CONTENTS

CHAPTER 1. INTRODUCTION

1.1 Antecedents

Electric power demand in Bolivia has been growing in recent years at a relatively high rate of 8.3% annually. In order to cope with this growing power demand Empresa Nacional de Electricidad S.A. (ENDE) is actively pushing ahead with construction of hydroelectric power plants, and also, diesel and gas turbine power plants.

With the objective of development of new hydroelectric power sources in the southern part of Bolivia, ENDE, with the cooperation of the United Nations, studied hydroelectric power projects on the Pilaya River of the Pilcomayo River system, and selected the Huacata Project, and as an alternative, the Aguas Calientes Project.

In 1977, ENDE requested the Japanese Government through the Bolivian Government for cooperation in making a comparative study of the above two proposals and for carrying out a feasibility study on the more promising project of the two.

In response to this request, the Japanese Government in January 1978, in order to ascertain the necessity and possibility of a feasibility study, dispatched engineers through the Japan International Cooperation Agency (JICA) to conduct field investigations, and in March 1978 prepared a prefeasibility study report on the Project.

Based on the recommendations in that prefeasibility study report, the Japanese Government, again through JICA, dispatched a Survey Team consisting of four persons, mainly engineers of the Electric Power Development Co., Ltd. (EPDC), in September 1979 for field investigations necessary for a comparison of the Huacata Hydro Power Project and the alternative Aguas Calientes Hydro Power Project and also for formulating plans on geological survey works carried out in 1980.

Based on the results of the investigations, the Survey Team submitted a preliminary investigation report to the Japanese Government in March 1980, and in addition to selecting the Aguas Calientes Project (Pilaya Hydro Power Project), recommended that necessary geological survey works be carried out. ENDE, based on the recommendations of the above-mentioned report, carried out geological and topographical survey works from April to December 1980.

In 1981, the Japanese Government again organized a Survey Team consisting of EPDC engineers of various specialties and dispatched this Survey Team through JICA for the purpose of carrying out a feasibility study based on the results of the geological survey. From June 19 to August 2, 1981, the Survey Team, with the cooperation of engineers of ENDE, carried out surveys of the Project area and related areas, and upon returning to Japan, prepared this Feasibility Report from August 1981 to March 1982 based on data and informations collected in the field and discussions with ENDE.

1.2 Existing Reports

The Pilaya Hydro Power Project was first planned by ENDE and the United Nations and some part of field investigations had been made previously, but in 1980 geological survey works over a period of 8 months were carried out. Reports prepared in relation to the Pilaya Project since 1973 are as follows:

(1) Proyectos Hidroeléctricos en el Río Pilaya, (ENDE), Junio 1973.

(2) Planta Hidroeléctrica Pilaya: Estudio de Prefactibilidad, (ENDE), Abril 1978.

(3) Progress Report of Feasibility Study on Pilaya Hydro-Electric Power Project, (JICA), March 1980.

(4) Proyecto Hidroeléctrico Pilaya, Materiales de Construcción, (ENDE), Septiembre 1981.

1.3 Objective and Scope of Report

The objective of this Report is to conduct a feasibility level study to establish the technical and economic justifications for the hydro power project planned for the Aguas Calientes site on the Pilaya River based on the results of prefeasibility studies, geological survey works carried out on the dam and powerhouse sites, and supplementary surveying works, thereby to formulate the optimum development plan.

The scope of study in this Feasibility Report, with regard to the Pilaya power generating facilities (output 87 MW), covers dam, intake, sedimentation basin, headrace tunnel, powerhouse and outdoor switchyard facilities. Concerning access roads, they are to be planned for routes to the dam and powerhouse sites.

Power transmission facilities are to be studied for the section below.

Section	Voltage (kV)	Length (km)	Number of Circuits (cct)
Pilaya-Camargo	115	65	2
Camargo-Telamayu	115	115	1
Camargo-Potosi	115	170	1
Pilaya-Tarija	115	60	1

Regarding the 115 kV power transforming facilities, studies are to be made of Camargo Substation equipped with transfer bus arrangements and Tarija Substation equipped with double bus arrangements.

1.4 Basic Principles in Preparation of Report

- This Report is a study report of feasibility level and the construction cost is to be estimated at price in December 1981 as the basis.
- The Pilaya Power Plant is to be tied to the National Power System and is to

serve as a power source for all of Bolivia.

- With regard to the construction schedule in the future, detail design is to be started in 1982 with preparatory works carried out for one and half (1.5) years from 1984 followed by construction work for five and half (5.5) years, and operation is to be started at the end of 1990.
- Since it is forecast that the annual growth rate in power demand from 1980 to 1990 will be 8.5%, the maximum power demand in 1990 will be approximately 600 MW.
- The loan conditions to be adopted for financial analysis, in view of the construction funds required for the Project, are to be predicated on joint financing loans from international financing institutions such as the International Bank for Reconstruction and Development (World Bank) and government-to-government aid.

1.5 Composition of Survey Team and Period of Survey

The Survey Team was composed of the six engineers and one economist below, all of EPDC.

	Name	Specialty	Period in Field
Chief	Toshio Enami	General Supervision	19 Jun. '81 to 2 Aug. '81
Member	Hiroshi Kagami	Electric Engineering	4 Jul. '81 to 2 Aug. '81
"	Takeshi Kawashima	Civil Design	19 Jun. '81 to 2 Aug. '81
"	Tadashi Ogura	Power Transmission	- Ditto -
"	Koji Mishima	Civil Planning	- Ditto -
"	Ken Niimi	Geology	- Ditto -
"	Masaru Hamada	Electric Power Economics	4 Jul. '81 to 2 Aug. '81

The advance team of the Survey Team spent 45 days from June 19, 1981 and the remainder 30 days from July 4, 1981, and these together with ENDE engineers carried out field investigations of the Project area and related areas. After returning to Japan, the Survey Team conducted studies from August 1981 to March 1982 based on data and informations collected in the field and on discussions with ENDE to prepare this Feasibility Report.

CHAPTER 2

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 2 CONCLUSIONS AND RECOMMENDATIONS

CONTENTS

CHAPTER 2. CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

As a result of investigations and studies regarding the Pilaya Hydro Power Project the conclusions below were arrived at. The result of review for the alternative plan to this plan is described in the APPENDIX-VI.

(1) It is forecast that the average annual growth rate in electric power demand in Bolivia for the next 10 years will be 8.5%. The electric power systems in the country are the Northern Power System which includes La Paz, capital city and the Central Power System which includes Oruro-Cochabamba, these two systems being interconnected. It is expected that the Eastern Power System which includes Santa Cruz will also become interconnected to the National Power System by the end of 1984. The 87 MW of power generated by the Pilaya Project will be supplied to the National Power System from the beginning of 1991. It is forecast that the maximum power demand at that time will have reached approximately 600 MW.

(2) As a result of investigations and studies concerning the technical and economic feasibility of the Pilaya Project the conclusions described below were arrived at. The outline of electric power facilities is the following:

Civil Structures

Dam: concrete gravity type, height 73 m, length 89 m.

Sedimentation basins: tunnel type, width 13 m, length 50 m × 2.

Headrace: pressure-tunnel type, diameter 3.1 to 3.5 m, length 10,400m

Penstock: ground-surface type, 1 line, diameter 1.2 to 3.1 m, length 638 m

Powerhouse: surface type, width 24 m, length 56 m, height 28.5 m

Electric Equipment

Turbine: vertical-shaft Pelton type, discharge capacity 8.66 m^3/sec (effective head 398 m) × 3 units

Generator: vertical-shaft, revolving-field, enclosed hood circulating type, 32,400 kVA, 375 rpm, 50 Hz x 3 units

Main transformer: outdoor, 3 phase, air-cooled type, 32,400 kVA x 3 units

Switchyard: outdoor, 115 kV switchgear

Transmission Line: 115 kV, length 410 km

Telecommunications Facilities: PLC and VHF system

Installed Capacity: 87,000 kW

Annual Energy Production:

Average	536 GWh
Firm	472 GWh

(3) The direct construction cost of the Pilaya Project including transmission lines will be US$223,638,000 (foreign currency portion US$120,854,000 domestic currency portion US$102,784,000) in terms of December 1981 prices.

(4) The construction cost per kW at the generating end of the Pilaya Project will be US$1,960 at 1981 prices, while the energy cost per kWh will be 47.9 US mills. The costs are comparatively high for a hydroelectric power plant, but it is thought the Project should be evaluated from the standpoint of effective utilization of water resources and stable supply of non-petroleum energy.

(5) To make an economic analysis of the Project through benefit-cost ratio (B/C) in comparison with an alternative power plant, assuming that the time when natural gas is depleted will be in the year 2000 or 2010, with the price of petroleum rising by 100% and 50%, respectively, and evaluating by the opportunity cost of natural gas, it will be 1.45 and 0.67. The economic internal rate of return of the Project will be 9.2%.

(6) In financial analysis of the Project it was assumed that the domestic currency requirement would be covered by loans from an international financing institution such as the World Bank, and the foreign currency portion by government-to-government development aid, and on the condition that the electricity rate become triple the prevailing average unit sales price to be 136.9 US mill/kWh. As a result, the cumulative cash flow will show a surplus from 1996, the sixth year from start of operation.

(7) Taking into consideration the period required hereafter for investigations, detail design, tendering, preparatory works and construction, the start of construction on this Pilaya Project will be in 1985 with start of operation at the end of 1990. The construction schedule for this Project will be as shown in Table 10-1.

(8) The Project not only will contribute directly to the National Power System as a stable supply source of electric power, but also is thought will contribute greatly to furtherance of industry and the economy and employment in the Project area.

(9) As a result of the latest investigations and studies, the following judgments may be made regarding the design and construction of civil structures in this Project:

i) Both banks of the river at the dam site are steep to form a V-shaped, and as a result of geological investigations, river deposits reaching 40 m in thickness were confirmed at the river bed. For the dam foundation, excavation should be done to bedrock, and a concrete

gravity dam would be the most suitable type for the site. For aggregate for dam concrete, excavation muck is to be effectively utilized.
As embankment materials for cofferdams, deposits existing upstream and downstream of the dam are to be applied.

ii) The intake would be provided at the left bank immediately upstream of the dam.

Regarding a sedimentation basin, there is no suitable site for the sedimentation basin to be constructed at the surface and tunnel types therefore are to be provided, but with regard to structural details it will be necessary for a reexamination to be made upon further collection of data on sedimentation and analyses of data.

iii) The headrace tunnel is to be a long tunnel of 10.4 km and will govern the construction period of the Pilaya Project. In construction of the tunnel, the deployment of a tunnel boring machine should be considered.

iv) The penstock and powerhouse are to be ground-surface types as a result of comparative studies.

v) Since there will be concern about outflow of debris from the tributary Agua Caliente downstream of the powerhouse, the cost of constructing a debris dam at the ravine was included in the estimated construction cost for the Project.

vi) The tailrace was selected to be an open canal type and the design was made considering flooding.

(10) The principal figures of electric equipment for the Project were established as follows:

i) The number of units and output capacity are 3 units and 29,000 kW each, respectively, in view of power demand and supply reliability.

ii) It was decided the turbine type should be Pelton in view of the effective head and the available discharge per unit. With regard to whether the turbine should be vertical-shaft or horizontal-shaft, economically advantageous vertical-shaft was selected as a result of a comparative study.

(11) Transmission lines under this Project are to be interconnected with Potosi and Telamayu Substations via Camargo Substation composing a part of the National Power System. There is also to be interconnection with Tarija by 115 kV transmission line.

(12) As for access roads, with regard to the dam, a route from the town of Miskha Pampa was selected from the aspect of economy, and the width is to be 4 m and the length 38.7 km.

Regarding the access road to the powerhouse, taking it into consideration that heavy articles comprising electric equipment would be hauled, a route from Leon Cancha Village to the powerhouse site was selected, and the width is to be 5 m, and the length 25.8 m.

(13) With respect to electric power for construction, for the dam work a 24.9 kV distribution line is to be constructed in advance from Camargo to the dam site via Miskha Pampa, while for the powerhouse and headrace tunnel works a 115 kV transmission line from Tarija Substation is to be constructed in advance of the main work to supply electric power.

2.2 Recommendations

The following recommendations are made based on the conclusions described in Item 2.1.

(1) Timing of Construction

The economic internal rate of return for the Pilaya Project will be 9.2%, and the rate of return in comparison with the electricity charge revenue (computed from marginal cost) estimated by ENDE is low.

In contrast, in case it is assumed that natural gas in Bolivia will be depleted in the year 2000, the Pilaya Hydro Power Project will show a good economic effect in comparison with the opportunity cost of natural gas.

The economic effect of the Pilaya Project will differ in this manner depending on the measure used or evaluation. However, in any case, there will be some kind of power supply source required at the beginning of 1991. Accordingly, ENDE should carry out an economic comparison between the Misicuni Hydro Power Project (100 MW) and the Pilaya Hydro Power Project (87 MW) and determine which of these two hydros should be constructed first.

(2) Further Field Investigations

i) Geological Investigation

Although investigations of geology and materials necessary for detail design have been carried out in the past by ENDE, the investigations below are further required to be made.

Regarding the cofferdam, since it would be conceivable also to design a blanket type if core materials for cofferdamming were to be available in sufficient quantity, an investigation of the available quantity is necessary.

As for hot spring water found in the downstream of 7 km from the powerhouse site, further investigation and study described in Item 6.4.3 (3) should be made to find up possibility of the headrace tunnel which would become high temperature at the time of tunnel excavation.

ii) Topographic Surveying

Since some unconformities regarding elevations are noticed between the dam and powerhouse sites, levelling will be necessary for making a recheck of the gross head between them.

Since sedimentation is severe at downstream of the powerhouse site, control points should be provided hereafter and measurements of river-bed height continued.

Topographical maps of 1/1,000 scale will be necessary for areas where access roads are planned.

iii) Hydrological and Meteorological Observations

Precipitation and runoff observations which have been carried out continuously from the past should be continued in the future taking care that no blank periods will result. With regard to low-water observations at Chillcara Gauging Station selection of adequate measurement equipment (currentmeter) is required.

As regards observations of sediment transported by stream which have been made since 1980, further collection of data should be aimed for and the situation concerning sedimentation grasped, and it is requested for the results to be reflected in detail design of the various civil structures.

CHAPTER 3

ECONOMY AND ELECTRICITY INDUSTRY OF BOLIVIA

CHAPTER 3 ECONOMY AND ELECTRICITY INDUSTRY OF BOLIVIA

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 3. ECONOMY AND ELECTRICITY INDUSTRY OF BOLIVIA

3.1 Natural Conditions and Economic Situation in Bolivia

3.1.1 Natural Conditions

(1) Physiographic Features

Bolivia is situated at roughly the center of the South American continent and is located between 9° to 23° south latitude and 57° to 69° west longitude. The total area of the country is approximately 1.1 million km^2, approximately three times as large as that of Japan, and it is an inland country bounded on the north and east by Brazil, the southeast by Paraguay, the south by Argentina, the southwest by Chile, and the west by Peru. One fourth of the national territory is made up of a part of the Andes Mountain Range and the Altiplano at elevations higher than 3,000 m, with the rest being a vast plain forest area belonging to the Amazon River Basin, but since the boundary between the Altiplano and the plain is a valley area, or the Yungas, the country may be broadly divided into three areas.

As the Altiplano has many parts which were developed from a very long time ago and almost every kind of mineral except for gems are produced two thirds of the population is concentrated here. But generally speaking, traffic between various parts of the country is hindered by the high mountains and the vast virgin forests, so that development of underground resources of the Altiplano, agriculture in the plain area and other abundant resources has been retarded. Therefore, the problem lies in the method of developing the enormous land area which had been left untouched for so long.

(2) Climate

The climate varies greatly not by difference in latitude but according to elevation, with the plateau area 3,500 m above sea level and higher at the Pacific Ocean side being of sub-Arctic climate, while at the valley area 1,800 m or more above sea level the climate is temperate and presents appearances ranging from Temperate Zone to Sub-Tropical. Further, the plain area, or Llanos, spread out in the Amazon River Basin to the east is of high temperature, with the climate a tropical one, the annual mean air temperature being 24 - 25°C. As for the distinction between rainy and dry seasons, as a whole the rainy season is from December to April and the dry season from May to November, and although there is a clear difference at the Altiplano, there is a fairly substantial amount of rain at the lowlands even when not in the rainy season.

(3) The People and Population

The total population as of 1980 was 5,600,000 (male 2,760,000, female 2,840,000), the annual average growth rate being 2.7%, with approximately 70% of the total population living in the Altiplano and Yungas areas, and 30% in the vast Llanos area.

The racial composition is that of 54% native Indians, 31% mestizos, and 15% whites, with the greater part of the Indians living in the Altiplano and Yungas areas. Mainly, the Aymara tribe lives in the vicinity of La Paz while near Cochabamba lives the Quechua tribe, these tribes having their own languages. Other than these there are various tribes who have different dialects and customs.

3.1.2 Economic Conditions

(1) Economic Structure

The feature of the economic structure of Bolivia, like in many developing countries, is that a monoculturelike color is strong, and although in recent years petroleum and natural gas have come to make up roughly 20% of exports, basically, non-ferrous metals such as tin, lead and zinc make up 60 to 70%, and comprise the greatest source of foreign exchange income. The weight of such first industries is great in exports, while conversely, in imports, the principal items are products of secondary industries such as processing industries and assembly industries, with the weight of assembly industries of high degrees of fabrication. However, approximately two thirds of the population are still engaged in traditional agriculture of low productivity, with many making only a self-sufficient livelihood, and basic industries such as the energy industries of electric power and petroleum, the steel industry, and assembly industries centered on industrial machinery, which indicate the degree of development of a country, are at a stage where they are just beginning to grow.

The amounts of exports and imports of the principal items are given in Table 3-1.

(2) Gross National Product

Normally, in order to make an overall evaluation of the economic activity of a country, gross national product calculated based on objective market price evaluations is used as the analysis method. The gross national product in Bolivia achieved growth of rates of an annual average 6% or higher from 1972 to 1976, but the rate became 3.4% in 1977, 3.1% in 1978 and 2.0% in 1979 to indicate a continuing trend of slow-down, and finally, in 1980 the rate fell to 0.8%, the lowest in the recent 10 years.

The gross national products according to various sectors are as shown in Table 3-2, and when the economic activity in 1980 is examined by sector, "Commerce," "Public Services" and "Other Services" show growths of 1.5 to 2% and may be said to be relatively sound. "Agriculture" dropped from 2.0% growth of the preceding year to 1.7%, while in "Mining," since non-ferrous metals other than tin showed production increases, there was a turnaround from the minus 7.5% growth of the previous year to 1% growth. Although the "Petroleum and Natural Gas" sector showed a slight change for the better from the minus 9.9% of the previous year, it was still a minus 6.5% growth, while in the manufacturing sector the minimum since 1970 and the first minus growth of 1.0% was seen.

Table 3-1 Import and Export

Unit: US$$10^3$

	Item	1976	1977	1978
IMPORT	Cereals	14,133	20,103	30,876
	Medicine	15,360	16,675	23,081
	Iron and Steel	83,189	61,377	61,540
	Machinery	114,436	126,745	184,301
	Electric Apparatus	35,466	56,282	66,805
	Automobile	93,039	77,822	103,226
EXPORT	Mineral	378,693	492,668	514,957
	Petroleum	112,571	71,425	42,375
	Natural gas	54,896	66,803	78,506
	Sugar	42,762	27,089	14,995
	Wood	9,995	10,577	12,488
	Cotton	12,061	13,562	14,734

Source: Bolivia en Cifras 1980, Instituto Nacional de Estadistica

The "Construction" sector, after a boom from 1974 to 1977, showed 2.8% in 1978 and 2.5% in 1979 for a gradual drop in the growth rate, but in 1980 an abrupt drop to minus 5.0% in growth rate was indicated. In case of other sectors, similar to "Electricity, Gas and Water" which dropped from the growth rate of 5.7% of the previous year to 2.4%, "Transportation and Communications," "Commerce, Restaurants and Hotels," and "Public Services" showed slowdowns in growth rates.

(3) Commodity Prices

The rate of increases in commodity prices at La Paz, capital city (see Table 3-3) was 62.8% in 1974, the year following the oil shock, and was the maximum since surveys were started in 1967, while in 1980, because of the 25% devaluation in the exchange rate carried out in November of the previous year and the effects of wage increases, the inflation rate was 47.2%. To show the indices from 1967 to 1980 in Fig. 3-1, it can be seen that a condition of inflation is presented periodically. That is, a declining trend was indicated from 1967 to 1969, while from 1969 to 1971 the condition was that of flattening out. Commodity prices rose abruptly from 1972 and the maximum rise was indicated in 1974, after which there was a period of decline and stabilization, and from 1980 there has been a rising trend.

Seen according to sector, the inflation rate of foodstuffs showed variations similar to the overall inflation rate, but that of housing recorded a maximum of 47.9% in 1980 in spite of prohibition of raises in rentals in November 1979.

(4) Economic Development

According to the Bolivian five-year economic development scheme made in 1976, the following important policies was described. That is, in order to achieve the economic development of Bolivia it is necessary for real investments to be furthered centered around mining, energy and agriculture-livestock raising. For this purpose, it is thought necessary for Bolivia, which does not have adequate capital, to make investments giving priority to projects which will be the most efficient. For this purpose, along with raising the income per capita as the most important topic, in the agricultural administration sector it is important to increase substitutes for imported foodstuffs, increase production of export products such as cotton and sugar and make efforts for introducing new agricultural technology to increase production of wheat, soybeans, etc., while in the manufacturing sector, it is necessary to utilize domestic resources such as minerals and petroleum to nurture processing industries to expedite production of import alternative and export items.

Table 3-2 GNP of Bolivia

Unit: US$$10^6$

	1972	1973	1974	1975	1976	1977	1978	1979	1980
1. Agriculture	100.5	105.1	109.0	116.3	119.6	115.6	118.7	121.1	123.1
2. Mines	46.5	56.5	55.1	47.6	53.6	54.8	52.0	48.1	48.6
3. Petroleum	12.7	17.2	15.1	11.8	12.5	9.5	8.9	8.0	7.5
4. Manufacture	80.2	84.2	93.7	99.4	107.7	114.3	119.4	122.8	121.6
5. Construction	21.4	21.8	23.8	26.9	29.0	31.3	32.2	33.0	31.3
6. Electricity, Gas and Water	7.6	8.4	9.3	9.5	10.1	10.7	11.2	11.9	12.2
7. Transportation, Store. Communication	42.9	45.6	52.4	59.6	66.7	75.2	81.2	83.8	85.4
8. Commercial· Restaurant· Hotel	91.6	94.4	100.5	108.2	112.5	115.0	118.6	121.2	122.4
9. Finamcial Institution	10.4	12.3	13.6	16.0	19.1	21.4	22.5	24.0	24.7
10. Immovable Property	46.0	47.7	49.5	51.5	53.8	56.0	57.7	59.8	60.6
11. Other Services	43.0	44.9	48.3	52.8	55.2	57.3	59.2	60.8	62.2
12. Bank Service	-6.7	-7.7	-8.3	-9.8	-10.0	-11.1	-11.6	-12.1	-12.4
13. Public Services	53.3	56.2	60.5	64.3	69.0	72.5	75.2	78.1	79.2
G N P	549.4	586.6	622.5	654.1	698.8	722.5	745.2	760.5	766.4
GROWTH RATE (%)		6.8	6.1	5.1	6.8	3.4	3.1	2.1	0.8

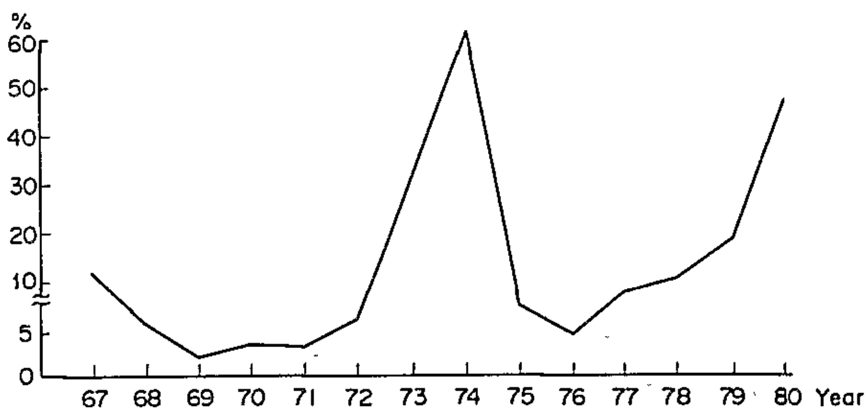
Source: Boletín Estadístico No. 240, Diciembre 1980, Banco Central de Bolivia

Table 3-3 Consumer's Price Index in La Paz

Unit: %

YEAR \ ITEM	General Index	Food	Housing	Clothing	Others
1967	11.2	16.1	12.3	0.4	2.1
1968	5.5	7.4	5.1	1.8	1.6
1969	2.2	2.1	2.1	3.1	2.1
1970	3.9	4.6	4.0	3.7	1.0
1971	3.7	4.0	4.4	4.6	0.6
1972	6.5	6.4	5.6	9.0	5.8
1973	31.5	35.0	14.9	38.6	29.6
1974	62.8	81.7	22.2	46.1	35.4
1975	8.0	5.3	14.1	15.8	9.9
1976	4.5	2.4	9.5	11.0	4.3
1977	8.1	8.2	12.1	4.1	8.5
1978	10.4	10.0	11.3	8.9	13.1
1979	19.7	18.6	21.4	15.9	28.8
1980	47.2	47.6	48.0	42.7	49.5

Fig. 3-1 Inflation Rate of General Index



Source: Indice de Precios al Consumidor, Boletin Mensual No.12, Diciembre 1980

3.2 Present State and Future Outlook of Electricity Industry

3.2.1 Present State of Electric Power Supply

The electric energy consumption per capita (generating end) of Bolivia reached 263 kWh in 1979, but this is low compared with other Central and South American countries and only approximately 30% of the entire population enjoys the benefits of electricity. Of the entire power generating facilities of Bolivia, the proportion for public services was 78% in 1979 with the remainder being privately-owned generating facilities. The installed capacities by hydro and by thermal and the generating performances of public services and private generating facilities from 1975 to 1979 are as shown in Table 3-4 and Table 3-5. The energy consumptions by types of customers and the proportions are given in Table 3-6, and it may be seen that the proportion of demand of the mining sector makes up 35% of electric energy consumption. This figure, compared with the proportion of this sector in 1974, is approximately 10 percentage points lower, but it is still the highest. Of the public services generating facilities, the proportion made up by hydro is 90% with the remaining being gas turbine and diesel power generating facilities.

Table 3-4 Installed Capacity in Bolivia

Unit: MW

Year	Public services		Self-producers		Total		Total
	Hydro	Thermal	Hydro	Thermal	Hydro	Thermal	
1975	214.1	71.0	27.4	63.7	241.5	134.7	376.2
1976	214.1	91.7	27.4	65.7	241.5	157.4	398.9
1977	214.1	92.7	27.4	71.4	241.5	164.1	405.6
1978	214.1	113.2	27.4	73.1	241.5	186.3	427.8
1979	214.1	113.2	24.3	69.7	238.4	182.9	421.3

Source: Bolivia en Cifras 1980, Instituto Nacional de Estadistica

Table 3-5 Generation in Bolivia

Unit: GWh

Year	Public services		Self-producers		Total		Total
	Hydro	Thermal	Hydro	Thermal	Hydro	Thermal	
1975	642.1	127.9	157.6	129.4	799.7	257.3	1,057.0
1976	684.6	164.9	151.9	130.6	836.5	295.5	1,132.0
1977	765.6	205.5	142.7	145.9	908.3	351.4	1,259.7
1978	810.1	241.2	154.4	148.5	964.5	389.7	1,354.2
1979	860.1	266.2	153.1	153.3	1,013.2	419.5	1,432.7

Source: Bolivia en Cifras 1980, Instituto Nacional de Estadística

Table 3-6 Consumption of Electricity

Unit: GWh

Year	Domestic	General	Industry	Mining	Others	Total
1975	226.0	98.6	185.2	395.9	18.3	924.0
1976	242.4	106.9	223.9	409.5	27.7	1,010.4
1977	260.4	107.2	276.4	448.6	29.6	1,122.2
1978	292.2	120.1	308.0	454.4	33.1	1,207.8
1979	331.2	129.3	330.6	449.4	41.7	1,282.2
(%)	25.8	10.1	25.8	35.0	3.3	100.0

Source: Bolivia en Cifras 1980, Instituto Nacional de Estadistica

3.2.2 Electric Power Enterprises

The electric power enterprises in Bolivia consist of nine companies, of which the principal enterprises are ENDE and BPC. ENDE sells wholesale to distribution companies in the major cities and also supplies directly to large-volume customers, while BPC is engaged in integrated power supply, from power generation to distribution, in La Paz, capital city. These two own 93% (as of July 1981) of the power generating facilities, while the other electric power enterprises except for COMIBOL are engaged in power distribution purchasing electric power from the above-mentioned two companies for supply to customers in general. COMIBOL owns 21.4 MW of generating capacity corresponding to 5.4% of the whole in order to supply electric power required for mine development. The power generating facilities of each enterprise are as follows.

	Installed capacity (MW)	Effective capacity (MW)
ENDE	227.2	214.8
BPC	144.0	112.6
COMIBOL	21.4	17.6
ELFEC	6.2	3.0
Total	398.8	348.0

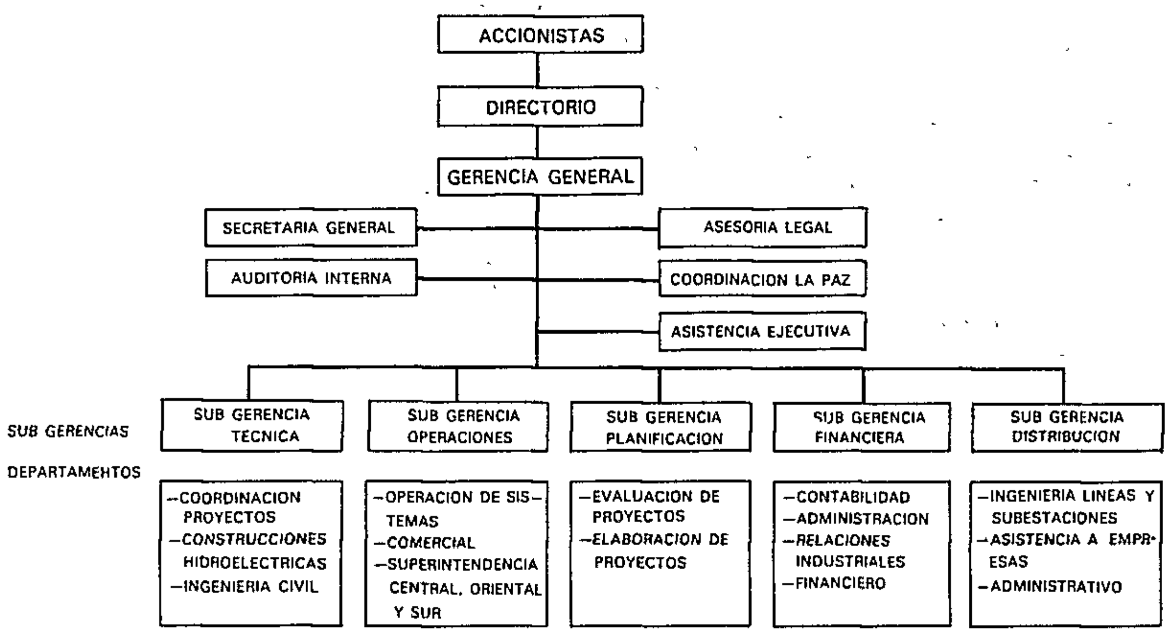
(as of July in 1981)

The electric power enterprises of Bolivia are obligated to undergo control, supervision and regulation from the Dirección Nacional de Electricidad (DINE), a Bolivian Government organ, in accordance with the electric enterprise law, "Codigo de Electricidad" promulgated in 1968. Consequently, implementation of new electric power development projects, application of new electricity rates, etc., all require the approval of DINE.

(1) ENDE

ENDE is a government-owned company established by the Bolivian Government in accordance with the supreme law of February 1962, "Decreto Supremo No. 05999," and its authorized capital is US$40 million. The business objectives of ENDE are to construct hydro and thermal power generating facilities, and to construct transmission line and transforming facilities necessary for transmission of the power generated, in addition to which the role of planning, designing and constructing transmission line and transforming facilities for nation-wide interconnection was assigned newly by the supreme law promulgated in September 1969, "Decreto Supremo No. 8952." Up to this time, ENDE has constructed 227.2 MW of power generating facilities combining hydro and thermal, and 1,580 km of transmission lines including 655 km of 115 kV transmission and distribution lines, and related transforming facilities. The organization of ENDE is as shown below in Fig. 3-2.

Fig. 3-2 Organization of ENDE



(2) BPC

BPC is the second largest electric power enterprise in Bolivia next to ENDE. Its power generating facilities are composed of Zongo Power Stations (total output 117.1MW) located along the Rio Zongo northeast of La Paz, capital city, and power is supplied by 69 kV transmission line to the Northern and Central Power System areas (mainly the cities of La Paz and Oruro). BPC having the customers in La Paz made up 39% of the total customers in 1979 will continue to be responsible for supply to the Northern Power System centered at La Paz by agreement with the Bolivian Government.

(3) Power Distribution Companies

The power distribution companies are ELFEC located in Cochambamba City, ELFEO in Oruro City, SETAR in Tarija City, CRE in Santa Cruz City, CESSA in Sucre City, and SEPSA in Potosi City. ENDE owns stock in ELFEC and CESSA among these power distribution companies while BPC owns stock in ELFEO.

3.2.3 Power System Expansion Plan of ENDE

According to the electrification plans of ENDE from 1980 to 1990, it is estimated that power demand in the service areas of the Central, Southern, Eastern and Northern Power Systems will be increased from 1,572 GWh to 3,007 GWh, while generating capacity will also be increased from 363.3 MW to 664 MW. In order to cope with this increase in demand, ENDE has plans to push ahead with the Pilaya Hydro Power Project and the following hydroelectric power station construction and transmission line expansion works.

(1) Hydroelectric Power Development Plans

Sakahuaya Hydro Power Project planned in Departamento de La Paz, was a project which could have gone into operation at the beginning of 1984 if construction had been started at the beginning of 1981, but start-up will be pushed back one year and completion of the first phase (36 MW) is scheduled for 1985. As for the second phase (36 MW), it is cheduled for start-up in 1986.

Regarding Palillada Hydro and San Jose Hydro Power Projects, prefeasibility studies have been finished, but if the periods for feasibility studies and access road construction were to be taken into account, it is thought commissioning before 1988 - 1989 will be fairly difficult. Similarly, a feasibility study has been finished for Rositas Hydro Power Project, but start-up is planned for 1990 or later. As regards Icla Hydro Power Project (90 MW) and Misicuni Hydro Power Project for which feasibility studies have been made, their start-ups are expected to be in 1986 and the early part of the 1990s, respectively, while with respect to San Jacinto Hydro Power Project (7.0 MW), it is scheduled for completion in 1983. Besides these new hydroelectric projects, addition of Unit No. 4 (18 MW) of the existing Santa Isabel Hydro Power Plant is scheduled for the beginning of 1984.

(2) Transmission Line Expansion Plans

Beginning with construction of Punutuma-Telamayu (115 kV, 105 km) and Chuquiaquillo-Chojlla (115 kV, 65 km) in 1981, construction of Santa Isabel-Villa Tunari (33 kV, 60 km), Telamayu-Chilcobija (69 kV, 59 km), and further, Chilcobija-Tumari-other locations (25 kV, 130 km), Viacha-Corocoro (69 kV, 62 km), and Villamontes-Yacuiba (69 kV, 74 km) are scheduled for 1983, while in 1985, completion of interconnection (220 kV, 360 km) between the Central Power System and the Eastern Power System is scheduled, and in 1987, expansion of Icla-Potosi (220 kV, 110 km) is scheduled.

(3) Thermal Power Development Plans

Construction of Villamontes Diesel Power Plant (2.4 MW) in 1981 and Trinidad Diesel Power Plant (2.5 MW) in 1982 are scheduled, in addition to which the expansions of the two thermals are planned respectively for 1984 (First Phase Expansion, 2.0 MW), 1989 (Second Phase Expansion, 3.0 MW), and 1985 (2.0 MW addition), besides which, in 1982, the gas turbine power stations of Potosi and Santa Cruz (16 MW and 20 MW) are scheduled to be constructed.

3.2.4 Electricity Rates

The electricity rates in Bolivia differ considerably according to electric power company, and the rates at cities other than La Paz and Oruro were approximately double in 1974 compared with the above two cities as shown in Table 3-7, and double to triple in 1980 as shown in Table 3-8.

Table 3-7 Electricity Rates in 1974

Unit: US mills/kWh

Name of company	Domestic	General	Industries	Average
BPC	12.0	39.1	14.5	13.9
ELFEO	11.5	15.5	13.0	13.1
ELFEC	26.5	31.0	25.0	26.1
CRE	31.0	39.0	28.0	31.3
SETAR	29.5	35.0	25.0	30.9
CESSA	35.5	42.0	32.5	30.3
SEPSA	26.0	36.5	26.5	31.3

Table 3-8 Electricity Rates in 1980

Unit: US mills/kWh

Name of company	Domestic	General	Industries	Average
BPC	41.0	72.5	34.1	28.0
ELFEO	37.0	52.7	28.4	26.2
ELFEC	73.8	-	66.8	44.4
CRE	88.0	81.6	45.6	46.0
SETAR	89.0	112.4	59.3	88.0
CESSA	76.8	86.0	62.6	48.4
SEPSA	71.0	91.6	58.6	56.8

The electricity rates of ENDE selling wholesale as of June 1981 are shown in Table 3-9, and compared with the rates in November 1975, they have become approximately double.

Table 3-9 Electricity Rates (As of June, 1981)

Distributors, Large Industries, Mining	Demand charge (US$/kW)	Energy charge (US mills/kWh)	Reference
ELFEC	4.7	18.5	Cochabamba city
CRE	-	36.6	Santa Cruz city
CESSA	2.9	28.6	Sucre city
SEPSA	3.4	28.0	Potosi city
SETAR	2.5	38.9	Tarija city
COBOCE	7.2	32.4	
YPFB	4.8	32.2	
COMIBOL	8.8	30.4	

3.2.5 Energy Resources

Bolivia has petroleum and natural gas as energy resources and various metals and non-metallic minerals as mineral resources.

(1) Petroleum, Natural Gas

With respect to petroleum and natural gas, exploration, extraction, refining and sales are all done in principle by the Yacimientos Petroliferos Fiscales Bolivianos (YPFB). Crude oil production reached a peak in 1973, a daily average 42,300 barrels, and coupled with the fact that domestic demand was small, it was possible for 32,400 barrels to be exported daily, but production subsequently fell and became a daily 23,800 barrels in 1980 while domestic consumption was increased, and it is considered that the balance between production and consumption has now been reversed. Particularly, since the crude petroleum of Bolivia is light, it has become necessary to import heavy oil.

The production of natural gas has been an average of 4,392,000 m^3 from 1976 to 1980, but domestic consumption was only 2.3%, with the remainder either returned underground or exported to Argentina. There is a plan going ahead to export to Brazil also, and an agreement was signed in April 1981 in the form of a reconfirmation of the understanding of April 1974 that natural gas would be supplied over a 20 year period.

(2) Non-ferrous Metallic Minerals

Bolivia has tin, silver, tungsten, zinc, antimony and lead as non-ferrous metallic minerals. Mining is the most important industrial sector of Bolivia, and although the proportion of mining production in gross domestic product was not quite 7%, non-ferrous metals made up 61.5% (1980) of exports. Table 3-10 shows the production of non-ferrous metals.

Table 3-10 Production of Minerals

Unit: Metric Ton

	1977	1978	1979	1980
Tin	33,896	30,827	27,753	27,271
Lead	20,739	17,963	15,349	17,225
Zinc	65,424	57,611	44,141	50,260
Tungsten	3,071	3,106	3,107	3,359
Silver	186	201	178	190
Antimony	16,252	12,977	13,115	15,465

CHAPTER 4

POWER DEMAND FORECAST

CHAPTER 4 POWER DEMAND FORECAST

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 4. POWER DEMAND FORECAST

4.1 Demand Forecast

Construction of new power plants, transmission lines and substations requires vast sum of investments and a long period of 3 to 10 years. To spend the limited sum of investments most effectively, future power demand must be estimated correctly and accurately. In developing countries, it would be pretty difficult to make accurate forecast of power demand, since the nation's economic activities tend generally to fluctuate violently with excessive fluidity and power demand follows such economic tendency very closely.

Power supply under this Project is planned by way of the interconnection power grid which is now being constructed by ENDE to complete the tie-up between the East Power System with Santa Cruz as the center of system and the National Power System by end of 1984. Proposed consuming will then include power demand in major urban areas including La Paz, capital city demand for the mine to be connected with the power system and rural electrification under the ENDE's development program. In the meantime, ENDE has forecasted future power demand on the National Power System over 20 years from 1980 to 2000 by* analysis and evaluation of the past power demand trend.

Although the Survey Team deemed the ENDE's demand forecast appropriate, the Team decided to make its own forecast by a different method from that used by ENDE with particular attention to the correlation, for cross-check of the ENDE's evaluated values, between power demand and population as one of basic factors for power demand forecast. Since the Pilaya Project is proposed for power generation development, the period of demand forecast covers the long term projection and up to including the year 2000, same as evaluated by ENDE, in view of coordination to be required with evaluation of the Project.

The proposed area of power supply under this Project will encompass, when viewed from geographic and topographic features of the Project, three provinces such as Tarija, Chuquisaca and Potosi, in which cities of Tarija, Sucre and Potosi will become the consuming centers, together with the existing mines in the province of Potosi.

4.2 Present Status of Power Demand

4.2.1 Comparison of Per-Capita Energy of Latin American Countries

As for consumption between Bolivia and some countries of South America generally, there exists a close correlation between per-capita power demand and gross national product (GNP). Population, GNP per-capita, installed capacity and generated energy in 1979 in South American countries are compared in Table 4-1.

* Evaluacion de la Demanda de Energia Electrica, Periodo 1980 - 2000 Agosto de 1980, ENDE

Table 4-1 Comparison of Generated Energy and Other Indices of Latin American Countries in 1979

Name of Countries	Population (10⁶)	GNP per capita (US$)	Installed capacity (MW)	Generated energy (GWh)	Per Capita	
					Insta. cap. (Watt)	Gen. energy (kWh)
Argentina	26.7	2,004	11,511	38,000	431	1,423
Bolivia	5.4	550	445	1,450	82	268
Brazil	118.7	1,592	28,394	110,600	239	932
Chile	10.9	1,410	2,931	11,133	269	1,021
Colombia	26.4	929	4,921	17,999	186	681
Ecuador	8.2	910	1,047	2,895	128	353
Peru	17.3	731	2,612	9,150	151	529

Source: Electric Power Industry Statistics, 1980
by Overseas Electrical Industry Survey Institute, Inc. Japan

As noted from Table 4-1, it is well predictable that power demand in Bolivia will continue further increase with the nation's economic development. Especially, when compared with other Latin countries of topographical and economic structural similarity, it can be said that Bolivia has her own greater potentiality in future growth of power demand.

Fig. 4-1 shows graphic chart of the correlation between per-capita GNP and energy consumption as indicated in Table 4-1.

4.2.2 Energy Consumption by Categories and Special Features

Energy consumption in Bolivia is featured by a remarkably large share accounted for by mining in total consumption. As a matter of fact, however, it has been showing the tapering tendency of its ratio in recent years as shown in Table 4-2, while the share ratio of consumption for residential and industrial uses has been on the increase.

As widely known to everybody, electricity has been of wider acceptance to the human society with evolution of the times and has come to hold the vital position as the largest energy source essential to various activities of the human community at large including daily living, culture and industry. This general tendency applies, as shown in Table 4-2, also to the case of Bolivia where electricity has begun to spread into home life at a steady growth rate, by increase of consumption, not only for lighting, but also for washers, television sets and heaters, as inferable from the today's urban life style, and even coolers in Santa Cruz situated in the tropical zone.

Fig. 4-1 Correlation between GNP/Capita and Generated Energy/Capita

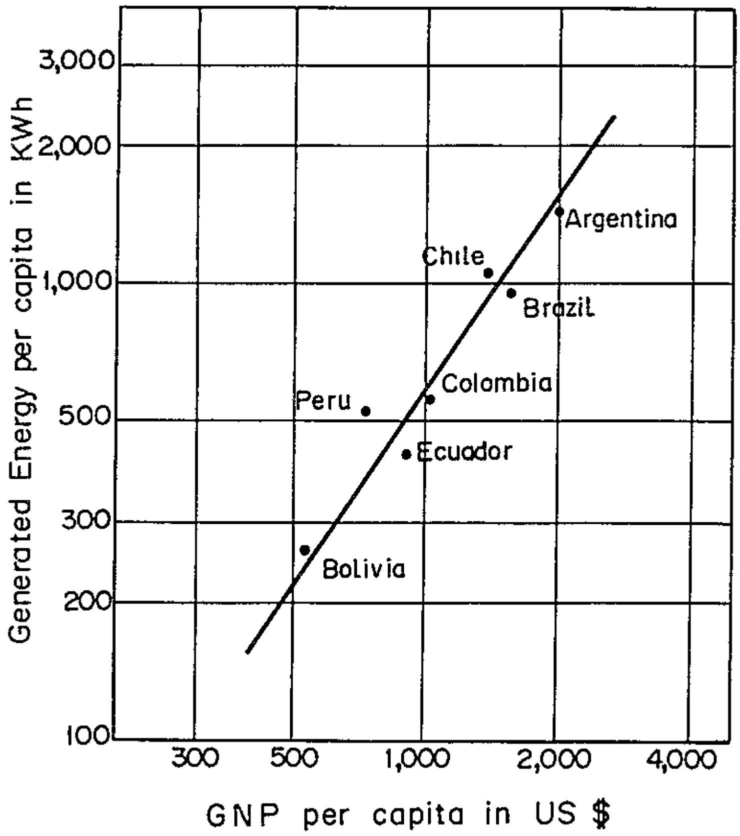


Table 4-2 Energy Consumption by Category

	Unit	1972	1974	1976	1978	1980
Total consumption	(GWh)	798.2	867.0	1,010.4	1,207.9	1,399.3
Consumption ratio						
Mining	(%)	44.9	44.1	40.5	37.7	33.0
Industrial	(%)	19.2	19.3	22.2	25.5	26.8
Residential	(%)	24.2	24.4	24.6	24.7	26.1
General	(%)	9.8	10.2	10.6	9.9	11.3
Public light	(%)	1.9	2.0	2.1	2.2	2.8
Total	(%)	100.0	100.0	100.0	100.0	100.0

Source: Evaluación de la Demanda de Energia Eléctrica (1980 - 2000)
1980, by ENDE

On the other hand, however, there still remain many homes far away from the benefits of electricity in the rural area. In this respect, ENDE endeavors to carry out construction of power plants, transmission lines and substations for electrification of the rural area beyond the serviceable range of the National Power System, keeping abreast of the nationwide power development being executed in Bolivia.

Meanwhile, industrial demand is increasing conspicuously, manifesting notably that the industrial structure in Bolivia is shifting from its traditional pattern of the primary industry depending solely on development of mineral resources to the secondary process industry.

4.2.3 Energy Demand by Power Systems

By end of 1984, upon scheduled completion of the interconnection network between the Central Power System and the East Power System, the main consuming areas existing throughout the country will be served through the National Power System. The National Power System is termed by four (4) separate local systems such as North, Central, South and East. The past trend of each demand ratio for each of those local systems is shown in Table 4-3. Although there remain many local municipalities being served through other isolated systems than those main systems, the share ratio of demand through such isolated systems shows a relatively declining trend.

Table 4-3 Energy Demand Ratio by Power Systems

	Unit	1972	1974	1976	1978	1980
Total generation	(GWh)	891.0	993.2	1,132.0	1,353.8	1,572.3
Power system						
North	(%)	31.8	31.0	29.3	27.7	27.1
Central	(%)	33.3	33.2	33.7	34.3	34.8
South	(%)	12.5	11.0	11.3	10.7	9.6
East	(%)	4.8	6.5	8.5	10.5	12.9
Isolated	(%)	17.6	18.3	17.2	16.8	15.6
Total	(%)	100.0	100.0	100.0	100.0	100.0

Source: Evaluación de la demanda (1980 - 2000) by ENDE

As noted from Table 4-3, the Central Power System running in the country's center and serving Cochabamba, Oruro and other main mining areas is the largest in the energy demand ratio. The East Power System serving Santa Cruz as its consuming center is being given increasing weight in the National Power System as its service territory is developed with petroleum, natural gas and agricultural projects at rapid paces.

The North Power System centered in La Paz, capital city is featured by its highest demand density and is expected to take a share of about 30 percent in the future when the service area will remain as the nation's political and economic centers.

Table 4-4 and Fig.4-2 show the past trend of energy demand and generation in Bolivia.

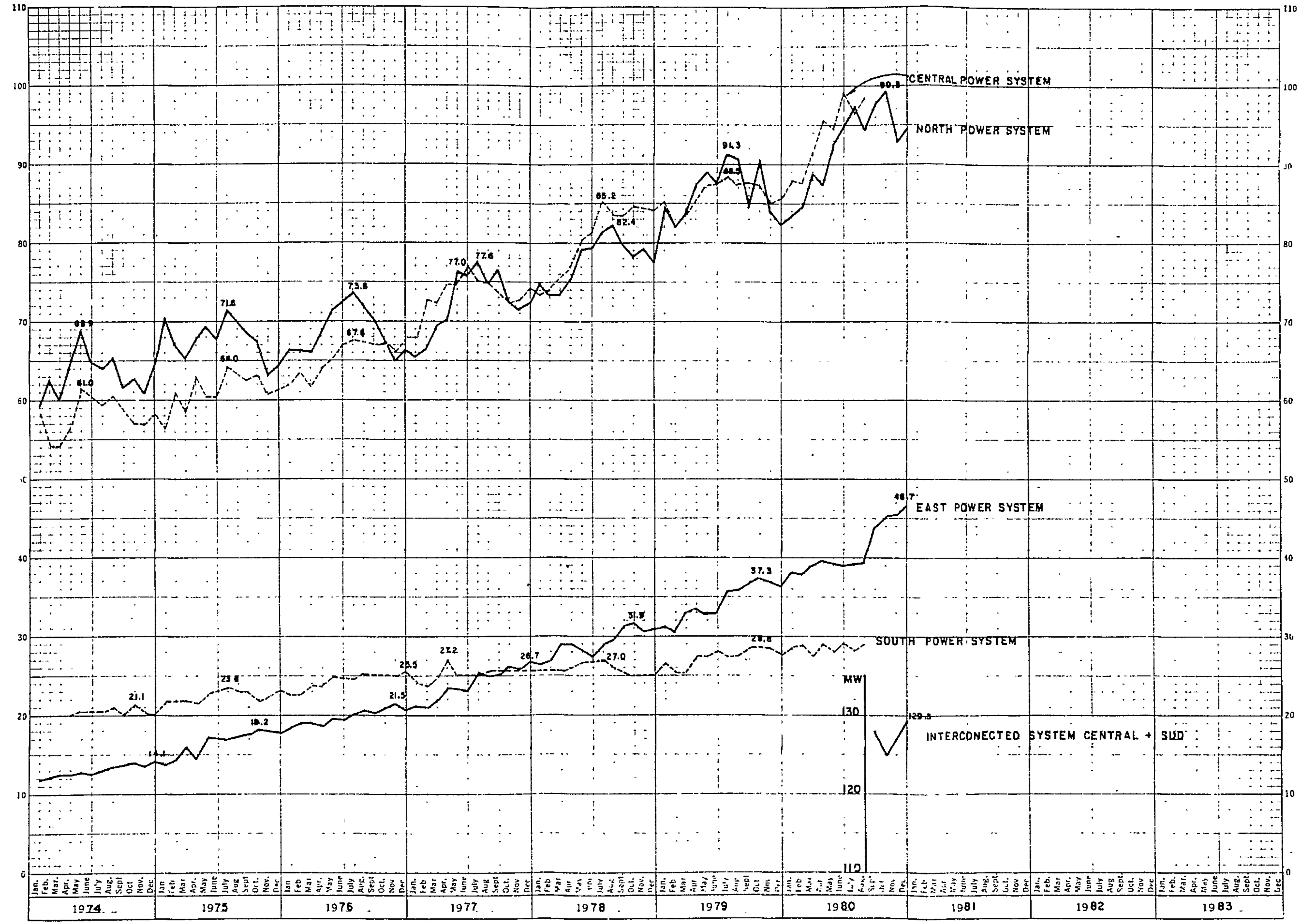
4.3 Power Demand Forecast

4.3.1 Premises to Demand Forecast

Some prerequisite conditions must be given prior to power demand forecast. Above anything else, the first premise should be that the nation's economy of Bolivia would continue its stabilized growth at an annual rate of 6 percent in the real term in the long perspective projection over many years. Judging from the past trend of growth that the real economic growth* could be well maintained at a level of 5.6 percent for the period of 1971 to 1978, except acute decline to 2.0 and 0.8 percent

* Boletín Estadístico No.240, Dic.1980 Banco Central de Bolivia

Fig. 4-2 Bolivia –Main Systems– Monthly Peak Demand



in 1979 and 1980, respectively, it may be probable that the future growth could be achieved to a level of 6 percent or so without any difficulty.

Secondly, the construction projects of power plants, transmission lines and substations, which will be promoted further mainly in charge of ENDE, should require the total investment sum of 443.2 million U.S. dollars by the year 1989 according to the estimation at present. Such vast sum of funds for the projects would not be available without governmental active supports to ENDE. The implementation of such investment program as planned and scheduled could be the only way to turn the potential power demand into the real manifestation.

The third one of premises should be that ENDE would exert its further effort toward rural electrification and take into consideration the possibility to incorporate further growth of the electrified ratio presently estimated at 30 percent into the future expansion program of the National Power System.

The fourth prerequisite should be that the power tariff rate, though largely increased in 1980, could be well maintained at the lowest possible level so as to be attractive to all consumers.

As stated above, all these four premises of assumption are of equal importance in the forecast of power demand. In particular, however, it is expected that the economic growth rate should be, because of its close relationship with power demand growth, increased on a stabilized basis of 5 to 6 percent annually over many years to come.

4.3.2 Method of Power Demand Forecast

The basic requirement as the practicable approach to power demand forecast is to seek the result of forecast in as realistic a pattern as possible by close investigation on the local conditions of consuming areas concerned, together with review of various basic data available, such as past power demand trend, flow of population and national development plan versus power demand. In line with this general considerations, the Survey Team conducted the following site surveys.

(a) Survey was conducted at the office of ENDE on the nation's total energy consumption at both generating and consuming ends over 10 years from 1971 up to 1980 inclusive in order to seek the actual conditions of power demand at present. That is to say, with regard to power demand at generating end survey was made to look into energy demand by classification of North, Central, South, East and other isolated systems.

Energy consumption at consuming end was also investigated by such categories as classified in the country of Bolivia.

(b) Pilaya Hydro Power Project is planned at the site proposed in the southern part of the country. Naturally, electric energy to be generated from that power plant will be consumed mainly within the three (3) provinces of Potosi, Chuquisaca and Tarija. With this in mind, the Survey Team visited Sucre and Tarija cities as the typical consuming centers in those provinces to investigate the present progress of electrification. The Team was given the opportunity to hear about the present status of power demand and the rural electrification program from Servicios Electricos Tarifa S.A. (SETAR) visited by the Team for this purpose.

(c) The Team visited two (2) diesel power plants of Aranjuez (21 MW) and Villa Abaroa (5.2 MW) and Angosto Hydro Power Station (0.3 MW) owned and operated by ENDE in the service area of the South Power System so as to investigate the past trend of power supply, load curve, scheduled outage for maintenance of power plants and their forced outage.

(d) Observation tour was made for comparison of electrification in main consuming areas. The Survey Team made a round of calls to large cities such as La Paz, Cochabamba, Sucre, Tarija and Santa Cruz for comparative observation.

(e) Study was made to clarify the present status of power demand through construction, operation and maintenance of the ENDE's power facilities in the service territories of the Central and East Power Systems.

(f) At Bermejo in the sourthern part of Tarija Province, the Team visited the sugar manufactory of Corporación de Fomento y Desarrollo Boliviano, where survey was made as to the present status of power demand and the future availability of power supply from the ENDE's power system.

In parallel with actual surveys conducted as stated above, future energy consumption was forecasted by the following methods by due reference to the basic data available from ENDE.

Needless to say, it is the well-known fact that energy consumption has very close correlation with economic potential of a nation.

The economic activities of the nation are expressed in the most comprehensive term of the "GNP". Since electric power is utilized in almost all of the people's economic activities as may be expressed in the terms of "production" and "consumption", it is well conceivable that energy consumption may have, in a long run, very close correlation with the GNP.

The method of macroscopic forecast of energy consumption is to estimate power demand on a nationwide scale over a super-long term basically by due reference to the correlation between the GNP per capita and energy consumption in kWh per capita. Such correlation may be defined by the scale of nation's economy and the level of personal income in each different country and may therefore be varied largely from one country to another. In fact, however, according to the statistic result of survey conducted by EPDC and approved by the IAEA (International Atomic Energy Agency) and the IBRD (World Bank) for each country, there should exist the approximate trend line on each different scale of energy consumption for some categories of income scale. Necessary parameters for the long-term forecasting method are as itemized hereunder:

- Average growth rate of GNP per capita estimated from the past trend of growth at the present stage of the nation's economy
- Scale of GNP per capita at present
- Scale of kWh per capita at present
- Elasticity of kWh per capita in response to the change in the scale of GNP per capita

The GNP per capita of Bolivia in 1977, 1978 and 1979 was registered at 480, 510 and 550 US dollars respectively and its rate of real growth was averaged at 3.8 percent for a past few years. The per-capita GNP of 550 US dollars in 1979 may be revalued at 383 US dollars by conversion into the 1968's price level.

Meanwhile, the per-capita energy consumption at generating end in 1979 was recorded at 263 kWh. (See Fig. 4-3 and Fig. 4-4.)

4.3.3 Result of Demand Forecast

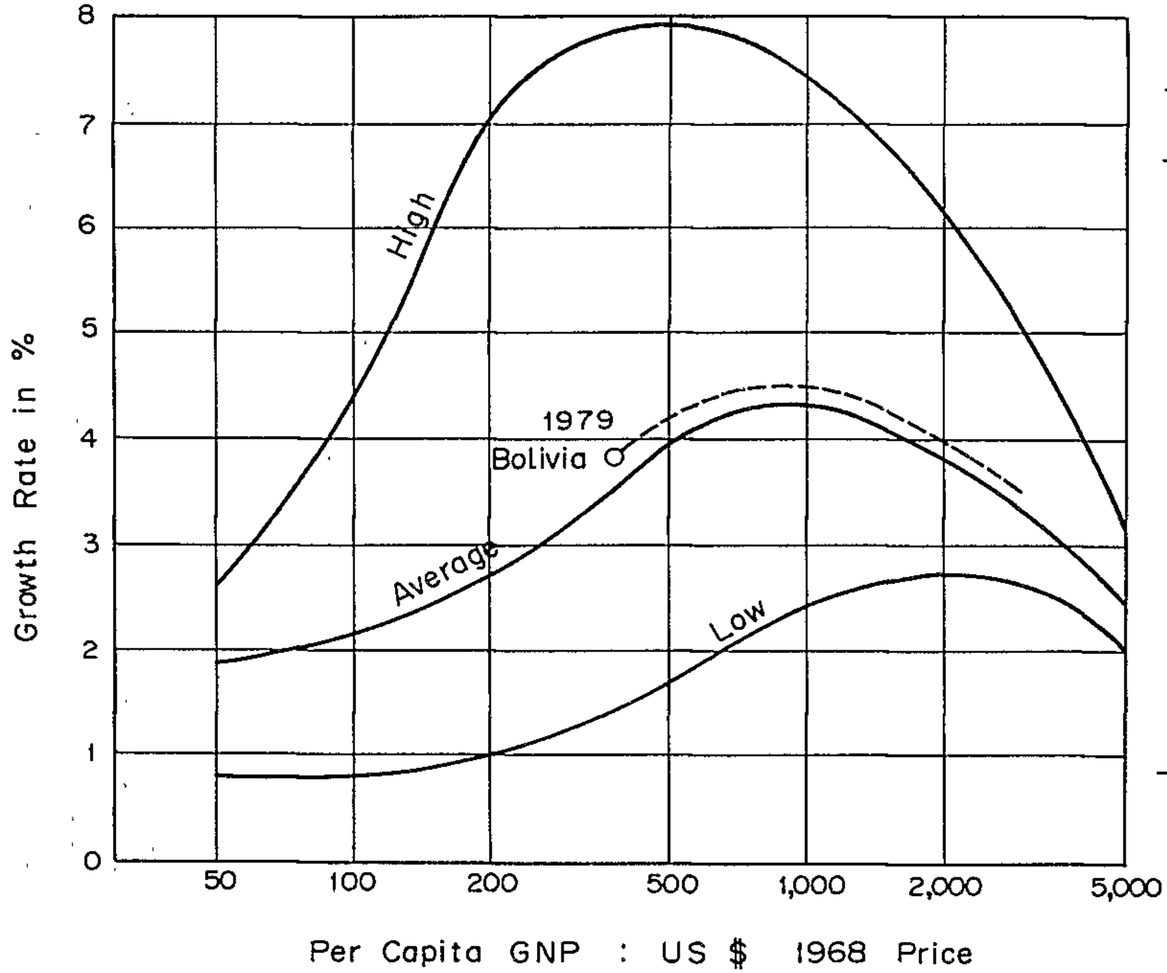
According to the United Nations's Statistical Yearbook of 1978 edition, the population in Bolivia was increased at an annual average rate of 2.7 percent for the period of 1970 to 1977. To update this statistic data, reference was made to the survey result entitled "Infrastructure Development Planning for A Zinc Refinery, Bolivia, June, 1976, prepared for Metal Mining Agency of Japan by International Development Center of Japan (IDC) and the predicted population was sought as shown in Table 4-5 by correction into the present level of population as of 1980. Those figures obtained by prediction are somewhat conservative as compared with the predicted figures in 1976. The population and its increase rate may be predicted as follows:

Year	Population (Thousand)	Increase rate (%)
1980	5,585	
1985	6,280	) 2.4
1990	6,990	) 2.2
1995	7,710	) 2.0
2000	8,460	) 1.8

Prediction of the population growth is projected up to and including the year 2000 with due consideration to the scheduled timing for initial operation of the Pilaya Hydro Power Project. Prediction is also based on the per-capita GNP as of 1979 as the starting point of projection. The rate of 3.8 percent was adopted as the average growth in the past years at that starting point. The nationwide trend of consumption by years is as shown in Table 4-7. Energy consumption and its average increase rate estimated from Table 4-7 at every interval of five (5) years from 1980 to 2000 are predicted as shown below:

	1980 (Actual)	1985	1990	1995	2000
Energy consumption (GWh)	1,572	2,323	3,425	4,934	7,021
Increase rate (%)		8.1	8.0	7.6	7.3

Fig. 4-3 Correlation between Per Capita GNP and its Growth Rate



GNP/Capita (US $)	Growth rate (%)	Average growth rate (%)
383	3.80	
		3.85
400	3.90	
		4.15
500	4.20	
		4.28
600	4.35	
		4.43
700	4.50	
		4.53
800	4.55	
		4.55
900	4.55	
		4.53
1,000	4.50	

Table 4-5 Predicted Population

Unit: 1,000 inhabitants

Year	Actual	IDC (in 1976)	JICA (in 1980)	Remarks
1962	3,863	—	—	
1963	3,951	—	—	
1964	4,040	—	—	
1965	4,136	—	—	
1966	4,234	—	—	
1967	4,335	—	—	
1968	4,439	—	—	
1969	4,547	—	—	
1970	4,658	—	—	National Census was carried out in Sep. 1976
1971	4,773	—	—	
1972	4,891	—	—	
1973	5,014	—	—	
⋮	⋮	⋮	⋮	
1975		5,222		
1980	5,585	5,820	5,585	
1985		6,466	6,280	
1990		7,158	6,990	
1995		7,896	7,710	
2000		8,680	8,460	

Fig. 4-4 Correlation between Per Capita GNP and Per Capita Electricity Production

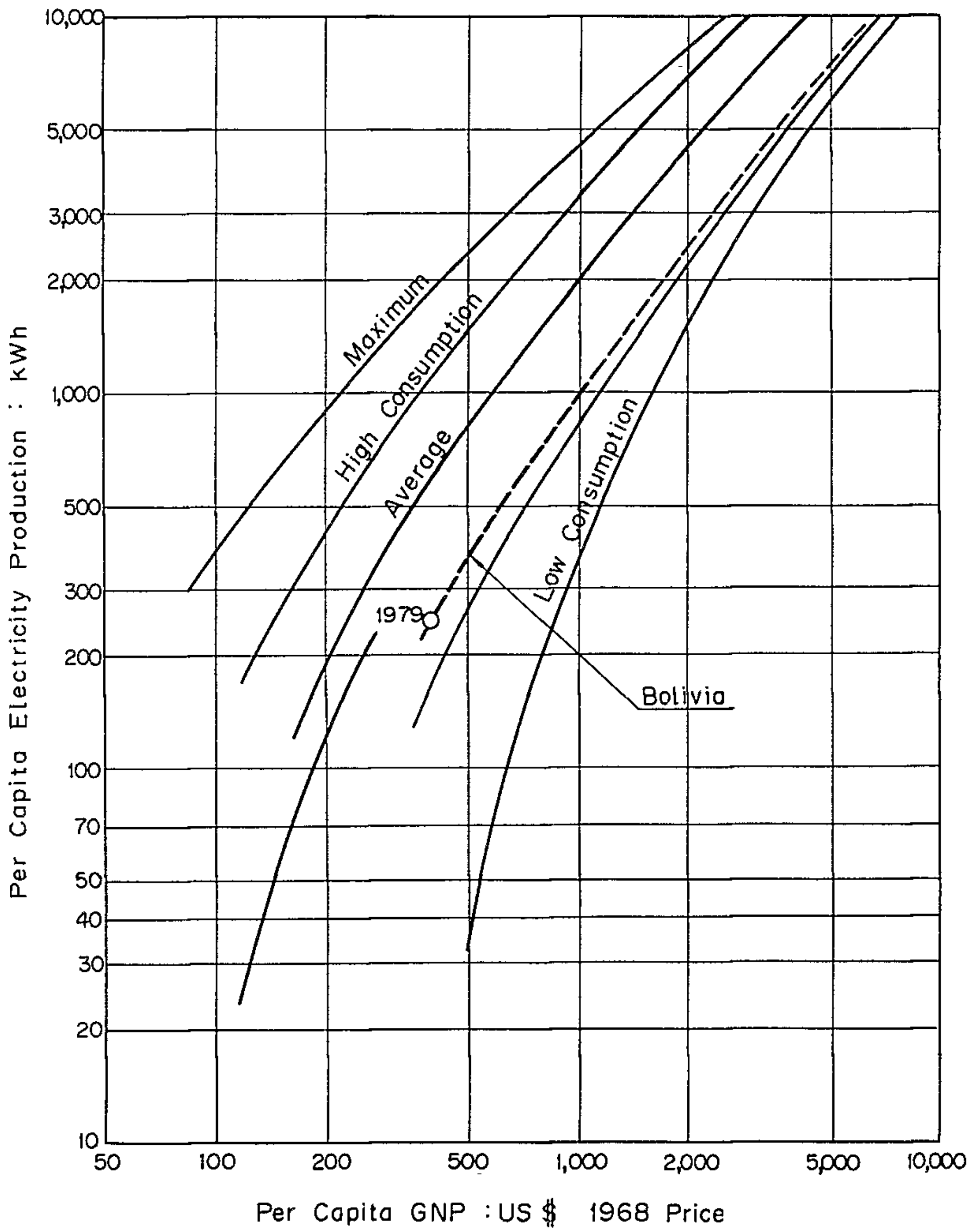


Table 4-6 Energy Demand Forecast by Macroscopic Method

Year	Growth rate in GNP/capita (%)	GNP/capita price in 1968 (US$)	Energy consumption per capita (kWh/capita)	Predicted population (1,000)	Energy consumption in entire country (GWh)	Annual increase in energy consumption (%)
1979	3.85	383	263	5,444	1,433	
80	3.85	397	281	5,585	1,572	
81	4.15	414				
82	4.15	431				8.1
83	4.15	449				
84	4.15	467				
85	4.15	487	370	6,280	2,323	
86	4.15	507				
87	4.28	529				8.0
88	4.28	551				
89	4.28	575				
1990	4.28	600	490	6,990	3,425	
91	4.43	626				
92	4.43	654				7.6
93	4.43	683				
94	4.43	713				
95	4.53	745	640	7,710	4,934	
96	4.53	779				
97	4.53	815				7.3
98	4.55	852				
99	4.55	890				
2000	4.55	931	830	8,460	7,021	

Table 4-7 Power Demand Forecast for National Power System

	Performance and prediction from data of ENDE								Prediction by macroscopic method						
	North (GWh)	Central (GWh)	South (GWh)	East (GWh)	Isolated (GWh)	Total (GWh)	(a) Maximum demand (MW)	Annual L.F (%)	Entire country (GWh)	Isolated (GWh)	Power System Energy (GWh)	Power System (b) Max. demand (MW)	Power System L.F (%)	(a)/(b) (%)	
1971	283.3	276.4	107.0	29.7	143.1	839.5	—	—	839.5	143.1					
72	282.9	295.9	111.9	43.2	157.1	891.0	—	—	891.0	157.1					
73	284.9	308.4	115.0	52.9	156.8	918.0	—	—	918.0	156.8					
74	307.8	330.1	109.6	64.0	181.7	993.2	162.6	56.9	993.2	181.7	811.5	162.6	56.9		
75	322.2	348.7	114.7	79.0	192.4	1,057.0	176.2	56.0	1,057.0	192.4	864.6	176.2	56.0		
76	331.0	381.8	127.8	96.7	194.7	1,132.0	185.0	57.8	1,132.0	194.7	937.3	185.0	57.8		Performance
77	352.8	437.9	142.7	119.0	207.3	1,259.7	201.0	59.8	1,259.7	207.3	1,052.4	201.0	59.8		
78	375.3	463.8	144.8	142.7	227.2	1,353.8	222.7	57.7	1,353.8	227.2	1,126.6	222.7	57.7		
79	403.6	489.3	139.4	165.6	234.8	1,432.7	243.6	56.1	1,432.7	234.8	1,197.9	243.6	56.1		
1980	426.0	547.7	151.5	202.7	244.4	1,572.3	262.3	57.8	1,572.3	244.4	1,327.9	262.3	57.8		
81	446.1	584.3	163.1	231.1		1,424.6	271.0	60.0		259			58.0		
82	470.1	633.7	174.7	269.0		1,547.5	294.4	60.0		275			58.0		
83	495.5	687.3	202.8	313.3		1,698.9	323.2	60.0		292			58.0		
84	522.0	745.5	225.6	364.6		1,857.7	353.4	60.0		309			58.0		
85	550.1	808.5	245.7	424.4		2,028.7	401.5	57.5	2,323	309	2,014	396	58.0	101.4	
86	584.0	872.3	267.1	472.5		2,195.9	435.7	57.5		309			58.0		
87	619.3	941.3	290.5	524.6		2,375.7	471.1	57.5		309			58.0		
88	656.3	1,015.7	315.7	582.2		2,569.9	509.1	57.6		309			58.0		
89	694.4	1,095.9	343.4	646.3		2,780.0	550.7	57.6		309			58.0		Prediction
1990	734.0	1,182.5	373.4	717.4	No data available	3,007.3	595.4	57.7	3,425	309	3,116	613	58.0	97.1	
91	774.7	1,275.9	406.2	796.2		3,253.0	643.9	57.7		309			58.0		
92	816.5	1,376.7	441.6	883.9		3,518.7	696.3	57.7		309			58.0		
93	859.2	1,485.5	480.6	981.1		3,806.4	752.8	57.7		309			58.0		
94	902.6	1,602.8	522.6	1,089.0		4,117.0	814.1	57.7		309			58.0		
95	946.6	1,729.5	568.7	1,208.8		4,453.5	880.5	57.7	4,934	309	4,625	910	58.0	96.7	
96	990.8	1,866.0	618.1	1,341.8		4,817.3	951.9	57.7		309			58.0		
97	1,034.7	2,013.5	673.1	1,489.4		5,210.7	1,029.5	57.7		309			58.0		
98	1,078.0	2,172.5	732.5	1,653.2		5,636.2	1,113.1	57.7		309			58.0		
99	1,119.9	2,344.2	797.1	1,835.1		6,096.3	1,203.9	57.7		309			58.0		
2000	1,160.1	2,529.4	867.4	2,037.0		6,593.9	1,282.6	57.7	7,021	309	6,712	1,321	58.0	97.1	
Increase (%)															
'71 - '80	4.6	7.9	3.9	23.8	6.1	7.2	—	—	7.2	6.1	—	—	—	—	
'80 - 2000	5.1	8.0	9.1	29.2	—	7.4	8.3	—	7.8	1.2	8.4	8.4	—	—	

The result of forecast reflects future energy consumption on the nationwide scale, including partly consumption of non-utility generation and consumption through other local systems isolated from the National Power System. After exclusion of such extra consumption, the net energy demand through the National Power System was forecasted as shown in Table 4-6. After all, the forecasted demand on the part of ENDE was deemed most appropriate because of its close approximation to the result forecasted by the Survey Team. For this reason as stated, the Survey Team used the ENDE's forecasted demand to be incorporated into the planning of Pilaya Hydro Power Project, as the referential data for feasibility study on the subjects of schedules time of onset for construction, power system analysis and salable energy production from Pilaya Power Plant.

4.3.4 Power Demand and Supply Balance

The future power system of ENDE will constitute mainly hydro power generating sources. This absolutely necessitates cross-check of power demand and supply balance in the relation between the hydro power supply capability in dry and wet seasons and the power demand throughout the system.

To further explain this, it should be borne in mind that available energy in the future installed hydro power capacity would vary between dry and wet seasons depending upon the type of power generation, whether reservoir type or run-of-river type. Namely, both Corani (54.0 MW) and Santa Isabel (72.0 MW) Power Plants of reservoir type are estimated to be able to generate 74 percent of annual available hydro energy for seven (7) dry months, while power plants of run-of-river type on the Zongo River are able to generate 50 percent and Palillada and Sakahuaya Power Plants generate about 40 percent respectively of annual available hydro power for the corresponding seven (7) dry months.

As cited above from actual instances, each power plant may be varied in its supply capacity between dry and wet seasons. Therefore, study must be made on the balance between energy supply and demand by clarification of total hydro power generating capacity in both dry and wet seasons.

(1) Available Supply Capacity

The power system of Bolivia will be completed by end of 1984 to serve all main consuming areas throughout the whole country. The generating sources to be connected to this nationwide power grid will consist of hydro power, diesel and gas-turbine generating plants. Total installed generating capacity as of July 1981 amounts to 398.8 MW as shown in Table 4-8, which may be broken down as follows:

Existing Generating Facilities in 1981

	Installed capacity (MW)	Effective capacity (MW)
Hydro power plants	274.6	238.0
Diesel power plants	33.0	30.0
Gas turbine plants	91.2	80.0
Total	398.8	348.0

Out of the total generating capacity, a part of hydro power and diesel power plants can no longer afford to the maximum of their nominal output because of their time-worn facilities. The gas turbine power plant was installed in Santa Cruz with its first unit entered into initial operation in 1975.

Meanwhile, the proposed power development projects are planned for total installed capacity of 1,072 MW, about 2.5 times as much as installed at present, as shown in Table 4-9, in the perspective future up to and including the year 2000. These projects envisage construction of hydro power plants in all instances except the gas turbine plant to be constructed in 1982. Table 4-10 shows available energy supply estimated for each hydro power plant, including those existing plants, for both wet (5 months) and dry (7 months) seasons of a year. Available energy supply is calculated on the basis of actually recorded river discharge for the period of 1964 to 1973 (except Pilaya Hydro Power Project calculated on the 15 year discharge basis from 1965 to 1981).

(2) Power and Energy Demand

To estimate power and energy demand to be well balanced with available hydro power supply energy calculated as aforestated by seasons, annual total energy consumption was shared by dry and wet seasons in proportion to 7 months and 5 months respectively. Maximum power demand was forecasted to emerge in the dry season, as noted so from the past trend, and maximum demand in the wet season was sought by application of the multiplier of 0.967 to maximum demand during the dry season.

Table 4-11 includes the study result on the power demand and supply balance by seasons, predicting the available hydro power supply capacity by seasons starting from 1990, one year ahead of scheduled initial operation of Pilaya Power Plant, up to and including 1995.

As shown in Table 4-11, the total installed capacity of Pilaya Power Plant will be fully utilized, in terms of kW balance, from 1991 as the target year of initial operation. In terms of kWh balance, however, available energy supply during the wet season will not be utilized to the full and will be spilled over for the season. Such spilled energy will continue for three years until 1994 but, after that year, available energy supply will be totally turned into effective utilization as shown in Table 4-12.

The estimated maximum demand and projected installed capacity of Bolivian power system are indicated in Fig. 4-5.

Table 4-8 Existing Hydro and Thermal Powe

Power system & power plants	Type	Installed capacity (MW)	Effective capacity (MW)	Avail. energy Firm (GWh)	Avail. energy Secondary (GWh)	Remarks
(1) Northern System						
Zongo River	H	117.1	90.0	529.5	26.7	
Achachicara	H	4.6	3.5	9.5	0	
Total		121.7	93.5	539.0	26.7	BPC
(2) Central System						
Corani	H	54.0	54.0	347.4	114.6	
Santa Isabel	H	54.0	54.0			
Subtotal		108.0	108.0	347.6	114.6	ENDE
Miguilla	H	4.0	2.7	118.0	2.0	
Angostura	H	4.6	4.0			
Choquetanga	H	7.4	6.3			
·Carabuco	H	6.3	6.1			
Subtotal		22.3	19.1	118.0	2.0	BPC
Pequeño Oruro	H	4.8	4.8	23.0	0	COMIBOL
Incachaca	H	3.9	3.0	11.0	0	
Angostura	H	2.1				
Chocaya	H	0.2				
Subtotal		6.2	3.0	11.0	0	ELFEC
Total		141.3	134.9	499.6	116.6	

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Note: H : Hydro
D : Diesel
GT: Gas Turbine

Table 4-8 Existing Hydro and Thermal Power Plants (July, 1981)

Power system & power plants	Type	Installed capacity (MW)	Effective capacity (MW)	Avail. energy Firm (GWh)	Avail. energy Secondary (GWh)	Remarks
(1) Northern System						
Zongo River	H	117.1	90.0	529.5	26.7	
Achachicara	H	4.6	3.5	9.5	0	
Total		121.7	93.5	539.0	26.7	BPC
(2) Central System						
Corani	H	54.0	54.0	347.4	114.6	
Santa Isabel	H	54.0	54.0			
Subtotal		108.0	108.0	347.6	114.6	ENDE
Miguilla	H	4.0	2.7			
Angostura	H	4.6	4.0			
Choquetanga	H	7.4	6.3	118.0	2.0	
Carabuco	H	6.3	6.1			
Subtotal		22.3	19.1	118.0	2.0	BPC
Pequeño Oruro	H	4.8	4.8	23.0	0	COMIBOL
Incachaca	H	3.9				
Angostura	H	2.1	3.0	11.0	0	
Chocaya	H	0.2				
Subtotal		6.2	3.0	11.0	0	ELFEC
Total		141.3	134.9	499.6	116.6	

Power system & power plants	Type	Installed capacity (MW)	Effective capacity (MW)	Avail. energy Firm (GWh)	Avail. energy Secondary (GWh)	Remarks
(3) Southern System						
Aranjuez	D	22.2	21.0	—	—	
Villa Abaroa	D	5.5	5.5	—	—	
El Angosto	H	0.3	0.3	1.9	0.2	
Subtotal		28.0	26.8	—	—	ENDE
Killpani	H	6.0				
Landora	H	2.8	9.3	70.0	—	
Puntuma	H	2.5				
Telamayu	D	5.3	3.5	—	—	
Subtotal		16.6	12.8	—	—	COMIBOL
Total		44.6	39.6	—	—	
(4) Eastern System						
Huaracachi	GT	91.2	80.0	—	—	ENDE
(5) Entire Power System						
Hydro	H	274.6	238.0	1,110.5	143.5	
Diesel	D	33.0	30.0	—	—	
Gas Turbine	GT	91.2	80.0	—	—	
Total		398.8	348.0	—	—	

Note: H : Hydro
D : Diesel
GT: Gas Turbine

Table 4-9 Proposed Power Facility Expansion Program

Power Plant	Type	Installed capacity (MW)	Effective capacity (MW)	Avail. Energy Firm (GWh)	Avail. Energy Secondary (GWh)	Remarks
Scheduled						
Oruro	G	22.5	16.0	—	—	1982
Santa Cruz	G	22.5	20.0	— 1)	—	1982
Santa Isabel (No.4)	H	18.0	18.0	24.6	12.5	1984
Sakhahuaya (1st)	H	36.0	36.0	164.5	20.4	1985
Sakhahuaya (2nd)	H	36.0	36.0	157.8	19.9	1986
Icla	H	90.0	90.0	341.0	51.0	1987
Subtotal		225.0	216.0			
Proposed Plants						
Pallillada	H	110.0	110.0	554.0	0.9	1989
Pilaya	H	87.0	87.0	480.2	55.3	1991
Misicuni	H	100.0	100.0	391.8	68.2	1993
San Jose	H	150.0	150.0	683.5	207.0	1994
Rositas (1st)	H	200.0	200.0	1,787.0 (Rositas 1st and 2nd)	394.2 (Rositas 1st and 2nd)	1996
Rositas (2nd)	H	200.0	200.0			1998
Subtotal		847.0	847.0			
Total		1,072.0	1,063.0			

Note : The years shown on the remarks indicate the beginning of each year to be put in service

1) : Incremental energy due to Malaga and Vinto Rivers diversion and increased dam height (5 m)

Source: Plan Nacional de Electrificacion, Agosto de 1980, prepared by ENDE

Table 4-10 Available Energy Production in Hydro and Thermal Plants

	Installed capacity	Available supply power		Firm energy for supply			Average available supply energy			Remarks
		Dry	Rainy	Dry	Rainy	Total	Dry	Rainy	Total	
	(MW)	(MW)	(MW)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	
Existing Hydro										
Corani plus Sta. Isabel	108.0	108.0	108.0	230.0	70.5	300.5	278.0	120.7	398.7	Firm energy is based on the driest year
Zongo	117.1	90.0	90.0	283.0	256.0	539.0	281.7	284.0	565.7	
Miguillas	22.3	19.1	19.1	70.0	48.0	118.0	69.4	50.6	120.0	
Peque. CBBA	6.2	3.0	1.5	6.5	4.5	11.0	6.5	4.5	11.0	
Peque. Oruro	4.8	4.8	2.6	15.0	8.0	23.0	15.0	8.0	23.0	
Rio Yura	11.3	9.8	9.8	40.0	30.0	70.0	40.0	30.0	70.0	
Achachicala	4.6	3.5	2.0	7.5	2.0	9.5	7.5	2.0	9.5	
El Angosto	0.3	0.3	0.3	0.9	0.9	1.8	1.0	1.1	2.1	
Subtotal	274.6	238.5	233.3	652.9	419.9	1,072.8	699.1	500.9	1,200.0	
Existing Thermal										
Santa Cruz G.T	91.2	80.0	80.0	—	—	—	—	—	—	
Aranjuez Diesel	22.2	21.0	21.0	—	—	—	—	—	—	
COMIBOL Diesel	5.3	3.5	3.5	—	—	—	—	—	—	
Villa Abaroa	5.5	5.5	5.5	—	—	—	—	—	—	
Subtotal	124.2	110.0	110.0	—	—	—	—	—	—	
Proposed Hydro										
Adittional Sta. Isabel (No.4)	18.0	17.2	17.2	207.4	39.0	* 246.4	202.3	56.6	* 258.9	* Additional energy from Vinto and Malaga Rivers and also increased dam height of Corani
Sakhahuaya	72.0	72.0	72.0	92.6	229.7	322.3	129.7	232.9	362.6	
Icla	90.0	90.0	90.0	181.4	159.6	341.0	213.6	178.4	392.0	
Palillada	110.0	110.0	110.0	277.7	317.3	595.0	277.2	355.0	632.2	
Pilaya	87.0	87.0	87.0	186.2	294.0	480.2	244.4	291.1	535.5	
Misicuni	100.0	100.0	100.0	238.4	133.1	371.5	281.9	178.1	460.0	
San Jose	150.0	150.0	150.0	308.5	375.0	683.5	410.5	480.7	891.2	
Rositas	400.0	400.0	400.0	905.5	881.5	1,787.0	1,173.2	1,008.0	2,181.2	
Subtotal	1,027.0	1,026.2	1,026.2	2,397.7	2,429.2	4,826.9	2,932.8	2,780.8	5,713.6	
Proposed Thermal										
Gas turbine	45.0	36.0	36.0	—	—	—	—	—	—	
Total (Hydro)	1,470.8	1,410.7	1,405.5	3,050.6	2,849.1	5,899.7	3,631.9	3,281.7	6,913.6	

Table 4-11 Demand and Supply Balance

Name of Power Plants	Installed capacity	1990		1991		1992		1993		1994		1995	
		Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
Maximum power demand		575.6	595.4	622.5	643.9	673.2	696.3	727.8	752.8	787.0	814.1	851.2	880.5
Effective power supply													
Existing small hydro	49.5	40.5	35.3	40.5	35.3	40.5	35.3	40.5	35.3	40.5	35.3	40.5	35.3
Zongo	117.1	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Corani & Santa Isabel	126.0	125.2	125.2	125.2	125.2	125.2	125.2	125.2	125.2	125.2	125.2	125.2	125.2
Sakahuaya	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0
Icla	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
Palillada	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0	110.0
Pilaya	87.0	—	—	87.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0
Misicuni	100.0	—	—	—	—	—	—	100.0	100.0	100.0	100.0	100.0	100.0
San Jose	150.0	—	—	—	—	—	—	—	—	72.3	104.6	116.5	150.0
Rositas	400.0	—	—	—	—	—	—	—	—	—	—	—	—
Subtotal	(1,301.6)	(527.7)	(522.5)	(614.7)	(609.5)	(614.7)	(609.5)	(714.7)	(709.5)	(787.0)	(814.1)	(831.2)	(859.5)
Gas turbine	112.5	47.9	72.9	7.8	34.4	58.5	80.0	13.1	43.3	0	0	20.0	21.0
Diesel	33.0	0	0	0	0	0	6.8	0	0	0	0	0	0
Subtotal	(145.5)	(47.9)	(72.9)	(7.8)	(34.4)	(58.5)	(86.8)	(13.1)	(43.3)	(0)	(0)	(20.0)	(21.0)
Total	1,447.1	575.6	595.4	622.5	643.9	673.2	696.3	727.8	752.8	787.0	814.1	851.2	880.5
	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)
Energy demand		1,754.3	1,253.0	1,897.6	1,335.4	2,052.6	1,466.1	2,220.4	1,586.0	2,401.6	1,715.4	2,597.9	1,855.6
Average available energy													
Existing small hydro	235.6	139.4	96.2	139.4	96.2	139.4	96.2	139.4	96.2	139.4	96.2	139.4	96.2
Zongo	565.7	281.7	284.0	281.7	284.0	281.7	284.0	281.7	284.0	281.7	284.0	281.7	284.0
Corani & Santa Isabel	657.6	480.3	177.3	480.3	177.3	480.3	177.3	480.3	177.3	480.3	177.3	480.3	177.3
Sakahuaya	362.6	129.7	232.9	129.7	232.9	129.7	232.9	129.7	232.9	129.7	232.9	129.7	232.9
Icla	392.0	213.6	178.4	213.6	178.4	213.6	178.4	213.6	178.4	213.6	178.4	213.6	178.4
Palillada	632.2	277.2	252.3	277.2	300.0	277.2	355.0	277.2	355.0	277.2	355.0	277.2	355.0
Pilaya	535.5	—	—	244.4	51.5	244.4	107.3	244.4	207.6	244.4	291.1	244.4	291.1
Misicuni	460.0	—	—	—	—	—	—	281.9	35.6	281.9	52.4	281.9	104.8
San Jose	891.2	—	—	—	—	—	—	—	—	353.4	48.1	410.5	126.7
Rositas	2,181.2	—	—	—	—	—	—	—	—	—	—	—	—
Subtotal	6,913.6	(1,521.9)	(1,221.1)	(1,766.3)	(1,320.3)	(1,766.3)	(1,431.1)	(2,048.2)	(1,567.0)	(2,401.6)	(1,715.4)	(2,458.7)	(1,846.4)
Gas turbine	591.3	232.4	31.9	131.3	15.1	286.3	35.0	172.2	19.0	0	0	139.2	9.2
Diesel	202.3	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	(793.6)	(232.4)	(31.9)	(131.3)	(15.1)	(286.3)	(35.0)	(172.2)	(19.0)	(0)	(0)	(139.2)	(9.2)
Total	7,707.2	1,754.3	1,253.0	1,897.6	1,335.4	2,052.6	1,466.1	2,220.4	1,586.0	2,401.6	1,715.4	2,597.9	1,855.6

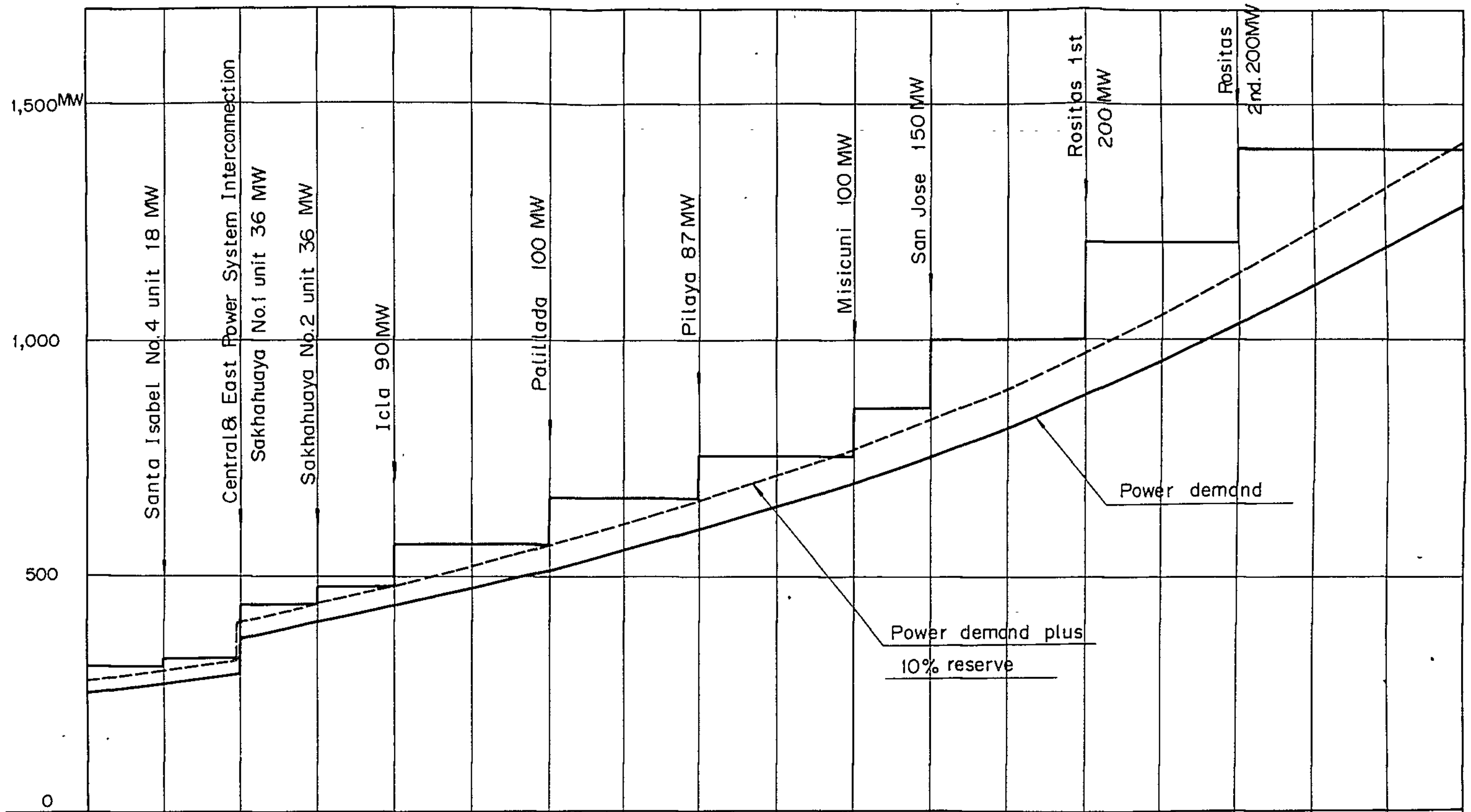
Table 4-12 Pilaya Hydro Power Plant
Generated Effective Power & Energy

Year	Installed capacity (MW)	Average energy (GWh)	Effective power (MW)	Effective energy Dry (GWh)	Effective energy Rainy (GWh)	Effective energy Total (GWh)
1991	87.0	535.5	87.0	237.1	51.5	288.6
1992	87.0	535.5	87.0	237.1	107.3	344.4
1993	87.0	535.5	87.0	237.1	207.6	444.7
1994	87.0	535.5	87.0	237.1	282.4	519.5
1995	87.0	535.5	87.0	237.1	282.4	519.5

Effective energy = Average energy × (1 - outage rate)

outage rate : 3.0%

Fig. 4-5 Estimated Maximum Demand & Installed Capacity of Entire Power System



Year	Maximum demand (MW)		Installed Capacity (MW)
1983	264.0	271.4	304
1984	283.8	291.8	322
1985	388.5	401.5	438
1986	421.5	435.7	474
1987	455.5	471.1	564
1988	492.3	509.1	564
1989	532.4	550.7	664
1990	575.6	595.4	664
1991	622.5	643.9	751
1992	673.2	696.3	751
1993	727.8	752.8	851
1994	787.0	814.1	1001
1995	851.2	880.5	1001
1996	920.3	951.9	1201
1997	995.3	1,029.5	1201
1998	1,076.1	1,113.1	1401
1999	1,163.9	1,203.9	1401
2000	1,239.9	1,282.6	1401

CHAPTER 5

METEOROLOGY AND HYDROLOGY OF BASIN

CHAPTER 5 METEOROLOGY AND HYDROLOGY OF BASIN

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 5. METEOROLOGY AND HYDROLOGY OF BAISN

5.1 Basic Considerations

The hydrologic data required for the Pilaya Hydro Power Project are the run-off data for determining the quantity of discharge that can be used for power generation which will be the basis of calculating available energy production, and the hydrologic data on the design flood discharge for determining the dam and other civil structures. With regard to the former, measurements during an 8 year period from 1972 through 1980 at Chillcara Gauging Station close to the dam site are available in the way of records.

In case of the observation records of Chillcara Gauging Station, water levels were measured and run-off computed employing Q-H curves. However, it is thought questions remain about the cross-sectional area of the river channel and measurements of flow velocity (scope of application of flow velocity for current meter). Accordingly, the Survey Team carried out macroscopic studies regarding correlation with rainfall and flow depletion characteristics in the dry season using the run-off records for the 8 year period from 1972 through 1980 to examine the appropriateness of the run-off data. The run-off during the 15 year period from 1966 to 1980 required for computation of energy production were calculated taking into account the results of these macroscopic studies.

With regard to the latter, since sufficient observation records were not available, the records for 35 years of Villamontes Gauging Station and of La Paz Gauging Station in Argentina were included in the study.

5.2 Outline of Meteorology and Hydrology

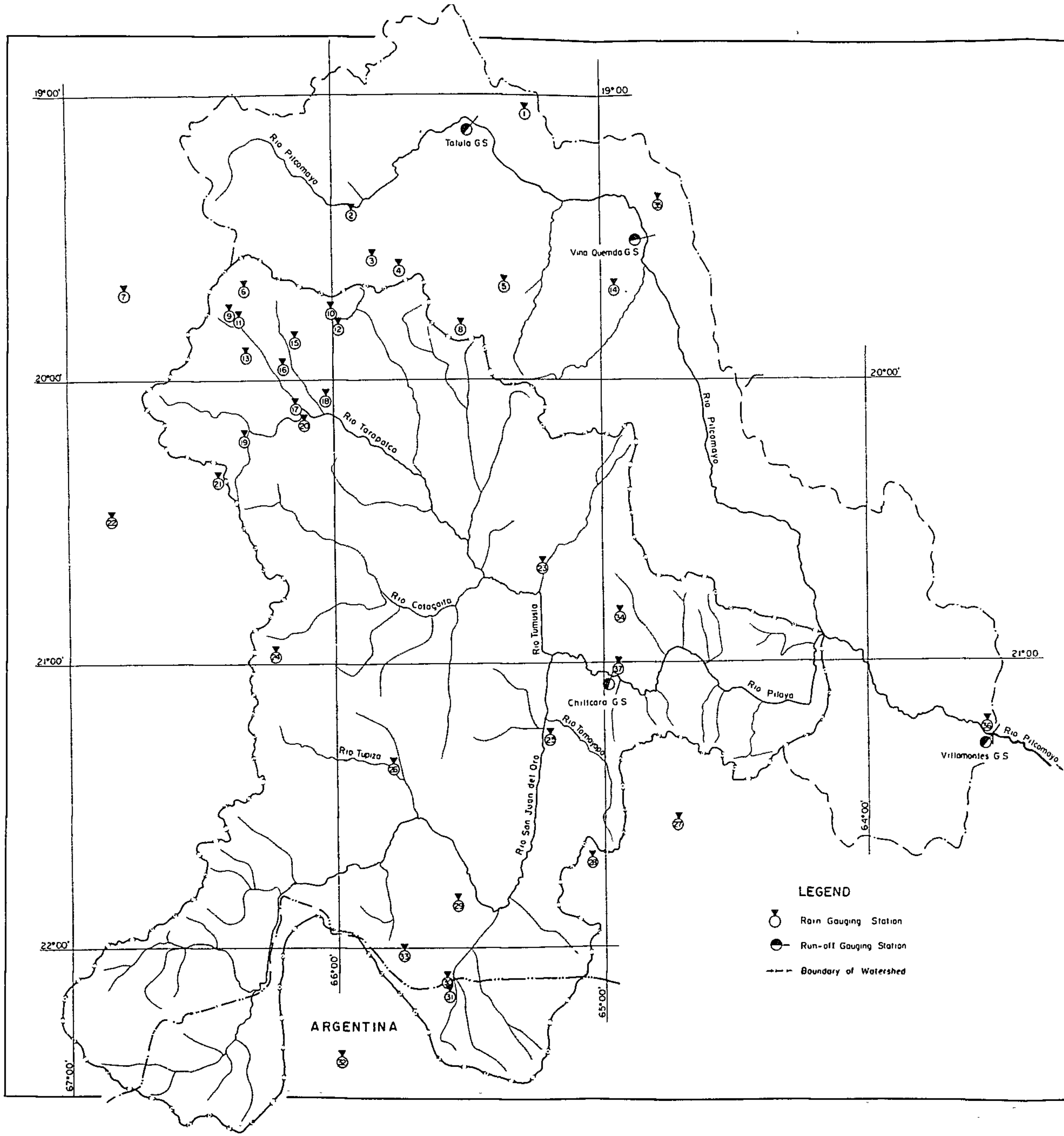
The annual mean temperatures in the Pilaya Project area differ according to elevation. The temperature is approximately 20°C at around EL 2,000 m and becomes lower with added height, and at around EL 3,500 m it is approximately 10°C. The mean for the basin as a whole is roughly around 10°C to 15°C.

Annual precipitation is 200 mm in the western area of the basin, which increases going northward to become 450 mm. The average for the entire basin is approximately 320 mm.

The annual total inflow at the dam site is approximately 1,900 million m^3, up to 85% of which flows in during the rainy season from December through April. The annual average run-off is approximately 60 m^3/s, but the average run-off during the 5 month period from December to April is 126 m^3/s, while the average run-off during the 7 month period from May to November is 16 m^3/s and exceedingly small.

5.3 Gauging Stations and Meteorological Observatories

There are five (5) run-off gauging stations and many meteorological observatories in the Pilaya Project area and its surroundings. The locations are as shown in Fig. 5-1. The observation periods at the principle run-off gauging stations and precipitation observation stations are given in Table 5-1 and Table 5-2.



RAIN GAUGING STATION

No	Station	Coordinates Latitude	Coordinates Longitude	Altitude (m)
1	Sucre	19°03'	65°16'	2,790
2	Yocalla	19°23'	65°55'	3410
3	Santa Lucia	19°33'	65°51'	3,000
4	Potasi	19°35'	65°45'	3 976
5	Chinoli	19°39'	65°21'	1 450
6	Lago Tara	19°41'	66°24'	4,400
7	Rio Mulatos	19°42'	66°47'	3 820
8	Puna	19°45'	65°27'	3 420
9	Toma Kilipani	19°46'	66°22'	4,300
10	Agua Castilla	19°46'	66°00'	4,100
11	Kilipani	19°48'	66°19'	4,180
12	Porco	19°48'	66°00'	4,200
13	Pta Landara	19°49'	66°19'	3,900
14	Turuchipa	19°49'	64°57'	2 450
15	Chaguilla	19°51'	66°08'	3 800
16	Pintumani	20°04'	66°08'	3,500
17	Punutuma	20°04'	66°08'	3 500
18	Yura	20°04'	66°07'	3 500
19	Tica Tica	20°08'	66°19'	3 600
20	Saito León	20°08'	66°07'	3,300
21	Tholapampa	20°13'	66°34'	4,000
22	Uyuni	20°28'	66°49'	4 300
23	Camargo	20°38'	65°13'	2,400
24	Atocha	20°56'	66°13'	3,700
25	El Puente	21° 14'	65°12'	2 300
26	Oploca	21°20'	65°48'	3 150
27	Tarija	21°40'	64°43'	1 862
28	Taxara	21°42'	65°04'	4 300
29	Mojo	21°49'	65°33'	3,400
30	Villazón	22°05'	65°35'	3 400
31	La Quiaca	22°08'	65°37'	3 500
32	Rinconada	22°21'	66°90'	4,100
33	Yacuiba	22°01'	65°45'	580
34	Culpina	20°44'	64°56'	2 970
35	Icla	19°22'	64°47'	2 252
36	Villamontes	21° 17'	53°28'	383
37	Chilicara	21°01'	64°56'	2,060

RUN-OFF GAUGING STATION

Station	Catchment Area km²	Remark
Villamontes	82,000	Mainstream of Rio Pilcomayo
Chilicara	43,150	Rio Pilaya (Tributary of Rio Pilcomayo)
Tatula	7,310	Upstream part of Rio Pilcomayo
La paz	96,000	Downstream part of Rio Pilcomayo (Argentine)
Vinã Quemda	13,200	Upstream part of Rio Pilcomayo

FIG. 5 - 1

LOCATION MAP OF RAIN GAUGING STATION AND RUN-OFF GAUGING STATION

Table 5-1 Existing Precipitation Data

Station NO.	Station Name	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	Sucre	Jan.'49~																										
2	Yocalla	Jan '46~																										
3	Santa Lucia																											
4	Potosi																											
5	Chinoli																											
6	Lago Toro																											
7	Rio Mulatos	Jan.'46~																										
8	Puna																											
9	Toma Killpani																											
10	Agua Castilla	Jan.'46~																										
11	Killpani	Feb.'46~Sep.'52																										
12	Porco																											
13	Pta. Landara																											
14	Turuchipa																											
15	Chaguilla																											
16	Pintumani																											
17	Punutuma																											
18	Yura	Aug.'46~																										
19	Tica Tica																											
20	Salto León																											
21	Tholapampa																											
22	Uyuni	Jan.'43~Dec.'48																										
23	Camargo																											
24	Atocha	Jan.'46~																										
25	El Puente																											
26	Oploca	Jan.'51~																										
27	Tarija	May.'54~																										
28	Taxara																											
29	Mojo																											
30	Villazón	Jan.'53~																										
31	La Quiaca	Jan.'46~																										
32	Rinconada	Oct.'46~																										
33	Yocuiba																											
34	Culpina																											
35	Icla																											
36	Villamontes	Jan.'43~																										
37	Chillcara																											

Note: ═══ Daily Data ├──┤ Monthly Data

Table 5-2 Existing Run-off Data

Station	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Chilicara								—	—	—	—	—	—	—	—	—	—
Villamontes	Oct '41 ~ Sep.'56										—	—	—	—	—	—	
Tolula	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Viña Quemada														—	—	—	—
La Paz (Argentina)	—	—	—	—	—	—	—	—						—	—	—	

(— : observation period shown as a bar in the original chart)

5.4 Precipitation

5.4.1 Data

Of the twenty precipitation observation stations located in the catchment area of the Pilaya Project, ten were selected for the present study, so that conditions such as their distribution and observation periods would not be overly concentrated at one side. The observatories taken up for the study here and the periods of observation are as shown in Table 5-3.

Table 5-3 Rain Gauging Stations Selected, for Calculating Average Precipitation in the Project Catchment Area

Station NO	Station Name	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
15	Chaguila			—	—	—	—	—	—				—	—	—	May
17	Punutuma	—	—													
23	Camargo							Jun. —	—	—	—	—	—	—	—	—
25	El Puente	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	Oploca	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	Mojo					—	—	—	—	—	—	—	—	—	—	—
30	Villazon			—	—											
31	La Quiaca	—	—													
16	Pintumani									—						
20	Salto Leon										—	—	—			

(— : observation period shown as a bar in the original chart)

Table 5-4 Monthly Precipitation in the Catchment Area of Pilaya Project

(Unit : mm)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep	Oct.	Nov.	Dec.	Total
'66	33.3	33.3	16.5	14.0	0	0	0	0	0.4	14.9	38.9	74.2	226.4
'67	35.7	52.2	35.9	12.2	1.1	0	0	0	7.1	4.5	2.8	88.6	240.1
'68	82.0	138.1	45.4	1.5	4.7	0	0	0.1	0.8	4.6	48.9	27.9	354.0
'69	113.8	50.7	9.8	2.4	0	3.2	0	0	0.6	0.9	12.8	125.7	319.9
'70	114.3	55.9	64.3	26.3	0	0	0	0	0	9.2	11.4	77.8	359.2
'71	94.1	141.3	17.4	0.3	0	0	0	0	0	5.2	40.7	57.8	356.8
'72	93.0	74.9	43.1	9.8	0.7	1.8	0	0	1.1	11.0	10.5	75.9	325.8
'73	105.5	42.5	51.5	10.8	20.2	8	0	1.6	0	1.8	6.9	22.5	272.0
'74	71.2	90.5	40.4	27.0	0	0	0	13.3	0.5	0.7	11.9	39.4	294.9
'75	115.8	82.9	32.4	3.4	1.1	0	0	0.1	1.9	17.1	0.5	66.7	321.9
'76	132.6	38.8	27.9	5.5	1.5	0.6	0	5.3	8.6	0.5	15.2	28.9	265.4
'77	77.9	70.7	68.3	0.3	0	0	0	0	5.8	25.1	75.3	133.1	457.1
'78	89.3	85.2	43.6	3.7	0	0	0	0.7	0.6	14.9	31.8	118.8	388.6
'79	133.8	26.6	80.8	5.3	0	0.7	2.2	0	0	14.1	16.4	71.7	351.6
'80	44.8	42.6	57.3	1.4	0.8								
Average	89.5	68.4	42.3	8.3	2.0	1.1	0.2	1.5	2.0	8.9	23.1	72.1	323.8

5.4.2 Average Precipitation in Project Basin

The computation of average precipitation was done for the 15 year period from 1966 to 1980 employing the Thiessen polygon method. The records of observatories located in the San Juan del Oro River Basin have great weight in run-off calculations for the Project, and since these records were only for monthly precipitation quantities, the computations were made on a monthly basis.

The results of computations are as shown in Table 5-4 and Fig.5-2.

5.5 Run-off at Dam Site

5.5.1 Catchment Area of Dam Site

The catchment areas of three gauging stations excluding La Paz Gauging Station were calculated based on 1/50,000 topographic maps. For the catchment area of La Paz Gauging Station located in Argentine territory, the figure obtained from ENDE was adopted.

The figures below are the catchment area of each gauging station and the dam site.

Chillcara Gauging Station	43,150 km^2
Dam site	43,640 km^2
Villamontes Gauging Station	82,000 km^2
La Paz Gauging Station	96,000 km^2

5.5.2 Representative Gauging Station

There is a catchment area of 490 km^2 remaining between Chillcara Gauging Station and the dam site, but since this remaining catchment area is approximately 1 % of the whole catchment area and extremely small, and also since there are no large tributaries, it was considered that the run-off recorded at Chillcara Gauging Station and the run-off at the dam site are identical.

5.5.3 Verification of Chillcara Gauging Station Run-off

Calculations of run-off at this gauging station have been made up to the present by the Servicio Nacional de Metorologia e Hidrologia (SNMH) and ENDE.

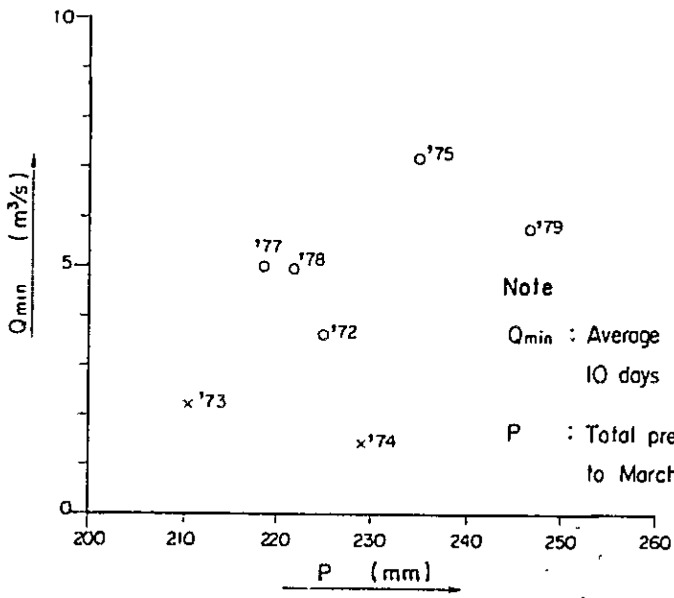
The daily observation figures are water levels according to a staff-gauge (with flow velocity and cross-sectional area of flow measured as necessary). Run-off have been calculated from the rating curves, but rating curves of the past are corrected in later years. That is, reviews of the run-off are being made, and as a result, there is a myriad of run-off data existing. Consequently, the Survey Team carried out comprehensive studies of the whole run-off records of the past in terms of the relation between precipitation and run-off, flow depletion characteristics of run-off, and observation methods, and a run-off thought to be reasonable was selected from among past run-off records. However, since it was judged that the records in the dry seasons of 1973 and 1974 required correction, corrective calculations were made as described later.

The results of comprehensive studies were as follows:

(1) Relation Between Low-water Flow and Precipitation

Fig. 5-3 shows the relation between the total precipitation during the 3 month period from January to March and the average run-off of the 10 days of least flow during the year out of the run-off at Chillcara Gauging Station.

Fig. 5-3 Relation between Low-water Flow and the Total Precipitation during the Rainy Season



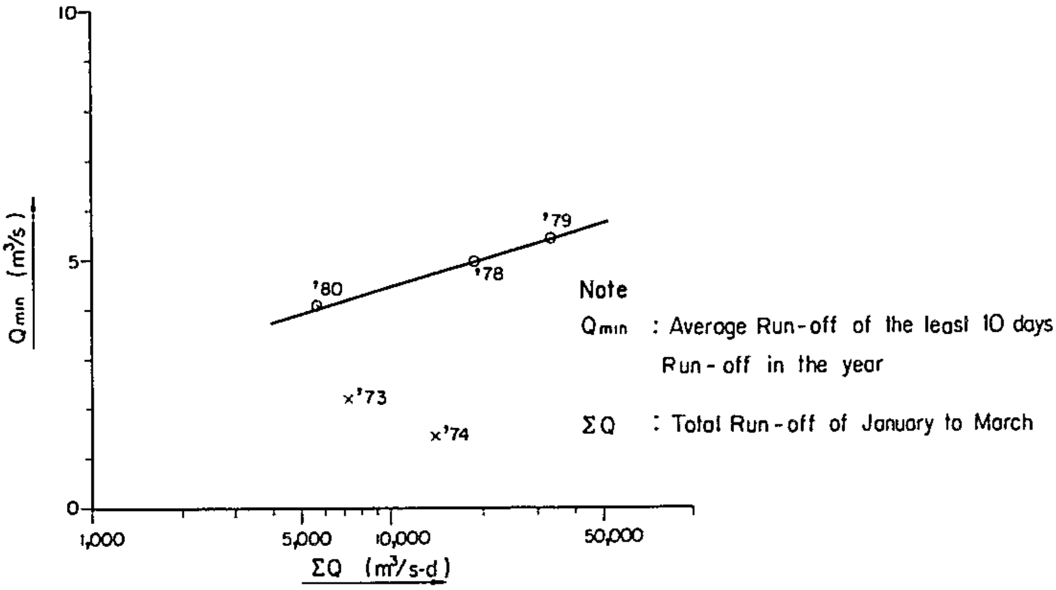
The dry season run-off of this site is mainly due to outflow of groundwater, the source of which is rainfall in the rainy season.
Consequently, the dry season run-off should be large in case the rainfall during the rainy season is plenty. The figure as shown in Fig. 5-3 indicates such a trend although scatter is great. However, it may be seen that the run-off in 1973 and 1974 were exceedingly small compared with other years.

(2) Relation Between Low-water Flow and Rainy Season Flow

Fig. 5-4 shows the relation between the total inflow during the 3 month period from January to March and the average run-off of the 10 days of least flow during the several years.

There were parts with measurements lacking in the data to be compared, while since the number of samples was small, definite statement could not be made, but it was indicated that the figures for 1973 and 1974 at the initial stage after opening of Chillcara Gauging Station compared with the figures for the most recent three years should low-water flows in dry seasons which were small compared with the other low-water flows as shown in Fig.5-4.

Fig. 5-4 Relation between Low-water Flow and the Total Flow during the Rainy Season



(3) Characteristics of Flow Depletion in Dry Season

The characteristics of flow depletion in the period from May 1 of the dry season to October 31 using the selected flow at Chillcara Gauging Station were investigated. The depletion in natural flow is generally given by $Q_t = Q_0 \cdot e^{-\alpha t}$ In the present study, an examination is made regarding $Q_t = -\Delta Q_t + Q_0$ in addition to the above equation.

Table 5-5 and Figs.5-5 and 5-6 show the trends in depletion of flow. The correlation of Q_t and t show good values as a whole. However, the rates of depletion constant α for the 3 years from 1972 through 1974 showed large values compared with other years. That is the trends in depletion of flow is large.

Fig. 5-5 Hydrograph and Depletion Curve (Original Data) (1-2)

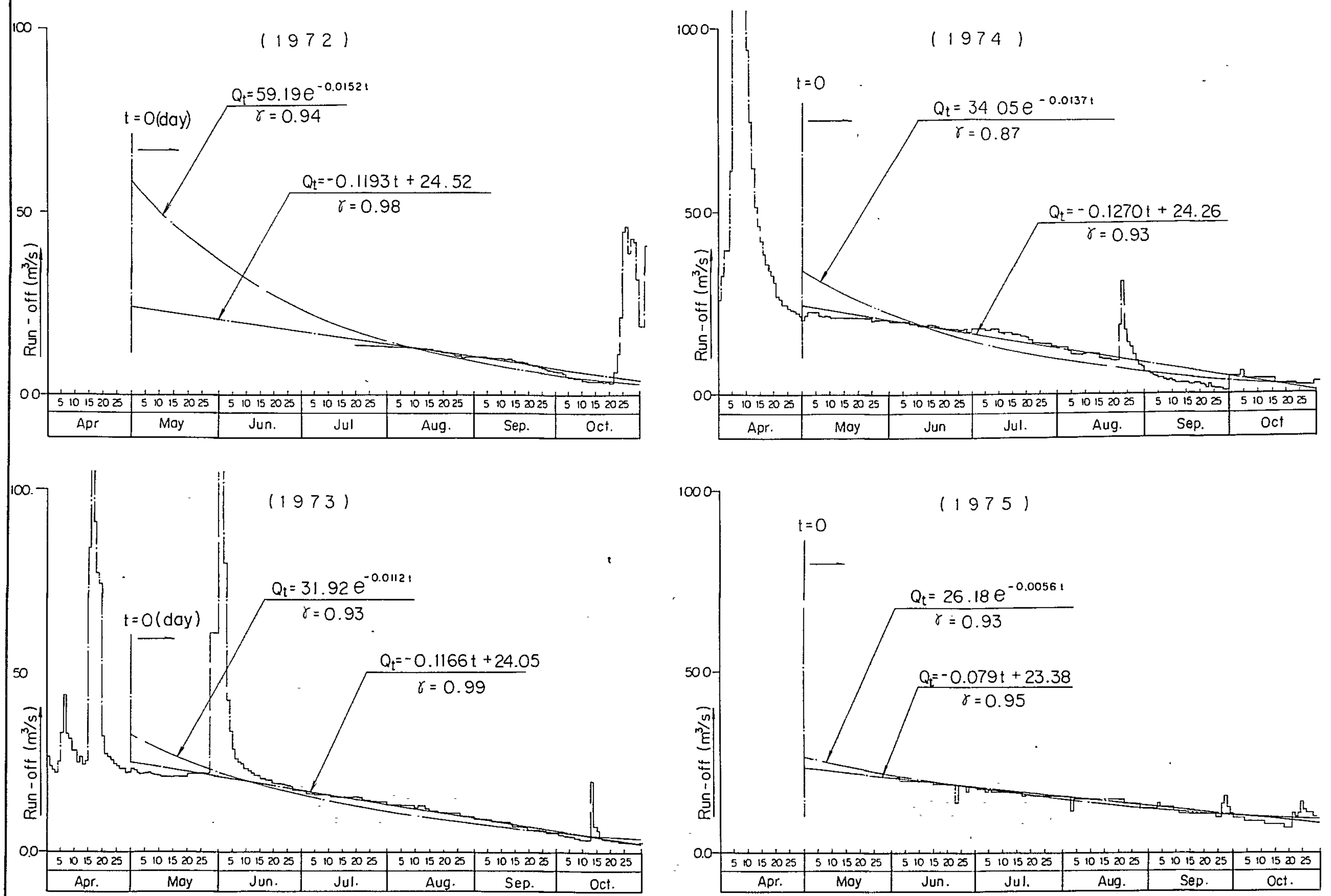
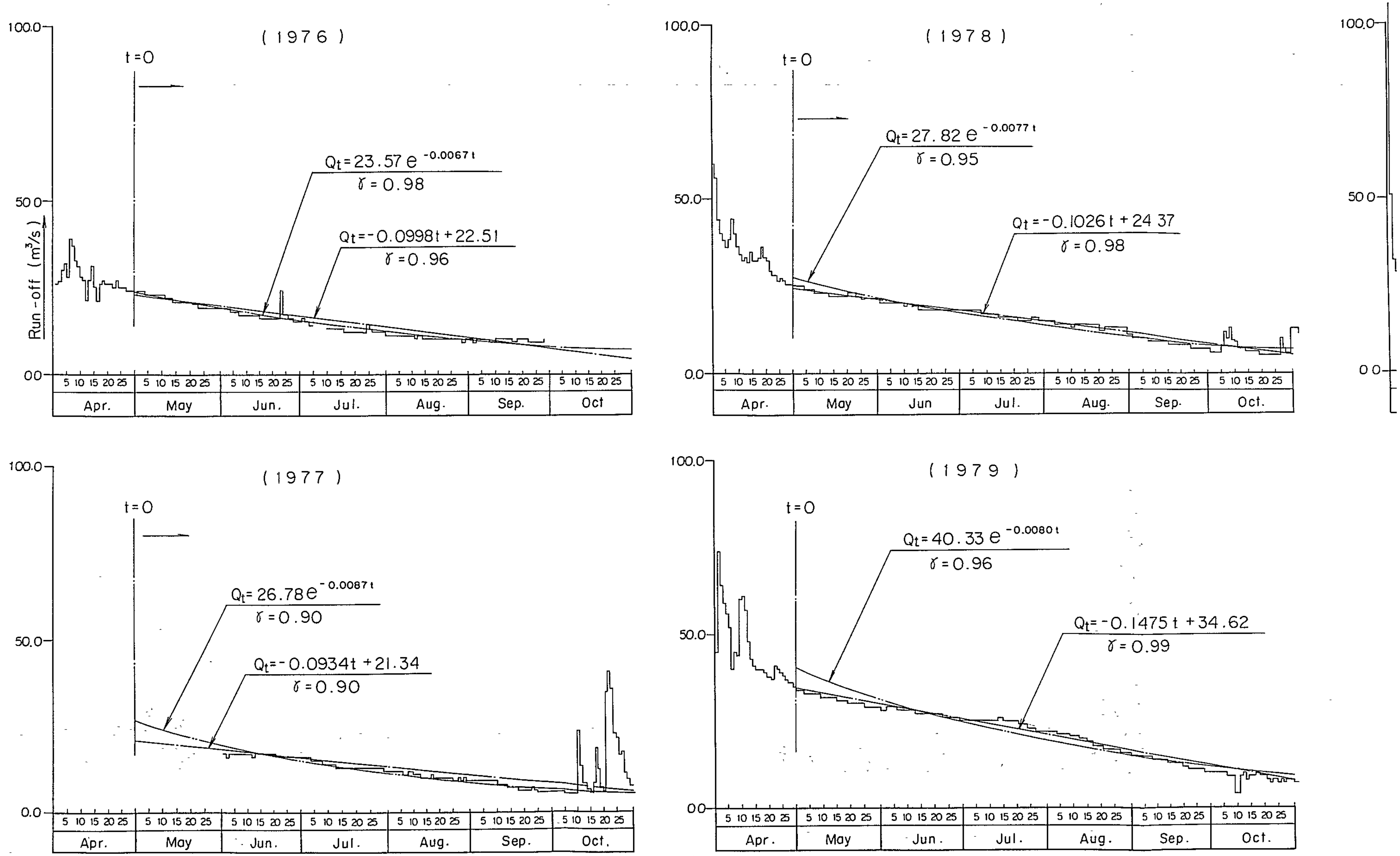
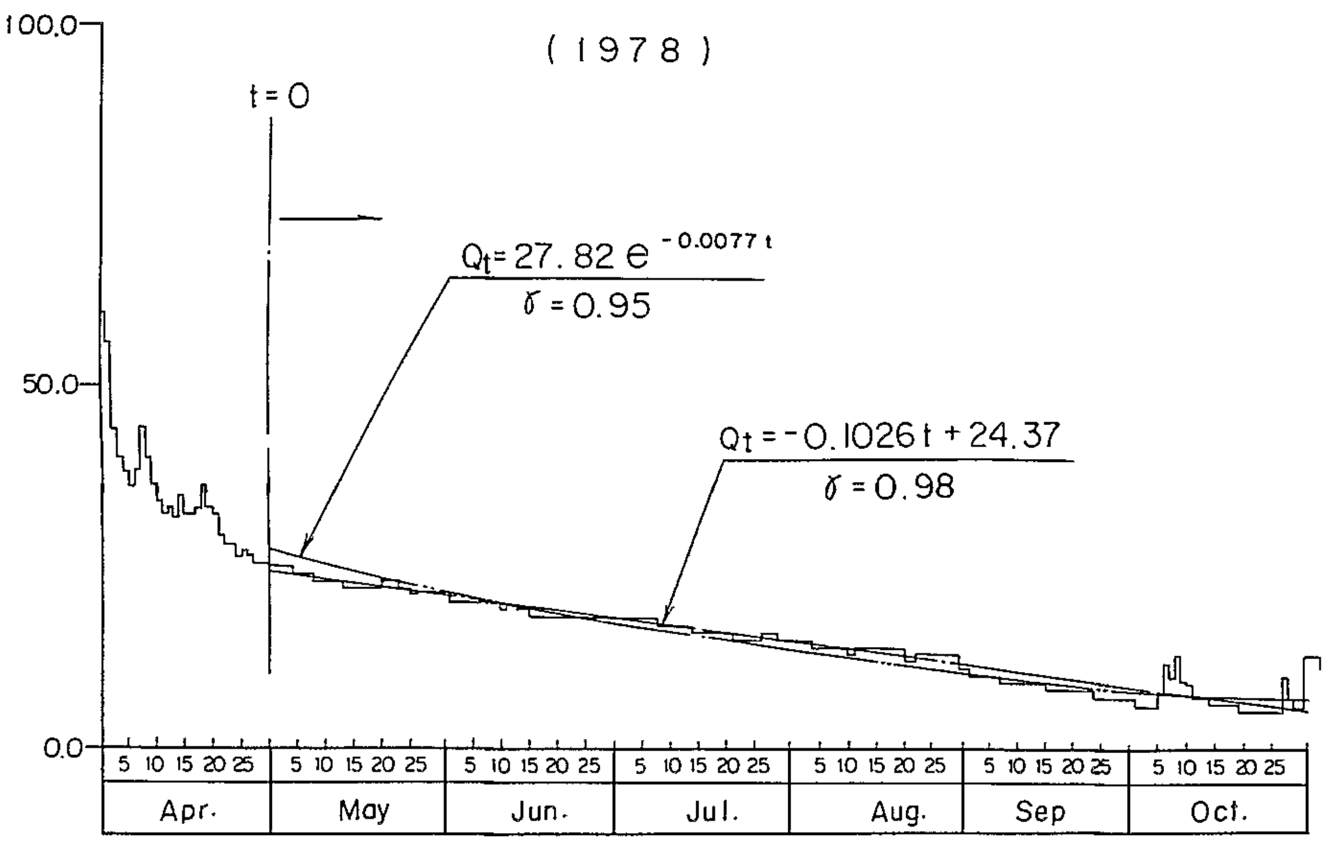
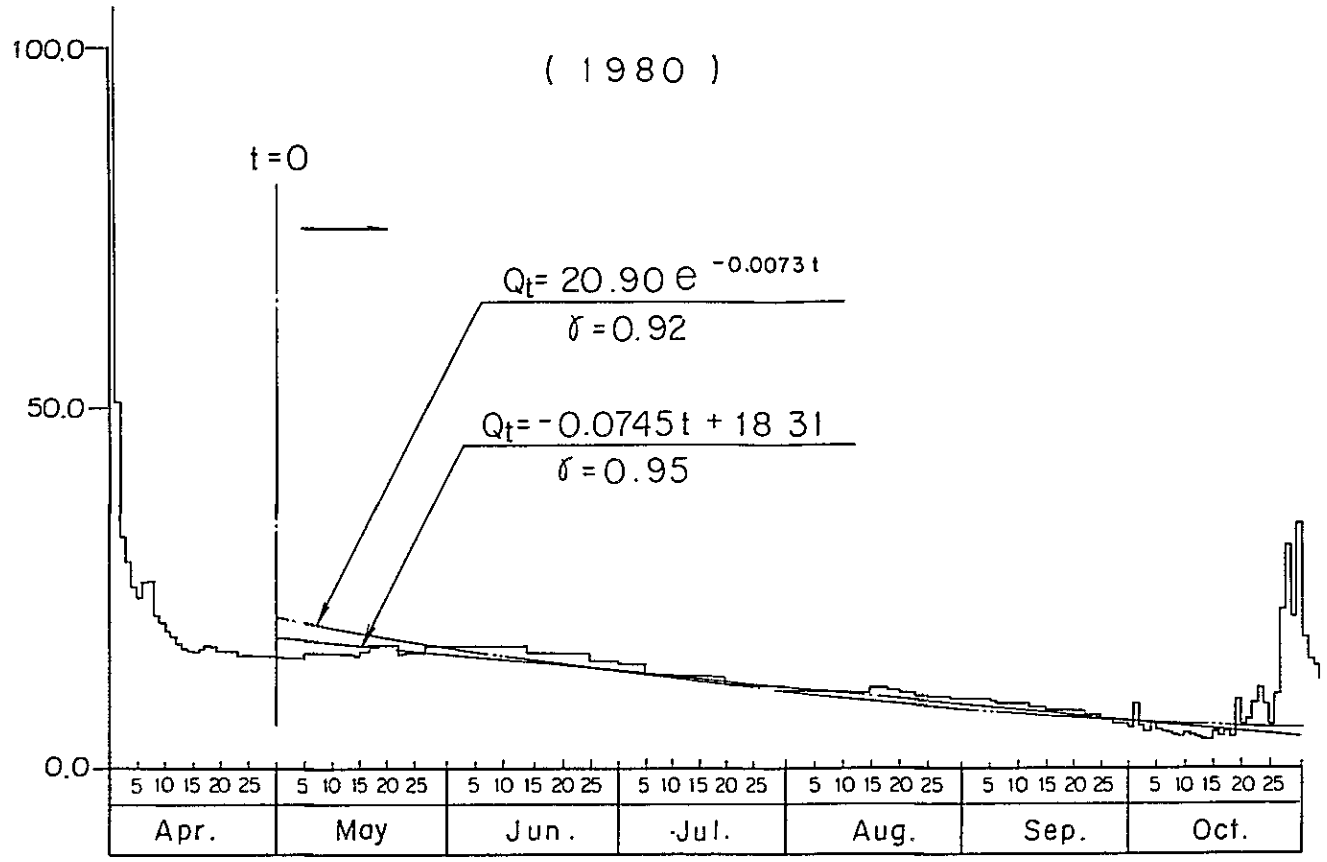


Fig. 5-6 Hydrograph and Depletion Curve (Original Data)



epletion Curve (Original Data)





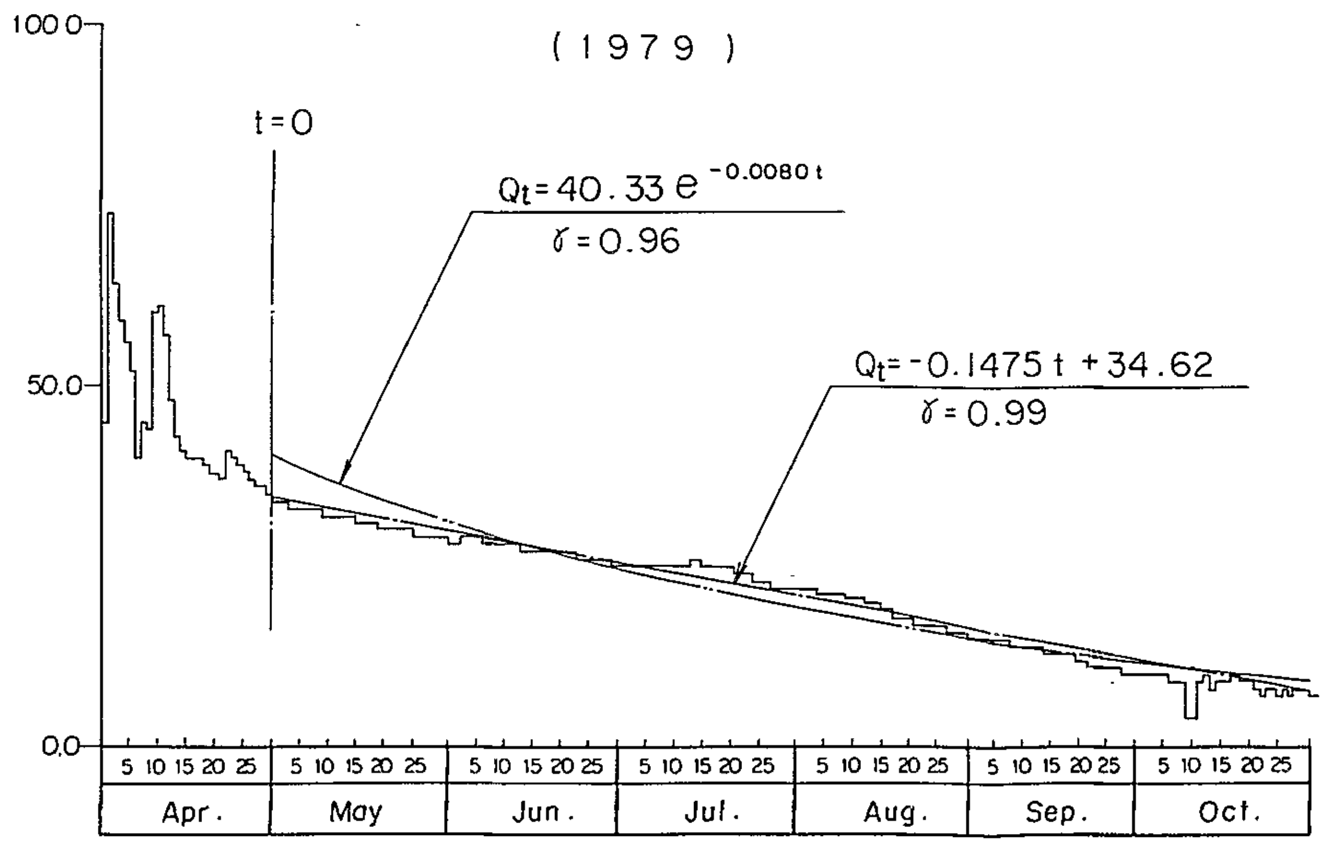


Table 5-5 Correlation between Time (Days) and Run-off in Dry Season

Item	$Q_+ = -\Delta Q t + Q_o$			$Q_+ = Q_o e^{-\alpha t}$		
Year	Q_o	ΔQ	γ	Q_o	$-\alpha$	γ
1972	24.52	0.1193	0.98	59.19	0.0152	0.94
1973	24.05	0.1166	0.99	31.92	0.0112	0.93
1974	24.26	0.1270	0.93	34.05	0.0137	0.87
1975	23.38	0.0790	0.95	26.18	0.0056	0.93
1976	22.51	0.0998	0.96	23.57	0.0067	0.98
1977	21.34	0.0934	0.90	26.78	0.0087	0.90
1978	24.37	0.1026	0.98	27.82	0.0077	0.95
1979	34.62	0.1475	0.99	40.33	0.0080	0.96
1980	18.31	0.0745	0.95	20.90	0.0073	0.92

(4) Relation Between Rainy Season Precipitation and Dry Season Natural Depletion Constant

The relation of the natural flow-depletion constant to the total inflow for the 4 month period of January through April is shown in Fig.5-7.

Although a given trend is not seen in the figure, the values from 1972 through 1974 are larger compared with other years.

(5) Relation Between Rainy Season Run-off and Dry Season Natural Flow Depletion Constant

Fig.5-8 shows the relation between the total inflow during the 3 month period from January through March and the natural flow depletion constant.

Although a definite statement cannot be made since data for comparison are incomplete, similarly to the relation with precipitation, the values for 1973 and 1974 are larger than for other years.

Fig. 5-7 Relation between Depletion Constant α and the Total Precipitation during the Rainy Season

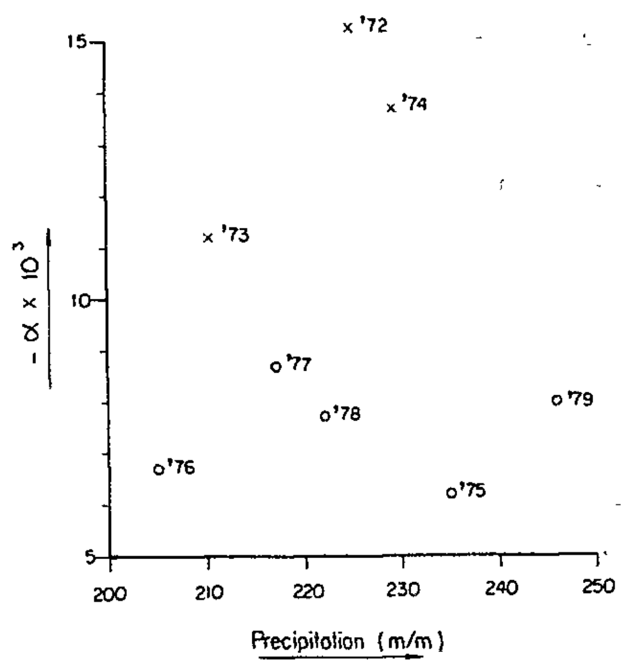
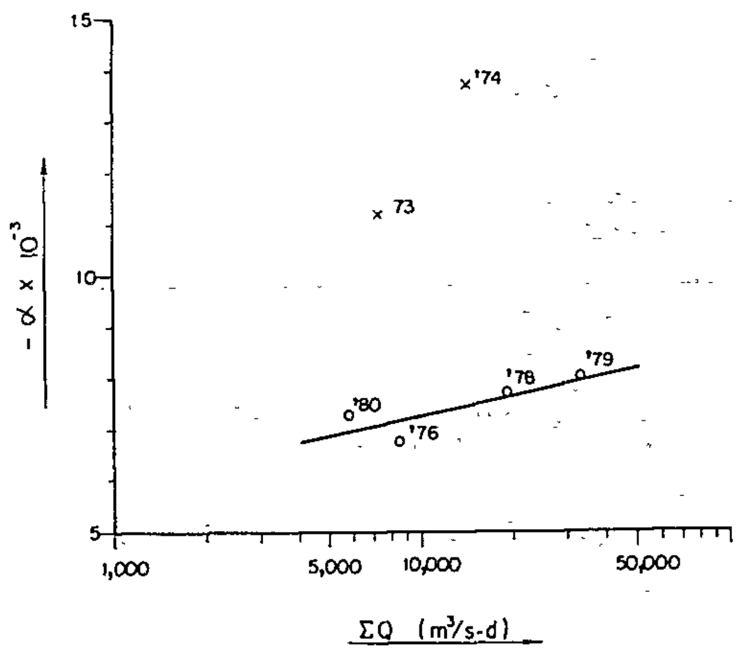


Fig. 5-8 Relation between Depletion Constant α and the Total Run-off ΣQ during the Rainy Season



(6) Relation Between Measured Water Level and Run-off (Method of Observation)

Although the relation between water level and run-off will vary if there is a change in the river bed, when a sudden river-bed change as in the dry season does not occur, the river flow will not change much either. However, since a part of large change in river flow was seen in the dry season records of measurements, it was decided to clarify the cause of this phenomenon.

An example which can be given is the case of September 30 and October 1, 1974 when water levels measured were both 1.59 m, but the run-off of the former was 0.8 m^3/s whereas that of the latter was 5.16 m^3/s.

In comparison with other years, it is thought that the 0.8 m^3/s of the former was undervalued.

Further, upon investigation of run-off against identical water levels in the low-water season by year, it was found that the figures for 1973 and 1974 were low compared with the run-off figures for the most recent 5 years. Meanwhile, with regard to the river profile, the river bed has recently risen approximately 1 m and the bottom parts of staff-gauges have become buried.

In case the reading of the staff-gauge were to be 1.5 m, the run-off in 1980 would be 6.0 m^3/s and cross-sectional area of flow approximately 30 m^2. Consequently, the mean flow velocity is 0.2 m/s. In contrast, the run-off of 1973 was 3.2 m^3/s, while the cross-sectional area of flow is thought to have been at least about 60 m^2, and the mean flow velocity in that case was 0.05 m/s.

The current meter used at this run-off gauging station is a comparatively large Price type, and generally speaking, the lower limit of application of this type is at around 0.2 - 0.3 m/s.

Accordingly, it may be surmised that the current meter did not work normally in the dry season with the cross section at the time Chillcara Gauging Station was first opened, and it is thought flow velocity had been undervalued as a result.

(7) Verification Results

As described in (1) - (6) above, the run-off records of Chillcara Gauging Station from 1972 through 1980 were comprehensively examined, and as a result it may be judged that the run-off in the dry seasons of 1973 and 1974 had been undervalued.

Therefore, from Item 5.4.4, run-off corrections for this period will be described below.

5.5.4 Correction of Chillcara Gauging Station Run-off in Two-year Dry Period

Corrections were made of the run-off in the dry seasons of 1973 and 1974 by the method below. In effect, it was decided to compute the run-off from measured water levels by the reliable rating curve in 1978.

The equation below is the rating curve equation applied from March to December 1978 calculated by ENDE.

$$Q = 10^{0.6565} (H - 0.5)^{5.28682}$$

The run-off used for this plan after corrections are given in Table 5-6.

Table 5-6 Monthly Run-off Data at Chillcara Gauging Station

(Unit: $m^3/s \cdot d$)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
'72	—	—	—	—	—	—	—	11.8	8.6	13.0	19.5	38.1
'73	83.0	74.9	80.8	36.9	33.4 (25.0)	63.5 (32.3)	21.0 (14.8)	16.5 (12.1)	10.3 (7.7)	5.7 (4.1)	4.6 (3.2)	33.0 (26.9)
'74	114.6	286.4	79.2	51.5	23.8 (20.6)	22.1 (18.7)	19.9 (16.1)	16.7 (11.9)	10.1 (3.1)	4.8 (3.9)	8.0 (6.5)	59.5
'75	224.6	413.3	—	—	—	19.8	17.4	15.0	12.4	9.8	10.2	34.9
'76	116.1	98.4	78.0	27.8	21.8	17.5	13.7	10.8	10.0	—	—	—
'77	—	—	—	—	—	17.2	14.2	11.1	7.8	12.5	74.7	123.0
'78	194.5	371.0	90.4	34.8	22.5	19.8	16.8	13.3	9.2	7.6	17.6	106.8
'79	642.0	292.3	146.3	47.0	31.3	27.8	24.7	19.3	13.4	9.1	13.9	91.1
'80	69.8	43.5	77.5	22.2	15.8	15.9	13.2	10.9	7.7	8.9	10.0	10.1

Note ; ( ) Original Data

Fig. 5-9 Hydrograph in Modified

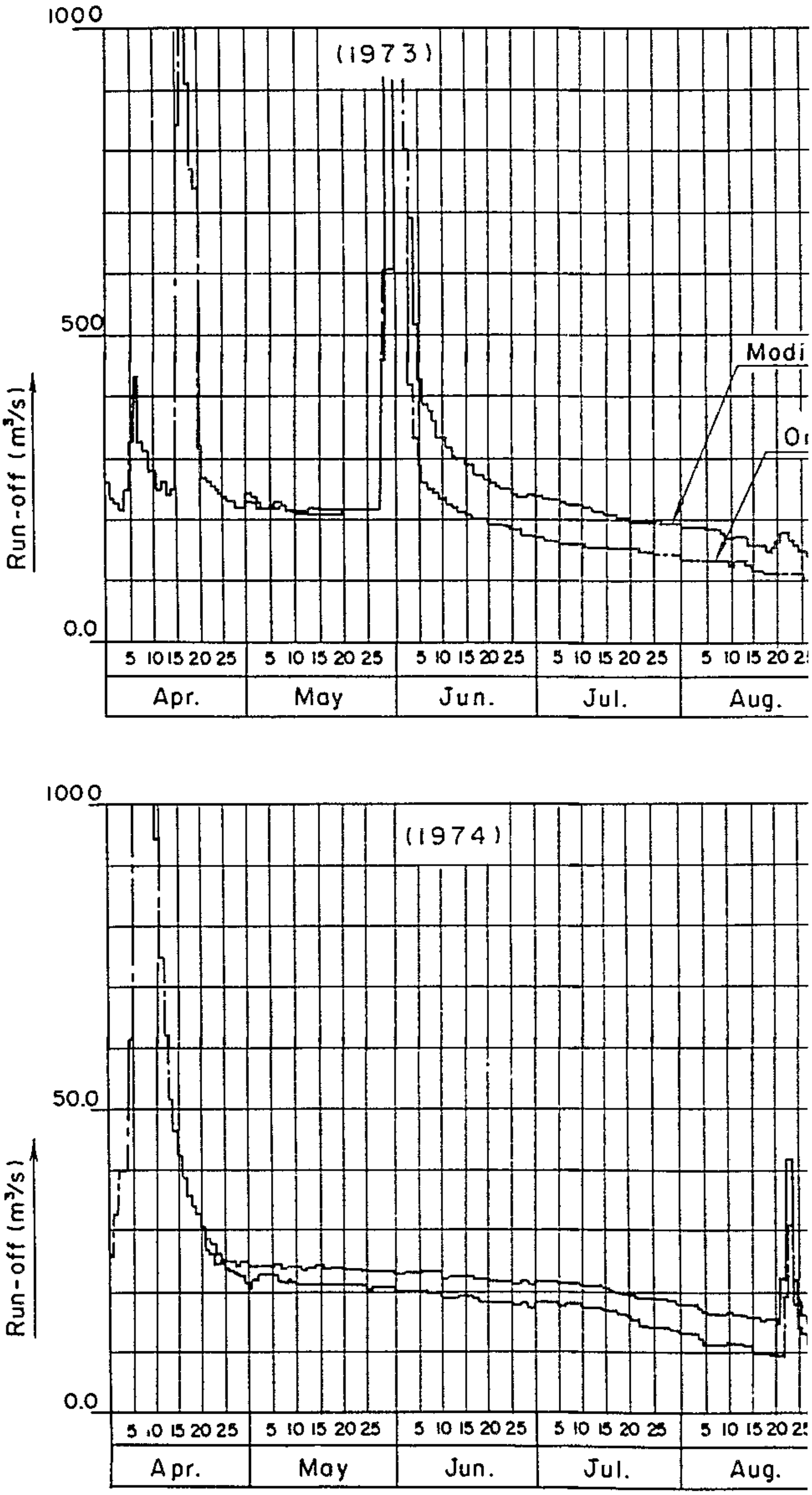


Fig. 5-9 Hydrograph in Modified Period (Dry Season '73 and '74)

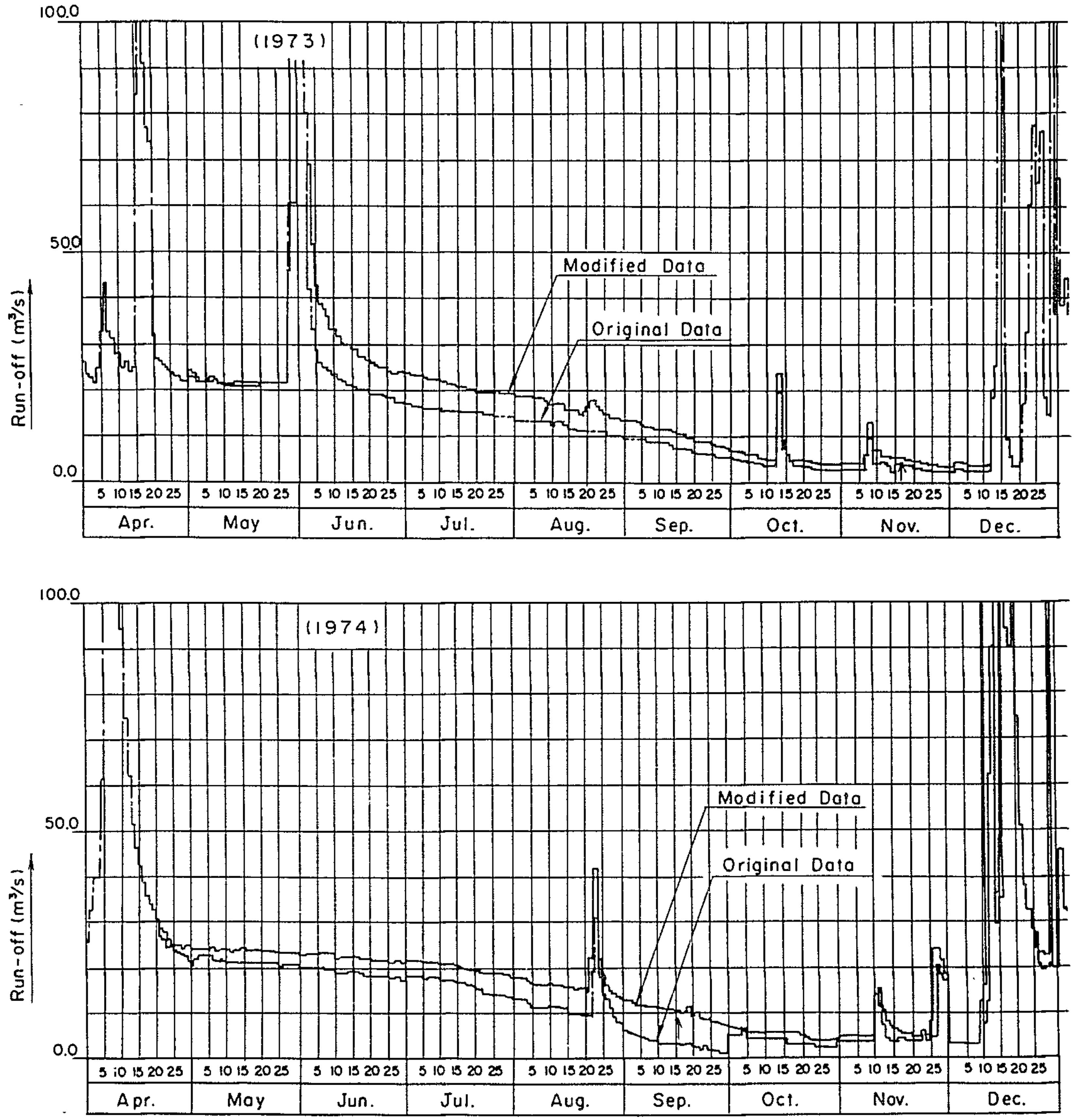


Fig. 5-10 Run-off Duration Curve (2-1)

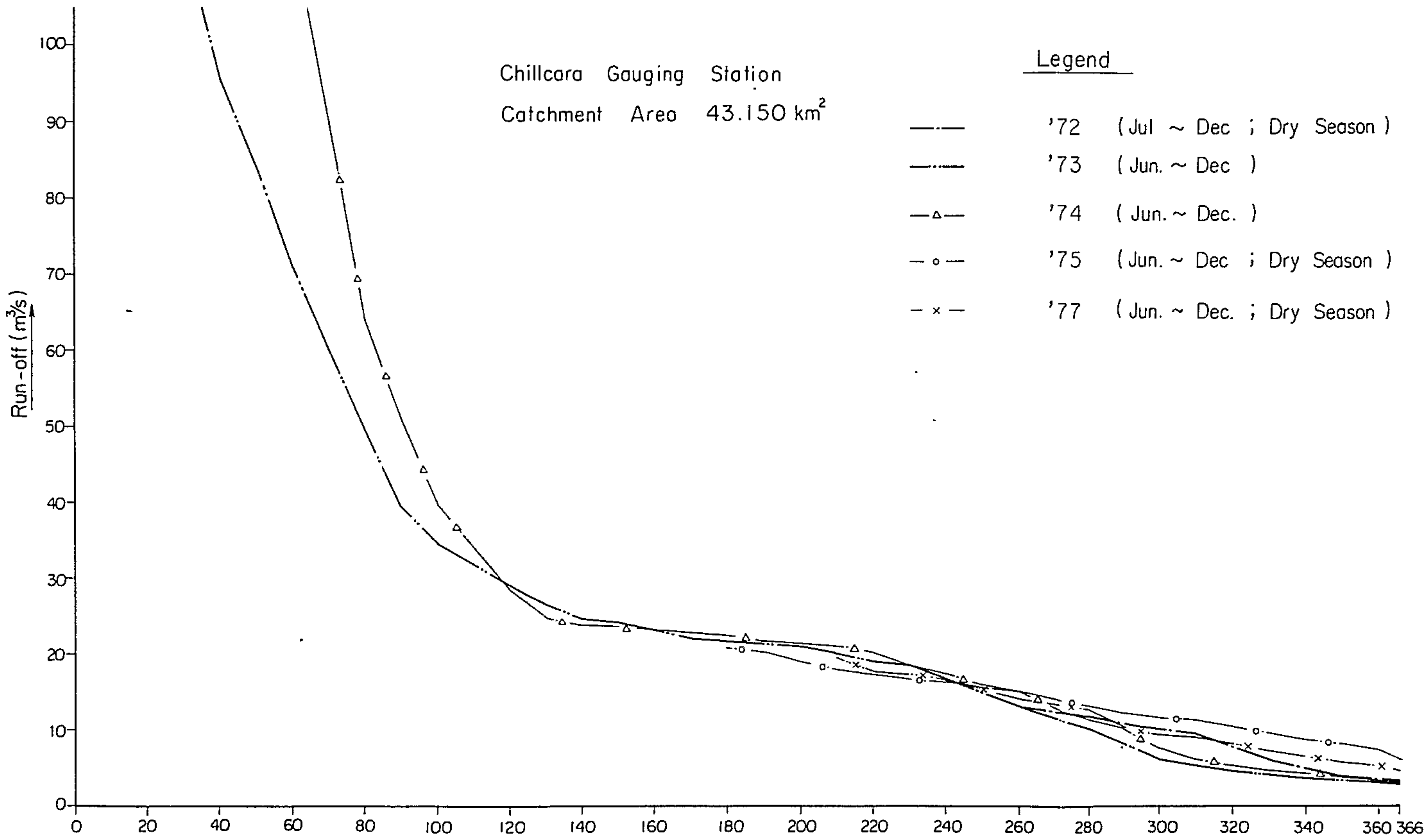
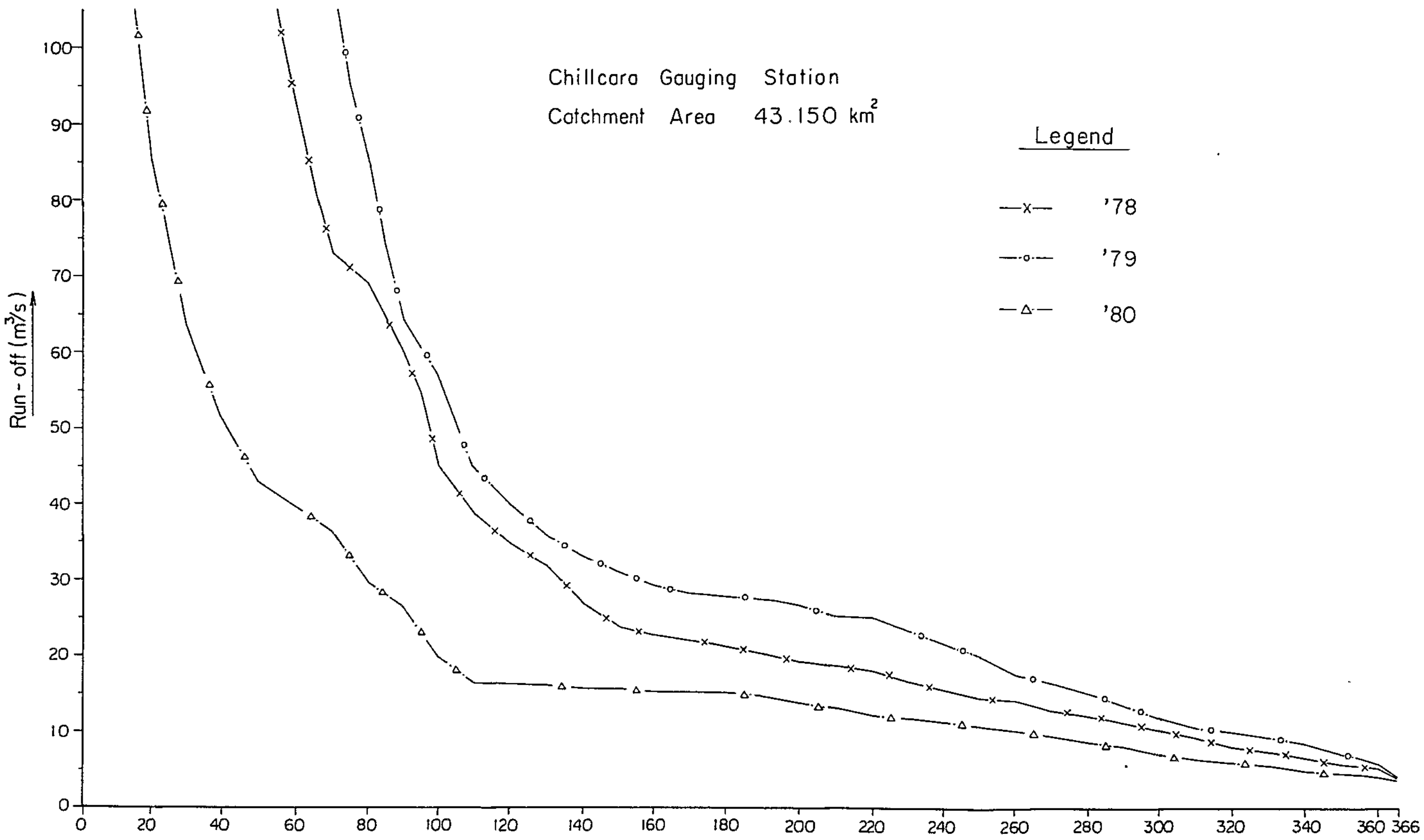


Fig. 5 - 11 Run - off Duration Curve (2 - 2)



5.5.5 Period of Computation of Run-off

The period of computation of run-off used in examination of the Project was taken to be the 15 years from January 1966 through December 1980.

Since precipitation data prior to 1966 used for augmenting the periods lacking measurements of run-off do not satisfy the previously-mentioned requirements for precipitation observation station records, while the Project is to be daily regulation reservoir types (that is, roughly to say run-off-river type from view point of run-off utilization rate) where the river water utilization factor will be low, it is judged that run-off data for a 15-year period will be adequate.

5.5.6 Method of Augmenting Run-off Data

In order to complete the run-off data for the above-mentioned 15-year period, studies were made of the method below regarding measurements lacking for Chillcara Gauging Station and data unavailable for the 15 year period. In effect, the method combining correlations with average precipitation and flow depletion characteristics in the dry season was adopted.

The method of augmenting run-off data is described below.

(1) November - April

The precipitations during unrecorded periods were computed utilizing the correlation between average precipitation and measured run-off. As a result, it was confirmed that there was agreement with the general trend. In effect, a high proportion of rainfall from the end of the dry season to the early part of the rainy season is absorbed by soil, because of which the outflow is relatively small compared with the amount of rain. Conversely, in the latter part of the rainy season the moisture in soil is increased so that run-off is large compared with the rainfall.

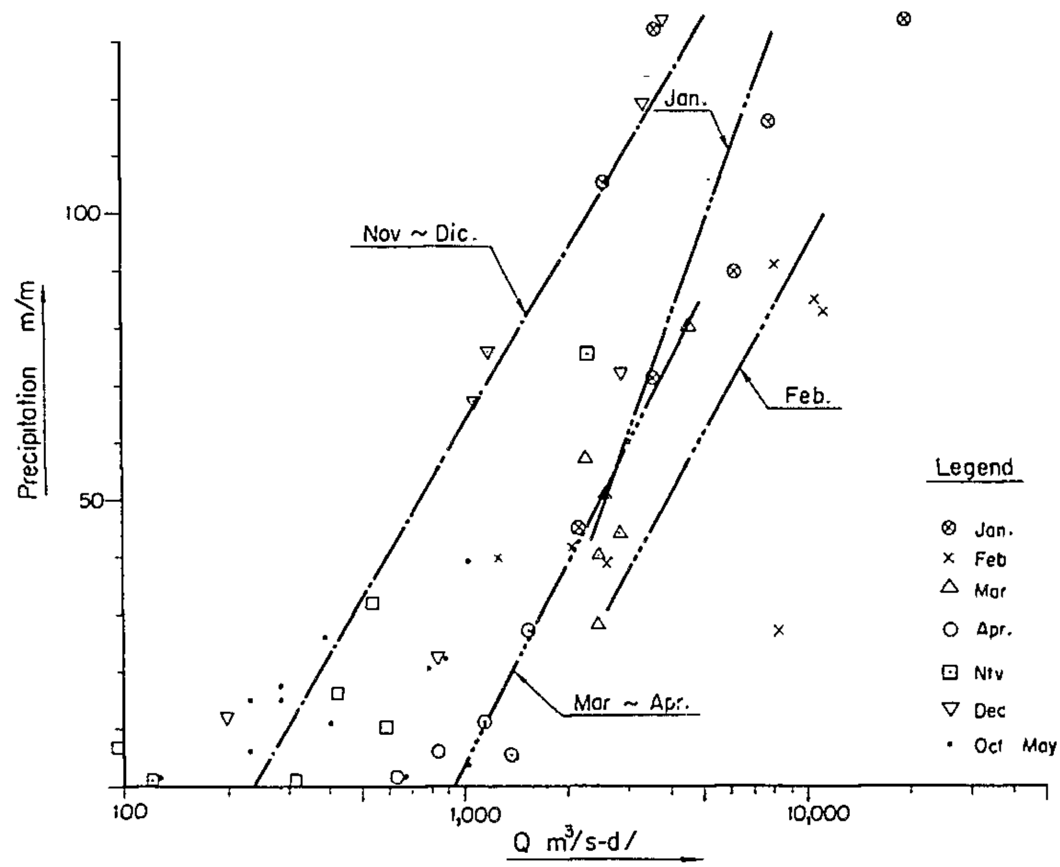
The relations between monthly precipitations and monthly run-off are shown in Fig.5-12. The equations below are the correlation formula.

Period

Nov. to Dec.	$Q = 238.0\ e^{0.0226P}$	$\gamma = 0.88$
Jan.	$Q = 1,174.8\ e^{0.0144P}$	$\gamma = 0.62$
Feb.	$Q = 1,410.9\ e^{0.0207P}$	$\gamma = 0.62$
Mar. to Apr.	$Q = 931.9\ e^{0.0203P}$	$\gamma = 0.91$

Of the above, correlations are poor for January and February. However, this will not affect the Project very much. This is because the river flow during January and February is very large compared with the discharge used for power generation and it is considered there will be overflow almost every day at the dam site.

Fig. 5-12 Relation between Monthly Precipitation and Run-off



(2) May - October

Since there is practically no precipitation during the dry season it is not possible to obtain the run-off from correlation with precipitation. Here, the run-off from May to October was obtained from the relations between the flow depletion characteristics in the dry seasons during the period measurements were made and the run-off in the latter halves of the rainy seasons during the period.

Table 5-7 shows the trends of flow depletion in the dry seasons of the respective years obtained applying two different equations.

As previously described, the decrease in natural flow is generally given by $Q_t = Q_0 \cdot e^{-\alpha t}$ but according to the records of this particular gauging station, the equation $Q_t = -\Delta Q \cdot t + Q_0$ matches the condition more. The correlation coefficient is equal to or higher than the former for seven out of the eight years from 1972 to 1980 for which there are measurement records in the past. Further, values closer to actual are obtained with the latter for early run-off which serves as a key for determining the run-off in the dry season.

Accordingly, the equation $Q_t = -\Delta Q \cdot t + Q_0$ will be used for the Project.

Table 5-7 Correlation between Time (Days) and Run-off during the Dry Season for Two Depletion Equations

Item / Year	Average Run-off from Apr. 25 to May 5	$Q_t = Q_o e^{-\alpha t}$			$Q_t = \Delta Qt + Q_o$		
		Q_o	$-\alpha$	γ	Q_o	ΔQ	γ
1972	—	59.19	0.0152	0.94	24.52	0.1193	0.98
1973	23.40	28.38	0.0124	0.89	26.66	0.1150	0.92
1974	24.27	35.50	0.0100	0.91	27.66	0.1250	0.97
1975	—	26.18	0.0056	0.93	23.38	0.079	0.95
1976	24.41	23.57	0.0067	0.98	22.51	0.0998	0.96
1977	—	26.78	0.0087	0.90	21.34	0.0934	0.90
1978	25.29	27.82	0.0077	0.95	24.37	0.1026	0.98
1979	34.56	40.33	0.0080	0.96	34.62	0.1475	0.99
1980	15.15	20.90	0.0073	0.92	18.31	0.0745	0.95

Fig.5-13 shows the relation between initial run-off Q_o and depletion per day ΔQ. In effect, a trend is distinctly shown of depletion per day being increased as initial run-off becomes larger.

Fig.5-14 shows the relation between the average run-off Q_M for the two months of March and April comprising the latter half of the rainy season and the initial run-off Q_o of the dry season.

This also shows a distinct trend of initial run-off becoming larger as the run-off in the latter half of the rainy season is increased.

The method of computing run-off adopted for this season was that of first calculating the initial run-off based on the run-off of the latter half of the rainy season (average run-off for March and April), then calculating the depletion per day at that time, and substituting into $Q_t = -\Delta Q \cdot t + Q_o \cdot$ to obtain the run-off of the individual months.

Fig. 5-13 Relation between Initial Run-off Qo and Depletion per Day (ΔQ)

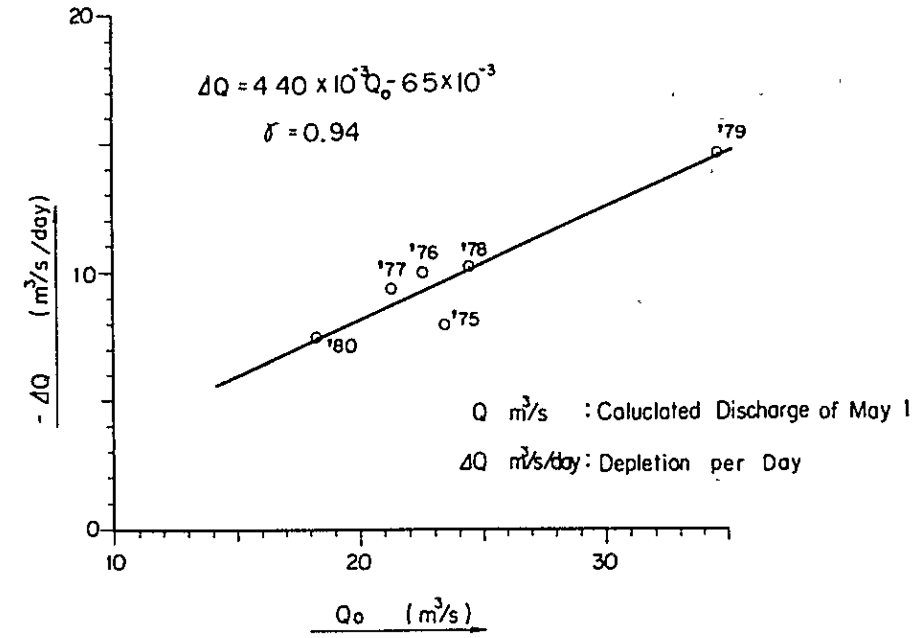
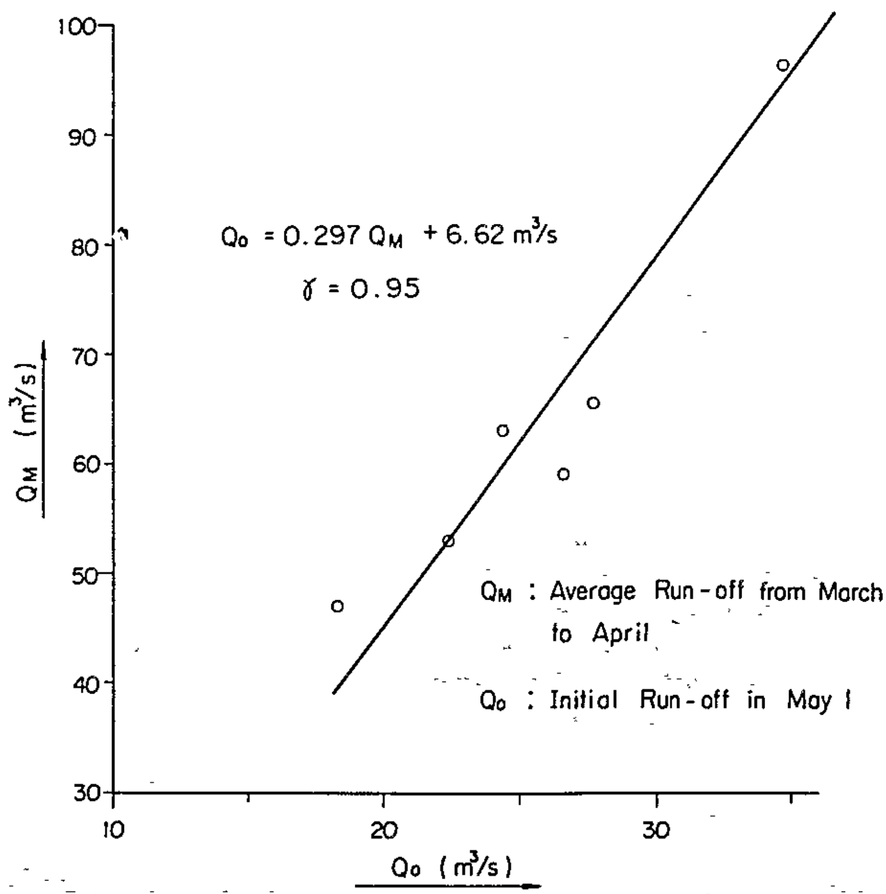


Fig. 5-14 Relation between the Initial Run-off on May 1 and the Average Run-off from March to April



5.5.7 Computation of Run-off at Project Site During Blank Periods

For the period between December and April, monthly average inflows were calculated by the equations below using monthly precipitation figures.

Nov.	$Q = 7.93 \cdot e^{0.0226P}$
Dec.	$Q = 7.68 \cdot e^{0.0226P}$
Jan.	$Q = 37.90 \cdot e^{0.0144P}$
Feb.	$Q = 50.39 \cdot e^{0.0207P}$
Mar.	$Q = 30.06 \cdot e^{0.0203P}$
Apr.	$Q = 31.06 \cdot e^{0.0203P}$

For the dry season period from May to October, the equations for depletion shown below were obtained following the lines of the above-mentioned method based on the average run-off for March and April as determined from precipitation.

1966	$Q_t = -0.0775 \cdot t + 19.09$
1967	$Q_t = -0.0896 \cdot t + 21.84$
1968	$Q_t = -0.0934 \cdot t + 22.71$
1969	$Q_t = -0.0679 \cdot t + 16.92$
1970	$Q_t = -0.1302 \cdot t + 31.07$
1971	$Q_t = -0.0712 \cdot t + 17.65$
1972	$Q_t = -0.0944 \cdot t + 22.93$

For periods lacking measurements in 1973 and after, since the durations of the periods were approximately one month and thus short, the depletion equation for actual was applied.

The correlation coefficient γ on an annual basis for the values calculated based on the above equation and the measured values γ is 0.84. This is because the figures for the 3 month period from December through February in the rainy season are not in good agreement with the measured figures. However, as mentioned previously, since the run-off during this period is large and exceeds the power generation intake capacity almost all of the time, the effect on the Project is only very slight. For the period from March through November excluding the above period the correlation coefficient γ is high at 0.94. Accordingly, for use in the Pilaya Project the hydrologic data will be reasonable.

Table 5-8 shows the monthly average run-off at the dam site for the 15 year period from 1966 through 1980.

Table 5-8 Monthly Average Run-off at Project Dam Site

(Unit : $m^3/s.d$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
'66	61.2	96.9	42.0	42.0	17.9	15.5	13.2	10.8	8.4	6.0	19.1	41.1	11.221
'67	63.4	148.5	62.3	39.8	20.5	17.7	15.0	12.2	9.5	6.7	8.5	56.8	13.767
'68	123.4	879.3	75.6	32.0	21.3	18.4	15.6	12.7	9.8	7.0	23.9	14.4	36.346
'69	195.1	144.0	36.7	32.6	15.9	13.8	11.7	9.6	7.6	5.5	10.6	131.5	18.668
'70	170.2	160.1	110.8	53.0	29.1	25.1	21.1	17.1	13.1	9.1	10.3	44.6	19.884
'71	146.8	938.5	42.8	31.2	16.6	14.4	12.2	10.0	7.8	5.7	19.9	28.3	36.652
'72	155.5	229.3	72.2	37.1	21.5	18.6	15.7	11.8	8.6	13.0	19.5	38.1	19.096
'73	83.0	74.9	80.8	36.9	33.4	63.5	21.0	16.5	10.3	5.7	4.6	33.0	14.026
'74	114.6	286.4	79.2	49.8	23.8	22.1	19.9	16.7	10.1	4.8	8.0	59.5	20.643
'75	224.6	413.3	58.0	33.3	22.8	19.8	17.4	15.0	12.4	9.8	10.2	34.9	25.701
'76	116.1	98.4	78.0	27.8	21.8	17.5	13.7	10.8	10.0	7.5	43.5	155.4	18.320
'77	137.1	293.8	72.9	33.5	22.0	17.2	14.2	11.1	7.8	12.5	74.7	123.0	24.399
'78	194.5	371.0	90.4	34.8	22.5	19.8	16.8	13.3	9.2	7.6	17.9	106.8	26.846
'79	642.0	292.3	146.3	47.0	31.3	27.8	24.7	19.3	13.4	9.1	13.9	91.1	41.121
'80	69.5	43.5	77.5	22.2	15.8	15.9	13.2	10.9	7.7	8.9	10.0	10.1	9.322
Average	166.5	298.0	75.0	36.9	22.4	21.8	16.4	13.2	9.7	7.9	19.6	64.6	22.401

Fig. 5 - 2

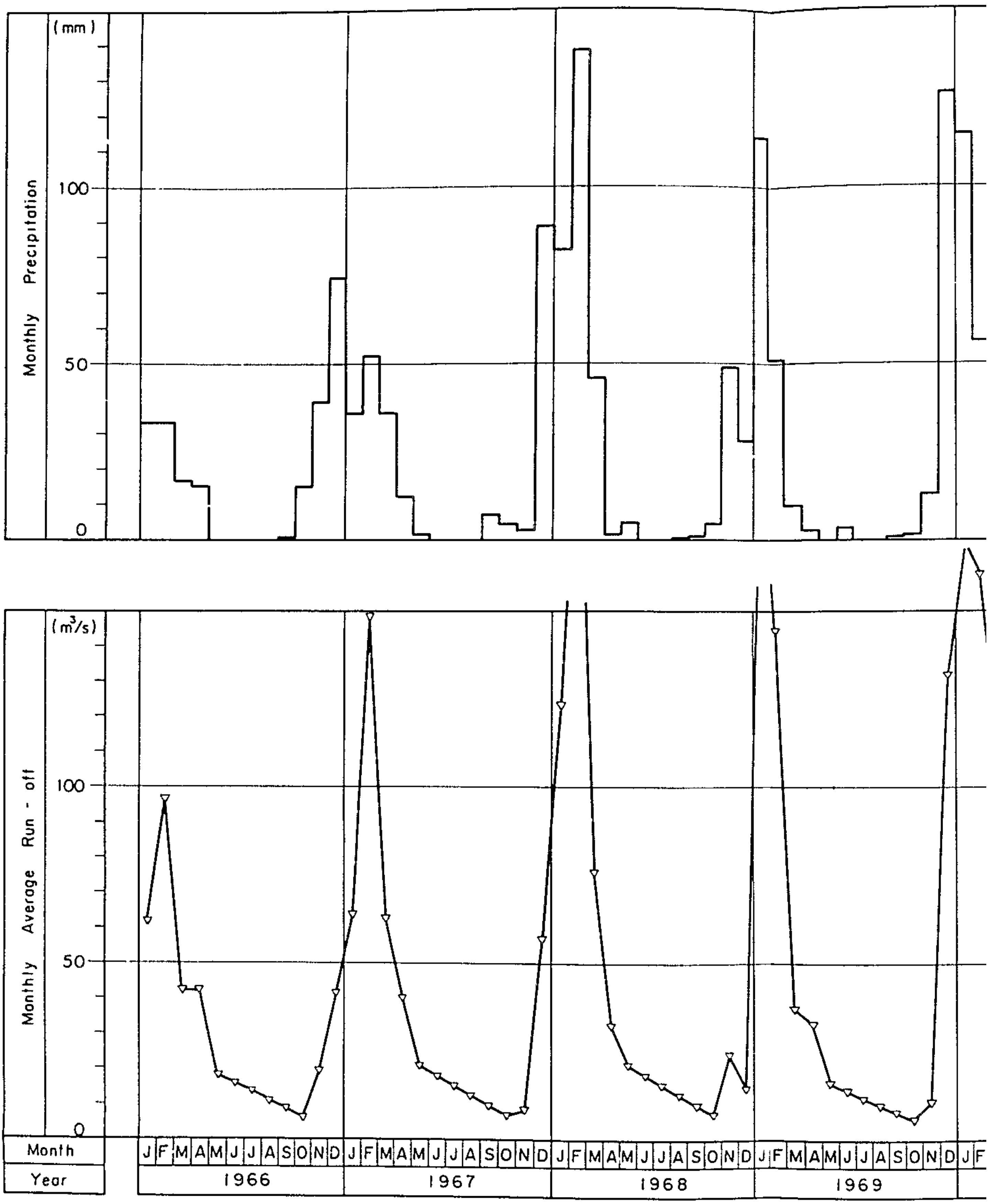
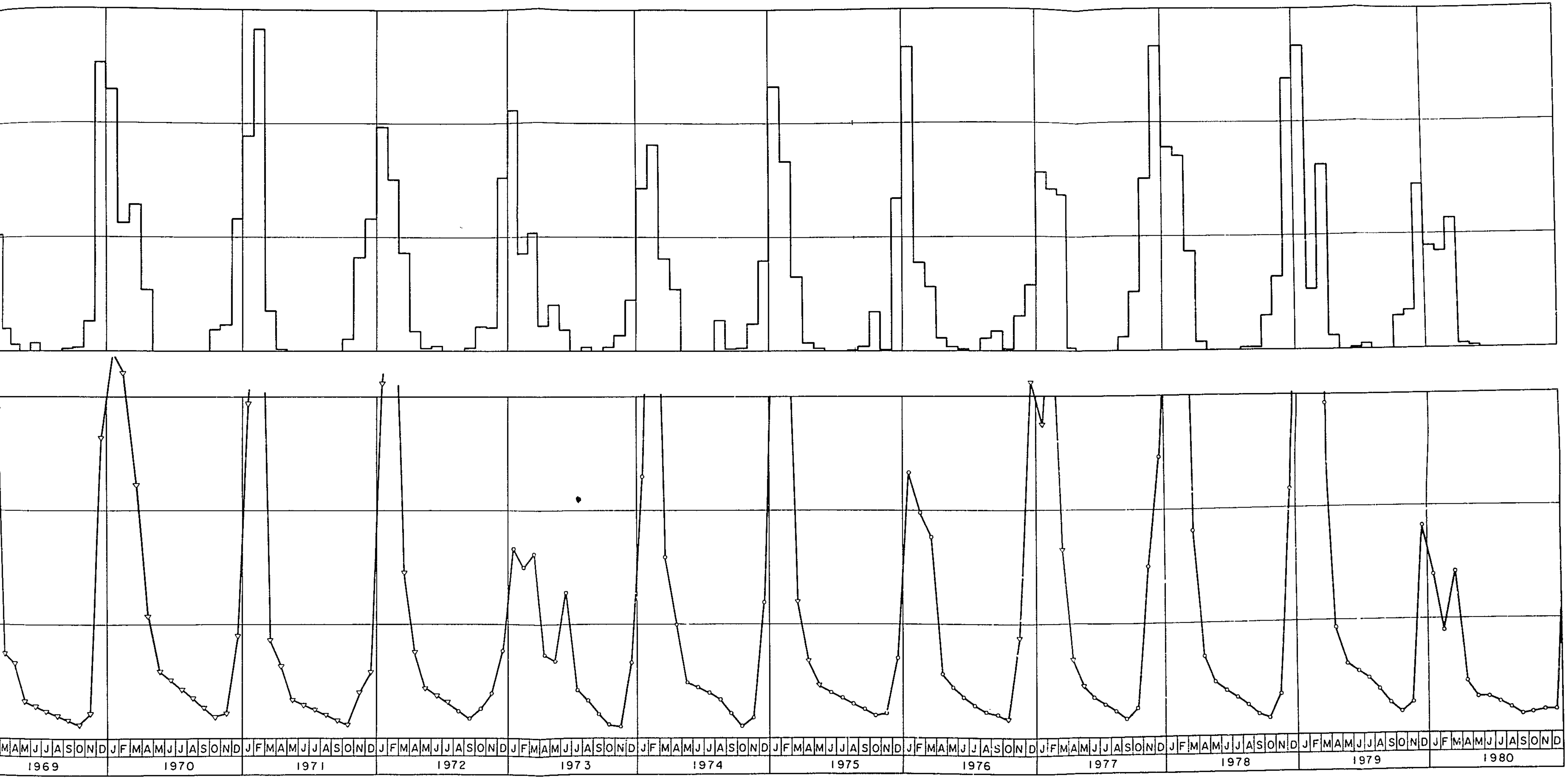

(mm)
Monthly Precipitation
100
50
0
(m³/s)
Monthly Average Run - off
100
50
0
Month
Year
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1966
1967
1968
1969

Fig. 5 - 2 Hyetograph in the Project Area and Hydrograph at Chillcara Gauging Station



5.6 Design Flood Discharge

5.6.1 Past Floods at Chillcara Gauging Station

The records of floods at Chillcara Gauging Station consist only of water level measurements, and flow velocities have not been observed. Table 5-9 gives the maximum water level each year.

The past maximum annual floods were calculated here by the two methods below.

(1) Manning Formula

The flood discharge is computed by Manning's uniform flow formula using the transverse cross section of the river at the gauging station, the average stream gradient, and the water level measured.

Manning's uniform flow formula is indicated below.

$$V = \frac{1}{n} \cdot I^{1/2} \cdot R^{2/3}$$

where,

V : mean velocity, m/s
n : coefficient of roughness, 0.045
I : stream gradient

$$I = \frac{2060 - 1770}{22.5 \times 10^3} = 0.0129$$

EL of Chillcara GS	2,060 m
EL of dam site	1,770 m
Distance	22.5 km

R : hydraulic radius

$$Q = A \cdot v$$

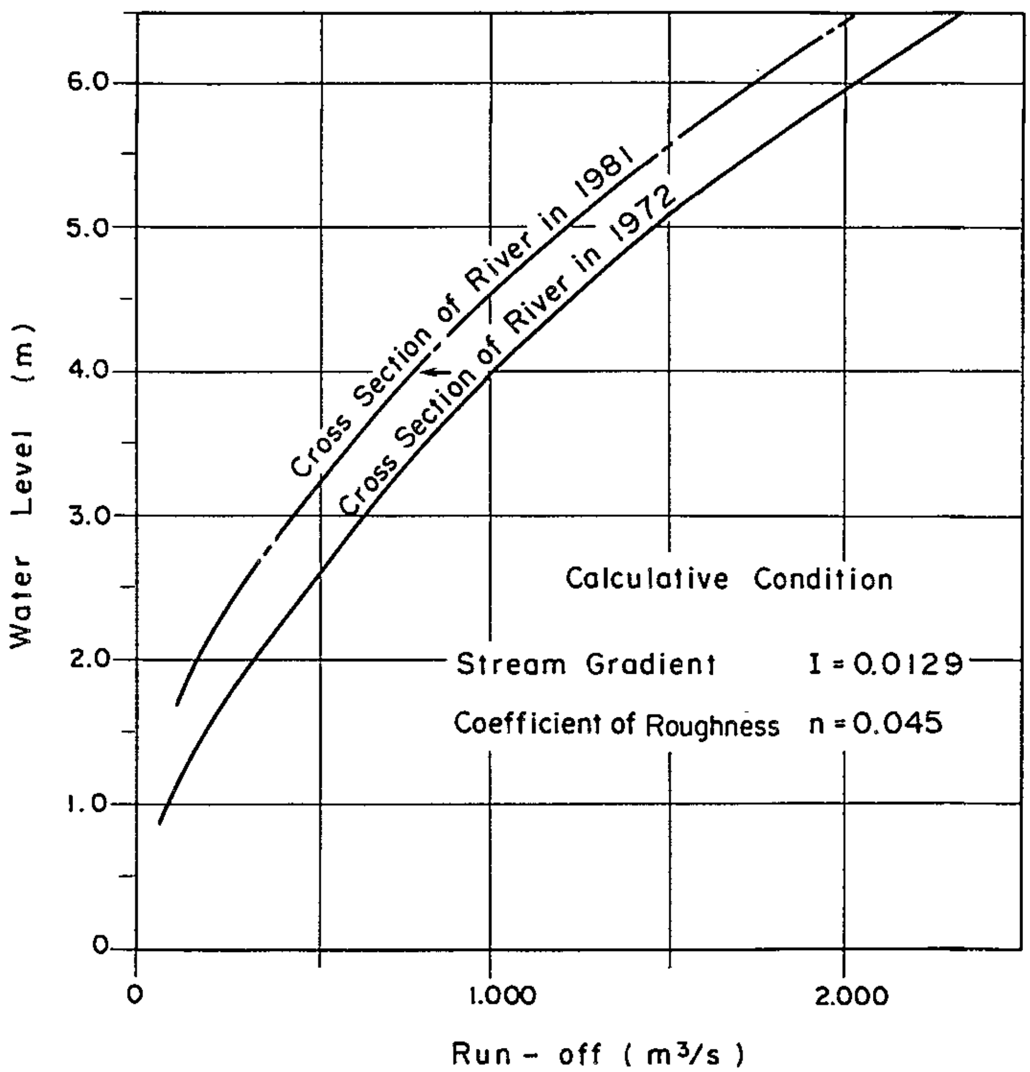
where,

Q : run-off, m^3/s
A : cross-sectional area of flow, m^2

Calculations of rating curves were made for the cross sections of 1972 and 1981. Discharges at times of past annual maximum water levels were determined by interpolation by time between these two curves. The results are given in Fig.5-15.

$$Q_n = (Q'_{72} - Q'_{81})\ (n - 1972)/9 + Q'_{72}$$

Fig. 5-15 Rating Curve at Chillcara Gauging Station
(uniform flow ; Manning Formula)



(2) Rating Curve for High-Water

The observed discharges at times of relatively high water level of 2.0 m and higher were used to establish the rating curve considering high-water.

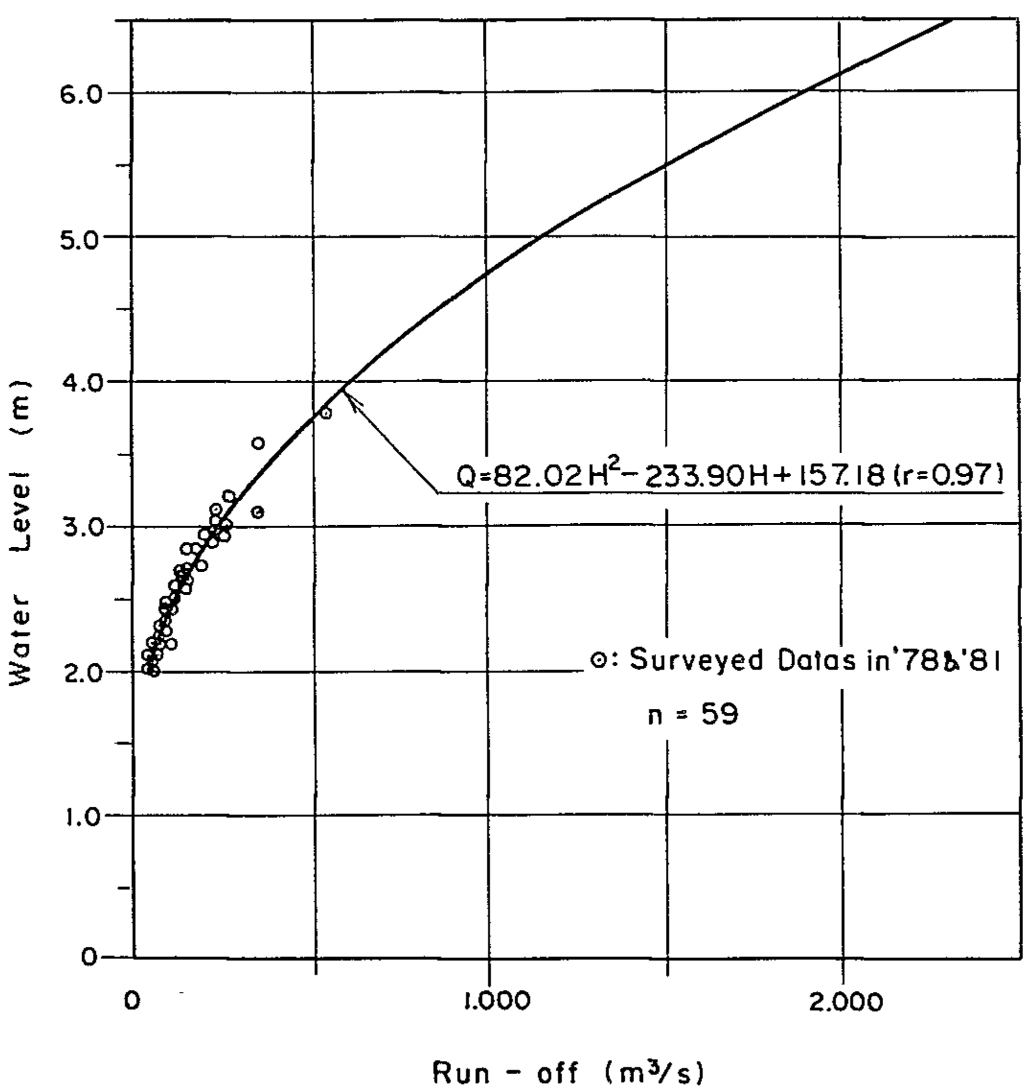
Samples used totaled fifty-nine (59) for the years 1978 and 1980, with the maximum water level 3.79 m.

The rating curve equation is given below.

$$Q = 87.02H^2 - 233.90H + 157.18 \qquad \gamma = 0.97$$

Fig. 5-16 Rating Curve at Chillcara Gauging Station (Calculated by Method of Least Squares from Surveyed Data)

$H \geqq 2.0$ m



The results of the two methods are given in Table 5-9.

Table 5-9 Past Annual Maximum Flood Discharge

Date of Occurrence	Observed Water Level (m)	Annual Maximum Flood Discharge (m^3/s)	
		by Manning Formula	by Rating Curve
9, Feb. 1973	3.44	800	390
14, Feb. 1974	4.82	1,350	1,060
22, Feb. 1975	5.40	1,620	1,440
12, Feb. 1976	4.10	960	660
7, Feb. 1978	6.00	1,850	1,890
28, Jan. 1979	6.00	1,820	1,890
1, Jan. 1980	3.60	660	450
10, Feb. 1981	4.60	1,040	930

5.6.2 Calculation of Flood Discharge

The flood discharge used for design was obtained by probability calculations.

Probability calculations were studied from the two aspects of determination using Chillcara Gauging Station data and the data of Villamontes Gauging Station and La Paz Gauging Station (in Argentine territory), and computed by the Gumbel technique.

(1) Method of Determination from Chillcara Gauging Station Data

Table 5-10 gives the probability flood discharges calculated with the maximum flood discharges for various return periods calculated in 5.5.1 as samples.

Table 5-10 Probability Flood Discharge at Project Site

(Unit: m^3/s)

Case	Return Period (Years)			
	5	10	100	1,000
by Manning Formula	1,750	2,110	3,240	4,350
by Rating Curve	1,720	2,180	3,640	5,070

To compare the two cases, whereas the values of samples calculated using the Manning formula were higher as a whole in Table 5-9, the trend was reversed for return periods of 5 years and longer with the method applying the extended rating curve considering high water obtained in actual measurements, to result in larger flood discharges.

(2) Method of Determination Using Villamontes Gauging Station and La Paz Gauging Station

Calculations of probability flood discharges were first made for the Villamontes Gauging Station site.

A total of 35 samples were used, 18 for Villamontes Gauging Station for the periods 1942 to 1956 and 1976 to 1978, and 17 for La Paz Gauging Station for the periods 1961 to 1975 and 1979 to 1980.

Conversion of measurements at La Paz Gauging Station to figures for Villamontes Gauging Station were made by the equation below.

$$Q_{Vi} = Q_{LP} \times \sqrt{\frac{CA_{Vi}}{CA_{LP}}} = 0.924 Q_{LP}$$

where,

Q_{Vi} : Villamontes Gauging Station daily average run-off, m^3/s

Q_{LP} : La Paz Gauging Station daily average run-off, m^3/s

CA_{Vi} : Villamontes Gauging Station catchment area, 82,000 km^2

CA_{LP}: La Paz Gauging Station catchment area, 96,000 km^2

The conversion from daily average run-off to peak run-off was done by Fuller's formula.

$$Q_{MaxVi} = Q_{Vi} \times \left(1 + \frac{2.66}{CA^{0.3}}\right) = 1.0893$$

The probability flood discharges of the Villamontes Gauging Station site calculated by the above two methods are shown in Table 5-11.

Table 5-11 Probability Flood Discharge at Villamontes G.S

(Unit: m^3/s)

Return Period (Years)			
5	10	100	1,000
2,320	2,800	4,300	5,770

The flood discharges of the projected dam site were obtained by the equation below.

$$Q_P = Q_{MaxVi} \times \sqrt{\frac{CA\ (dam\ site)}{CA\ (Villamontes)}} = 0.73\, Q_{MaxVi}$$

where,

CA (projected site) : 43,640 km^2
CA (Villamontes) : 82,000 km^2

Table 5-12 Probability Flood Discharge at Project Site

(Calculated by data collected at Villamontes G.S and La Paz G.S)

Return Period (Years)			
5	10	100	1,000
1,700	2,050	3,140	4,220

The calculation results were not very much different from the values obtained from Chillcara Gauging Station data, and slightly on the small side.

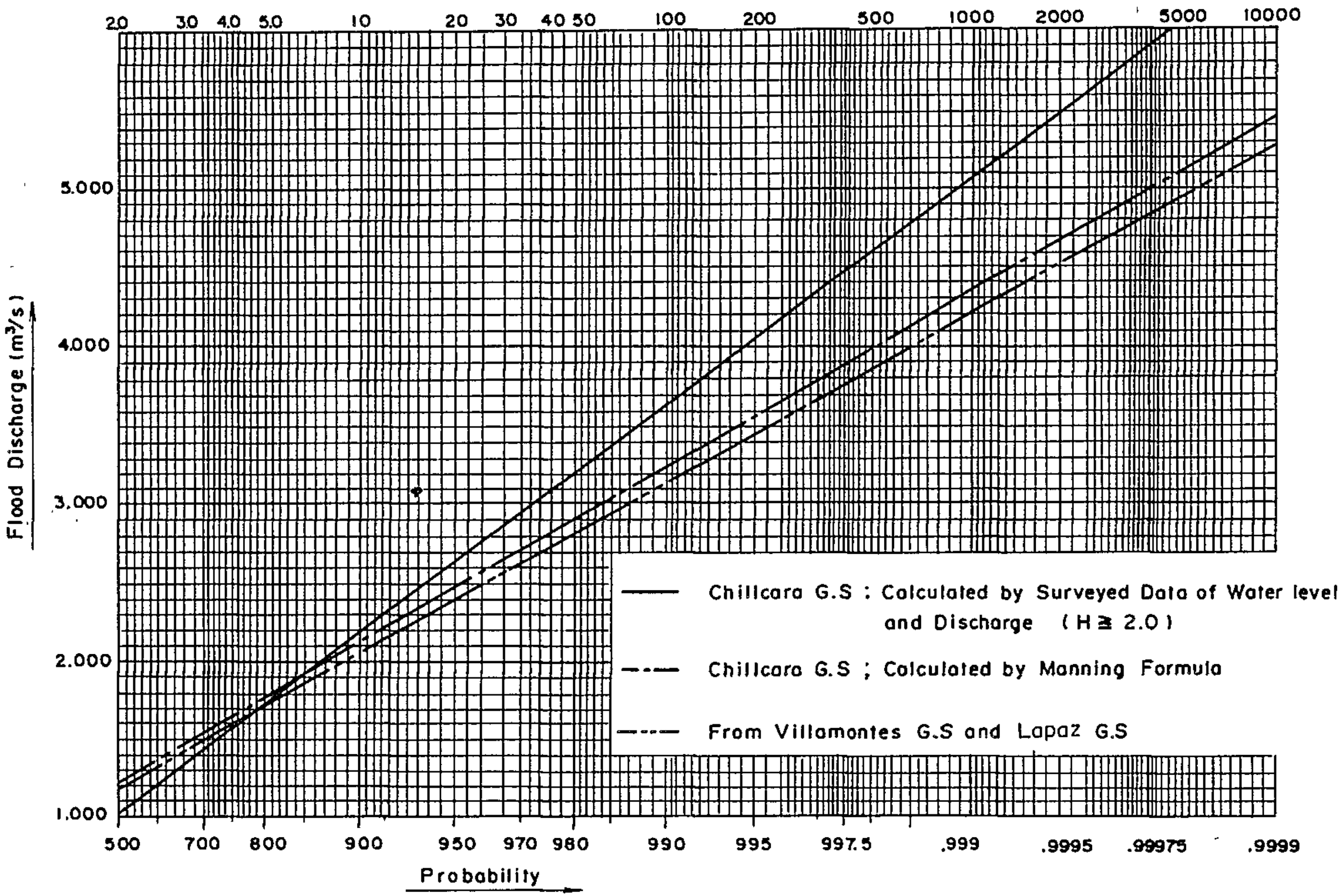
The results of the above are shown in Fig. 5-17.

5.6.3 Design Flood Discharge

For the design flood discharge of the Project, the value adopted was that from the method of determination based on the rating curve according to Chillcara Gauging Station measurements which gave the higher results of the methods studied in 5.6.2.

The design flood discharge for the dam was taken to be 5,100 m^3/s corresponding to a 1,000 year return period, while for the diversion tunnel, it is to be taken as 1,800 m^3/s corresponding to a return period of 5 years.

Fig. 5-17 Flood Discharge at the Project Dam Site (Gumbel Method)



5.7 Sedimentation

A regulating pond or a reservoir is created by constructing a dam across a natural stream, and in such case the phenomenon of sediment is unavoidable.

The sedimentation data submitted by ENDE to the Survey Mission were those on the relation between river run-off and sediment transported for the two periods of February to April 1980 and December 1980 to May 1981 measured by ENDE (see APPENDIX-I, Fig.A-I-2).

Although it is difficult to obtain an accurate figure on sedimentation because the periods of measurement were short and were in the rainy season, it is estimated according to the above sedimentation data that the sediment inflow to the dam will be of the order of one million to ten million m^3 (10^6 to 10^7 m^3) annually, and in case of a flood of around 1,000 m^3/s corresponding to the annual maximum, it is thought approximately 1.5 to 2.0 million m^3 of sediment will flow in all at once.

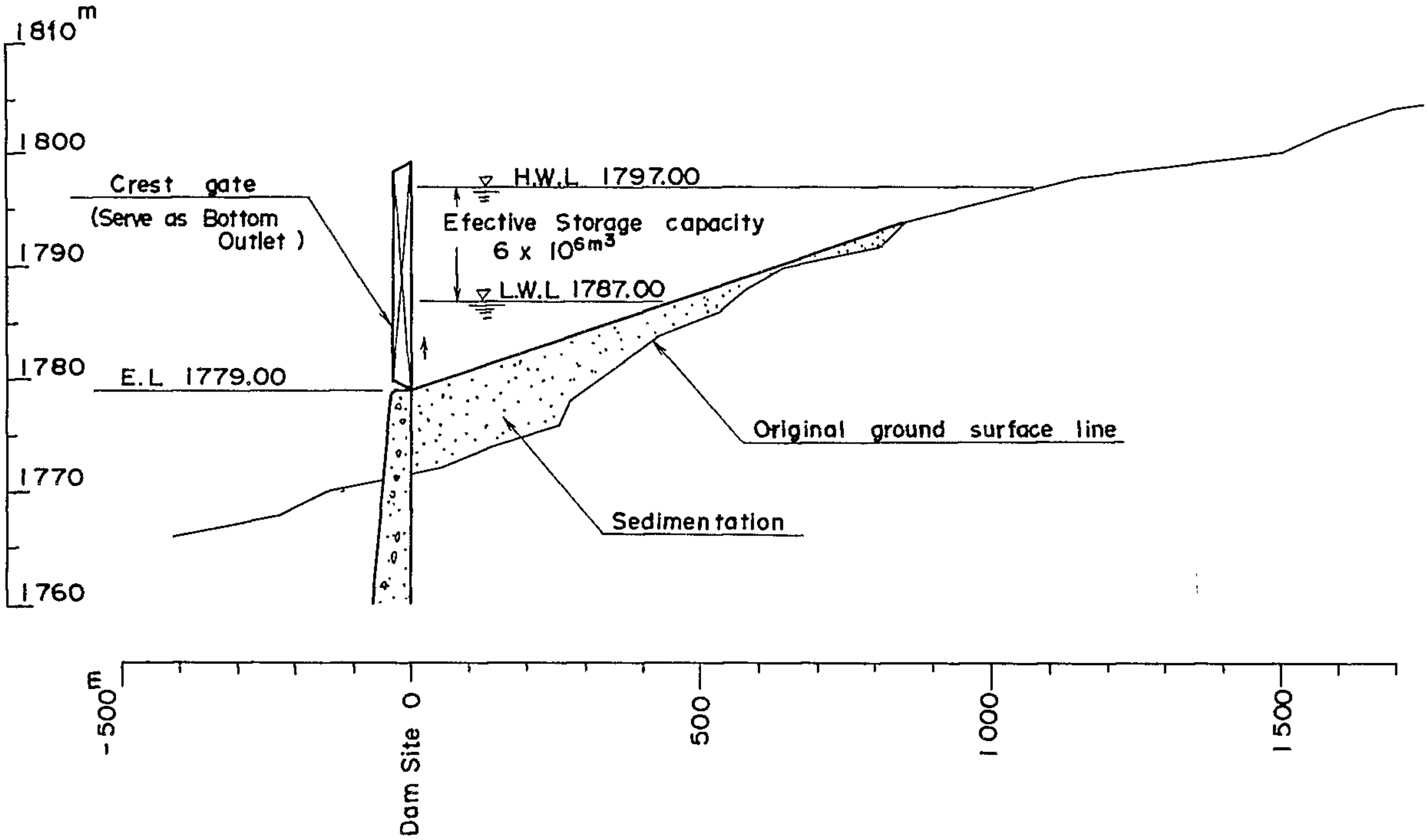
Consequently, practically all of the sedimentation occurs in the rainy season and it is thought the quantity supplied by flood will be especially large.

In contrast, necessary effective storage capacity of the Pilaya Project will be 600 thousand m^3 (see Chapter 7, Hydro Power Generation Plan).

As described above, the inflow of sediment at the dam is far larger compared with the effective storage capacity required for the power generation scheme. Consequently, it will be necessary for sand-flush facilities to be provided at the dam. Fig.5-18 shows the longitudinal profile of the regulating reservoir of the dam, and indicates the relation between sedimentation and capacity.

With regard to the structure of the dam it will be discussed in Chapter 7, Hydro Power Generation Plan, and in case the overflow crest of the spillway gates (used concurrently for sand flushing) is made EL 1,779 m, the sediment in the regulating reservoir would be flushed downstream by opening the spillway gates. Consequently, the capacity of the regulating reservoir is secured by effectively utilizing the spillway gates.

Fig. 5 – 18 Profile of Regulating Reservoir



CHAPTER 6

GEOLOGY

CHAPTER 6 GEOLOGY

CONTENTS

TABLE LIST

FIGURE LIST