JICA

# FEASIBILITY STUDY
# ON
# SMALL-SCALE POWER PLANTS REHABILITATION PROJECT
# IN
# THE REPUBLIC OF COLOMBIA

## F/S REPORTS
## OF
## EACH POWER PLANT

(VOL.2/2)

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

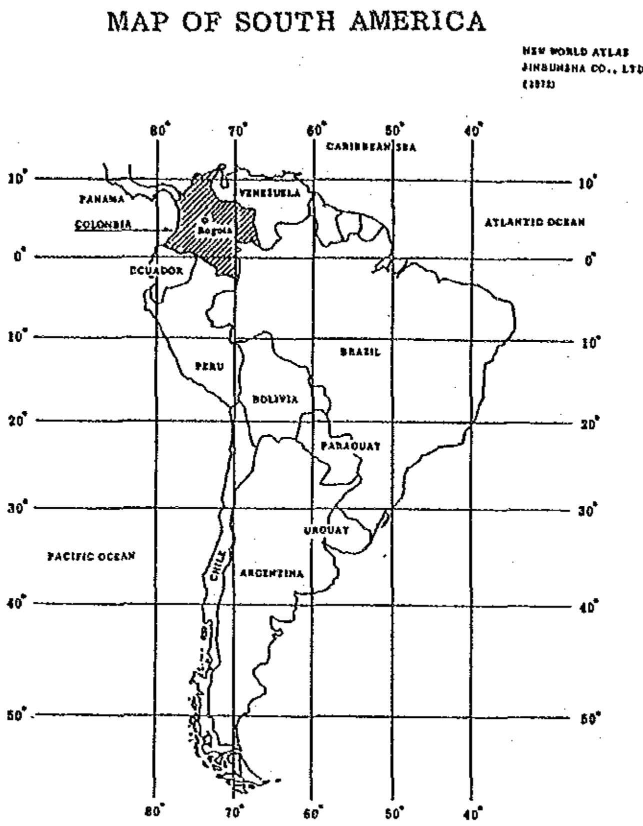
# FEASIBILITY STUDY
# ON
# SMALL-SCALE POWER PLANTS
# REHABILITATION PROJECT
# IN
# THE REPUBLIC OF COLOMBIA

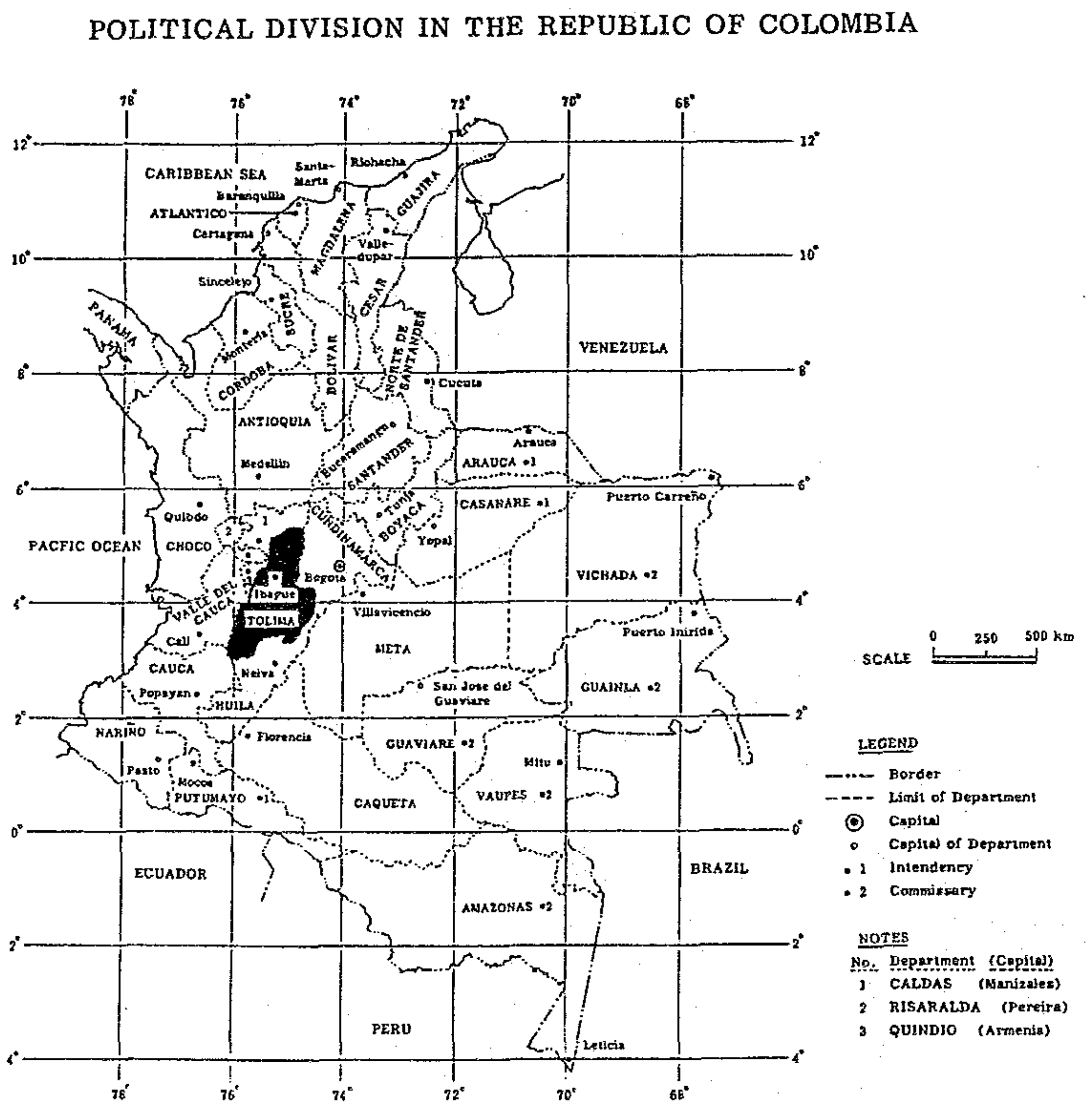
# LAGUNILLA HYDROELECTRIC POWER PLANT

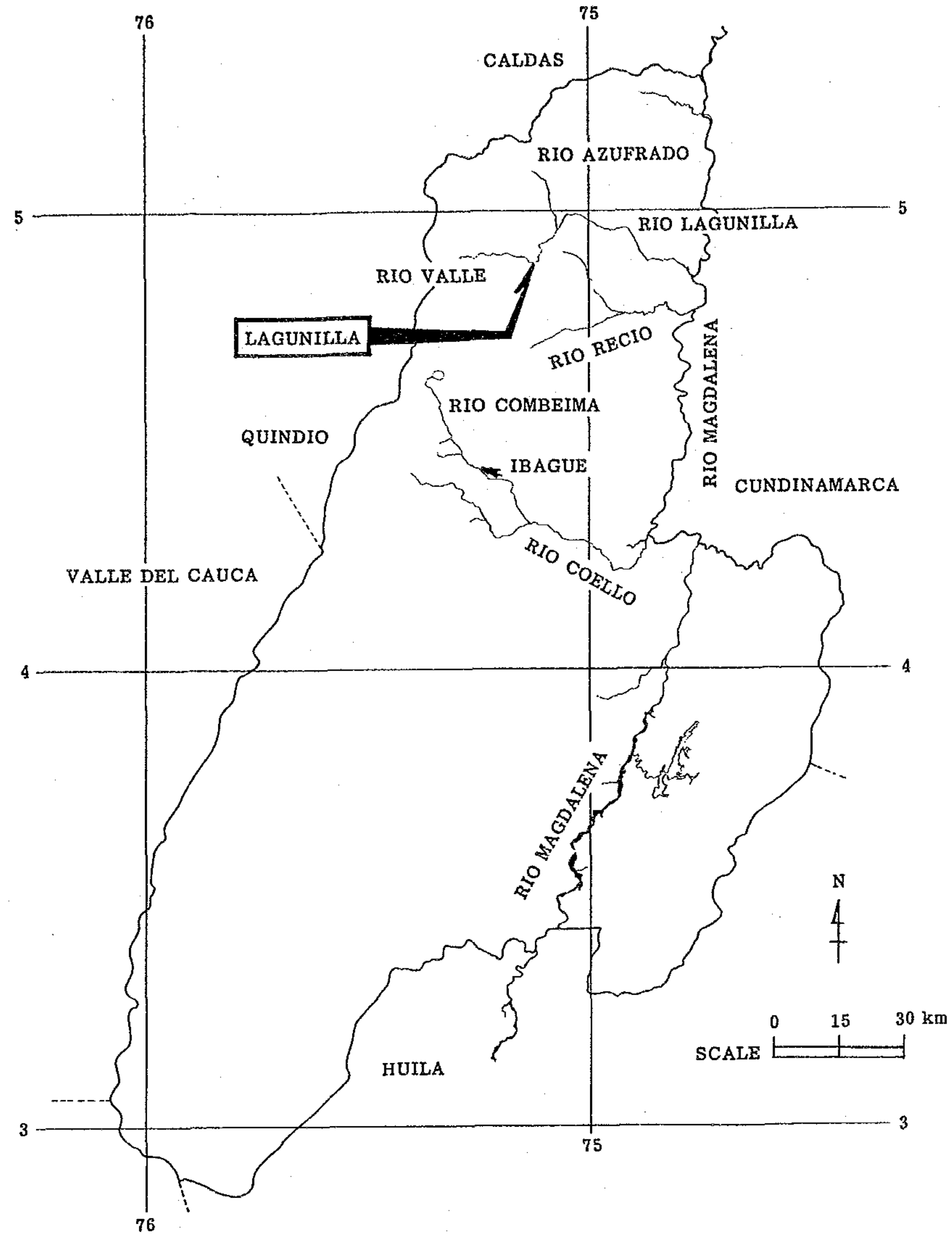
20951

MARCH 1990

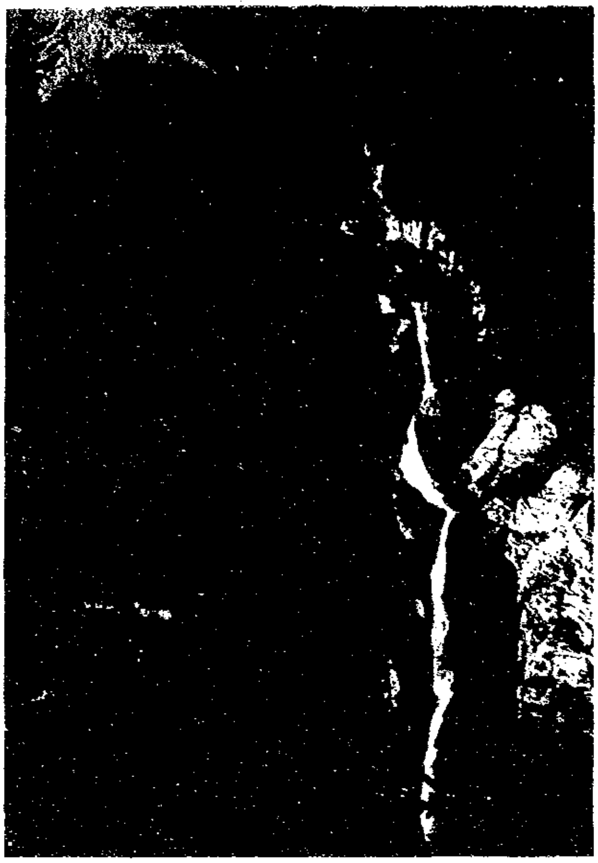
Japan International Cooperation Agency



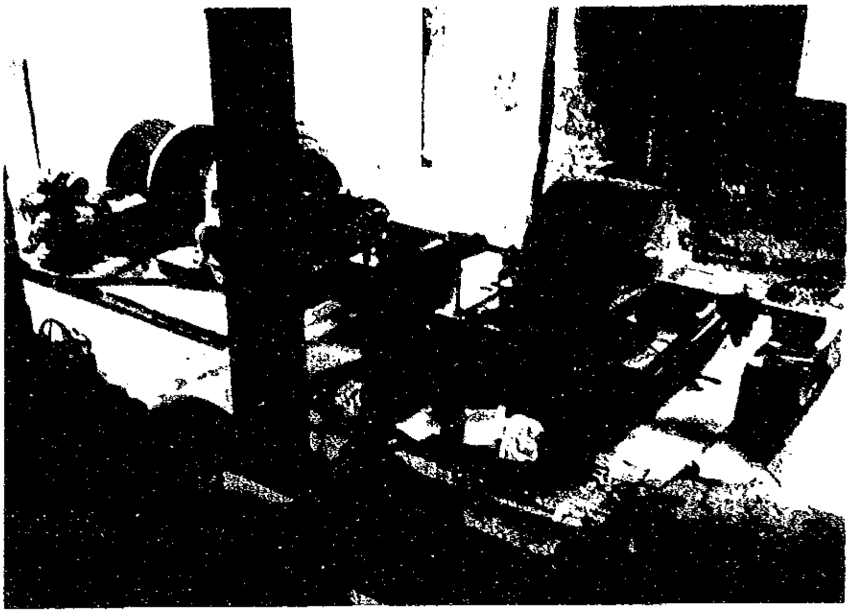




Location Map of Study Area



Powerhouse and waterfall

The crest of waterfall



Pelton turbine

CONTENTS

# CHAPTER 1 INTRODUCTION

The feasibility study (hereinafter referred to as the FS) for the rehabilitation plan of Lagunilla run-of-river type hydroelectric power plant (rated output of 0.392 MW) was conducted following the pre-FS that was carried out for eight months from November, 1987 to June, 1988. This report is prepared to summarize the results of the FS.

This FS was performed in accordance with the Scope of Work (S/W) agreed and signed in July 1988 between Japan International Cooperation Agency (JICA) and Instituto Colombiano de Energia-Electrica (ICEL). The study was conducted from November, 1988 to March, 1990.

From among 62 small-scale hydroelectric power plants operated by ICEL that were nominated for the study of the rehabilitation plan, Lagunilla hydroelectric power plant (hereinafter referred to as Lagunilla P/P) was selected as a candidate for the FS for the following reasons:

1) Aerial photographic survey had been conducted and a survey map had been drawn on a scale of 1/5000.

2) This power plant site is located favorably to a 300-meter harnessed waterfall.

3) Though hydrological gauging stations were washed away by debris flow caused by the eruption of Mt. Nevado del Ruiz in November 1985, this power plant site has a high river discharge rate.

From this FS, post-rehabilitation generating scale for which JICA Study Team proposes as an optimum rehabilitation plan is as follows:

| | | | |
|---|---|---|---|
| - Maximum output | : | 5.0 | MW |
| - Annual potential generated power | : | 43.2 | GWh |
| - Facility utilization factor | : | 99.0 | % |

# CHAPTER 2 SUMMARY OF STUDY RESULTS

Lagunilla P/P operated by E. TOLIMA, is the run-of-river type with a rated output of 392 kW, utilizing a waterfall, and is located along the Lagunilla River in Tolima Department. Operation started in 1940, but was stopped in 1972, because of the breakdown of generating equipment and the transmission facilities were then removed. Presently, it has been left unattended, and intake structures were washed away by debris flow from the eruption of Mt. Nevado del Ruiz in 1985.

(1) Present condition of generating facilities and their problems

The plant was washed away, and there is nothing remaining at the original site. However, a simple diversion weir was constructed upstream from the waterfall, and water flows to the head tank through a 56-meter-long open channel. The gross head of the waterfall is about 300 m. Because of topographic restrictions, 120-meter-high, approximately 1/3 of the gross head, was utilized for the power plant.

In 1984, a feasibility study was conducted to cover the following areas:

A diversion weir will be constructed at an elevation of 1,960 meters upstream of the waterfall to generate power under the following conditions by constructing two hydroelectric power plants.

| | | | |
|---|---|---|---|
| 1) | Planned available discharge | : | $Q = 9.0\ m^3/s$ |
| 2) | Maximum output | : | P = 66.5 MW |
| 3) | Gross head | : | H = 897 m |
| 5) | Total length of headrace | : | L = 4,960 m on the right side of the river |

However, this study has yet to be implemented because of volcanic eruption of Nevado del Ruiz in 1985.

The biggest problem of the Lagunilla P/P rehabilitation plan is the lack of hydrological gauging station along the Lagunilla River. In this report, the generation plan was formulated in accordance with the discharge data observed by Instituto de Aprovechamiento de Aguas y Fomento Electrico (IAAFE; the predecessor of HIMAT) at the El Bosque gauging station for eight years from 1957 to 1964. To implement this plan, a hydrological gauging station needs to be established at an earlier date and data on the recent hydrological regime of the Lagunilla River is also needed.

(2) Alternative rehabilitation plans

In the rehabilitation plan of the Lagunilla P/P, comparative studies are made for the power generation-optimizing plan. The following conditions are considered in formulating alternative plans.

1) The design available discharge is set up with cases of 2.0 $m^3/s$, 3.0 $m^3/s$ and 4.0 $m^3/s$ within the range that the facility utilization factor does not exceed 50%. (refer to Fig. 2.1)

2) The power generation plan intends to fully utilize the 300-meter-high waterfall head. The slope on the right bank of the waterfall is too steep for the conduction channel route, so a new structure must be built underground, below the existing powerhouse building (elevation: 1,650 m). A right-bank conduction channel plan limits the use of head to an elevation of 1,650 m.

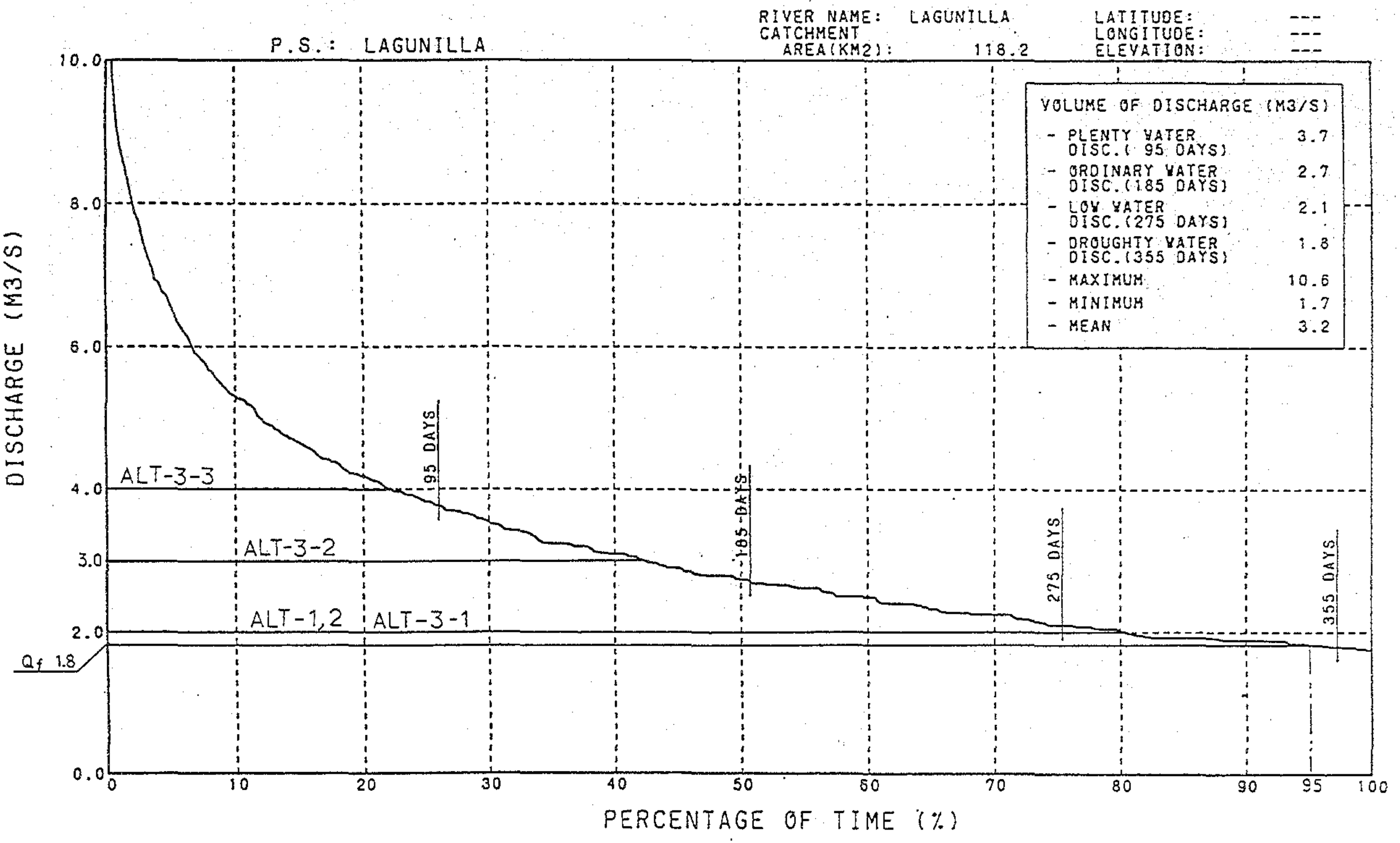
3) According to a survey debris flow occurs once in 70 years. The layout of structures and facilities, except for intake facilities, will be planned to prevent debris flow.

A summary and layout of the alternative plans are shown in Table 2.1 and Fig. 2.2.

Table 2.1 Alternative Plans for Lagunilla Power Plant Rehabilitation

| Item | Alternative Plans | | | | |
|---|---|---|---|---|---|
| | Alternative-1 | Alternative-2 | Alternative-3 | | |
| Elevation at the intake (m) | 1,782.5 | 1,821 | | | |
| Headrace route | Right-bank route | | Left-bank route | | |
| Location of power plant | Existing power plant site (Elev = 1,650 m) | | Left bank (Elev = 1,500 m) | | |
| Net head, He (m) | 125.9 | 161.5 | 309.0 | | |
| Discharge, Q ($m^3/s$) | 2.0 | 2.0 | 2.0 | 3.0 | 4.0 |
| Max. output, P (MW) | 2.0 | 2.6 | 5.0 | 7.7 | 10.2 |
| Facility utilization coefficient (%) | 99 | 99 | 99 | 85 | 71 |

Fig-2.1 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



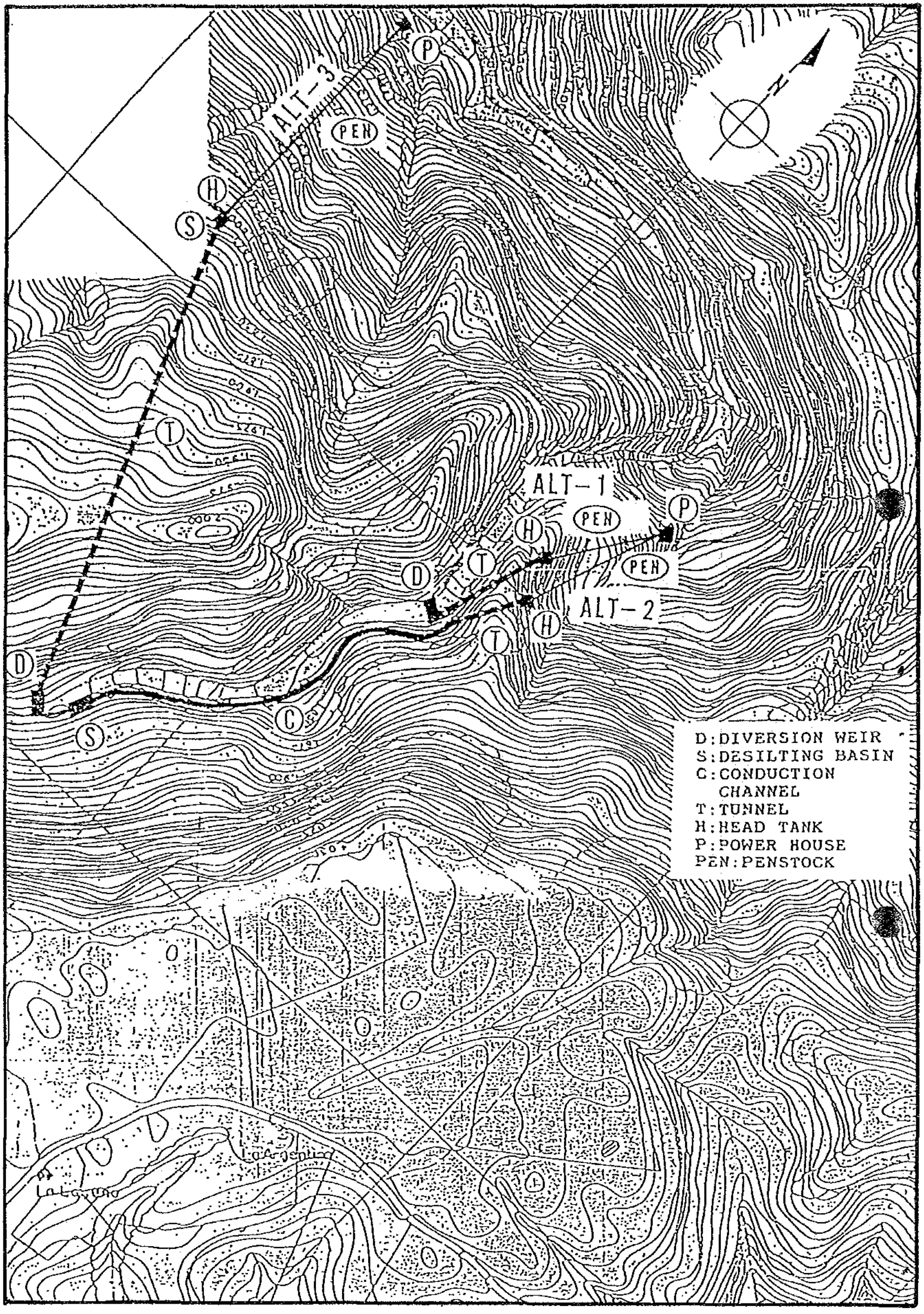



Fig. 2.2 Layout for the Alternative Plans

(3) Selection of optimum plan

Comparative study results of alternative plans are shown in Table 2.2. ALT-3-1 ($Q = 2.0\ m^3/s$) is selected as an optimum plan from a cost-benefit perspective. The basic design for ALT-3-1 plan to be conducted in the feasibility study stage is described in Chapter 11.

## Table 2.2 Comparison of Rehabilitation Plan for the Lagunilla Power Plant

| Alternative Plan | ① Specifications for Existing Generating Facilities | | | | | ② Rehabilitation Plan | | | | | | | ③ Recovered or Increased Energy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ⑩ | ⑪ | ⑫ | ⑬ Present facility capacity | | ⑳ | ㉑ | ㉒ | ㉓ | ㉔ | ㉕ | ㉖ | ㉚ | ㉛ |
| | Max. available discharge Qo ($m^3$/s) | Net head Ho (m) | Rated output Po (kW) | ⑭ Output Pe (kW) | ⑮ Generated energy Ee (GWh) | Max. available discharge $Q_1$ ($m^3$/s) | Standard net head $H_1$ (m) | Theoretical output =9.8x⑳ x㉑ (kW) | Resultant efficiency η | Output =㉒x㉓ $P_1$ (kW) | Annual probable generated energy $E_1$ (GWh) | Facility utilization factor ε (%) | Output =㉔-⑭ ΔP (kW) | Annual probable generated energy ㉕-⑮ ΔE (GWh) |
| ALT-1 | 0.5 | 120.0 | 392 | 0 | 0 | 2.0 | 125.9 | 2,468 | 0.830 | 2,000 | 17.6 | 99 | 2,000 | 17.6 |
| ALT-2 | | | | | | 2.0 | 161.5 | 3,165 | 0.830 | 2,600 | 22.6 | 99 | 2,600 | 22.6 |
| ALT-3-1 | | | | | | 2.0 | 309.0 | 6,056 | 0.830 | 5,000 | 43.2 | 99 | 5,000 | 43.2 |
| ALT-3-2 | | | | | | 3.0 | 309.0 | 9,084 | 0.850 | 7,700 | 56.7 | 85 | 7,700 | 56.7 |
| ALT-3-3 | | | | | | 4.0 | 309.0 | 12,112 | 0.850 | 10,200 | 62.4 | 71 | 10,200 | 62.4 |

| Alternative Plan | ④ Rehabilitation Work Cost (US$1000) | | | | | ⑤ Construction Cost per kW (US$/kW) | | ⑥ Total of Annual Cost at Generating Terminal (US$1000) | | | | | ⑦ Average Generating Cost per kWh (mills/kWh) | | ⑧ Cost/ Benefit | ⑨ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ㊵ Generating Equipment Cost | | | ㊹ | ㊺ | ㊿ | 51 | 60 | 61 Principal repayment amount for construction cost (25-year average) | | | 65 | 70 | 71 | | |
| | ㊶ Foreign currency portion $C_{1f}$ | ㊷ Local currency portion $C_{1\ell}$ | ㊸ ㊶+㊷ $C_1$ | Civil work cost $C_2$ | ㊸+㊹ C | Cost per ΔP =㊺/㉚ C/ΔP | Cost per $P_1$ =㊺/㉔ C/$P_1$ | Operation and maintenance costs AOM | 62 Foreign currency portion 2.610 x ㊶ ÷ 25 | 63 Local currency portion 2.016 x (㊷+㊹) ÷ 25 | 64 62+63 | 60+64 | per $E_1$ =65/㉕ ÷0.95 | per ΔE =65/㉛ ÷0.95 | C/B | Priority order |
| ALT-1 | 2,000 | 800 | 2,800 | 700 | 3,500 | 1,750 | 1,750 | 8.0 | 207 | 121 | 228 | 336 | 20 | 20 | 1.28 | 4 |
| ALT-2 | 2,400 | 1,000 | 3,400 | 900 | 4,300 | 1,650 | 1,650 | 10.4 | 251 | 154 | 405 | 415 | 19 | 19 | 1.24 | 3 |
| ALT-3-1 | 3,800 | 1,500 | 5,300 | 1,600 | 6,900 | 1,400 | 1,400 | 20.0 | 401 | 252 | 653 | 673 | 16 | 16 | 1.06 | 1 |
| ALT-3-2 | 5,600 | 2,300 | 7,900 | 1,900 | 9,800 | 1,300 | 1,300 | 30.8 | 587 | 335 | 922 | 953 | 18 | 18 | 0.96 | 1 |
| ALT-3-3 | 7,300 | 2,900 | 10,200 | 2,200 | 12,400 | 1,200 | 1,200 | 40.8 | 764 | 414 | 1,178 | 1,219 | 21 | 21 | 1.29 | 5 |

(Notes)

① : For the existing generating equipment specifications, refer to the facility register record attached to the pre-FS report.

⑦ : $\text{Generating cost} = \dfrac{\text{Total of annual average cost at generating terminal}}{\text{Annual average supplied electric power}}$

⑧ : C/B is the value of cost and benefit ratio calculated according to the financial analysis.

⑮ : Ee is computed according to the average annual operation record for 5 years from 1984 to 1988 .

㉓ : η is the resultant efficiency of turbine and generator.

㉕ : E1(Energia Media)

㉖ : $\varepsilon = \dfrac{\text{Annual water amount for turbine } (m^3/s\cdot hr)}{Q_1 \times 365 \times 24} \times 100(\%)$

60 : The annual AOM is the amount which is equivalent to US$4 per kW.

61 : Interest is calculated by a repayment of principal in equal annual amounts under the following conditions.
Foreign currency portion: Annual interest rate of 10%, unredeemable for 4 years, repayment over 25 years
Local currency portion : Annual interest rate of 21%, unredeemable for 1 year, repayment over 8 years

# CHAPTER 3 STUDY PLAN

## 3.1 Organization of Study Team

### 3.1.1 JICA FS Study Team

JICA FS Study Team, listed below, includes the team leader and two members who participated in the pre-FS, engineers, geologists, a hydrologist and an economist.

| Name | Position | Assignment |
|---|---|---|
| Masami Ono | Team leader | Total coordinator (civil engineer) |
| Murao Toyama | Team member | Power generation planner (civil engineer) |
| Susumu Nonaka | " | Hydrologist |
| Yoshio Kawasaki | " | Generating equipment planner (civil engineer) |
| Akira Takahashi | " | Generating equipment planner (mechanical engineer) |
| Masayuki Tamai | " | Generating equipment planner (electrical engineer) |
| Nobuhiko Uchiseto | " | Geologist |
| Takashi Inoue | " | Geologist |
| Masaaki Ueda | " | Economist |

3.1.2 Counterpart Engineers from ICEL

Engineers who were engaged in this study as counterparts of the JICA FS Study Team are as follows:

| Name | Field | Position |
|---|---|---|
| Juvenal Peñaloza Rosas | Civil Engineering | Head of Central Eng. Div. |
| Jairo E. Gonzalez Morales | Civil Engineering | Central Eng. Div. |
| Mario Gutierrez Ospina | Civil Engineering | Central Eng. Div. |
| Rafael Torres Mariño | Civil Engineering | Central Eng. Div. |
| Rafael Gomez Florez | Civil Engineering | Central Eng. Div. |
| Jorge E. Hurtado Muños | Civil Engineering | Central Eng. Div. |

3.1.3 Supporting Technical Staff from ELECTROLIMA

JICA FS Study Team obtained cooperation and support from the technical staff listed below, in conducting the site reconnaissance, collecting data and performing engineering consultation necessary for this study.

| Supporting Staff | Position |
|---|---|
| Ivan Nicholls N. | President |
| Hugo Neira S. | Chief of Planning Division |
| Francisco Corrales | Chief of Small Power Plants |

3.2 Study Items and Study Schedule

This FS was conducted for 17 months from November, 1988 to March, 1990 in accordance with S/W agreed and signed in July, 1988 between JICA and ICEL.

3.2.1 Study Items

Study items for the FS as described in the S/W are as follows:

(1) Review of the existing data
(2) Site reconnaissance

(3) Field work

1) Topographic survey
2) Photogrammetric mapping
3) Geological investigation
4) Data collection

(4) Power survey

(5) Optimum plan

(6) Feasibility design

(7) Stability and safety analyses

(8) Construction method

(9) Cost estimation

(10) Economic and financial analyses

(11) Maintenance manual

### 3.2.2 Study Schedule

Table 3.1 shows the overall study schedule as indicated in the S/W.

## Table 3.1 Time Schedule of FS

| | | Year | 1988 | | 1989 | | | | | | | | | | | | 1990 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Month | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 |
| | | Project month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | |
| Working item | | 1. Review of existing data | | | | | | | | | | | | | | | | | | |
| | | 2. Site reconnaissance | | | | | | | | | | | | | | | | | | |
| | Field works | (1) Programming | | | | | | | | | | | | | | | | | | |
| | | (2) Procurement procedure | | | | | | | | | | | | | | | | | | |
| | | (3) Ground survey | | | | | | | | | | | | | | | | | | |
| | | (4) Photogrammetric mapping | | | | | | | | | | | | | | | | | | |
| | | (5) Geological investigation | | | | | | | | | | | | | | | | | | |
| | | (6) Data collection | | | | | | | | | | | | | | | | | | |
| | | 4. Power survey | | | | | | | | | | | | | | | | | | |
| | | 5. Optimum plan | | | | | | | | | | | | | | | | | | |
| | | 6. Feasibility design | | | | | | | | | | | | | | | | | | |
| | | 7. Stability & safety analyses | | | | | | | | | | | | | | | | | | |
| | | 8. Construction method | | | | | | | | | | | | | | | | | | |
| | | 9. Cost estimation | | | | | | | | | | | | | | | | | | |
| | | 10. Economic and financial analyses | | | | | | | | | | | | | | | | | | |
| | | 11. Maintenance manual | | | | | | | | | | | | | | | | | | |
| Report | | 1. Inception report | △ | | | | | | | | | | | | | | | | | |
| | | 2. Progress report | | | | ① △ | | | | | | | | | | ② △ | | | | |
| | | 3. Interim report | | | | | | | | | | | △ △ | | | | | | | |
| | | 4. Draft final report | | | | | | | | | | | | | | | △ △ | | | |
| | | 5. Final report | | | | | | | | | | | | | | | | | | △ |

Legend: JICA field operation; ICEL field operation; JICA operation in Japan; Report submission

Two field surveys were conducted at Lagunilla P/P, as shown in Table 3.2.

In the first site reconnaissance, the team leader and two civil engineers conducted the present-condition study of the existing facilities (mainly civil structures) and collected necessary data.

In the second field survey, a geologist and hydroelectric power generation planner gathered data relating to the geological survey.

Table 3.2 Field Survey Schedule

The first site reconnaissance

| Date | Schedule | Detail of Study Item | Member | |
|---|---|---|---|---|
| | | | ICEL | JICA |
| Feb. 8 | Bogota → Ibague | Discussion at ELECTROLIMA | J. Gonzalez | Masami Ono<br>Yoshio Kawasaki |
| Feb. 9 | | Field survey at Lagunilla P/P | | |
| Feb. 10 | | Discussion at ELECTROLIMA, and data collection | | |

The second field survey

| Date | Schedule | Detail of Study Item | Member | |
|---|---|---|---|---|
| | | | ICEL | JICA |
| July 4 | Bogota → Ibague | Discussion at ELECTROLIMA, and data collection | Mario Gutierrez Ospina | Murao Toyama<br>Nobuhiko Uchiseto |
| July 5 | | Field survey at Lagunilla P/P | | |
| July 6 | | Same as above | | |
| July 7 | | Discussion at ELECTROLIMA | | |

## 3.3 Detail of Field Survey Work

The field survey work planned in consultations between JICA Study Team and ICEL counterpart staff according to the results of the site reconnaissance, included topographic surveying and boring survey as described below, but did not include photogrammetric mapping.

### 3.3.1 Scope of Topographic Surveying

The alternative plan prepared by JICA Study Team is shown in Fig. 3.1. The scope of topographic surveying is indicated in Fig. 3.2 through Fig. 3.4

The drawing of the site's present conditions is on a scale of 1/200 with a contour line of 2 m. Main structures for the existing facilities and positions of bench marks and boring are illustrated.

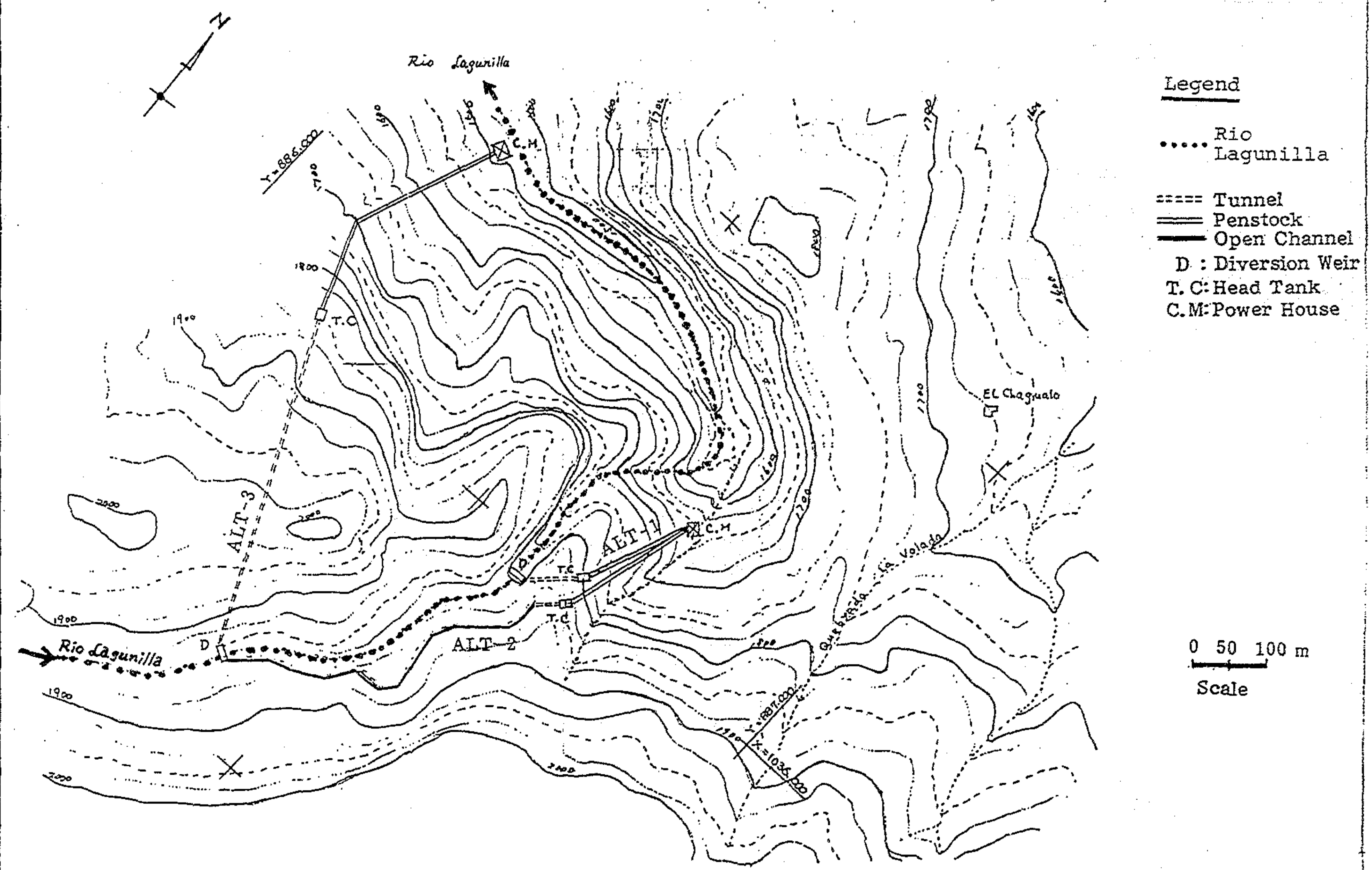



Fig. 3.1 General Plan

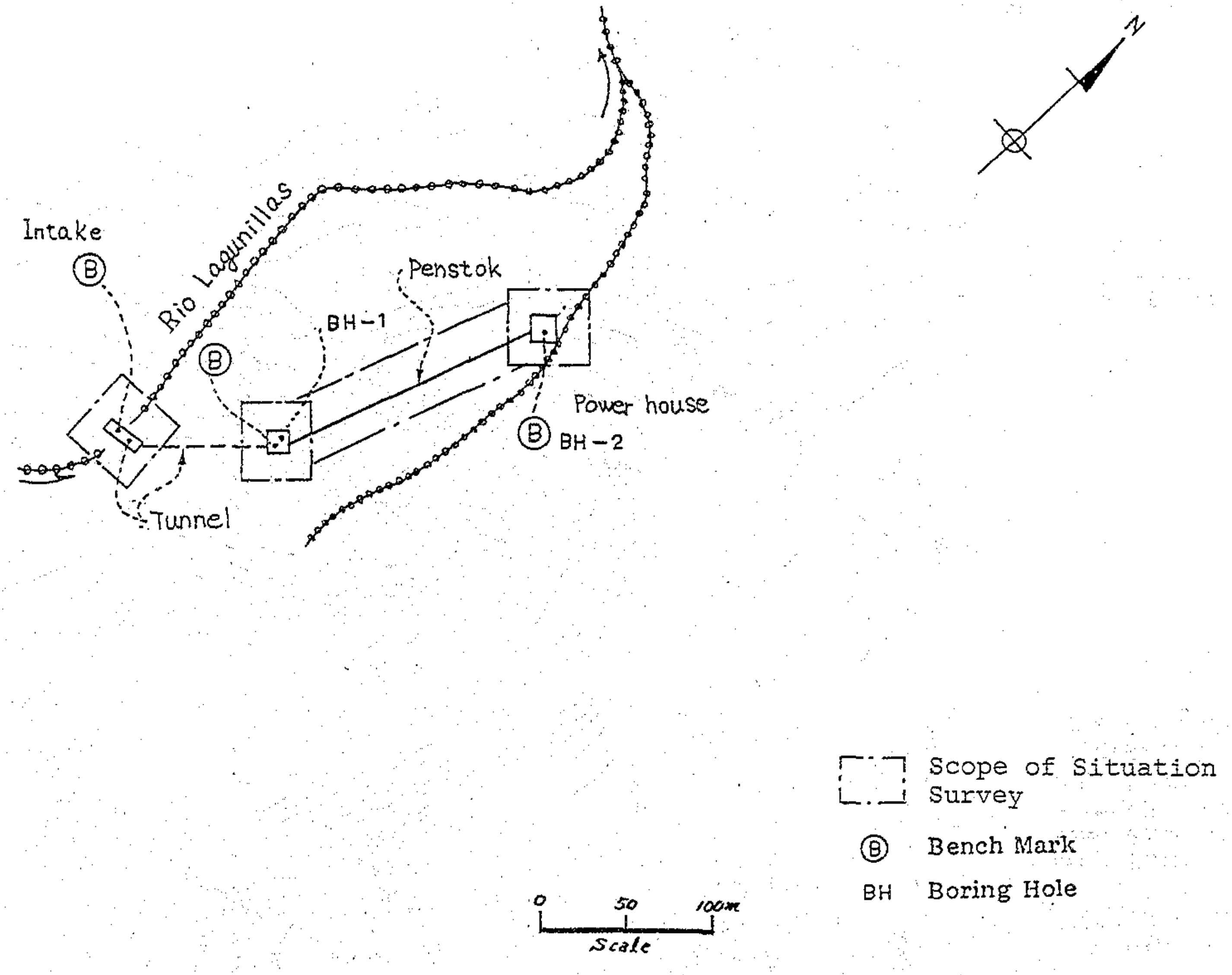

Intake
Rio Lagunillas
Penstok
BH-1
Power house
BH-2
Tunnel
Scope of Situation Survey
Bench Mark
BH Boring Hole
0
50
100m
Scale

Fig. 3.2 ALT-1

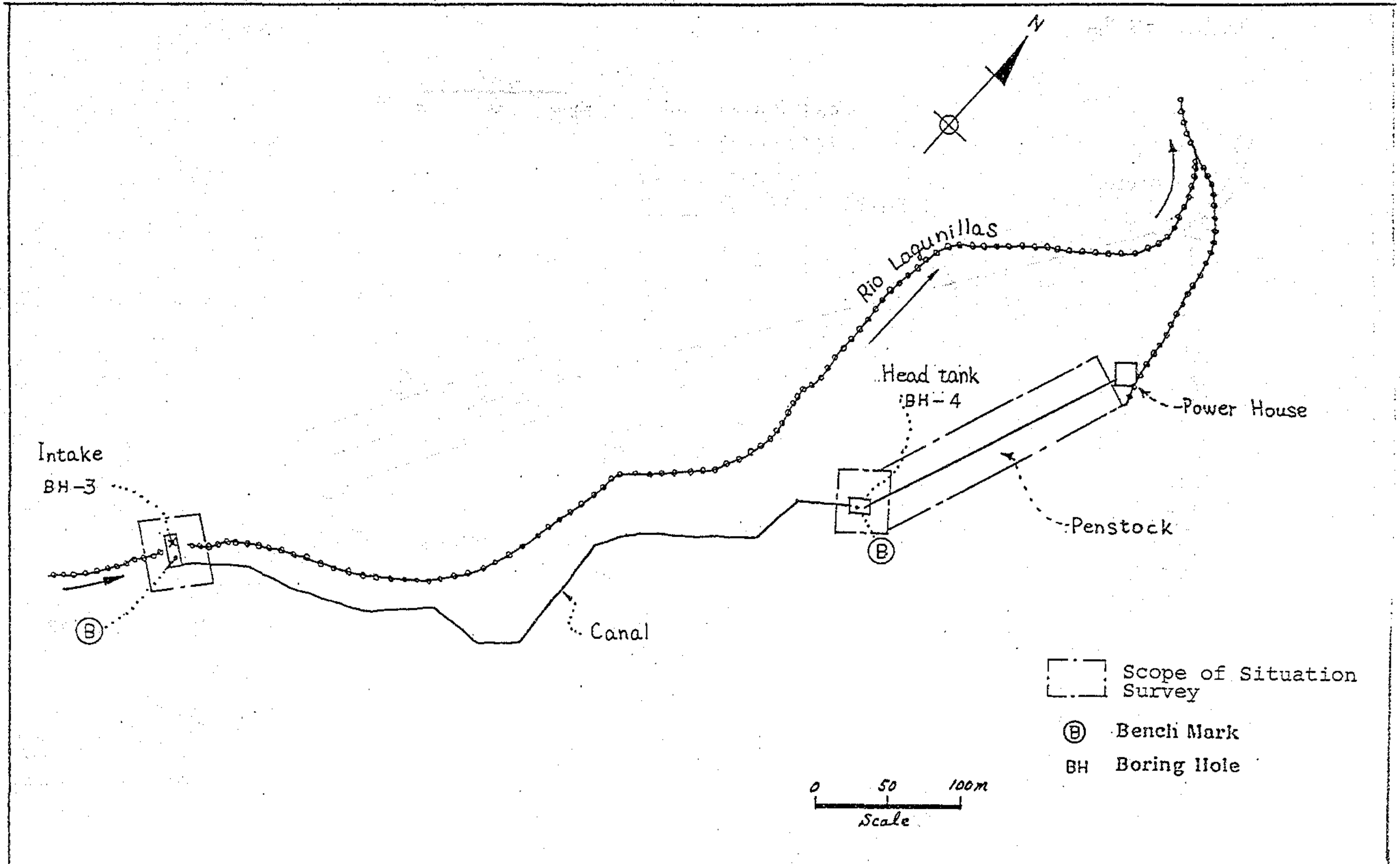
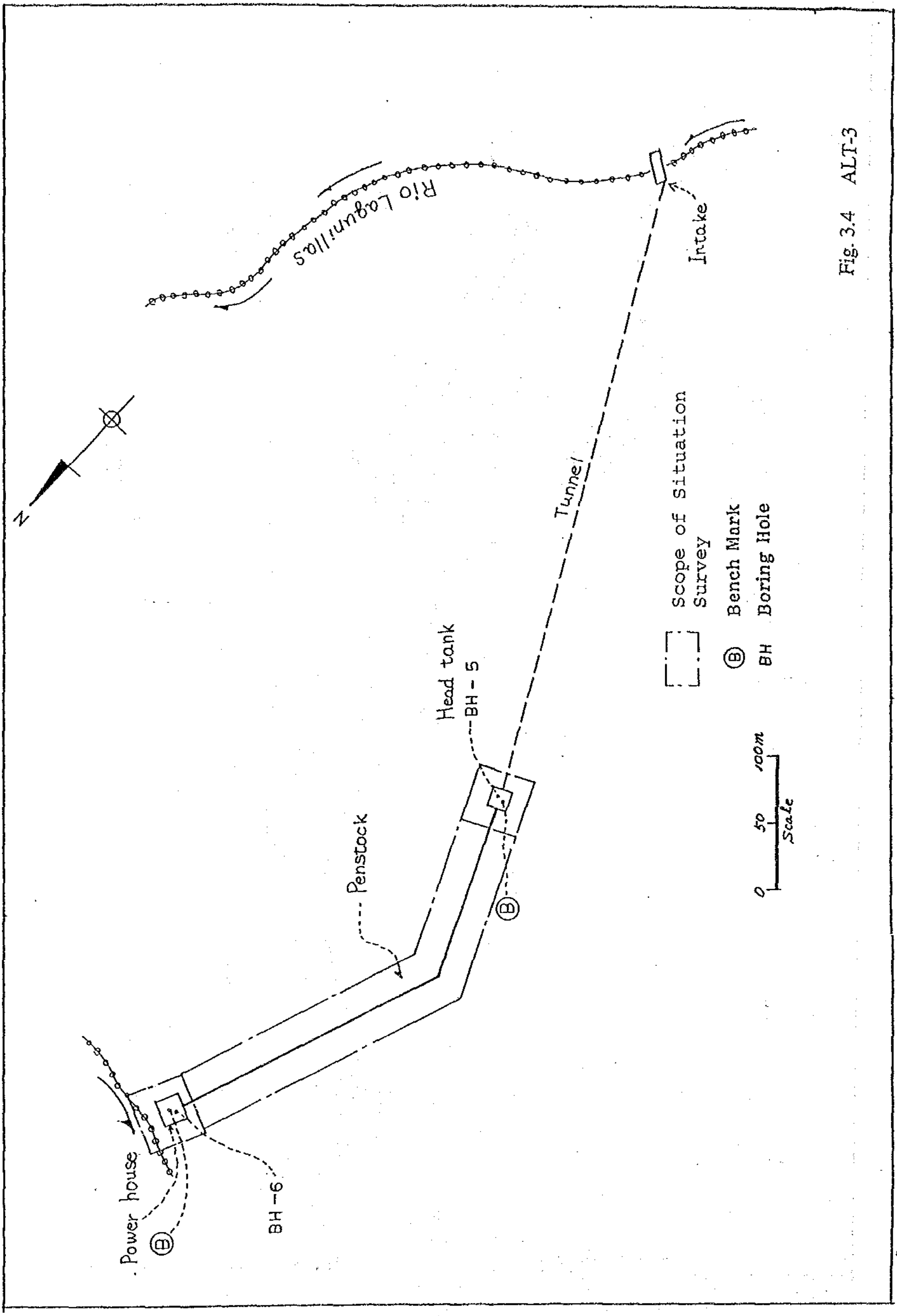

N
Rio Lagunillas
Head tank
BH-4
Power House
Penstock
Intake
BH-3
B
Canal
Scope of Situation Survey
B Bench Mark
BH Boring Hole
0 50 100m
Scale

Fig. 3.3 ALT-2


Rio Lagunillas
Intake
Tunnel
N
Head tank
BH - 5
Penstock
Power house
BH -6
B
Scope of Situation Survey
B Bench Mark
BH Boring Hole
0
50
100m
Scale
Fig. 3.4 ALT-3

# CHAPTER 4 PRESENT CONDITION OF THE STUDY AREA

## 4.1 Power Conditions in the Power Sector

Power conditions of the public electric power company operated power plant under study for rehabilitation (hereinafter called public electric power company) are described below.

### 4.1.1 Balance of Power Supply and Demand

Table 4.1 shows figures for power supply and demand during the five years from 1983 to 1987. In 1987 peak demand was 130 MW, while installed capacity was 66 MW (about 51%). In 1987, electric power was 495 GWh, while supplied power was 170 GWh, which is about 34% of total electric power. The public electric power company bought the equivalent of 455 GWh of electricity from another electric power company.

The breakdown of power demand in 1987 indicates that power demand for residential, commercial, industrial, and miscellaneous uses was 38%, 9%, 5% and 25% respectively. Power demand for residential use was high, while that for commercial use was low.

Annual average rate of increase in power demand from 1983 to 1987 is 2.5%, while that of generated energy was -8.9%; the rate of buying electricity was high.

Table 4.1 Transition of Power Supply and Demand (1983 - 1987)

| Item | 1983 | 1984 | 1985 | 1986 | 1987 | Annual Average Increase Rate (%) * |
|---|---|---|---|---|---|---|
| DEMAND | | | | | | |
| 1. Peak Demand (MW) | 83 | 97 | 103 | 106 | 130 | 11.9 |
| 2. Electric Power (GWh) | | | | | | |
| 1) Residential | 157 | 164 | 174 | 178 | 189 | 4.7 |
| 2) Commercial | 44 | 45 | 45 | 45 | 47 | 1.7 |
| 3) Industrial | 111 | 119 | 128 | 136 | 139 | 5.8 |
| 4) Miscellaneous | 136 | 186 | 134 | 171 | 120 | -3.1 |
| Total | 448 | 514 | 481 | 530 | 495 | 2.5 |
| SUPPLY | | | | | | |
| 1. Installed Capacity (MW) | 67 | 67 | 66 | 66 | 66 | -0.4 |
| 2. Generated Energy (GWh) | 247 | 338 | 239 | 304 | 170 | -8.9 |
| 3. Power Loss (GWh) | 123 | 131 | 129 | 125 | 130 | 1.4 |

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

* Annual average increase rate is calculated as follows:

Example: When peak demand is 11.9%,

$83 \times (1 + x)^4 = 130$

$x = 0.119$ (11.9%)

### 4.1.2 Present Conditions of Generating Facilities

(1) Generating facilities

Table 4.2 shows total installed capacity of a public electric power company. Its generating system includes hydroelectric power and thermal power.

Table 4.2 Total Installed Capacity of Public Electric Power Company (1983 - 1987)

| Item | 1983 | 1984 | 1985 | 1986 | 1987 | Annual Average Increase Rate (%) |
|---|---|---|---|---|---|---|
| Total Installed Capacity (MW) | | | | | | |
| 1. Thermal | 0 | 0 | 0 | 0 | 0 | 0 |
| 2. Hydroelectric | 67 | 67 | 66 | 66 | 66 | -0.4 |
| 3. Others | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 67 | 67 | 66 | 66 | 66 | -0.4 |

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

The power plant of the FS broke down in 1972, so operation ceased. At present, the generating facilities are left unattended.

(2) Transmission facilities

The public electric power company provides 115 kV transmission lines to its transmission and substation facilities. However, transmission facilities are not provided for Lagunilla P/P.

### 4.1.3 Generating Cost and Electric Charges

Table 4.4 indicates the transition of generating cost and electric charges for the five years from 1983 to 1987.

Table 4.4 Generating Cost and Electric Charges

| Item | 1983 | 1984 | 1985 | 1986 | 1987 | Annual Average Increase Rate( %) |
|---|---|---|---|---|---|---|
| Generating Cost (COL$/kWh) | 3.66 | 4.04 | 5.63 | 6.65 | 10.61 | 30.5 |
| Electric Charge (Average): (COL$/kWh) | | | | | | |
| 1. Residential | 2.92 | 2.99 | 3.05 | 3.92 | 4.91 | 13.9 |
| 2. Commercial | 5.24 | 5.79 | 6.97 | 9.39 | 12.37 | 24.0 |
| 3. Industrial | 5.32 | 6.05 | 6.16 | 7.63 | 10.01 | 17.1 |
| 4. Public use | 3.56 | 3.70 | 5.17 | 6.37 | 10.02 | 29.5 |
| 5. Average | 3.46 | 3.57 | 4.26 | 5.23 | 7.36 | 20.8 |
| Breakdown of Power Demand by customer | | | | | | |
| 1. Residential | 101,315 | 110,665 | 114,968 | 118,400 | 125,622 | 5.5 |
| 2. Commercial | 8,555 | 8,725 | 8,829 | 8,984 | 9,530 | 2.7 |
| 3. Industrial | 422 | 404 | 405 | 367 | 385 | -2.3 |
| 4. Others | 1,798 | 1,903 | 1,930 | 1,969 | 1,886 | 1.2 |
| 5. Total | 112,090 | 121,697 | 126,132 | 129,720 | 137,423 | 5.2 |
| Diffusion of Electricity | | | | | | |
| 1. Overall (1000 households) | 1,025 | 1,038 | 1,052 | 1,065 | 1,079 | 1.3 |
| 2. Power demand (1000 households) | 459 | 501 | 521 | 536 | 569 | 11.3 |
| 3. Electrification rate (%) | 45 | 48 | 50 | 50 | 53 | 4.2 |

(Source: INFORME ESTADISTICO: RESUMEN 1983-1987)

### 4.1.4 Forecast of Power Supply

ELECTROLIMA forecast for the power supply in 1995 and 2000 is shown in the following table.

Table 4.5 Forecast of Power Supply

(Units: GWh)

| | 1995 | 2000 |
|---|---|---|
| Supply | | |
| 1. Generated energy | 210 | 210 |
| 2. Amount of electricity-buying | 566.1 | 794 |
| Total | 776.1 | 1,004 |

## 4.2 Operation Record of the Existing Power Plant

Although the existing power plant started operation in 1940, it has not been operating since 1972 because the generating equipment broke down. Thus, no past record for operation and generated energy exists.

## 4.3 General Condition of Generating Equipment and Civil Structures

### 4.3.1 General Condition of Generating Equipment

The present condition of the generating equipment is summarized below:

(1) Generating equipment

Although Lagunilla P/P started operation in 1940, it has stopped operation since 1972 because of breakdown of the generating equipment.

Since 1972 generating equipment has been left unattended without any maintenance. Operation of such equipment is ill-advised. The control panel for water turbine and generator was removed from the plant site.

(2) Substation and distribution

The substation and distribution line were removed from the plant site.

### 4.3.2 General Condition of Civil Structures

Lagunilla P/P ceased operation 16 years ago. The diversion weir was destroyed by debris flow from the volcanic eruption of Mt. Nevado del Ruiz, and it has been left unattended.

(1) Intake facilities

The intake facilities are built in the 300-meter-high waterfall head, but there is no desilting basin. The intake (unlined tunnel structure) is on the right bank. The screen was washed away and no gate was installed.

(2) Conduction channel

There is a 46-meter-long conduction channel with a cross section of 0.7 x 0.6 m and RC cover.

(3) Head tank and desilting basin

The head tank is combined with the desilting basin, and total storage capacity is 17 $m^3$. The head tank/desilting basin has no capacity for desilting or adjustments of the head tank.

(4) Penstock

The two 114-meter-long penstocks (diameter: 300~500Ømm) cannot be used because of damage.

(5) Powerhouse building

RC building (size: 12.90 x 11.55 m) is built on a slope below the intake. The gross head of the waterfall is 300 m, but only a 120-meter-section, approximately 1/3 of the gross head, is utilized for this power plant because of topographic restriction.

(6) Tailrace

No tailrace is provided.

# CHAPTER 5 BASIC DATA COLLECTION

The pre-FS was conducted from November, 1987 to July, 1988. The FS was carried out in November, 1988 to collect topographical, geological, hydrometeorological and other related data as detailed below:

## 5.1 Topographic Maps

The fountainhead of the Rio Lagunilla is Nevado del Ruiz. The Rio Lagunilla flows through Libano, Armero and joins the Rio Magdarena. Lagunilla P/P is located about 25 km west of Armero.

JICA Study Team collected the following topographic maps.

- Topographic maps (scale: 1/10,000 - 1/400,000) published by IGAC
- Topographic maps that were actually measured by ELECTROLIMA for the study of this power plant
- Topographic maps (scale: 1/5,000) drawn in 1984 by ELECTROLIMA according to aerial photographic survey to conduct the FS

(1) Topographic maps published by IGAC

| Scale | Drawing No. | Description |
|---|---|---|
| 1:400,000 | - | the whole area of Tolima Department |
| 1:100,000 | 225<br>226 | } power plant and vicinity |
| 1: 25,000 | 225-II-A,B,C,D<br>226-I-A,C | } power plant and upstream area |
| 1: 10,000 | 226-I-A-1,2 | power plant and vicinity |

(2) Topographic maps measured by ELECTROLIMA

Topographic survey maps actually measured by ELECTROLIMA from March to August, 1989 for the study of this power plant are as follows:

| Scale | Drawing No. | Description (planned area) |
|---|---|---|
| 1:500 | 1 | ALT-1 whole area, ALT-2 Powerhouse |
| " | 2 | ALT-2 conduction channel route |
| " | 3 | ALT-2, 3 diversion weir |
| " | 4 | ALT-3, conduction channel |
| " | 5 | ALT-3 penstock, Powerhouse |
| 1:200 | 6 | ALT-1 head tank, Powerhouse ALT-2 Powerhouse |
| " | 7 | ALT-1 diversion weir, ALT-2 head tank |
| " | 8 | ALT-2 diversion weir, ALT-3 diversion weir, head tank |
| " | 9 | ALT-3 Powerhouse |
| " | 10 | ALT-2 head tank expansion |

(3) Topographic maps drawn according to aerial photographic survey

| Scale | Drawing No. | Application |
|---|---|---|
| 1:5000 | LE-01 | |
| " | LE-02 | |
| " | LE-03 | |
| " | LE-04 | |

## 5.2 Geological Survey Data

Geological survey data collected for this survey is as follows:

- Mapa Actualizado de Amenaza Volcanica Potencial del Nevado del Ruiz; 1986 INGEOMINAS

- Projecto Hidroelectrico Lagunilla Factibilidad Tecnica; 1984 ICEL

In addition, ELECTROLIMA conducted a boring survey for this study, which is included in the following report.

- Estudios de Geologia Nueva Planta Lagunilla Perforaciones Exploratorias; 1989 Consultoria Colombia S.A.

## 5.3 Hydrometeorological Data

Since Lagunilla P/P does not have the facilities for monitoring precipitation levels and discharge, JICA Study Team gathered HIMAT's hydrometeorological data for this survey.

At present, there is no discharge-observing facility along the Lagunilla River. JICA Study Team gathered the discharge data recorded in the past years at the Quinta Cobla gauging station operated by HIMAT and at the E1 Bosque gauging station operated by IAAFE. These two gauging stations no longer exist. In addition, the Study Team collected discharge data recorded at the Pte Sanfrancisco gauging station, located along the Sabandja River flowing in the northern part of the Lagunilla River; and at the Nueva La gauging station, located along the Recio River flowing in the southern part of the Lagunilla River. Collected hydrolometeorotogical data is categorized and summarized below.

Table 5.1 List of Data Collected Relating to Hydrometeorology

(1) Precipitation observation record

| Meteorological station No. | Meteorological station Name | Controller | Location Latitude | Location Longitude | Altitude (m) | Observation period |
|---|---|---|---|---|---|---|
| 2125-007 | Sierra La | HIMAT | 0448 | 7456 | 477 | 1955-85 |
| 2125-011 | Murillo | " | 0453 | 7511 | 2960 | 1970-86 |
| 2125-012 | Villoheronos | " | 0502 | 7507 | 2025 | 1970-86 |
| 2125-037 | Florida Hda La | " | 0456 | 7449 | 340 | 1970-85 |
| 2125-045 | Potosi Hda | " | 0506 | 7455 | 341 | 1971-86 |
| 2125-050 | Libano | " | 0456 | 7504 | 1585 | 1958-86 |
| 2125-051 | Anmero Gza-C Unive | " | 0458 | 7455 | 390 | 1977-86 |
| 2125-508 | Salto El | " | 0448 | 7448 | 450 | 1970-85 |
| 2125-512 | Villa Hermosa | " | 0503 | 7506 | 2029 | 1975-85 |
| 2125-514 | Quinta La | " | 0449 | 7456 | 500 | 1984-85 |

(2) Discharge observation record

| Hydrological gauging station No. | Hydrological gauging station Name | River | Controller | Establish-ment | Location Latitude | Location Longitude | Altitude (m) | Catchment area ($km^2$) | Observa-tion period |
|---|---|---|---|---|---|---|---|---|---|
| 2125-708 | Quinta Cobla | Lagunilla | HIMAT | 1972-04 | 0458 | 7456 | 360 | 460 | 1974-75 |
| 4-132 | El Bosque | " | IAAFE | 1956-02 | 0458 | 7506 | 1900 | 155 | 1957-64 |
| 2125-707 | Pte Sanfrancisco | Sabandiza | HIMAT | 1972-03 | 0503 | 7455 | 260 | 230 | 1972-87 |
| 2125-710 | Nueva La | Recio | " | 1977-01 | 0448 | 7459 | 470 | 010 | 1978-85 |

(3) Water quality observation record

1) Lagunilla River — April 22 to June 11, 1989
Observation items : pH, S, Cℓ, Fe

2) Recio River — February 11, 1980 to October 23, 1985
Observation items : pH, Ma, Na, Cℓ, $SO_4$, $HCO_3$, S, conductivity

3) Sabandja River January 19, 1988
Observation items : pH, Cℓ, S, conductivity

(4) Sediment observation record

1) Lagunilla River

2) Recio River
Sediment observation record for seven years from 1981 to 1987

## 5.4 Other Related Data

### 5.4.1 Construction Price Data

CAMCOL (Camera Colombiana de la Construccion) publishes "Catalogo de Precios de Materiales de Construccion (Catalog of Construction Material Prices)" monthly, in each department, which covers construction prices for civil work in Colombia. However, the above publication is not published in all departments of Colombia; e.g., Tolima Department where the study was conducted. Accordingly, construction prices used for this study are based on price data used by ELECTROLIMA (refer to Table 5.2).

### 5.4.2 Power Condition Data

(1) JICA Study Team collected the following data for the purpose of examining ELECTROLIMA's power condition.

1) Operation and maintenance costs at five hydroelectric power plants (1984-88)

2) Record of generated energy at five hydroelectric power plants (1984-88)

3) Power schematic diagram for ELECTROLIMA

Table-5.2 UNIT PRICE LIST
表-5.2 建設工事単価表

<table>
<tr><th rowspan="3"></th><th rowspan="3">UNIT</th><th rowspan="2">EADE</th><th rowspan="2">CHEC</th><th colspan="2">CEDELCA</th><th rowspan="2">E.CHOCO</th><th rowspan="2">CEDENAR</th><th rowspan="2">ESSA</th><th rowspan="2">ELECTROLIMA</th></tr>
<tr><th>SILVIA</th><th>OVEJAS</th></tr>
<tr><th>NOV./88</th><th>FEB./89</th><th>JUN./89</th><th>JUN./89</th><th>MAR./89</th><th>JUN./89</th><th>APR./89</th><th>MAY/89</th></tr>
<tr><td>1. EARTH WORK (EARTH)</td><td>p/m$^3$</td><td rowspan="2">2,400</td><td>2,925</td><td rowspan="2">700</td><td rowspan="2">800</td><td rowspan="2">2,950</td><td>990</td><td rowspan="2">2,500</td><td>1,100</td></tr>
<tr><td>2. EARTH WORK (ROCK)</td><td>p/m$^3$</td><td>3,965</td><td>1,900</td><td>2,800</td></tr>
<tr><td>3. CONCRETE WORK (MASS CON.)</td><td>p/m$^3$</td><td>-</td><td>-</td><td>-</td><td>-</td><td>24,000</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>4. CONCRETE WORK (STRUCTURAL)</td><td>p/m$^3$</td><td>26,300</td><td>27,625</td><td>34,000</td><td>40,000</td><td>26,800</td><td>20,500</td><td>15,600</td><td>17,900</td></tr>
<tr><td>5. REINFORCING BAR</td><td>p/t</td><td>354,000</td><td>454,000</td><td>350,000</td><td>360,000</td><td>447,500</td><td>300,000</td><td>320,000</td><td>215,000</td></tr>
<tr><td>6. GATE</td><td>p/t</td><td>1,682,000</td><td>500,000</td><td>1,310,000</td><td>1,420,000</td><td>1,100,000</td><td>1,100,000</td><td>1,100,000</td><td>480,000</td></tr>
<tr><td>7. SCREEN</td><td>p/t</td><td>1,682,000</td><td>5,00,000</td><td>804,195</td><td>874,125</td><td>1,000,000</td><td>1,000,000</td><td>1,000,000</td><td>650,000</td></tr>
<tr><td>8. PENSTOCK</td><td>p/t</td><td>1,000,000</td><td>1,000,000</td><td>1,250,000</td><td>1,250,000</td><td>-</td><td>815,000</td><td>1,260,000</td><td>420,000</td></tr>
<tr><td>9. POWER HOUSE (REPAIR)</td><td>p/m$^2$</td><td>-</td><td>10,000</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>10. POWER HOUSE (NEW CONST.)</td><td>p/m$^2$</td><td>-</td><td>40,000</td><td>47,000</td><td>55,000</td><td>50,000</td><td>50,000</td><td>50,000</td><td>50,000</td></tr>
<tr><td>11. CYCLOPEAN CONCRETE</td><td>p/m$^3$</td><td>-</td><td>14,000</td><td>17,000</td><td>20,000</td><td>-</td><td>-</td><td>8,000</td><td>9,000</td></tr>
<tr><td>12. DEMOLITION CONCRETE</td><td>p/m$^3$</td><td>13,000</td><td>14,000</td><td>17,000</td><td>20,000</td><td>-</td><td>-</td><td>8,000</td><td>9,000</td></tr>
<tr><td>13. STEEL PIPE</td><td>p/t</td><td>-</td><td>-</td><td>-</td><td>1,250,000</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>14. GABION</td><td>p/m$^3$</td><td>-</td><td>-</td><td>8,800</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>15. TUNNEL EXCAVATION</td><td>p/m$^3$</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>19,600</td></tr>
<tr><td>16. TUNNEL CONCRETE</td><td>p/m$^3$</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>25,000</td></tr>
</table>

# CHAPTER 6 PRESENT CONDITION OF TOPOGRAPHY AND GEOLOGY

## 6.1 Topography and Geology in the Area

### 6.1.1 Topography

The fountainhead of the Lagunilla River is the top of Nevado del Ruiz volcano (elevation: 5,400 m), an active volcano (the Quaternary period) in the central mountains. The Lagunilla River winds around the western slope of the above volcano and flows south down. It joins the Magdalena River through Armero City, which was hit by debris flow in a 1985 disaster. The project site is located in a mountain district, upstream of the Lagunilla River. The topography in the vicinity forms steep slopes and V-shaped valleys. The elevation of the riverbed ranges from 1,450 to 1,750 m. There is a 300-meter waterfall head within the range of this elevation. River width at the existing riverbed is approximately 30 m. River slopes on the right and left banks are very steep. From aerial photographs, unusual contours are not observed in the vicinity of the project site.

### 6.1.2 Geology

The Nevado del Ruiz volcano bedrock (the Quaternary period) consists of metamorphic rocks. The project site is located in an area of metamorphic rocks.

As shown in Table 6.1, the geology at the low elevation area consists of crystalline schist which is subdivided into three schists, i.e., green schist, black schist and quartz schist.

On the right bank, andesite lava from the Tertiary period covers the upper part of the schist. Volcanic breccia, pumice, volcanic ash etc. (the Quarternary period) cover the andesite lava. It is assumed that the riverbed consists of andesite (about 70%), crystalline schist (20%) and granite (about 10%).

Table 6.1 Stratigraphy in the Vicinity of Project Site

| Era | | | Lithology | Remarks |
|---|---|---|---|---|
| Cenozoic era | Quartenary period | | Riverbed materials (gravel & sand) | |
| | | | Pyroolastic fall deposit (braccia,pumice, ash) | |
| | Tertiary period | | Andesite lava | |
| Pre-Cambrian | | | Crystalline schist<br>(green schist, black schist, quartz schist) | |

6.1.3 Geological Structure

Fig. 6.1 shows the geological structure of the surrounding area of the project site. Schistosity of crystalline schist comprising the bedrock strikes and dips N10°E ~ N10°W and 70°E ~ 80°W, i.e., it strikes from north to south and dips steeply. It is presumed that the boundary surface of andesite lava and crystalline schist is nearly horizontal.

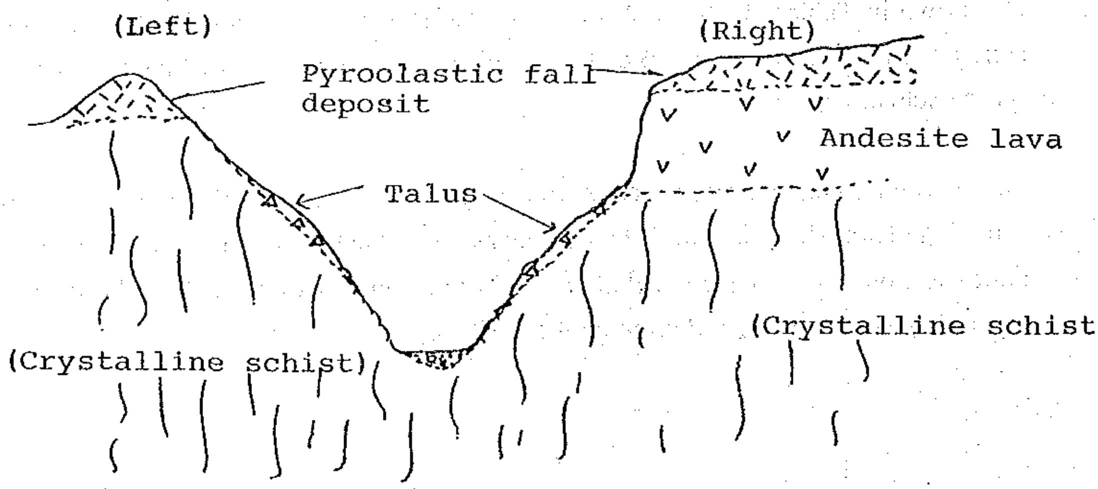



Fig. 6.1 Schematic Geological Profile

## 6.2 Geology at the Project Site

The geological condition of the foundation for the various civil structures is described below:

(1) Diversion weir

Since the green schist on the bedrock is fresh and hard, it is suitable for ALT-1, ALT-2 or ALT-3. Unstable slopes of deposited gravel and sand have been found at the project site for ALT-2 and ALT-3. These slopes must be stabilized.

(2) Tunnel (ALT-3)

The foundation at the entrance and exit of the tunnel consists of fresh and hard crystalline schist, so there is no problem of strength. However, the geology near the exit of the tunnel has become loose. A boring survey (BH-5) indicated that the geology has turned into volcanic breccia or weathered crystalline schist.

(3) Head tank (ALT-3)

The geology has become loose, as in the tunnel exit. The geology may consist of volcanic breccia (the Quaternary period) or weathered crystalline schist.

(4) Penstock (ALT-3)

The geology of the steep slope consists of crystalline schist, and on gentle slopes, talus.

(5) Power plant (ALT-3)

This power plant site lies between the two small streams. The powerhouse building could be half-built in the ground, as the bedrock is believed to be fresh crystalline schist (boring BH-6).

In the case of ALT-3, the foundation for the diversion weir, tunnel and powerhouse building consists of fresh and hard crystalline schist, as described above, and therefore there poses no geologic problem.

However, the boring survey (BH-5) indicates that the foundation for the head tank for ALT-3 is weathered and has become loose, so that the foundation design for the head tank will be conducted with this consideration. Since debris flow or lahar triggered by an expected eruption of the Nevado del Ruiz volcano may occur, the diversion weir will be designed taking these into account.

## 6.3 Distribution of Concrete Aggregates

Andesite lava or gravel is suitable for concrete aggregate.

1) Andesite lava is widely distributed below the plateau on the left bank of the Lagunilla River. A great amount of andesite lava can be obtained, but the quality has yet to be confirmed. If it is confirmed by an aggregate test, andesite lava will be considered as one of the candidate materials.

2) Gravel is distributed along the riverbed of the Lagunilla River. This gravel contains flat gravel (about 20%) of crystalline schist, which may reduce the strength of the concrete. Since the distribution of this material is limited to the existing riverbed, both points of quantity and quality must be confirmed.

   Lahar deposits from Nevado del Ruiz volcano are another candidate material for concrete aggregate.

   Since there is graveyard in the area where lahar deposits are distributed, it is difficult to collect this material. Lahar deposit, which is similar to gravel, includes a lot of sand and mud. Aggregate test must be conducted to confirm quality.

# CHAPTER 7 HYDROLOGICAL ANALYSIS

The locations of the existing gauging stations for monitoring precipitation and discharge in the watershed of the project site are shown in Fig. 7.1.

## 7.1 General Meteorology in the Planned Area

Tolima Department located in the west part of Colombia lies at 2°53' to 5°20' north latitude, and is situated near the equator. Tolima Department is divided into three districts --- mountainous district (the Central Andes Mountains), slope and plan district in the watershed of the Magdalena and Saldana rivers and slope district on the East Andes Mountains.

Generally, the lowland areas enjoy a tropical climate and have a hot and very humid rainy season. The areas at higher elevation change from the temperate climate to the cold climate. The lowland areas have an average temperature of 28°C, while the highland areas (at the elevation of 1,800 to 2,800 m) range from 12 to 18°C.

Ibague, capital of Tolima Department, lying in the highland (elevation: 1,400 m), has an average temperature of 18°C.

The annual maximum precipitation in the lowland areas between the Central and West Andes Mountains is about 2,000 mm, while the annual precipitation in the north part of Tolima Department is about 3,000 mm.

The fountainhead of the Lagunilla River, flowing through the project site, is at the eastern slope of the Central Andes Mountains from which the Lagunilla River flows east down, and joins the Magdalena River. Total length of the Lagunilla River is about 88 km.

The project site with the elevation of about 1,650 m above sea level is situated in the north of Ibague. The annual precipitation in the project site is about 1,000 mm, but it fluctuates year to year, with no distinct rainy and dry seasons. (Refer to Fig. 7.2.)

| Observation Item | Gauging Station | | Latitude | Longitude |
|---|---|---|---|---|
| | No | Name | | |
| Preciptation | 2125-007 | Sierra La | 0448 | 7456 |
| | 2125-011 | Murillo | 0453 | 7511 |
| | 2125-012 | Villahermosa | 0502 | 7507 |
| | 2125-037 | Florida Hda La | 0456 | 7449 |
| | 2125-045 | Potosi Hda | 0506 | 7445 |
| | 2125-050 | Livano | 0456 | 7504 |
| | 2125-051 | Armero Gja-C Uinive | 0458 | 7455 |
| | 2125-508 | Salto El | 0448 | 7448 |
| | 2125-512 | Villa Hermosa | 0503 | 7506 |
| | 2125-514 | Quinta La | 0449 | 7456 |

| Observation Item | Gauging Station | | Latitude | Longitude |
|---|---|---|---|---|
| | No | Name | | |
| Discharge | 2125-708 | Quinta Cobla | 0458 | 7456 |
| | 4-132 | El Bosque | 0458 | 7506 |
| | 2125-709 | Pte Sanfrancis | 0503 | 7455 |
| | 2125-710 | Nueva La | 0448 | 7459 |

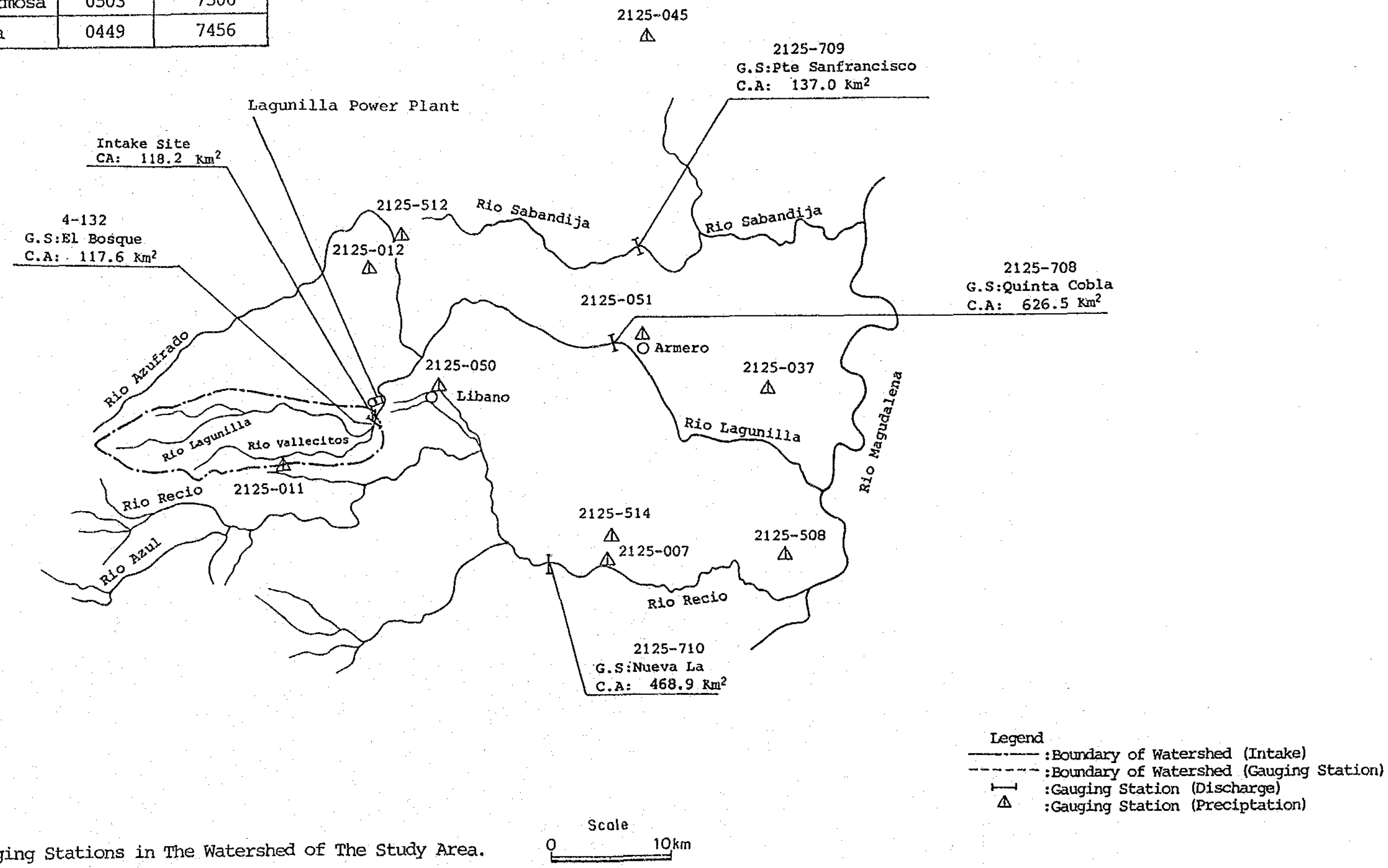



Fig-7.1 Location Map of Gauging Stations in The Watershed of The Study Area.

Meteorological station No.2125-011 Murillo
North latitude: 4°53'
West longitude: 75°11'
Elevation: 600 m
Annual average precipitation: 1,887.5 mm

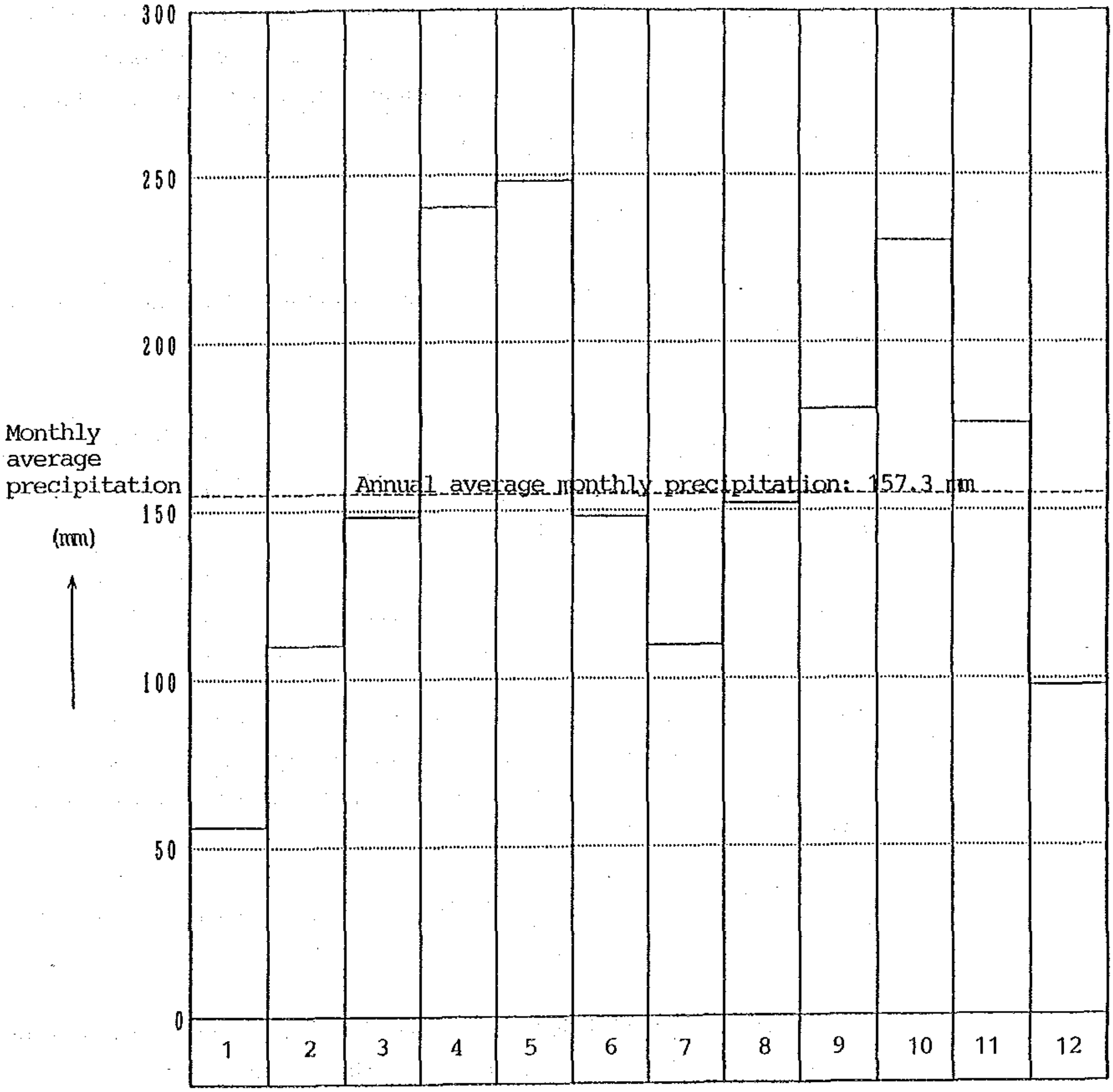



Fig.7.2 Monthly Average Precipitation in the Project Site (1970-86)

## 7.2 Discharge Analysis

The study team compiled observations recorded at the gauging stations of El Bosque, Quinta Cobla, Pte Sanfrancisco and Nueva La, and then prepared discharge and flow-duration curves according to the 7-year data observed at the El Bosque gauging station, lying near the intake for a newly constructed power plant, by converting river basin. (Refer to Drawing No. LA-H-01(4).)

### 7.2.1 Comparison of Discharge Observation Data

Observation periods of discharge data obtained by the study team during this study are as follows:

| Gauging station | Period | | Establishment |
|---|---|---|---|
| El Bosque | 1957 ~ 64 | 8 years | Feb., 1956 |
| Quinta Cobla | 1974 ~ 75 | 2 years | Apr., 1972 |
| Pte Sanfrancisco | 1972 ~ 87 | 15 years | Feb., 1972 |
| Nueva La | 1978 ~ 85 | 8 years | Jan., 1977 |

El Bosque and Quinta Cobla gauging stations are situated along the Lagunilla River. Observation period of discharge at the Quinta Cobla gauging station was two years. Since discharge was not monitored continuously, these recorded observations are unreliable as year-round data.

On the other hand, observation period of discharge at the Bosque gauging stations was 8 years, but it was not recent years.

Non-observed dates are included in the above discharge record. Years in which discharge record is reliable as year-round data are shown below:

| Gauging station | Period | |
|---|---|---|
| El Bosque | 1958 ~ 64 | 7 years |
| Quinta Cobla | | 0 |
| Pte Sanfrancisco | 1973 ~ 78 | 6 years |
| | 1980 ~ 85, 87 | 7 years |
| Nueva La | 1978 ~ 85 | 8 years |

(1) Collation to catchment area at the gauging station

To confirm the present location of the existing gauging stations, the longitude and latitude indicated on HIMAT's gauging register are plotted on the topographic maps (1/100,000) published by IGAC. As a result of this, there was a difference in latitude from the location of gauging station observed by the Study Team through a field reconnaissance. Therefore, the Study Team compared the catchment area at the gauging station using the topographic map (scale: 1/100,000) published by IGAC. However, there was significant difference in the catchment area, as shown in Table 7.1.

Table 7.1 Result of Comparison of Gauging Station Location and Catchment Area

| Item | Gauging Station | | |
|---|---|---|---|
| | Quinta Cobla | El Bosque | |
| | Catchment area ($km^2$) | Latitude | Catchment area ($km^2$) |
| HIMAT register | 460 | 0458 | 155 |
| Compared value | 468.9 | 0455 | 117.6 |
| Difference | 8.9 | 0003 | 37.4 |

Therefore, the catchment area ratio, when discharge and flow-duration curves at the intake are converted using the discharge record at the El Bosque gauging station, is calculated using the values measured by the Study Team.

(2) Comparing unit average flow-duration curves per 100 km$^2$

If the unit flow-duration curves per 100 km$^2$ at the gauging stations of El Bosque (the Lagunilla River), Pte Sanfrancisco (the Sabandija River) were drawn and compared, respective characteristic of the watershed was different, as can be seen from Fig. 7.3.

Though discharge record was observed at the gauging stations of Pte Sanfrancisco and Nueva La during the recent long years, it can not be used as discharge analysis data for Lagunilla P/P.

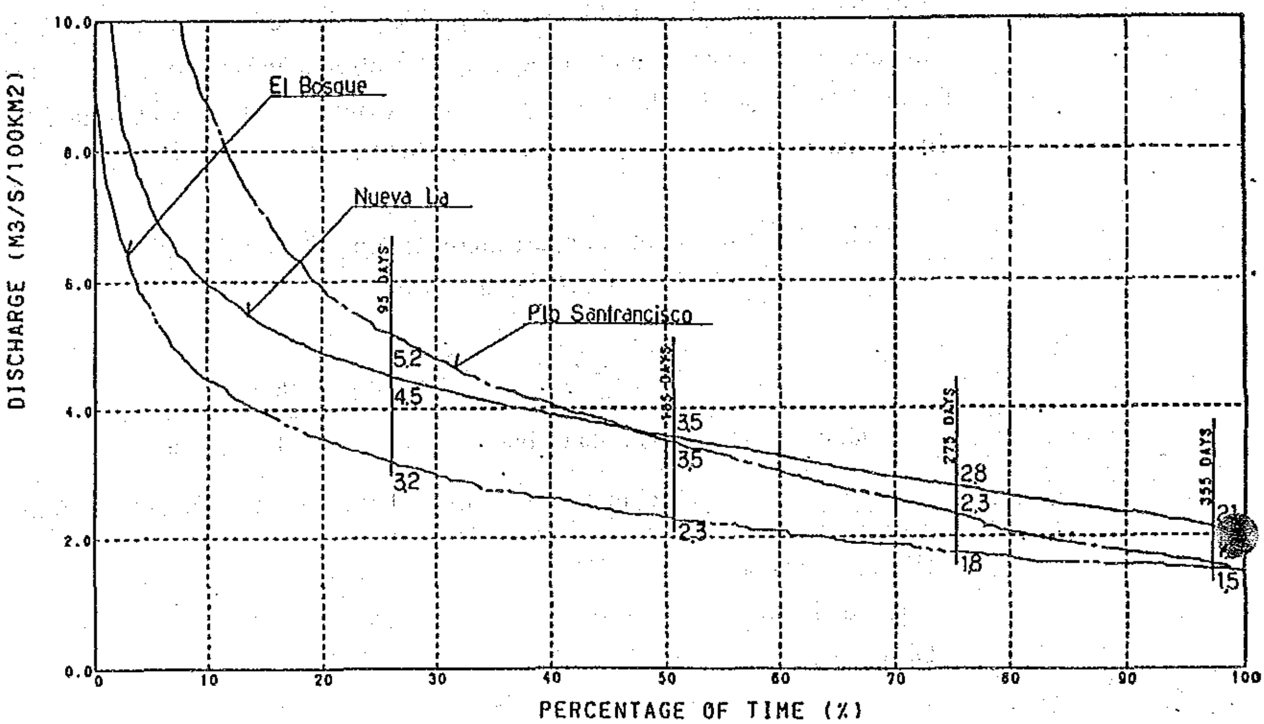



Fig. 7.3 Comparison of Unit Average Flow-duration Curves per 100 km$^2$

(3) Necessity of comparison based on discharge observation at the site

A simplified discharge-observing facility must be immediately installed in the project site, so that discharge data could be kept in constant readiness. t is desirable that a program for simultaneous observation of discharge at the Pte Sanfrancisco and Nueva La gauging stations to be formulated.

Either of the upstream area at a candidate site for the intake, the downstream area at a candidate site for power plant or the area with good shape of river cross section and gentle river gradient is suitable for gauging station.

### 7.2.2 Typical Flow-duration Curve Form

Year-to-year fluctuations of the river-duration curve occur at this site. In drawing a normal flow-duration curve, the following methods were considered:

a) Parallel method

The daily average discharge for 365 days is arranged in descending order and the flow-duration curve for each year is drawn and averaged.

b) Standard year method

Flow-duration curves for each year are drawn. The median curve is then selected and set as the flow-duration curve for a standard year.

c) Series method

Daily average discharge for 15 years is arranged in descending order with only the Y-axis adjusted for the one-year curve.

d) Curve insertion method

Average values from 355-day flow, 9-month flow, ordinary water discharge and three-month flow observed for a minimum of 10 years are calculated and plotted from a discharge handbook for the flow-duration curve.

Normal flow-duration curves are drawn based on the parallel-method. Non-observed years are not included. The X and Y axes are expressed as daily average discharge ($m^3/s$) and number of days (%), respectively.

### 7.2.3 Discharge and Flow-duration Curve at El Bosque Gauging Station

Discharge data at the El Bosque gauging station, located about 0.5 km upstream from the intake site of Lagunilla hydroelectric power plant, are arranged using the 7-year observation data, excluding non-observed dates, as shown in Table 7.3.

In calculating the monthly average discharge as shown in Table 7.4, months in which the observation time was less than 10 days are excluded from the calculation. As seen in Drawing LA-H-01 number (1), a graphic representation of the monthly average discharge, three-month flow periods can not be clearly distinguished from drought periods.

However, four months from April to July and three months from October to December are considered three-month flow periods.

Typical flow-duration curves calculated from the 7-year flow-duration curves (1958-1964) according to the parallel method are indicated in Drawing LA-H-01 number (3). Periods of three-month flow, ordinary water discharge, nine-month flow and 355-day flow in flow-duration curves are indicated in numerical values, as shown in Table 7.4.

Table 7.5 shows the maximum discharge recorded at El Bosque gauging station during 8 years from 1957 to 1964.

Table-7.3 MONTHLY FLOW TABLE OF DAILY AVERAGE FLOW AT G.S. SITE

GAUGING ST.: 4-132 EL BOSQUE
RIVER NAME: LAGUNILLA

(UNIT: M3/S)

| GAUGING YEAR | TYPE | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1957 | MAX. | (1) | (1) | 4.7 | 11.1 | 8.6 | 7.9 | 5.0 | 2.9 | 6.5 | 7.9 | 6.6 | 5.9 | 11.1 |
| | MEAN | (1) | (1) | (2) | 4.4 | 5.0 | 3.9 | 2.8 | 2.1 | 2.3 | 3.0 | 3.0 | 2.6 | 3.2 |
| | MIN. | (1) | (1) | 2.0 | 2.2 | 3.0 | 2.7 | 1.9 | 1.8 | 1.7 | 1.7 | 1.9 | 1.9 | 1.7 |
| 1958 | MAX. | 2.0 | 2.9 | 8.0 | 6.2 | 6.5 | 6.2 | 4.4 | 5.6 | 6.5 | 4.7 | 5.5 | 2.9 | 8.0 |
| | MEAN | 1.8 | 1.8 | 2.0 | 2.6 | 3.1 | 2.3 | 1.8 | 2.3 | 1.9 | 2.5 | 2.5 | 1.9 | 2.2 |
| | MIN. | 1.7 | 1.6 | 1.6 | 1.7 | 1.9 | 1.8 | 1.5 | 1.6 | 1.5 | 1.7 | 1.7 | 1.6 | 1.5 |
| 1959 | MAX. | 1.7 | 1.7 | 3.0 | 8.0 | 11.0 | 8.4 | 3.8 | 8.2 | 2.7 | 11.7 | 7.6 | 4.5 | 11.7 |
| | MEAN | 1.6 | 1.5 | 1.6 | 2.0 | 4.3 | 5.1 | 2.6 | 2.6 | 1.9 | 4.1 | 4.0 | 2.5 | 2.8 |
| | MIN. | 1.5 | 1.4 | 1.5 | 1.5 | 1.6 | 2.0 | 1.9 | 1.7 | 1.7 | 1.7 | 2.2 | 1.9 | 1.4 |
| 1960 | MAX. | 5.3 | 5.5 | 11.4 | 9.3 | 9.5 | 10.7 | 7.8 | 5.9 | 7.7 | 9.5 | 10.4 | 10.4 | 11.4 |
| | MEAN | 2.4 | 2.1 | 2.7 | 4.3 | 3.9 | 3.7 | 3.6 | 2.5 | 2.6 | 3.3 | 4.8 | 4.0 | 3.3 |
| | MIN. | 1.8 | 1.7 | 1.7 | 2.3 | 2.3 | 2.2 | 2.0 | 1.7 | 1.8 | 1.8 | 3.0 | 2.3 | 1.7 |
| 1961 | MAX. | 5.7 | 4.1 | 7.5 | 8.9 | 5.0 | 10.2 | 9.3 | 2.4 | 5.0 | 8.6 | 10.0 | 7.5 | 10.2 |
| | MEAN | 2.6 | 2.8 | 2.7 | 5.2 | 3.1 | 3.2 | 3.8 | 2.0 | 2.6 | 4.6 | 6.3 | 3.2 | 3.5 |
| | MIN. | 2.0 | 1.8 | 1.8 | 2.6 | 2.2 | 2.2 | 2.2 | 1.8 | 1.9 | 1.9 | 4.4 | 2.4 | 1.8 |
| 1962 | MAX. | 3.2 | 4.6 | 7.3 | 9.6 | 7.8 | 9.1 | 6.4 | 3.7 | 4.8 | 10.0 | 6.6 | 4.4 | 10.0 |
| | MEAN | 2.5 | 2.6 | 3.5 | 3.9 | 4.5 | 5.4 | 3.2 | 2.4 | 2.5 | 4.9 | 4.6 | 3.4 | 3.6 |
| | MIN. | 2.2 | 2.0 | 2.0 | 2.3 | 2.2 | 3.7 | 2.4 | 2.0 | 1.9 | 3.2 | 3.3 | 2.8 | 1.9 |
| 1963 | MAX. | 3.3 | 4.6 | 7.7 | 12.3 | 10.8 | 9.5 | 4.6 | 3.2 | 7.5 | 4.5 | 9.0 | 3.3 | 12.3 |
| | MEAN | 2.4 | 2.6 | 3.8 | 5.5 | 5.7 | 3.8 | 2.6 | 2.1 | 2.3 | 2.6 | 4.6 | 2.4 | 3.4 |
| | MIN. | 2.2 | 1.9 | 2.3 | 3.7 | 3.5 | 2.6 | 2.2 | 1.9 | 1.9 | 2.0 | 3.2 | 2.0 | 1.9 |
| 1964 | MAX. | 2.3 | 3.5 | 3.0 | 6.2 | 8.4 | 10.0 | 8.7 | 5.9 | 7.3 | 8.2 | 6.9 | 5.3 | 10.0 |
| | MEAN | 2.0 | 2.1 | 2.1 | 3.5 | 4.1 | 5.8 | 4.0 | 3.3 | 3.5 | 4.6 | 4.5 | 3.5 | 3.6 |
| | MIN. | 1.9 | 1.9 | 1.9 | 2.0 | 2.6 | 3.7 | 2.8 | 2.6 | 2.6 | 2.8 | 3.3 | 2.8 | 1.9 |
| TOTAL | MAX. | 5.7 | 5.5 | 11.4 | 12.3 | 11.0 | 10.7 | 9.3 | 8.2 | 7.7 | 11.7 | 10.4 | 10.4 | 12.3 |
| | MEAN | 2.2 | 2.2 | 2.6 | 3.9 | 4.2 | 4.1 | 3.1 | 2.4 | 2.5 | 3.7 | 4.3 | 2.9 | 3.2 |
| | MIN. | 1.5 | 1.4 | 1.5 | 1.5 | 1.6 | 1.8 | 1.5 | 1.6 | 1.5 | 1.7 | 1.7 | 1.6 | 1.4 |

NOTE) (1) ALL DATA MISSING
(2) NOT ENOUGH NUMBERS OF DATA FOR MONTHLY MEAN VALUE TO BE CALCULATED.

Table-7.4 FLOW DURATION TABLE AT GAUGING STATION SITE

P.S.: LAGUNILLA GAUGING ST.: 4-132 EL BOSQUE
RIVER NAME: LAGUNILLA (UNIT: M3/S)

| GAUGING YEAR | MAX. (1ST DAY) | PLENTY ( 95 DAY) | ORDINARY (185 DAY) | LOW (275 DAY) | DROUGHTY (355 DAY) | MIN. (LAST DAY) | MEAN |
|---|---|---|---|---|---|---|---|
| 1958 | 8.0 | 2.3 | 1.8 | 1.7 | 1.6 | 1.5 | 2.2 |
| 1959 | 11.7 | 3.3 | 2.0 | 1.6 | 1.5 | 1.4 | 2.8 |
| 1960 | 11.4 | 3.9 | 3.0 | 2.0 | 1.7 | 1.7 | 3.3 |
| 1961 | 10.2 | 4.2 | 2.8 | 2.2 | 1.9 | 1.8 | 3.5 |
| 1962 | 10.0 | 4.2 | 3.2 | 2.4 | 2.0 | 1.9 | 3.6 |
| 1963 | 12.3 | 4.1 | 2.7 | 2.2 | 1.9 | 1.9 | 3.4 |
| 1964 | 10.0 | 4.1 | 3.2 | 2.4 | 1.9 | 1.9 | 3.6 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| MEAN | 10.5 | 3.7 | 2.7 | 2.1 | 1.8 | 1.7 | 3.2 |

Table-7.5 MØNTHLY ABSØLUTE MAXIMUM FLØW TABLE AT G.S. SITE

GAUGING ST.: 4-132 EL BØSQUE
RIVER NAME: LAGUNILLA

(UNIT: M3/S)

| GAUGING YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | ØCT | NØV | DEC | ANNUAL TØTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1958 | 2.2 | 3.3 | 10.9 | 7.1 | 7.3 | 6.9 | 5.3 | 7.3 | 8.7 | 5.7 | 10.2 | 3.9 | 10.9 |
| 1959 | 1.9 | 1.9 | 5.1 | 12.2 | 13.4 | 10.4 | 4.1 | 11.6 | 2.8 | 14.1 | 8.7 | 8.7 | 14.1 |
| 1960 | 6.8 | 6.9 | 15.9 | 10.2 | 11.1 | 12.3 | 12.0 | 6.9 | 12.3 | 14.1 | 14.1 | 8.4 | 15.9 |
| 1961 | 6.6 | 4.4 | 9.1 | 14.1 | 5.0 | 12.7 | 10.9 | 2.6 | 8.7 | 9.3 | 10.5 | 8.7 | 14.1 |
| 1962 | 3.3 | 6.8 | 8.7 | 10.5 | 11.4 | 10.5 | 8.2 | 3.9 | 5.9 | 11.4 | 6.9 | 4.6 | 11.4 |
| 1963 | 3.3 | 5.1 | 8.7 | 16.3 | 12.7 | 13.4 | 5.0 | 3.3 | 10.5 | 5.9 | 10.5 | 3.3 | 16.3 |
| 1964 | 2.3 | 4.1 | 3.3 | 7.3 | 9.8 | 12.3 | 10.5 | 6.2 | 12.3 | 9.8 | 8.4 | 6.2 | 12.3 |
| TØTAL | 6.8 | 6.9 | 15.9 | 16.3 | 13.4 | 13.4 | 12.0 | 11.6 | 12.3 | 14.1 | 14.1 | 8.7 | 16.3 |

### 7.2.4 Discharge and Flow-Duration Curves at the Intake Site

Discharge and flow-duration curves at the intake site of Lagunilla P/P are calculated by multiplying respective catchment area ratio by recorded observations at the El Bosque gauging station located about 0.5 km upstream of the existing intake.

Since numerical values of the catchment area at the intake site are not officially approved, catchment areas measured by the Study Team are adopted. Therefore, a ratio of catchment area between Lagunilla P/P's intake site and El Bosque gauging station is set at 118.2/117.6 ≒ 1.01.

Discharge and flow-duration curves at the intake site converted according to the catchment area ratio are shown in Drawing LA-H-01, and representative values of monthly and daily average discharge and of three-month flow, ordinary water discharge, nine-month flow and 355-day flow are indicated in Table 7.6.

Table 7.6 Representative Discharge at the Intake Site

1) Monthly average discharge

| Item | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
| Max. average discharge ($m^3/s$) | 2.6 | 2.6 | 3.8 | 5.5 | 5.7 | 5.8 | 4.0 | 3.3 | 3.5 | 4.9 | 6.3 | 4.0 | 3.6 |
| Daily average discharge ($m^3/s$) | 2.2 | 2.2 | 2.6 | 3.9 | 4.2 | 4.1 | 3.1 | 2.4 | 2.5 | 3.7 | 4.3 | 2.9 | 3.2 |
| Min. average discharge ($m^3/s$) | 1.6 | 1.5 | 1.6 | 2.0 | 3.1 | 2.3 | 1.8 | 2.0 | 1.9 | 2.5 | 2.5 | 1.9 | 2.2 |

2) Typical discharge of flow-duration curve

| Three-month flow (95-day flow) | Ordinary water discharge (185-day flow) | Nine-month flow (275-day flow) | 355-day flow |
|---|---|---|---|
| 3.7 $m^3/s$ | 2.7 $m^3/s$ | 2.1 $m^3/s$ | 1.8 $m^3/s$ |

River utilization factor of a certain available discharge to typical flow-duration curves at the intake site (a ratio of total available discharge and total river discharge flowing into the intake site) and facility utilization factor (a ratio of total discharge for which water can be taken in to the available discharge throughout the year and total water amount in the event that available discharge is secured throughout the year) are represented graphically in Drawing LA-H-01 number (5).

## 7.3 Flood Runoff Analysis

Flood discharge is important to maintain the safety of facilities. The design flood discharge is obtained by converting the statistical processing of the recorded observations of the discharge at El Bosque gauging station by the catchment area ratio.

### 7.3.1 Frequency of Flood

In order to obtain potential flood discharge, annual maximum discharge which is shown in Table 7.7 is summarized according to the discharge data.

Table 7.7 Annual Flood Discharge

| Year Observed | Maximum Discharge ($m^3$/sec) |
|---|---|
| 1957 | 15.93 |
| 1958 | 10.90 |
| 1959 | 14.13 |
| 1960 | 15.93 |
| 1961 | 14.10 |
| 1962 | 11.40 |
| 1963 | 16.30 |
| 1964 | 12.30 |

The observation data recorded over 8 years is a comparatively short sample. There are several methods to calculate the probability of flood, but the following three methods are considered.

1. Logarithm normal distribution method (slade method)
2. Order probability method

3. Gumbel method

For the order probability method and Gumbel method, both the Thomas plot and Hazen plot are studied.

Figs. 7.4 and 7.5 show that maximum yearly discharge is plotted on X-axis of abscissa and that percentage of excess probability calculated is plotted on Y-axis by using the extreme probability paper. Table 7.8 shows the potential flood discharge for major years of return period obtained from the probability curve shown in the figure.

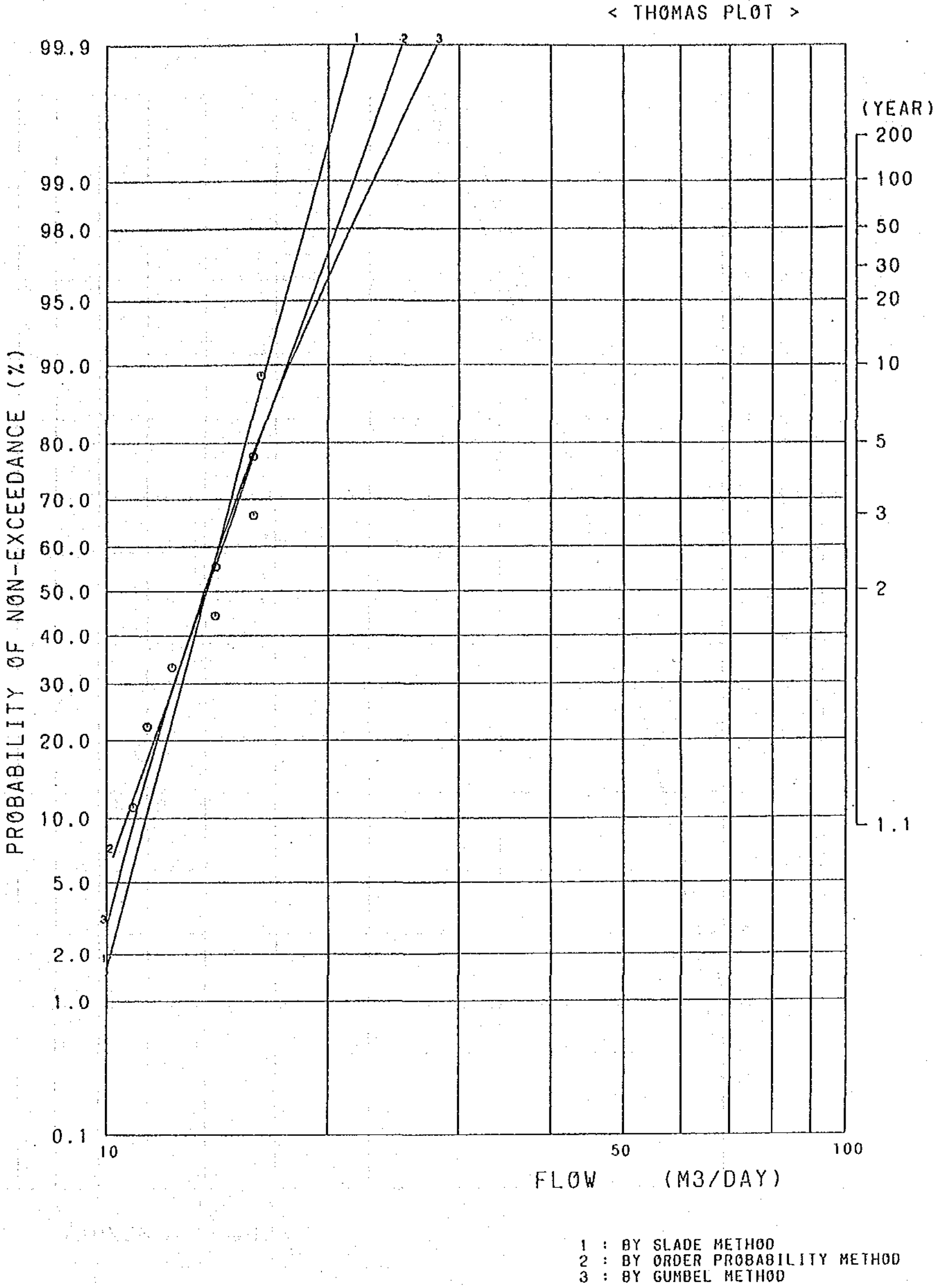



Fig. 7.4 Probability Curve of the Lagunilla River (Thomas Plot)

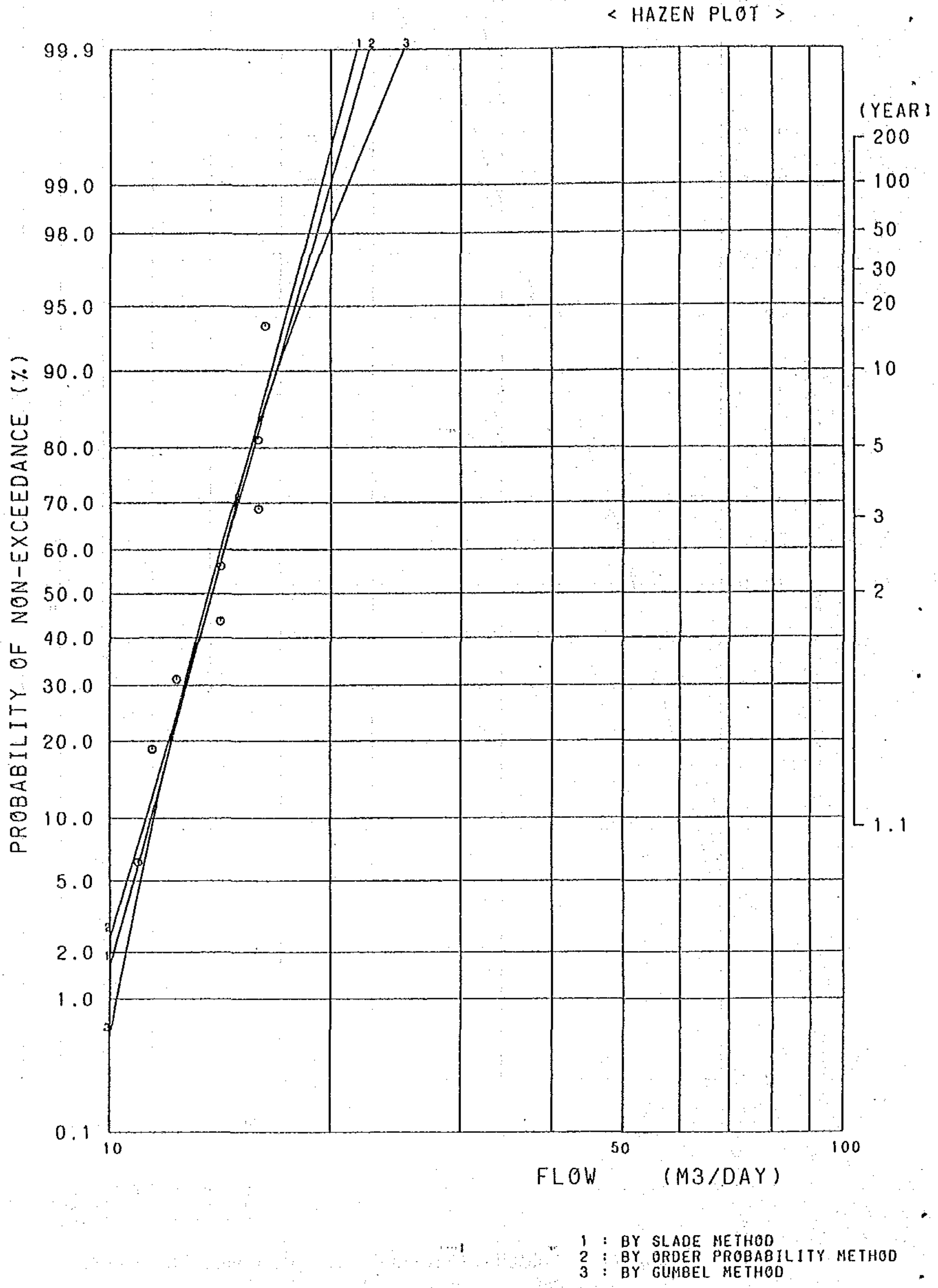



Fig. 7.5 Probability Curve of the Lagunilla River (Hazen Plot)

Table 7.8 Potential Flood Discharge

| Method | Return Period in Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 50 | 100 | 200 | 500 | 1000 |
| Logarithm normal distribution method ($m^3/s$) | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 22 |
| Order probability method: | | | | | | | | |
| Thomas plot ($m^3/s$) | 16 | 18 | 19 | 21 | 22 | 23 | 24 | 25 |
| Hazen plot ($m^3/s$) | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Gumbel method: | | | | | | | | |
| Thomas plot ($m^3/s$) | 16 | 18 | 19 | 21 | 23 | 25 | 27 | 28 |
| Hazen plot ($m^3/s$) | 16 | 17 | 18 | 20 | 21 | 22 | 24 | 25 |

### 7.3.2 Design Flood Discharge

With reference to the "Generalized design criteria for water-control structures"* the 100-year probability discharge is employed from 50 to 100 years of the return period which is applied to the structures.

The design flood discharge (Q) in the intake site is calculated by converting with the catchment area ratio.

$$Q = 2.3 \text{ m}^3/\text{s} \times 118.2 \text{ km}^2/117.6 \text{ km}^2 = 23.1 \ldots\ldots 25 \text{ m}^3/\text{s}$$

The specific discharge per catchment area ($km^2$) will be $q = 0.21$ $m^3/s$. This value is the Creager curve of Fig. 7.6 indicating the relationship between specific discharge and catchment area is C = 7.2.

* Applied Hydrology Editor Ven Te Chow

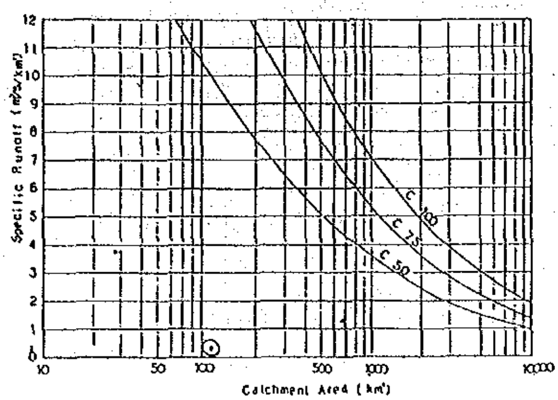


Fig. 7.6    Design Flood Discharge and Creager Curve

## 7.4 Sediment Analysis

The debris produced at the catchment mountain flows down to the intake point, and flows further downstream via channel and river. The debris flow process is shown in Fig. 7.7, and the debris flow volume is studied by this process.

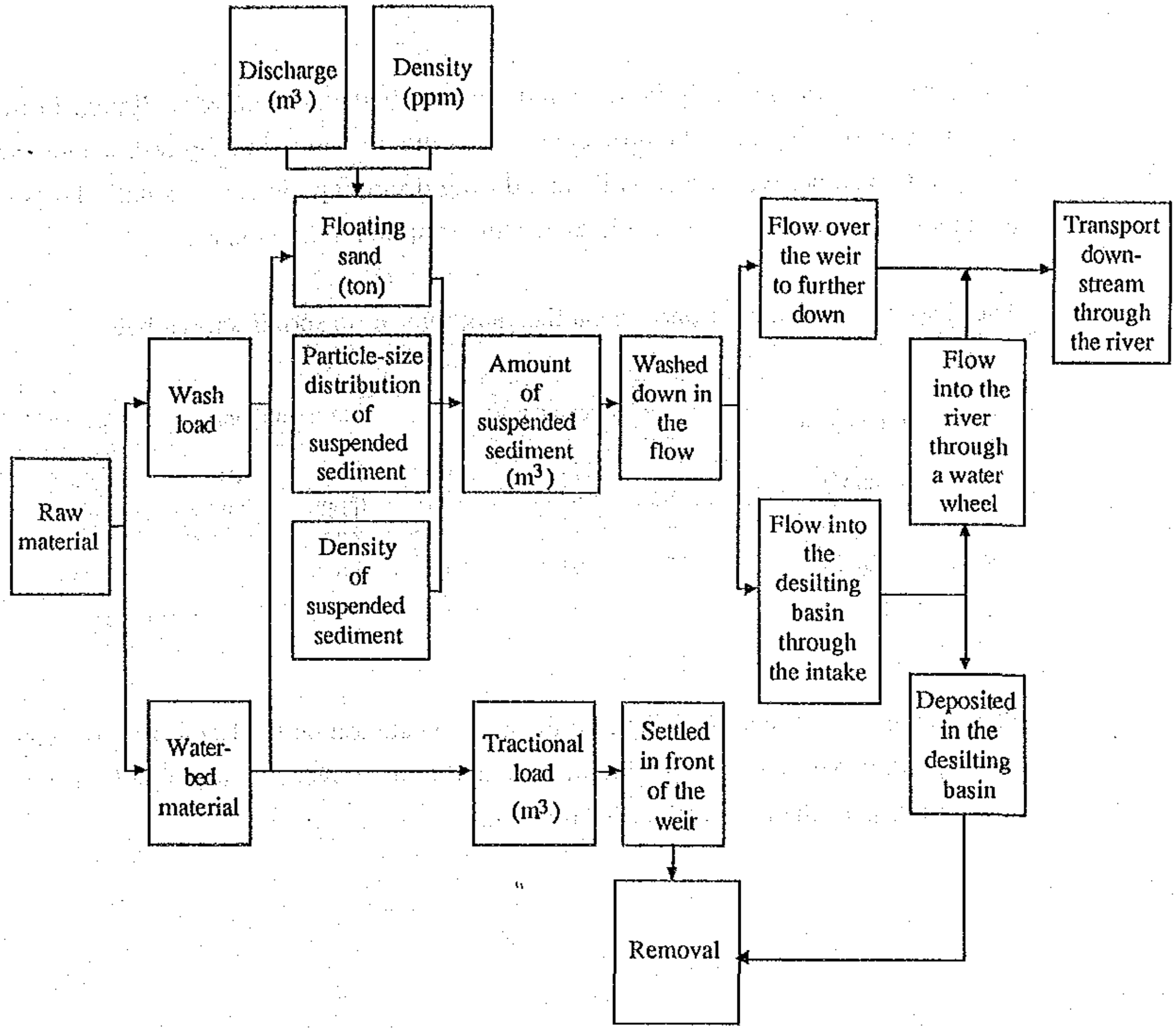



Fig. 7.7 Mechanism of Debris Flow and Calculation Flow of Debris Volume

### 7.4.1 Debris Flow Status

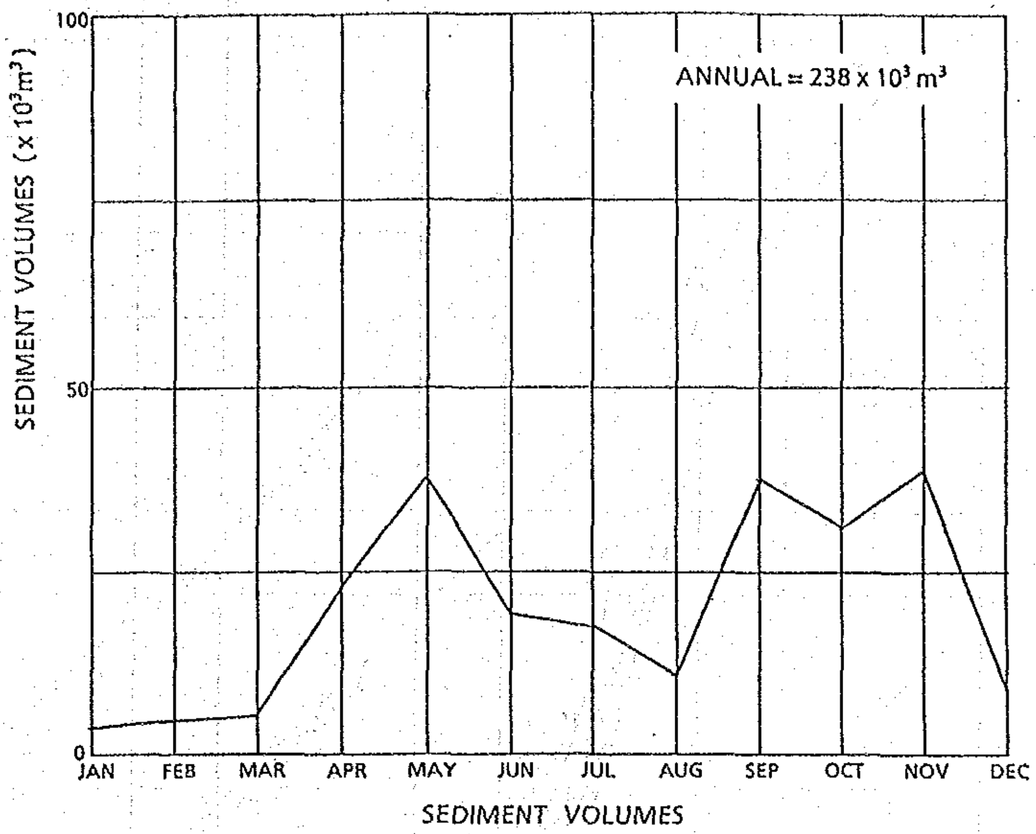
The watershed at the Lagunilla River includes Nevado del Luiz, and the upstream area near the watershed is a comparatively steep ravine. The vegetation of the watershed is good. The debris flowing from these watersheds is mainly debris and city waste generated by city development, erosion of riverbed and bank, gully erosion by terrace collapse, etc.

Fig. 7.8 shows the monthly volume and density of the suspended sediment in the Recio River flowing near the project site. Sediment volume in May and September through November was large, while that during drought periods was small. Density tendency was not clear. Fig. 7.9 indicates the sediment rating curve.

The suspended sediment (ton/year) at the gauging station spot is shown below.

| River | Catchment Area ($km^2$) | River Discharge Rate | | | Concentration | | Suspended Sediment Rate |
|---|---|---|---|---|---|---|---|
| | | Total x $10^3$ $m^3$/year | Max. ($m^3$/s) | Min. ($m^3$/s) | Max. (ppm) | Min. (ppm) | $10^3$ tons/year |
| Recio | 621.7 | 818,000 | 101.8 | 15.01 | 6,820 | 6 | 238 |

The suspended sediment flowing into the gauging station on the Recio River reaches 400 tons/$km^2$ per year per catchment area, and annual average suspended sediment concentration of the Recio River is 300 ppm.



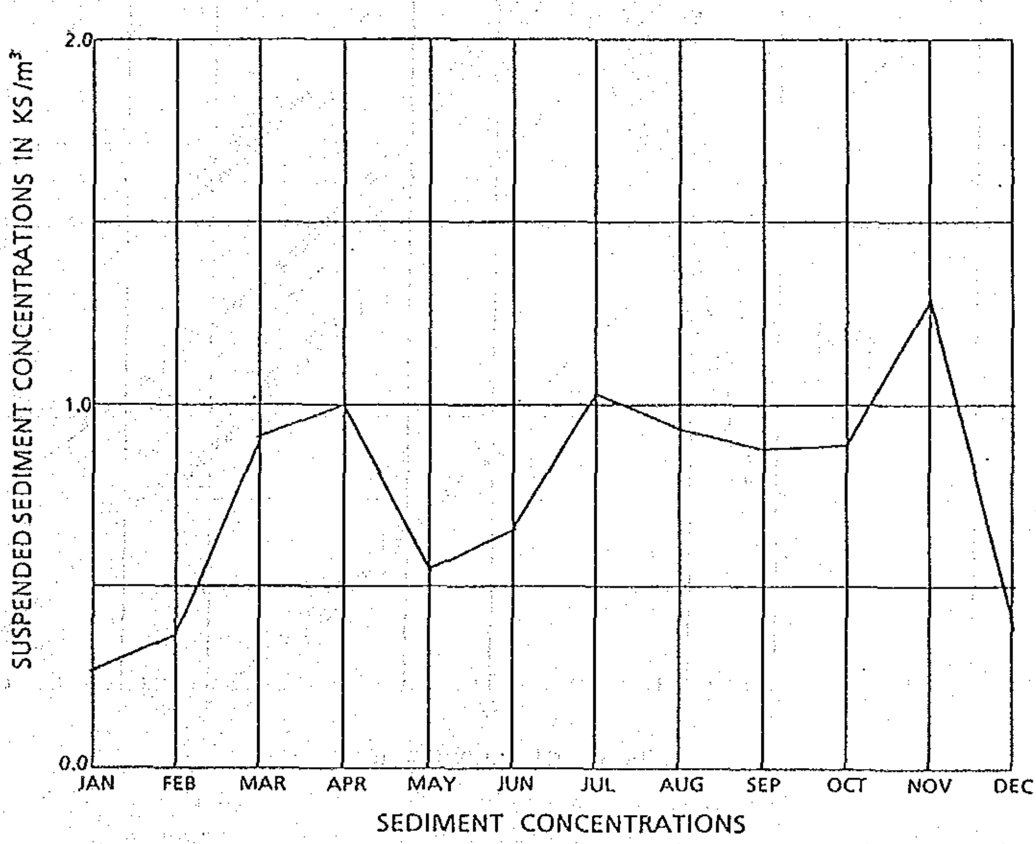




Fig. 7.8 Monthly Sediment Volume and Density

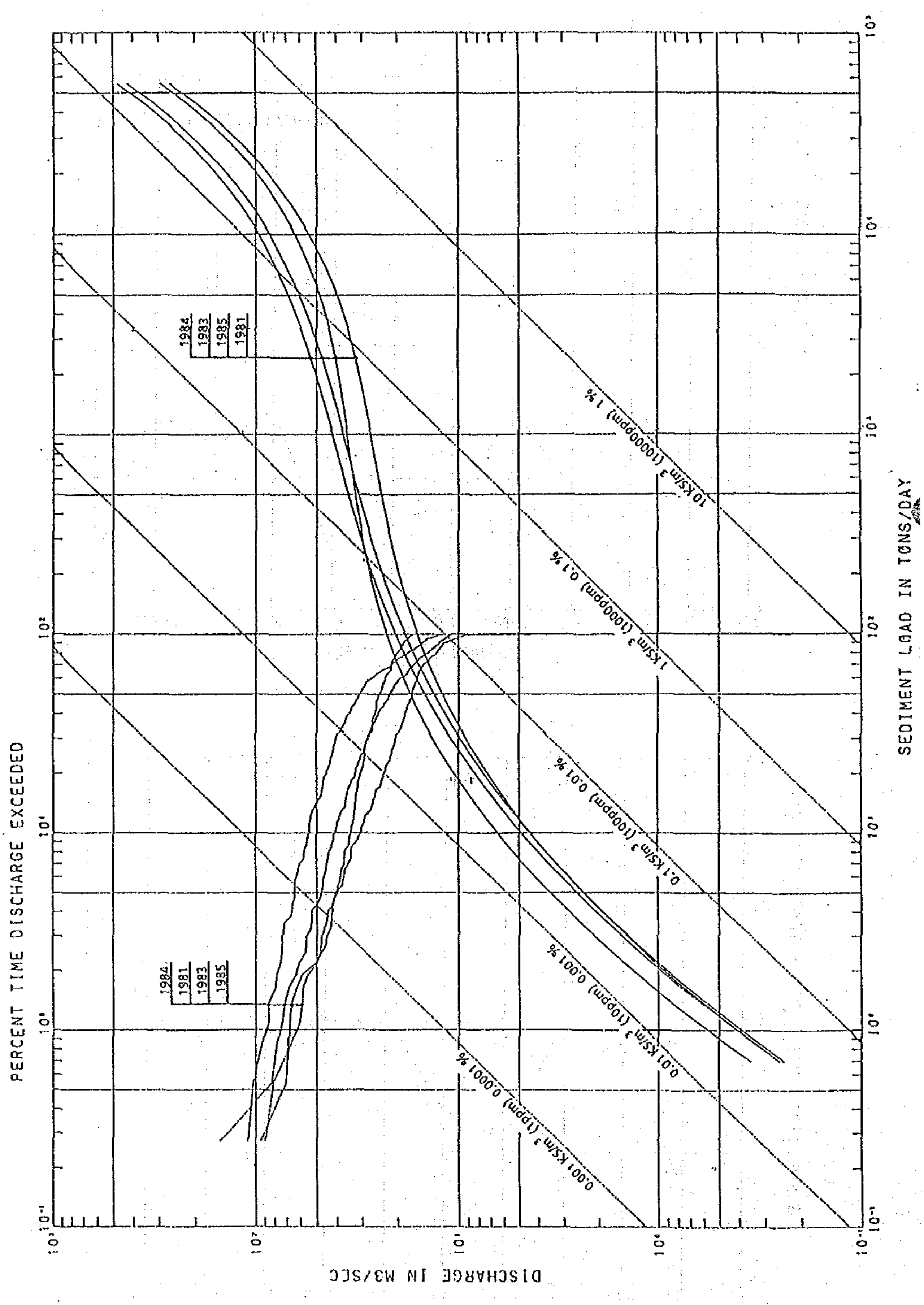



Fig. 7.9 Sediment Rating Curve

7.4.2 Assumption of Sediment Rate

(1) Major physical properties

(a) Grain size distribution

JICA Study Team was unable to obtain the bed-load data. The grain-size distribution is assumed by referring to the past bed-load data, and the grain size constitution is as follows:

Gravel = 10%  Sand = 80%  Silt = 10%

The Study Team was unable to obtain either the suspended sediment data or settled sediment data. For the suspended sediment, the grain-size distribution is assumed, referring to the past data regarding sediment of the reservoir, as shown in Fig. 7.10. The grain size constitution is as follows:

Sand = 10%  Silt = 60%  Clay = 30%

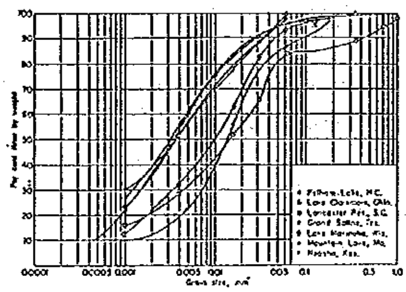


Fig. 7.10 Grain Size Constitution of Suspended Sediment *

* Handbook of Applied Hydrology

(b) Unit volume weight

Since JICA Study Team could not obtain unit volume weight of sediment data, it will be determined from existing studies.

The unit volume weight of sand and gravel affects the consolidation load, but the consolidation is completed in a comparatively short time. However, fine particles of clay, colloid, etc. will require a longer time. The unit volume weight range from the grain size constitution of sediment at reservoir from the past case example and the active conditions (under or above water) of the load at that time, as shown in Table 7.9.

Table 7.9 Range of Unit Volume Weight*

(units: ton/m$^3$)

| Grain | Almost submerged | Above water |
|---|---|---|
| Clay | 0.64 - 0.96 | 0.96 - 1.28 |
| Silt | 0.88 - 1.20 | 1.20 - 1.36 |
| Mix of clay and silt (equal volume) | 0.64 - 1.04 | 1.04 - 1.36 |
| Mix of sand and silt (equal volume) | 1.20 - 1.52 | 1.52 - 1.76 |
| Mix of clay, silt and sand (equal volume) | 0.80 - 1.28 | 1.28 - 1.60 |
| Sand | 1.36 - 1.60 | 1.36 - 1.60 |
| Gravel | 1.36 - 2.00 | 1.36 - 2.00 |
| Sand and gravel | 1.52 - 2.08 | 1.52 - 2.08 |

* Handbook of Applied Hydrology

(2) Discharge rate of sediment

When the discharge rate of sediment at the intake spot is examined, the suspended sediment and the bed-load are considered. Suspended sediment can be calculated from the concentration measurement and the discharge record. The quantitative record for the flown sand has not been obtained.

Generally flowing sand is 10 to 50% of total sediment rate, and the flowing sand of the Colorado River is 12 to 50% of total sediment rate. The World Bank study team estimates the flowing sand of the Indus River at the Tarubera dam (Pakistan) spot will be 5% of suspended sediment.

(3) Yearly flowing sediment rate

The yearly flowing sediment rate at the intake spot is obtained by referring to values at the gauging station.

| Catchment Area ($km^2$) | River Discharge Rate ($10^6$ $m^3$) | Suspended Sediment Rate ($10^3$ ton) | Flown Sand Rate ($10^3$ ton) | Sediment Rate ($10^3$ ton) |
|---|---|---|---|---|
| 118.2 | 100 | 40 | 4 | 44 |

Average grain size of the flowing sediment is calculated from the unit weight by average grain size constitution and each grain diameter as follows.

| | Flown Sand | | | |
|---|---|---|---|---|
| | Gravel | Sand | Silt | Total |
| Grain size constitution(%) | 10 | 80 | 10 | 100 |
| Unit volume weight (ton/$m^3$) | 1.68 | 1.48 | 1.04 | |
| Unit weight per grain size (ton/$m^3$) | 0.168 | 1.184 | 0.104 | 1.456... 1.46 |

| | Suspended Sediment | | | |
|---|---|---|---|---|
| | Sand | Silt | Clay | Total |
| Grain size constitution(%) | 10 | 60 | 30 | 100 |
| Unit volume weight (ton/$m^3$) | 1.48 | 1.04 | 0.80 | |
| Unit weight per grain size (ton/$m^3$) | 0.148 | 0.624 | 0.240 | 1.01 |

All the flowing sands are deposited at the diversion weir and in front of the intake, and do not flow into the channel.

The suspended sediment is contained in the discharge within the range of design discharge, and flows down the channel from the intake. Partial rough particles in the suspended sediment flowing into the channel are settled at the desilting basin, and the remaining suspended sediment is discharged into the river by a water wheel with discharge. Suspended sediment contained in the river discharge exceeding the design discharge overflows the diversion weir and flows down the river.

| Catchment area ($km^2$) | River discharge ($10^6$ ($m^3$)) | Bed-load $10^3$ (ton) | Suspended sediment $10^3$ (ton) |
|---|---|---|---|
| 118.2 | 100 | 4 | 40 |
| | | ↓ | ↓ |
| | | x $10^3$ $m^3$ | x $10^3$ $m^3$ |
| | | 2.5 | 39 |

| Design discharge Q $m^3$/s | Sediment in water channel x $10^3$ $m^3$ | Flow down the river x $10^3$ $m^3$ |
|---|---|---|
| 2 | 23 | 16 |
| 3 | 31 | 8 |
| 4 | 35 | 4 |

| Design discharge Q $m^3$/s | Settled in the desilting basin ($m^3$) | Flow down the channel ($m^3$) |
|---|---|---|
| 2 | 2000 | 21000 |
| 3 | 3000 | 28000 |
| 4 | 3000 | 32000 |

From this analysis the annual average sediment in front of the diversion weir is assumed to be about 7 $m^2$/day and sediment settled in the desilting basin 8 $m^3$/day (if available discharge is 2 $m^3$/s). A counterplan for removing the sediment will be fully considered.

## 7.5 Water Quality Analysis

The acidity, etc. and specific resistance of water which most greatly affects the facilities are studied.

### 7.5.1 Criteria of Judgement

(1) Acidity, etc.

To judge effect of acidity, etc., the criteria shown in Table 7.10 and the past instances shown in Table 7.11 shall be referred to.

Table 7.10 Judgement Criteria of Erosion of Water (DIN 4030)

| Item | Grade of Erosion | | |
|---|---|---|---|
| | Weak Erosion | Strong Erosion | Very Strong Erosion |
| pH | 6.5 - 5.5 | 5.5 - 4.5 | Less than 4.5 |
| $CO_2$ mg/1 | 15 - 30 | 30 - 60 | More than 60 |
| $NH_4^+$ mg/1 | 15 - 30 | 30 - 60 | More than 60 |
| $Mg^{2+}$ mg/l | 100 - 300 | 300 - 1500 | More than 1500 |
| $SO_4^{2-}$ mg/l | 200 - 600 | 600 - 3000 | More than 3000 |

Table 7.11 Damage Example of Concrete in Erosive Environment of Water

| Item | Water Characteristics | Damage Status |
| --- | --- | --- |
| Groundwater | pH : 2.3 - 6.7 | Tunnel concrete<br><br>Indication of leakage is observed 4 years after construction.<br>Peeling of mortar and cracks in concrete are noted after 7 years. |
| River water (Azuma River) | pH : 3.1 - 2.7<br>$Mg^{2+}$ : 13.5 ppm<br>$SO_4^{2-}$ : 316.8 ppm<br>$C\ell^-$ : 101.8 ppm | Dipping test concrete specimen (ϕ15cm)<br><br>When unit cement volume 320 kg/m$^3$, W/C=35.1% and 3-month old material was put into the river, the diameter reduced to 14.6 cm after 15 months.<br>About 2 mm of the surface was dissolved, and another 2-3 mm was weakened. |

(2) Specific resistance

Since water with a low specific resistance includes many soluble salts which will accelerate the corrosion of steel. The effect of specific resistance to corrosion is clear. The results of the National Bureau of Standard (NBS) investigation are shown in Table 7.12; but there are exceptions, and evaluation of the corrosive nature from only specific resistance is not often done.

Table 7.12 Specific Resistance and Corrosive Nature

| Corrosive nature | Degree of acidity | | Specific resistance Ω . cm | Maximum hole corrosion depth for 12 years (mm) |
|---|---|---|---|---|
| | pH | Total acidity | | |
| Weak | 7.8 | 3.0 | 1770 | 0.74 |
| | 4.5 | 4.6 | 11200 | 1.19 |
| | 7.3 | 2.6 | 2980 | 0.99 |
| | 5.9 | 12.8 | 45000 | 1.02 |
| Strong | 7.6 | alkaline | 350 | 3.02 |
| | 7.4 | ditto | 263 | 3.48 |
| | 9.4 | ditto | 278 | 4.39 |
| | 6.8 | 36.0 | 800 | 2.62 |

### 7.5.2 Evaluation of Water Quality

The results of the water quality test on the Lagunilla River and Recio River are given below:

| Year observed | pH | Specific resistance (Microohms) | SO mg/ | C mg/ | River |
|---|---|---|---|---|---|
| 1980 | 8.5 - 6.3 | - | 27.5 - 7 | 15.2 - 2.8 | Recio |
| 1981 | 7.0 - 6.5 | - | 26.5 - 13.2 | 9.9 - 4.2 | " |
| 1982 | 6.3 - 6.2 | - | 11.0 - 9.2 | 7.1 - 6.7 | " |
| 1983 | 8.4 - 55.5 | - | 21.5 - 1 | 10.3 - 3.9 | " |
| 1984 | 7.2 - 6.0 | - | 19.5 - 3 | 7.8 - 3.5 | " |
| 1985 | 7.4 - 6.1 | - | 29.5 - 6.6 | 5.7 - 2.3 | " |
| 1987 | 6.7 - 6.6 | 124.6 - 89 | 27.3 - 10 | 6.1 - 4.8 | " |
| 1989 | 6.4 - 5.7 | - | | 38 - 12 | Lagunilla |

The minimum pH value in the Lagunilla River was 5.7, and this value indicates weak corrosive nature.

Specific resistance is small and corrosive nature is strong. According to WHO water quality standards, hardness of chloride and sulfate is low. Though the water quality was observed in the Lagunilla for one year only, the values of pH and specific resistance indicate that acid-resistance materials should not be used for generating facilities.