CHAPTER 4

OUTLINE OF PROJECT

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CHAPTER 4 OUTLINE OF PROJECT

4.1 Location and Outline of Project Area

4.1.1 Location of Project Area

The Julumito Hydroelectric Power Project area consists of the catchment basin of approximately 1,120 km^2 of the upstream reaches of the Rio Cauca springing from the eastern part of Departamento del Cauca, the Republic of Colombia, the waters of which basin are to be utilized for power generation, the locations of major facilities such as the dam, reservoir, waterways and powerhouse being planned to be situated approximately 10 km northwest of Popayan, the capital city of Departamento de Cauca, at $2^{o}30'$ north latitude, $76^{o}40'$ west longitude and elevation of roughly 1,700 m.

4.1.2 Outline of Project Area

Topographically, the Republic of Colombia is divided broadly into 3 regions. These are the coastal region on the Pacific Ocean side, the mountainous region in the central part and the Amazona region to the east.

The mountainous area corresponds to the northern end of the Andes Mountain Range forming the western rim of the South American continent which is subdivided on entering Colombia into a western mountain range (Cordillera Occidental), central mountain range (Cordillera Central) and eastern mountain range (Cordillera Oriental). These mountain ranges forming the skeleton of the country run more or less parallel in a north-south direction disappearing in the northern part of the country. In the valleys between the Cordillera Occidental and Cordillera Central and between the Cordillera Central and Cordillera Oriental there are the Rio Cauca and the Rio Magdalena respectively, the two major rivers of Columbia, which run from south to north parallel to the mountain ranges, and the catchment basin of each comprises a long and narrow great plain with a width of 60 to 80 km. The Rio Cauca merges with the Rio Magdalena in the northern region where the mountain ranges disappear to flow into the Caribbean Sea.

The Rio Cauca springs from Paramo de las Papas, the southern tip of the Cordillera Central at the eastern part of Departamento de Cauca, flowing down in V- or U-shaped gorges from the steep mountain lands of elevations of 4,000 m to 2,000 m, and changes course to the west in the vicinity of Popayan City from where it gently meanders forming a flood plain on the volcanic plateau of elevation of about 1,700 m. On both banks, river terraces are developed in several steps. From the outskirts of Popayan City and downstream, the river again shows a steep gradient flowing through U-shaped gorges of 50- to 80- m width and 100- m height, and annexes tributaries such as the Rio Sate and Rio Palacé while changing its course to the north to form the so-called Valle de Cauca and flows down toward the wide flood plains of Departamento de Valle. The river gradient is extremely steep being 1/30 - 1/60 in the mountainous area upstream of Popayan City becoming slightly gentle at 1/100 - 1/200 in the hilly region near Popayan, but again becoming a rapid flow of about 1/100 in the Cauca Gorge downstream from this hill district.

The catchment area of the Rio Cauca belongs to a zone of mild climate unaffected by cold fronts and tropical atmospheric depressions. Rainfall in the catchment basin is fairly abundant in the upstream mountain area and according to observation data gathered at Puracé and Coconuco. the annual average reaches 2,000 - 2,500 mm. In the vicinity of Popayan City the annual average is about 1,800 mm. In general, March - May and October - December are rainy seasons in this area with comparatively abundant rainfall for the year, with the most rain in the three-month period from October through December, roughly half of the rainfall during a year being seen in this season.

From July through September is a dry season with extremely little rainfall. The characteristics of rainfall in this area is for extremely localized precipitation of so-called shower type lasting for short periods of time.

There is almost no variation in temperature throughout the year it being more or less around 20°C in the vicinity of Popayan City during the daytime.

The geology of the project area is comprised of Quaternary volcanic ejecta with the surface on the whole covered by a thick layer of volcanic ash. In the area surrounding Popayan the thickness of this layer is roughly 30 to 40 m. Underlying this volcanic ash layer there is an adnesite lava of thickness of 100 m or more comprising the basal rock. Further underneath is a fundamental geological structure in which tuff breccia is widely distributed. The various civil structures in the Julumito Project are planned with these two strata as foundations.

4.2 Outline of Development Scheme

4.2.1 Power Generation Scheme

The Julumito Hydroelectric Power Project aims for power generation of 53,000 kW using the waters of the catchment basin of the most upstream part of the main stream of the Rio Cauca and its bributaries of approximately 1,120 km^2 and taking advantage of the head obtained through the steep terrain.

In effect, Julumito Reservoir having an effective storage capacity of 50 x 10^6 m^3 would be provided on the Rio Sate, a tributary of the Rio Cauca. Water from the 857 - km^2 basin of the Rio Cauca mainstream is to be taken in near Popayan and conducted by Cauca Diversion Waterway 2,620 m long (maximum water passage capacity 40.0 m^3/sec) to this reservoir. Also, the waters of the tributary Rio Palacé and Rio Blance catchment areas totalling 236 km^2 will be collected by the 8,430-m long Palacé No. 1 and and No. 2 Diversion Waterways (maximum water passage capacity 12.0 m^3/sec and 13.8 m^3/sec respectively). Upon regulating the water conducted to Julumito Reservoir in the above manner in accordance with the reservoir operation rule, intake of maximum available discharge of 50.0 m^3/sec will be made and the water conducted to Julumito Power Station to be provided at the right bank of the Rio Cauca through a headrace tunnel (inner diameter 4.2 m) 1,793 m long, and with the effective head of 125.5 m obtained, power generation of a maximum output of 53,000 kW and annual energy production of 285.4 x 10^6 kWh will be carried out.

This water after power generation will be discharged and returned again to the Rio Cauca mainstream.

The Julumito dam site, as a result of surveys and studies of several sites in the middle stream of the Rio Sate, was selected to be the No. 2 site approximately 6,300 m upstream from the confluence with the main stream of the Rio Cauca. For Julumito Dam, in consideration of the topography and geology of the site and the properties of the dam materials avaialble in the neighborhood, a curving rockfill dam with an inclined core design was adopted. The dam will have a height of 80.0 m, crest length of 350.0 m and volume of 1,050 x 10^3 m^3.

Besides the abovementioned main dam, two dikes will be provided at the saddles of the left bank in the upstream part of the reservoir. Dike No. 1 would be an earth dam of height of 22.5 m, crest length of 190.0 m and volume of 65,000 m^3. Dike No. 2 will be an embanked levee 3.0 m tall at the lowest place with a crest length of 560 m.

It is planned for one diversion dam each to be provided on the main stream of the Rio Cauca, and the tributaries Rio Palacé and Rio Blanco for a total of three dams. The largest of the three, Rio Cauca Diversion Dam will be built at a point 500 m upstream from Cauca Bridge crossing the Rio Cauca approximately 2 km upstream from the urban area of Popayan City and will be a concrete gravity dam of free overflow type. The height and length of the overflow section will be 4.0 m and 50.0 m respectively with the total length of the dam being 69.5 m. The diversion dams on the Rio Palacé and Rio Balanco will be small-scale concrete gravity dams.

Practically the entire 2,620-m length of the Cauca Diversion Waterway will be an open concrete channel with a gradient of 1/600 and a cross section to provide a maximum capacity of 40.0 m^3/sec.

As for the Palacé No. 1 and No. 2 Diversion Waterways, 7,660 m of the total length of 8,430 m will be open channel, the remaining 770 m being comprised of 3 tunnels. The water passage capacities are designed to be 12.0 m^3/sec for Diversion Waterway No. 1 and 13.8 m^3/sec for Diversion Waterway No. 2.

The intake would be provided at the left bank immediately upstream of Julumito Dam on the Rio Sate and will be an inclined-type structure with maximum intake capacity of 50.0 m^3/sec.

The headrace tunnel is to be a reinforced concretelined pressure tunnel having an inner diameter of 4.2 m and length of 1,793 m with maximum capacity of 50.0 m^3/sec. The tunnel route was determined taking into consideration the topographical and geological conditions along the course while the elevations of the center line of the tunnel were selected to fall adequately inside the andesitic lava which is possible to use as a foundation for structures.

A surge tank will be provided at the end of the headrace tunnel and in consideration of the geological conditions it will be an orifice type surge tank. The surge tank will have an inner diameter of 8.0 m and height of 65.6 m while the diameter of the orifice will be 2.2 m.

The penstock will be a surface type with one line of ring girder-type. This penstock will be bifurcated into two lines at the bottom to lead to the powerhouse. The inner diameter will vary from 4.0 m to 1.6 m and the length will be 239.0 m.

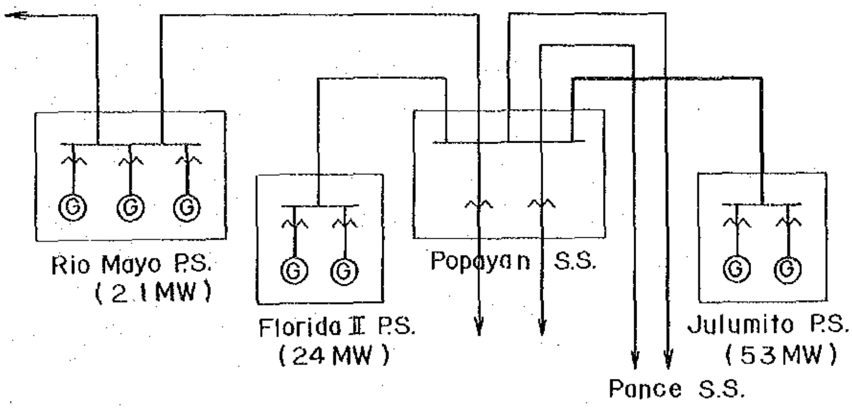
For the powerhouse, several sites on the right bank of the Rio Cauca were contemplated besides which a proposal for provision of an underground powerhouse at the left bank immediately below Julumito Dam was investigated and studied in detail, as a result of which a final selection was made of the site offering maximum economy taking into account the various conditions such as available head, topography, geology, etc. The site is located approximately 2,400 m upstream from the junction of the Rio Cauca and Rio Sate, where the river meanders in a large U-shaped sweep.

The powerhouse will be a conventional surface type of reinforced concrete structure 27.0 m long, 20.1 m wide and 29.5 m high.

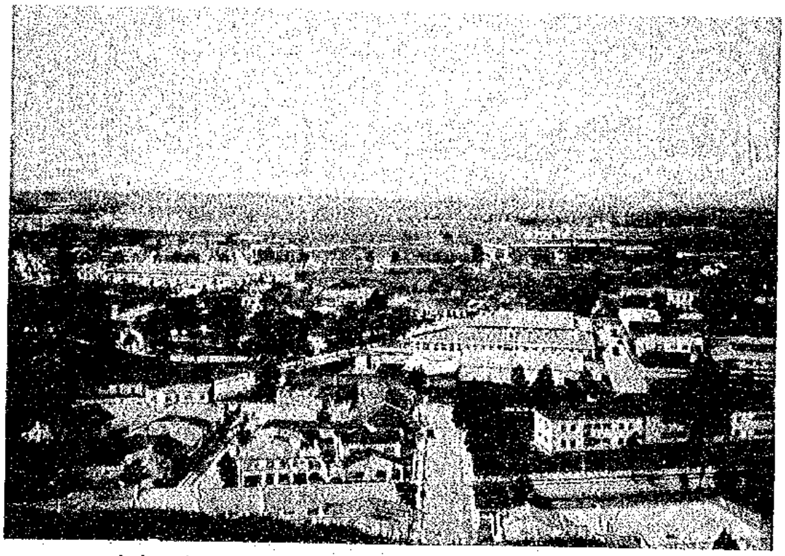
It is planned for two turbine-generator units each of 29,500 kVA to be installed in the powerhouse.

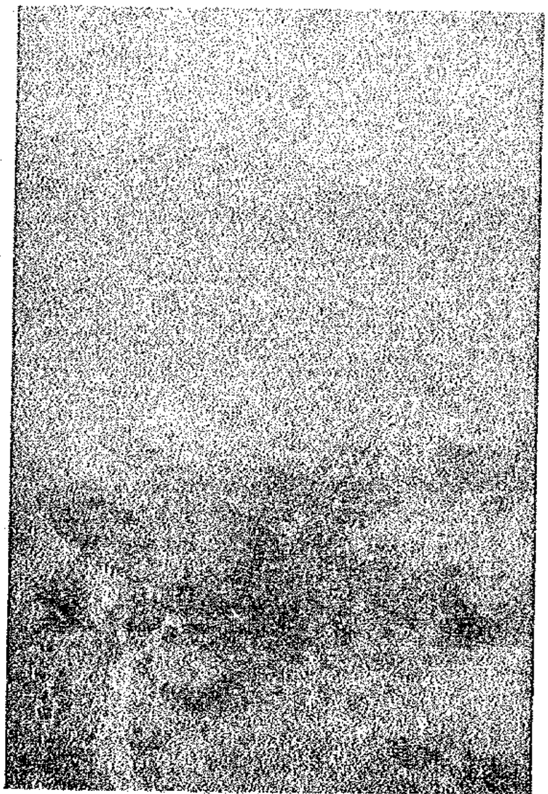
4.2.2 Power Transmission, Transformation and Telecommunication Plans

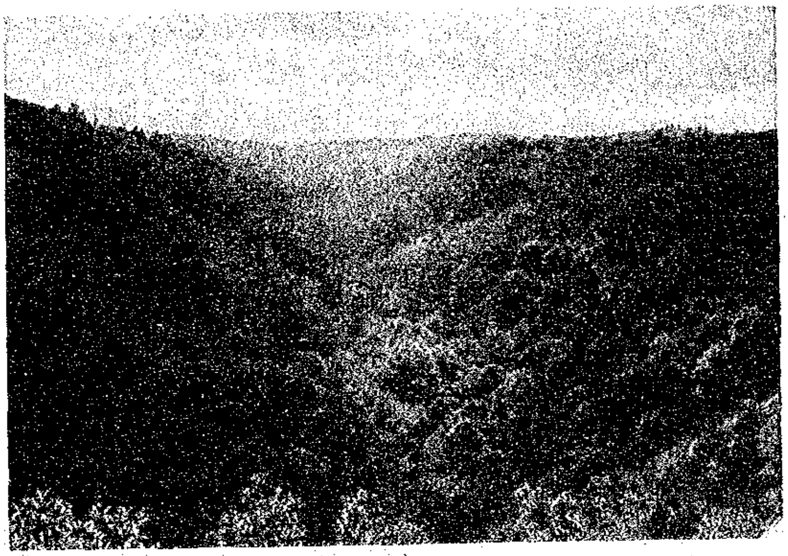
The power generated is to be stepped up to 115 kV at the outdoor substation and transmitted to Popayan Substation by a transmission line (1 circuit, 10 km) to be constructed for the Project. An interconnection will be made with the Central System at Popayan Substation. One 30,000 kVA, 3-phase transformer will be additionally installed at Popayan Substation which together with the existing facilities will be used to supply power to Popayan City and the neighboring communities, while also, transmission will be made at the same time to the CEDENAR System which is interconnected by an existing 115-kV transmission line.



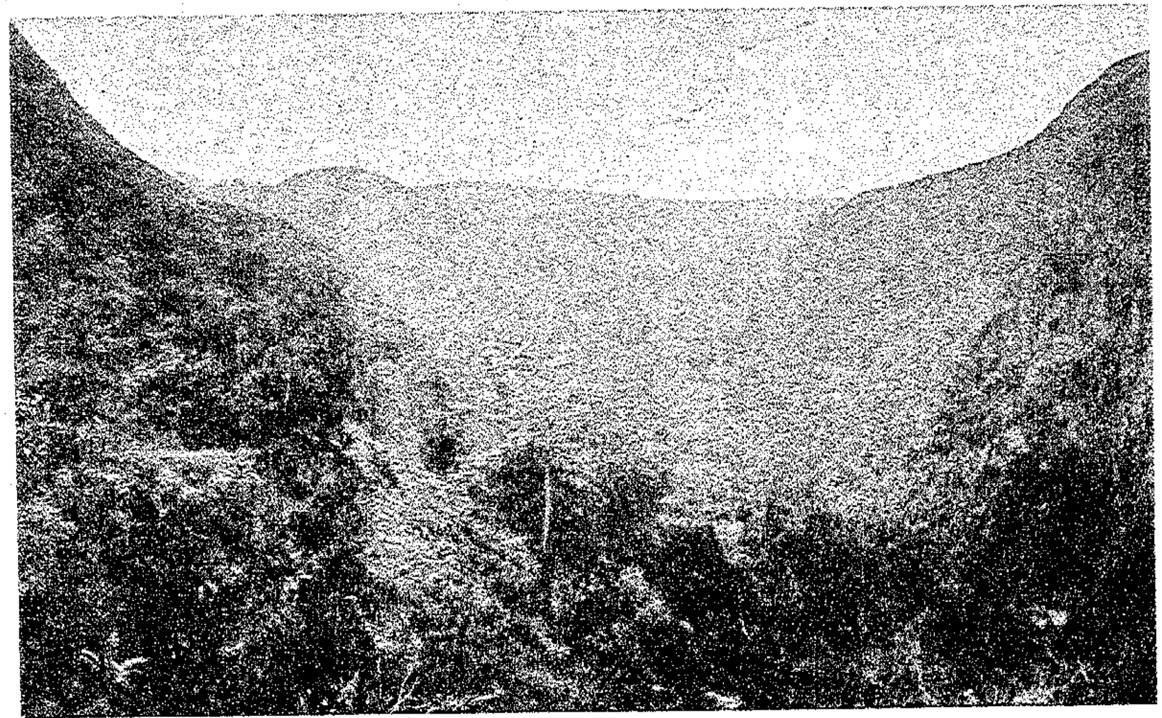
Further, between Julumito Power Station and Popayan Substation, one circuit each of a load dispatching telephone channel and a transmission line protective relay channel will be provided as telecommunication facilities.


Julumito Project site viewed from Popayan


Rio Cauca, flowing to west near Popayan


Julumito dam site viewed from downstream

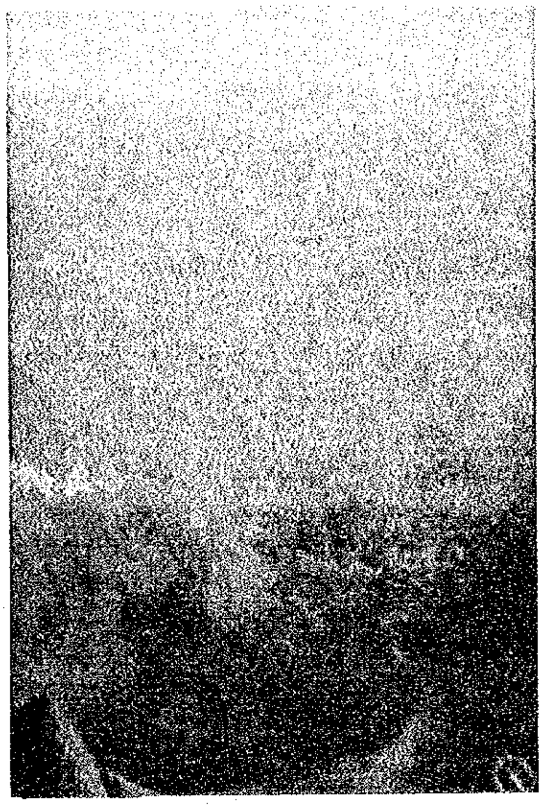

Borrow area for Julumito dam embankment – on the left bank of Rio Sate



Mountain to the right proposed as quarry for Julumito dam embankment
Dome shaped top to the left will be the Julumito powerhouse site

Dike No.1 site viewed outside the reservoir

Dike No.2 site viewed outside the reservoir


Julumito powerhouse site viewed from upstream of Rio Cauca


Slope proposed to install penstock

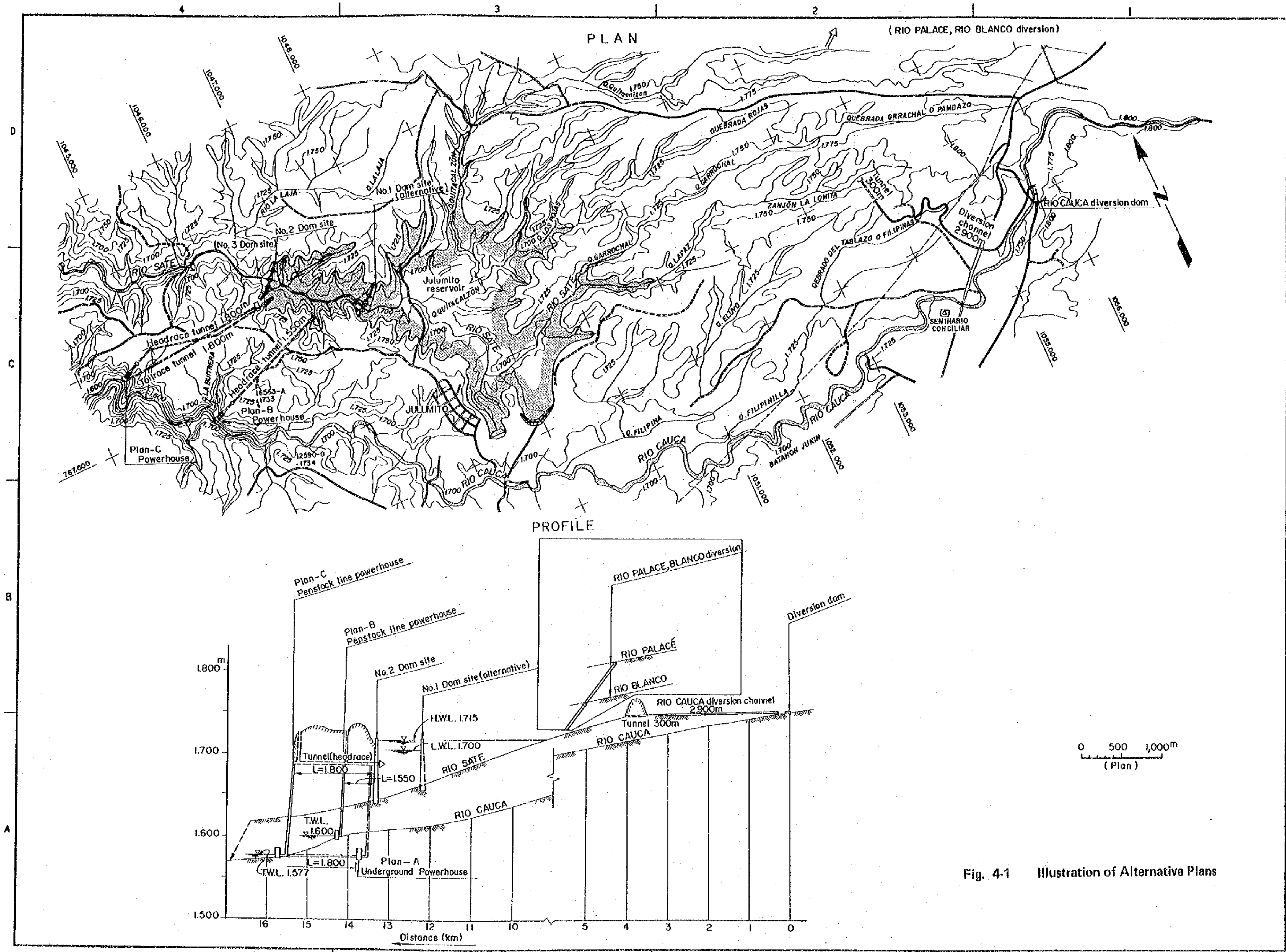


Fig. 4-1 Illustration of Alternative Plans

Fig. 4-2 Transmission Line Route Map

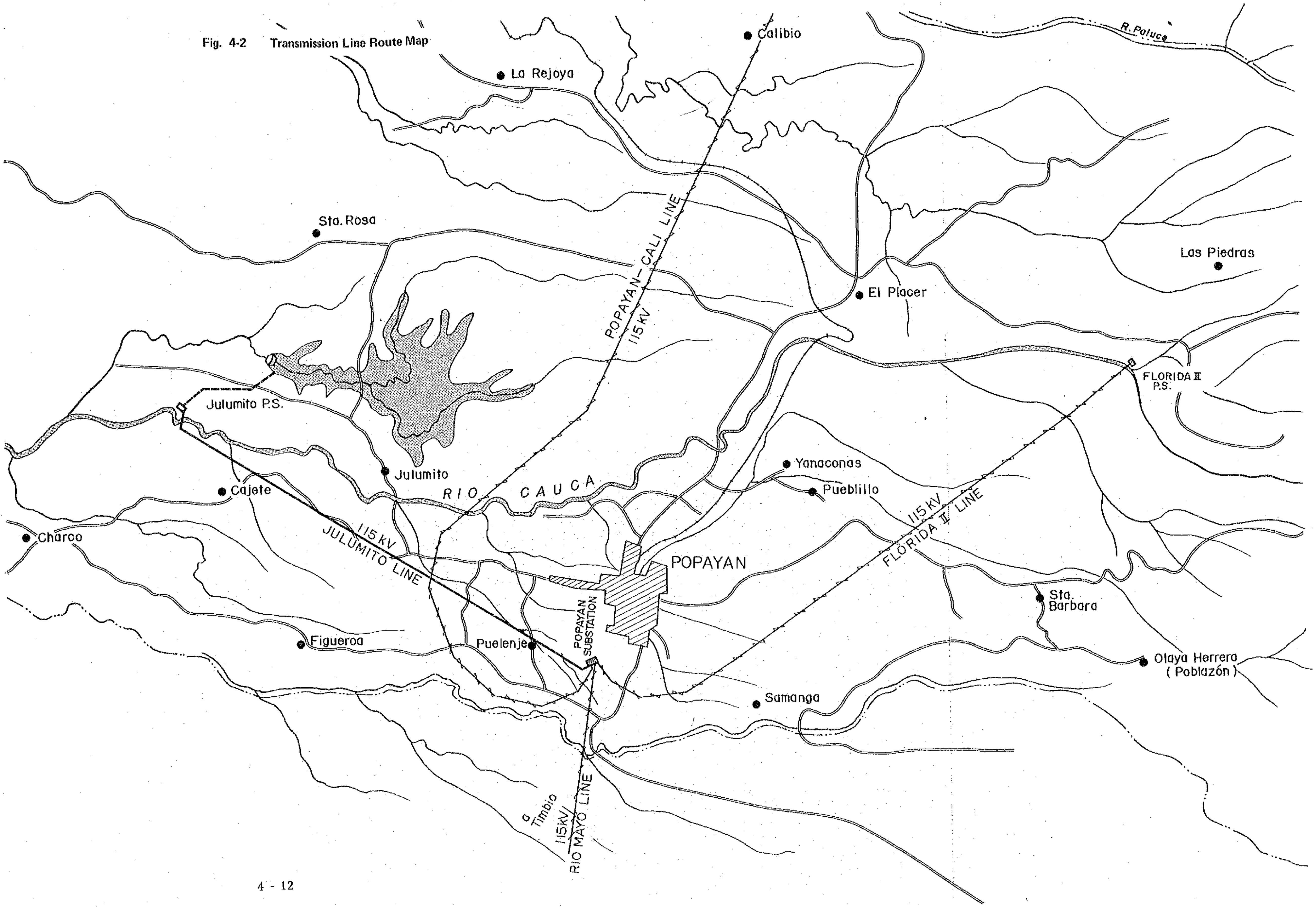
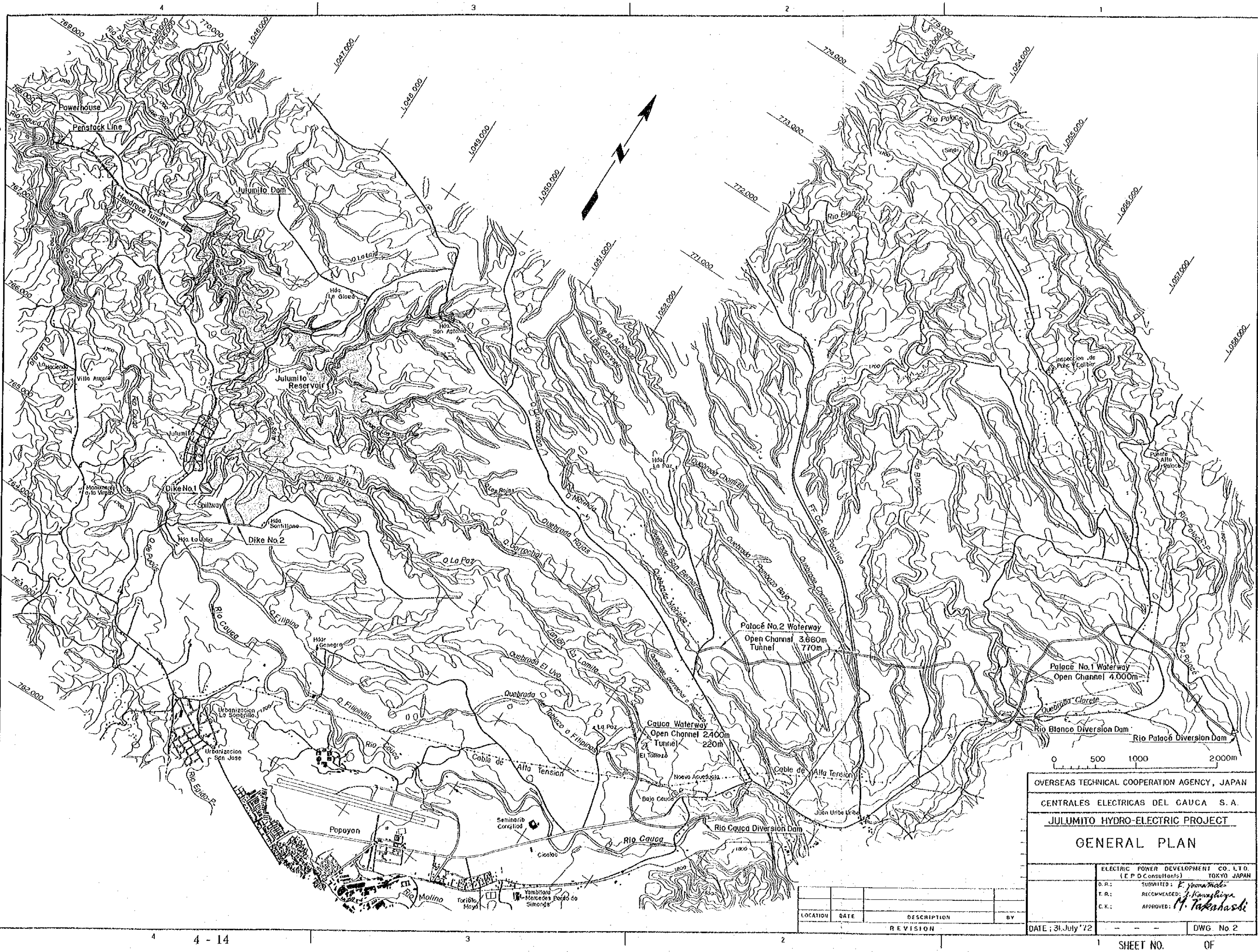


Table 4-1 General Description of Project

Item	Units	Description	Remarks
Method of Power Generation		Dam-Waterway Type	
Catchment Area			
Rio Cauca	km^2	857	
Rio Palacé	km^2	197	
Rio Blanco	km^2	39	
Rio Sate	km^2	31	
Total	km^2	1,124	
Reservoir and Dam			
Annual Inflow			
From Rio Cauca	10^6m^3	688	
From Rio Palacé	10^6m^3	206	
From Rio Blanco	10^6m^3	31	
From Rio Sate	10^6m^3	26	
Total	10^6m^3	951	
Reserovir			
Normal High Water Surface	m	1,715.0	
Water Surface Area	km^2	4.4	
Total Storage Capacity	10^6m^3	60.8	
Effective Storage Capacity	10^6m^3	50.4	
Available drawdown	m	15.0	
Dam (Main Dam)			
Type	-	Rockfill	
Height x Crest Length	m	80 x 350	
Volume	10^3m^3	1,050	
Waterway			
Headrace (Diameter x Length)	m	4.2 x 1,793	
Diversion Waterway (Length)			
Cauca Diversion Waterway	m	2,620.0	Open Channel 2,400 Tunnel 220
Palacé Diversion Waterway	m	8,430.0	Open Channel 7,660 Tunnel 770
Power Production			
Normal Intake Level	m	1,710.0	
Tailwater Level	m	1,577.0	
Normal Effective Head	m	125.5	
Powerhouse Discharge			
Maximum	m^3/sec	50.0	
Firm	m^3/sec	25.0	
Output			
Installed Capacity	kW	53,000	
Firm Peak Output	kW	47,300	
Annual Energy Production	10^6kWh	285.4	At generating end
Transmission Line			
Section	-	Power house–Popayan Sunstation	
Distance	km	10	
Voltage & (Number or Circuit)	kv (cct)	115 (1)	
Substation			
Location	-	Existing Popayan Substation	
Voltage	kv	115/13.2 ± 1.3	
Construction Cost			
Generating Facilities	10^3 Pesos	341,600	
Transmission Line & Other Facilities	10^3 Pesos	10,800	
Total Construction Cost	10^3 Pesos	352,400	
Economics			
Cost of Energy	CVS/kWh	13.1	
Benefit-Cost Ratio	-	1.67	


Powerhouse
Penstock Line
Headrace Tunnel
Julumito Dam
Julumito Reservoir
Dike No.1
Spillway
Dike No.2
Rio Cauca
Rio Sate
Palacé No.2 Waterway
Open Channel 3,660m
Tunnel 770m
Palacé No.1 Waterway
Open Channel 4,000m
Cauca Waterway
Open Channel 2,400m
Tunnel 220m
Rio Blanco Diversion Dam
Rio Palacé Diversion Dam
Rio Cauca Diversion Dam
Cable de Alta Tension
Popayan
Rio Blanco
Rio Palacé
0 500 1,000 2,000m
OVERSEAS TECHNICAL COOPERATION AGENCY, JAPAN
CENTRALES ELECTRICAS DEL CAUCA S.A.
JULUMITO HYDRO-ELECTRIC PROJECT
GENERAL PLAN
ELECTRIC POWER DEVELOPMENT CO., LTD.
(E P D Consultants) TOKYO JAPAN
D. R.: SUBMITED: E. Yamashita
T. R.: RECOMMENDED: J. Kawashima
C. K.: APPROVED: M. Takahashi
DATE ; 31.July '72
DWG. No. 2
LOCATION DATE DESCRIPTION BY
REVISION
SHEET NO. OF

CHAPTER 5

HYDROLOGY

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CHAPTER 5 HYDROLOGY

5.1 RUN-off Gauging Stations and Meteorological Observation Stations

The locations of river run-off gauging stations and meteorological observation stations in the catchment basin and surrounding areas of the Julumito Hydroelectric Power Project are as indicated in Fig. 5-1.

The periods of measurements at the above run-off gauging stations and meteorological observation stations are indicated in Table 5-1 and Table 5-2.

5.2 Catchment Area of Project Area

The catchment areas of the various intake sites of the Julumito Hydroelectric Power Project are as indicated below (see Fig. 5-2, Catchment Area).

Rio Sate (at Julumito dam site)	31 km^2
Rio Cauca (at diversion dam site)	857 km^2
Rio Palacé (at diversion dam site)	197 km^2
Rio Blanco (at diversion dam site)	39 km^2
Total	1,124 km^2

Note 1) The above catchment areas were measured based on the 1/65,000 ~ 1/80,000 topographical maps prepared by "Departamento Administrativo Nacional de Estadistica, Republic of Colombia."

5.3 Precipitation

As indicated in Table 5-1 and Fig. 5-1, there is a comparatively large number of meteorological observation stations in the Julumito Hydroelectric Power Project Area and the surrounding districts, and moreover, there are observation data covering fairly long periods.

The monthly and daily precipitation data for the various observation stations are given in Appendix-III-4,5.

The trend of annual precipitation in the project area for the 10-year period from 1961

Fig. 5-1 Location Map of Run-off and Meteorological Gauging Station

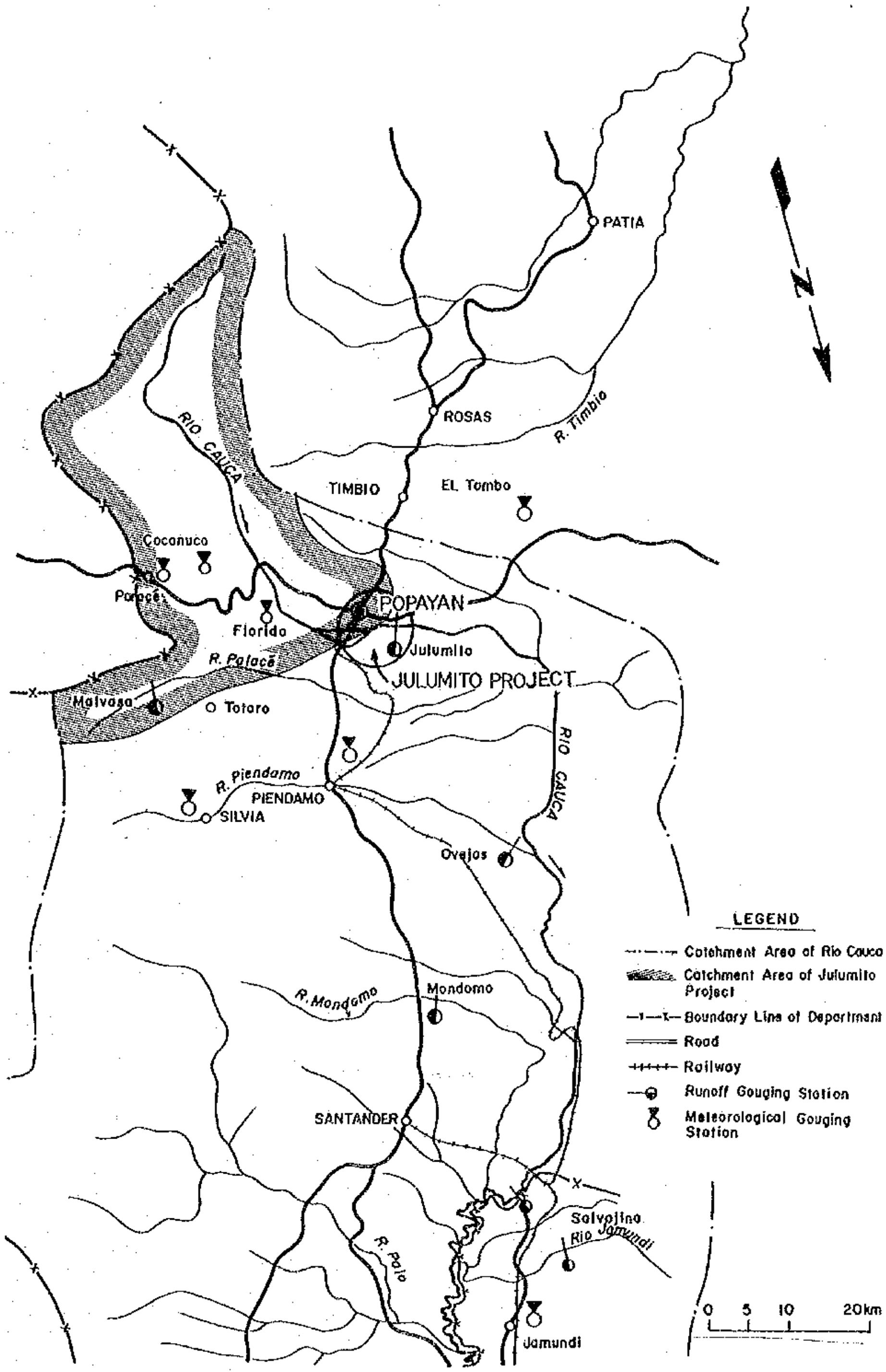


Table 5-1 Existing Precipitation Data

Station	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Data Obtained
Popayan (universidad)	—	—	—	—	—	—	—	—	—	—	—	—	Monthly
Popayan (Electraguas	—	—	—	—	—	—	—	—	—	—	—	—	Daily
Florida		—	—	—	—	—	—	—	—				Monthly
Coconuco	—	—	—	—	—	—	—	—	—	—	—	—	Daily
Palacé	—	—	—	—	—	—	—	—	—	—	—	—	"
Piendamo	—	—	—	—	—	—	—	—	—				Monthly
Silvia	—	—	—	—	—	—	—	—	—				"
El Tambo							—	—	—				"

Table 5-2 Existing Run-off Data

Station	River	Catchment Area (km^2)	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Data Obtained
Julumito	Rio Cauca	939.					—	—	—	—	—	—	—	—	Daily
Malvasa	Rio Palacé	35.		—	—	—	—	—	—	—	—	—	—	—	"
Mondomo	Rio Mondomo	185.	—	—	—	—	—	—	—	—					Monthly
Ovejas	Rio Ovejas	640					—	—	—	—					"
Jamundi	Rio Jamundi	98			—	—	—	—	—	—	—				"
Salvajina	Rio Cauca	3,830	—	—	—	—	—	—	—	—	—				"

Table 5-3 Existing Temperature and Humidity Data

Station	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Data Obtained
Popayan	—	—	—	—	—	—	—	—	—	—	—	—	Daily

Fig. 5-2 Catchment Area

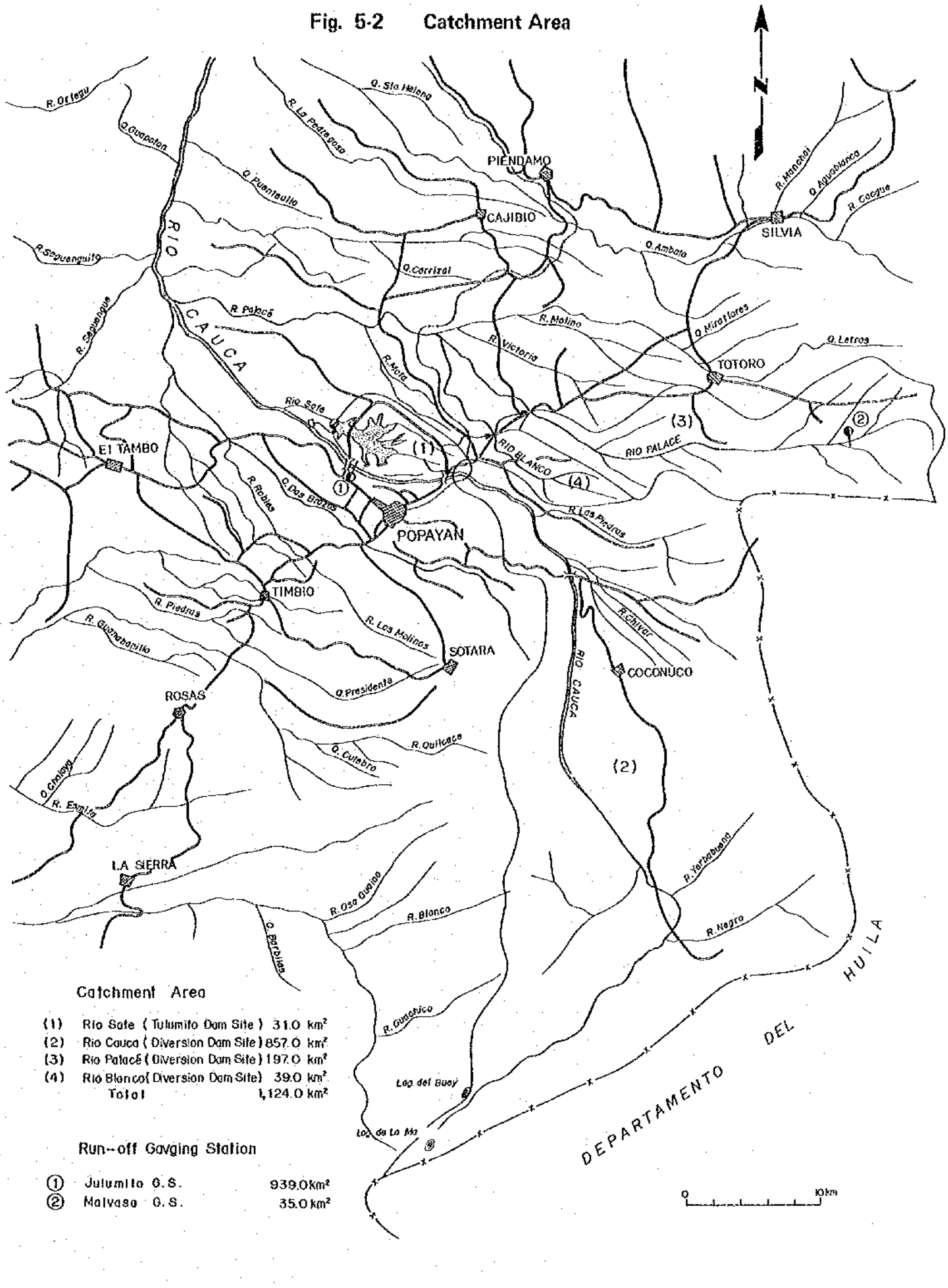


Fig. 5-3 Annual Precipitation

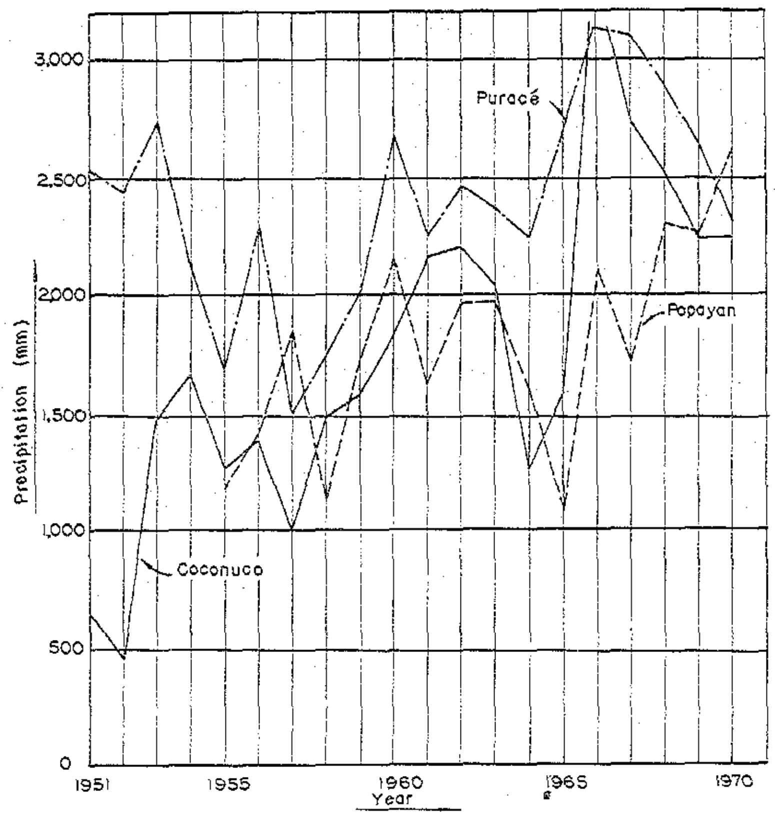


Fig. 5-4 Monthly Precipitation

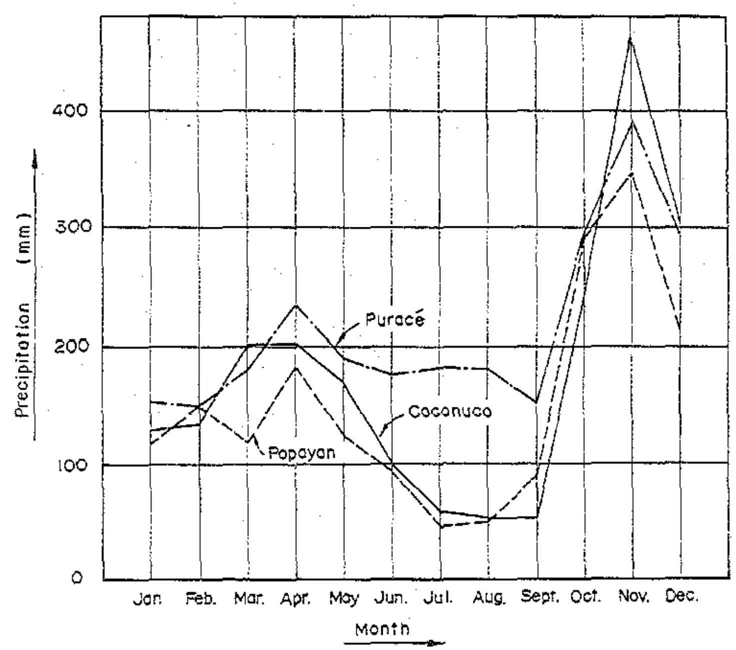
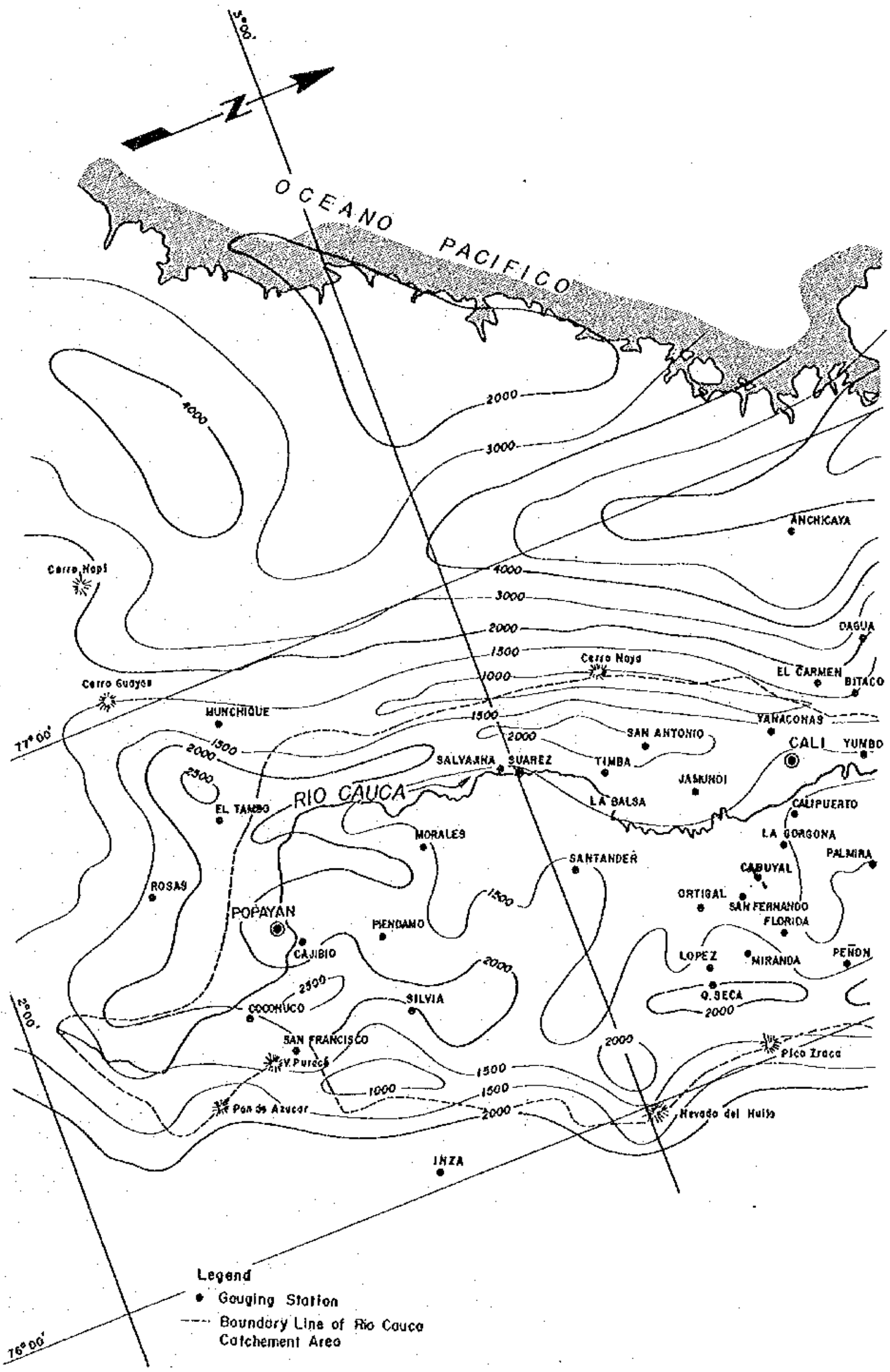


Fig. 5-5 Isohyetal Map of Project Area



to 1970 is as shown in Fig. 5-3. It is approximately 2,000 mm at Coconuco roughly at the center of the catchment basin, whereas Puracé in the mountainous area upstream, around 2,600 mm is reached. Downstream in the vicinity of Popayan City in the hill district the precipitation is approximately 1,800 mm. The precipitation trend of the latest 10-year period shows a larger precipitation in more recent years and that there are large fluctuations by year. Fig. 5-5 gives an isohyetal map of the project area and its surroundings.

The variation in monthly precipitation, as indicated in Fig. 5-4 shows precipitation to be small during the 2-month period of January ~ February and the 4-month period of June - September which are termed dry seasons. Particularly, precipitation is especially light in the dry season of July through September. As for the 3 months from March through May and the 3 months from October through December, these comprise so-called rainy seasons and the rainfall is fairly abundant. This is particularly so in the rainy season from October through December with the total precipitation during this 3-month period reaching roughly 50% of the annual amount.

The rainfall characteristics in this region show the rain to be extremely localized and presenting so-called shower-type rainfall phenomena concentrated in short periods of time.

5.4 River Run-offs

The locations of river run-off observation facilities in the Julumito Hydroelectric Power Project Area and the periods for which observation data exist are as given in Fig. 5-1 and Table 5-2. In regard to the main stream of the Rio Cauca which comprises roughly 80% of the entire catchment area of this Project, there is Julumito Gauging Station provided at Julumito located approximately 11 km downstream from the Rio Cauca diversion dam site where daily periodical run-off measurements have been conducted since April 1964. As of the end of 1971, there are daily run-off data for approximately 7 years.

Regarding the Rio Cauca tributary, the Rio Palacé accounting for approximately 18 % of the total catchment area, there is Malvasa Gauging Station on the upstream of Rio Palacé, where run-off measurements have been carried out since May 1961. As of the end of 1971 there had been daily run-off records taken for a period of approximately 11 years.

In the catchment area of the Julumito Project, besides the two abovementioned gauging stations directly concerned, there are a number of other gauging stations on the main stream and tributaries in the Rio Cauca basin, and observations have been made for comparatively long periods.

The monthly average run-offs at the various abovementioned gauging stations for 1965 and 1966 are given in Table 5-4.

Table 5-4 Monthly Average Run-off at Gauging Stations

(Unit m^3/sec)

Station	Catchment Area (km^2)	Jan.	Feb.	Mar.	April	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Rio Cauca (Julumito)	939	20.7	23.4	21.0	24.5	26.6	24.0	24.9	23.5	17.1	18.9	34.6	33.8	24.4
Rio Cauca (Salvajina)	3,830	145.1	91.3	79.1	107.8	135.7	91.3	90.3	65.8	52.2	103.9	241.0	422.6	135.5
Rio Palacé (Malvasa)	35	2.7	1.5	1.5	2.1	3.6	4.2	4.6	4.5	2.6	2.6	7.1	10.0	3.9
Rio Mondomo	185	6.5	4.6	4.2	5.3	6.0	5.1	3.2	2.5	2.2	3.7	7.6	13.1	5.3
Rio Ovejas	640	19.6	13.1	11.6	15.6	19.3	13.6	9.6	7.2	6.4	11.3	24.8	43.5	16.3
Rio Jumundi	98	6.5	3.7	4.9	11.2	14.5	6.5	3.4	2.2	1.5	7.0	12.5	12.7	7.2
Rio Timba	310	25.7	13.5	12.8	27.1	22.6	16.9	11.4	7.3	7.7	15.4	26.3	28.3	17.9

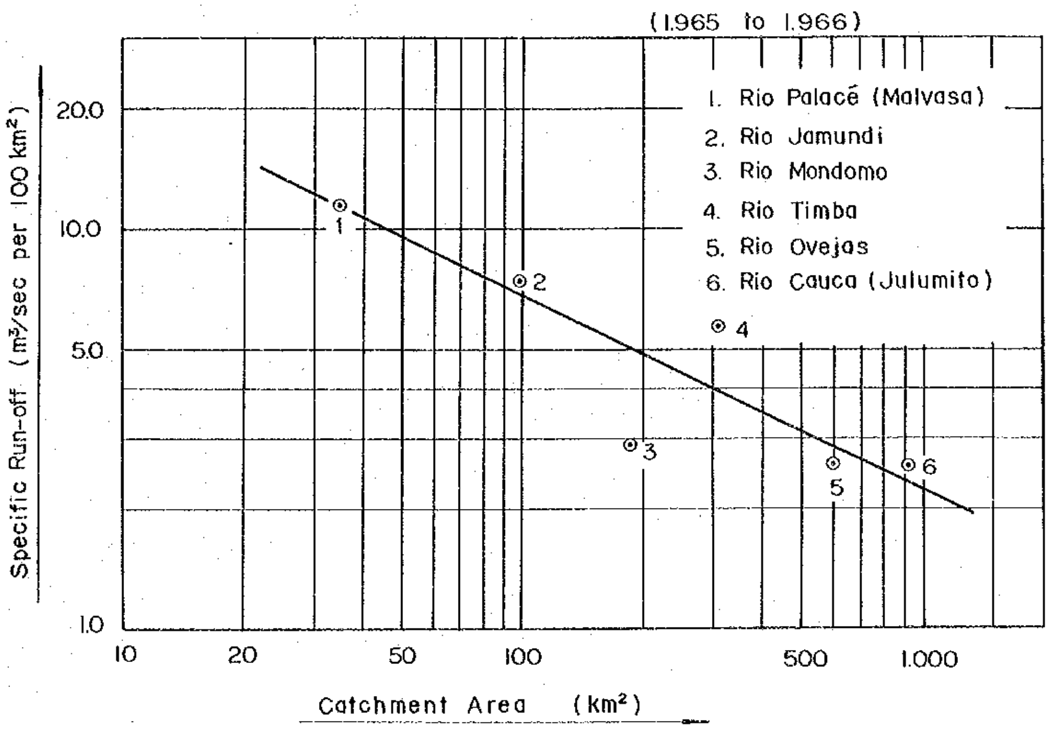
Note; Average of 1965 and 1966

The specific run-offs (run-off per 100 km^2) for each gauging station mentioned above are as shown in Table 5-5 and Fig. 5-6. According to the above table, the specific run-offs of the upper part of the tributaries are extremely large comparing with those of the main stream of Rio Cauca. For example, the specific run-off of the tributary Rio Palacé (at Malvasa site, catchment area 35 km^2) is 11.2 m^3/sec (2-year average for 1965 and 1966) or as much as 4.3 times the 2.6 m^3/sec specific run-off at the mainstream Julumito site (catchment area 939 km^2). This trend is seen fairly prominently in the precipitation data also.

Table 5-5 Specific Run-off at Gauging Stations

Gauging Station	Catchment Area (km^2)	Specific Run-off per km^2 (m^3/sec)			Ratio
		1965	1966	Average	
Rio Palacé (Malvasa)	35	11.86	10.63	11.24	1.00
Rio Jamundi	98	7.04	7.55	7.30	0.65
Rio Mondomo	185	3.03	2.70	2.86	0.25
Rio Timba	310	6.46	5.07	5.77	0.51
Rio Ovejas	640	2.59	2.49	2.54	0.23
Rio Cauca (Julumito)	939	2.78	2.42	2.60	0.23

Fig. 5-6 Correlation between Specific Run-off and Catchment Area



The average run-offs by month and the maximum and minimum run-offs for 10 years from 1962 through 1971 at Julumito Gauging Station on the Rio Cauca mainstream and at Malvasa Gauging Station on the tributary Rio Palacé directly connected with the Julumito Hydroelectric Power Project are as indicated in Table 5-6.

Note

Regarding the actual observation data of Julumito Gauging Station, as shown in Table 5-2, data for approximately 3 years in the last 10 years do not exist. These are supplemented by the method indicated in 5.5.3.

Further, the 10-year run-off at the two gauging stations are given in Table 5-7 and Fig. 5-7.

Table 5-6 Monthly Run-off at Julumito and Malvasa

(Unit; m^3/sec)

Station		Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
	Max.	108.6	76.8	69.2	148.2	56.1	119.8	154.3	194.7	48.0	75.3	104.0	94.0	Max. (194.7)
Julumito	Mean	23.4	23.0	22.3	27.0	23.1	26.5	30.3	28.3	19.4	22.5	32.6	24.9	25.3
	Min.	10.6	10.4	9.4	11.4	11.2	12.0	11.2	12.3	11.6	11.0	13.9	7.8	Min. (7.8)
	Max.	10.0	6.6	5.8	10.5	16.3	28.6	24.9	28.1	13.9	16.4	28.3	36.2	Max. (36.2)
Malvasa	Mean	1.9	1.6	1.7	2.6	4.0	6.3	7.2	5.7	2.9	3.1	4.6	4.1	3.8
	Min	0.4	0.4	0.5	0.9	0.6	0.9	1.4	1.1	0.9	0.9	0.9	0.6	Min. (0.4)

Table 5-7 Run-off Duration at Julumito and Malvasa Gauging Station

(1) Julumito Gauging Station (Catchment Area 939.0 km^2)

(Unit; m^3/sec)

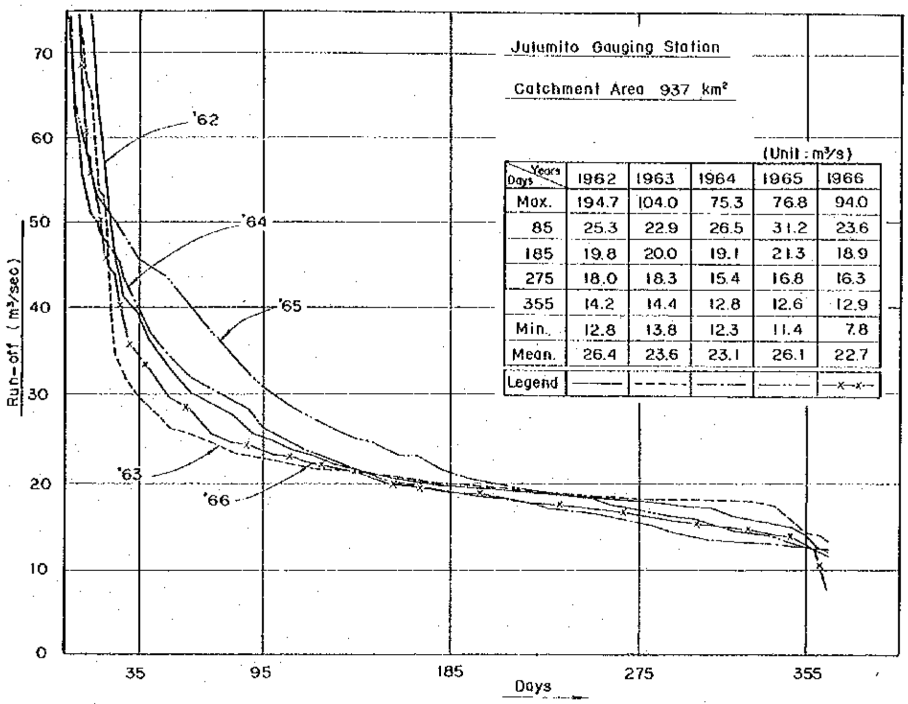
Year	Max.	95 day	185 day	275 day	355 day	Min.	Mean
1962	194.7	25.3	19.8	18.0	14.2	12.8	26.4
1963	104.0	22.9	20.0	18.3	14.4	13.8	23.6
1964	75.3	26.5	19.1	15.4	12.8	12.3	23.1
1965	76.8	31.2	21.3	16.8	12.6	11.4	26.1
1966	94.0	23.6	18.9	16.3	12.9	7.8	22.7
1967	141.5	28.2	20.8	18.2	14.2	12.5	26.8
1968	81.3	25.6	18.6	14.8	11.9	10.4	23.1
1969	148.2	33.1	24.2	18.3	11.8	9.4	27.2
1970	90.2	33.3	24.2	19.2	12.6	11.2	27.3
1971	135.6	29.8	23.4	19.2	14.6	11.0	26.7
Average	–	28.0	21.0	17.5	13.2	–	25.3

(2) Malvasa Gauging Station (Catchment Area 35.0 km^2)

(Unit; m^3/sec)

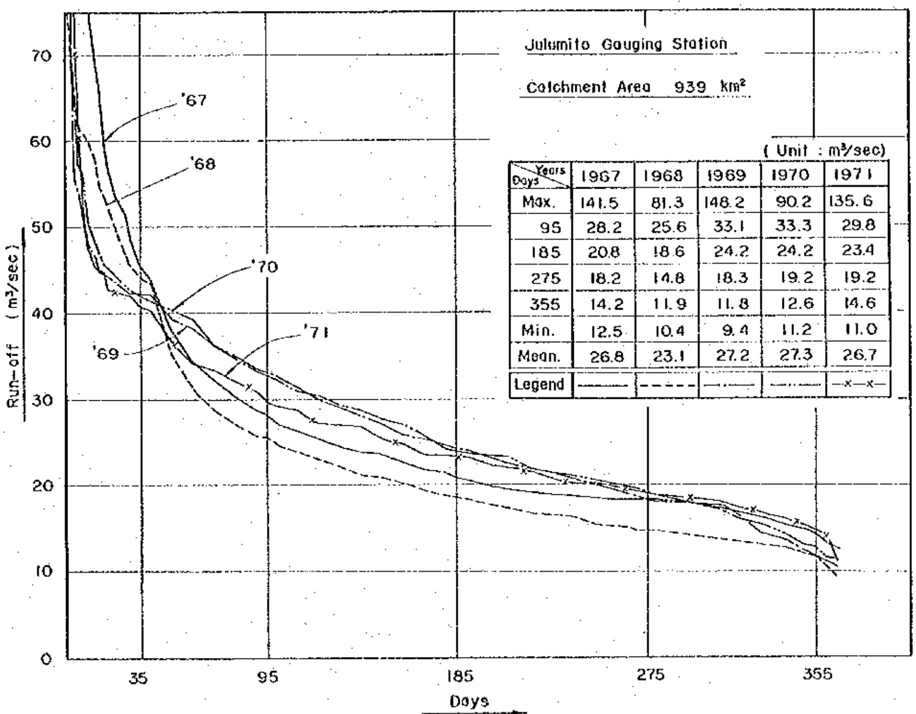
Year	Max.	95 day	185 day	275 day	355 day	Min.	Mean
1962	27.53	3.97	2.52	1.44	0.92	0.85	3.89
1963	16.52	3.12	2.02	1.54	1.21	0.96	2.83
1964	16.57	4.79	2.68	1.12	0.59	0.54	3.50
1965	28.26	4.87	3.00	1.85	0.96	0.85	4.15
1966	36.22	3.91	1.80	1.12	0.79	0.62	3.72
1967	28.60	3.97	2.32	1.68	1.02	0.85	4.10
1968	24.88	5.04	2.32	1.47	1.09	0.96	5.37
1969	10.50	3.88	2.02	1.24	0.68	0.49	3.05
1970	13.01	5.47	3.34	2.02	0.64	0.40	4.01
1971	11.28	4.16	2.80	1.82	1.08	0.87	3.49
Average	–	4.32	2.48	1.53	0.90	–	3.81

Fig. 5-7 (1) Run-off Duration Curve



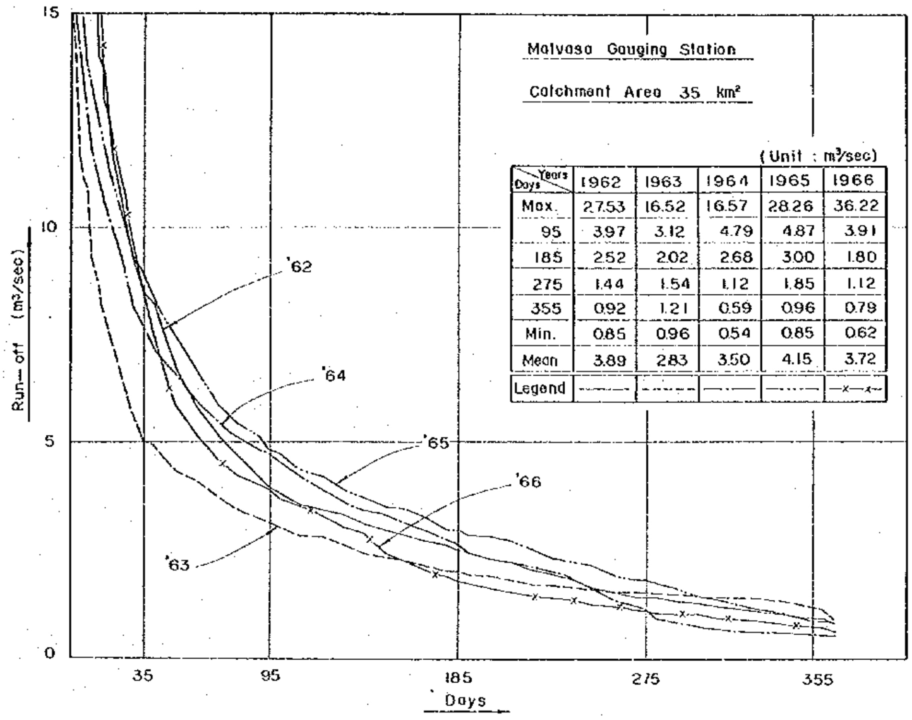
Days \ Years	1962	1963	1964	1965	1966
Max.	194.7	104.0	75.3	76.8	94.0
85	25.3	22.9	26.5	31.2	23.6
185	19.8	20.0	19.1	21.3	18.9
275	18.0	18.3	15.4	16.8	16.3
355	14.2	14.4	12.8	12.6	12.9
Min.	12.8	13.8	12.3	11.4	7.8
Mean.	26.4	23.6	23.1	26.1	22.7
Legend	———	- - - - -	—·—	—··—	—x—x—

Fig. 5-7 (2) Run-off Duration Curve



Days \ Years	1967	1968	1969	1970	1971
Max.	141.5	81.3	148.2	90.2	135.6
95	28.2	25.6	33.1	33.3	29.8
185	20.8	18.6	24.2	24.2	23.4
275	18.2	14.8	18.3	19.2	19.2
355	14.2	11.9	11.8	12.6	14.6
Min.	12.5	10.4	9.4	11.2	11.0
Mean.	26.8	23.1	27.2	27.3	26.7
Legend	———	- - - - -	—·—	—··—	—x—x—

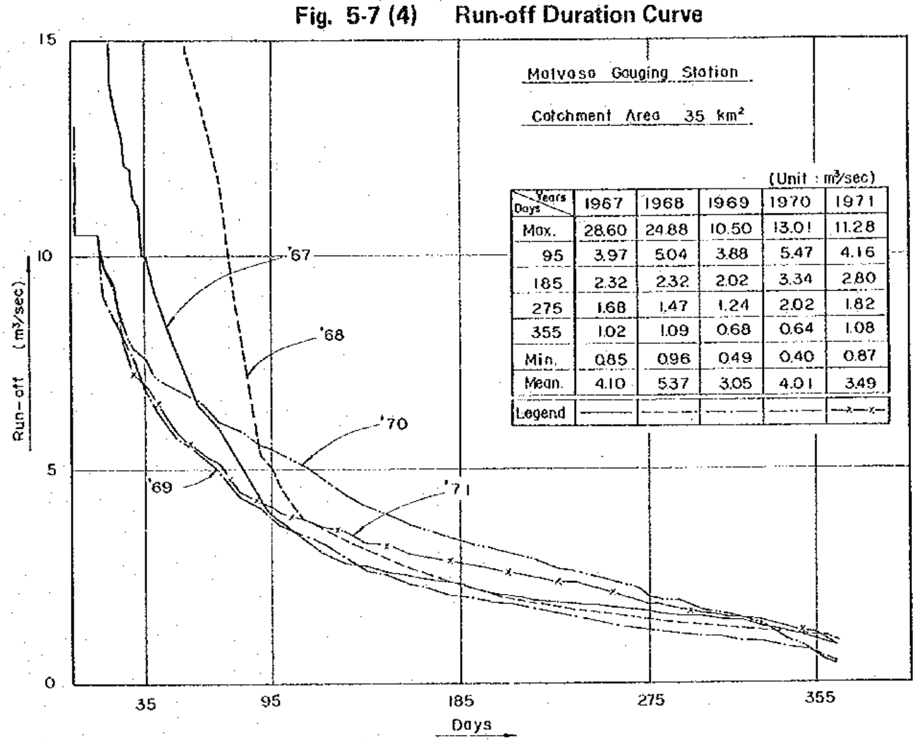
Fig. 5-7 (3) Run-off Duration Curve



(Unit : m³/sec)

Days \ Years	1962	1963	1964	1965	1966
Max.	27.53	16.52	16.57	28.26	36.22
95	3.97	3.12	4.79	4.87	3.91
185	2.52	2.02	2.68	3.00	1.80
275	1.44	1.54	1.12	1.85	1.12
355	0.92	1.21	0.59	0.96	0.79
Min.	0.85	0.96	0.54	0.85	0.62
Mean	3.89	2.83	3.50	4.15	3.72
Legend	——	------	—·—	—··—	—x—x—

Fig. 5-7 (4) Run-off Duration Curve



(Unit : m³/sec)

Days \ Years	1967	1968	1969	1970	1971
Max.	28.60	24.88	10.50	13.01	11.28
95	3.97	5.04	3.88	5.47	4.16
185	2.32	2.32	2.02	3.34	2.80
275	1.68	1.47	1.24	2.02	1.82
355	1.02	1.09	0.68	0.64	1.08
Min.	0.85	0.96	0.49	0.40	0.87
Mean.	4.10	5.37	3.05	4.01	3.49
Legend	——	------	—·—	—··—	—x—x—

5.5 Calculation of Run-off at Project Site

5.5.1 Standard Run-off Gauging Station

The run-off calculations for each diversion site of the Julumito Hydroelectric Power Project were made by selecting a standard gauging station for each catchment area is respect to their locations and degree of compilation of run-off data on which supplementations and corrections are made based on the results of hydrological analysis.

Based on the conditions above mentioned, the standard gauging stations for each intake catchment area are decided as following:

River	Diversion Dam Site	Catchment Area (km^2)	Gauging Station Applied
Rio Cauca	Rio Cauca Diversion Dam	857.0	Julumito
Rio Sate	Julumito Dam	31.0	Julumito
Rio Blanco	Rio Blanco Diversion Dam	39.0	Julumito
Rio Palacé	Rio Palacé Diversion Dam	197.0	Malvasa

5.5.2 Period of Run-off Calculation

The energy production calculations and determination of the scale of the Julumito Hydroelectric Power Project were made based on the run-off data for the latest 10 years from January 1962 to December 1971.

5.5.3 Supplementation Method for Run-off Data

In order to carry out the calculations for the abovementioned 10 years, there is a necessity for the deficiencies in run-off data of the two standard gauging stations of Julumito and Malvasa to be supplemented and put in order. Table 5-8 shows the available observation records at the two gauging stations and the periods for which supplementation should be made.

Table 5-8 Run-off Data Existing at Julumito and Malvasa Gauging Station

Station	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Julumito			4/30		11/30	4/30 6/30	3/30			12/31
Malvasa							8/15 10/5			

Note; (double solid line) Period daily records exist

(double dashed line) Period deficiency of daily obsavation frequently exist

(double dashed line) Period no daily records exist

Further, in regard to Julumito Gauging Station, besides the deficiencies indicated in Table 5-8, there are a considerable number of days during the 3-year period from 1969 through 1971 on which no observations were made. All these are to be supplemented.

Supplementation of run-off data is made by determining the correlation between the available run-offs of the two gauging stations.

The results of this study are described below.

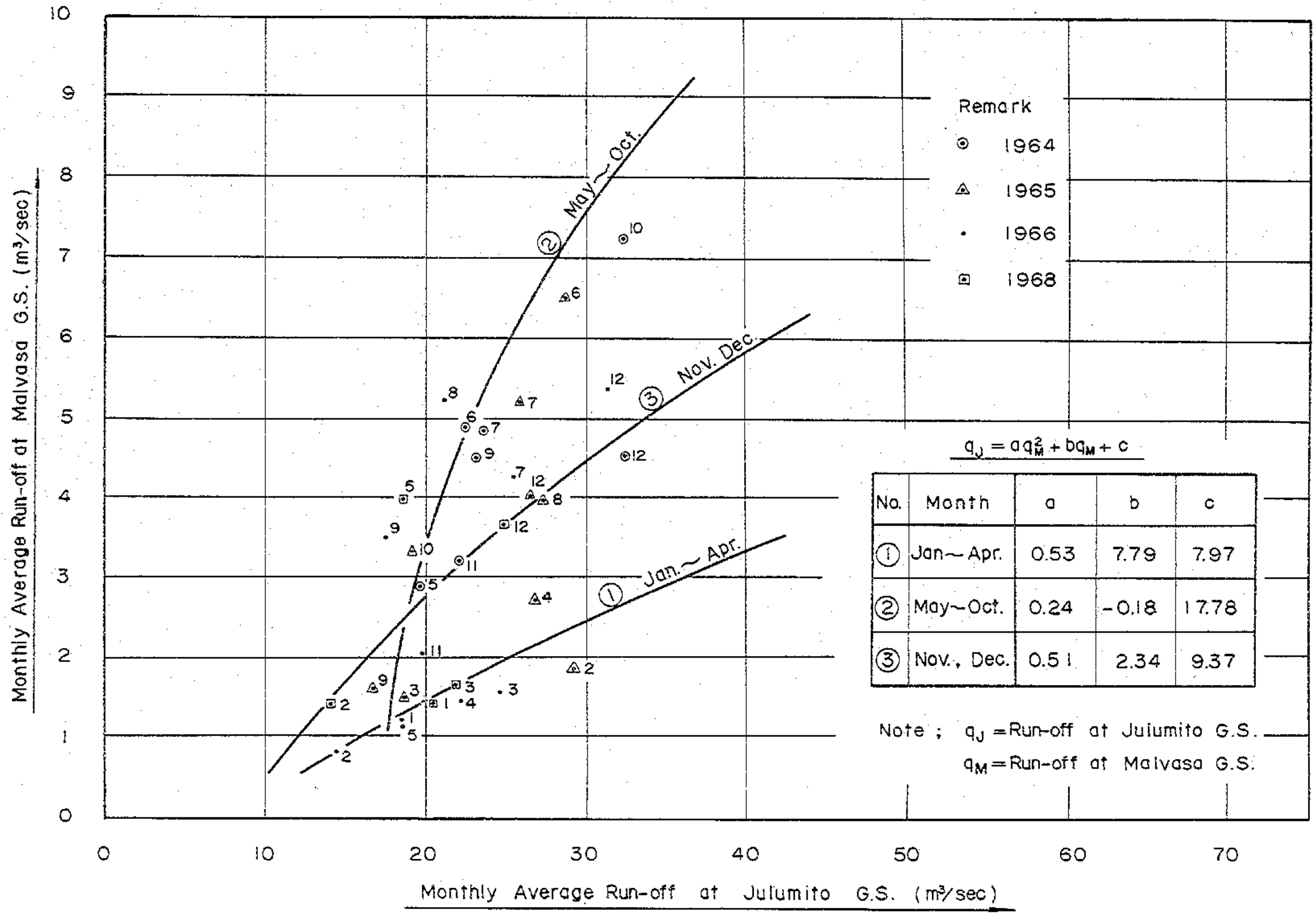
The correlation between monthly average run-offs at the two gauging station sites for the 4 years from April 1964 to the end of 1968 for which period there completely exist daily run-off records is determined as shown in Fig. 5-8. When one year is broadly divided into the 3 periods of January to April, May to October and November to December, fairly good correlations are obtained.

The results are given in Fig. 5-8. These correlations can both be expressed by quadratic equations. The run-off of the days for which observation records of the two gauging stations do not exist can be estimated employing these equations.

The correlation between the annual cumulative run-off at Julumito Gauging Station for the 10 years from 1962 through 1971 and the annual cumulative precipitation at Coconuco situated at the central part of the catchment area is shown in Fig. 5-9.

The daily run-offs for the 10-year period of Julumito and Malvasa Run-off Gauging Stations compiled according to the above are indicated in Appendix III-2.

Fig. 5-8 **Correlation between Run-off at Julumito and MaLvasa Gauging Station**

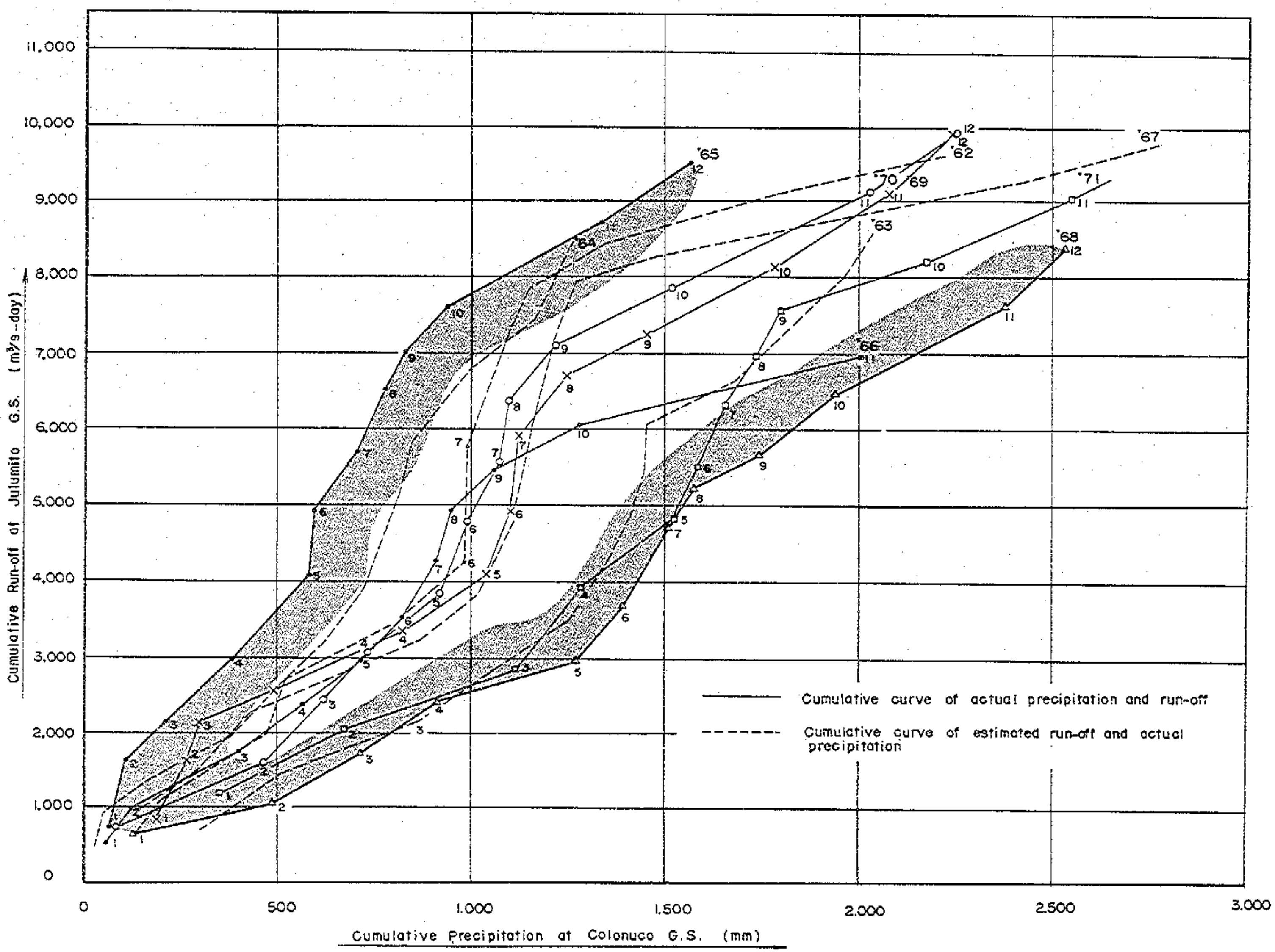


$$q_J = aq_M^2 + bq_M + c$$

No.	Month	a	b	c
①	Jan~Apr.	0.53	7.79	7.97
②	May~Oct.	0.24	-0.18	17.78
③	Nov., Dec.	0.51	2.34	9.37

Note ; q_J = Run-off at Julumito G.S.
q_M = Run-off at Malvasa G.S.

Fig. 5-9 Correlation between Run-off at Julumito and Precipitation at Coconuco



5.5.4 Calculation of Run-off at Project Site

The river run-off at each project diversion dam site may be calculated according to the following:

(a) Calculation of Run-off at Rio Cauca Diversion Dam Site

$$q_C = q_J \cdot \frac{Ac}{A_J}$$

where

q_C : Run-off at Rio Cauca Diversion Dam site (m^3/sec)

q_J : Run-off at Julumito Gauging Station (m^3/sec)

Ac : Catchment area at Rio Cauca Diversion Dam site (km^2)

A_J : Catchment area at Julumito Gauging Station site (km^2)

(b) Calculation of run-off at Julumito Dam site on Rio Sate

$$q_S = q_J \cdot \frac{As}{A_J}$$

where

q_S : Run-off at Rio Sate Julumito Dam site (m^3/sec)

q_J : Run-off at Julumito Gauging Station site (m^3/sec)

As : Catchment area at Rio Sate Julumito Dam site (km^2)

A_J : Catchment area at Julumito Gauging station (km^2)

(c) Calculation of Run-off at Rio Palacé Diversion Dam Site

$$q_P = q_M \cdot \alpha \cdot \frac{Ap}{A_M}$$

where

q_P : Run-off at Rio Palcé Diversion Dam site (m^3/sec)

q_M : Run-off at Malvasa Gauging Station site (m^3/sec)

α : Run-off correction coefficient

A_P : Catchment area at Rio Palcé Diversion Dam site (km^2)

A_M : Catchment area at Malvasa Gauging Station site (km^2)

(d) Calculation of Run-off at Rio Blanco Diversion Dam Site

$$q_B = q_J \cdot \frac{A_B}{A_J}$$

where

q_B : Run-off at Rio Blanco Diversion Dam site (m^3/sec)

q_J : Run-off at Julumito Gauging Station site (m^3/sec)

A_B : Catchment area at Rio Blanco Diversion Dam site (km^2)

A_J : Catchment area at Julumito Gauging Station site (km^2)

The abovementioned coefficient, α , is the correction coefficient for specific run-off in use of the Malvasa Gauging Station run-off records. The specific run-offs of the Rio Cauca main stream and the tributaries within and without the project area studied in 5.4 show a trend of reduction accompanying increase in catchment area as indicated in Fig. 5-6.

In case the specific run-off of the Malvasa Gauging Station is taken to be 1.00, it is estimated this reduction rate will be roughly as shown in Fig. 10. According to this, the specific run-off of the Rio Palacé diversion dam site (catchment area 197.0 km^2) is approximately 40% that at the Malvasa site. Therefore, in calculations of run-off at the Rio Palacé Diversion Dam site using run-off data of Malvasa Gauing Station, α = 0.40 is taken as the run-off correction coefficient.

The average monthly run-offs from January 1962 to December 1971 of the Rio Cauca and Rio Palacé diversion dam sites calculated by the above method are as indicated in Table 5-9 and 5-10 respectively.

Fig. 5-10 Ratio of Specific Run-off

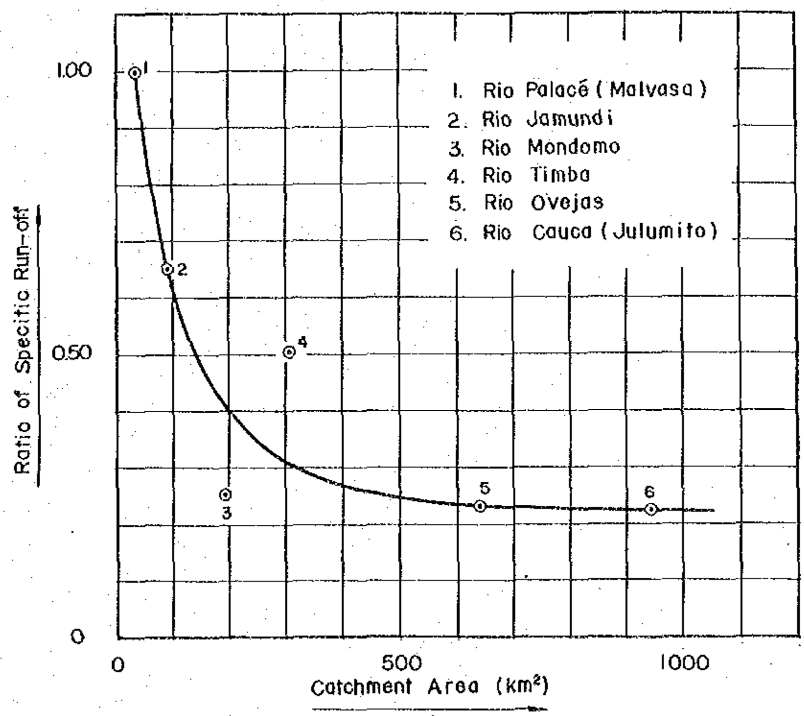


Table 5-9 Run-off Rio Cauca Diversion Dam Site

Catchment Area 857.0 km^2 (Unit: m^3/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1962	18.2	15.5	26.0	22.1	20.0	26.5	44.8	43.4	18.7	17.6	19.9	15.0	24.1
1963	20.4	24.1	20.9	21.4	19.4	23.2	17.2	18.5	18.1	16.8	40.7	17.3	21.4
1964	13.6	13.8	12.0	18.9	17.5	20.5	20.8	36.6	21.1	28.4	20.1	29.4	21.1
1965	21.6	28.6	16.5	24.5	32.1	26.2	22.9	24.2	15.3	16.9	34.4	23.5	23.8
1966	16.2	14.2	21.9	20.3	16.3	17.7	22.5	18.7	15.9	17.6	28.7	38.3	20.7
1967	25.5	20.4	21.7	29.3	18.3	30.2	41.0	35.7	16.8	16.8	22.7	15.0	24.5
1968	18.2	13.9	19.3	21.3	16.3	22.5	30.0	14.6	14.0	24.5	35.7	22.1	21.0
1969	24.3	25.5	15.8	36.8	21.4	25.7	29.1	24.1	17.2	25.7	28.9	23.6	24.8
1970	21.0	27.8	25.5	18.7	23.4	28.7	23.2	23.9	22.0	22.0	39.2	23.2	24.8
1971	35.0	27.1	24.2	32.9	26.4	21.0	24.6	18.9	18.1	19.2	25.5	19.7	24.3
Average	21.4	21.0	20.4	24.6	21.1	23.4	27.6	25.9	17.7	20.5	29.6	22.7	23.1

Table 5-10 Run-off at Rio Palacé Diversion Dam Site

Catchment Area 197.0 km^2 (Unit; m^3/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1962	3.1	2.4	5.0	4.1	9.6	12.6	24.0	18.7	7.4	6.0	6.9	4.6	8.8
1963	3.7	4.5	3.9	4.0	7.5	10.6	5.2	7.6	6.9	4.1	13.0	5.6	6.4
1964	1.9	1.9	1.4	4.4	6.3	11.1	10.6	13.5	10.2	15.8	7.2	9.9	7.9
1965	9.8	4.5	3.3	6.2	13.7	14.7	11.4	8.7	3.7	7.3	19.9	8.8	9.3
1966	2.5	2.1	3.4	3.3	2.7	4.3	9.3	11.4	7.9	4.4	12.1	36.4	8.4
1967	5.0	3.7	4.1	6.2	5.1	25.6	20.2	19.8	4.3	4.2	7.8	4.5	9.2
1968	3.1	3.3	3.6	6.7	9.0	30.5	43.8	19.8	4.0	4.3	8.2	8.0	12.1
1969	4.0	3.0	2.0	9.6	8.0	11.0	16.0	7.4	3.7	9.1	5.2	3.0	6.9
1970	2.8	6.1	4.2	5.7	12.2	15.2	9.2	12.7	10.4	9.4	14.1	6.3	9.0
1971	7.1	4.9	6.4	7.4	15.5	5.5	12.7	9.3	6.8	5.9	8.1	4.5	7.9
Average	4.3	3.6	3.7	5.8	8.9	14.1	16.2	12.9	6.5	7.1	10.3	9.1	8.6

Fig. 5-11 Hydrograph at Gauging Stations in Project Area (1)

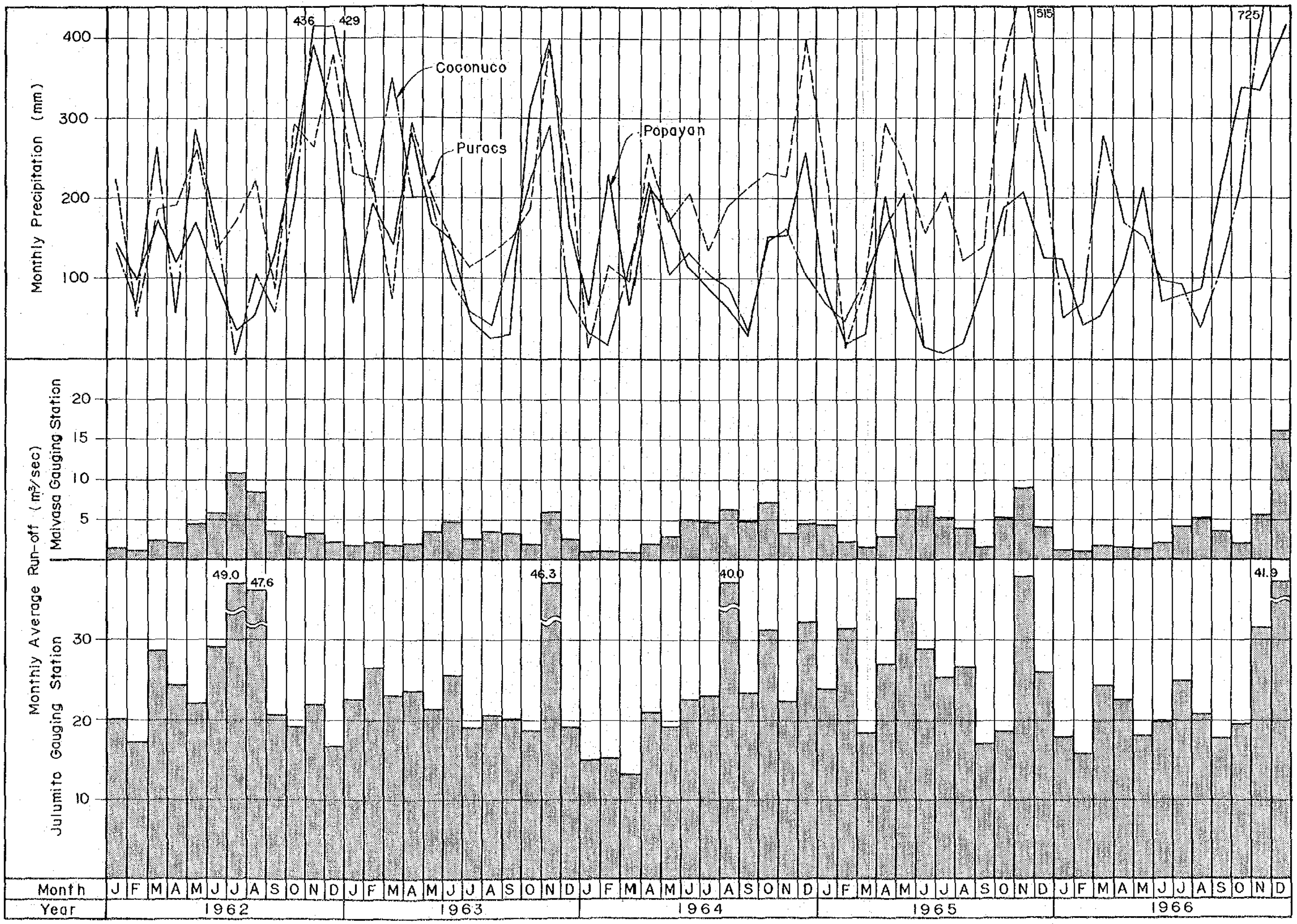
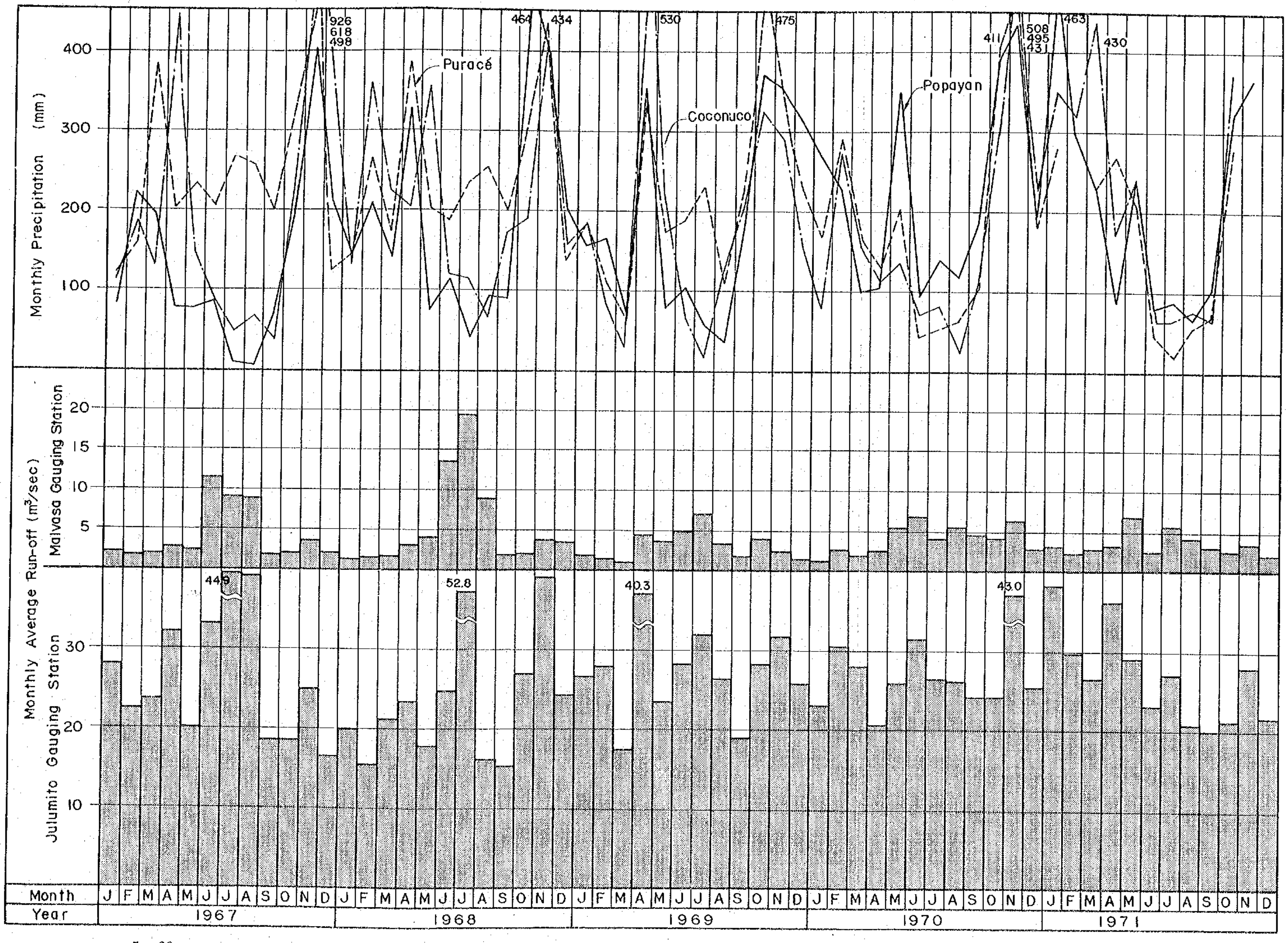


Fig. 5-11 Hydrograph at Gauging Stations in Project Area (2)



5.6 Design Flood Discharge

Julumito Dam to be built on the Rio Sate is planned as a rockfill dam and the design flood discharge at this site is calculated by the method below.

Observation of floods of the Rio Cauca and tributaries in the surrounding area have not been carried out. Consequently, the probabale daily precipitation is estimated from the records of maximum daily precipitation in each year for the 8-year period from 1961 through 1968 at Florida in the projected catchment area and the probable flood discharge is calculated from the estimated precipitation by use of the Rational Formula.

The design flood discharges of the Rio Cauca, Rio Palacé, Rio Blanco diversion dam sites, etc., are similarly calculated as probable flood discharge from the probable daily precipitation.

5.6.1 Calculation of Probable Daily Precipitation

The calculation is made employing the maximum daily precipitation in each year (X_i mm/day) at Florida indicated in Table 5-11 based on the Iwai Method which utilizes logarithmic normal distribution.

Table 5-11 Maximum Daily Precipitation in each Year

No.	Date	Xi (mm/day)	log Xi	Xi + b	log (Xi + b)	$\{\log (Xi + b)\}^2$
1	Oct. 1966	90.2	1.9552065	52.74	1.7221401	2.9657665
2	Mar. 1967	53.2	1.7259116	15.74	1.1970047	1.4328202
3	Nov. 1965	47.9	1.6803355	10.44	1.0182843	1.0369029
4	Dec. 1961	46.4	1.6665180	8.94	0.9513375	0.9050430
5	Dec. 1968	46.0	1.6627578	8.54	0.9314579	0.8676138
6	Oct. 1963	41.1	1.6138418	3.64	0.5611014	0.3148347
7	Nov. 1962	40.0	1.6020600	2.54	0.4048337	0.1638903
8	Apr. 1964	39.9	1.6009729	2.44	0.3873898	0.1500708
1/n			1.6884505		Xo = 0.8967	X^2 = 0.9796

(a) Calculation of X_g

$$\log_{10} X_g = 1/N \cdot \sum_{1}^{n} \log_{10} X_i = 1.6884505$$

$\therefore \quad X_g = 48.80$

$\therefore \quad X_g^2 = 2,381.44$

(b) Estimation of b

Since $m \fallingdotseq N/10 = 0.8$, b_1 is determined by the equation below.

$$b_1 = \frac{X_1 \cdot X_8 - X_g^2}{2 \cdot X_g - (X_1 + X_8)} = -37.46$$

(c) Estimation of 1/a

$$1/a = \sqrt{\frac{2N}{N-1}} \cdot \sqrt{\overline{X^2} - X_o^2} = 0.6334$$

(d) Probale Daily Precipitation by the Iwai Method

1/T	ϵ	$(1/a)\epsilon$	$(1/a)\ \epsilon + Xo$	X + b	X
10	0.9062	0.5740	1.4707	29.56	67.0
20	1.1631	0.7367	1.6334	42.99	80.5
30	1.2967	0.8213	1.7180	52.24	89.7
50	1.4520	0.9197	1.8164	65.52	103.0
100	1.6450	1.0419	1.9386	86.82	124.3
200	1.8214	1.1537	2.0504	112.30	149.8

5.6.2 Calculation of Design Flood Discharge

(1) Flood Arrival Time

The flood arrival time is calculated by the formula of Rziha.

$$W = 72 \cdot \left(\frac{H}{L}\right)^{0.6}$$

$$T = \frac{L}{W}$$

where

W : Flow velocity of flood (km/hr)

H : Elevation difference (km)

L : Sectional length of flow channel (km)

T : Flood arrival time (hr)

The flood arrival time of each rivers calculated by the above formula are as follows:

Rio Cauca	10.0 hr
Rio Palacé	6.6 hr
Rio Blanco	2.4 hr
Rio Sate	5.5 hr

(2) Calculation of Flood Discharge

The flood discharge of each site is calculated by the Rational Formula.

$$Q = \frac{1}{3.6} \cdot f \cdot r \cdot A$$

where

Q : Peak discharge of flood (m^3/sec)

f : Run-off coefficient 0.7

r : Average rainfall within flood arrival time (mm/hr.)

Calculated by the following formula

$$r = \frac{R_{24}}{24} \cdot \left(\frac{24}{T}\right)^n$$

A : Catchment area (km^2)

The design flood discharges of each site calculated according to the above are indicated in Table 5-12.

Table 5-12 Design Flood Discharge

Diversion Dam	Catchment Area (km^2)	Frequency (1/year)	Flood Discharge
Rio Cauca	857	1/50	850
Rio Palacé	197	1/50	215
Rio Blanco	39	1/50	52
Rio Sate	31	1/200	50

5.6.3 Calculation of Diversion Tunnel Capacity

In order to carry out work on Julumito Dam to be constructed on the Rio Sate it is necessary to temporarily divert the flow of the Rio Sate by a diversion tunnel.

The capacity of this diversion tunnel is determined to be 25.0 m^3/sec based on considerations of the maximum values of the observed records of the past at Julumito Gauging Station and Malvasa Gauging Station and the results of estimations by probable daily precipitations.

5.7 Sedimentation

As described in Chapter 6 "GEOLOGY AND CONSTRUCTION MATERIALS" the catchment area of Julumito Reservoir to be provided on the Rio Sate is a hill district with gentle undulations located at the suburbs of Popayan City and the area is very small, only 31 km^2.

The greater part of the overburden of this catchment area and the reservoir area is comprised of a more or less uniform volcanic ash layer, but at the vicinity of the dam site and the valley bottom upstream there are distributions of andesitic lava. The ground surface is protected with a cover of turf-like weeds and shrubs.

According to the results of reconnaissance of the Rio Sate catchment area, there are no traces of marked sand flows, sand deposits and landslides, and judging also from the abovementioned topography and geology of the catchment area, it is not conceivable that a large-scale sliding of land would occur with the impoundment of water.

From the above, it is believed that inflow of sediment and the quantity of sedimentation at Julumito reservoir would be very small, but in the following the sedimentation at the reservoir will be estimated based on various empirical formulae taking into account several factors which are considered to be causes of sedimentation.

(1) Calculation Based on Reservoir Capacity and Catchment Area

Calculations are made by the empirical formula of Witzig which was established on the concept that sedimentation should be determined by the 2 factors of reservoir capacity and catchment area.

$$q_s = K_1 \cdot (V/A)^{0.83}$$

where

q_s : Specific sedimentation (acre-feet/100 sq. miles/yr)
V : Reservoir capacity, 49,289 (acre-feet)
A : Catchment area, 11.969 (sq. miles)
K_1 : Regional index = 0.10

q_s = 100 (acre-feet/100 sq. miles/yr)

(2) Calculation Based on Reservoir Capacity, Catchment Area and Reservoir Inflow

When estimated based on the formula of Kira which takes into consideration reservoir inflow on top of Witzig's formula, the result would be as follows:

$$q_s = K_2 \cdot V^{0.527} \cdot Q^{0.473} \cdot A^{-1}$$

where

q_s : Specific sedimentation ($m^3/km^2/yr$)
V : Reservoir capacity, 60.8 x 10^6 (m^3)
A : Catchment area, 31 (km^2)
Q : Annual average reservoir inflow 30.2 (m^3/sec)
K_2 : Coefficient = 0.214

Therefore:

$$q_s = 438 \ m^3/km^2/yr$$

(3) Calculation Based on Geological Conditions, Topographical Conditions and Precipitation in Catchment Area

Also, estimation of sedimentation is made according to the empirical formula of Sekigai which considers that sedimentation is governed by topography, geology and precipitation in the catchment area and is deduced based on actual data indicated in Fig. 5-12.

The abovementioned conditions for the catchment area of Julumito reservoir, are considered as follows:

Geological conditions: Group C
(Cenozoic sedimentary rock, medium basic plutonic rock, semiplutonic rock, effusives, crystalline schiest, serpentine, etc.)

Maximum annual precipitation (P): 2,058 (mm)

Relief of topography (R_f): 150 (m)

The formula of Sekigai for geological conditions of (C) is given by the following equation:

$$\log q_s = 1.50 \log X - 5.58 \pm 0.65 \sqrt{0.09 + (\log X - 5.41)^2}$$

where

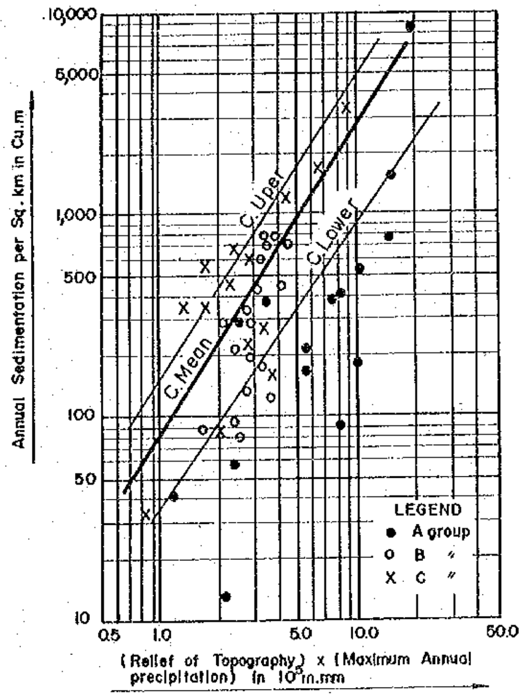
q_s : Specific sedimentation ($m^3/km^2/yr$)

X : P · R_f = 308,700 (m.mm)

Therefore

q_s = 717 $m^3/km^2/yr$ or 284 $m^3/km^2/yr$

Fig. 5-12 Relation between Sedimentation, Geology, Topography and Precipitation



Note ;

Group A. ; Catchment area consisting mainly of Paleozoic and Mesozic sedimentary rocks

Group B. ; Catchment area consisting mainly of acidic plutonic, hypobyssal and their metamorphic rocks represented by granite and schist

Group C. ; Catchment area consisting mainly of Cenozoic sedimentary rocks and effusive rocks

The results of calculations based on the various empirical formulae above are summerized in Table 5-13.

Table 5-13 Sedimentation at Julumito Reservoir

Case	Sedimentation (m^3/km^2/year)	Sedimentation ($10^3 m^3$/100 years)	Factors Considered
1	476	1,480	Storage Capacity, Catchment Area
2	438	1,360	Storage Capacity, Catchment Area, Reservoir Inflow
3	717	2,220	Georogy, Topographical Relief Precipitation

Note: Catchment-Area; 31 km^2

Consequently, upon study of sedimentation in Julumito Reservoir based on the above 3 methods, the method of (3) gives the largest figure of 717 m^3/km^2/yr, and if this is to be adopted, the sedimentation in a period of 100 years will be 2.2 x 10^6 m^3.

The design low water level of Julumito Reservoir is 1,700 m, and since the capacity below this elevation is 10 x 10^6 m^3, there is adequate safety in regard to securing of effective storage capacity.

As for inflow of sediment into waterway from intake, this can be adequately prevented through suitable design of the intake.

CHAPTER 6

GEOLOGY AND CONSTRUCTION MATERIALS

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CHAPTER 6 GEOLOGY AND CONSTRUCTION MATERIALS

6.1 Outline and Conclusion

6.1.1 Purpose and Content of Geological Investigation

The purpose of the investigation was to select the most suitable sites in expediting the Julumito Project from the standpoint of geology keeping in mind the safety of civil structures and technical and economic feasibilities, and to perform geological analyses of these sites. Consequently, besides studying the geologic feasibilities of the Julumito dam, reservoir, powerhouse and appurtenant structures — intake, headrace tunnel, surge tank, penstock, etc. — and the two diversion systems — Rio Cauca and Rio Palacé, the geological surveys and tests of construction materials for the civil structures projected were carried out.

In this Report, the geological studies in regard to the foundations and construction materials selected for the civil structures are described, while recommendations on geological investigations and laboratory tests are given in Appendix I, and data on geological investigation works, field permeability tests of foundation and tests of construction materials are contained in Appendix IV.

The scope of the geological survey covers the entire project area and the results of this survey have been made to be amply reflected in the study of the Project and in determination of the layout and design of civil structures.

6.1.2 Previous Investigation

Geological surveys in regard to the Project were initiated by Centrals Electricas del Cauca S.A. (CEDELCA) in 1969. In the following year, 1970, the Japanese Government at the request of the Colombian Government dispatched a survey mission including one geologist from the Overseas Technical Cooperation Agency. The survey mission, with the cooperation of the engineering staffs of Instituto Colombiano de Energia Electrica (ICEL) and CEDELCA, prepared a preliminary study report[1].

The survey mission made up numerous alternative plans as listed below, carried out outline study for the respective plans and performed comparison studies thereof.

(1) Plan A: No. 2 dam and No. 4 powerhouse (underground, left bank of dam site)

(2) Plan B: No. 2 dam and No. 2 powerhouse (approximately 1.2 km upstream from No. 3 powerhouse)

(3) Plan C: No. 2 dam and No. 3 powerhouse (proposed plan)

(4) Alternative dam sites: No. 1 Dam - approximately 1.2 km upstream from No. 2 dam and No. 3 dam - approximately 0.5 km directly downstream from No. 2 dam.

Of all these plans, on making comparisons in regard to the dam sites, the No. 1 site is found to be covered by a thick volcanic ash and as outcrops of sound andesite lava are extremely limited, the foundation of a dam to be constructed here would become fairly deep compared with the No. 2 site. The geologic feature of the No. 3 dam site is similar to that of the No. 2 site. However, the ridge on the right bank of the No. 3 site is very lean and as a volcanic ash occupies the ground from the middle portion up to the ridge, this site is disadvantageous from the standpoints of topography and geology.

Therefore, the No. 2 dam site is superior to the other sites.

Meanwhile, in regard to the powerhouse, three out door type (No.1, No. 2 and No. 3) and one underground type (No. 4) were contemplated of which No. 3 and No. 4 were evaluated to be worthy of consideration.

Consequently, taking into account the recommendations of the Japanese Government Survey Mission, CEDELCA performed investigation works including core borings, test pits and test adits, field permeability tests and laboratory tests of impervious materials. The results of these investigations and tests have been summarized in the present studies and compiled in Appendix IV.

The quantities of the major geological investigation works are indicated in Table 6-1.

6.1.3 Conclusion

The geological conclusions reached in the present investigation are the following:

(1) In regard to the dam site, the No. 1, No. 2 and No. 3 sites selected in the previous Preliminary Studies[1] have been studied based on various data of investigation works provided by ICEL or CEDELCA and the present field survey. As the results of the examination of these data, especially in respect to the geologic

Table 6-1 Summary of Geological Investigation Works carried out by CEDELCA

Site	Core boring			Test adit			Test pit			Remarks
	Name	El.(m)*1	L (m)*2	Name	El. (m)	L (m)	Name	El (m)	L (m)	
Julumito damsite	DH-203	1650.37	14.00	A-1	1690.00	50.00	DH-201	1721.00	21.05	
	DH-204	1653.00	14.00	A-2	1650.00	12.85	DH-202	1714.00	15.10	
				A-3	1660.00	28.05	DH-205	1719.80	17.00	
				A-4	1690.00	28.30				
				A-5	1670.00	25.20				
				A-6	1680.00	50.00				
	Total : 2 holes, 28.00 m long.			6 adits, 194.40 m long.			3 pits, 53.15 m long			
Dike sites	DDH-1	1715.12	20.00							Dike No. 1 site
	DDH-2	1716.48	23.00							Dike No. 2 site
Power-house sites	DH-1	1728.60	160.00							Underground Power-house site
	DH-4	1568.66	20.00							Proposed site
Headrace tunnel	DH-2	1733.97	43.00							
	DH-3	1708.08	35.00							
Quarry site	DH-5	1745.16	60.00							
Borrow area	DH-6		55.00				TP 101 - 104,	3m deep each.		
	DH-7		31.00				TP 201 - 204,	3m deep each.		

* 1 Elevation of top of hole or potal of adit in meter.

* 2 Length in meter.

states of weathering component and bearing capacity of dam foundation, or the watertightness concerning the dam foundation and the reservoir, it was reconfirmed that the No. 2 site is superior.

(2) Regarding the powerhouse, an underground powerhouse site (Site No. 4) and three out door powerhouse sites (Site No. 1, 2 and 3) were proposed in the Preliminary Studies[1] subsequent to which investigations were carried out. For the underground powerhouse (Site No. 4), it was found that soft tuff existed at the elevation of the powerhouse and it was anticipated that construction for the structure would be difficult.

In contrast, of the out door powerhouse proposals, Site No. 3, the farthest downstream of the abovementioned three sites, has a flat area topographically. The basement of this site consists of tuff breccia having compressive strength of 50 to 100 kg/cm^2, and possesses sufficient bearing capacity. Also, this site is superior in the economy of power generation so that it is judged that Site No. 3 (a out door type) is most desirable as the powerhouse site.

(3) For the reasons of (1) and (2) above, and the result of the engineering studies of the development project patterns, Plan A, Plan B and Plan C, proposed in the previous Preliminary Studies [1], it is judged that Plan C is the most excellent.

(4) At Julumito Dam site (No. 2 dam site) the right bank is a roughly broad monotonous slope, but the left bank is a lean ridge. From the topographic condition and the state of weathering of the dam foundation in the left bank, it is judged desirable for the dam to be a curving rock fill dam with the impervious core touching bed rock along the ravine upstream from the ridge.

Further, the geology comprising the foundation of this dam is weathered andesite and poorly consolidated volcanic ash near the high water surface level and careful engineering considerations are paid in this feasibility study.

(5) It is thought that leakage and sedimentation in the reservoir formed by Julumito Dam will be of degrees that are negligible. However, saddle dams will be required at two places at the divide between the reservoir and the Rio Cauca and the sites of these dikes possess geologic conditions allowing construction of these structures.

(6) The headrace tunnel connecting Julumito Reservoir with the powerhouse is routed in andesite lava while the penstock is to be provided at a steep cliff comprised of sound andesite lava. Since there are some places along the head-race tunnel where fissures are abundant in the lava, spalling and cave-ins must be prevented in construction at these parts, while it is necessary for preparations to be made against occurrence of water springing.
It should be possible for the anchor blocks of the penstock to be provided on bedrock having sufficient bearing power.

(7) The foundations of the diversion dams in the Rio Cauca and Rio Palacé diversion systems are all unconsolidated deposits. The dams are low, but these dams should be founded on adequately compacted deposits and suitable foundation treatments should be necessary.
The diversion waterways, although comprised of tunnels in part will chiefly be open channels. The routes are comprised of unconsolidated foundation consisting of river terrace deposits and volcanic ásh, but since the topography of the routes comprises hill areas presenting gentle undulations, it is inconceivable that destruction of the waterways could be caused by land slides under normal conditions. The tunnels are to be driven through volcanic ash therefore it will be necessary to cut the vicinities of the tunnel portals adequately. The important matter is that concrete placement must be carried out carefully in order to prevent uneven settlement of the open channel and tunnel foundations, and sliding of the ground due to leakages from the waterways must be prevented. be prevented.

(8) It is assumed that construction materials can all be obtained in the vicinities of the civil structures. Volcanic ash would be mainly used as the impervious material, but this would be a special type of soil. Consequently the dam design beforementioned has been carried out, but all the more the characteristics of the soil should be completely grasped through appropriate tests. Detailed design and construction methods based on these characteristics must be carried out. Rock materials, filter materials and concrete aggregates are intended to be obtained mainly from the ridge on the opposite bank of the powerhouse, while it should be possible for excavation muck from penstock installation work and the headrace tunnel to be used as parts of these materials. These materials are of sound andesite lava and are judged to have suitable properties as the

result of the laboratory tests.

Further, in regard to concrete aggregates it is possible to consider river deposits being taken for Florida Power Station under construction at the outskirts of Popayan City, but the survey of the quantities is necessary on the deposits of sand and gravel.

(9) In order to carry out detailed designing, geological investigations should be carried out based on the recommendations made in Appendix I.

6.2 General Geology of Project Area

6.2.1 Outline of Topography and Geology

A. Topography (cf. Fig. 6-1)

The Andes Mountain System which comprises the western rim of the South American Continent stretches north and south with its peak in Peru, the extension to the north decreasing in elevation as it goes through the central part of Ecuador to reach into Colombia.

The Andes Mountain System on entering Colombian territory is divided into the following three mountain ranges:

(1) Cordillera Oriental

(2) Cordillera Central

(3) Cordillera Occidental

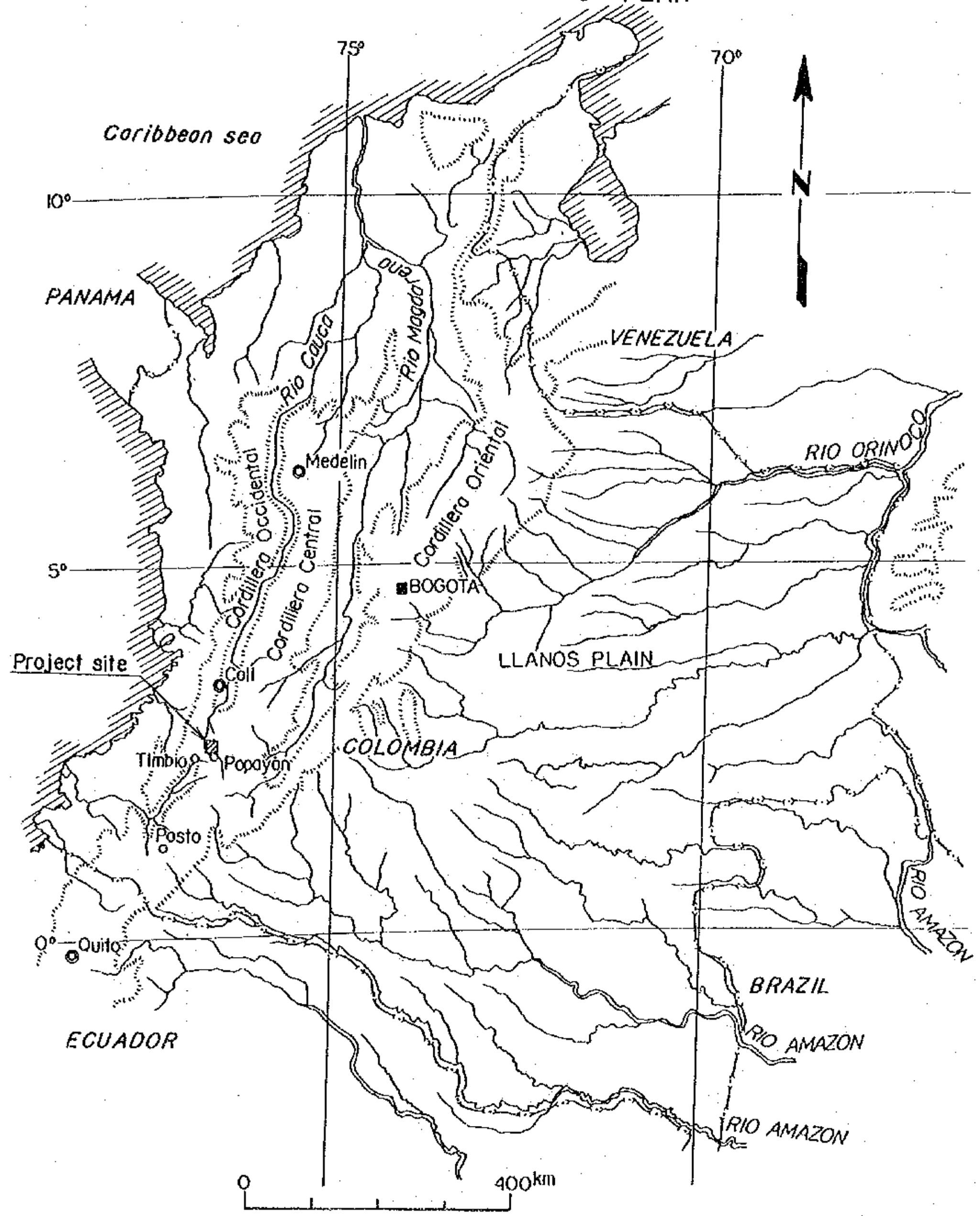
Of these mountain ranges, the highest one is the Cordillera Central which has an average elevation close to 3,000 m and moreover has several peaks exceeding elevations of 5,500 m above sea level, while the length reaches 800 km. Between the Cordillera Central and the Cordillera Occidental, the Rio Cauca with a length of more than 1,500 km flows from south to north and the catchment basin comprises one large plain with a width of 60 to 80 km.

The Rio Magdalena flows north between the Cordillera Central and the Cordillera Oriental, merges with the Rio Cauca in the northern part of Colombia to feed the Caribbean Sea.

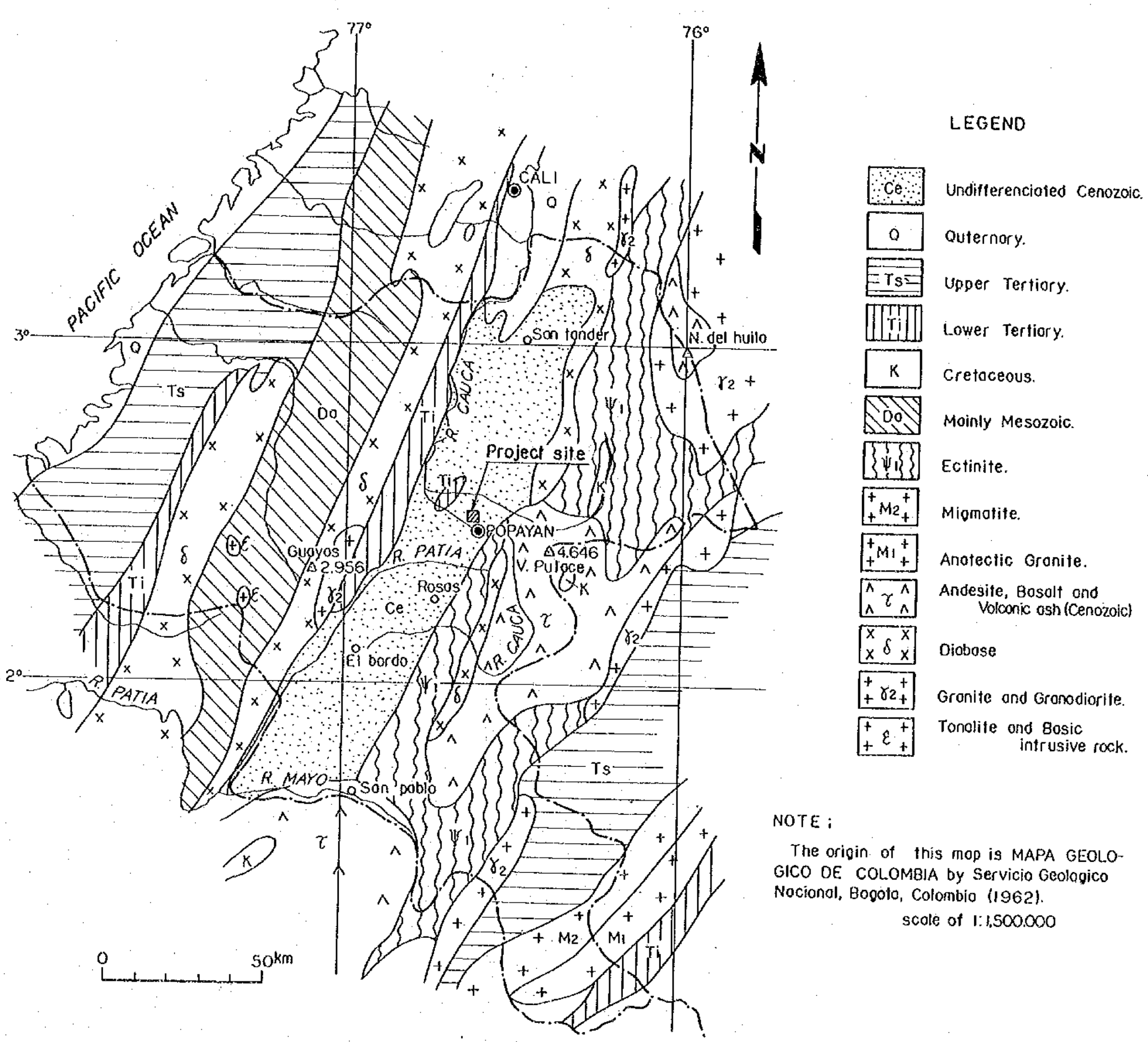
The plains extending to the east from the Cordillera Oriental are the sources of the Rio Amazon and the Rio Orinoco, comprising a vast grass plain and wide forest area

Fig. 6-1 General Map of Topography and Geology in Cauca District

TOPOGRAPHIC PLAN



GEOLOGIC PLAN



NOTE ;

The origin of this map is MAPA GEOLOGICO DE COLOMBIA by Servicio Geologico Nacional, Bogota, Colombia (1962).

scale of 1:1,500,000

called Llanos.

The Julumito Project Area is centered at a point approximately 10 km northwest of Popayan City in the Upper Rio Cauca Valley and is located where the Rio Cauca flows out to a plateau area from the gentle foothills of the western side of the Cordillera Central. The vicinity of Popayan City is a plateau with an elevation of about 1,750 m, this surface being gently sloped to the west and dissection is not very advanced. The drainage system in this area indicates a distinct parallel pattern flows from east to west of tributaries such as the Rio Sate and Rio Palacé.

The Rio Cauca comprises a wide flood plain in the vicinity of Popayan City where it meanders gently and there are river terraces in four stages at the both banks. The Rio Cauca passes the northwestern part of Popayan City and the river gradient is gentle to the outskirts, but further downstream the river gradient becomes steep and forming the canyan with a width of 50 to 80 m in the river bed and a hight of about 100 m within a considerable distance.

B. Geology (cf. Fig. 6-1 and DWG. NO. 1)

Topographically, Colombia may be clearly divided into the Llanos at the eastern half which comprises the fountainheads of the Rio Amazon and Rio Orinoco and the Andes Mountain System comprised of the three mountain ranges in the western half at this country. The Llanos corresponds to the northwestern fringe of the Guayana Shield which extends from Colombia to Brazil and presents a comparatively simple geologic structure. The Andes Mountain System is comprised of sedimentary rocks from the Devonian period to the Tertiary Period and igneous rocks and metamorphic rocks. This mountain system is a fold belt formed by the Andes orogenic movement of the Tertiary period and is roughly parallel to the western fringe of the Guayana Shield and extends more or less in the NNE-SSW direction.

The project area is located in the vicinity of Popayan City at the western part of the Andes Mountain System - Cordillera Central.

The geology comprising the surrounding area of Popayan City is in most part volcanic products called Popayan Formation and Rio Cauca Formation. The geology comprising the basement of the area is that of metamorphic rocks and basic igneous rocks said to be a Mesozoic group. Since this Mesozoic group is thickly covered (roughly more than 300 m) by volcanic products, it is only seen scatteredly where the Popayan Formation is deeply eroded by the Rio Cauca and other rivers. For example, the powerhouse site and intake dam site in the Florida II Hydroelectric Power Project now being constructed on the Rio Vinagre, a tributary of the Rio Cauca, may be cited. The former is metamorphic rock consisting of green schist while the latter is basic igneous rock comprised of schalstein and diabase. The geologic times of these strata are estimated based on the information[2,3,4] collected, as shown in Table 6-2.

Table 6-2 Generalized Geologic Chronology in the Julumito Project Area

Period or era	Stage	Formation	Rock
Quaternary	Pleistocene	Popayan formation	Volcanic ash.
			~~ Unconfomity*1 ~~~
Neogene to Quaternary	Plio-pleistocene		Andesite lava
			—— Conformity*2 ——
Neogene	Pliocene	Rio Cauca formation*3	Tuff breccia
			~~ Unconformity ~~~
Mesozoic		Dagua formation	Metamorphic rocks; green schist and graphite schist. Basic igneous rocks diabase, dolerite and so on.

*1 : Slight recognition of hiatus (time gap of sequence seen as unconformity).

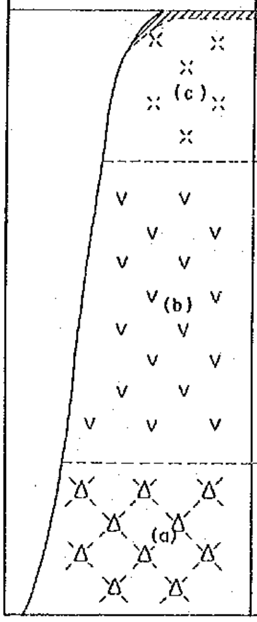
*2 : Between the tuff breccia (Rio Cauca Formation) and andesite lava (Popayan Formation) there are no facts in the survey area which particularly indicate unconformity such as basal conglomerate. Rather, it appears that tuff breccia is of the same geologic age as andesite lava.

The civil structures of this Project will all be provided in the Popayan Formation and the Rio Cauca Formation.

6.2.2 Stratigraphy and Rock Type

The outline of stratigraphy and rock types comprising the Julumito Project Area and the relation between the foundations of civil structures and rock types are given in Table 6-3.

Table 6-3 Outline of Stratigraphic Sequence and Rock Type of Foundation Rock in Civil Structure on Julumito Project

Diagramatic column	Rock type	Thickness*1 (m)	Distribution
	Top soil	less than 10	Wide spread.
	Volcanic ash	30 to 40	Wide spread. Damsite and reservoir area, etc.
	Andesite lava	about 120	Damsite, headrace tunnel route, penstock line, tributary diversion waterway route, etc.
	Tuff breccia		Powerhouse site and vicinity of it.

*1 : data originated from boring DH-1 on the left bank of the Julumito damsite.

The characteristics of the various rock types and the evaluations as foundation rock and materials for civil structures are as described below.

(a) Tuff breccia

This stratum is situated at the lowest part of the geology comprising the Julumito Project Area. This is exposed at the bottom of the valley where the overlying andesite lava is eroded out by the Rio Cauca from the outskirts of Popayan City to the downstream area. Also, according to Core boring DH-1 (vertical, length 160 m) drilled at the vicinity of Julumito dam site in order to investigate the feasibility of the underground powerhouse plan (Plan A) on the left bank, the existence of tuff breccia was recognized at a depth of 143.0 m (EL. 1,585.6 m). From the previously mentioned outcrops and core boring data the boundary between the tuff breccia and the andesite lava is at around EL. 1,585 m and is estimated to be more or less horizontal. The Julumito powerhouse site planned on the right bank of the Rio Cauca is comprised of this rock. This tuff breccia is greenish gray, includes volvanic lapilli of diameters of 3 to 5 cm, is dacitic and is a soft rock easily crushed with hammer blows. The unconfined compressive strengths are from 50 to 100 kg/cm^2. These values are adequate for the foundation of powerhouse.

(b) Andesite lava

This lava is widely and thickly distributed in the Popayan City area and most of the foundations of Julumito dam, and headrace tunnel, are designed to be located in this rock. This rock typically crops out at cliffs on both banks deeply eroded by the Rio Cauca near the powerhouse site. At the outcrops there are several series of prominent cooling joints (columnar joints) indicating that there were several times when lava flows had occurred.

According to data of core boring DH-1, the andesite lava has a thickness of approximately 120 m, and moreover, may be divided into four flows. The three-flows from the bottom are of identical rock characters but the lava at the top is of slightly different character. In effect, the lower three flows are comprised of grayish purple andesite with prominent phenocrysts of feldspar. In contrast, the top flow presents grayish blue, includes biotite and crystals of quartz and indicates a rock character close to liparite.

Between the flows of andesite lava there are intercalated weathered zones of 3 to 4 m thick and thin layers of tuff from which the differences in time of eruption are recognized.

The petrographic descriptions and physical characteristics of these lava flows are described in detail in A-2 (F) of 6.3.2.

This andesite lava is thickly covered by a volcanic ash and the contact is surprisingly flat. In other words, according to the core borings DH-1, DH-2, DH-3 and DH-5 drilled for the purpose of geological investigations of the headrace tunnel route, the surfaces of the andesite were confirmed to be at the elevations of 1,703.2 m, 1.696.8 m, 1,702.0 m and 1,704.3 m respectively, roughly at 1,700 m. However, on tracing the distributed area of volcanic ash, it is seen that it is deposited on the slopes of both banks far lower than the elevation of 1,700 m along tributaries such as the Rio Sate and the Rio Palacé and of course the mainstream Rio Cauca. This indicates that after eruption of the andesite lava and until deposition of volcanic ash, there was the term of erosion occurring to form a relief extremely similar to the present topography.

This geologic phenomenon -erosion and weathering-, as described in 6.3.2 and 6.5.1 and 2, has an important factors related on foundation treatment of the weathered andesite lava at the dam site and in selection of quarry for rockfill materials.

(c) Volcanic ash

This volcanic ash is widely distributed south from Cali City to the vicinity of Timbio City and is clearly ash fall deposits which at the Julumito project area has a thickness of 30 to 40 m. The lowest portion is fairly solidified and there are parts which could be called tuff. The volcanic ash was deposited more or less parallel to the topography existing before the falling of the ash. Although the thickness of the ash has been reduced at rivers and valley, it has remained more or less in the same thickness at hilly area. This ash has been subjected to unique weathering and present a peculiar soil profile. This will be described in detail in the section on the volcanic ash at the dam site (cf. A-2 (e) in 6.3.2). This volcanic ash presents brownish white to milky white in the fresh part. The grain size is so fine that more than 90% passes a No. 200 sieve. In visual observation, fine grains of quartz and scales of biotite are prominent and the material is a liparitic volcanic ash.

6.2.3 Geologic Structure

The geologic structure of Colombia governed by the Andes Orogenic Movement shows a NNE-SSW direction to be very predominant. The Andes Mountain System also runs in the direction of the geologic structure and the Rio Cauca and the Rio Magdalena which flow north originating from the mountain system also follow the geologic structure. As stated in 6.2.1.A, "Topography," the Colombian Andes is divided into the three mountain ranges of Cordillers Oriental, Cordillera Central and Cordillera Occidental. As the ridges of the respective mountain ranges mostly correspond to anticlinal parts, old rocks and formations are distributed, while on the other hand, the valleys which are synclinal are occupied by young formations of the Cenozoic era.

The Colombian Andes is broadly divided into the following two geologic provinces in this Chapter.

(1) Cordillera Oriental Geologic Province

This is mostly made up of sedimentary rocks and there is little new volcanic rock. The mountainsides of the mountain system and valleys (synclines) have distributions of Tertiary and Mesozoic formations. While, the ridges (anticlines) have distributions of Paleozoic formations in zones along the axis in the NNE-SSW direction, but Cretaceous marine deposits are most widely distributed.

This geologic province differs in geology from the main Andes Mountain System of Chile, Bolivia, Peru and Ecuador in which igneous rocks and metamorphic rocks are predominant.

(2) Cordillera Central and Cordillera Occidental Geologic Province

This is mainly comprised of igneous and metamorphic rocks accompanied by sedimentary rocks. These rocks and formations comprise a northward extension of the main Andes Mountain System in Ecuador and to the south, while the northern end of the complex plunges into the northern coastal lowlands near El Blanco. Volcanoes are distributed along the direction of the mountain system and were quite active in the Miocene period, some of which are still active today. Active volcanoes are particularly prominent in the southern part of the Cordillera Central.

Similarly to the Cordillera Oriental Geologic Province, there are distributions of Paleozoic rocks such as acidic to basic plutonic rocks and gneisses at the ridges of the mountain ranges, while in the valleys there are distributions of formations and rocks of the Cenozoic era, and in between, distributions of Mesozoic formations in zones in the direction of the axis of fold.

The project area locates between the Cordillera Central and Cordillera Occidental Geologic Provinces. This area has andesite lava as its basal rock covered thickly by volcanic ash, the boundary appearing to be more or less flat.

As a result of the investigations there were almost no faults found in the project area. It is considered there of course exist no large faults or active faults of scales to endanger the feasibility of the Project.

6.2.4 Earthquake

Colombia is situated on the Circum Pacific Earthquake Belt and active seismicity is recognizable. This seismic activity is limited mostly to the Andes Mountain System and the Pacific Ocean coast. Earthquakes are rare in the eastern Llanos close to Venezuela and Brazil and any that do occur are not severe and this part of the country may be considered as a non-earthquake zone. According to the records of past earthquakes, the locations of epicenters in Colombia may broadly be divided into the following four zone.

Zone - 1 Southern part of Cordillera Central — vicinity of border with Ecuador centered around Pasto City.

Zone - 2 Northern part of Cordillera Oriental — Northern Departamento de Santander and near Táchira State (Venezuela).

Zone - 3 Central and northern part of Cordillera Occidental and Pacific Ocean coast.

Zone - 4 Scattered in northern and eastern parts of Colombia.

The earthquake records[6] which had been kept from 1566 to 1956 are complited by Institute Geofisico de Los Andes Colombianos shown in Appendix IV-7. Of these, those marked with white circles are earthquakes which occurred between 1566 and 1900 and not measured with seismographs, and the scales and epicenters of these were estimated from various old documents. Regarding the records from 1900, which indicated as painted circles, geophysical computations were made based on data from measurements in Colombia and at earthquake observation organs throughout the world.

These earthquakes are classified according to the intensities as given in Table 6-4.

Table 6-4 Classification of Seismic Intensity in Columbia

Intensity	Degree	Correlation with scale of Rossi-Forel	Accelleration-Part of gravity
I	Slight	I II III IV	0 - 0.3 g (0 - 10 gal)
II	Strong	V VI VII	0.03 - 0.05 g (10 - 80 gal)
III	Destructive	VIII IX X	0.05 - (80 gal -)

The Julumito Project Area is outside the four earthquake zones of Colombia mentioned above. In other words, it is 150 to 200 km distant from Zone - 1 and -2 and may be said to be an area with little earthquake occurrence for the Andes Mountain System. The occurrences of earthquakes around the project area based on the record[6] are indicated in Table 6-5.

Table 6-5 Earthquake around the Julumito Project Area

Epicenter *1	Intersity *2	Frequency document	Frequency Scismograph	Occured year
within 50 km	II	2		1751 and 1878
	III	2		1735 and 1736
within 100 km	I	1	1	1556 and 1946 (twice Mar. 29 and 30)
	II	3		1751, 1827, and 1878
	III	3		1735, 1736, and 1884

*1. Centering around the Julumito project area
*2. Classified by Instituto Geofisico de Los Andes Colombianos

As shown in Table 6-4 and Appendix IV-7, earthquakes actually measured are concentrated in the four seismic zones, and around Popayan City there is only one earthquake measured. Nevertheless, the old earthquakes not measured are greater in number. In judging earthquakes from old documents, the records tend to be for areas of population concentrations and in many cases cannot be handled as applicable data, while it is extremely difficult to determine the locations of epicenters. Consequently, in determining the probability of future earthquakes in the Julumito Project Area, whether to make judgments based on earthquakes from 1900 and after or to take earlier earthquakes into consideration poses a problem. Naturally, the fact that an earthquake occurred in the past indicates the possibility of earthquakes occurring at the same site in the future.

If an extremely cautious standpoint is taken here and records of all earthquakes are taken into consideration, the following may be said. From 1560 to the present, there have been two earthquakes of Intensity III in the area within 50 km of the Julumito project area. This is a frequency of once in 200 years. In the area within 100 km, there were three earthquakes of Intensity III which is a rate of once in 130 years. From the above it is thought there is a possibility of earthquake of Intensity III occurring once in 100 years at the project area.

6.3 Main Project

6.3.1 Catchment Area and Reservoir

A. Topography (cf. DWG. NO. 3)

The Julumito reservoir area presents a gently undulated topography and except for the valley bottom is uniformly covered by a thick volcanic ash. Only the main stream of the Rio Sate is eroded down to the andesite lava underlying the volcanic ash.

The original topography before deposition of the volcanic ash appears to have had undulations and to have been similar to the present topography. It is considered that after uniform covering of the volcanic ash in a thickness of 30 to 40 m over the paleorelief, the Rio Sate again eroded approximately the same location to produce the present relief. This can easily be surmised from the condition of deposition of volcanic ash at the upstream and downstream parts of the Rio Sate and the Rio Cauca.

From the topographic features, the reservoir area may be broadly divided into the following two districts:

(1) Upstream Area

In this area the Rio Sate and its tributaries show the parallel drainage pattern running from east to west. The channels in this area indicate very young erosion stage deepening in the direction of gravity on the surface of that time after deposition of the volcanic ash. At these valleys, the catchment areas are small and the eroding agent of the water is small. Moreover, since the geologic components are soft and isotropically homogeneous, the ravines run in the direction of slope and only deepening agent has occurred. As a result, the ravines run at interval of roughly 500 m each other and formed the parallel pattern. Between the adjacent ravines, the flat initial plane has been remained.

In the future, headward erosion should progress in the catchment area, but since the area does not suffer heavily concentrated rainfall, the problem of sedimentation in Julumito Reservoir cannot be thought to be significant.

(2) Middle Stream Area and Dam Site

The topography of this area corresponds to the valley of the paleorelief (the former Rio Sate). In this area, the deepening has reached the weathered surface layer of the andesite lava and comparatively hard rock is exposed at the valley bottoms. The channels have not been subjected to much lateral erosion and there are narrow flood plains and river terraces.

In this area, the tributaries of the Rio Sate have small discharges and since deepening agent in weak the erosion has not reached down to the andesite lava and at the junction with the Rio Sate a small-scale hanging valley is formed.

In the reservoir area the condition calling for the greatest attention is that there are two places at the western part whick are lower than the proposed high water level. The locations are to the southwest of Julumito Village, where tributaries of the Rio Sate and the Rio Cauca have eroded the plateau from both sides. The construction of saddle dams is necessary for this topography, details of which are given in 6.3.2. The ground around the reservoir is comprised of an impermeable volcanic ash and the pass lengths to other catchment basins are great except the above mentioned dike sites. Consequently, it is thought there is no fear of leakage from the reservoir.

B. Geology (cf. DWG. NO. 3)

The greater part of the reservoir area is comprised of a more or less uniform volcanic ash, but andesite lava is distributed at the valley bottom at the dam site and upstream. Regarding the volcanic ash, according to the results of permeability tests conducted at the dam site and the borrow areas, the coefficient of permeability indicates values in the orders of 10^{-4} cm/sec to 10^{-5} cm/sec, on top of which there is a tendency for the permeability to be even smaller when saturated with water (cf. Appendix IV-2). Regarding the andesite lava, according to Lugeon s test carried out utilizing bore holes at the dam site, the value is less than 30 Lugeon. Consequently, it is thought there will be no leakage from the foundation of the reservoir.

The proposed high water surface level (El. 1,715 m) is in the horizon of the volcanic ash where the slope of a gently undulating hill area is presented. The slope is covered with topsoil of 50 m to 1 m thickness on which shrubs and miscellaneous grasses thickly grow. Because of such a topography and geology it is not conceivable that large-scale sliding will occur due to impounding of water.

6.3.2 Julumito Dam and Dikes

A. Julumito Dam Site

A-1. Topography

The Rio Sate flows in a roughly straight line to the northwest at the dam site. The river channel comprises the form of a trough of 7 to 10 m in width and 3 to 5 m in height and both banks extending from the channel comprise relatively steep slopes of 35^{o} to 40^{o} up to around the elevation of 1,700 m and are covered by tall latifoliate trees. From around EL. 1,700 m and above, the slopes become gentle and continue on to the Popayan Plateau of elevation on 1,730 to 1,750 m and is covered with growths of short shrubs and grass.

On the right bank side, there are ravines upstream and downstream of the dam axis and the mountain side between the ravines has few creases and is of a size that the dam can be conveniently accommodated. In contrast, on the left bank side immediately upstream of the dam axis, there is a comparatively large ravine cutting deeply in to EL. 1,690 m from the conjunction with the main stream. There is a series of small waterfalls in this section. Meanwhile, at a point 180 m downstream from the dam axis, the main stream bends sharply and the mountainside on the left bank is eroded by the ravine merging at this bend and by the ravine upstream of the dam and the mountain hulk has become samll. This ridge, when overburden and weathered layers are excavated and removed for construction of dam, is expected to become even smaller. Therefore, it is desirable for the dam axis at the left bank to be located at the upstream ravine considering not only this topographic conditions but also the geologic features described below.

A-2. Geology

The geology of the dam site is comprised in addition andesite lava and volcanic ash, overbuden such as deposits of talus, river terraces, present river and topsoil.

The geology of the dam foundation is mainly the andesite lava. Besides, the volcanic ash is distributed in the higher portion of the dam foundation with a considerable thickness. As a whole the andesite lava has been subjected to strong weathering. The weathering has extended to a considerable depth and parts close to the ground surface have been altered into residual soil. The volcanic ash covering the andesite lava is also weathered from the ground surface and a peculiar weathered profile is presented.

(a) Topsoil

The topsoil is humus of the vegetation growing on the ground surface, and is blackish brown, high in water content and clayey. This naturally must be removed for the dam foundation.

(b) Talus deposit

Distributions are seen at the ravine on the right bank at the upstream end of the dam, the dam foundation at the downstream side of the axis at the left bank and the left bank side of the downstream end of the dam. These deposits are sandy silt and silty clay containing boulders of weathered andesite here and there. The thicknesses are 2 to 3 m and since they are unsolidified they should be excavated and removed.

(c) River deposit

Besides at the bottom of the Rio Sate, deposits can be seen as narrow shoals on the inside of the bent portion. There is a high content of cobbles of weathered andesite having a diameter of 20 to 40 cm and the deposits are densely compacted with sandy silt.

According to the data of core boring DH-203 drilled near the river bed at the left bank of the dam axis, this river deposit has a thickness of approximately 5 m and the surface of the bed rock is 1,637.40 m. in elevation.

However, the thickness of the river deposit at the center line of the stream and the right bank, and the variation in the upstream to downstream direction are unknown.

The deposit has high permeability for the foundation of the impervious core and should be excavated and removed. Also, even the rockfill portion, this deposit is insecure to some extent in regard to bearing power for the dam and there should be a need for considerations to excavate and remove these portions in accordance with the load of the dam.

(d) Terrace deposit

This deposit forms flat areas about 10 m wide at both banks near the upstream end of the dam, the left bank at the dam axis and the right bank at the down-stream end of the dam. These terraces are located 2 to 3 m higher than the river bed and can also be considered as present flood plains. The terrace deposit consists of sand and gravel and as the thicknesses are extremely small (1 to 2 m), they should be removed at the dam foundation.

(e) Volcanic ash

The volcanic ash at the dam site is distributed at about EL. 1,670 m and higher and becomes thicker the higher the elevation. The thickness in the vicinity of the crest at either bank is 15 m on the right bank and 18 m on the left bank.

The volcanic ash has produced a peculiar soil profile due to weathering from the ground surface. Since the proposed high water surface level is 1715 m in elevation, the upper part of the dam would be naturally founded on the volcanic ash.

From results of field investigations, the fresh volcanic ash is thought to have adequate bearing capacity and watertightness for a dam foundation, as described below.

In regard to the volcanic ash, CEDELCA requested the Universidad del Cauca to carry out soil tests. Of the samples, those of interest from the standpoint of pedology were again tested by INGEOMINAS*[1]. Table 6-6 is a soil profile of the Julumito Project area experimentally prepared referring to the field surveys and the test reports[5]. Such a weathering process can also be recognized in the weathered residual soil of the andesite lava (cf. A-2, (f) of 6.3.2) described next.

Geological surveys and field permeability tests were conducted on this volcanic ash by digging test pits of 3 m deep. According to the results of permeability tests (see Appendix IV-6), the coefficient permeability of Layer 2 and 3 of ranges 5.0×10^{-4} cm/sec to 4.0×10^{-5} cm/sec. These test profiles were above the ground water table.

On looking at these permeability test results, it is seen that at the constant head of water the coefficient of permeability becomes smaller than at the start of testing with the elapse of time and after approximately five hours becomes more or less constant. This indicates that the coefficient of permeability becomes smaller as this soil layer becomes saturated with water.

However, since layer II and III are not necessarily judged to be satisfactory from the standpoint of bearing power, these layers should be excavated and removed and the dam foundations selected to be layer IV to VI. Layer IV, V and VI are more solidified than the upper parts and are thought to have smaller coefficient of permeability, but it is desirable for compaction test, Shear test, loading test and permeability test, to be conducted.

(f) Andesite lava

The andesite lava distributed at this site has been strongly affected as a whole by weathering and no fresh parts can be seen at the ground surface. This andesite lava may be divided into three layers from the degrees of weathering.

i. Non-weathered andesite lava,

ii. Weathered andesite lava (presents a bed rock appearance but the component minerals are almost all changed to secondary minerals

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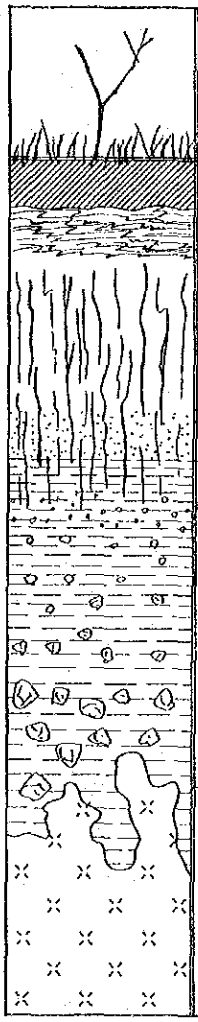
*[1] Instituto Nacional de Investigaciones Geologico Mineras

Table 6-6 Pedological profile of weathering process in volcanic ash



Layer	Explanation	Soil Classification ※5	Technical Judgment: Degree of Compaction	Technical Judgment: Permeability	Remarks
(I)	Blackish brown humus 1m	O			
(II)	Brown leached layer ※1	A_1	loose ↑	more ↑	
(III)	High content of gibbsite ※2 1.5m Yellowish white to grayish white Bauxitic clay layer ※3 2m	A_2			Cf. Appendix IV-6
(IV)	accumulated zone of colloidal material. high content of silica. 0.5m				
(V)	Yellowish white Altered *chiefly kaolinite and halloysite* ※4 ±7m	B_1 to B_2			
(VI)	Non-weathered volcanic ash.	C_1	↓ compact	↓ less	

※ 1. Leaching of sillica (SiO_2)

※ 2. Gibbsite ($Al_2O_3 \cdot 3H_2O$) confirmed by X-ray diffraction and differential thermal curve analysis.

※ 3. Silica-Alumina ratio (SiO_2 / Al_2O_3) = 1

chemical analysis of clay of Unit (III)

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	MgO	P_2O_5	Others	Total
43.00	31.66	10.00	0.64	1.12	0.92	0.09	11.40	98.83%

※ 4. Silica-Alumina ratio = 2

※ 5. U.S. Department of Agriculture (1951) ; Soil survey manual.

by weathering),

iii. Residual soil originating from andesite lava (weathering exceedingly progressed with rock forming minerals changed to clay minerals such as halloysite and kaolinite. The surface layer is comprised or bauxitic clay.

i. Non-weathered andesite lava

Outcrops of this type of bedrock cannot be recognized at the dam site and this rock is barely seen in the core of bore hole DH-204 at 9 m and deeper.

This core is of bluish gray andesite with prominent feldspar and is slightly liparitic. Microscopic observations of this rock are described in Appendix IV-6-3. Biotite is recognizable in the lava even by visual observation and there are numerous phenocrysts of quartz and the characteristics of the rock are more those of dacite or rhyolite. However, the greater part of the groundmass and phenocrysts is plagioclase (albite) and it would be safe to term the rock andesite. In the present survey the term "andesite lava" used as a field name.

ii. Weathered andesite lava

This rock is seen at the Rio Sate banks and at the depths of Exploratory Adits A-2, A-3 and A-4. It is a massive rock of grayish white to milky-white, is weathered and can be said to be a soft rock, but compressive strengths are 100 kg/cm^2 or higher (cf. Specimens No. 16, 17 in Appendix IV-6-2 and 3). This bedrock is thought to have adequate bearing capacity for the foundation of a fill dam of 80 m class, but this should be confirmed by field tests including loading test in future.

At Test Adit A-3 excavated at the right bank of the dam site, springing of water can be seen from open cracks in this weathered andesite. The volume of spring water is about 3 l/min, the water pressure is low and it is thought to be clearly infiltration water from the ground surface (cf. IV-6-1). Also, at Test Adit A-4 at the right bank of the dam site, vertical open cracks similar to those at A-3 are recognized. In the origimal rock of the weathered andesite there can be seen distinct columnar joints and there is a possibility that the beforementioned open cracks are marks of these joints. The scale and condition of this joint system has a relationship with the watertightness of the dam foundation. Therefore, the permeability of the bedrock at the dam site should be investigated over a considerable area through core borings and Lugeon tests utilizing bore holes.

iii. Residual soil originating from andesite lava

The upper part is reddish brown to grayish-brown and is loose. The thickness of the upper part layer according to data from test adits and bore holes is from 3 m to 5 m, and from the degree of compaction and thickness, it should be excavated and removed for the dam foundation.

The bottom part of this layer presents a grayish white to milky white, is coarse grained and is slightly compacted.

The boundary between this residual soil and weathered andesite is distinct at the side walls of trenches and adits, but not always clear at outcrops and in boring cores. It is thought necessary for criteria for judging the strengths as a dam foundation to be provided for the residual soil and weathered andesite in carrying out construction. It is necessary besides field loading test and CBR test, for direct shear test and triaxial shear test on undisturbed samples to be made, and the data studied to be reflected in construction. In particular, since CBR test can readily be performed, it is thought to be effective.

B. Dike Sites

Two dikes will be provided at Julumito Reservoir for the reasons stated in 6.3.1, Catchment Area and Reservoir.

B-1. Dike No. 1 Site (cf. DWG. No. 6)

This site is located where the headwaters of a tributary of the Rio Sate and the headwaters of a tributary ravine of the Rio Cauca are close to each other. The lowest elevation at this site is about 1,690 m and the both sides are gentle slopes continuing up to hills of elevations of around EL. 1,725 m. At both banks near the valley bottom, there are flat areas at elevation of 1,708 m. The widths of those flat areas are 45 m at the right bank and 10 m at the left bank. The river bed section comprises a trough of width of about 10 m.

The geology comprising this site is a volcanic ash covered by oberburden. According to core boring DDH-1 (EL. 1,715.116 m) drilled at this site, there are alternations of sand layers and silty sand layers down to a depth of 16.00 m, while at 16.00 m to 16.30 m, there is found humus thought to be topsoil of an ancient period below which there is a volcanic ash. The deposits shallower than the beforementioned 16 m are distinctly deposits transported by the river and have been subjected to some degree of sorting. The distribution of the deposits cannot be clarified with only field reconnaissance as the ground surface is completely covered by humus. The deposits probably are distributed only at the flat area at EL. 1,708 m, but it is necessary for confirmations to be made through investigations by core boring, test pit and trenching along the dam axis.

Concerning Dike No. 1, the problem of bearing capacity for a foundation is considered in exactly the same manner as for the volcanic ash at the main dam site (cf. 6.3.2. (e)).

The yield point should be clarified in the future for foundation through jack test, consolidation test and triaxial test and permeability test also carried out to provide data for designing.

Further, regarding the problem of piping due to infiltration of stored water, it is thought there would be no severe problem based on the trends or permeability tests carried out at other sites, but this should be ascertained from the following tests. This consideration should be given in exactly the same manner for the No. 2 Dike site.

(i) Measurement of variation in value of coefficient of permeability for time elapsed carrying out permeability tests under triaxially confined conditions corresponding to design load using undisturbed samples.

(ii) Performance of permeability tests in the field by water injection using pressures of about 1.5 times the reservoir water pressure utilizing bore hole to observe the variation in injection quantities in unit periods of time. It is necessary for such tests to be continued for at least six hours at one test section.

From the results of these tests, it is thought that the necessities of treatments for prevention of piping and drainage system should be considered for the downstream side of the dam.

B-2. Dike No. 2 Site

This site is a flat hill area and the ground surface is grazing grassland covered by humus. According to the data of core boring DDH-2 (23 m deep) at the center of the site, there is a volcanic ash under the topsoil of thickness of 1 m, the thickness of the volcanic ash being more then 23 m.

As the height of this dike is low (3 m), problems in regard to the dam foundation are alleviated, compareing with Dike No. 1 Site.

6.3.3 Headrace Tunnel (cf DWG. No. 7)

The geology comprising the headrace tunnel route, except for the vicinity of the intake, is fresh andesite lava.

Weathered andesite and its residual soil are distributed in the vicinity of the intake. The foundation of the intake is at the weathered andesite, but is thought to possess adequate bearing capacity.

The tunnel route passes the top flow of the andesite lava, this flow being grayish blue, slightly coarse grained, and sound. (cf. 6.5.2 Rock Material). The distributions and properties of the andesite lava have been confirmed from core boring of DH-1, DH-2 and DH-3 drilled at the headrace tunnel route.

Judged by the observation of outcrops at both banks of the Rio Cauca and the inspection of the boring core, this through which the tunnel will pass is slightly porous compared with the underlying andesite lava, but is massive and thought to have few cooling joints. In driving the tunnel, it is thought there will be no great problems as it appears and there are no faults along the route. However, during excavation of the tunnel, there is a possibility that breaking may occur at side walls or spring sections due to cooling joints (columnar joints). Also, cooling joints often comprise continuous water bassage. Therefore, depending on the conditions of existence of underground water along the route of the tunnel, there might be occasions when small amount of spring water would be encountered during excavation.

6.3.4 *Surge Tank, Penstock and Powerhouse (cf DWG. No. 7)*

A. Surge Tank and Penstock

The foundation of the bottom part of the surge tank is comprised of andesite lava, but from EL. 1,690 m and above is volcanic ash and it is thought consideration should be given to construction methods such as provisionary lining or inverted lining during excavation.

The penstock is to be located at the right bank of the Rio Cauca where the mountain-side is a steep slope of 40^{0} to 60^{0} and there are broad outcrops of fresh andesite lava. Most of the excavated muck of this fresh bedrock is planned to be used as rockfill material for the dam and it is anticipated that anchor blocks for the penstock can be readily provided on sound andesite lava with adequate bearing power. The andesite lava is comprised of four flows ejected at different times and each flow has its own cooling joint system. Especially, between EL. 1,600 m and 1,650 m, columnar joints are prominent, and at the joint planes tend to separate, caution must be exercised in regard to collapse of the slope during cutting work and to stability of the slope after cutting.

B. Powerhouse Site

B-1. Topography

The powerhouse is located where the Rio Cauca meanders widely to the west. The powerhouse will be on a river terrace of a width of 25 m back of which is the steep cliff of 40^{0} to 60^{0} where the penstock is to be located. A small-scale talus deposit exists at the skirt of the cliff.

B-2. *Geology*

According to the Core Boring DH-4 (EL. 1,585.66 m) drilled at the powerhouse site, a talus deposit of 9.5 m thickness and a terrace deposit of 5.2 m thickness underneath are passed to reach the tuff breccia to be the foundation of the powerhouse. This tuff breccia presents a greenish gray, is coarse grained and has a high content of andesite breccia. This is in the category of soft rock, but as the compressive strength is 50 to 100 kg/cm^2 (cf. IV-6-2.3) and the rock is homogeneous and massive, it is considered to have adequate bearing capacity as the foundation for the proposed powerhouse.