EMPRESA NACIONAL DE ELECTRICIDAD S.A.

REPUBLICA DE BOLIVIA

PROGRESS REPORT OF FEASIBILITY STUDY ON PILAYA HYDROELECTRIC POWER PROJECT

MARCH 1980

JAPAN INTERNATIONAL COOPERATION AGENCY

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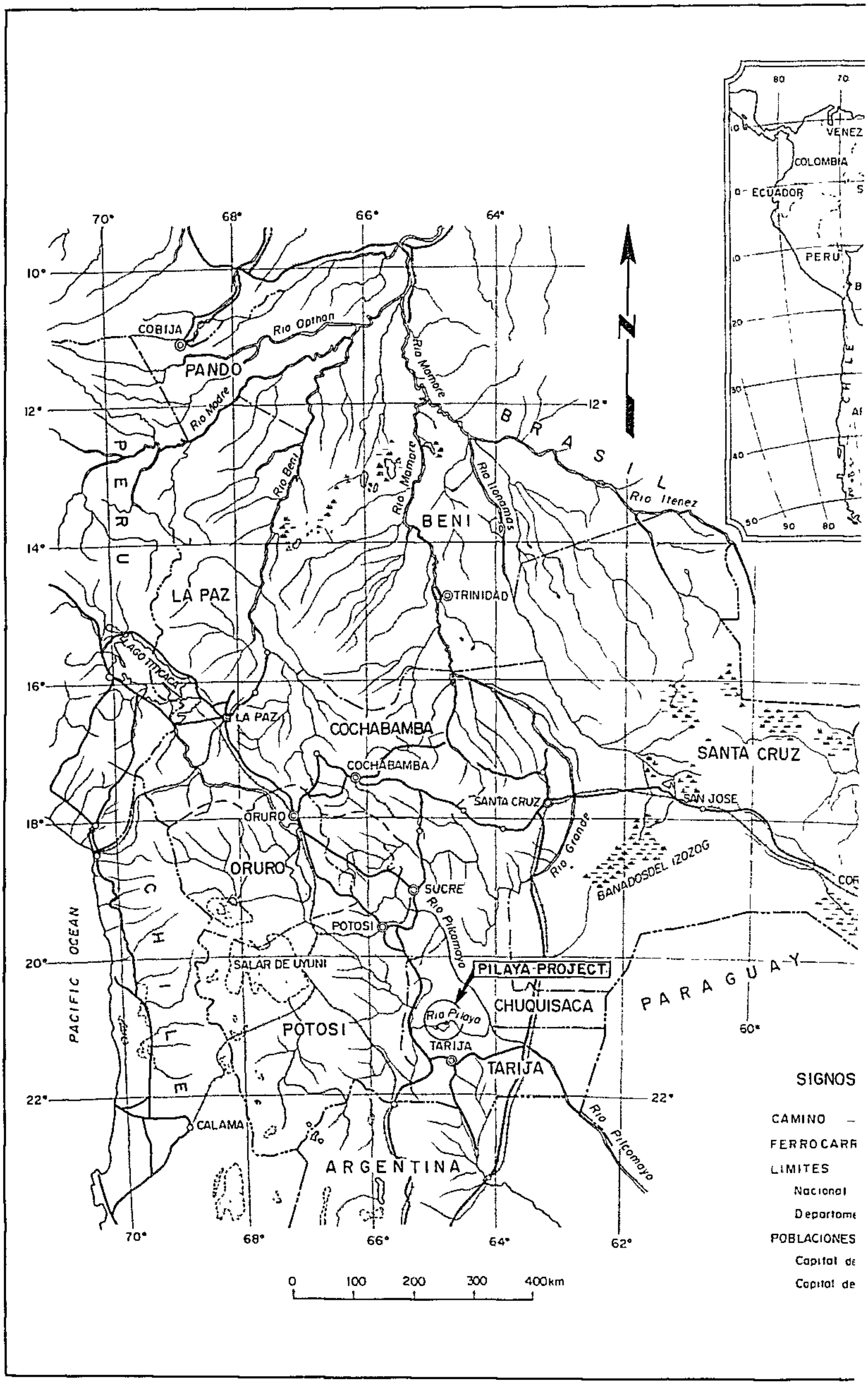
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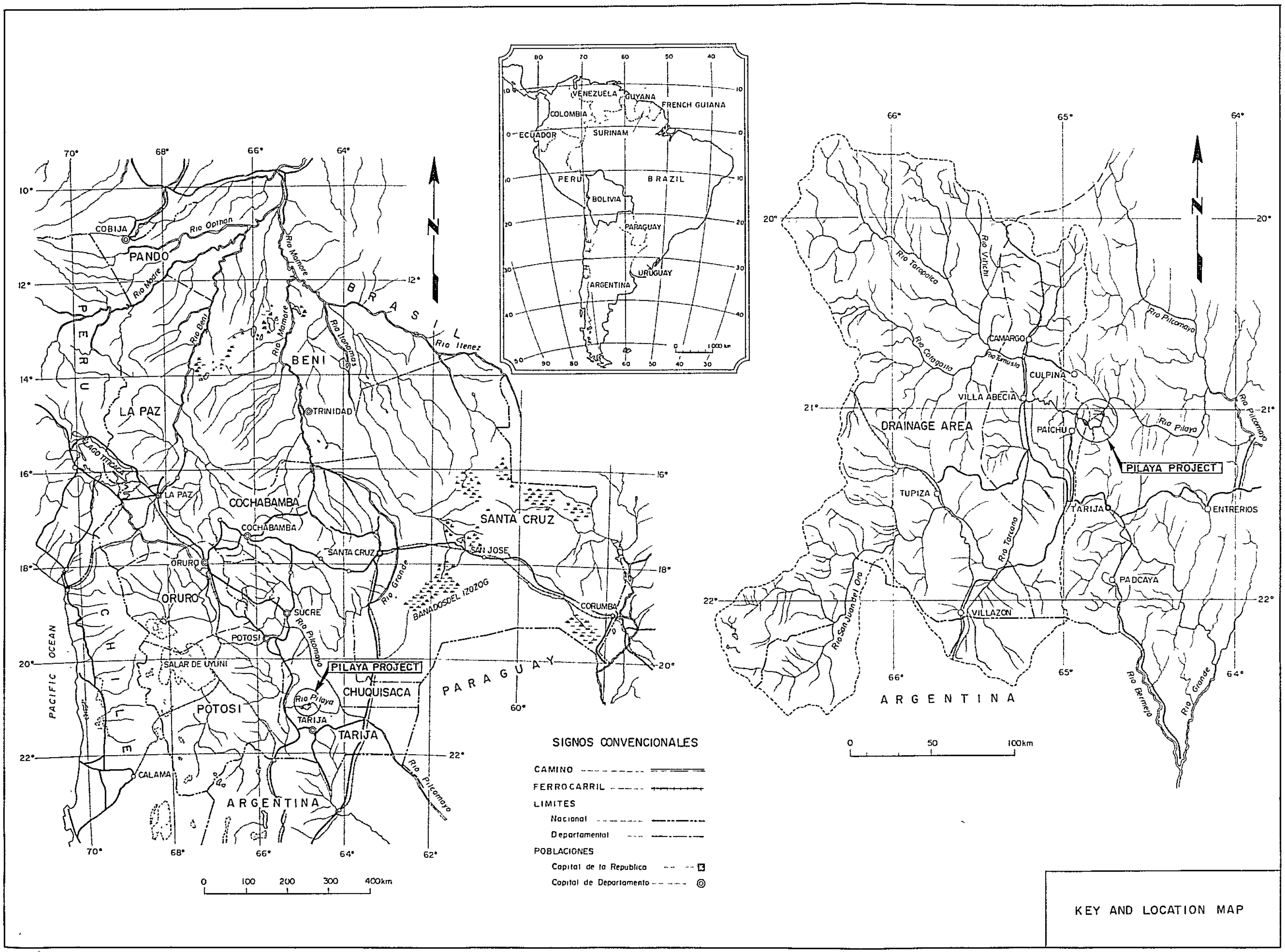

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CHAPTER 1. INTRODUCTION

1.1 Background

The demand for electric power in the Republic of Bolivia has been growing at 8% per year, which is a relatively high pace, and the Departamento de Tarija and Potosi, which are in the southern part of Bolivia, also have high growth rates in demand, especially from the residencial and industrial categories including mining and food oil industries. To meet this increasing demand for power, the Government of the Republic of Bolivia has been applying much effort to the development of power sources such as hydroelectric power stations, diesel power stations and gas turbine power stations.

Both Tarija and Potosi areas also need development of additional power sources. Empresa Nacional De Electricidad S.A. (ENDE), with cooperation from the United Nations, planned the Pilaya Hydroelectric Project on the mid-stream of the Rio Pilaya. They presented two alternative schemes for the project, the Huacata scheme and the Aguas Calientes scheme.

In 1977, ENDE requested of the Government of Japan through the Government of the Republic of Bolivia to evaluate the above two schemes and to carry out a feasibility study on the scheme chosen as the more favorable one.

In compliance with this request, the Government of Japan commissioned Japan International Cooperation Agency (JICA) to verify the necessity for conducting a feasibility study on the project. For that purpose JICA sent three specialists in geology, economics and civil engineering to Bolivia for 24 days from January 29 to

February 11, 1978 and submitted a preliminary report to the Japanese Government in March, 1978. On the basis of the recommendations in the preliminary report, the Japanese Government then dispatched through JICA a 4-member survey team made up mostly of engineers from Electric Power Development Co., Ltd. (EPDC) for 34-day long field investigations from September 26 to October 29, 1979 in order to collect information necessary for comparisons between the Huacata scheme and the Aguas Calientes scheme, and to plan geotechnical investigations scheduled for 1980.

Since returning home from Bolivia, the survey team has examined the collected information and data and prepared this Interim Report.

1.2 Existing Reports

The Pilaya Hydroelectric Project was conceived by ENDE with assistance from the United Nations and supplemented by some field investigations. In connection with the project, the following reports have been made since 1973:

(1) PROYECTOS HYDROELECTRICOS EN EL RIO PILAYA (ENDE), JUN., 1973

(2) PLANTA HIDROELECTRICA PILAYA; ESTUDIO DE PREFACTIBILIDAD, ABRIL, 1978

1.3 Purpose and Scope of The Report

The purpose of this report is to choose the more favorable one between the two schemes for the project, the Huacata scheme and the Aguas Calientes scheme, both presented in April, 1978 by ENDE and the United Nations together and to prepare geotechnical investigation program for the selected scheme.

The technical assistance for the above geotechnical investigations and the second stage of the feasibility study are scheduled for 1980.

1.4 Investigations and Studies

1.4.1 Field Investigations

Field investigations for this project were made for 34 days, from September 26 to October 29, 1979, by the survey team with the help of ENDE and the Bolivian Air Force.

1.4.2 Members of Survey Team

The survey team which undertook the field reconnaissance and data collection consisted of the following members:

Toshio Enami, EPDC	:	Leader; Superintendence
Masaru Tateishi, JICA	:	Coordination
Junichi Asano, EPDC	:	Civil engineering planning
Mamoru Yamada, EPDC	:	Geology

1.4.3 Survey Schedule

No.	Date	Journey	Stay	Activities
	Sep. '79			
1	26	Tokyo → Lima	Lima	Trip
2	27		Lima	Trip
3	28	Lima → La Paz → Cochabamba	Cochabamba	Trip
4	29		Cochabamba	Meeting with ENDE
5	30		Cochabamba	Meeting
	Oct. '79			
6	1		Cochabamba	Meeting with ENDE
7	2	Cochabamba → Tarija	Tarija	Trip
8	3		Tarija	Visiting the site by helicopter
9	4	Tarija → Cochabamba	Cochabamba	Trip
10	5		Cochabamba	Data collection and meeting
11	6		Cochabamba	Data collection and meeting
12	7		Cochabamba	Data collection and meeting
13	8		Cochabamba	Data collection and meeting
14	9	Cochabamba → Tarija	Tarija	Trip
15	10	Tarija → Aguas Calientes	Aguas Calientes	Field survey at Aguas Calientes
16	11		Aguas Calientes	Field survey at Aguas Calientes
17	12	Aguas Calientes → Huacata → dam site	dam site	Field survey at Huacata and dam site
18	13		dam site	Field survey at dam site
19	14	dam site → Tarija	Tarija	Field survey at dam site
20	15		Tarija	Data collection
21	16		Tarija	Data collection
22	17	Tarija → Cochabamba	Cochabamba	Trip
23	18		Cochabamba	Data collection
24	19		Cochabamba	Visiting Corani Power Plant and Santa Izabel Power Plant
25	20	Cochabamba → Santa Cruz	Santa Cruz	Visiting Santa Cruz Gas Turbine Power Plant
26	21	Santa Cruz → Cochabamba	Cochabamba	Trip
27	22		Cochabamba	Data collection
28	23		Cochabamba	Data collection
29	24		Cochabamba	Meeting with ENDE
30	25	Cochabamba → La Paz	La Paz	Trip
31	26		La Paz	Visiting the Japanese Embassy and the Department of Energy, Meeting
32	27	La Paz → New York	New York	Trip
33	28	New York →	in flight	
34	29	→ Tokyo		

1.4.4 Work in Japan

After coming back from Bolivia, the survey team examined the findings of the field investigations and the collected data together with EPDC's technical staff and under the direction of the team leader from November 1979 to March 1980 at the head offices of EPDC, Tokyo. This report is the fruits of the many efforts including: review of hydrological data, analysis of geological data, preliminary design, construction cost estimate, planning of geotechnical investigations.

1.5 Basic Data

Among the information and data concerned with this project supplied by ENDE and the Bolivian Government's agencies concerned the principal ones are shown below:

(1) Hydrometeorological and sedimentation data
Measurements in and around the project area, including temperature, humidity, precipitation, run-off and suspended load etc.

(2) Topographic maps
Topographic maps of the project area
(Scale: 1/250,000; 1/50,000; 1/10,000; 1/1,000)

(3) Data for cost estimate

(4) Geological information

(5) Power demand data

(6) Information on energy development projects

(7) Data of social and economical situations

CHAPTER 2. CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

(1) Our comparative study of the two alternative schemes, Huacata and Aguas Calientes, for the Pilaya Hydroelectric Project, shows that the Aguas Calientes scheme is the more favorable.

(2) Our surface reconnaissance of geology at the possible dam site and powerhouse site and along possible headrace tunnel route did not reveal major adverse conditions for either scheme.

(3) The construction cost per kW and the energy cost per kWh are US$1,505 and US$0.027 for the Huacata scheme and US$1,424 and US$0.024 for the Aguas Calientes scheme, which shows that the Aguas Calientes scheme is more economical.

(4) According to the latest forecast of power demand by ENDE, it is judged reasonable to add a capacity of 90 MW around the end of 1992. The power demands and project timings shown in Fig. 4.1 should be subjected to a re-examination in the second stage of the feasibility report.

2.2 Recommendations

Based on these conclusions, the following recommendations are made:

(1) To serve the second stage of the feasibility study on the selected Aguas Calientes scheme, hydrological and meteorological observations should be done for precipitation, suspended load, run-off and water level of river, as described in sub-section 4.2.6.

(2) Geotechnical investigation should be executed as shown in Chapter 5.

(3) In the second stage of the feasibility study general review should be made on the project, including optimization study of dam type and height and power output.

CHAPTER 3. BASIC CONCEPT OF THE PROJECT IN THE PREFEASIBILITY REPORT

This chapter presents a brief review of the basic concept of the project proposed in the Prefeasibility Report prepared by ENDE and the United Nations.

3.1 Location and Description of The Project Area

3.1.1 Location of The Project Area

The Pilaya Hydroelectric Project will utilize hydraulic potential existing in the middle reaches of the Rio Pilaya running eastward in the southern part of Bolivia by constructing a dam to divert water into a power station through a headrace tunnel. The drainage area of the project is located in latitude 19°35' to 22°38' S and longitude 64°32' to 67°06' W, covering an area of 43,640 km^2. Major structures such as the dam and powerhouse will be situated about 50 kilometers north of Tarija, the capital of Departamento de Tarija.

3.1.2 Description of The Project Area

The Rio Tumusla and the Rio San Juan del Oro join to form the Rio Pilaya. The Tumusla rises from the south of the Frailes Mountains and flows along the Altiplano. The headwaters of this river, called the Rio Yura, is in a mountainous area 5,000 meters above sea level, running southeastward, and changes its course southward suddenly near Palca Grande continuing to join the Rio San Juan del Oro at a point 2,200 meters above sea level. The Rio San Juan del Oro, rising from the Chocaya Mountains with peaks 5,700 m above sea level, flows northward to meet the Rio Tumusla.

From the junction, the Rio Pilaya, in turn, extends about 200 kilometers eastward to join the Rio Pilcomayo, a tributary of the Rio La Plata, which is the second largest of the South American Continent.

In its upper reaches the Rio Pilaya has an average gradient of about 3‰, which is relatively gentle, but with rather steep slopes on both banks. In the mid-stream where a dam will be constructed, the average gradient is as steep as 20‰ and the valley is so narrow as to form a gorge very difficult of access. Farther in the downstream, the gradient is gentle, ranging from 4‰ to 7‰ and the river width becomes greater gradually.

The drainage area of the Rio Pilaya stretches over three Departamentos: Potosi, Chuquisaca and Tarija, in the south of Bolivia, covering an area of 47,440 km at the confluence with the Rio Pilcomoyo.

The drainage area has rainfall of 200 mm in the western area and 450 mm in the northern area, averaging 300 mm. 70% to 80% of the rainfall occurs during the rainy season from December through April, and little rain during the dry season from May to November. In and around the project area, the annual average temperature is about 20°C and the annual average humidity about 40%.

Sedimentary rocks such as quartzite, sandstone, shale and mudstone said to be Ordovician are widely distributed in the catchment area including the project area to compose their basement. The catchment area is located geographically in Las Cordilleras Central and Las Cordilleras Oriental, while the

geological structure is that of a faltengebirge having a fold axis in the north-south direction.

The project area presents a topography of the stage of youth to the stage of maturity. The mountain slopes along the Rio Pilaya and its tributaries are steep with extensive distribution of rockfalls and slopewash indicative of remarkable erosion.

3.2 Description of The Basic Concept of The Project

Preliminary studies have been made on some possible sites for the Pilaya Hydroelectric Project. In 1978, ENDE and UN worked together for prefeasibility study on both the Huacata and Aguas Calientes schemes shown in Fig.-3.1, presenting the results in the report "PLANTA HIDROELECTRICA PILAYA; ESTUDIO DE PREFACTIBILIDAD ABRIL 1978". This report concludes that the Aguas Calientes hydroelectric project is more economical although both projects are feasible.

Those two schemes are described in the succeeding sections and their main features are shown in Table-3.1.

3.2.1 Huacata Hydroelectric Scheme

This scheme proposes construction in the mid-stream of the Rio Pilaya of a 60 m high arch dam to create a pondage of an effective storage of about $1.8 \times 10^6 m^3$ for daily regulation of the stream flow. Water in the pondage will be conducted through a headrace tunnel, 6.3 km long and 3.2 m in inside diameter, into an underground powerhouse to be located on the left bank of the Rio Pilaya, and then, after generation, will be discharged into that river.

The powerhouse will have four Francis turbines - generators to produce electricity at a maximum output of 60 MW with an effective head of 267 m and a maximum discharge of 26 m^3/sec. Annual power production will be 368 GWh, 212 GWh during the rainy season and 156 GWh during the dry season.

The construction cost is estimated at US$54.4 x 10^6.

3.2.2 Aguas Calientes Hydroelectric Scheme

This scheme locates the powerhouse farther downstream than the Huacata scheme without changing the location of the dam. The scheme proposes a headrace tunnel, about 10.8 km long and 3.1 m in inside diameter to conduct water in the regulating pondage into a surface powerhouse to be located on the left bank of the Rio Pilaya.

The powerhouse will generate at a maximum output of 90 MW with three Francis turbines - generators, utilizing an effective head of 439 m and a maximum discharge of 24 m^3/sec. Annual power production will be 579 GWh, 322 GWh during the rainy season and 257 GWh during the dry season.

The cost of construction is estimated at US$70.6 x 10^6.

Table-3.1 Main Features of the Project

Features	Unit	Huacata	Aguas Calientes
Type of Development		Divided-fall Type	
Annual Inflow	$10^6 m^3$	1,340	
Pondage and Dam			
Normal Water Level	m	1,791	
Dam Type		Arch concrete	
Height x Crest Length	m	59.50 x 140.00	
Volume	m^3	43,900	
Headrace Tunnel			
Section		Circular	Circular
Diameter x Length	m, m	3.2 x 6,330	3.1 x 10,800
Effective Head	m	267	439
Maximum Available Discharge	m^3/sec	26	24
Installed Capacity	KW	60,000	90,000
Annual Energy Production	GWh	368	579
Rainy Season (Nov. ∿ Mar.)	GWh	212	322
Dry Season (Apr. ∿ Oct.)	GWh	156	257
Construction Cost	10^6US$	54.4	70.6

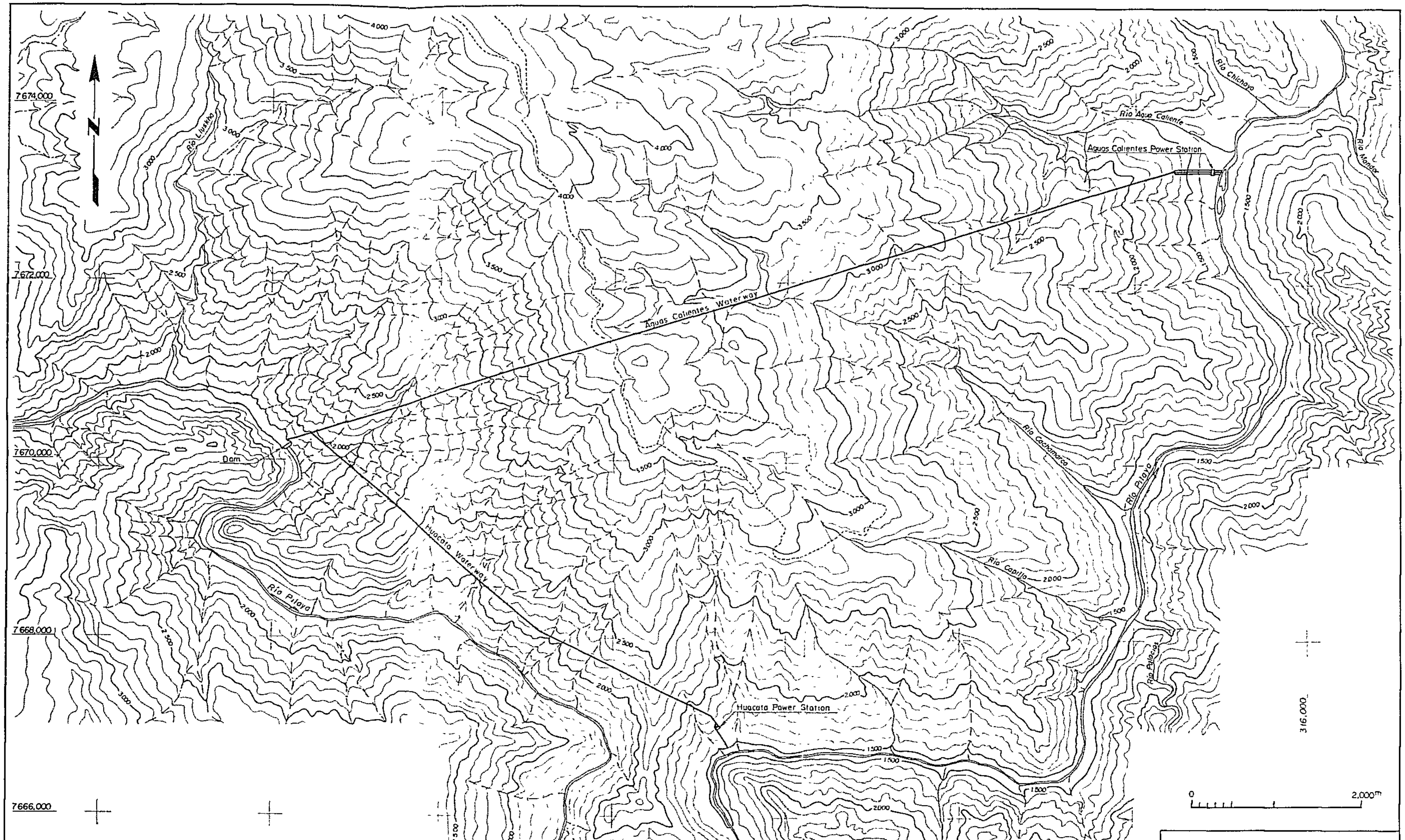


FIG. – 3. 2

ALTERNATIVE PLAN

CHAPTER 4 COMPARATIVE STUDY ON ALTERNATIVE SCHEMES OF THE PROJECT

In this chapter, comparative study is made to choose the more advantageous one out of the two schemes, Huacata and Aguas Calientes, from a technical and economical point of view. In proceeding to this study, review was made of the Prefeasibility Report prepared by ENDE and the United Nations, making reference to the findings of our field investigations, and the information and data that the survey team obtained in Bolivia. The review has found that the said Prefeasibility Report is considered to be reasonable only judging from the available hydrological and meteorological data, topographical maps, the results of the site survey including the geological survey and other available information.

The items of the study made in this Chapter as well as the items to be studied in the future are described as follows.

4.1 Balance of Power Demand and Supply and Development Schedule

The total power capacity in Bolivia was 457 MW at the end of 1978. The growth rate of power demand from the end of 1967 to that of 1978 was 7% per year, and for the last five years, the power demand has increased at 8% per year. According to the forecast by ENDE the power demand will continue to increase at the same rate in the future and the power demand in 1990 will be 1,930 GWh in energy and 678 MW in maximum power.

In order to cope with the increasing power demand, hydroelectric and thermal power plants as shown in Table-4.1 are under construction by ENDE.

Table-4.1 Generating Facilities Under Construction in Bolivia

Name of Power Plant	Installed Capacity (MW)
Corani Hydroelectric Power Station	27.0
Sta. Isabel Hydroelectric Power Station	18.0
Sta. Cruz Gas Turbine Power Plant	22.1
Tarija Diesel Power Plant	1.2

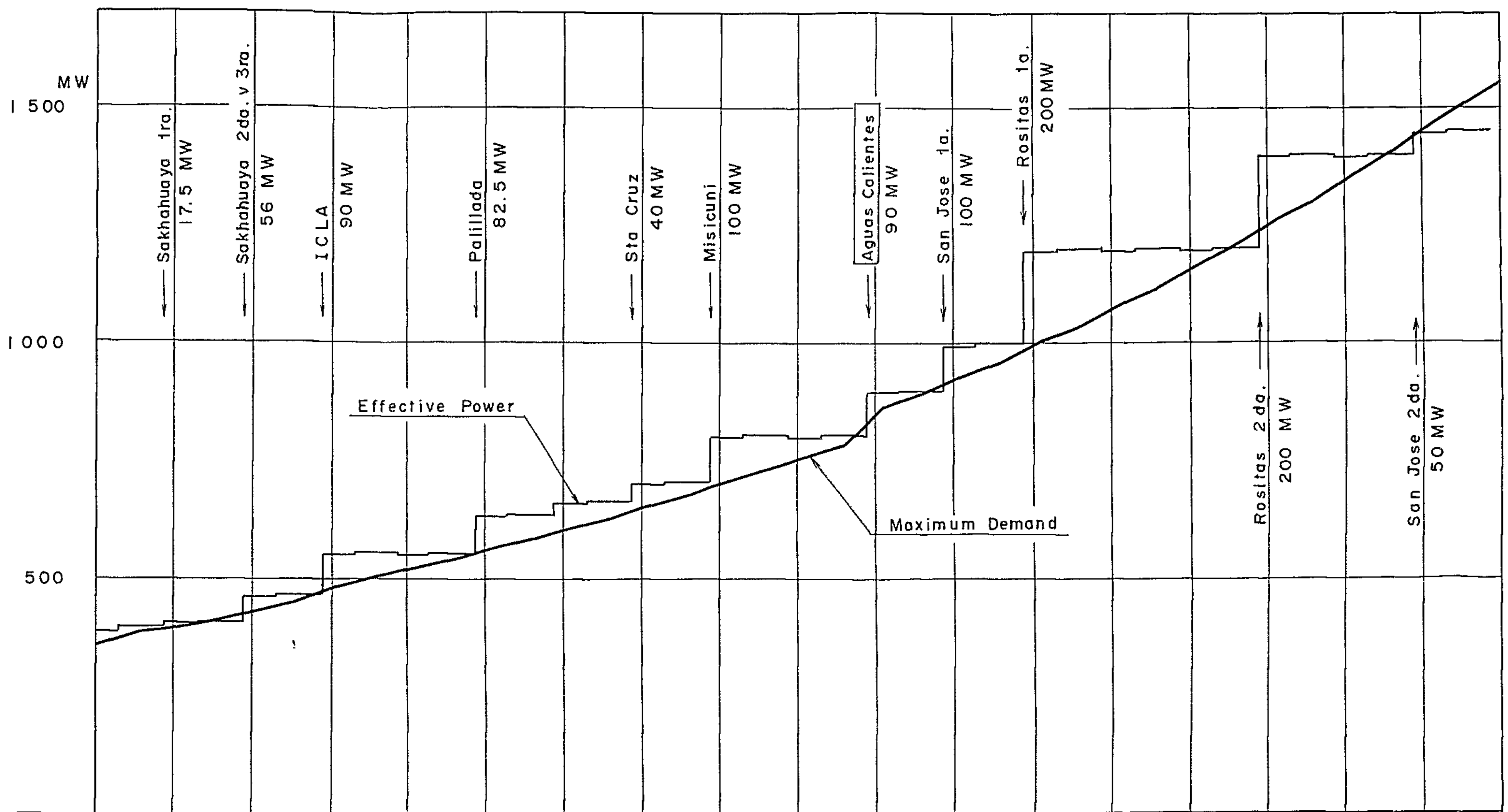
The power plants that ENDE envisages to construct are shown in the following Table-4.2.

Table-4.2 Generating Facilities to be Constructed in Bolivia

Name of Power Plant	Installed Capacity (MW)
Sakahuaya	50
Icla	90
Palillada	82.5
Misicuni	100
Aguas Calientes	90
San José	150
Rositas	400

According to the balance of power demand and supply estimated by ENDE shown in Fig.-4.1, the Aguas Calientes power station is scheduled to be in commission at the end of 1992.

Fig.-4.1 Estimated Maximum Demand and Installed Capacity of Entire Power System



Year	Maximum Demand (MW)		Maximum Available Capacity (MW)	
1983	366.5	389.5	387.0	389.6
1984	399.3	413.6	404.5	407.1
1985	436.5	452.0	460.5	463.1
1986	483.9	500.8	550.5	553.1
1987	522.0	540.2	550.5	553.1
1988	562.7	582.5	633.0	635.6
1989	607.2	628.4	660.5	663.1
1990	655.1	677.8	700.5	703.1
1991	706.6	731.2	800.5	803.1
1992	762.2	788.8	800.5	803.1
1993	863.0	891.6	895.5	898.1
1994	930.4	961.0	995.5	998.1
1995	1 003.2	1 036.4	1 195.5	1 198.1
1996	1 081.7	1 117.5	1 195.5	1 198.1
1997	1 166.4	1 205.1	1 195.5	1 198.1
1998	1 257.8	1 299.6	1 395.5	1 398.1
1999	1 356.6	1 401.7	1 395.5	1 398.1
2000	1 463.2	1 511.9	1 445.5	1 448.1

4.2 Hydrology

The hydrological analysis made in the Prefeasibility Report was reviewed as follows.

4.2.1 Precipitation Observatory and Run-off Gauging Station

The precipitation data of the 33 observatories which were selected out of 45 observatories located in the basin and which could provide records for more than 5 years, were used for the hydrological analysis in the Prefeasibility Report. There are two run-off gauging stations: one is the Chillcara gauging station on the Rio Pilaya and the other is the Villamontes gauging station on the Rio Pilcomayo. The locations of these observatories and gauging stations are indicated in Fig.-4.2.

4.2.2 Precipitation

In order to estimate run-off from precipitation data the following studies were made in the Prefeasibility Report: however, the estimated run-off data is not completely reliable for the following reasons.

- The record period of the gauging stations is rather short for studying the relations between precipitation and run-off in the drainage area.
- The precipitation observatories (45 places) are small in number compared with the drainage area of 43,640 km^2.
- The distribution of the observatories installed in the drainage area is not adequate.

(1) Analysis of Precipitation Data

Logarithmic normal distribution method and double mass curve method were used to verify the reliability and homogeneity of precipitation data. The study results are in general judged satisfactory.

(2) Supplementing Precipitation Data

In order to supplement annual and monthly precipitation data, correlations between data of long-period observatories and those of short-period ones were studied. The correlation coefficients were in between 0.80 and 0.95, showing some degree of correlationship.

(3) Average Precipitation in Drainage Area

The average precipitation in the drainage area was estimated by means of the Thiessen method, a Sub-basin method and Isohyetal method. The results are shown in Table-4.3. However, the average precipitation estimated by the Isohyetal method was excluded from this study because the available data was insufficient for this method.

Table-4.3 Mean Precipitation in the Basin

Unit: mm

Year	Thiessen			Sub-basin		
	P_{LL}	P_S	P_T	P_{LL}	P_S	P_T
1950/51	276.50	34.00	310.50	276.34	49.22	325.56
52	268.30	56.40	324.70	239.11	50.81	289.92
53	246.30	85.80	332.10	202.43	24.60	227.03
54	318.90	106.80	425.70	255.77	77.09	334.86
55	310.10	54.30	364.40	268.89	82.91	351.80
56	176.20	94.30	270.50	138.66	65.96	204.58
57	216.30	46.30	262.60	184.51	80.07	264.58
58	269.20	74.00	343.20	208.01	49.16	257.17
59	245.70	53.20	298.90	228.74	85.91	314.65
1959/60	307.80	50.80	358.60	254.01	34.64	288.65
61	250.70	47.10	297.80	202.93	51.08	254.01
62	247.20	45.60	292.80	208.02	49.47	257.49
63	348.40	23.90	372.30	267.85	32.53	300.48
64	255.20	53.90	309.10	213.09	36.01	249.10
65	257.00	56.20	313.20	213.96	43.03	256.99
66	189.90	81.00	270.90	179.47	54.95	234.42
67	226.00	28.60	254.60	218.43	89.69	300.38
68	395.40	89.00	484.40	386.96	58.14	445.10
69	189.60	29.90	219.50	160.74	63.98	224.63
1969/70	308.10	25.20	333.30	282.99	41.56	324.55
71	342.60	55.70	398.30	319.85	41.01	360.86
72	311.80	39.60	351.40	279.36	48.14	327.50
73	331.90	37.80	369.70	299.56	55.11	354.67
74	281.60	30.00	311.60	262.43	23.17	285.60
75	345.40	68.60	414.00	330.10	35.40	365.50
76	265.60		281.80	253.26	112.82	366.08
Mean	276.20	54.70	329.50	243.70	55.30	299.00

P_{LL}: Rainy season from December to April

P_S : Dry season from May to November

P_T : Total

4.2.3 Estimation of Run-off at Project Site

(1) Catchment Area

The catchment areas measured at the three points on the basis of a 1/50,000 topographical map are:

i) At Chillcara gauging station : 43,150 km^2

ii) At the proposed dam site : 43,640 km^2

iii) At Villamontes gauging station : 82,000 km^2

There is a residual basin with an area of 490 km^2 between the Chillcara gauging station and the proposed dam site. From the facts that the residual basin is small compared with the drainage area at the proposed dam site and that there is no tributary with a large run-off, the run-off recorded at the Chillcara gauging station can be considered to be identical to that at the proposed dam site.

(2) Analysis of Run-off Data

The verification of the reliability and homogeneity of the run-off data recorded at the Chillcara gauging station was made by the double mass curve method using the run-off and annual mean precipitation in the basin, which was proved to be satisfactory in the Prefeasibility Report.

(3) Supplementing

Supplementation of the run-off records at the Chillcara gaguing station was made by the following two methods:

i) Correlation method between the run-off at the Villamontes gauging station on the Rio Pilcomayo and that at Chillcara gauging station.

ii) Correlation method between the precipitation and the run-off and adjustment of the dry-season run-off by depletion curve.

The river run-off estimated by the methods i) and ii) is indicated in Tables-4.4 and 4.5, respectively.

The run-off obtained by means of the method i) was adopted for the study of this project in the Prefeasibility Report. This is because the scale of hydroelectric projects with a small capacity for flow regulation depends on the dry-season run-off and the smaller run-off can figure out a conservative scale of project.

Table-4.4 Monthly Mean Run-off at Chillcara Gauging Station

(Unit: m^3/sec)

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Mean
1950/51	17.07	27.50	26.84	65.86	104.30	83.33	34.37	23.45	21.84	21.20	18.87	16.96	38.47
52	14.79	25.53	30.38	78.33	101.51	42.34	28.80	18.62	16.39	19.31	16.43	18.43	34.24
53	14.15	16.43	28.33	28.90	116.69	38.76	27.52	19.91	18.49	15.70	13.81	12.96	29.30
54	17.24	27.04	33.01	53.00	206.75	152.02	55.06	24.82	19.58	17.31	16.41	14.31	53.05
55	13.20	27.01	24.57	54.07	225.68	139.00	46.15	22.58	19.61	17.16	15.70	13.97	51.58
56	12.05	12.72	27.54	88.21	158.00	43.65	23.89	19.93	18.62	16.17	15.60	13.60	37.50
57	17.46	26.76	28.77	40.54	123.11	65.73	32.24	25.75	17.66	14.10	9.93	7.40	34.12
58	12.31	18.43	37.78	144.12	115.79	89.34	32.55	22.17	18.06	15.58	11.97	8.80	43.90
59	15.83	23.71	51.80	155.32	228.34	233.56	57.79	23.80	17.03	13.79	10.96	10.96	70.24
1959/60	16.58	22.82	57.31	139.29	314.54	95.98	37.43	27.76	22.82	19.94	15.30	17.24	65.58
61	20.44	22.78	33.10	32.90	69.09	34.87	43.23	19.49	14.77	12.37	15.18	18.93	28.10
62	23.02	28.57	61.92	65.16	69.01	63.83	30.84	20.91	16.13	17.90	17.03	8.53	35.24
63	8.99	10.52	48.99	77.39	204.23	139.99	56.40	23.95	23.49	19.40	16.27	13.79	53.62
64	11.94	15.36	38.57	48.41	46.53	87.76	36.82	25.78	22.26	17.61	14.63	12.28	31.50
65	8.20	18.04	31.31	48.48	57.98	34.86	24.46	20.73	14.86	12.72	9.75	9.57	24.25
66	8.00	12.37	36.57	58.32	50.48	41.90	28.58	21.86	14.93	11.15	8.78	7.40	25.12
67	12.24	13.60	50.29	33.03	73.08	100.36	26.22	17.28	15.54	10.40	8.40	7.40	30.65
68	16.33	20.93	42.43	62.16	353.90	90.54	58.36	22.58	20.90	18.84	18.07	14.33	61.61
69	18.41	30.69	42.99	60.28	90.59	28.72	23.04	18.36	15.99	13.71	11.34	8.99	30.26
1969/70	9.47	16.37	35.35	81.35	91.12	111.41	53.47	24.25	20.19	16.56	13.23	11.15	40.33
71	8.63	9.09	28.16	51.76	225.93	139.07	39.86	22.73	18.55	15.66	13.08	9.43	48.50
72	9.57	22.87	40.84	77.68	66.96	60.22	33.39	19.94	18.24	14.05	10.46	9.15	31.95
73	11.07	18.89	33.54	80.29	68.43	76.49	32.00	18.75	19.40	18.36	15.36	10.86	33.62
74	9.80	15.30	16.47	101.94	313.14	72.99	48.14	20.55	18.84	16.87	13.71	12.40	55.01
75	9.60	8.99	36.96	260.60	413.30	104.58	39.42	21.63	19.83	14.95	12.41	12.41	79.14
76	9.81	10.24	34.88	116.12	98.45	78.04	27.75	21.76	17.53	13.69	10.78	10.03	37.42

Qa = 42.47
q = 0.98

Major run-off data are obtained by the correlation method based on the run-off data observed at Villamontes Gauging Station on the Rio Pilcomayo and those at Chillcara Gauging Station.

Table-4.5 Monthly Mean Run-off Chillcara Gauging Station

(Unit: m^3/sec)

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July.	Aug.	Sep.	Mean
1950/51	9.53	11.32	28.30	94.50	155.80	60.70	28.30	21.90	20.00	18.30	16.80	13.10	39.88
52	10.14	13.30	35.80	97.20	120.00	42.50	22.00	22.10	20.20	18.50	17.00	13.26	35.78
53	10.26	14.09	33.30	72.10	160.40	76.80	30.40	22.80	20.70	19.00	17.40	13.57	40.90
54	10.50	32.30	65.80	72.60	208.50	141.80	43.10	20.80	18.90	17.30	15.90	12.40	55.00
55	9.59	46.30	83.70	75.00	247.40	135.70	39.30	21.10	19.10	17.50	16.10	12.56	60.28
56	9.71	20.50	40.60	77.90	96.30	20.50	17.40	24.90	22.60	20.60	18.90	14.74	32.05
57	11.40	29.70	60.00	80.00	112.00	40.80	21.20	23.70	21.50	19.70	18.10	14.12	37.69
58	10.90	16.30	39.30	103.50	73.40	76.20	30.70	22.20	20.10	18.40	16.90	13.18	36.76
59	10.20	20.30	45.70	77.50	114.50	77.90	30.90	22.80	20.70	19.00	17.40	12.57	39.12
1959/60	10.50	14.60	43.50	76.90	127.40	112.00	41.40	21.10	19.20	17.60	16.10	12.56	42.74
61	9.71	16.10	38.90	53.80	186.30	81.90	34.20	22.70	20.60	18.90	17.30	13.49	42.83
62	10.44	15.50	42.90	67.90	93.30	79.10	35.00	22.80	20.70	19.00	17.40	13.57	36.47
63	10.50	15.90	43.10	102.30	152.80	96.10	40.20	20.00	18.10	16.60	15.20	11.86	45.22
64	9.17	9.30	33.90	71.80	103.30	75.40	29.00	22.60	20.50	18.80	17.20	13.42	35.37
65	10.38	17.40	34.70	93.80	120.60	94.40	32.40	22.50	20.50	18.80	17.20	13.42	41.34
66	10.38	18.20	41.60	66.40	64.50	55.90	28.90	24.40	22.20	20.40	18.70	14.59	32.18
67	11.28	27.30	65.20	53.00	95.00	73.90	32.60	23.40	21.20	19.40	17.80	13.88	37.83
68	10.79	32.10	35.10	91.80	263.30	106.20	32.90	18.70	17.00	15.00	14.30	11.15	45.31
69	8.63	35.60	62.30	89.00	111.30	26.20	17.80	24.40	22.20	20.40	18.70	14.59	37.59
1969/70	11.28	14.40	40.00	92.40	100.10	109.00	42.60	21.10	19.20	17.60	16.10	12.56	41.34
71	9.71	21.80	24.80	101.90	253.10	40.90	21.60	20.10	18.30	16.80	15.40	12.01	46.37
72	9.29	18.60	42.70	100.90	165.70	81.90	35.50	21.00	19.10	17.50	16.10	9.15	44.80
73	11.07	18.89	33.54	80.29	68.43	76.49	32.00	18.75	19.40	18.36	15.36	10.86	33.62
74	9.80	15.30	16.47	101.94	313.14	72.99	48.14	20.55	18.84	16.87	13.71	12.40	55.01
75	9.60	8.99	36.96	250.60	413.30	81.30	39.42	21.63	19.83	17.38	14.95	12.41	77.20
76	9.81	10.24	34.88	116.12	98.45	78.04	27.75	21.76	17.53	13.69	10.78	10.03	37.42

a = 43.03
q = 0.98

Major run-off data are obtained based on the precipitation (Nov. ∿ Apr.) and adjusted by the depletion curve (May ∿ Oct.)

4.2.4 Design Flood Discharge

The design flood discharge at the dam site was determined by the following frequency analysis: Gumbel, Goodrich, Log.-Pearson type III, Galton and Frechet methods. However, the Chillcara Gauging Station could provide run-off data for only four years, which are insufficient for estimating probable flood discharges.

Therefore, 1000-year flood discharge at the Villamontes Gauging Station was first estimated, and that at the dam site was proportionately estimated using the ratio of catchment areas.

(1) Peak Run-off

No measurement of the peak run-off has been performed. Only daily average run-off are measured at both the Chillcara and the Villamontes Gauging Stations. Therefore, the maximum daily run-off estimated by the Fuller's empirical formula was regarded as the peak run-off for calculating the design flood discharge.

(2) Design Flood Discharge

Probable flood discharges were calculated by Gumbel, Good-rich, Log.-Pearson Type III, Galton and Frechet methods, bringing the following results:

i) The 1000-year flood discharge calculated by the Frechet method was three or four times as great as that calculated by other methods. In general, flood discharges calculated by means of the Frechet distribution method tend to be great especially in the extreme part. Hence, the flood discharges by the Frechet method were used only for reference in the Prefeasibility Study.

ii) The probable flood discharges calculated by Goodrich, Log.-Pearson type III and Galton methods were nearly the same. Only the flood discharge calculated by the Gumbel method was larger than those abovementioned.

Taking into consideration the above calculations and for the safety of spillway design, a 1000-year flood discharge of 8,500 m^3/sec. calculated by the Gumbel method was finally adopted as the design flood discharge at the dam site.

Table-4.6 shows the probable flood discharge at the dam site which was estimated by Gumbel method.

Table-4.6 Probable Flood Discharge by Gumbel method

(Unit: m^3/sec.)

Return Period Years	Q	Return Period Years	Q
5	2,840	100	5,800
10	3,550	500	7,100
20	4,250	1000	8,500
50	5,100		

4.2.5 Sedimentation

A study on sedimentation was made by the following two methods:

i) Simple arithmetic using dada obtained through observation for 10 months at the Chillcara Gauging Station.

ii) Proportion to catchment area using data obtained at Villamontes, Talula, Puerto La Paz and Fortin Pilcomayo Gauging Stations, which are all located on the Rio Pilcomayo.

Table-4.7 Sedimentation

Method	Sediment Production Rate $m^3/km^2/year$	Sedimentation $10^6 m^3/year$
i)	450.3	19.4
ii)	678.7	29.3

The Prefeasibility study adopted the sedimentation-amount of $29.3 \times 10^6 m^3$.

4.2.6 Consideration

As described above, the hydrological analysis in the Prefeasibility Report was appropriately performed within the reach of the currently available data. Several problems which were raised in the course of the review and the items to be further studied in the second stage of the feasibility study are as follows.

(1) Concerning precipitation, run-off and flood discharge, re-examination will be required using also the latest data at the time of the second stage of the feasibility study.

(2) In order to confirm whether the Fuller's empirical formula is adaptable to the Rio Pilaya, it is necessary to observe the peak run-off at the Chillcara gauging station on the Rio Pilaya during the rainy season.

(3) It is necessary to observe continually suspended load, particularly in the rainy season.

(4) In order to prepare the rating curve at the tailrace of the proposed power house, it is necessary to observe water levels of the river in the vicinity of the proposed Aguas Calientes power plant. This observation shall be made simu-

ltaneously with the observation of run-off at the Chillcara Gauging Station.

4.3 Geology

4.3.1 Foreword

The reports listed below have been prepared up to the present on the geology of the project area.

(1) Informes de Empresa Nacional de Electricidad, Nos. 6/73, 5/77.

(2) Investigación geofisica del sitio de Presa (Bloque B) SOMGEX, 1977.

(3) Pilaya River Hydraulic Power Development Project. Pilcomayo System BOLIVIA, March 1978, Japan International Cooperation Agency.

(4) Planta Hidroelectrica Pilaya; Estudio de Prefactibilidad. ENDE, Naciones Unidas, Abril 1978.

In this time, the field reconnaissances covering the damsite, regulating reservoir areas, the penstock routes and powerhouse sites of the two alternative schemes, Huacata and Aguas Calientes, are performed using 1/10,000 topographic maps made from 1/55,000 aerial photographs. In carrying out the investigations, photo-geological surveys (1/55,000) were made of the project area including the headrace tunnels.

4.3.2 General Geology of Basin

(1) Location and Topography

The catchment area of this Project is at the southern end of Bolivia, and geographically, is located between Las Cordilleras Central and El Altiplano. The project site is located between 21°00' - 21°10' south latitude and 64°45' - 64°55' west longitude approximately 50 km north of Tarija, a basin in Las Cordilleras Central.

El Altiplano in the catchment area comprises an upheaval zone of 5,000 - 6,000 m and Las Cordilleras Central one of 4,000 - 5,000 m to form a faltengebirge extending roughly north-south. The Rio Pilaya collects the flows of streams rising from El Altiplano and crosses the geologic structure of Las Cordilleras Central from west to east at the project site to join the Rio Pilcomayo.

The catchment area generally presents a topography in the stage of youth or the stage of maturity, with the terrain especially rugged along the Rio Pilaya, with many places forming V-shaped gorges.

The vegetation in the project area is sparse with bare ground seen almost everywhere. The scarce vegetation consists mostly of plants belonging to the cactus family.

(2) Geology (See Fig.-4.3)

According to Mapa Geologico de Bolivia (1/1,000,000) prepared by Servicio Geologico de Bolivia (1978), Ordovician sedimentary rocks widely comprise the basement. The Ordovician sedimentary rocks are mainly clastic rocks consisting of quartzite, sandstone, shale and mudstone, with folds of a fold axis extending more or less north-south repeated with part of the rocks subjected to low-grade metamorphism.

Cambrian sedimentary rocks are exposed partially at an anticlinal structure south of the project site, while upstream of the project area in the vicinity of the confluence

of the Rio Tumusla and the Rio San Juan del Oro there is a synclinal structure with distributions of Cretaceous and Tertiary sedimentary rocks. Distributions of alluvium are seen in the mountainland basins of Tarija and Potosi.

(3) Earthquakes

The southwestern part of Bolivia is located in the circum-Pacific seismic zone and much earthquake activity is seen. Although the project area is fairly distant from the seismic zone, according to the previously-mentioned Prefeasibility Report, it is considered as being in a zone where there is possibility of occurrence of a strong earthquake and the magnitude is said will be 7.9.

Earthquakes in the project area and seismic intensities are to be studied in detail at the second stage of the feasibility study.

4.3.3 Geology of Project Area

(1) Outline of Topography and Geology

1) Topography

The Rio Pilaya shows repeated small-radius meandering in the project area, but it runs southeast at the damsite, and east at the Huacata powerhouse site, after which it changes its course north-northeast to form a large arc. Inside the arc there is a rugged mountain mass with its ridge extending northward, the highest peak of which, Cerro Alto, reaches an elevation of 4,400 m. South of the Rio Pilaya, mountains of elevations of 3,000 to 3,700 m continue in succession, with

the major tributaries taking their courses roughly north-south. The tributaries have steep river gradients near their confluences with the Río Pilaya and distinct V-shaped gorges are formed.

The slopes on both sides of the Río Pilaya are steep at around 45° with cliffs formed at numerous places. The relative height differences of the slopes are as much as 1,500 to 2,500 m and slope-wash and rockfall topographies are seen practically everywhere.

In contrast, the upstream parts of tributaries and high-elevation portions of mountain masses indicate youth stage topographies with slopes that are gentle.

2) Geology

Clastic rocks such as quartzite, sandstone, shale and mudstone said to be Ordovician widely make up the basement of the project area. These indicate either alternations of strata or massive distributions, and where fresh the rocks are all dense and hard, quartzite especially being so. The rocks collected at the project area have all been subjected to low-grade metamorphism.

All major structures will have these clastic rocks as foundation rocks.

As overburden, distributions of talus deposits at river-bank slopes and of slope-wash at mountainsides are often seen. Whereas the distributions of river deposits at the Río Pilaya river bed from the projected damsite

to the Huacata powerhouse site are narrow and the grain sizes are extremely large, the distribution of river deposits in the vicinity of the proposed Aguas Calientes powerhouse site is wide with grain sizes generally small. In addition to the above, tributaries such as the Aguas Calientes form fan deposit at the banks of the Río Pilaya.

3) Structure

The results of geologic structure analyses using ERTS data (1/250,000) and aerial photographs (1/55,000) were previously reported, and analyses were made this time using the same photographs (see Fig.-4.4).

i) Fold Structures

There is a large anticlinal structure having a fold axis plunging south rouhgly in the north-south direction passing west of the Huacata powerhouse site. The west limb of the fold axis indicates small syncline and anticline structures near the Río Lluskha upstream of the damsite, while further, in the westward direction, there is a continuation to the synclinal structure extending along the Río Paichu. On the other hand, the east limb of the anticlinal structure passing the Huacata powerhouse site indicates a slight synclinal-anticlinal tendency, and this continues to the east of the Aguas Calientes powerhouse site.

These fold axes all possess a north-south direction, and dips of limbs indicate structures close to symmetrical folds of 30° to 40°.

ii) Faults and Joints (Lineation)

Faults recognized by aerial photographs may roughly be divided into those having the three kinds of strikes of N50° - 60°W, N50° - 60°E and N-S. The faults having the strike of N50° - 60°W are most prominent in this area, are continuous over a long distance, while some among them indicate they are left-slip faults. Faults in the N50° - 60°E direction are seen in quantity to the north of the project area, and compared with the former, the distribution frequency and continuity are small. Faults in the N-S direction are recognized in large numbers south of the Huacata powerhouse site, and left-slip faults are predominant.

In small lineations seen in aerial photographs, there are those which are in rough agreement with the three fault directions described above, and these are likely to be related to small faults. Small lineations of E-W and N-S characters are recognized at this site. These were found to be joints in field surveys. Joints in the E-W direction were found to be especially predominant in the project area.

(2) Geology of Principal Project Sites (See Fig.-4.5)

1) Regulating Reservoir Area

The Río Pilaya in the regulating reservoir area assumes an easterly to southeasterly course, has a valley width of several tens of meters to about 100 m, and the mountain slopes at both banks are very steep. The right bank slope is particularly steep with cliffs frequently seen.

The basement rocks consist of Ordovician clastic rocks such as quartzite, quartzose sandstone and shale, and the strike and dip of strata are N-S, 30° - 50°W crossing the river and tilting in the upstream direction.

Talus deposits may be seen here and there at the banks of the Río Pilaya, while slope-wash is widely distributed at the left bank mountainside. The river bed of the Río Pilaya has many boulders of diameters more than several meters thought to have been supplied from nearby rockfall areas, while since the river gradient is steep there are only small amounts of sand and gravel to be seen.

It is judged from the topography and geology of the catchment area that suspended load and bed load to the regulating reservoir area by the Río Pilaya will amount to an extremely large quantity.

2) Damsite

The Rio Pilaya runs in the southeast direction at the damsite and with a valley width of approximately 60 m, the left bank rises at a slope of 40° and the right bank in the form of a cliff of approximately 80° up to an elevation of about 1,860 m. The valley width at the proposed dam crest elevation of 1,803 m is approximately 90 m, and bedrock is exposed widely at both banks.

In the vicinity of the dam axis there are distributions of talus deposits upstream of a point approximately 60 m upstream of the dam axis and downstream of a point approximately 100 m downstream, and for about 100 m centered at the dam axis, the topography is such that rockfalls can be avoided. River gravels consisting mainly of boulder and cobble gravels are distributed at the valley bottom, and according to the results of seismic prospecting performed in the neighborhood of the dam axis, the thickness is approximately 15 m.

The foundation rocks of the dam are grayish-green sandy shale and grayish-white quartzose sandstone. Both rocks have been subjected to low-grade metamorphism, and are dense and hard. These comprise strata of thicknesses from several centimeters to about 10 cm depending on slight differences in grain size to form alternations of thickness about several tens of centimeters. The

strike and dip are N10°E, 40°W to cross the river diagonally tilting in the upstream direction.

At the damsite, joints of two directions of N75°W, 85°S and N35°E, 40°SE are predominant. The former joints are distributed at intervals of 20 to 50 cm and are continuous, whereas the latter are infrequent and lacking in continuity. Faults are not recognized in the mountain masses at the left and right banks, but according to photogeological surveys, there is a possibility of a weak line existing at the river bed with a strike of NE-SE.

3) Waterway Route and Powerhouse (See Fig.-4.6)

a) Aguas Calientes Scheme

i) Headrace Tunnel

The headrace tunnel would be approximately 10.6 km in length and since the tunnel route roughly in the N74°E direction would run through a mountain mass of high elevation, the cover to the ground surface will reach a maximum of 2,000 m. Topographically, it will be difficult to provide adits part way along the tunnel route, and tunnel driving would be done from only two faces, the intake side and the surge tank side.

The geology along the tunnel route consists of sedimentary rocks such as quartzite, sandstone and shale and both are dense and hard rocks.

The headrace tunnel will cross a large anticlinal structure in the N-S direction having a fold axis at a point slightly on the intake side of the mid-point of the tunnel. Regarding faults, according to photogeological surveys there is a possibility of crossing a fault running N50° - 60°W at an obtuse angle.

A fault will be of concern with regard to springing of water during tunnel excavation and it will be necessary to confirm its location by field surveys.

According to information obtained locally, at a different Río Agua Caliente also joining the Río Pilaya at the left bank at a point approximately 4 km downstream of the Río Agua Caliente on which the powerhouse is to be located, there is gushing of a thermal spring. Consequently, it will be necessary to clarify the gushing of the thermal spring, the geological structure and the relation with the tunnel route.

ii) Penstocks, Powerhouse

The penstocks and the powerhouse would be located at the left-bank mountain mass of the Rio Pilaya near the confluence of the Río Pilaya and the Río Aguas Calientes. The slope at which the penstocks will be located is

about 60° where steep, but as a whole it is approximately 45°. There are distributions of slope-wash seen at parts, but bedrock is exposed at many places. There are distributions of talus deposits along gullies at the foot of the mountain.

There is a large-scale rockfall area in the vicinity of El. 3,000 m upstream on the Rio Aguas Calientes and sediment supplied from this area forms an alluvial fan at the confluence with the Río Pilaya, with the skirt of this sediment reaching close to the powerhouse site. The sediment forming this alluvial fan has often dammed up the Río Pilaya, the most recent occurrence having been in November of 1977. Because of this, there are thick river deposits at the Río Pilaya upstream of the confluence, while a depositional surface indicating the water level to have risen in the part up to an elevation of approximately 1,330 m can also be seen.

The foundation rocks of both the penstock and powerhouse sites are clastic rocks consisting of quartzite, quartzose sandstone and shale in layered form, and fresh rocks are all dense and hard. The strike and dip of the strata are roughly N10°E, 40° - 50°E, and the

slope at which the surge tank and penstock are to be located is with partial exception a slope along a bedding plane of a stratum. Joints are predominant in the N80°E, 90° direction crossing the Río Pilaya.

Outcrops are seen here and there at the slope along the penstock route, and although there is partially rock indicating loosening of a creep nature, the condition of the rock is good as a whole.

The powerhouse will have its foundation at around El. 1,330 m. Talus deposits are distributed at the foot on the mountain side higher than this elevation, while on the river side at lower elevation there is a thick deposit of river gravel. Meanwhile, the alluvial fan deposit of the Río Aguas Calientes extends to the vicinity of the planned powerhouse site, and thickness of this deposit is thicker the farther downstream.

b) Huacata Scheme

i) Headrace Tunnel

The headrace tunnel would have a length of approximately 6 km with the route running in the S50°E - S60°E direction roughly parallel with the Río Pilaya to reach the powerhouse site approximately 4 km downstream of the

confluence with the Río Huacata. Since the tunnel passes under the left-bank slope of the Río Pilaya, the cover to the ground surface will be thinner than for the Aguas Calientes route and the thickness will be from 200 to 800 m.

The geology of the tunnel route consists of clastic rocks such as quartzite, quartzose sandstone and shale similarly to the Aguas Calientes route. The previously-mentioned large anticlinal structure stretching in the N-S direction exists approximately 600 m west of the Huacata powerhouse site and the head-race tunnel would cross this anticlinal structure diagonally. According to the direction of lineation in photogeological surveys, there is a possibility that the headrace tunnel will intersect a fault running in the N50° - 60°E direction, roughly orthogonal to the tunnel direction.

ii) Penstocks, Powerhouse

Both the upstream and downstream neighborhoods of the left-bank slope where the penstocks and powerhouse would be located consist of abrupt cliffs with slope-wash distributed at the foots of the cliffs. Meanwhile, the width of the valley bottom of the

Río Pilaya is approximately 70 to 80 m, and talus deposits have been pushed out here and there to the river banks.

The geology of the penstock and powerhouse sites, similarly to the headrace tunnel route, consists of bedded clastic rocks such as shale, sandstone and quartzose sandstone, and fresh rocks are all dense and hard. The penstocks and the powerhouse will be located east of the anticlinal structure, and the strike and dip of strata are roughly N60°E, 10°S. Joints with strike and dip of E-W, 70° - 90°N are predominant, the intervals generally being from several tens of centimeters to about 2 m.

Because of such topographical and geological conditions, it is thought that the proposal made in the past for the penstocks and powerhouse to be provided underground will be appropritate.

(3) Concrete Aggregates

The Río Pilaya from the damsite to about 7 km downstream of the Huacata powerhouse site has a narrow river-bed width while the river gradient is steep, and the quantities of gravel and sand distributed are extremely small compared with quantities of cobble and boulder gravels. Consequently, concrete aggregates will be obtained by crushing rock. Since

all rocks comprising the basement are dense and hard, it will be possible to obtain aggregates from a quarry.

On the other hand, the Aguas Calientes powerhouse site has river deposits containing small-grained gravel and sand distributed over a wide area and it is thought concrete aggregates can be obtained by screening.

(4) Consideration

It may be said from the results of investigations up to the present that from the standpoint of geology both the Aguas Calientes Scheme and the Huacata Scheme are plans which are amply feasible. However, it was judged based on the plans that the Aguas Calientes Scheme will have better economic effect. Consequently, only the Aguas Calientes Project will be discussed hereafter.

1) It is anticipated that the inflow of suspended load and bed load into the regulating reservoir during the rainy season will amount to an extremely large quantity. Quantitative studies will be required including measurements of suspended load.

2) The damsite has been selected where rockfalls from higher elevations on the slopes at both banks can be avoided, and based on field surveys, it is thought the bedrock has adequate strength for construction of a concrete gravity dam of height of about 50 m. Therefore, it is desirable for a detailed field survey to be made using the 1/1,000 topographic maps prepared by ENDE and

to carry out the geological investigation works indicated under Item 5.1.

3) The headrace tunnel will be a long one with a length as much as 10.6 km, but it will be need to be driven from two faces only. It will be desirable for analysis of the geological structure to be made using a 1/10,000 topographic map to carry out field surveys including the thermal spring area of the downstream Rio Agua Caliente.

4) The penstock and powerhouse sites have been selected at a slope where there are many outcrops and the gradient is approximately 45°. The location of the powerhouse should be selected at site where the flood level of the Rio Pilaya can be avoided in case a mud flow supplied along the Rio Agua Caliente dams up the Rio Pilaya.

As the penstock routes, two schemes can be considered. The distance of these two routes is 120 m. In this case, with the upstream route for the penstocks, excavation quantities for the powerhouse and tailrace will be small, but the penstock parts will have somewhat thick distribution of slope-wash. With the downstream route for penstocks, whereas outcrops can be widely seen as a whole, the excavation quantities for the powerhouse and tailrace will be very large. Further detailed field surveys using 1/1,000 topographic maps and execution of geological investigation works indicated in Item 5.1 will be desirable.

5) Access roads for construction will pass slopes which are steep and where there will be many places of slope-wash distributions, and detailed studies will be required for route selection.

4.4 Power Production

As a result of the review made on the power production planning, it is decided that our development program shall essentially depend on the basic development conception described in Chapter 3; however, some modifications were introduced in our study for comparison of Huacata and Aguas Calientes schemes.

Our report has determined that the maximum available discharges for the Huacata and Aguas Calientes schemes are the same.

The hydrological analysis for ten years from 1963/64 to 1973/74 carried out by ENDE revealed that the maximum available discharge for both schemes would be 30 m^3/sec. if the peak generation must be continued for six hours even in the dry year. Since the rainy season is for five months from December to April and the dry season is for seven months from May to November, the available discharge in the dry season changes little as shown in Table-4.8, even if the maximum available discharge becomes larger.

Table-4.8 Average Available Discharge

Unit: m³/sec.

	Q \ Qmax.	20	22	24	26	28	30	35	40
Rainy Season	70.6	18.9	20.8	22.6	24.4	26.2	27.8	31.7	35.1
Dry Season	15.1	14.4	14.7	14.9	15.0	15.0	15.1	15.1	15.1
Annual Average	38.2	16.3	17.2	18.1	18.9	19.7	20.4	22.0	23.4

Notes: Qmax. = Maximum available discharge

Q = Average river run-off of 10 years (1963/64 to 1973/74)

As shown in Table-4.8, the advantage accruing from increasing the maximum available discharge is increment of generated energy in the rainy season. But, generally in Bolivia, seasonal fluctuations in power demand between the dry and rainy seasons are seen little. Hence, in order to substantiate that advantage, it must be clarified whether the increase of power generation in the rainy season by the Pilaya Hydroelectric Project can reduce the burden on other reservoir-controled hydroelectric power plants for efficient operation of such power plants as supplementary power capability in the dry season, or whether the fuel consumed in the thermal power plants can be saved.

This report is at the preliminary level for an economical comparison between the Huacata and the Aguas Calientes schemes, setting the maximum available discharge at 26.0 m^3/sec. for both schemes, which allows for a peak generation not less than 6 hours throughout the year, even in the dry year.

4.5 Preliminary Design

4.5.1 Civil Structures

(1) Huacata Scheme

1) Dam

As shown in Fig.-4.9, the dam would take the concrete gravity type with a height of 52 m, a crest length of 95 m and a downstream slope of 1:0.8. The spillway has three roller gates with a height of 18.5 m and a width of 15.0 m and allows for passage of a maximum discharge of 8,500 m^3/sec. at a surcharge water level of 1,801.00 m, in flooding.

In the second stage of the feasibility study, the most appropriate dam type shall be determined taking into consideration the topography of the dam site (the right slope is almost vertical and the left slope shows sharp gradients of 45° to 50°.), deep alluvial deposit (the depth of the deposits from the current river bed is reported to be approx. 15 m at its maximum.), an expected large quantity of sediments, great flood discharge (8,000 to 10,000 m^3/sec. with a frequency of occurrence of once in 1,000 years), geological conditions, etc.

2) Intake

An intake will be built at the left bank of the Rio Pilaya approx. 15 m upstream from the dam. The elevation of the intake floor is to be at El. 1,781.00 m, 6 m below the low water level of the reservoir. A trash rack and

a roller gate will be installed at the front and the rear of the intake, respectively. The intake has a capacity of 26 m^3/sec.

3) Sedimentation Basin

A sedimentation basin will be built in the beginning part of the headrace tunnel at the left bank of the Rio Pilaya. The sedimentation basin is of underground type of 11.0 m wide, 11.0 m high and 64.0 m long and provided with three sand flush gates which remove sediment in the sedimentation basin to the downstream of the dam. The maximum flow velocity in the sedimentation basin will be 0.29 m/sec.

In the second stage of the feasibility study, the necessity of the sedimentation basin must be examined on the basis of data to be obtained in the future, and then its size, its structure, etc. are to be fully studied.

4) Headrace Tunnel

The headrace tunnel is to have a circular cross section with an inside diameter of 3.2 m. The length is 6.0 km and its maximum discharge capacity is 26 m^3/sec. A work adit is to be provided near the middle of the headrace tunnel. The tunnel is to be lined with reinforced concrete through its entire length.

5) Surge-tank

The surge-tank is to be a chamber-type surge-tank which consists of a shaft, 3.5 m in inside diameter in

the lower part and 10.0 m in the upper part and 61.0 m high, and of a horizontal lower chamber with an inside diameter of 4.0 m and a length of 150.0 m.

6) Penstock

The penstock is to be of the underground type in consideration of the topographical and geological conditions of the site. The penstock has varied inside diameters between 2.9 and 2.6 m and branches into four conduits immediately before the powerhouse. The length of each conduit is 360 m.

7) Powerhouse

Taking into consideration the topography and geology, the powerhouse is to be of the underground type and of reinforced concrete structure with a width of 12.0 m, a height of 22.0 m and a length of 38.0 m. The draft tube is to be of the elbow type. And at its outlet (below the transformer room), four draft gates are to be installed.

An underground transformer room with a width of 6.0 m, a height of 6.0 m and a length of 38.0 m is to be built in parallel with the powerhouse.

8) Tailrace Tunnel

The tailrace tunnel is to have a circular section with an inside diameter of 3.8 m and length 300.0 m.

(2) Aguas Calientes Scheme

1) Dam

Same as the Huacata Scheme

2) Intake

Same as the Huacata Scheme

3) Sedimentation Basin

Same as the Huacata Scheme

4) Headrace Tunnel

The headrace tunnel is to have a circular section with an inside diameter of 3.2 m, a length 10.6 km and its maximum discharge capacity is 26 m^3/sec. The tunnel is to be lined with reinforced concrete.

5) Surge-tank

The surge-tank is to be a chamber-type surge tank which consists of a shaft, 3.0 m in inside diameter in the lower part and 12.0 m in inside diameter in the upper part and 101.0 m high, and of a horizontal lower chamber with an inside diameter of 3.5 m and a length of 200.0 m.

6) Penstock

The penstock is to be a surface type in consideration of the topography and geology of the site. The penstock will consist of three conduits with inside diameters of 1.7 to 1.4 m. The length of each conduit is 800.0 m.

7) Powerhouse

Taking the topography and geology into consideration, the powerhouse is to be of the surface type with a width of 31.5 m, a height of 27.0 m and a length of 40 m.

4.5.2 Electrical Facilities

(1) Basic Concepts for Preliminary Design

The installed capacity is determined by the maximum discharge of 26.0 m^3/sec for both of the Huacata and Aguas Calientes schemes as is described in section 4.4 and the head between the high water level of reservoir and the tail-race water level. The unit capacity is determined for up to 5% of the power demand in the commissioning year of the Project early in the 1990s. The turbine is selected taking into account the available unit discharge and the effective head.

The Huacata powerhouse is planned to be constructed underground, and therefore, the main transformer will be installed also underground adjacently to the powerhouse. 115 kV switchyard equipment for this power plant is to employ GIS (Gas Insulated Switchgear) and 115 kV bus system is to be single bus system.

The Aguas Calientes powerhouse is planned to be constructed on the ground, and therefore, the 115 kV switchyard equipment and the main transformer to be connected to its transmission line are also planned to be installed on the ground.

(2) Type of Turbine and Specifications of Major Equipment

(i) Huacata Powerhouse

The Francis turbine is selected in consideration of effective head and unit available discharge. Major specifications of turbine, generator and main transformer are as indicated below.

Turbine

Type	: Vertical-shaft Francis Type
Output	: 15,400 kW
Effective head	: 273 m
Max. available discharge	: 6.5 m^3/sec.
Revolution	: 750 rpm

Generator

Type	: Vertical-shaft AC Generator
Capacity	: 16,700 kVA
Voltage	: 11,000 V

Main transformer

Capacity	: 16,700 kVA
Voltage	: 115 kV/10.5 kV

The number of generating units is to be 4 as in the preliminary design of the Prefeasibility Report to provide a total output of 60 MW.

(ii) Aguas Calientes Powerhouse

The Pelton turbine is selected in consideration of effective head and unit available discharge, though the Francis turbine selected in the preliminary design of the Prefeasibility Report. The past performarce of the Francis turbine puts its use in this scheme on the borderline of applicability and so the Pelton turbine, which can be easily inspected and maintained, is preferable in consideration of water quality of Rio Pilaya. Major specifications of turbine, generator and main transformer are as indicated below.

Turbine

Type	:	Vertical-shaft Pelton Type
Output	:	32,400 kW
Effective head	:	436 m
Max. discharge	:	8.66 m^3/sec.
Revolution	:	375 rpm

Generator

Type	:	Vertical-shaft AC Generator
Capacity	:	34,900 kVA
Voltage	:	11,000 V

Main Transformer

Capacity	:	34,900 kVA
Voltage	:	115 kV/10.5 kV

The number of generating units is to be 3 as in the preliminary design of the Prefeasibility Report. The unit output is 31,400 kW, corresponding to 5% of the system load, and the total output is 90 MW.

Economic comparison shall be made between vertical-shaft and horizontal-shaft Pelton turbines in the second stage of the feasibility study.

4.5.3 Major Specifications

Major specifications of both schemes are indicated below.

Item	Unit	Huacata	Aguas Calientes
Type of Development		Divided-fall type	
Annual Inflow	$10^6 m^3$	1,340	
Pondage and Dam			
Normal Water Level	m	1,797	
Dam Type		Concrete Gravity	
Height x Crest Length	m	52 x 95	
Volume	m^3	55,000	
Headrace Tunnel			
Section		Circular	Circular
Diameter x Length	m, m	3.2 x 6,000	3.2 x 10,600
Effective Head	m	273	436
Maximum Available Discharge	m^3/sec	26	26
Installed Capacity	Kw	60,000	90,000
Annual Energy Production	Gwh	386	609
Rainy Season (Nov. - Mar.)	Gwh	223	353
Dry Season (Apr. - Oct.)	Gwh	163	256
Construction Cost	10^3US$	90,300	128,200

4.6 Major Problems of Construction

The Huacata scheme will be faced with some difficulties in constructing access roads on the extremely steep slopes. Further, much congestion will probably be seen during the construction of the underground powerhouse because the site will not allow for sufficient space for temporary works.

On the other hand, the Aguas Calientes scheme will construct an access road from Carapari to the power plant passing through a zone characterized by a relatively wider river bed and gentle-slopes on either bank. In view of these facts the Aguas Calientes scheme is more advantageous than the Huacata scheme. The Aguas Calientes scheme will be faced with few problems in construction of the penstock, powerhouse, tailrace and other works, since they are to be constructed on the surface and there will be suitable spaces for temporary works.

The Huacata scheme needs a headrace tunnel having a total length of 6.0 km, divided by a work adit into two portions, while the Aguas Calientes scheme needs a headrace tunnel having a total length of 10.6 km, probably having some difficulties in construction period and construction method.

Because the topography at the damsite and the place adjacent to the Huacata powerhouse shows very steep slopes, it is very difficult to set up a suitable disposal area, and therefore, in the second stage of the feasibility study a very prudent study will be required on a method of treatment of excavated muck.

4.7 Construction Costs

4.7.1 Basic Conditions

The construction costs of the Huacata and the Aguas Calientes schemes are roughly estimated to study economically both schemes.

(1) These construction costs have taken the unit prices given by ENDE for these schemes, those in the Feasibility Study Report of the ICLA Hydroelectric Project also given by ENDE,

and those for hydroelectric power plants in Japan of the same scale as this project. The natural conditions and socio-economic conditions of the project area, construction scale and the results of field investigations at the planned site were also considered.

(2) The construction costs are calculated as of October 1979.

(3) The scope of the estimate includes the outdoor switch yard, but excludes transmission facilities.

4.7.2 Particulars of Construction Costs

(1) Civil Works

Work quantities of dam, powerhouse and headrace tunnel were calculated based on the drawings attached to Item 4.5 "Preliminary Design," while those of other structures were those in the prefeasibility report. The work quantity for each item of works are shown in Table-4.11.

(2) Hydraulic Equipment and Electrical Equipment

It was assumed that hydraulic equipment such as main gates and penstock pipes, and electrical equipment such as turbines, generators and transformers would all be manufactured and supplied outside Bolivia, and the costs were calculated including ocean freight, insurance, landing costs, overland transportation costs in Bolivia and field installation costs.

(3) Preparatory Works

The Cost of Preparatory works includes the costs of access roads required to be constructed prior to commencement of the project construction, but does not include costs of

the geological surveys, meteorological and hydrological data collection and topographical mapping to be carried out by ENDE for detail design.

(4) Engineering Cost and Management Cost

As engineering cost and management cost, 12% of the direct construction cost was taken.

(5) Contingency

As contingency, 30% of the direct construction cost was taken.

(6) Escalation Cost and Interest During Construction

The escalation and interest during construction was not taken into account.

4.7.3 Construction Cost

The total construction cost at generating level is estimated at US$90,300,000 for Huacata Scheme and US$128,200,000 for Aguas Calientes Scheme.

The summary of the estimated construction cost for both schemes are shown in Table-4.10.

Table-4.10 Summary of Estimated Construction Costs
As of Nov. 1979

(Unit: 10^3US$)

Item	Huacata	Aguas Calientes
A. Generating Facility	57,540	82,710
A.1 Civil Works	42,500	59,100
(1) Dam	11,730	11,730
(2) Intake	580	580
(3) Sedimentation Basin	2,410	2,410
(4) Headrace Tunnel	17,590	32,640
(5) Surge Tank	810	1,070
(6) Penstock	2,920	6,700
(7) Powerhouse Building	6,310	3,920
(8) Switch Yard	150	50
A.2 Electrical Equipment	15,040	23,610
(1) Turbine		
(2) Generator		
(3) Transformer	15,040	23,610
(4) Miscellaneous		
(5) Installation Cost		
B. Preparation Work	6,090	7,540
(1) Access Road	6,090	7,540
Total Direct Cost (A + B)	63,630	90,250
C. Engineering Cost	7,640	10,830
D. Contingency	19,030	27,120
Total Construction Cost as of Nov. 1979	90,300	128,200

Table-4.11 Summary of Principal Work Quantities

Description	Unit	Quantity	
		Huacata	Aguas Calientes
(I) Civil Work			
1. Dam			
1-1 Common Escavation	m^3	100,600	100,600
1-2 Rock Excavation	"	37,400	37,400
1-3 Concrete	"	55,000	55,000
2. Intake			
2-1 Rock Excavation	m^3	1,700	1,700
2-2 Tunnel Excavation	"	2,700	2,700
2-3 Concrete	"	1,040	1,040
3. Sedimentation Basin			
3-1 Tunnel Excavation	m^3	13,500	13,500
3-2 Concrete	"	5,800	5,800
4. Headrace			
4-1 Length of Tunnel	m^3	6,000	10,600
5. Surge Tank			
5-1 Tunnel Excavation	m^3	5,600	7,100
5-2 Concrete	"	1,600	2,000
6. Penstock			
6-1 Length of Penstock	m	355	800
7. Powerhouse and Tailrace			
7-1 Excavation (Common and Rock)	m^3	14,600	20,000
7-2 Tunnel Excavation	m	865	0
7-3 Concrete	m^3	6,900	8,300

4.8 Energy Cost

The construction cost per kW and energy cost per kWh at generating level for Huacata and Aguas Calientes schemes are shown in Table-4.12.

In the calculation of energy cost, it was assumed that the service period of the power facilities is 50 years, the residual value is 0, such cost as repair cost, personnel cost and administrative cost is 1.5% of the total constructin cost, and annual interest is 10%.

Therefore the ratio of the constant annual cost of the project spread over the service period to the total construction cost would be 11.586%.

Table-4.12 Energy Cost of Huacata and Aguas Calientes Schemes

Power plant	Construction cost 10^3US$	Installed capacity MW	Average annual power production GWh	Annual cost 10^3US$	Cost per kW US$	Cost per kWh mills US$
Huacata	90,300	60	386	10,460	1,505	27.10
Aguas Cali-enters	128,200	90	609	14,850	1,424	24.38

RAIN GAUGING STATION

No	Station	Coordinates Latitude	Coordinates Longitude	Altitude (m)	Period	Remark
1	Sucre	19°03'	65°16'	2,790	Jan 1949 ~ Feb 1979 (Observed continuously)	Daily
2	Yocalla	19°23'	65°55'	3,410	Jan 1946 ~ Dec 1976 (Observed intermittent)	Daily
3	Santa Lucía	19°33'	65°51'	3,000	Jan 1966 ~ Jan 1979 (No observed Apr to Dec 1976)	Daily
4	Potosi	19°35'	65°45'	3,976	1955 ~ Dec 1978 (No observed 1966)	Daily
5	Chinoli	19°39'	65°21'	1,450	Jan 1963 ~ Dec 1978 (No observed Dec 1975~Sep 1978)	Daily
6	Lago Toro	19°41'	66°24'	4,400	Apr 1967 ~ Feb 1975 (Observed continuously)	Daily
7	Rio Mulatos	19°42'	66°47'	3 820	Jan 1936 ~ Sep 1972 (No observed Jan. ~ Sep 1964)	Monthly
8	Puna	19°45'	65°27	3,420	Jan 1961 ~ Dec 1978 (No observed Aug and Sep 1978)	Daily
9	Toma Killpani	19°46'	66°22'	4,300	Apr 1967 ~ Feb 1975 (Observed continuously)	Daily
10	Agua Castilla	19°46'	66°00'	4,100	Feb 1945 ~ Dec 1971 (No observed 1967)	Monthly
11	Killpani	19°48'	66°19'	4,180	1947 ~ 1975 (No observed 1954 ~ 1966)	Monthly
12	Porco	19°48'	66°00'	4,200	Apr 1967 ~ Feb 1974 (No observed Dec 1967)	Daily
13	Pta Landara	19°49'	66°19'	3 900	Apr 1967 ~ Dec 1974 (Observed continuously)	Daily
14	Turuchipa	19°49'	64°57'	2,450	Jan. 1960 ~ Dec 1978 (〃)	Daily
15	Chaguilla	19°51'	66°08'	3,800	May 1967 ~ Jan 1979 (No observed Mar 1974-Dec 1975)	Daily
16	Pintumani	20°04'	66°08'	3 500	Apr 1967 ~ Feb 1975 (Observed continuously)	Daily
17	Punutuma	20°04'	66°08'	3 500	Jan 1964 ~ Feb 1975 (No observed Jul ~ Dec 1965)	Daily
18	Yura	20°04'	66°07'	3,500	Aug 1946 ~ Dec 1973 (Observed continuously)	Daily
19	Tica Tica	20°08'	66°19'	3 600	Apr 1967 ~ Mar 1975 (〃)	Daily
20	Salto León	20°08'	66°07'	3,300	Apr 1967 ~ Feb 1979 (〃)	Daily
21	Tholapampa	20°13'	66°34'	4,000	Apr 1967 ~ Mar 1975 (〃)	Daily
22	Uyuni	20°28'	66°49'	4,300	Jan 1943 ~ Dec 1948 , Jan 1975 ~ Dec 1977	Daily
23	Camargo	20°38'	65°13'	2,400	Jan 1972 ~ Dec 1978 (No observed Jan ~ Aug 1976)	Daily
24	Atocha	20°56'	66°13'	3,700	Mar 1942 ~ Dec 1973 (Observed continuously)	Monthly
25	El Puente	21°14'	65°12'	2 300	Jan 1963 ~ Dec 1975 (〃)	Monthly
26	Oploca	21°20'	65°48'	3 150	Jan 1976 ~ Dec 1978 (〃)	Daily
27	Tarija	21°40'	64°43'	1 862	Mar 1954 ~ Dec 1978 (〃)	Daily
28	Taxara	21°42'	65°04	4,300	Oct 1965 ~ Mar 1975 (Observed intermittent)	Daily
29	Majo	21°49'	65°33'	3,400	1970 ~ 1976 (Observed continuously)	Monthly
30	Villazón	22°05'	65°35'	3 400	Jan 1943 ~ Dec 1972 (No observed Jan 1949~Dec 1952)	Monthly
31	La Quiaca	22°08'	65°37'	3,500	Jan 1946 ~ Dec 1975 (Observed continuously)	Monthly
32	Humahuaca	23°13'	65°21'	2,980	1952 ~ 1974 (Observed at Argentina)	Monthly
33	Rinconada	22°21'	66°90'	4,100	1946 ~ 1955 (〃)	Monthly

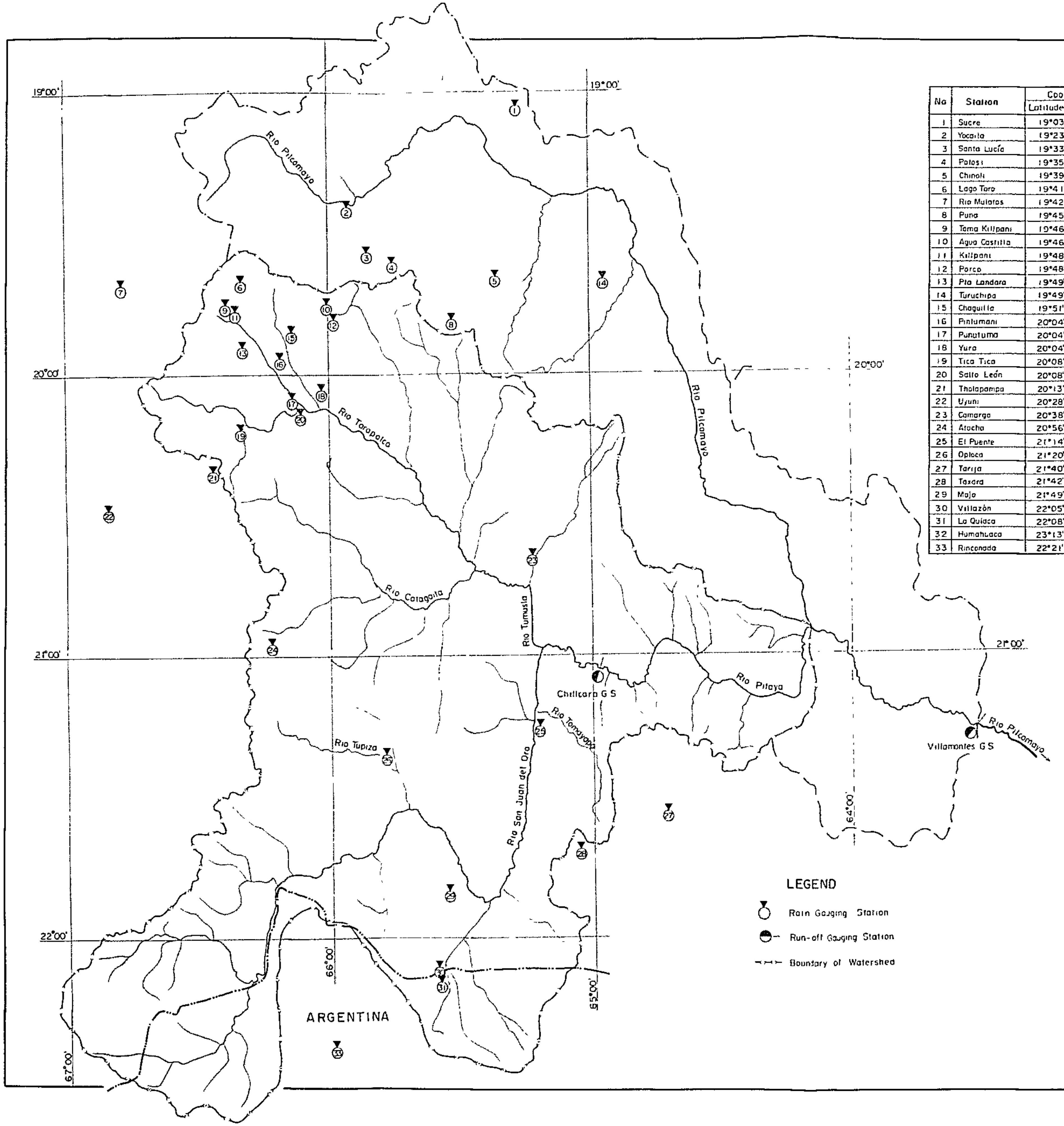


FIG. - 4 2

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

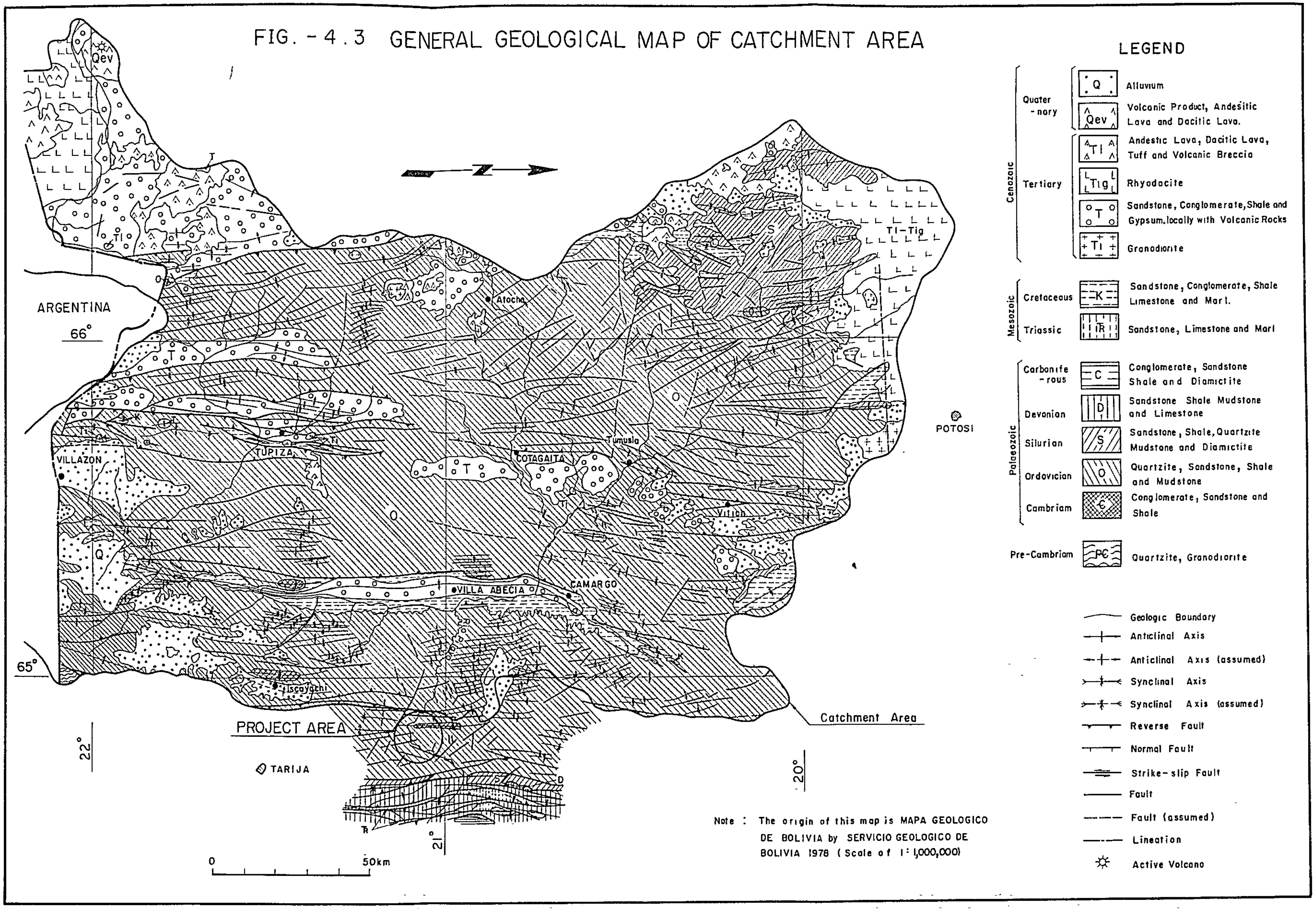


FIG. - 4.3 GENERAL GEOLOGICAL MAP OF CATCHMENT AREA

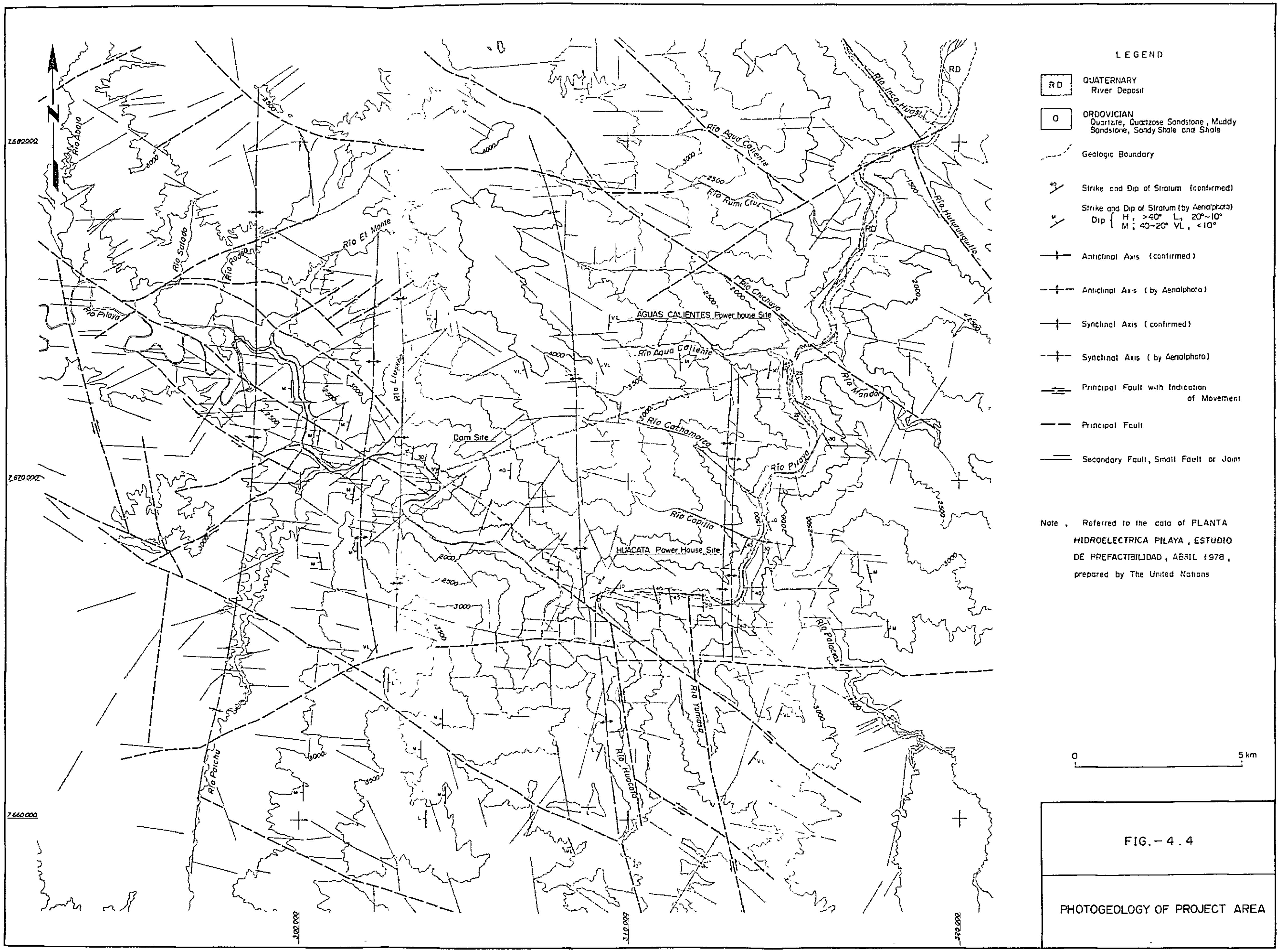


FIG.－4.4

PHOTOGEOLOGY OF PROJECT AREA

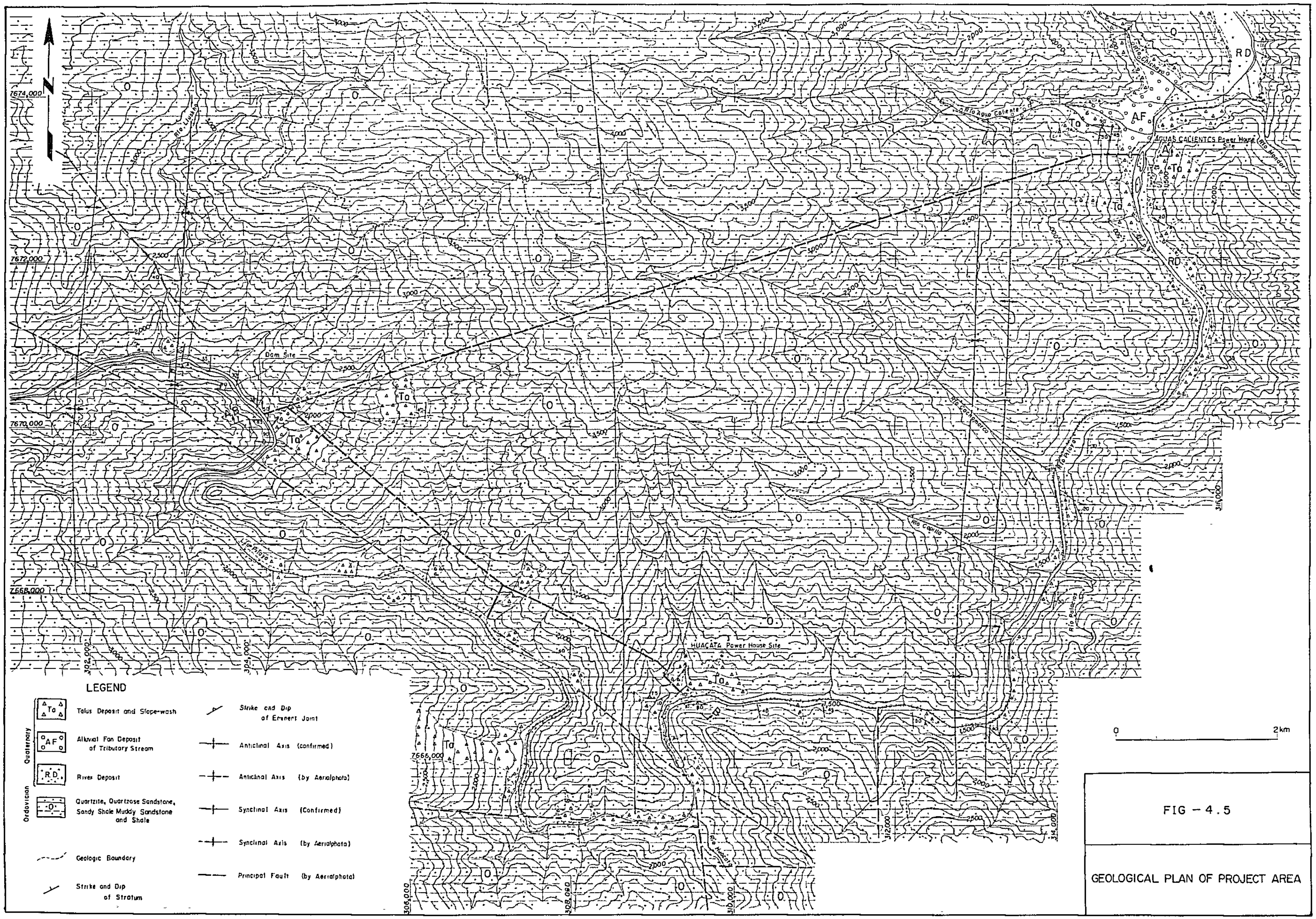


FIG - 4.5

GEOLOGICAL PLAN OF PROJECT AREA

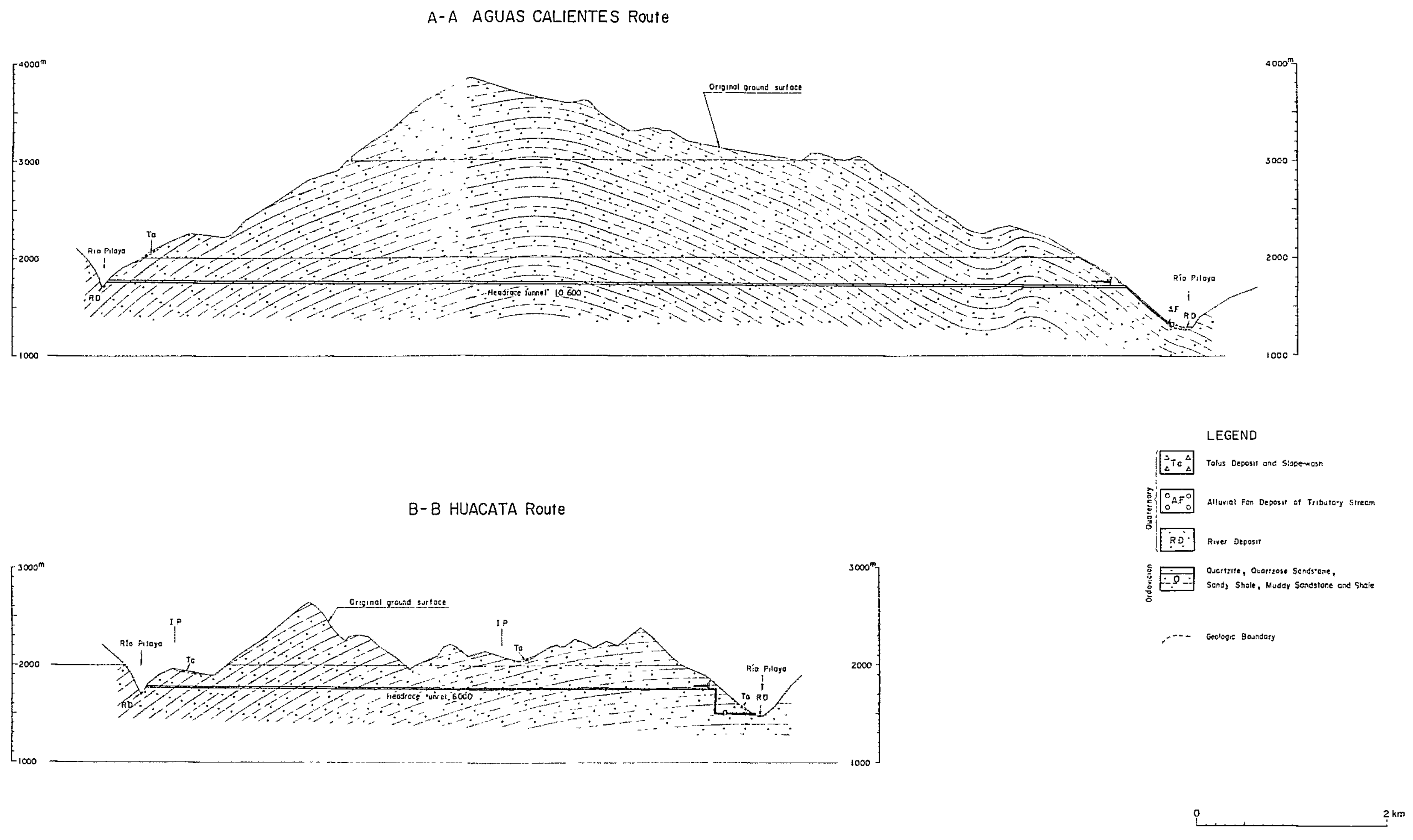


FIG - 4.6

PROFILE OF WATER WAY

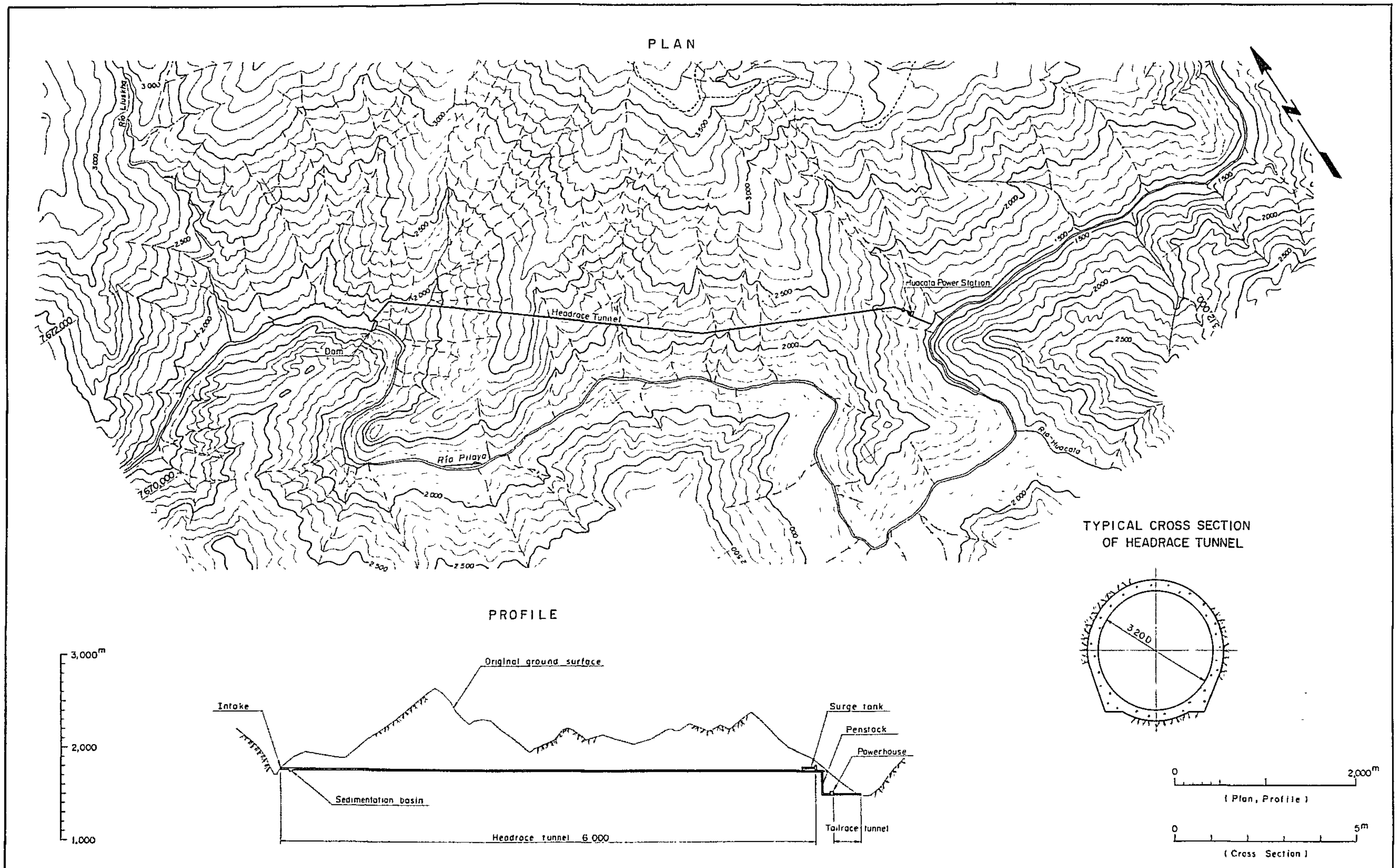


FIG. - 4.7

HUACATA WATERWAY

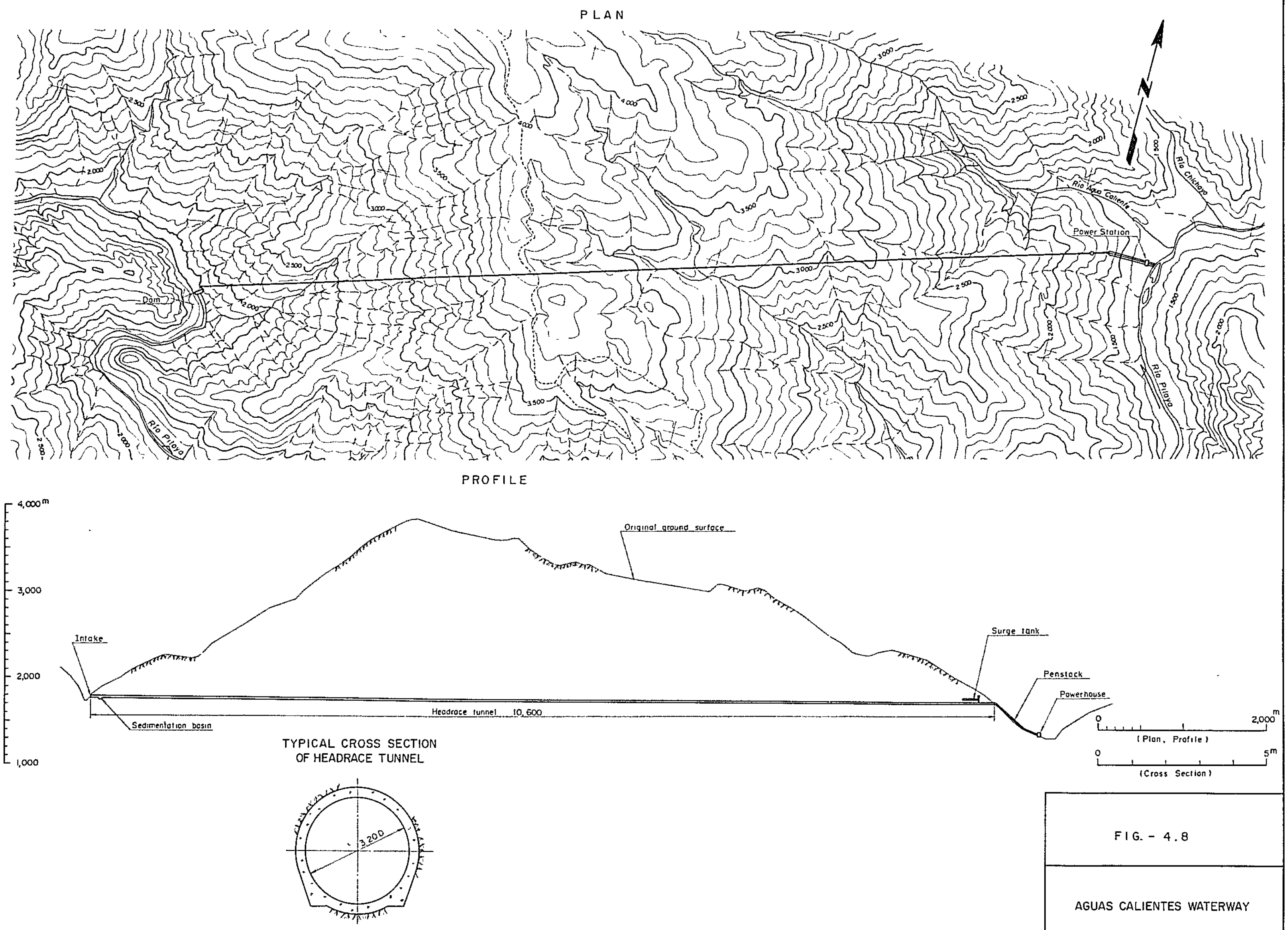


FIG. - 4.8

AGUAS CALIENTES WATERWAY

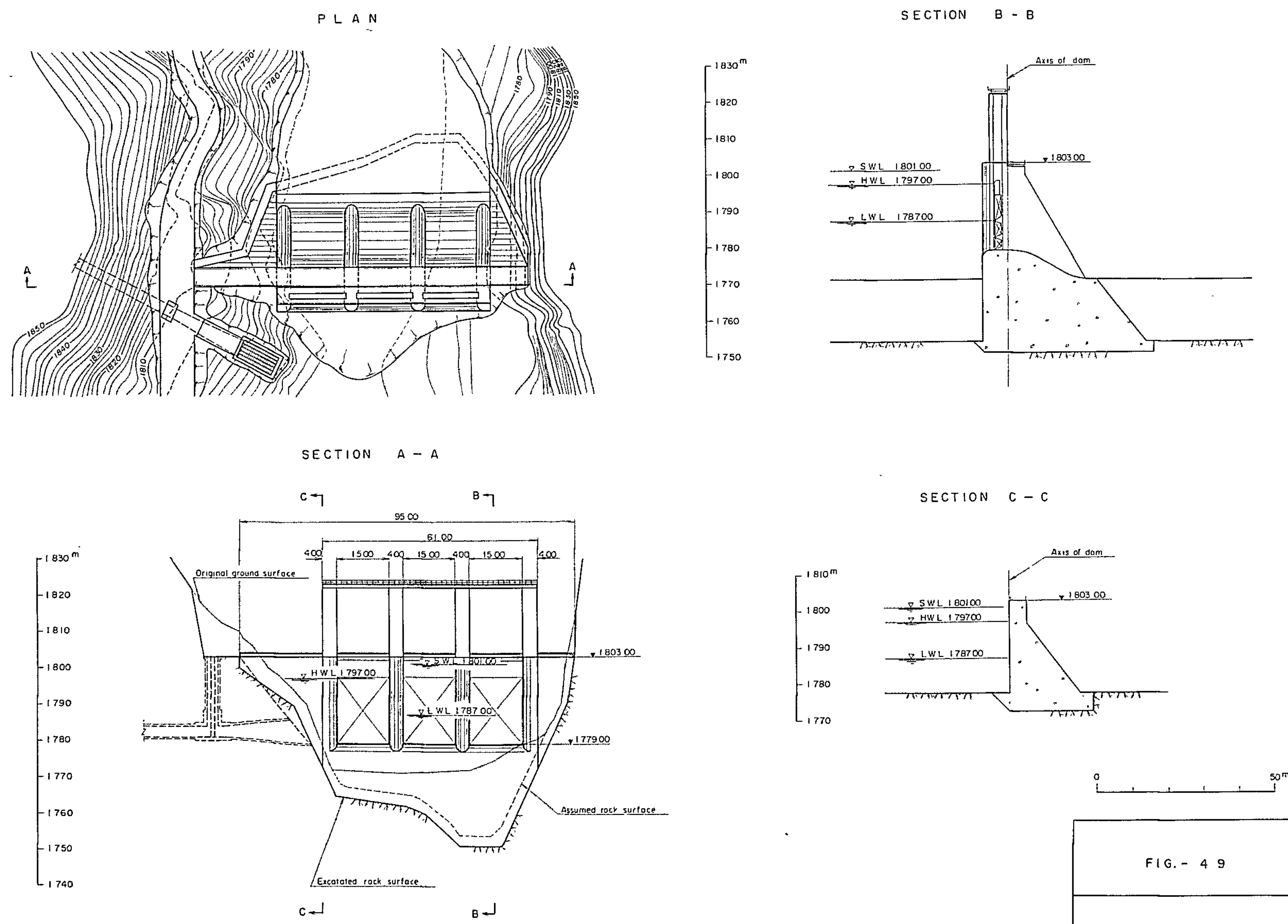

PLAN
SECTION B - B
Axis of dam
SWL 1801.00
HWL 1797.00
LWL 1787.00
1803.00
1830m
1820
1810
1800
1790
1780
1770
1760
1750
SECTION A - A
95.00
61.00
4.00
15.00
4.00
15.00
4.00
15.00
4.00
Original ground surface
1803.00
SWL 1801.00
HWL 1797.00
LWL 1787.00
1779.00
Assumed rock surface
Excavated rock surface
1830m
1820
1810
1800
1790
1780
1770
1760
1750
1740
SECTION C - C
Axis of dam
SWL 1801.00
HWL 1797.00
LWL 1787.00
1803.00
1810m
1800
1790
1780
1770
0
50m

FIG.- 49

DAM

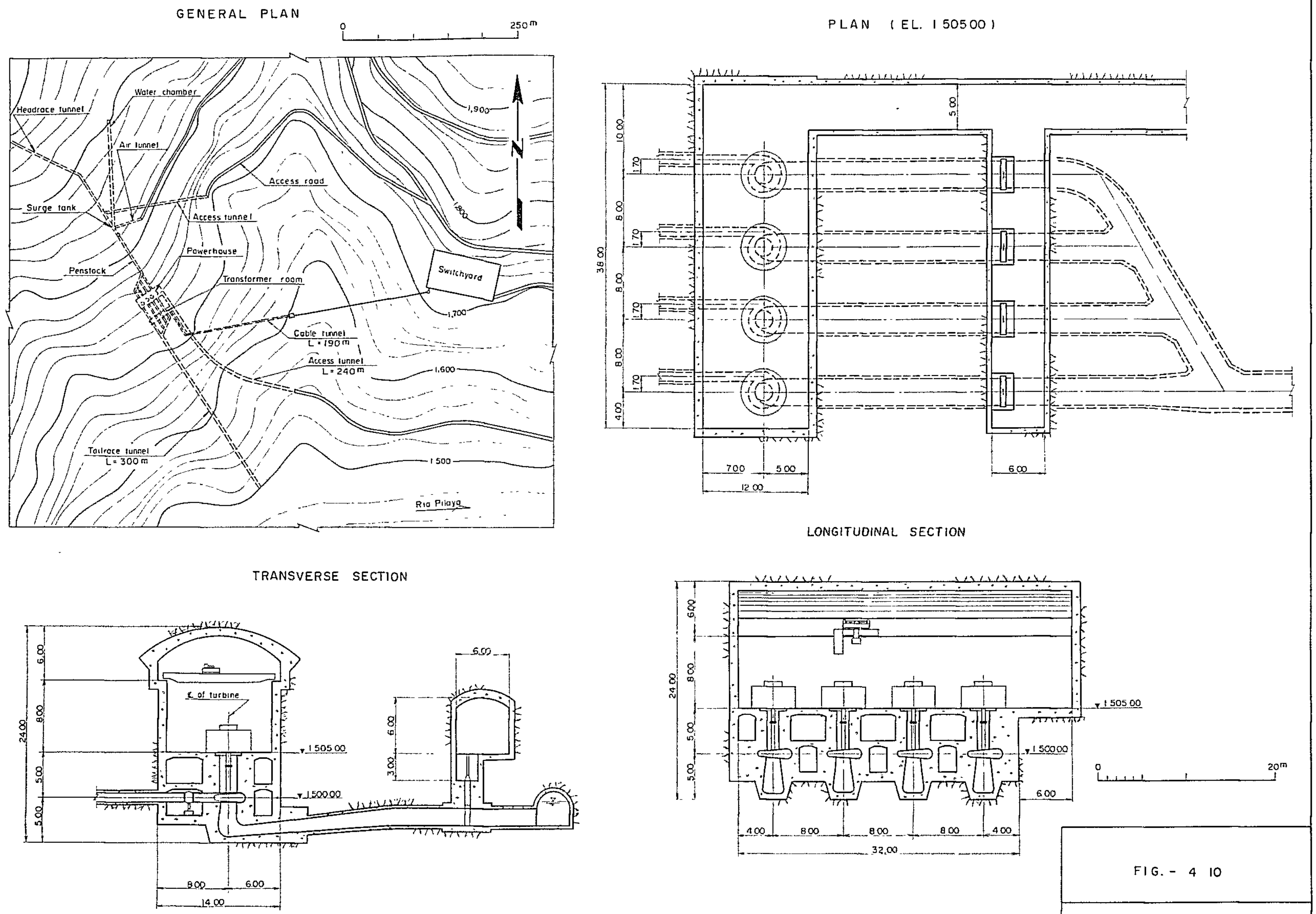


FIG. - 4 10

HUACATA POWERHOUSE

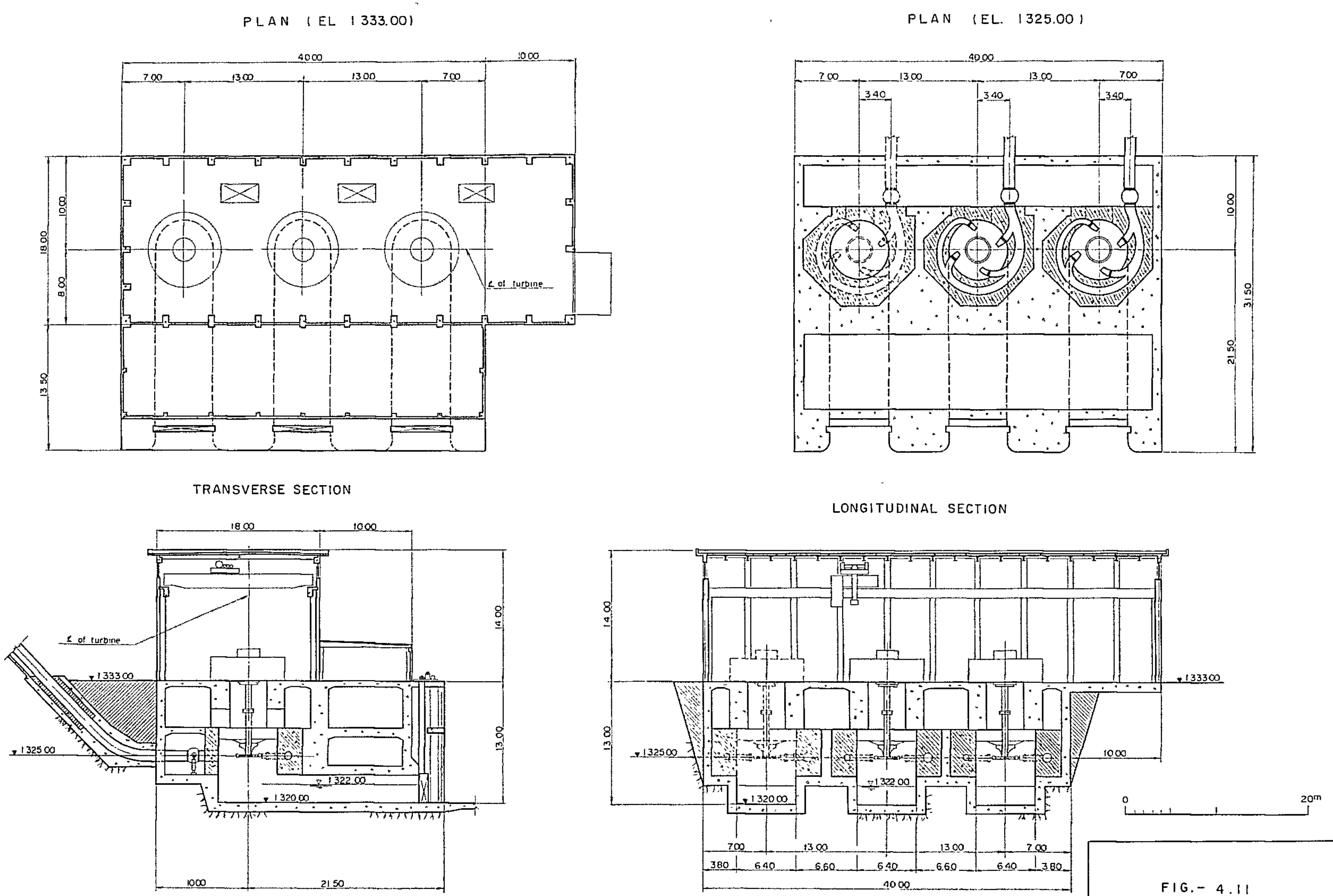


FIG.- 4.11

AGUAS CALIENTES POWERHOUSE

CHAPTER 5 GEOTECHNICAL INVESTIGATION AND GEOLOGICAL RECONNAISSANCES

5.1 Geotechnical Investigation Works

5.1.1 Drill Hole

The list and location of boring are indicated in Table-5.1 and Fig.-5.1 respectively. Boring will consist of 24 drillholes, a total length of 960 m. Permeability test shall be done in all of the drillholes at the dam site. The specifications of the boring and the permeabolity tests are indicated in Item 5.3.1.

Regarding boring at the surge tank and penstock sites, in case hauling in of drilling equipment to the sites is difficult, test adits may be substiuted.

5.1.2 Test Adits

The number of test adits to be excavated is indicated in Table-5.1 and the locations in Fig.-5.1. The number of test adits is to be a total of five, a total length of 140 m. The dimensions of the test adits are to be height of 2 m and width of 2 m.

5.1.3 Seismic Prospecting (Refraction Method)

The work quantity of seismic prospecting is shown in Table-5.1 and the locations in Fig.-5.1. Seismic prospecting is to be done at 5 measuring lines totalling 350 m at the damsite and 6 measuring lines totalling 1,470 m at the powerhouse site.

5.2 Geological Reconnaissances

In the second stage of the Feasibility Study, geological reconnaissance as discribing below shall be done.

5.2.1 Dam

Preparation of detailed geologic maps using the 1/1,000 surveyed topographic maps prepared by ENDE.

5.2.2 Headrace Tunnel

Preparation of detailed geologic maps using 1/10,000 aerial photographic maps.

5.2.3 Penstocks and Powerhouse

Preparation of detailed geologic maps using 1/1,000 surveyed topographic maps prepared by ENDE.

In addition to the topographical map (1/1,000) of Aguas Calientes site prepared by ENDE, additional mapping is to be made for the area as indicated in Fig.-5.1 to El. 2,000 m including the surge-tank site. And coordinates grids are to be entered in the topographical maps of the damsite and the Aguas Calientes site.

Table-5.1 List of Proposed Geological Investigation Works

Site		No.	Elevation (m)	Length (m) *	Direction	Remarks
Dam	Drill hole	R-1	1,780	40	S60°W, 50°	Water Pressure Test, Right Bank
		R-2	1,780	60	N60°E, 70°	ditto
		R-3	1,771	30	90°	ditto
		R-4	1,780	30	S60°W, 60°	ditto
		R-5	1,770	30	90°	ditto
		R-6	1,770	30	90°	ditto
		R-7	1,771	30	90°	ditto
		L-1	1,795	40	N60°E, 60°	Water Pressure Test, Left Bank
		L-2	1,772	40	90°	ditto
		L-3	1,772	70	S60°W, 45°	ditto
		L-4	1,776	30	N60°E, 50°	ditto
		L-5	1,770	30	90°	ditto
		L-6	1,770	30	90°	ditto
		L-7	1,775	30	90°	ditto
		Total: 14 holes 520 m				
	Adit	RA-1	1,785	30	S60°W, 0°	Right Bank
		RA-2	1,785	25	S60°W, 0°	ditto
		LA-1	1,775	30	N60°E, 0°	Left Bank
		LA-2	1,775	30	N60°E, 0°	ditto
		LA-3	1,785	25	N60°E, 0°	ditto
		Total: 5 adits 140 m				
Surge Tank	Drill hole	S-1	1,860	100 (50)**	90°	
Penstock		P-1	1,720	30 (20)	90°	
		P-2	1,570	30 (20)	90°	
		P-3	1,430	30	90°	
Power house		PH-1	1,341	40	90°	
		PH-2	1,329	40	90°	
		PH-3	1,334	40	90°	
		PH-4	1,350	40	90°	
		PH-5	1,339	40	90°	
		PH-6	1,334	50	90°	
		Total: 10 holes 440 m				

Site		No.	Elevation (m)	Length (m) *	Direction	Remarks
Dam	Seismic Prospecting	I		70		
		II		65		
		III		65		
		IV		70		
		V		80		
			Total:	5 traverses	350 m	
Power house		I		250		
		II		220		
		III		300		
		IV		250		
		V		250		
		IV		200		
			Total:	6 traverses	1,470 m	

* Length of drill hole and depth of test adit.

** Length of test adit when test adit substituted for drill hole in investigations for surge tank and penstock parts at high elevation.

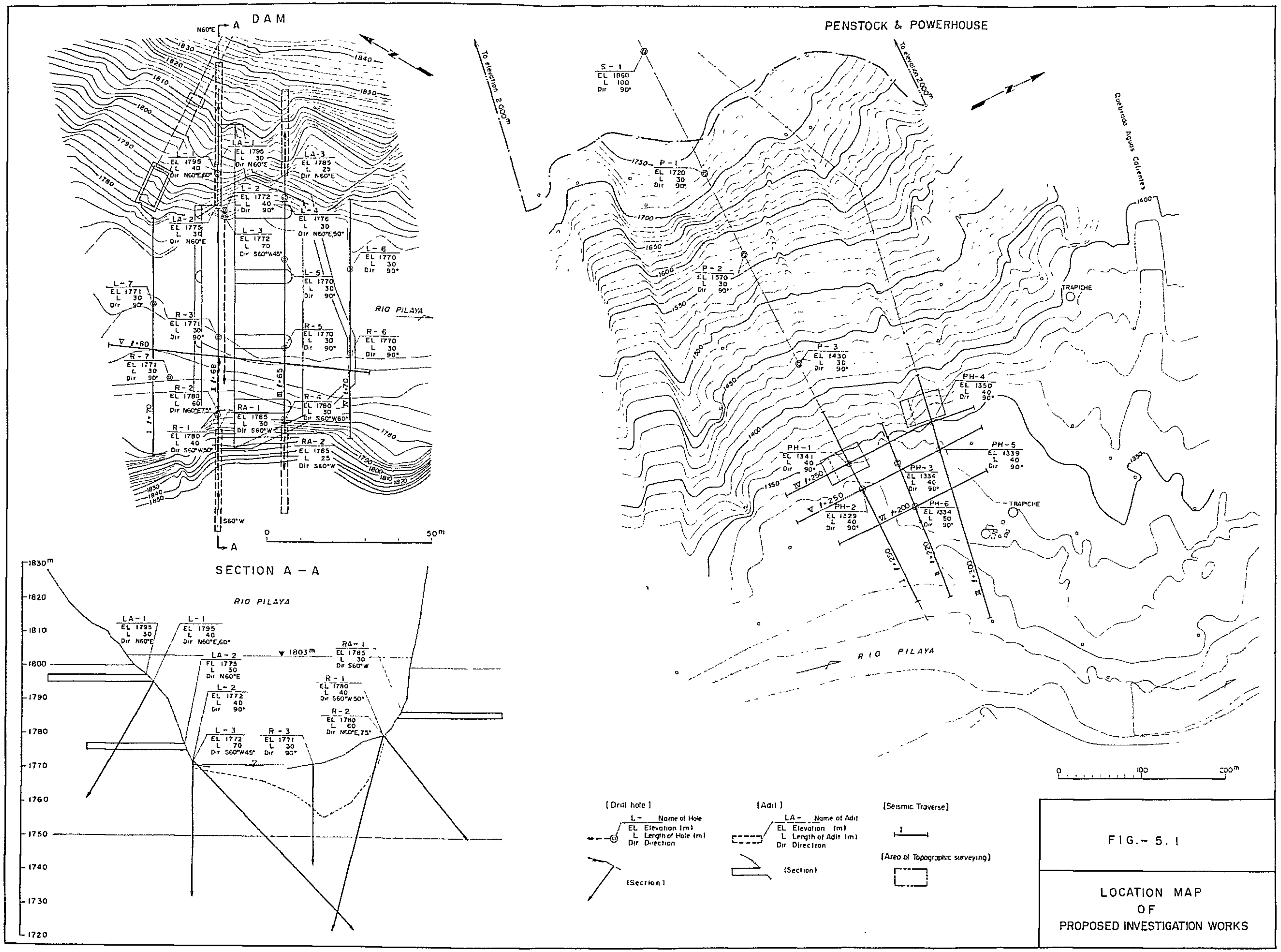


FIG.- 5. 1

LOCATION MAP
OF
PROPOSED INVESTIGATION WORKS

5.3 Specifications for Core Boring and Permeability Test

(1) Work Schedule, Personnel and Equipment

Prior to commencement of the Works, the Contractor shall submit for approval by the Employer a work schedule for boring and permeability test based on geologic conditions, professional history of chief of boring crew and a list of equipment to be used in the Works.

2) Drillers engaged in the Works shall be enough experienced and skilled in core boring with a high-speed boring machine and in permeability test using bore holes.

3) Equipment used for the Works shall conform to the following specifications:

a) Boring machine: High-speed boring machine capable of boring a hole to more than 100 m with a diameter of 66 mm at the end of the hole, furnished with a complete set of accessories including core barrels and diamond bits, suitable for achieving the best possible core recovery.

b) Pump: Discharging capacity over 150 ℓ/min. at the pressure of 10 kg/cm^2 with small pulse in discharging pressure and discharging amount.

c) Pressure gauge for water supply: Gauge of 0.5 kg/cm^2 graduate or smaller.

d) Flowmeter: An integrating flowmeter of gauge of 1 ℓ/min. graduate.

e) Packer: Extension (mechanical) packer shall be used except where rock conditions require leather packer.

f) Hole-water-level measuring instrument: Electrical water level measuring instrument with reading accuracy below 1 cm.

(2) Core Boring Procedure

1) Survey of boring location and installation of machines

a) The Contractor shall perform survey for boring spots from the datum points given in 'Location Map of Boring' by a method approved by the Employer and submit the survey results to the Engineer for his site verification of the survey results.

b) Boring machine shall firmly be settled on the spot to conform with the specified boring point, direction and inclination, in order to prevent shift during boring.

2) Boring and its record

a) Diameter of bore hole shall not be less than 66 mm.

b) The Contractor shall use bits and core barrels suitable to subsurface conditions and shall endeavor to attain 100% core recovery without spoiling the original subsurface conditions by adjusting bit pressure, drilling rotation, water supplying amount, length of each drilling shift and the like.

c) Prevention against collapse of drilling holes shall be taken by using the casing pipe or by cementation where such collapse is anticipated.

d) All the process of boring works shall be accurately recorded on the field note, transcribed in the daily report in a format approved by the Employer, and submitted to the Employer.

e) If the Contractor is evidently responsible for poor core recovery in the opinion of the Employer or if description in the daily report is not accurate in the opinion of the Employer, the Employer may order re-boring to the Contractor at the latter's expense.

f) Record of drilling shall be done in C.G.S. system of units.

g) RQD (Rock Quality Designation): For each section of 1 meter, the total length of cores not less than 10 cm long shall be measured and recorded in the daily report.

3) Arrangement and delivery of cores

a) Core in each drilling shift shall be measured for its clear length under the condition as it is in core barrel.

b) Core shall be directly transferred from core barrel into the corresponding section in depth of core box and firmly encased.

c) For sections incapable of core recovery, collection of slime, if possible, shall be done and the collected slime put in vinyle bag and encased in the corresponding section in depth of core box, or otherwise the vacant section of core box shall be protected against slide of the adjacent cores.

d) A core box shall be 1 m in inner length and comprise 5 or 10 rows.

e) Core box shall carry the name of the site, name of hole and number of box and depth marks at intervals of 10 cm.

4) Log of boring

The Contractor shall prepare log of boring based upon various phenomena which occurred in boring, measurements and observations of core. Log of boring shall be in the form approved by the Employer.

5) Photos of cores

Cores arranged in core boxes shall be pictured in color in each box. Photos shall be taken at a bright place shielded from direct rays of the sun. Dry cores shall be moistened with water on surface.

6) Measurement of water level in hole

Water level in hole shall be measured in cm every day before and after the work and recorded in the daily report.

7) Bore hole mark

Upon the completion of each boring wooden stopper shall be put into the hole and boring No. must be marked on the top of the wooden stopper.

(3) Permeability Test

Water pressure test shall be performed for the holes shown in Table 5-1.

1) The test shall be performed by the so-called 'Single Packer Stage Method', which inject limpid water into the

section of bore hole between the packer and the bottom of the hole.

2) The test shall be executed on rocks except topsoil, gravel and rocks where packer is difficult to set.

3) The length of each test section shall be 5 m, and yet may vary depending on the packer position which shall be determined as follows:

   a) Set the packer at the designated depth or at a place above that depth if there are cracks at that depth judging from observations of core.

   b) If water leakage into the upper part to the packer is inferred or observed after start of injection, the test shall be repeated after shifting packer position upward. But, at the first test nearby rock surface, water-tight position shall be selected by shifting packer step by step downward from the first point.

4) After completion of boring for test section, the inside of the hole shall be washed through a rod inserted to the hole bottom until muddy water and slime have been drained off.

5) The cycles of injection pressure shall be those shown in the table below to agree with the depths measured from the top of the hole to the packer:

Depth from Top of Rock Surface to Packer	Injection Pressure Cycle kg/cm^2
less than 5 m	1-2-3-2-1
from 5 m to 10 m	1-3-5-3-1
more than 10 m	1-5-10-5-1

The pressure designated here is that measured by a pressure gauge set near the top of the hole.

6) Measurement of injecting amount at each stage of injection pressure shall be started only when it is confirmed that the rate of injecting amount become constant after more than 10 minute preparatory injection.

7) Measuring time at each step of injection pressure shall be for 10 minutes.

   Measurement of injecting amount shall be performed every one minute and recorded in a format approved by the Engineer.

8) When injecting amount exceeds capacity of the pump at certain pressure, no further test shall be performed beyond that pressure.

   In such case, the packer's position shall be shifted downward to shorten the test section, on which injection test shall be executed according to the pressure cycles given herein.

9) Depth to hole bottom, position of packer, level of water table and height from top of hole to pressure gauge shall be accurately measured and recorded in the recording paper.

10) The test results shall be converted to Lugeon values for each injection pressure by the following equation.

The Lugeon values shall be recorded in the recording paper of drill log and arranged in a table.

$$Lu = \frac{10 \times Q}{PL}$$

Lu: Lugeon value

Q: Quantity of injecting water (ℓ/min.)

P: Effective injection pressure (kg/cm^2)

L: Length of test section (m)

The pressures indicated by the pressure gauge shall be modified for the effective injection pressure (P) by the following equation taking into account such factors as hydrostatic head between the position of the pressure gauge and the center of the test section, level of water table, loss of head by inner friction of rod:

$$P = P_0 + (h_3 - h_4) \times 0.1$$

P_0: Pressure indicated by pressure gauge (kg/cm^2)

h_3: See Figures in P.83 (m)

h_4: Loss of head by inner friction of rod (m): Hydraulically computed (For rod of 3 m length, inner diameter of 31 mm, length of joint 110 mm, inner dia. of joint 17 mm,

$$h_4 = Q^2\ \ell \times 10^{-4}$$

where, ℓ = injected length of rod)

(4) Delivery of Report

The Contractor shall submit to the Employer 5 copies of the report comprising the following items. The forms of report are attached herewith.

a) Boring location map (1/1,000 topographical map)

b) List of borings

c) Log of boring

d) Photos of cores

e) Records of permeability test and results of calculated Lugeon value

f) Curve of relation between pressure and water pumped-in at permeability test

The report shall be written in English.

WATER PRESSURE TEST IN DRILL HOLE   HOLE NO   Sheet NO.   of

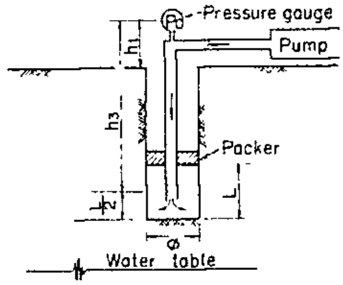
Feature   Project   Country

Location   Coordinates   Reporter

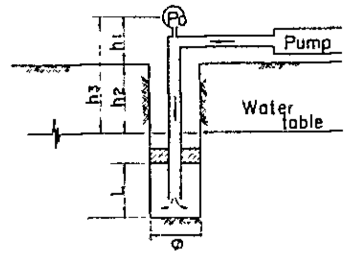
Date of test   -   - 19   Firm name (   )

Bore hole	Elevation of top	m	Diameter (φ)	mm, Size
	Dip	°	Bearing	
Test section	Stage NO		Geology	
	Depth of packer & hole bottom	m - m		
	Elev of packer & hole bottom	m - m		
	Length (L)	m		
Height of gauge (h_1)				
Water table (h_2)			Temperature of injected water	°C
Pump	Mfr model		Flow meter	Type	
	Max discharge	l/min		Min graduation	l
	Max pressure	kg/cm²	Pressure gauge Graduation	Min	kg/cm²
Type of packer		kg/cm²		Max	kg/cm²

Unsaturated strata



Saturated strata



- * Effective pressure (kg/cm²) $P = Po + 1/10\ (h_3 - h_4)$ h_4 – head loss
- ** Lugeon value (Lu) to be calculated by following equation
  Lugeon value (l/min/m/10kg/cm²) $Lu = 10\ Q/P\ L$

Time hr	Time min	Elapsed min	Gauge pressure Po(kg/cm²)	Effective pressure P(kg/cm²)	Water pumped-in Integrated (l)	Water pumped-in Sectional flow(l/min)	Water pumped-in Const rate of flow(l/min)	Lugeon value (Lu)	Remarks

Form A

ELECTRIC POWER DEVELOPMENT CO. Tokyo, JAPAN

WATER PRESSURE TEST IN DRILL HOLE HOLE NO. Sheet NO. of

Stage NO.		Depth of packer & hole bottom	m - m	Test length	m	Reporter

Time			Gauge pressure	Effective pressure	Water pumped-in			Lugeon value	Remarks
hr	min	Elapsed min	Po(kg/cm²)	P(kg/cm²)	Integrated (l)	Sectional flow(l/min)	Const. rate of flow(l/min)	(Lu)	

Form B

ELECTRIC POWER DEVELOPMENT CO, Tokyo JAPAN

Checked By

CORE BORING DAILY REPORT

Site ______ Boring NO. ______

Bearing and Angle of Hole ______

Daily Report NO. ______ Date ______ (Weather: ______) Hole Top EL. ______ m

Drilling time			Length of drilling	Depth of hole bottom	Core recovery		Hardness	Color of drained water or rock	Geology	Water pumped in	Water drained	Leakage	Remarks	Crown				Log	
From	To	Time			Length	%								Type	NO	rpm	Pressure applied	Geologic symbol	Elevation
h	h	min								l/min	l/min	l/min					kg/cm²		m

Miscellaneous work conditions

Borehole dia		Machine used	

Borehole water level m( )

Operating time ~

Boring superintendent	
Name	
Firm	

Category	Engineer	Technician	Laborer	Length advanced	Core length	Drilling time	Miscellaneous work time	Fuel		Supplies					
Today	Man-day .	Man-day .	Man-day .	m	m .	h	h								
Cumulative	.	.	.		.	.	.								

Note "Daily Report No" shall be put separately by each hole.

"Drilling time means actual drilling time, and time for inserting and lifting is not included.