CHAPTER 5 PRE-FEASIBILITY STUDY ON APOLO MICRO-HYDRO POWER PROJECT IN LA PAZ

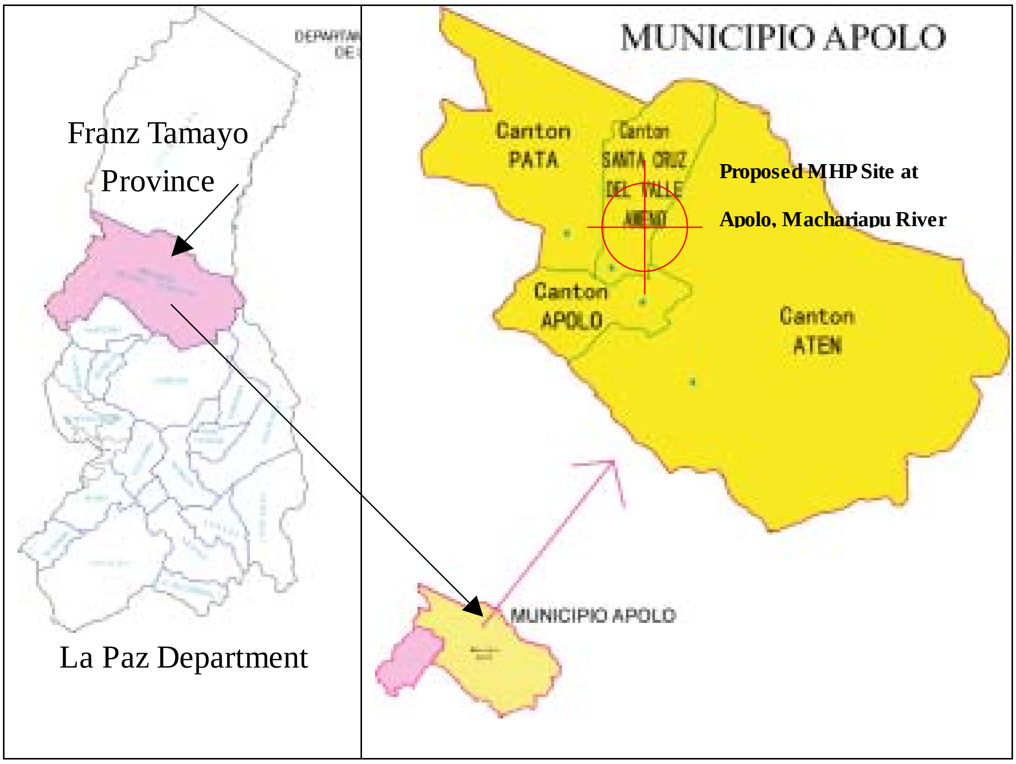
5.1 Location and Topography, Geology, and Hydrology

5.1.1 Location and Topography

(1) Location

The proposed site of Apolo is located at 382 km north from La Paz city and around 14 hours distance by vehicle.

The Apolo municipality is located in the province of Franz Tamayo, the department of La Paz. The municipality of Apolo consists of four (4) cantons, out of which Apolo canton is the largest having 39 communities. The micro-hydro site is located at Santa Cruz Del Valle Ameno. Cantons of Apolo and Santa Cruz are the area to be electrified by the proposed micro-hydro. The administrative map of Apolo including the project site is presented below:



Administration Boundary and Project Site

(2) Topography

The topography of the surrounding area of Apolo town is characterized by undulatory plain with scarce vegetation.

The project site is located at latitude 14° 36' S and longitude 68° 23' W. The proposed site for intake and power station is in the deep valley of the Machariapu River. Between the proposed intake site and outlet site there exists a steep ridge.

Overview of Proposed Project Site (Apolo,/F.Tamayo/La Paz)

5.1.2 Geology

The following geological map for the Apolo is available from SERGEOMIN (Servicio Nacional de Geologia y Mineria).

- "Centro de Investigacion y Aplicacion de Sensores Remitos Ciaser - Geobol", Estudio Integrado de Los Recursos Naturales del Departamento de La Paz, Geologia, Interpretado y Compilado por: Ing. Raul Ballon Ayllon, Mayo de 1985, Apolo.

The geological map of the site is presented in Figure 5.1. According to the map, the geological condition of the proposed site for the micro-hydro power is mainly classified *Carboniferous* as shown "C" in the map. The composition of the *Carboniferous* is as follows:

"C": *Carboniferous [Carbonifero]* (3.5 ~ 2.7 hundreds million years ago)

a) Gritty, limelight with thin diamictitas intercalations. (Altiplano and Oriental Mountain range)

b) Diamictitas, limelight, gritty, gritty conglome resides and diamictitas with intercalation of gritty and conglomerates in the superior part. (Subandino North)

At the lower layer of the *Carboniferous [Carbonifero]* and/or neighborhood, there might be another geological zone that was classified as *Devonian [Devonico]* and *Ordovician [Ordovicico]*. The compositions are as follows:

"D": *Devonian [Devonico]* (4.0 ~ 3.5 hundreds million years ago)

Shale, gritty and limelight

"O": *Ordovician [Ordovicico]* (4.9 ~ 4.3 hundreds million years ago)

Shale, gritty and limelight

According to the results of the field survey conducted in June and September, 2000, the geological condition of the bedrock at the proposed intake site is composed of sandstone (gritty), limestone and shale. Rocks at the site seem to have enough strength for tunnel construction and guarantee easy excavation.

	
Proposed Intake Site	**Proposed Entrance of Tunnel Site**

Proposed Intake and Entrance of Tunnel Site at Machariapu River (Apolo)

5.1.3 Hydrology

(1) Temperature

During the 1977-1996, the maximum average monthly temperature was 27.8 ^{o}C, while the minimum average temperature was 12.9 ^{o}C in July. Historical record of monthly mean temperature and humidity in Apolo is as presented in Table 5.1.

Monthly Maximum Temperature at Apolo

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1986	26.8	26.2	26.0	27.5	27.1	26.1	25.1	27.5	27.4	28.0	29.4	29.0
1987	26.9	28.6	28.8	28.5	25.4	25.6	27.4	28.2	27.4	29.1	28.0	28.7
1988	29.4	27.6	27.4	27.1	25.7	25.2	24.8	27.8	26.9	27.8	27.4	27.4
1989	27.5	26.7	26.7	26.5	24.4	26.2	25.7	27.6	27.4	28.7	28.9	27.9
1990	27.5	26.7	28.9	28.2	26.0	24.2	23.6	27.3	27.6	28.6	27.8	27.8
Average of 20 years	**26.6**	**26.3**	**26.4**	**26.1**	**25.3**	**24.3**	**24.5**	**26.1**	**26.9**	**27.8**	**27.4**	**27.4**

Source: SENAMHI Apolo (1996)

Monthly Minimum Temperature at Apolo

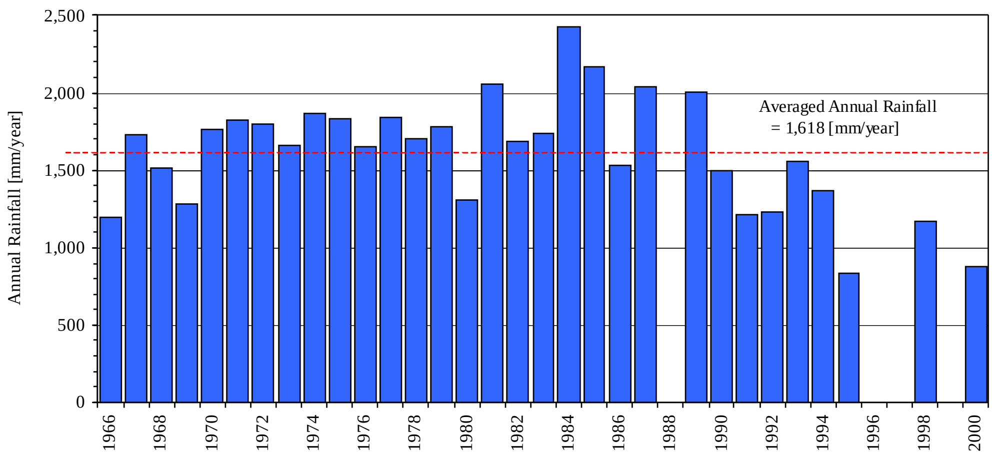
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1986	17.5	17.0	17.2	17.3	17.1	15.9	14.9	16.0	16.1	16.6	17.0	17.6
1987	17.4	17.2	16.7	16.9	15.3	13.8	14.8	14.1	15.0	15.8	18.0	17.0
1988	17.9	17.3	17.6	17.3	16.0	14.0	12.7	14.9	14.2	15.5	16.2	16.5
1989	16.6	16.4	16.2	15.9	14.6	14.7	12.3	13.8	14.5	15.7	16.1	16.9
1990	16.5	16.8	17.1	16.4	14.1	13.7	12.7	13.6	14.8	15.9	16.8	16.9
Average of 20 years	**16.5**	**16.1**	**16.1**	**15.6**	**14.8**	**13.5**	**12.9**	**13.8**	**14.2**	**15.5**	**16.2**	**16.5**

Source: SENAMHI Apolo (1996)

(2) Precipitation

The rainfall pattern is uniform and characterized by the distinct two seasons, rainy and dry seasons. According to the data from the National Meteorology and Hydrology Service in Bolivia (SENAMHI) the annual average precipitation in Apolo is 1,618 mm/year. About 76% of the annual precipitation concentrates in a period from October to March. The maximum monthly precipitation is 242 mm in January, while the minimum is 33 mm in July. Historical record of monthly precipitation in Apolo is as presented in Table 5.2.

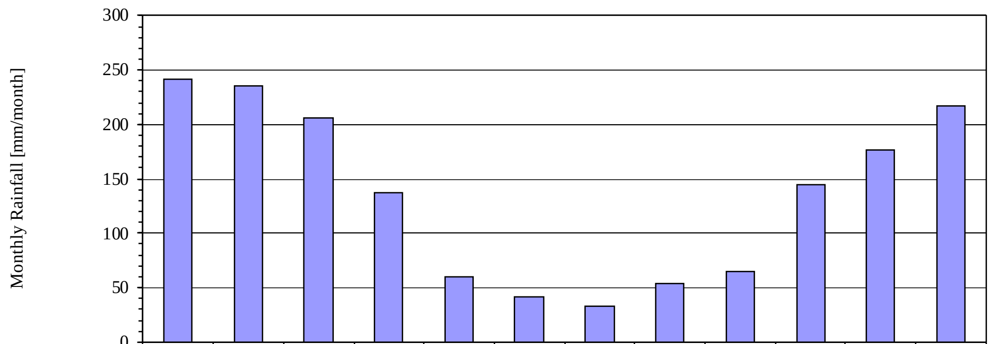
According to the rainfall record at Apolo airport (AASANA, EL 1,406 m) from 1966 to 2000, the annual rainfall in 2000 was the second driest year during the past 31 recorded years as shown in the following:



Source: SENAMHI, AASANA Aeropuerto de Apolo

Annual Rainfall at Apolo Airport (Apolo/ F.Tamayo/ La Paz)

The average monthly rainfall at Apolo airport is shown below:



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Ave.Monthly R	241.5	235.8	205.5	136.8	60.4	42.1	33.3	54.1	64.9	144.9	176.5	216.8

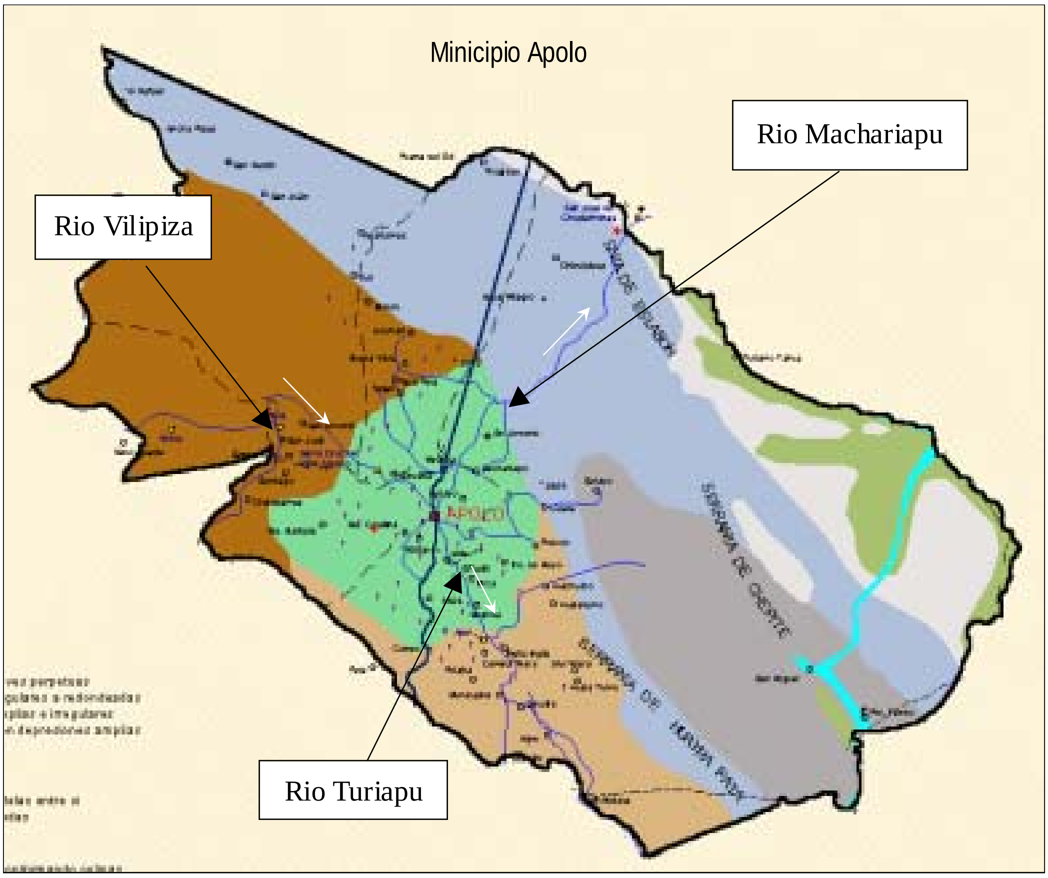
Average Monthly Rainfall at Apolo Airport (1966 - 2000)

(3) River Flow

The river system of Apolo comprises the following two sub-basins:

1) Turiapu River sub-basin: (Turiapu River to the south, Curisa River to the Southwest)

2) Machariapu River sub-basin: (Machariapu River to the north, Vilipisa River to the northwest)



River System of Apolo Municipality

Water level was measured on the daily basis using staff gauges installed at Turiapu River during the first field survey.

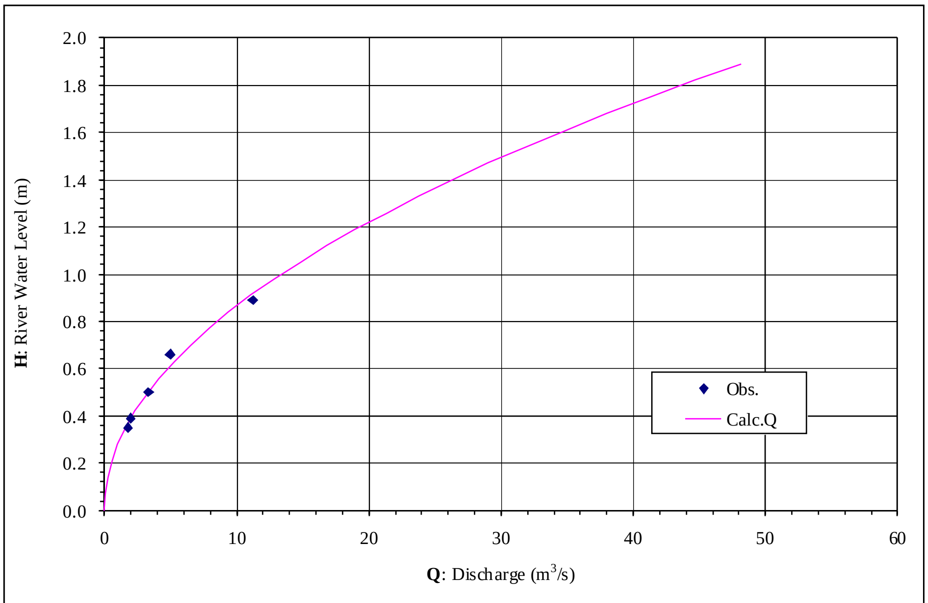
The results of the discharge measurement at the Turiapu River and the Machariapu River are summarized in the following table:

Department	Province	Municipality	Canton
La Paz	F. Tamayo	Apolo	Apolo

Name of River	Date (Year/ Month/ Day)	Obs. Q (m^3/s)	W.L. (m)
Rio Turiapu	1999/10/14	1.99	0.39
W.L. Station	2000/1/21	* 24.16	* 1.02
(U/S of Inca Bridge)	2000/6/3	4.97	0.66
(C.A. = 274.42 km^2)	2000/7/24	3.32	0.50
	2000/9/15	1.75	0.35
	2001/4/23	11.20	0.89
Rio Machariapu	2000/7/23	3.59	-
Propsed MHP Site	2000/9/14	2.67	-
(C.A. = 371.15 km^2)	2001/4/24	6.67	-

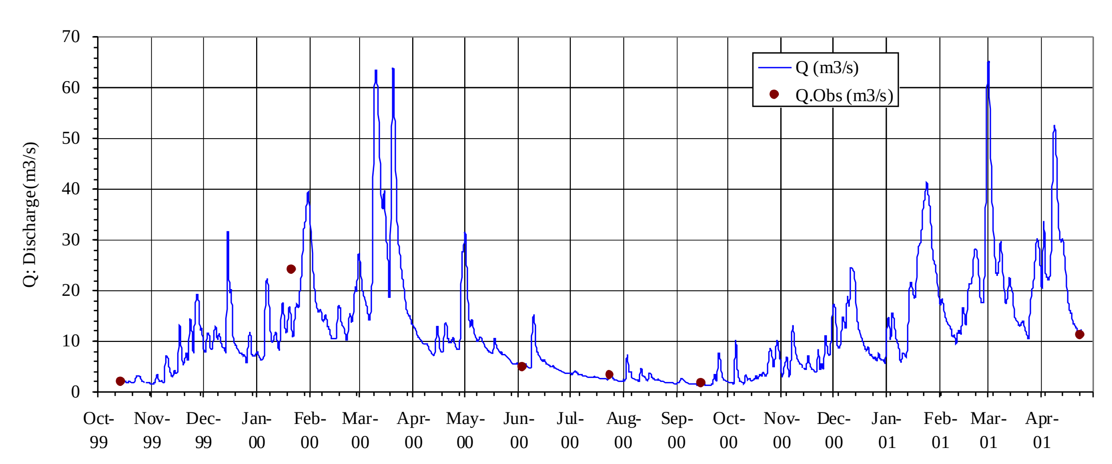
Source: JICA Study Team
Note * : Discharge was measured by float method due to the high water level.
The data measured (21 Jan.2000) were not used for preparation of H-Q curve.
Obs.Q: observed discharge, W.L.: river water level

Based on the collected data, H-Q curve (Water level and Discharge relation curve) was estimated at the Turiapu River water level station as shown below:



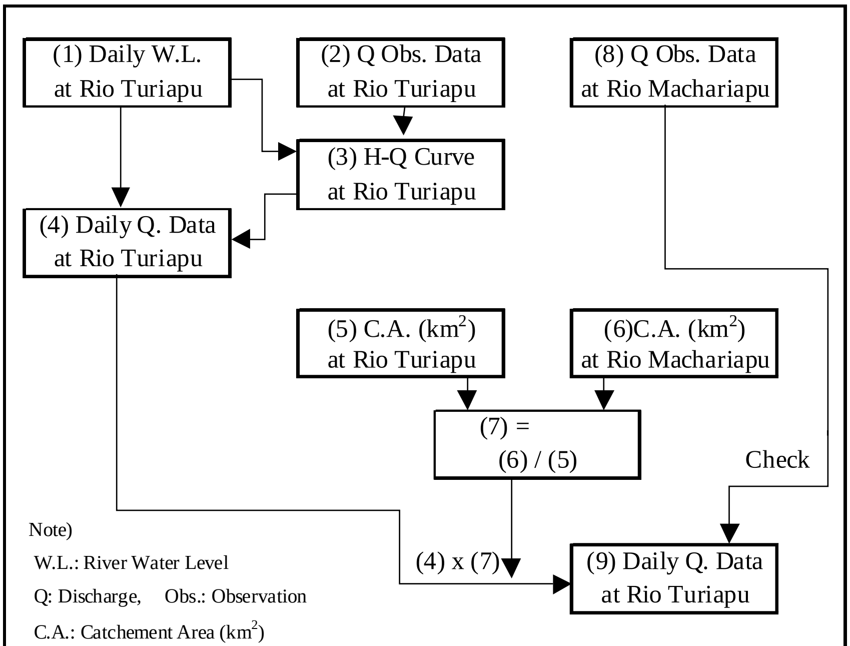
H - Q Rating Curve at Rio Turiapu/ Inca Bridge
(Apolo/ F.Tamayo/ La Paz)

The daily discharge hydrograph at Turiapu River was estimated using the above H-Q curve as shown below:



Daily Discharge at Rio Turipu WL.Station (Inca Bridge/ Apolo/ F. Tamayo/ La Paz)

The site for micro-hydro was finally selected in the Machariapu River during the third field survey. The water level data on daily basis was not available at Machariapu River. Therefore, the river flow at the proposed site of Machariapu River was estimated by referring that of the Turiapu River. The method of the estimation is described below:



Method of Estimation of Daily Discharge at Rio Machariapu MHP Site

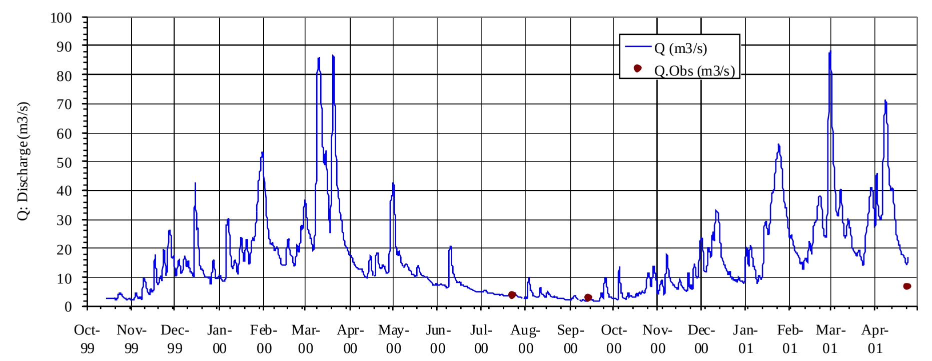
The catchment areas of the Turiapu River and Machariapu River were estimated as follows:

C.A. (km^2) at the Turiapu River W.L. station : 274.42 km^2

C.A. (km^2) at the Machariapu River MHP Intake site : 371.15 km^2

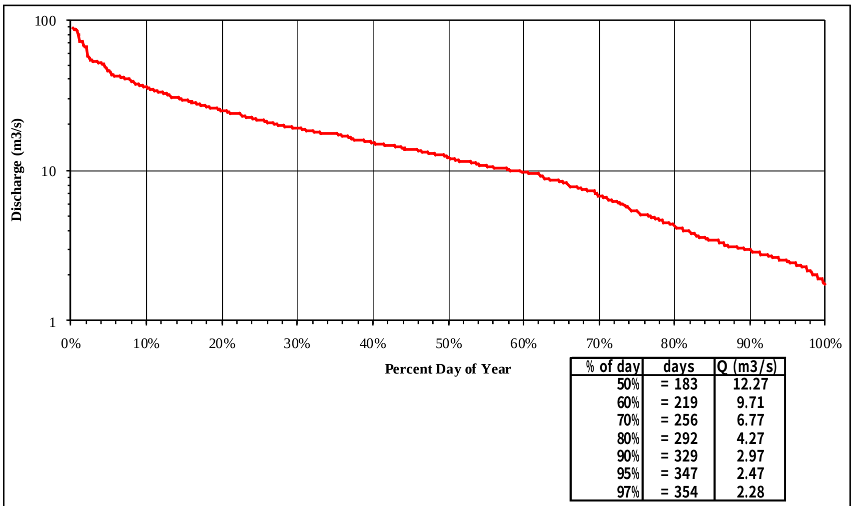
The location of the two catchment areas is shown in Figure 5.2.

Using these figures, the daily discharge hydrograph at the proposed intake site is estimated as presented below:



Estimated Daily Discharge Hydrograph at Rio Macharipu Propsed MHP Intake Site (Apolo/ F. Tamayo/ La Paz)

The flow duration curve at proposed intake site was also estimated as shown below:



Estimated Duration Curve at Rio Machariapu Proposed MHP Intake Site (Apolo/ F. Tamayo/ La Paz)

The water level staff gauge was installed in October 1999 at Turiapu River Inca bridge. The daily water level observation was conducted from 14 October, 1999 to 24 April, 2001 (18 months in total).

5.2 Socio-economic Conditions and Demand for Electricity

5.2.1 Socio-economic Conditions

For collecting basic data on socio-economy in Apolo a socio-economic survey was conducted by the JICA Study Team during June - September in 2000. The items of the socio-economic survey on Apolo are:

- Location and access
- Number of household and population
- Major economic source
- Economic infrastructure
- Social infrastructure

The results of socio-economic survey are summarized below:

(1) Population

The population of Apolo Municipality was 12,857 in 1992. About 54% of the municipal population or 6,989 are concentrated in the Canton of Apolo including urban areas.

Population Structure of Municipal Apolo in 1992

Canton	Population (1992)
Apolo	6,989
Santa Cruz del Valle Ameno	2,361
Aten	3,272
Pata	235
Total	**12,857**

Source: INE (1992)

(2) Local Economy

Agriculture still plays a dominant role in the local economy. About 46% of the land is used for grassland and cattle breeding is the main activity. About 14% of the land is used for cultivated (temporary and permanent) land where banana, citrus fruits and Yuca are the major crops produced.

Land Use in Apolo (1992)

Land Use (1992)	ha (%)
Grassland	5,669 (46)
Cultivated	1,703 (14)
Mountain	2,150 (17)
Fallow	1,125 (10)
Others	1,653 (13)
Total	12,300 (100)

Crop Production in Apolo (1992)

Crops	Cultivated Area (ha)	Production (M.T)
Banana	205	1,768
Citrus Fruits	92	624
Yuca	417	4,210
Coca	208	180
Coffee	268	214

Source: Pequeña central hidroelectrica de Apolo, Informe final, CORDEPAZ, Ingenieria Politecnica Americana SRL, 1994.

(3) Electricity

A diesel generator (222 kW) owned and managed by a cooperative is currently under operation in Apolo town. Electricity supply is restricted to the peak time (3 hours from 7 p.m. to 10 p.m.). Because of the fairly expensive tariff charged to consumers, the current number of users is just 300 with the peak demand of only 60kW. The capacity of the diesel (222 kW) is not fully utilized.

The average monthly household income is as low as Bs. 500 to 800 in Apolo town while monthly expenditure on electricity is Bs. 30 to 40. Thus, electricity is regarded as expensive goods for the majority of local people.

(4) Land Transport

Local network of land transport connecting Apolo is summarized as follows:

Route	Total (km)	Length of Pavement (km)	Distance to nearby Market (km)
Caranavi	382	176	382 La Paz
Sorata	420	184	335 Achacachi
Charazani	444	150	274 Escoma
Pelechuo	485	136	274 Puerto Acosta

Source: Pequeña central hidroelectrica de Apolo, Informe final, CORDEPAZ, Ingenieria Politecnica Americana SRL, 1994.

Four (4) roads connect the city of La Paz from Apolo, which are only passable during the dry season. Less than half of the above roads are paved.

5.2.2 Demand for Electricity

The target area to be electrified by the proposed micro-hydro project is determined depending on the hydropower potential. As the Machariapu River is endowed with abundant discharge, target area would encompass surrounding communities including Apolo town.

The scale of the project is determined by the future demand for electrification. Power demand in the future is affected by an increase of population and income. In this study, "population" is taken into account and purchasing power in the future is assumed to be the same as the current level.

(1) Target Area

Only a part of urban population in the Apolo town receives electricity service at present. The remaining communities including a part of Apolo town are not electrified yet. The potential target area for electrification is supposed to encompass cantons of Apolo and Santa Cruz del Valle Ameno where many communities remain non-electrified. The target area is divided into seven (7) blocks as presented below:

Block	Name of Block	Nos of Communities	
		Urban	Rural
A	Apolo central town	1	0
B	Apolo central town + Airport + Sta. Teressa	1	7
C	Sta. Cruz del Ameno	0	15
D	Sant. Domingo	0	7
E	Inca and San Pedro	0	8
F	San Jose de Mayo	0	5

G	San. Marcos and Altuncama	0	2
	Sub-total (B~G)	1	44

Note: Block B includes the area of Block A, airport and Santa Teresa village.

A more detailed map showing the target area is presented in Figure 5.3.

Target area consisting of seven (7) blocks accounts for 45 communities in total, one urban community plus 44 rural ones (Tables 5.3 and 5.4).

(2) Estimation of Households in 2005

a) Methodology

According to the INE (Instituto Nacional de Estadistica), the municipal population of Apolo during 1995-2000 was estimated as follows:

Year	1995	1996	1997	1998	1999	2000
Population	14,059	14,099	14,133	14,162	14,185	14,203

Source: INE

The municipal population is assumed to increase by the same rate observed during 1995-2000. Given the six (6) observation data on population, the future population of the target areas was projected using a regression model.

b) Projected Households in 2005

Suppose that the family size remains unchanged in the future, households would increase in proportion to population. Thus the number of households in the future were estimated as follows.

Block	Number of Households					
	1999 (Actual)			2005 (Estimated)		
	Urban	Rural	Total	Urban	Rural	Total
A	580	0	580	587	0	587
B	580	251	831	587	253	840
C	0	336	336	0	338	338
D	0	229	229	0	230	230
E	0	335	335	0	337	337
F	0	214	214	0	216	216
G	0	32	32	0	32	32
Total (B~G)	580	1,397	1,977	587	1,406	1,993

The numbers of households were 1,977 in the year of 1999 and are expected to increase 1,993 in 2005.

(3) Demand Projection

Projection of the demand for electricity in the target areas was made by separating it into domestic demand and non-domestic demand.

a) Domestic Demand

For estimating domestic demand, unit rates of power consumption were estimated both for urban area and rural area.

Given the number of electric apparatus (lighting bulb, radio, etc), unit rate of power consumption for the domestic was estimated at 267 W in urban and 135 W in rural area. In the estimate a day was divided into three periods, evening, midnight and daytime. The connection rate (how long electricity is consumed) was estimated in terms of percentage for each time range.

The estimated unit rates are summarized below.

Unit Rate of Power Consumption (for Domestic Demand)

	Urban Area			Rural Area		
	Evening	Midnight	Daytime	Evening	Midnight	Daytime
Unit Rate Pmax (W)	267	7	30	153	0	10.8

Details of the estimate are presented in Table 5.5.

Domestic demand for electricity in the target areas was estimated by multiplying these unit rates with number of household as summarized below.

(kW)

Block	Urban			Rural			Peak Demand
	Evening	Midnight	Daytime	Evening	Midnight	Daytime	
A	157.0	4.1	17.7	0	0	0	157.0
B	157.0	4.1	17.7	34.2	0	2.7	191.2
C	0	0	0	45.7	0	3.6	45.7
D	0	0	0	31.1	0	2.5	31.1
E	0	0	0	45.5	0	3.6	45.5
F	0	0	0	29.2	0	2.3	29.2

G	0	0	0	4.3	0	0.3	4.3
Total (B~G))	157.0	4.1	17.7	190.0	0	15.0	347.0

b) Non-domestic Demand

Power demand for business, industry and public was also estimated in the same way as domestic demand. Unit rates of non-domestic demand were estimated by classifying them into business, industry and public.

The detailed estimation of the unit rates for non-domestic demand is shown in Table 5.6 and summarized in the following. The demand in urban area is applied to Apolo town (block A) while the demand in rural area to other blocks (B-G) which belong to the rural area.

Category		Urban Area			Rural Area		
		Evening	Midnight	Daytime	Evening	Midnight	Daytime
Business	kW/block	14.00	0.81	1.33	9.57	0.44	1.00
Industry	kW/block	35.23	0.88	47.74	13.50	0.25	29.65
Public (Facilities)	kW/block	37.06	0.27	28.68	1.47	0.22	7.45
Sub-total	kW/block	86.29	1.96	77.75	24.54	0.91	38.10
Public (Streetlight)	kW/km/HH	0.04	0.04	0	0.06	0.06	0

c) Total Demand

Both domestic and non-domestic demands are aggregated to estimate total power demand, which is shown in Table 5.7 and is summarized below:

(kW)

Block	Urban Area			Rural Area			Peak Demand
	Evening	Midnight	Daytime	Evening	Midnight	Daytime	
A	267	30	95	0	0	0	270
B	267	30	95	75	17	41	340
C	0	0	0	92	23	42	90
D	0	0	0	70	16	41	70
E	0	0	0	92	22	42	90
F	0	0	0	68	15	40	70
G	0	0	0	31	3	38	40
Total (B~G)	270	30	100	430	100	240	700

Note: Numbers of total and peak demand are rounded.

The peak power demand in the target area is estimated to be around 700 kW in the year 2005.

5.3 Formulation of the Optimum Development Scheme

5.3.1 Approach to the Optimum Development Scheme

Approach to Formulation of Optimum Development Scheme of the micro-hydro power is shown in Figure 5.4.

The Apolo project endowed with abundant discharge guarantees electricity supply to an extensive service area. For selecting the optimum development scheme, incremental benefit and cost were measured for different scales of the project.

The target area to be electrified by the project is extensive, consisting of seven (7) zones. The term "optimum" is defined as the scale of the project generating the maximum net benefit (B-C). The scale of the project is determined by power demand. The following alternative cases for electrification were compared for the selection of the optimum development scheme.

Case-1	:	Apolo central town serving for 587 HH
Case-2	:	Case-1 + Airport + surrounding villages on the route of transmission line from MHP P/S to Apolo town serving for 840 HH
Case-3	:	Case-2 + Block F (San Jose) serving for 1,056 HH
Case-4	:	Case-3 + Block D (Sant. Domingo) serving for 1,286 HH
Case-5	:	Case-4 + Block C (Sant.Cruz.del.V.Ameno) serving for 1,624 HH
Case-6	:	Case-5 + Block E (San Pedro) serving for 1,961 HH
Case-7	:	Case-6 + Block G (San Marcos) serving for 1,993 HH

Note) HH: household

Power demand for the alternative cases was estimated as presented below.

Power Demand of Alternative Cases for Apolo MHP Project

Target Zone (Block Name)	Name of Block	No. of Electrified Communities: Urban (a)	No. of Electrified Communities: Rural (b)	Household (Estimated) in 2005: Urban (f)	Household (Estimated) in 2005: Rural (g)	Household (Estimated) in 2005: Total (h=f+g)	Proposed Transmission Line Length (km) (i)	HH/L Density (j=h/i)	Priority Rank (k)	Power Demand Total (kW) (l)	Case-1 A (kW)	Case-2 B (kW)	Case-3 B+F (kW)	Case-4 Case-3 +D (kW)	Case-5 Case-4 +C (kW)	Case-6 Case-5 +E (kW)	Case-7 Case-6 +G (kW)
A	Apolo Central Town only	**1**	**0**	587	0	**587**	**15.0**	**39.1**	**-**	**270**	270						
B	A + Apolo Airport + on the route (Cmd. Sta. Teresa)	**1**	**7**	587	253	**840**	**27.5**	**30.5**	**1**	**340**		340	340	340	340	340	340
C	Sta. Cruz del Ameno	**0**	**15**	0	338	**338**	**35.3**	**9.6**	**4**	**90**					90	90	90
D	Sant. Domingo	**0**	**7**	0	230	**230**	**17.0**	**13.5**	**3**	**70**				70	70	70	70
E	Cmd. Inca & San Pedro	**0**	**8**	0	337	**337**	**35.4**	**9.5**	**5**	**90**						90	90
F	Cmd. San Jose - 1 de Mayo	**0**	**5**	0	216	**216**	**13.5**	**16.0**	**2**	**70**			70	70	70	70	70
G	Cmd. San Marcos & Altuncama	**0**	**2**	0	32	**32**	**8.9**	**3.6**	**6**	**40**							40
	Total (B~G)	**1**	**44**	587	1,406	**1,993**	**137.6**	**14.5**	**-**	**700**	270	340	410	480	570	660	700

Source: JICA Study Team

Unless the Apolo micro-hydro power project is implemented, diesel generator would be the most likely scheme as an isolated power system for electrification in Apolo area. Cost saving by avoiding the investment in diesel power is regarded as the project benefit.

Both cost and benefit are discounted by the opportunity cost of capital to calculate present value of them and then the net benefit (B-C) to be calculated for each case. The project case attaining the maximum net benefit is regarded as the optimum development scheme.

5.3.2 Selection of the Optimum Scheme

To select the optimum scale of the project, cost and benefit were estimated in the following manner:

(1) Preliminary Cost Estimate

The project cost comprises 1) power investment cost, 2) cost of transmission and distribution line and 3) operation and maintenance cost.

a) Construction cost

The construction cost includes civil works, electrical-mechanical works and is preliminarily estimated. These costs are preliminarily estimated by estimating work quantities by using nomographs applied to scale optimization in Japan[*1] and unit cost of Bolivia at the present.
The estimated construction costs of micro-hydro power for alternative cases are shown in Table 5.8.

b) O&M cost

The operation and maintenance cost was estimated on the basis of the construction cost.

The estimated project costs including construction cost and operation and maintenance cost are summarized below:

Project Costs of Alternative Cases for Apolo MHP

(US$)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Civil/Mechanical/Electric Works	1,630,700	1,763,000	2,047,300	2,175,800	2,378,400	2,562,400	2,657,300
Transmission/Distribution	142,000	311,900	431,500	574,900	848,900	1,123,300	1,183,300
Total Cost	1,772,700	2,074,900	2,478,800	2,750,700	3,227,300	3,685,700	3,840,600
O&M per year	12,002	17,218	23,227	27,923	36,049	44,371	46,409

(2) Benefit

Daily load curve

Based on the present daily load curve, power (kW) and energy (kWh) demand in the future (target year of 2005) was estimated for different cases, which is shown in Figure 5.5. The pattern of power demand is identical for all cases.

Benefit

The benefit was estimated in terms of the cost saving of the alternative diesel power and comprises the following components:

*1 : Standard for Cost Estimation of Hydro Electric Power Development Plan and Optimization Study, Agency of Natural Resources and Energy, Ministry of International Trade and Industry Japan (1994)

a) Investment cost of diesel

The cost of generator was estimated based on unit cost per kW and installed capacity.

b) Distribution cost

Distribution lines are required for diesel power, the cost of which was estimated using the same rate applied to the micro-hydro power.

c) Fuel cost

Energy generation (kWh) was calculated for each alternative case based on daily load curve. The unit cost per liter is multiplied with fuel consumption (liter/kWh) to estimate fuel cost of diesel.

d) Operation and maintenance cost

The operation and maintenance cost of diesel generator was assumed to be 5% of the construction cost while that of distribution line to be 2.5% of capital costs.

Total benefit measured by the costs of diesel power is summarized below.

Project Benefit (Cost of Diesel Power) of Alternative Cases for Apolo MHP

(US$)

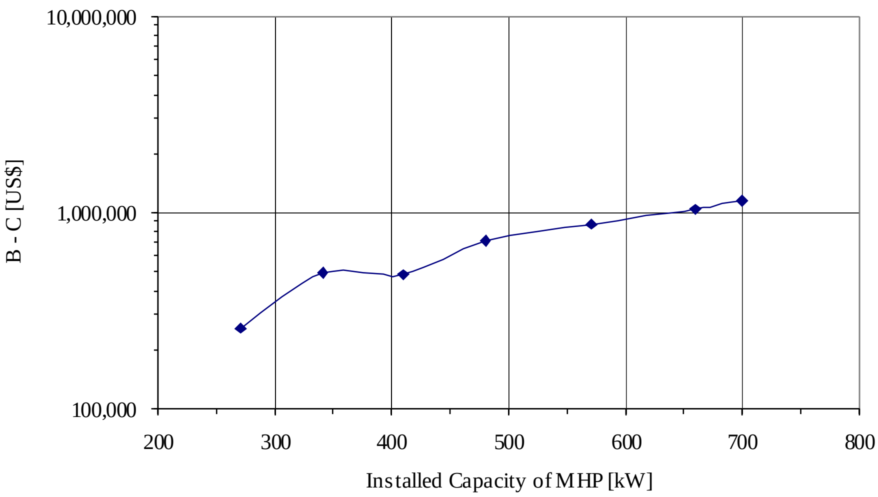
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Civil/Mechanical/Electric Works	206,827	259,327	311,827	364,327	431,827	499,327	529,327
Transmission/ Distribution	50,157	281,313	400,900	544,317	818,271	1,092,667	1,164,896
Total Cost	256,984	540,640	712,727	908,644	1,250,098	1,591,994	1,694,223
O&M per year	242,392	288,547	322,572	373,517	425,309	475,029	501,628

Details of the estimation of project cost and benefit are presented in Table 5.9.

(3) Selection of Optimum Scale

Based on the estimated cost and benefit, economic evaluation was made for selecting the optimum scale of the project. The results of the economic evaluation are presented in Table 5.10 and summarized below.

Case No.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	**Case 7**
P (kW)	270	340	410	480	570	660	**700**
EIRR (%)	12.4%	14.2%	13.6%	14.9%	15.3%	15.7%	**16.1%**
B–C (US$)	257,164	496,836	485,726	718,560	878,442	1,040,111	**1,154,299**
B/C	1.17	1.27	1.22	1.29	1.3	1.31	**1.33**



B - C (NPV) of Alternative Cases for the Apolo MHP Project

From the above analysis, the case 7 was selected as the optimum scale of the Apolo micro-hydro power project.

Potential power at the proposed intake site was estimated at more than 1.0MW at the 95% dependable discharge. However, in this study, the case for the development of more than 700kW was not considered because of the following reasons:

1) Incremental beneficiaries are quite limited due to the scattered and very low population, even if more than 700kW development is made with substantial cost of distribution line extension.

2) It is necessary to have the minimum return flow in the river for mitigating the environmental impact.

In due consideration of the above, the installed capacity of 700kW was selected as the optimum scale for the Apolo micro-hydro power project.

5.4 Preliminary Design and Cost Estimate

Preliminary design for the Apolo micro-hydro power project was prepared by JICA study team as follows:

5.4.1 Preliminary Design

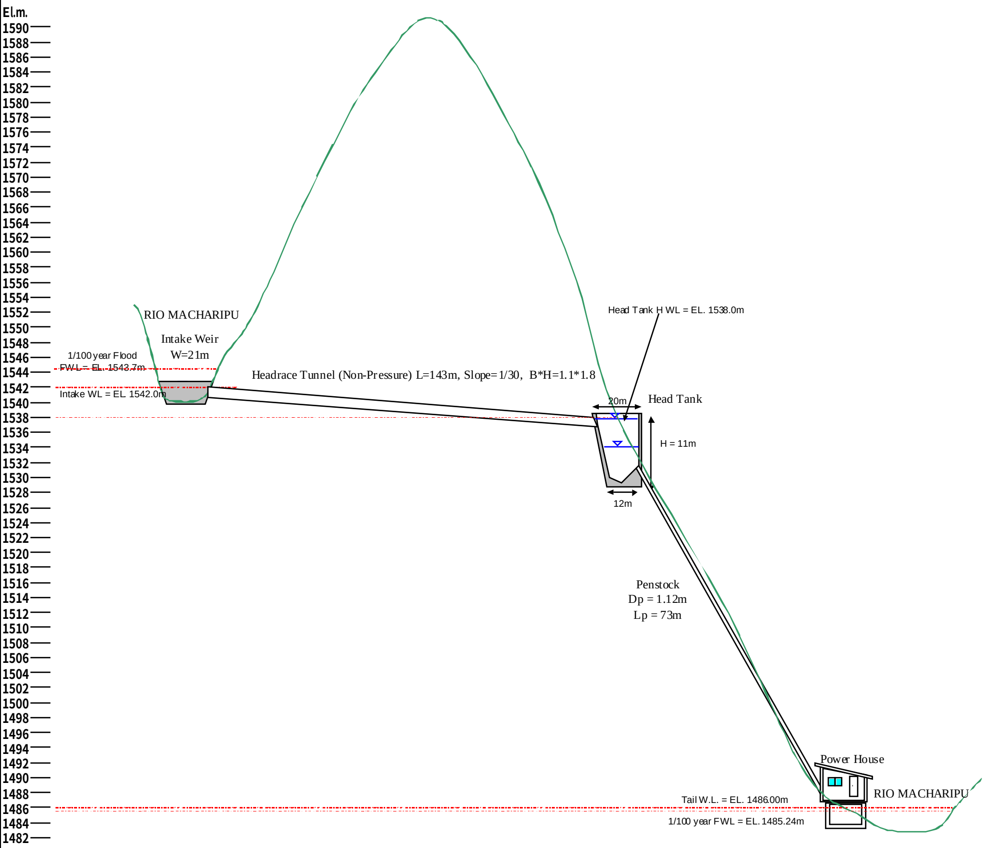
Proposed layout plan and preliminary design of the Apolo MHP is presented in Figure 5.6. Major items of the preliminary design are explained below.

(1) General Layout

The general layout of Apolo MHP project was planned in due consideration of following items.

- Catchment area
- Topographical and geological condition of intake
- Gross head
- Length of waterway (Headrace Tunnel, Penstock)
- Excavation volume and condition of waterway (tunnel, non- pressure (open)/ pressure)

The profile of the layout is shown below:



Profile of Waterway Route of the Apolo MHP Project

(2) Principal Features

Principal features of the project are shown below:

Principal Features of Apolo MHP Project

Items	Mark	Unit	Quantity	Note
Cathment area	C.A.	Km^2	371.15	
Discharge				
Maximum plant discharge	Qmax	m^3/s	1.815	
Firm Discharge	Qfirm	m^3/s	1.815	97% dependable discharge
Water level				
Intake water level	N.W.L	EL.m	1,542.00	
Tail water level	T.W.L	EL.m	1,485.50	
Head				
Gross head	Hg	m	56.50	N.W.L – T.W.L
Effective head	He	m	51.70	
Installed Capacity	P	kW	700	350kW x 2 unit
Annual Energy	E	MWh	6,132	

(3) Design of the Project

1) Intake weir and intake

Location of the intake weir and intake were determined considering the conditions of its foundation, riverbed stability against the erosion or sediment and minimizing the headrace tunnel.

- Weir type : bottom intake weir type (Tyrolean type)
- Design flood : 240 m^3/sec (100-year probable flood)
- Crest level : 1,542 EL.m
- Crest length : 21 m (Stop-log part=11.5m, Tyrolean intake part=10m)
- Maximum intake discharge: Q = 1.815 m^3/s

2) Sand Settling Basin

Since the headtank is planned close to intake, which will be used as a sand settling basin, a sand settling basin was not planned separately.

3) Headrace (Tunnel)

The headrace was designed as a non-pressure tunnel based on the topographic and geological condition of the project site. It was designed that the sand will be carried to the head tank through the steep slope (I=1/60) of headrace tunnel in order to prevent sand sedimentation in the tunnel.

- Type : tunnel (non-pressure type)
- Dimension : 1.8m (height) x 1.1m (width)
- Length / Slope : L= 143m / I = 1/60
- Method of excavation : Blasting method, carrying out by manpower

Bolivia has much experience of the tunnel excavation in mines. The method of excavation planned is using dynamite and manpower.

4) Head Tank

As mentioned above, water volume of the head tank was designed in order to have the function of a sand settling basin in addition to allowance of water volume for turbine operation. Water surface area of the head tank was designed more than forty times of the plant discharge to stabilize the water level of the tank.

- Design volume : $300m^3$
- Design area : $75m^2$ (> 1.815 x 40)

5) Penstock

The steel pipe was selected for the material of penstock considering the amount of the plant discharge and effective head.

- Type : Exposed type
- Material : Steel, Bending roll pipe
- Inner diameter : 1.1m (by applying Japanese nomogram)
  $Dm = 0.888 \times Qpmax^{0.370} = 1.1$ m
- Length : 74 m

6) Power house

The elevation of generator floor of power house was determined above the flood water level.. The inner area of the generator floor is designed considering the size of two turbines/ generators and some electric installations. The height of the superstructure for the power house was designed considering replacement of the turbine and generator for the maintenance. The height of substructure of the power house was designed considering condition of its foundation, capacity of tailrace bay and the size of draft tube.

a. Superstructure

- Structural type : Steel framed structure
- Size : 8.0m (width) x 23m (length) x 12m (height)

b. Substructure

- Structural type : Mass concrete structure

- Size : 8.0m (width) x 23m (length) x 5.5(height)

7) Tailrace

Since the water can be released to the river from tailrace bay directory, the tailrace was neglected.

(4) Turbine and Generator type

Taking into account the maximum plant discharge and effective head, a Francis turbine was selected. Two turbines and generators (350kW + 350kW) were proposed considering the stage-wise development of the project and required maintenance. Since the grid line of this project is isolated form national grid line, a three-phase alternating current synchronous generator was selected.

5.4.2 Cost Estimate

(1) Condition of the Estimate

The cost estimate was made on the basis of the following assumptions and conditions:

1) all the costs were estimated at the price level of June 2001;
2) equipment and materials imported includes related taxes;
3) construction work will be implemented under contract basis instead of under participation of local people;
4) cost of the administrative and engineering services was estimated at around 9 % of the direct construction cost;
5) IVA(13%) and transaction tax(3%) were additionally estimated as local taxes; and
6) Applied exchange rates are; US$ = Bs 6.53.

(2) Total Construction Cost

The estimated construction cost of the project is US$ 4.0 million as summarized in the following.

Construction Cost of Apolo MHP (Summary for Pre-F/S)

Financial Cost (with tax) Unit : US$.

Item	Pre-F/S Case (700kW)	Note
1. Preparation Works & Access, etc.	**625,300**	
1.1 Preparation Works	294,200	(2.+3.).*10%
1.2 Access Road	325,500	Gravel Paved, W=4m (Sta.Teresa - Site)
1.3 Mitigation for Environment	5,600	2.*0.01
2. Civil Works	**562,500**	
2.1 Intake Weir	19,300	
2.2 Intake	19,600	
2.3 Sand Settling Basin	0	
2.4 Headrace	195,200	
2.5 Head Tank	112,600	
2.6 Penstock	35,300	
2.7 Spillway	12,600	
2.8 Power House	153,700	
2.9 Tailrace	14,200	
2.10 Outlet	0	
3. Electric and Mechanical Woks	**2,379,600**	
3.1 Turbine/Generator	740,000	350kW x 2 set, include tax, transportation, installation
3.2 Transmission/Distribution Line	1,419,900	
3.3 Mechanical Works	219,700	
4. Transportation	**110,100**	(2.+3.2+3.3)*5% (La Paz - Apolo - Site)
5.Direct Cost Total	**3,677,500**	1.+2.+3.+4.
6. Administration and Engineering Service	**323,000**	{Admin.: (1.+2.+3.)*6%+D/D: US$20,000}*138%
Total Construction Cost	**4,000,500**	4. + 5.

Note: Access Road Cost = Mountain Area (Rock): 9.1km*30,000 US$/km + Flat Area (Standard): 3.5km*15,000US$/km

Details of the cost estimate of civil and electric/mechanical works are presented in Table 5.11.

5.5 Construction Schedule

In due consideration of the present situation in Apolo and required fund, two stage development was proposed. Stage-1 construction includes construction of all the civil works and one set of turbine and generator (350 kW) with the related transmission/distribution lines (for Block A and B), while Stage-2 construction includes construction of additional one turbine and generator (350k W) and the related transmission/distribution lines (for Block C, D, E, F and G).

Another aspect for preparing the construction plan is heavy rainfall during wet season in Apolo. Proposed construction plans to implement major civil works during dry season.

Assuming that required time for design including basic design is 6 months, total required period for completion of the project is around 4 years as presented in Figure 5.7.

5.6 Proposed Implementation Organization and O&M

The following implementation structure was proposed for sustainable development of the Apolo micro-hydro power project referring to the existing organizations for micro-hydro power projects.

5.6.1 Implementation Organization

A proposed organization for a project implementation of the Apolo micro-hydro power project is presented in Figure 5.8. Apolo municipality is responsible for the project implementation. Local consultants/NGO plays a leading role in the project implementation. The role of organizations related to the project implementation is summarized as follows.

DUF (fund source)

- to evaluate, approve and finance a project plan applied by Apolo municipality in cooperation with the VMEH

VMEH (technical support)

- to guide DUF for technical supports on rural electrification development when DUF evaluates the project plan applied by Apolo municipality

Apolo Municipality (implementing organization)

- to give a guidance of project scheme and user's responsibilities including initial payment and monthly fee for local people
- to make an agreement with the REC/cooperative after receiving the request of the rural electrification project
- to prepare a project plan with technical support of La Paz prefecture and/or consultants/NGO, and apply for the finance to DUF
- to select a consultant or NGO which manages and supervises the whole project implementation.

Consultant / NGO (supervision of the installation and training for operation and maintenance)

- to supervise installation of the system and carry out training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

REC/ cooperative (beneficiaries)

- to organize a rural electrification committee (REC) or cooperative after receiving the guidance of project scheme and beneficiary's responsibilities including initial payment and monthly fee through Apolo municipality and/or consultants/NGO
- to request the rural electrification project and make an agreement with Apolo municipality
- to provide labor force and some materials prepared in the community in kind
- to receive the training on the operation and maintenance for beneficiaries and technical assistants of REC

La Paz Prefecture (technical support or implementing organization)

- to support Apolo municipality for preparing the project plan when the municipality applies the plan to DUF
- In case of a project implemented not through DUF, La Paz prefecture is to be responsible for the project implementation in cooperation with VMEH.

5.6.2 Operation and Maintenance System

Proposed operation and maintenance system for the Apolo micro-hydro power project would be similar to the existing system because a well-organized system has already been established through cooperation with experienced NGOs and consultants for the operation and maintenance of micro-hydro power project.

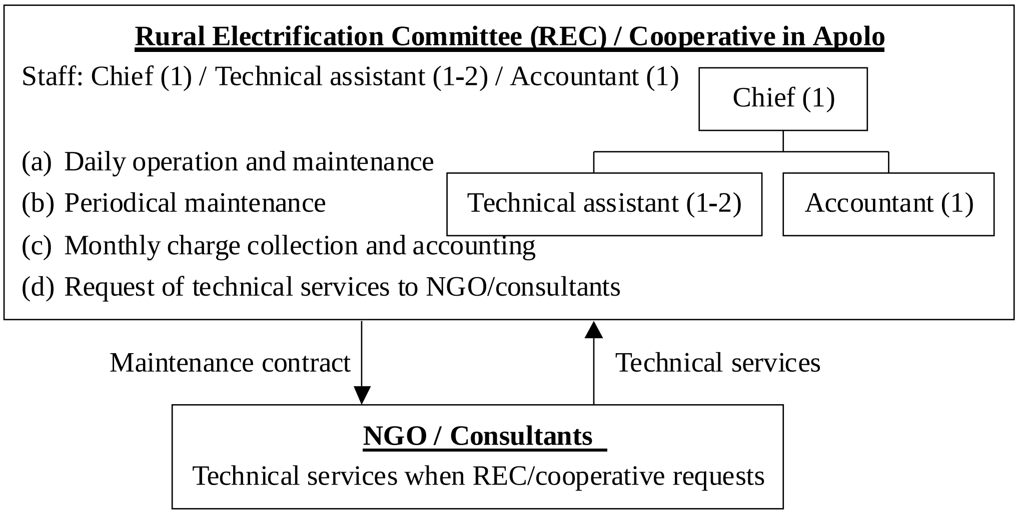
The technicians of REC/cooperative are to be trained on the operation and maintenance by NGO/consultants who are in charge of the installation during the project implementation. The REC/cooperative trained by NGO/consultants manages the daily operation and maintenance. The NGO/consultants carries out special maintenance services if REC/cooperative requests. Proposed operation and maintenance to be conducted by REC/cooperative and consultants/NGO is summarized as follows.

a) REC / cooperative

- to be responsible for the daily operation and maintenance
- to carry out the periodical maintenance
- to collect monthly charge and account
- to request technical services to NGO/consultants

b) NGO / consultants

- to provide REC/cooperative with technical services when requested (under a maintenance service contract).



In the operation and maintenance of micro-hydro power plant, the Manual should describe the essentials for operation, and the basic maintenance and inspection items for civil structures, electric facilities, and communication equipment. Operation and maintenance should be conducted based on the manual.

(1) Operation

The plant should be operated based on the operation manual, which specifies the operation procedures during normal operation and the countermeasures required in the event of any abnormality. Operators are required to observe the following:

- Be constantly aware of the conditions of the transmission system and of the load both inside and outside the power plant in order to take speedy and appropriate measure in response to any accident.
- Operation of equipment should be confirmed by the chief operator.
- Check all related instrumentation, display lamps and indicators, both before and after operating each and all components.

- Follow the safety standards at all times. Prevents which may result in injury or death. Improve the equipment and facility as required.

a) Precautions during normal operation

During operation, in addition to the monitoring of all instruments, the power plant should be patrolled at least once a day. The followings are the key check items during normal operation:

- Vibration of abnormal noise of equipment
- Lubricant and cooling water levels and temperature
- Abnormal instrument indication
- Generator load conditions including voltage, electric current, output, etc.
- Performance of compressors and oil pressure pumps
- Abnormality of equipment and other installations inside and outside the plant

b) Key items before start-up

When restarting the turbine and generator after a long shutdown period due to inspection or repair, visual inspection and simple tests and measurements must be conducted to check. The major activities are described below.

- Moisture absorption on the generator coil
- Rust or oil leak on the water tubes and the bearings
- Foreign matter intrusion
- Defective wiring during the said inspection or repair
- Measure the insulation resistance of each circuit
- Inspect the cooling equipment, brushes, regulators, oil pressure supply system, speed governor peripherals and other components

Should the generator automatically stop due to an accident, determine the cause and repair the defect. Ensure complete recover. Restart the operation.

c) Key steps to shutdown

- At parallel off, the generator circuit breaker if opened after main current is set to zero.
- At shutdown, apply brake at approximately 1/3rd rated rotating speed. Prevent long operation at low rotation.
- Stop the cooling water. Close the generator air duct shutters.
- Patrol the plant after shutdown.
- Provide anti-dewing measure for long shutdown.

d) Countermeasures against hazards

During flood, it is recommended that the generator be stopped and the intake gates be closed to prevent sediment and driftwood from entering the waterway.

Depending on the seismic intensity, an earthquake could adversely affect the entire power plant facilities. It is, therefore, necessary to inspect (inspect for cracks, breakage, tilting and other structural damages, the turbine and generator shaft centers, electric components and other facilities) all components and facilities.

e) Other precautions

- Operation should be conducted within and operative range depending on the discharge and the head. When the river discharge is extremely few, the operation shall be stopped in order to prevent unnecessary wear of the runner.
- Where multiple units are installed, the number of units to be operated should be controlled depending on the inflow, specifically to avoid operation at low level. The operations manual should be prepare by fully understanding the role of the plant.
- Loading in stages is recommended when starting plant operation in an isolated power system as this plan. If the entire load is loaded at once, the generator may trip due to momentary overload.

(2) Maintenance

For the operation of the micro-hydro power plant and to prevent accidents, it is necessary to conduct patrols and inspections of civil structures and electric facilities. It is also important that the results of these inspections and measurements be recorded and stored in the specified forms. These records are then used to determine the operational trends and patterns of the said equipment and facilities.
It is recommended to conduct the periodic inspections simultaneously for the equipment and facilities that require a turbine/ generator shutdown to minimize the shutdown period.

a) Patrol

Patrols are conducted to detect abnormalities in the civil structures/ electric facilities and to assess the surrounding conditions. As explained above (1)-a), it is recommended to pre-determine the patrol route and carry it out approximately once a day.

b) Inspection

The inspections of civil structures and electric facilities are generally classified below.

Classification and Frequency of the Inspections for Civil Structures

Classification			Explanation	Frequency
Inspe-ction	Periodic inspection	Visual inspection	Visual inspection is conducted to determine the conditions of civil structures, to detect any abnormalities and to check their performance.	Approximately once every month
		Internal inspection	Internal inspection is conducted by denaturing the waterway to inspect the presence of any abnormalities of channel interior and to observe the functions of water way.	Approximately once every year
	Emergency inspection	Emergency inspection	Emergency inspections are conducted before and after earthquakes, floods, heavy rain, etc., as deemed necessary.	whenever it is necessary
		Emergency detailed inspection	Emergency detailed inspection is conducted when deemed necessary after a patrol, visual inspection, internal inspection, or emergency inspection.	whenever it is necessary

Classification and Frequency of the Inspections for Electric Facilities

Classification			Explanation	Frequency
Inspe-ction	Periodic inspection	External inspection	The turbine and generator are shut down during this inspection to check for abnormal and to check their performance.	Approximately once every year
		Internal inspection	The turbine and generator are overhauled, thoroughly cleaned and repaired to restore their performance. It is recommended that the inspection cycle be so set as to consider the inspection results and the operation conditions.	Approximately once every five years
	Emergency inspection	Emergency inspection	Emergency inspection is conducted when an abnormality or problem occurs in an electric component. The turbine and generator are shut down during this inspection.	whenever it is necessary

Expressly after flood, sediment, leaves or driftwood should be taken clear at the intake, waterway, head-tank.

The major periodic inspection items of civil structures and electric facilities are listed in below tables.

Inspection Items of Civil Structures

Facility		Installations	Inspection items
1. Intake weir		Weir	Damage, frost damage, and cracks on surface, etc.
		Peripheral valley slope	Cracks, collapse, landslide, scouring, etc.
		Other facilities	Damage, loss, rust, etc.
2. Waterway			
(1)	Intake	Intake	Damage, deformation, cracks, frost damage, abrasion, scouring, screen clogging, etc.
(2)	Headrace	Peripheral bedrock	Collapse, landslide, spring water, etc.
		Headrace interior	Leakage, spring water, cracks, scouring, deformation, sedimentation, paint film deterioration, etc.
(3)	Head tank	Head tank	Damage, deformation, cracks, frost damage, abrasion, scouring, etc.
		Peripheral bedrock	Collapse, landslide, spring water and other abnormalities
(4)	Penstock and spillway	Steel penstock	Damage, deformation, settlement, etc.
		Penstock and Spillway conduit	Damage, deformation, vibration, leakage, paint film deterioration, tec., on pipe shell and saddle
		Peripheral bedrock	Collapse, landslide, spring water, etc.
3. Powerhouse			
(1)	Powerhouse	Foundation and peripheral structures	Deformation, cracks, spring water, etc.
(2)	Tailrace	Tailrace	Damage, deformation, cracks, frost damage, abrasion, scouring, etc.
4. Other installations			
(1)	Spoil bank	Peripheral bedrock	Collapse, landslide, spring water, etc.
(2)	Access road		Surface conditions, abnormalities on retaining wall, bridge and other structures and their state
(3)	Screen	Screen	Damage, deformation, loose fixing bolts, paint film deterioration, etc.
(4)	Gate	Gate guide	Damage, deformation, etc.
		Gate and hoist	Damage, deformation, abrasion, greasing, paint film deterioration, etc.
		Switchboard terminal (incase of automatic controlled gate)	Abnormalities and the state of switchboard terminal, wiring, electro-magnetic switch contact relay performance, insulation resistance, etc.
		Other components (incase of automatic controlled gate)	Conditions of indicators, switches, display lamps of each component

Inspection Items for Electro-mechanical Facilities (External Inspection)

Component	Inspections	Inspection items
1. Turbine	Turbine internal	Inspect and measure for abrasion, crack, erosion, and rust on the runner, guide vane and casing interior. Check the bearing lubricant quality.
2. Speed governing device	Mechanism	Inspect for abrasion of movable parts, loose wiring/ lever, and strainer overhaul.
	Controller	Inspect the conditions of the printed circuit board and position transducer. Measure the insulation resistance.
3. Inlet valve	Inlet valve internal	Measure leakage. Inspect for abrasion and erosion. Measure sheet surface clearance. Inspect position indicator conditions.
4. Oil pressure supply and lubrication oil system	Performance	Measure load operation time. Test oil quality.
	Oil filtration	Test oil quality.
5. Water supply and drainage system	Strainer overhaul	Inspect abrasion and erosion.
6. Automatic turbine control system	Performance test of all relays	(Performance test of all relays)
7. Generator	Generator internal	Inspect for loose electric circuit terminals, discolored, peeled or loose coil, abrasion and damage to slip ring, loose and rusted revolving part. Measure brush contact pressure and the insulation resistance of electric circuit.
	Control system	Inspect for shoe abrasion loss and operation state.
	Neutral grounding resistor	Measure resistance and insulation resistance.

5.7 Economic and Financial Evaluation

5.7.1 Economic Evaluation

The economic viability of the Apolo micro-hydro power project is examined by computing the Economic Internal Rate of Return (EIRR), which is calculated based on the following assumptions.

(1) Basic Assumptions

1) Project Life

The life of the proposed project is assumed to be 20 years after the three-year construction period, taking into account the economic life of the turbine/generator, the main facility of the projects.

2) Price Level and Price Escalation

All the costs and benefits are estimated at the price level of June 2001. Price escalation is not included in the evaluation in order to derive the EIRR net of price escalation impact.

3) Exchange Rate

The applied exchange rates are:

US$1=120.5 Yen = 6.53 Bolivianos

The analysis is made and shown in US dollar.

4) Economic Cost

Economic costs are derived by taking the domestic taxes and subsidies from the financial costs.

<u>Economic Project Cost</u>
Economic project costs are estimated as shown in Table 5.12 and summarized in the table below.

Economic Project Costs of the Apolo MHP Project (US$)

Preparation Workds and Access, etc.	539,000
Civil Works	484,900
Turbine/Generator	633,600
Transmission/Distribution Lines	1,183,300
Mechanical Works	189,400
Transportation	94,900
Administration and Engineering Service	278,400
Total Investment Cost	3,403,500

Source: JICA Study Team

Economic Life of the MHP System

Economic life of the major facilities is estimated as follows.

Economic Life of Major Equipment

Turbine/Generator	20 Years
Transmission/Distribution Lines	20 Years

Residual value of all the equipment is assumed to be zero as they will be used up to their economic life.

Economic O&M Cost

Annual operation and maintenance costs of the project facilities are estimated as follows.

Turbine/Generator:	2% of the investment cost
Civil Work:	0.5% of the cost
Transmission/Distribution Lines:	2.5% of the investment cost

Estimated economic construction cost and O&M cost are shown in Table 5.13.

5) Economic Benefit

Economic benefits are derived by taking the domestic taxes and subsidies from the financial costs (Table 5.14).

The costs of the least-cost alternative system, i.e., a diesel engine powered generation system with the capacity to generate the same amount of electricity as the proposed micro-hydro power, is considered to be the economic benefit.

Investment Cost of the Diesel Generation System

Investment cost of the alternative diesel generation system is estimated as follows.

Investment Cost of the Diesel Generation System

	Unit	Unit Cost	Apolo	
			Units	Cost
Capacity of the Diesel Generator	kW	750	700	525,000
Automatic Transfer Switch	-	1,910	1	1,910
Protection Box	-	917	1	917
Building	-	1,500	1	1,500
Transmission Lines	km	5,833	141	824,425
Distribution Lines	km	3,417	100	340,471
Total	-	-	-	1,694,223

Source: JICA Study Team

O&M Cost

Annual operation and maintenance costs of the alternative diesel generation system are estimated as follows.

Diesel Generation System: 5% of the investment

Transmission/Distribution Lines: 2.5% of the investment

Diesel Oil Cost

Economic cost of the diesel oil in Apolo is 3.88 Bs. per litter. Annual diesel oil cost is calculated based on the estimated power generation as summarized in the table below.

Annual Power Generation and Diesel Oil Cost

Power Generation (kWh/Year)	2,680,925
Fuel Consumption (Litter/Year)	750,805
Diesel Oil Cost (US$/Year)	446,114

Economic Life of the Diesel Generation System

Economic life of the major facilities is estimated as follows.

Economic Life of Major Equipment

Diesel Generator	10 Years
Automatic Transfer Switch	10 Years
Protection Box	10 Years
Building	10 Years
Transmission/Distribution Lines	20 Years

Residual value is estimated to be zero as all the equipment is to be used up to their respective economic life time.

(2) Results of Economic Analysis

1) EIRR

The EIRR of the Apolo micro-hydro power project on the basis of the above assumptions are computed to be 19.2% as in Table 5.15, using the economic cost and benefit stream shown above. It indicates that the proposed project is economically viable.

2) Sensitivity Analysis

Sensitivity analysis to examine flexibility of the proposed project in economic viability is made under the following adverse assumptions of key factors. The Apolo micro-hydro power project demonstrates sufficient economic viability even under the adverse conditions as follows.

Case I	+10% investment cost and -10% diesel fuel cost	16.6%
Case II	+20% investment cost and -20% diesel fuel cost	14.5%

5.7.2 Financial Evaluation

The financial viability of the Apolo micro-hydro power project is examined by computing the minimum power tariff to cover the investment and O&M costs of the project.

(1) Basic Assumptions

Financial evaluation of the proposed project is examined based on the following assumptions. Assumptions such as project life, price level and escalation, exchange rate, economic life of the equipment and O&M costs are the same as in the case of the economic evaluation.

1) Financial Project Cost

Financial project costs are estimated to be as follows.

Financial Project Costs of the Apolo MHP Project (US$)

Preparation Workds and Access, etc.	625,300
Civil Works	562,500
Turbine/Generator	740,000
Transmission/Distribution Lines	1,419,900
Mechanical Works	219,700
Transportation	110,100
Administration and Engineering Service	323,000
Total Investment Cost	4,000,500

Source: JICA Study Team

The tax rates included in the financial costs are summarized below.

Taxes for Domestic Products

VAT (Value Added Tax):	13% for all the categories of products
Transaction tax:	3% for all the categories of products

Taxes for Imported Products

Effective VAT:	14.94% for all the categories of products
Import tax:	5% (turbine/generator)
	20%* (transmission/distribution lines)

* Adjusted rate in consideration of the different products used to produce distribution lines

2) Power Demand

Power demand by the sector is summarized in the following table.

Power Demand (kWh/Year)

	Residential	Non-Residential	Total
Number	1,993	-	-
Average Demand	322	-	-
Total Demand	642,400	2,038,525	2,680,925

3) Calculation of Power Tariff to Cover the Investment and O&M Costs

Minimum power tariffs of the residential sector to cover both the investment cost and O&M cost are calculated as follows. The power tariff from the non-residential sector is assumed to be 50% higher than that of the residential sector.

The minimum power tariff is calculated by annualizing the investment by multiplying CRF (Capital Recovery Factor) of respective discount rates, adding annual O&M cost, and then dividing it by annual power demand.

Minimum Power Tariff to Cover Investment and O&M Costs (US$)

Discount Rate	10%	20%
Residential per kWh	0.05	0.08
Residential per Month	1.27	2.12

(2) Results of Financial Analysis

At present, the diesel generation cooperative in Apolo receives subsidy on diesel oil for approximately Bs. 3.45 per litter. Residential users of the diesel generation system, however, pay as much as Bs. 30., or US$ 4.59 per month for the service. Since each residential user of the micro-hydro power project in Apolo is estimated to use 322 kWh per year, the monthly payment even with the discount rate of 20% would be US$ 2.12 (0.08 US$/kWh x 322 kWh / 12 months), which is still less than 50% of the amount they pay at present. The micro-hydro power project in Apolo is concluded to be financially viable.

5.8 Initial Environmental Evaluation

The study on Initial Environmental Evaluation (IEE) was conducted during the fifth field survey in May 2001. According to the results of survey, no serious impact is anticipated in implementing this micro-hydro power project. Expected environmental impacts of the project are summarized in the table below. Local people will receive not only rural electrification but also the following socio-economic benefits in the target area.

- to promote irrigated agriculture with water pumping system and cottage industry for getting cash income,
- to give local people more convenient public services including education and public health in public facilities, and
- to improve safety and order at night for rural life.

A change of hydrological situation is anticipated as a moderate impact due to the decrease of water volume of the Apolo River and impacts slightly on the flora in the limited area of the riverside. Organizations of project implementation and the operation and maintenance are to monitor the natural condition around the project site during the construction stage and the operation.

IEE Matrix for Apolo Micro-hydro Power Project, La Paz

Item			Evaluation	Remarks
Social Environment	1	Resettlement	-	
	2	Economic activities	○	Irrigated agriculture with water pumping system and cottage industry will be promoted.
	3	Traffic and public facilities	○	Public facilities including schools and hospitals will be electrified.
	4	Split of communities	-	
	5	Cultural property	-	
	6	Water rights/Right of common	-	
	7	Public health condition	○	Clean water will be provided by water pumping system.
	8	Waste	-	
	9	Hazards	○	Lighting will enhance safety at night for rural life.
Natural Environment	10	Topography and geology	△	Topography will change in a small part of project site.
	11	Soil erosion	-	
	12	Groundwater	-	
	13	Hydrological situation	□	Water volume of the river will decrease.
	14	Coastal zone	-	
	15	Flora and fauna	△	Some plants will be influenced in the limited area of the riverside.
	16	Climate	-	
	17	Landscape	-	
Pollution	18	Air pollution	-	
	19	Water pollution	-	
	20	Soil contamination	-	
	21	Noise and vibration	△	Noise will occur in the construction stage.
	22	Land subsidence	-	
	23	Offensive odor	-	

Notes: ○= Positive impact, - = Negligible impact, △= Minor impact, □= Moderate impact, × = Serious impact, ? = Not clear
This IEE study was implemented by an environmental consultant registered by the Ministry of Sustainable Development and Planification in May, 2001.
The study report of this IEE was submitted to the the Ministry of Sustainable Development and Planification through the Vice Ministry of Energy and Hydrocarbons.
Source: JICA Study Team

CHAPTER 6 PRE-FEASIBILITY STUDY ON TAMBO QUEMADO MICRO-HYDRO POWER PROJECT IN ORURO

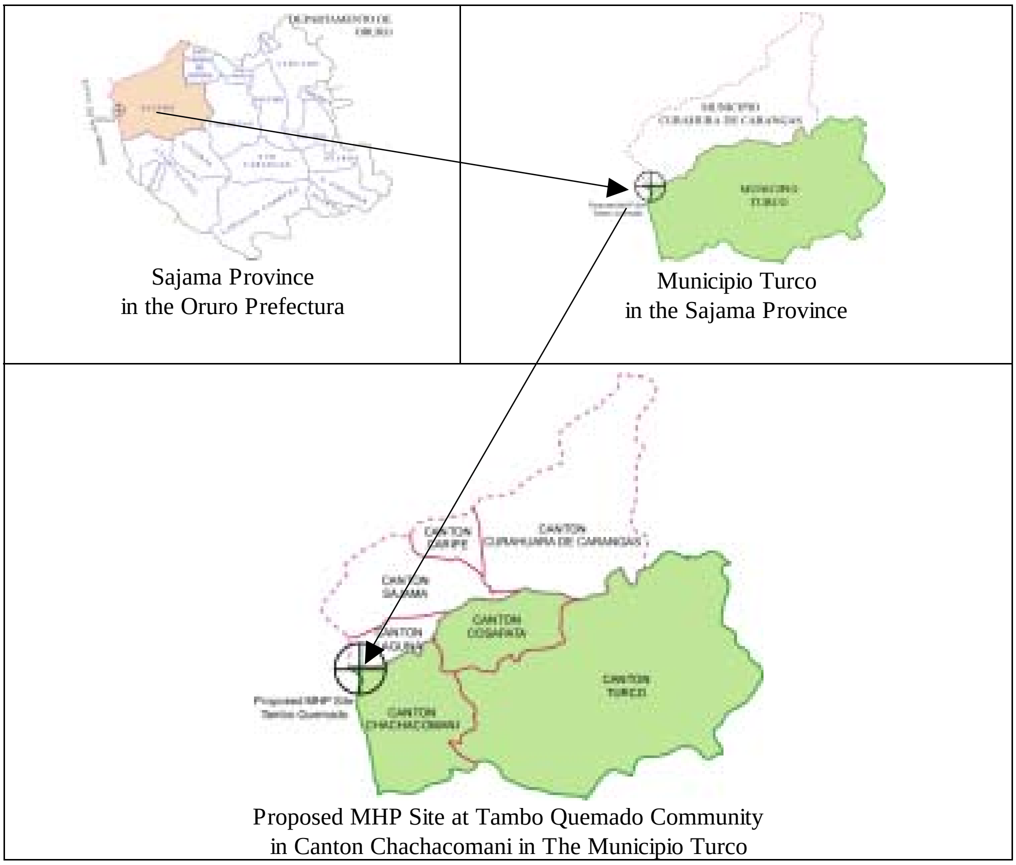
6.1 Location and Topography, Geology, and Hydrology

6.1.1 Location and Topography

(1) Location

The proposed site of Tambo Quemado is around 200 km west from Oruro city and around 5 hours distance by vehicle.

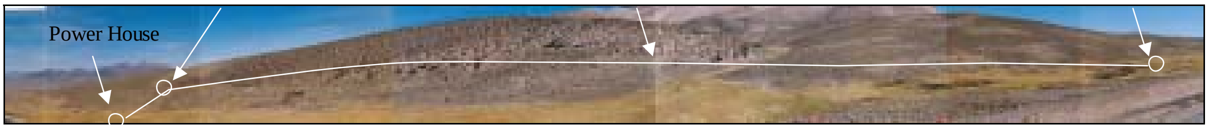
Tambo Quemado is located in the municipality of Turco, the province of Sajama, the department of Oruro. The municipality of Turco consists of three (3) cantons, namely, Turco, Cosapata and Chachacomani. The Tambo Quemado village is the target area to be electrified by the proposed micro-hydro. The administrative map of the Tambo Quemado including the project site is presented below.



Location Map of Proposed Tambo Quemado MHP Site

(2) Topography

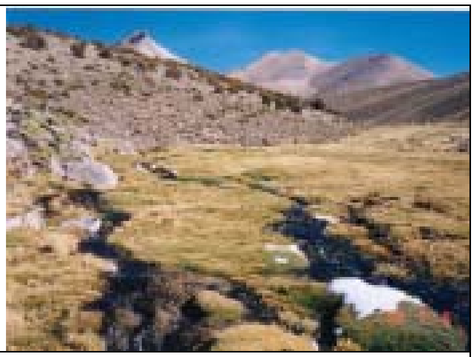
The proposed site of Tambo Quemado is located at latitude 18^{o} 17' S and longitude 69^{o} 02' W in the zone of the Sajama National Park. The National Park includes the snow-covered Mt. Sajama (El. 6,542m). The elevation of proposed intake site is around El. 4,500.



Overview of Proposed Micro-Hydro Power site at Tambo Quemado River (Chachacomani/Turco/Sajama/Oruro)

6.1.2 Geology

The field survey was conducted at the proposed site in September, 2000 and January, 2001. The geology of the proposed intake site consists of volcanic alluvial sand/gravel and peat soil. The geological map of the site is presented in Figure 6.1.

	
Proposed Intake Site-1 (Left)	**Proposed Intake Site-2 (Right)**

Proposed Intake Site of Tambo Quemado Micro-Hydro Power (Sajama/Oruro)

6.1.3 Hydrology

(1) Temperature

According to the meteorological data observed at Sajama from 1960 to 1990, the highest monthly average temperature was recorded at 6.8 ^{o}C in November, while the lowest temperature at 1.9 ^{o}C in June.

(2) Precipitation

According to the data from the National Meteorology and Hydrology Service in Bolivia (SENAMHI) the annual average precipitation is 327 mm. About 97% of the annual precipitation concentrates during the period from October to March, while the remaining 3% on April to September. The highest record of precipitation is 108 mm observed in January, while precipitation is nil from June to August. The observation of the meteorological station at Sajama was stopped after 1990.

Monthly Average Precipitation at Sajama (30 Years)

Station : Sajama Altitude : 4,220 m Period : 1960 - 90
Latitude : 18 08 S Longitude : 68 59 W

	Unit	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Precipitation	**mm**	108	80	49	2	1	0	0	0	1	9	20	57	327
T (mean)	**°C**	5.3	5.3	4.9	3.7	2.5	1.9	2.7	3.0	4.6	5.4	6.8	6.0	4.3
Hum. Rel	**%**	53	53	52	50	50	47	43	43	43	43	47	48	47.7
V wind	**m/s**	2.8	2.8	2.8	2.8	3.2	3.6	3.6	3.6	3.6	3.6	3.2	3.2	3.2

Source: SENAMHI and "Plan de Manejo del Parque Nacional Sajama", Estudio de Hidrologia, Informe Final, Jorge Molina Carpio, La Paz, 17 Junio 1996.

(3) River Flow

A staff gauge was installed at the Jaruma River during the first field survey in November 1999. The daily water level was measured until October 2000.

Results of the discharge measurement at the Jaruma River and Tambo Quemado River are summarized in the following table.

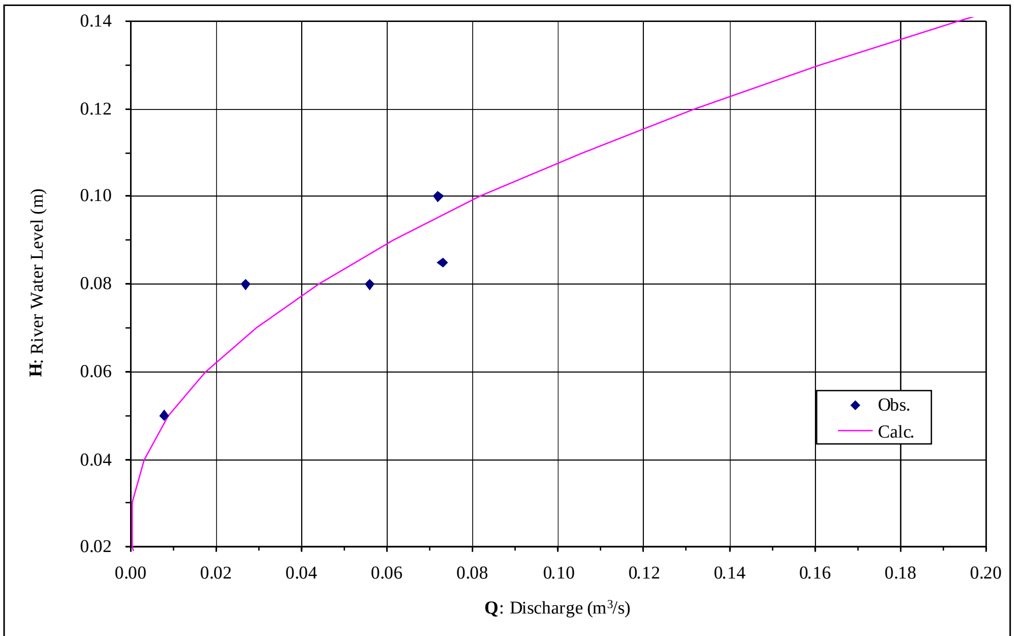
Department	Province	Municipality	Canton
Oruro	Sajama	Turco	Chachacomani

Name of River	Date (Year/ Month/ Day)	Obs. Q (m^3/s)	W.L. (m)
Rio Jaruma	1999/9/9	0.04	N.A.
W.L. Station	1999/11/6	0.06	0.08
(C.A. = 19.5 km^2)	2000/1/30	0.07	0.10
	2000/6/10	0.03	0.08
	2000/9/9	0.01	0.05
	2001/1/20	0.07	0.09
Rio Tambo Quemado	2000/6/9	0.07	N.A.
Proposed MHP Site	2000/9/9	0.06	N.A.
(C.A. = 15.2 km^2)	2001/1/20	0.09	0.23

Sorce: JICA Study Team
Note: "N.A." not available because the staff gauge was not installed.
Obs.Q: observed discharge, Q: discharge, W.L. river water level

The number of observed discharge data at Jaruma River and Tambo Quemado River are not enough to evaluation of hydrological conditions. Therefore, it is required to carry out continuous measurement of water level and discharge measurement for the two water level stations.

Based on the collected data, H-Q curve (Water level and Discharge relation curve) was estimated at the water level station of the Jaruma River as shown below.



H - Q Rating Curve at Rio Jaruma (Sajama/Oruro)

The site for micro-hydro was finally selected at the Tambo Quemado River during the third field survey. The water level data on daily basis was not available at Tambo Quemado. Therefore, the river flow at the proposed site of the Tambo Quemado River was estimated by using river flow data of the Jaruma River.

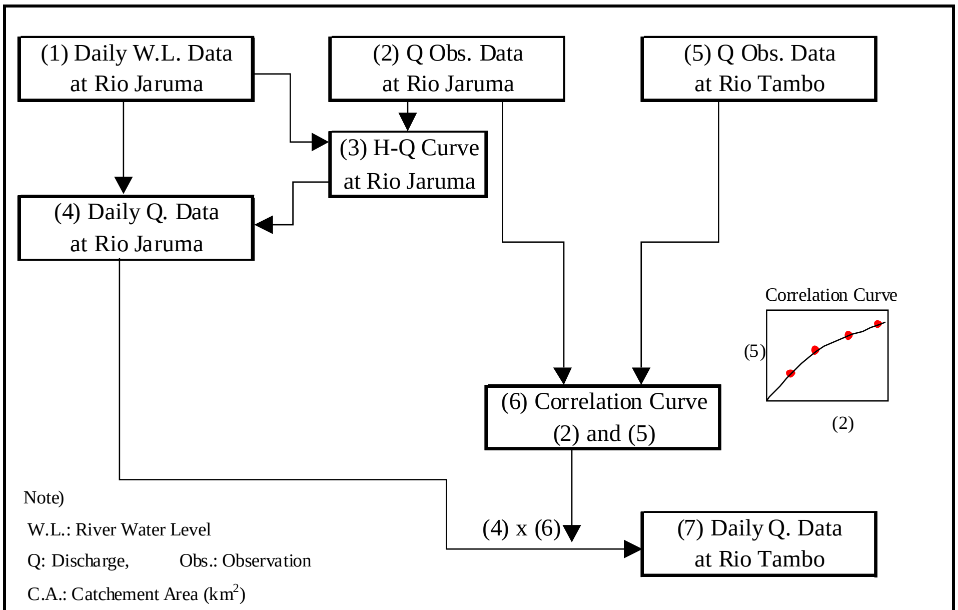
The catchment areas of the two rivers were measured as follows:

C.A. at the Jaruma River water level station : 19.5 km^2

C.A. at the Tambo Quemado River MHP Intake site : 15.2 km^2

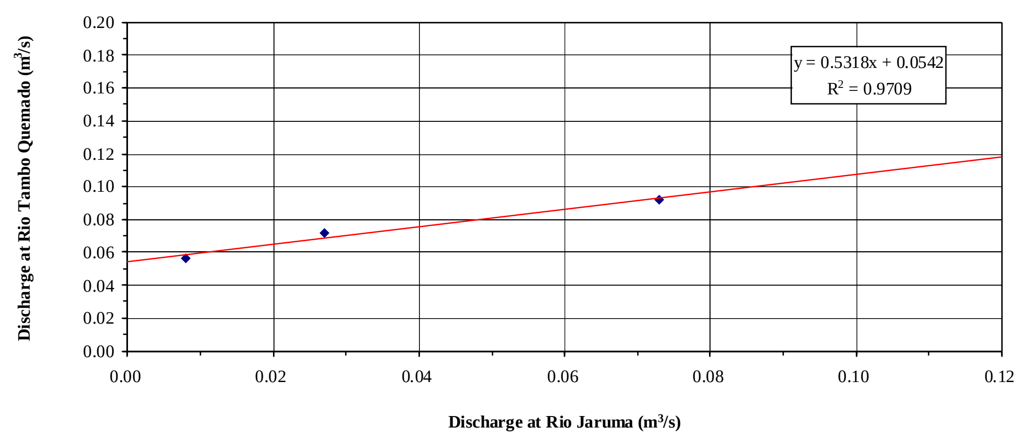
The location of the two catchment areas is shown in Figure 6.2.

Discharge of the Jaruma River is smaller than that of the Tambo Quemado River though the catchment area of the Jaruma River is larger than that of the Tambo Quemado River. Therefore, the estimation of daily discharge at the Tambo Quemado River was made using correlation as shown in the following.



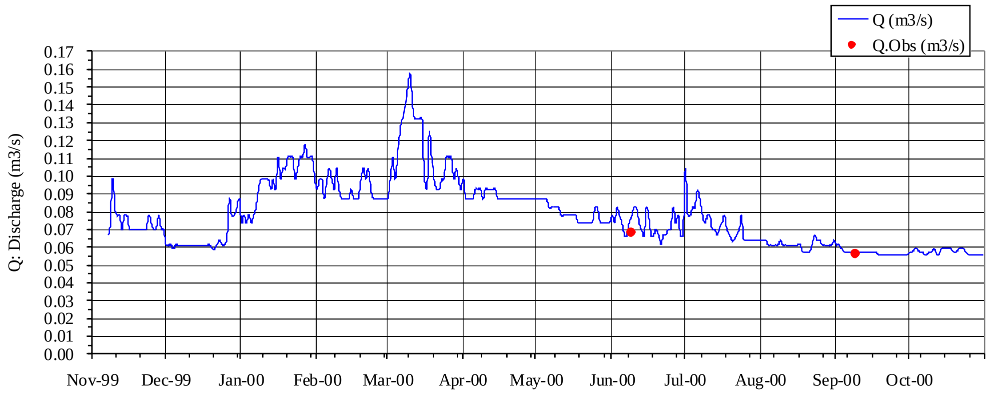
Method of Estimation of Daily Discharge at Rio Tambo Quemado MHP Site

The correlation between the observed discharge at the Jaruma River and the Tambo Quemado River is as shown below.



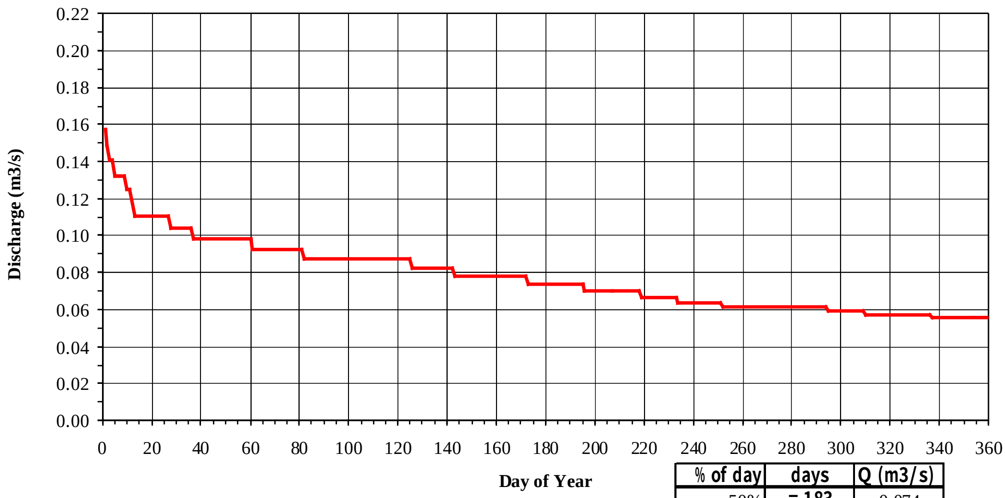
Discharge Relation between Rio Jaruma and Rio Tambo Quemado

Using this correlation, daily discharge at the Tambo Quemado River was estimated as shown as follows.



Estimated Daily Discharge at Rio Tambo Quemado WL.Station (Turko/ Sajama/ Oruro)
(by JICA Study Team)

The flow duration curve at the Tambo Quemado River was also prepared as shown below.



% of day	days	Q (m3/s)
50%	= 183	0.074
60%	= 219	0.070
70%	= 256	0.061
80%	= 292	0.061
90%	= 329	0.057
95%	= 347	0.056
97%	= 354	0.056

Estimated Flow Duration Curve at Rio Tambo Quemado (Turco/Sajama/Oruro)

6.2 Socio-economic Conditions and Demand for Electricity

6.2.1 Socio-economic Conditions

Collection of the basic data on socio-economy in Tambo Quemado was conducted during June - September in 2000. The items of the socio-economic survey cover the following.

- Location and access
- Number of household and population
- Major economic source
- Economic infrastructure
- Social infrastructure

(1) Population

According to the National Census in 1992, the population and the number of households in the Turco municipality was 3,799 and 1,159, respectively. The population of Turco in 2000 was estimated to be 3,716 by the INE.

Tambo Quemado located in the Turco municipality is a small village. The number of households in the village is around 55 (45 household + 10 residences/offices). Assuming that the family size per household is 3.3, the population was estimated at about 235 (150 + 90 in residences/offices) in 2000.

(2) Local Economy

Services related to the customs are major economic activity in Tambo Quemado, which is located in the border town with Chile.

Livestock breeding in the extensive grassland is another economic activity. The annual average income per household is reported to be Bs 600 (around US$100).

Tambo Quemado currently receives drinking water supplied from a stream, two (2) kilometers away from the town. The community organization operates and manages the water supply system.

(3) Electricity

Electricity is available with a diesel generator of the installed capacity of 112 kW. The distribution line is extended along the main streets of the town, supplying electricity for 17-18 hours a day from 7:30 AM to 1:30 AM. The company called "FRONTERA" started the electricity supply in 1997. Main users of the electricity are private companies and the government offices.

The average monthly power tariff is around Bs. 25 per household.

6.2.2 Demand for Electricity

(1) Target Area and Methodology of the Estimate

Since the hydropower potential of the Tambo Quemado is quite limited, the target area for electrification is confined to the Tambo Quemado village.

The methodology and process of the estimate of demand for electricity are as follows.

1) estimate present demand for electricity in Tambo Quemado
2) project future population/household and establishment of business in 2005
3) project future demand for electricity in 2005

(2) Estimate of Electricity Demand

Based on the collected socio-economic data in Tambo Quemado, consumption of electricity per user was estimated in due consideration of their hourly demand structure. For the estimate of the demand, users were classified into two groups, namely domestic demand and non-domestic demand and the domestic demand is the demand of households. The non-domestic demand was further divided into business and public.

Using the number of households and business establishments, present demand for electricity was estimated at 135 kWh per day with the peak power demand of 42 kW. Details of the calculation are presented in Tables 6.1 to 6.2.

To estimate future demand for electricity, projection of the households, new establishment for business and public facilities was made taking into account the current trend of the development in Tambo Quemado. In 2005, the number of households are expected to increase from 55 to 69, while the number of business establishments, industry and public facilities are from 21 to 37.

Based on these figures, future demand for electricity was projected as presented in Tables 6.3 to 6.4. The estimated demand for electricity in 2005 is 276 kWh per day with the peak demand of 62 kW as summarized in the next table.

Category	Present (2001)		Future (2005)	
	Number of HH or Facilities	Peak Demand (kW)	Number of HH or Facilities	Peak Demand (kW)
Domestic	55	40.2	69	58.8
Business	20	1.6	34	2.8
Industry	0	0.0	2	0.0
Public	2	0.0	1	0.0
Total	77	41.8	106	61.6

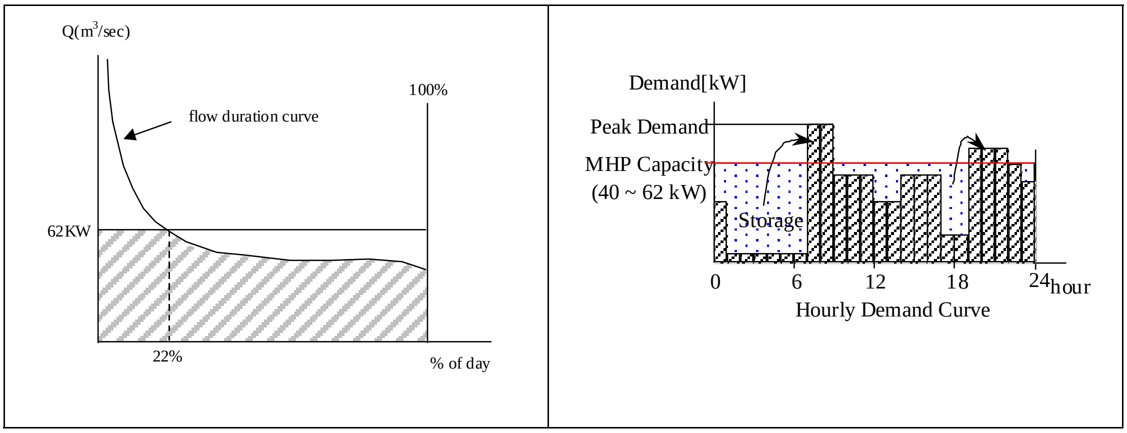
(3) Daily Load Curve

Based on the present daily load curve, power (kW) and energy (kWh) demand in the future (target year of 2005) was estimated as shown in Figure 6.3.

6.3 Formulation of the Optimum Development Scheme

6.3.1 Approach to the Optimum Development Scheme

As explained earlier, available water is limited in the Tambo Quemado River. From the hydrological analysis, the proposed micro-hydro power to be constructed guarantees the projected peak demand during only 22% of the day as illustrated below. To meet the peak demand during the remaining 78% of the day, additional power by diesel and/or construction of storage pond for the micro-hydro are required.



In this study, alternative development plans were formulated under the concept of how to meet the required demand with the constraints of the limited available water.

Considering the above, the following five alternative development plans were formulated for comparison.

Case 1:	MHP 40kW ($Q_{100\%}$)	+ Diesel (22kW)
Case 2:	MHP 50kW ($Q_{54\%}$)	+ Diesel (22kW)
Case 3:	MHP 50kW ($Q_{54\%}$) with storage pond	+ Diesel (12kW)
Case 4:	MHP 62kW ($Q_{22\%}$)	+ Diesel (25kW)
Case 5:	MHP 62kW ($Q_{22\%}$) with storage pond	(No Diesel)

6.3.2 Selection of the Optimum Scheme

For selecting the optimum scheme of the project, cost and benefit for five alternative plans were estimated. Economic internal rates of return and net present value were calculated for the five alternative plans.

(1) Preliminary Cost Estimate

The project cost comprises 1) power investment cost, 2) cost of transmission and distribution line and 3) operation and maintenance cost.

a) Construction cost

The construction cost includes civil works, electrical-mechanical works and is preliminarily estimated. These costs are preliminarily estimated by estimating work quantities by using nomographs applied to scale optimization in Japan[*1] and unit cost of Bolivia at the present.

b) Cost of transmission and distribution line

The length of transmission lines was measured based on a route map of the transmission lines. The distribution line was not planned additionally, since the lines exist in Tambo Quemado. Details of the estimated construction cost are presented in Table 6.5.

c) O&M cost

The operation and maintenance cost was estimated on the basis of the construction cost.

Details of the estimated project cost including construction cost and operation and maintenance cost are presented in Table 6.6 and summarized below.

Project Costs of Alternative Cases for Tambo Quemado MHP

(US$)

	Case 1	Case 2	Case 3	Case 4	Case 5
Civil/Mechanical/Electric Works (MHP)	142,900	151,100	158,700	171,400	185,600
Civil/Mechanical/Electric Works (Diesel)	20,827	20,827	13,327	23,077	0
Transmission line	21,800	21,800	21,800	21,800	21,800
Total Investment	**185,527**	**193,727**	**193,827**	**216,277**	**207,400**
O&M per year	**18,583**	**18,051**	**17,523**	**18,002**	**1,703**

(2) Benefit

The benefit was estimated by the cost of the alternative diesel power plant to be saved and comprises the following components:

a) Investment cost of diesel power plant

b) Fuel cost for energy generation (kWh)

*1 : Standard for Cost Estimation of Hydro Electric Power Development Plan and Optimization Study, Agency of Natural Resources and Energy, Ministry of International Trade and Industry Japan (1994)

c) Operation and maintenance costs

The benefits estimated for the alternative cases are summarized below and details are presented in Table 6.7.

Project Benefit of Alternative Cases (Cost of Diesel Power) for Tambo Quemado MHP

(US$)

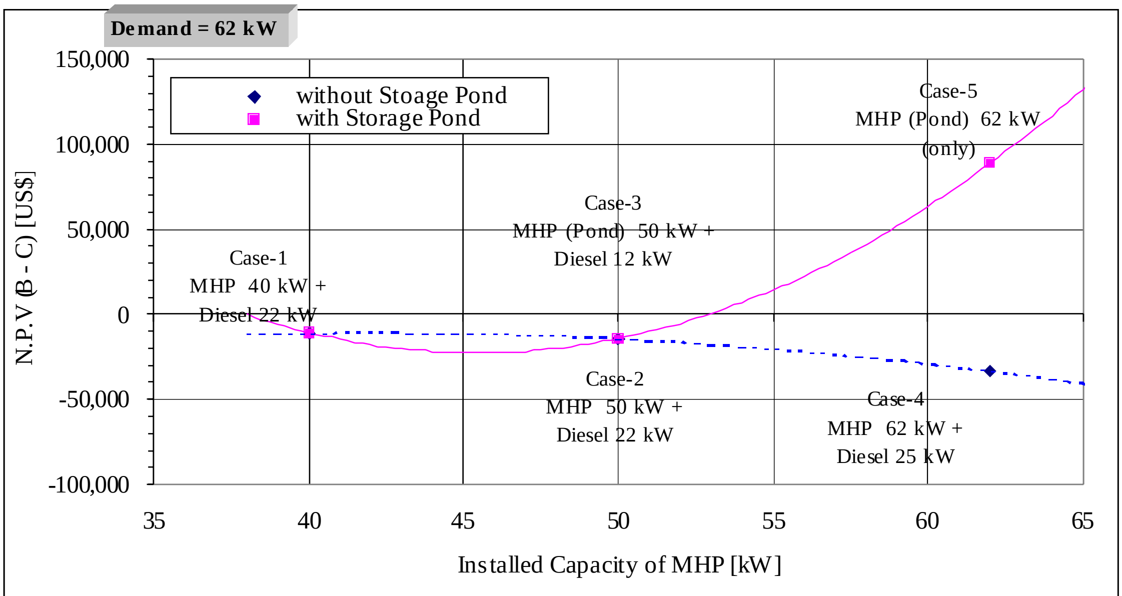
	Case 1	Case 2	Case 3	Case 4	Case 5
Civil/Mechanical/Electric Works (Diesel)	50,827	50,827	50,827	50,827	50,827
Total Investment (Diesel)	**50,827**	**50,827**	**50,827**	**50,827**	**50,827**
O&M per year (Diesel)	**35,185**	**35,185**	**35,185**	**35,185**	**35,185**

(3) Selection of Optimum Scale

The results of economic evaluation for the Tambo Quemado MHP Project are shown in Table 6.8 and are summarized in the next table. For the estimate of the Net Present Value (B-C), the applied discount rate was 10%.

Case No.	Case 1	Case 2	Case 3 With Storage Pond	Case 4	Case 5 with Storage Pond
P (kW) HMP	40 kW	50 kW	50 kW	62 kW	62 kW
P (kW) Diesel	22 kW	22 kW	12 kW	25 kW	0 kW
EIRR (%)	9.0%	8.7%	8.7%	7.2%	**16.2%**
B–C (US$)	-10,721	-14,062	-14,250	-32,927	**88,408**
B/C	0.964	0.954	0.953	0.898	**1.438**

Comparison of the Net Present Value (B-C) is as presented below:



Net Present Value (B - C) of Tambo Quemado MHP Project

The results of comparison indicate that the installed capacity of 62 kW with storage pond (Case-5) might be the optimum one. Considering the environmental negative effect of diesel generator and power generation corresponding to the future demand increase, Case-5 was finally selected as the optimum development plan.

6.4 Preliminary Design and Cost Estimate

Preliminary design for the Tambo Quemado micro-hydro power (MHP) project was prepared by JICA study team as follows:

6.4.1 Preliminary Design

Proposed layout plan and preliminary design of the Tambo Quemado MHP is presented in Figure 6.4. Major items of the preliminary design are explained as follows:

(1) General Layout

The general layout of Tambo Quemado MHP Project was planned in due consideration of the following items.

- Catchment area
- Topographical and geological condition of intake
- Gross head
- Length of waterway (canal)

- Excavation volume and condition of waterway (non- pressure (open)/ pressure)

(2) Principal Features

Principal features of the project are shown below;

Principal Features of Tambo Quemado MHP Project

Items	Mark	Unit	Quantity	Note
Cathment area	C.A.	Km^2	15.2	
Discharge				
Maximum plant discharge	Qmax	m^3/s	0.0879	
Firm plant discharge	Qpfirm		0.0879	100% dependable during 2hr-duration time
Firm discharge	Qfirm	m^3/s	0.056	97% dependable discharge
Water level				
Intake water level	N.W.L	EL.m	4,500.80	
Tail water level	T.W.L	EL.m	4,395.00	
Head				
Gross head	Hg	m	105.80	N.W.L – T.W.L
Effective head	He	m	99.18	
Installed Capacity	P	kW	62	
Annual Energy	E	MWh	451	

(3) Design of the Project

1) Headrace

The PVC pipe was planned for the headrace channel. Though the cost of PVC pipe (Rib-lok) is higher than concrete canal, the PVC pipe was selected to protect from freezing and damage by falling rocks. The PVC pipe will also be easy for installation and maintenance.

- Type : Embedded type
- Material : PVC pipe
- Inner diameter : 0.4m (water depth / height of the pipe < 0.8)
- Length : 2,400 m

2) Headtank

Water volume of head tank was designed in order to have function of regulating pond in addition to allowance of water volume for turbine operation. Water surface area of the head tank was designed more than forty times of the plant discharge to stabilize the water level of the tank.

- Peak duration time : Two hour
- Design Volume : > 230 m^3 (Regulating pond portion)

  V = (maximum peak discharge – firm discharge) x 2 hr x 60min x 60 sec

  = (0.0879 – 0.056) x 2 x 60 x 60 = 230m^3
- Design Area : > 4 m^2 (> 0.0879 x 40, Headtank portion)

3) Penstock

The steel pipe was selected for the material of penstock considering the amount of the plant discharge and effective head.

- Type : Embedded type
- Material : PVC pipe (upper part) and Steel pipe (lower part)
- Inner diameter : 0.36 m (by applying Japanese nomogram)

  $Dm = 0.888 \times Qmax^{0.370} = 0.36$ m
- Length : 300 m

4) Power house

The inner area of the generator floor is designed considering the size of turbine/ generator and some electric installations. The height of the superstructure for the power house was designed considering replacement of the turbine and generator for the maintenance. The height of substructure of the power house was designed considering condition of its foundation and capacity of tailrace bay.

a. Superstructure

- Structural type : Steel framed structure

- Size : 5.5m (width) x 6.5m (length) x 4.5m (height)

b. Substructure

- Structural type : Mass concrete structure
- Size : 5.5m (width) x 6.5m (length) x 2.2(height)

5) Tailrace

Since the amount of water volume released form turbine is very small, the tailrace channel was designed as no-protection type.

(4) Selection of Turbine Type

Taking into account the maximum plant discharge and effective head, a Pelton turbine was selected. Since the grid line of this project is isolated form national grid line, a three-phase alternating current synchronous generator was selected.

6.4.2 Cost Estimate

(1) Condition of the Estimate

The cost estimate was made on the basis of the following assumptions and conditions:

1) all the costs were estimated at the price level of June, 2001;
2) equipment and materials imported includes taxes related;
3) construction work will be implemented under contract basis instead of under participation of local people;
4) cost of the administrative and engineering services was estimated at around 10 % of the direct construction cost;
5) IVA (13%) and transaction tax (3%) were additionally estimated as local taxes; and
6) Applied exchange rates are; US$ = Bs 6.53.

(2) Total Construction Cost

The estimated construction cost of the project is 239,700US$ as summarized below.

Estimated Construction Cost of Tambo Quemado MHP

Financial Cost (With Tax) (62kW) **Unit : US$.**

Item	Cost	Note
1. Preparation Works & Access, etc.	**2,224**	
1.1 Preparation Works	1,112	2.*0.01
1.2 Access Road	0	
1.3 Mitigation for Environment	1,112	2.*0.01
2. Civil Works	**111,195**	
2.1 Intake Weir	133	
2.2 Intake	113	
2.3 Sand Settling Basin	0	
2.4 Headrace	77,873	
2.5 Head Tank	29,717	
2.6 Penstock	943	
2.7 Spillway	450	
2.8 Power House	1,904	
2.9 Tailrace	62	
2.10 Outlet	0	
3. Electric and Mechanical Woks	**94,626**	
3.1 Turbine/Generator	38,700	
3.2 Transmission/Distribution Line	26,056	
3.3 Mechanical Works	29,870	
4. Transportation	**10,291**	(2.+3.)*5%
5.Direct Cost Total	**218,336**	1.+2.+3.+4.
6. Administration and Engineering Service	**21,366**	6. *9.8%
Total Construction Cost	**239,700**	4. + 5.

Details of the cost estimate are presented in Table 6.9.

6.5 Construction Schedule

Assuming that required time for design including basic design is 4 months, total required period for completion of the project is around 10 months as presented in Figure 6.5.

6.6 Proposed Implementation Organization and O&M

After reviewing the existing organizations for the micro-hydro power project, the following implementation structure and system of the operation and maintenance were proposed for sustainable development of rural electrification by the Tambo Quemado micro-hydro power project.

6.6.1 Implementation Organization

Figure 6.6 presents a proposed organization for a project implementation of the Tambo Quemado micro-hydro power project. Tambo Quemado municipality is in charge of the whole project implementation and contracts local consultants/NGO for the installation of the micro-hydro power system and training of the operation and maintenance. The role of organizations related to the project implementation is summarized as follows.

DUF (fund source)

- to evaluate, approve and finance a project plan applied by Tambo Quemado municipality in cooperation with the VMEH

VMEH (technical support)

- to guide DUF for technical supports on rural electrification development when DUF evaluates the project plan applied by Tambo Quemado municipality

Tambo Quemado Municipality (implementing organization)

- to give a guidance of project scheme and user's responsibilities including initial payment and monthly fee for local people
- to make an agreement with the REC/cooperative after receiving the request of the rural electrification project
- to prepare a project plan with technical support of Oruro prefecture and/or consultants/NGO, and apply for the finance to DUF
- to select a consultant or NGO which manages and supervises the whole project implementation.

Consultant / NGO (supervision of the installation and training for operation and maintenance)

- to supervise installation of the system and carry out training on the operation and maintenance for beneficiaries and technical assistants of REC/cooperative

REC/ cooperative (beneficiaries)

- to organize a rural electrification committee (REC) or cooperative after receiving the guidance of project scheme and beneficiary's responsibilities including initial payment and monthly fee through Tambo Quemado municipality and/or consultants/NGO
- to request the rural electrification project and make an agreement with Tambo Quemado municipality
- to provide labor force and some materials prepared in the community in kind
- to receive the training on the operation and maintenance for beneficiaries and technical assistants of REC

Oruro Prefecture (technical support or implementing organization)

- to support Tambo Quemado municipality for preparing the project plan when the municipality applies the plan to DUF
- In case of a project implemented not through DUF, Oruro prefecture is to be responsible for the project implementation in cooperation with VMEH.

6.6.2 Operation and Maintenance System

Since a well-organized system has already been established through cooperation with experienced NGOs/consultants for the operation and maintenance of micro-hydro power project, proposed operation and maintenance system is similar to the existing system for the Tambo Quemado micro-hydro power project.

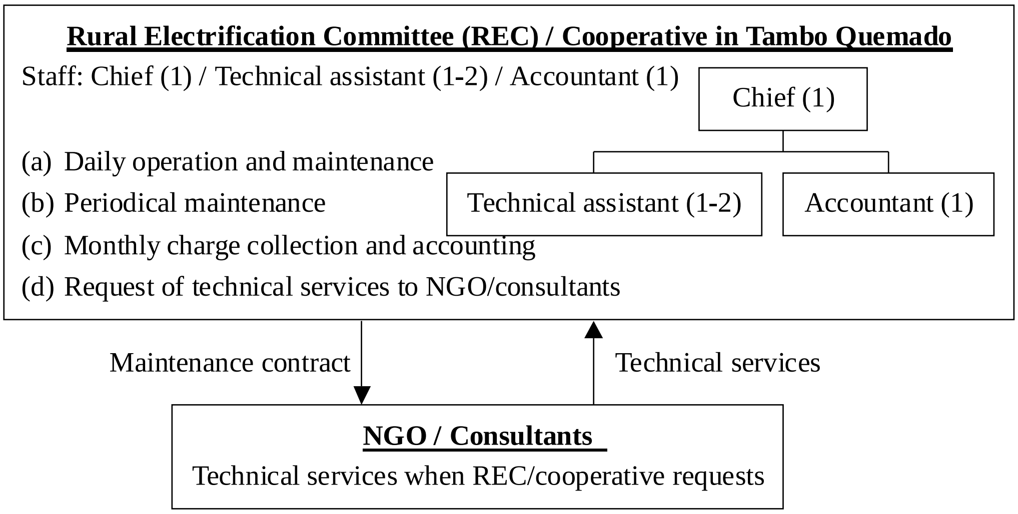
A rural electrification committee (REC)/cooperative trained by NGO or consultant manages the daily operation and maintenance. The NGO/consultants carries out special maintenance services if REC/cooperative requests. Proposed operation and maintenance to be conducted by REC/cooperative and consultants/NGO is summarized as follows and presented in detail in the section of 5.6.2.

a) REC / cooperative

- to be responsible for the daily operation and maintenance
- to carry out the periodical maintenance
- to collect monthly charge and account
- to request technical services to NGO/consultants

b) NGO / consultants

- to provide REC/cooperative with technical services when requested (under a maintenance service contract).



6.7 Economic and Financial Evaluation

6.7.1 Economic Evaluation

The economic viability of Tambo Quemado micro-hydro power project is examined by computing the Economic Internal Rate of Return (EIRR), which is calculated based on the following assumptions.

(1) Basic Assumptions

1) Project Life

The life of the proposed project is assumed to be 20 years after one year construction period, taking into account the economic life of the turbine/generator, the main facility of the projects.

2) Price Level and Price Escalation

All the costs and benefits are estimated at the price level of June 2001. Price escalation is not included in the evaluation in order to derive the EIRR net of price escalation impact.

3) Exchange Rate

The applied exchange rates are:

US$1=120.5 Yen = 6.53 Bolivianos

The analysis is made and shown in US dollar.

4) Economic Cost

Economic costs are derived by taking the domestic taxes and subsidies from the financial costs (Table 6.10).

Economic Project Cost

Economic project costs are as summarized in the table below.

Economic Project Costs of the Tambo Quemado MHP Project (US$)

	Tambo Quemado
Preparation Workds and Access, etc.	2,000
Civil Works	95,800
Turbine/Generator	33,100
Transmission/Distribution Lines	21,700
Mechanical Works	25,800
Transportation	8,900
Administration and Engineering Service	18,400
Total Investment Cost	205,700

Source: JICA Study Team

Economic Life of the MHP System

Economic life of the major facilities is estimated as follows.

Economic Life of Major Equipment

Turbine/Generator	20 Years
Transmission/Distribution Lines	20 Years

Residual value of all the equipment is assumed to be zero as they will be used up to their economic life.

Economic O&M Cost

Annual operation and maintenance costs of the project facilities are estimated as follows.

Turbine/Generator:	2% of the investment cost
Civil Work:	0.5% of the cost
Transmission/Distribution Lines:	2.5% of the investment cost

5) Economic Benefit

Economic benefits are derived by taking the domestic taxes and subsidies from the financial costs.

The costs of the least-cost alternative system, i.e., a diesel engine powered generation system with the capacity to generate the same amount of electricity as the proposed micro-hydro power, is considered to be the economic benefit.

Investment Cost of the Diesel Generation System

Investment cost of the alternative diesel generation system is estimated as follows.

Investment Cost of the Diesel Generation System*

	Unit	Unit Cost	Tambo Quemado	
			Units	Cost
Capacity of the Diesel Generator	kW	750	62	46,500
Automatic Transfer Switch	-	1,910	1	1,910
Protection Box	-	917	1	917
Building	-	1,500	1	1,500
Total	-	-	-	50,827

Source: JICA Study Team

* Since the new diesel generator, transmission lines and distribution lines were just installed in 2000, the initial investment costs of these equipment are excluded from the benefit calculation. Only the replacement costs of these equipment are included in the calculation.

O&M Cost

Annual operation and maintenance costs of the alternative diesel generation system are estimated as follows.

Diesel Generation System: 5% of the investment
Transmission/Distribution Lines: 2.5% of the investment

Diesel Oil Cost

Economic cost of the diesel oil in Tambo Quemado is 3.28 Bs. per litter. Annual diesel oil costs is calculated based on the assumed power generation as summarized below.

Annual Power Generation and Diesel Oil Cost

Power Generation (kWh/Year)	181,147
Fuel Consumption (L/Year)	65,137
Diesel Oil Cost (US$/Year)	32,718

Economic Life of the Diesel Generation System

Economic life of the major facilities is estimated as follows.

Economic Life of Major Equipment

Diesel Generator	10 Years
Automatic Transfer Switch	10 Years
Protection Box	10 Years
Building	10 Years
Transmission/Distribution Lines	20 Years

Residual value is assumed to be zero as all the equipment is to be used up to their respective economic life.

(2) Results of Economic Analysis

1) EIRR

The EIRR of the Tambo Quemado micro-hydro power project on the basis of the above assumptions are computed to be 16.4% as in Tables 6.11 and 6.12, using the economic cost and benefit stream shown above. It indicates that the proposed project is economically viable.

2) Sensitivity Analysis

Sensitivity analysis to examine flexibility of the proposed project in economic viability is made under the following adverse assumptions of key factors. The Tambo Quemado micro-hydro power project demonstrates economic viability even under the adverse conditions as follows.

Case I	+10% investment cost and -10% diesel fuel cost	14.6%
Case II	+20% investment cost and -20% diesel fuel cost	13.1%

6.7.2 Financial Evaluation

The financial viability of the Tambo Quemado micro-hydro power project is examined by computing the minimum power tariff of the residential sector to cover the costs of the project.

(1) Basic Assumptions

Financial evaluation of the proposed project is examined based on the following assumptions. Assumptions such as project life, price level and escalation, exchange rate, economic life of equipment and O&M costs are the same as in the case of the economic evaluation.

1) Financial Project Cost

Financial project costs are estimated to be as follows.

Financial Project Costs of the Tambo Quemado MHP Project (US$)

Preparation Workds and Access, etc.	2,224
Civil Works	111,194
Turbine/Generator	38,700
Transmission/Distribution Lines	26,056
Mechanical Works	29,870
Transportation	10,291
Administration and Engineering Service	21,366
Total Investment Cost	239,700

Source: JICA Study Team

The tax rates included in the financial costs are summarized below.

Taxes for Domestic Products

VAT (Value Added Tax): 13% for all the categories of products
Transaction tax: 3% for all the categories of products

Taxes for Imported Products

Effective VAT: 14.94% for all the categories of products
Import tax: 5% (turbine/generator)
20%* (transmission/distribution lines)

* Adjusted rate in consideration of the different products used to produce distribution lines

2) Power Demand

Power demand by the sector is summarized in the following table.

Power Demand (kWh/Year)

	Residential	Non-Residential	Total
Total Demand	66,609	114,538	181,147

(2) Calculation of Power Tariff to Cover the Costs

Minimum power tariffs to cover the costs are calculated as follows. The power tariff from the non-residential sector is assumed to be 50% higher than that of the residential sector.

The minimum tariff to cover all the investment cost and O&M cost is calculated as follows. The minimum power tariff is calculated by annualizing the investment by multiplying CRF (Capital Recovery Factor) of respective discount rates, adding annual O&M cost, and then dividing it by annual power demand.

Minimum Power Tariff to Cover Investment and O&M Costs (US$)

Discount Rate	10%
Residential per kWh	0.13
Residential per Month	3.2

(3) Results of Financial Analysis

At present, residential users of the diesel generation system pay on average Bs. 25, or US$ 3.83 per month for the service. Since each residential user of the micro-hydro power project in Tambo Quemado is estimated to use 300 kWh per year, the monthly payment with the discount rate of 10% to cover investment cost and O&M cost would be US$ 3.2 (US$ 0.13/kWh x 300 kWh / 12 months), which is lower than the amount they pay at present. It could be concluded that the micro-hydro power project in Tambo Quemado would be financially sustainable.

6.8 Initial Environmental Evaluation

During the fifth field survey in May 2001 the study on Initial Environmental Evaluation (IEE) was conducted. This micro-hydro power project will have no serious impacts in/around the project site according to the results of survey. Anticipated environmental impacts of the project are presented in the table below. The project will contribute to socioeconomic benefits as well as rural electrification as follows for the local communities:

- to develop commercial industry in the border area between Bolivia and Chile and promote cottage industry in rural area,

- to provide local people with more qualified public services for improving social environment and social welfare, and
- to maintain public peace and order at night.

Environmental considerations are, however, needed appropriately for the moderate and minor impacts on natural environment. Project executors take into account the natural environment, especially flora, around the project site because the Tambo Quemado River is in danger of the decrease of the water volume after the project completion.

IEE Matrix for Tambo Quemado Micro-hydro Power Project, Oruro

Item			Evaluation	Remarks
Social Environment	1	Resettlement	-	
	2	Economic activities	○	Commercial and cottage industries will be promoted.
	3	Traffic and public facilities	○	Public facilities including schools and hospitals will be electrified.
	4	Split of communities	-	
	5	Cultural property	-	
	6	Water rights/Right of common	-	
	7	Public health condition	○	Clean water will be provided by water pumping system.
	8	Waste	-	
	9	Hazards	○	Lighting will enhance safety at night for rural life.
Natural Environment	10	Topography and geology	-	
	11	Soil erosion	-	
	12	Groundwater	-	
	13	Hydrological situation	□	Water volume of the river will decrease.
	14	Coastal zone	-	
	15	Flora and fauna	△	Moss plant will be influenced in the limited area of the riverside.
	16	Climate	-	
	17	Landscape	△	Transmission line will be an obstacle to the sightseeing of Mt. Sajama.
Pollution	18	Air pollution	-	
	19	Water pollution	-	
	20	Soil contamination	-	
	21	Noise and vibration	△	Noise will occur in the construction stage.
	22	Land subsidence	-	
	23	Offensive odor	-	

Notes: ○= Positive impact, - = Negligible impact, △= Minor impact, □= Moderate impact, × = Serious impact, ? = Not clear
This IEE study was implemented by an environmental consultant registered by the Ministry of Sustainable Development and Planification in May, 2001.
The study report of this IEE was submitted to the the Ministry of Sustainable Development and Planification through the Vice Ministry of Energy and Hydrocarbons.
Source: JICA Study Team