CHAPTER 4 ELECTRIC POWER DEMAND FORECAST

4.1 PRESENT STATE OF ELECTRIC POWER INDUSTRY

4.1.1 ENERGY RESOURCES

Petroleum production in Peru, after completion of a northern pipeline in April 1977 followed by increase at an annual rate of 20%, reached a level of a daily average of 194,000 bbl in 1981.

The confirmed reserves as of 1982 amounted to 900 million bbl, the breakdown of which was 610 million bbl in the eastern jungle area, 90 million bbl in the northern Costa, and 200 million under the continental shelf. These reserves correspond to only a twelve-year supply at the present rate of production, and this is one of the reasons that conversion of thermal power generation to hydro power generation is being hurried.

Other than the above, the reserves of natural gas are estimated to be 35 billion m^3 and reserves of coal 110 million tons, while regarding hydroelectric potential, a West Germany energy survey team listed up approximately 330 sites capable of development economically, and the total output of these is estimated to be approximately 58,000 MW.

4.1.2 ELECTRIC POWER INDUSTRY

The electric power industry in Peru had previously consisted of SEN (Servicio Electrico Nacional) as a national agency supplying electric power to 28 districts in the country. In addition, as publicly-owned undertakings, electric power was being supplied to their respective districts by the Santa, Mantaro, Cuzco, Tacna, and Arequipa corporations, and by various municipalities and small communities.

In 1972, ELECTROPERU S.A. was established and the electric power undertakings of SEN, the various corporations, and other public agencies were all absorbed by ELECTROPERU. Besides the above, there had been 25 privately-owned companies, but now with the exception of Lima Electric Power Co. and several others, they are all being merged into ELECTROPERU.

As for enterprises with private power generating facilities, there are large enterprises engaged in mining and agriculture and numerous small-scale firms existing in various locations throughout the country.

The total power generating facilities in 1981 amounted to 3,300 MW, of which 1,900 MW, 57.6%, consisted of hydroelectric power generation, thermal power being 1,400 MW, 42.4%.

The transitions in total installed capacities by hydro and by thermal are shown in Table 4-1.

Table 4-1 Transitions of Generating Capacity

Unit: MW

Year	1976	1977	1978	1979	1980	1981
Hydro	1,406	1,413	1,409	1,633	1,831	1,918
Thermal	1,110	1,127	1,161	1,280	1,331	1,364
Total	2,516	2,540	2,570	2,913	3,192	3,282

Source: World Energy Statics, 1981

Regarding annual energy production, it reached 10,100 GWh in 1981, which converted to per capita figures, was 553 kWh, to rank at a medium level among Central and South American countries.

ELECTROPERU is the largest supplier of general electric power in Peru, and in 1981 had 1,396 MW, 42.5% of all power generating facilities, the annual energy production being 4,250 GWh, or 40.5%.

The energy sales of ELECTROPERU in 1981 were as shown in Table 4-2.

Table 4-2 Breakdown of Energy Sold of ELECTROPERU in 1981

	Energy Sold (GWh)	Ratio (%)
Major Mine and Industry		
Mining	332.3	7.8
Iron Industry	244.6	5.8
Fertilizer Industry	131.7	3.1
Paper Industry	75.0	1.7
Agriculture	11.0	0.2
Cement Manufactory	10.8	0.2
Fisheries	10.3	0.2
Others	118.8	2.8
Sub-Total	934.5	21.8
Public Use		
Residencial	264.3	6.2
Commercial	72.6	1.7
General	55.8	1.3
Street Lamp	49.3	1.1
Pump	44.0	1.0
Minor Industry	15.6	0.4
Others	8.1	0.2
Sub-Total	509.7	11.9
Loss, Station Service, Inter-connected System	624.0	14.5
Interchange of Electricity		
ELECTROLIMA	1,946.6	45.5
OGEM	99.7	2.3
COSERELEC	94.9	2.2
HIDARANDINA	73.8	1.7
Sub-Total	2,215.0	51.7
TOTAL	4,283.2	100

Source; Informacion Estadistica de ELECTROPERU, 1981

4.2 PRESENT SITUATION IN OBJECT AREA OF ARICOTA NO.3 HYDROELECTRIC POWER SCHEME

4.2.1 SOUTHWEST REGION

The service area of electric power in Peru, as shown in Fig. 4-1, is divided into the seven regions of North Region, North Middle Region, Oriental Region, Central Region, South Middle Region, South East Region, and South West Region.

The Aricota No. 3 Hydroelectric Power Scheme is located at the SPCC-Aricota Power System in the South West Region, and the service area to be the object of this Project will be that of the SPCC-Aricota System.

The electric power systems of the South West Region may be divided into the Arequipa-Cerro Verde System, SPCC-Aricota System, and Puno-Juliaca System, which at present respectively comprise independent systems.

Meanwhile, in the South West Region, there had been the Arequipa-Toquepala Interconnecting Transmission Line Project (scheduled for completion in 1983) planned for interconnection of the Arequipa-Cerro Verde System and the SPCC-Aricota System, but for reasons of such as difficulty in procuring funds, construction had not yet been started as of August 1983.

The energy production by region of ELECTROPERU in 1982 and the installed capacities are shown in Table 4-3, and the breakdown of the energy sales of the South West Region in Table 4-4.

Fig. 4-1 SERVICE AREA

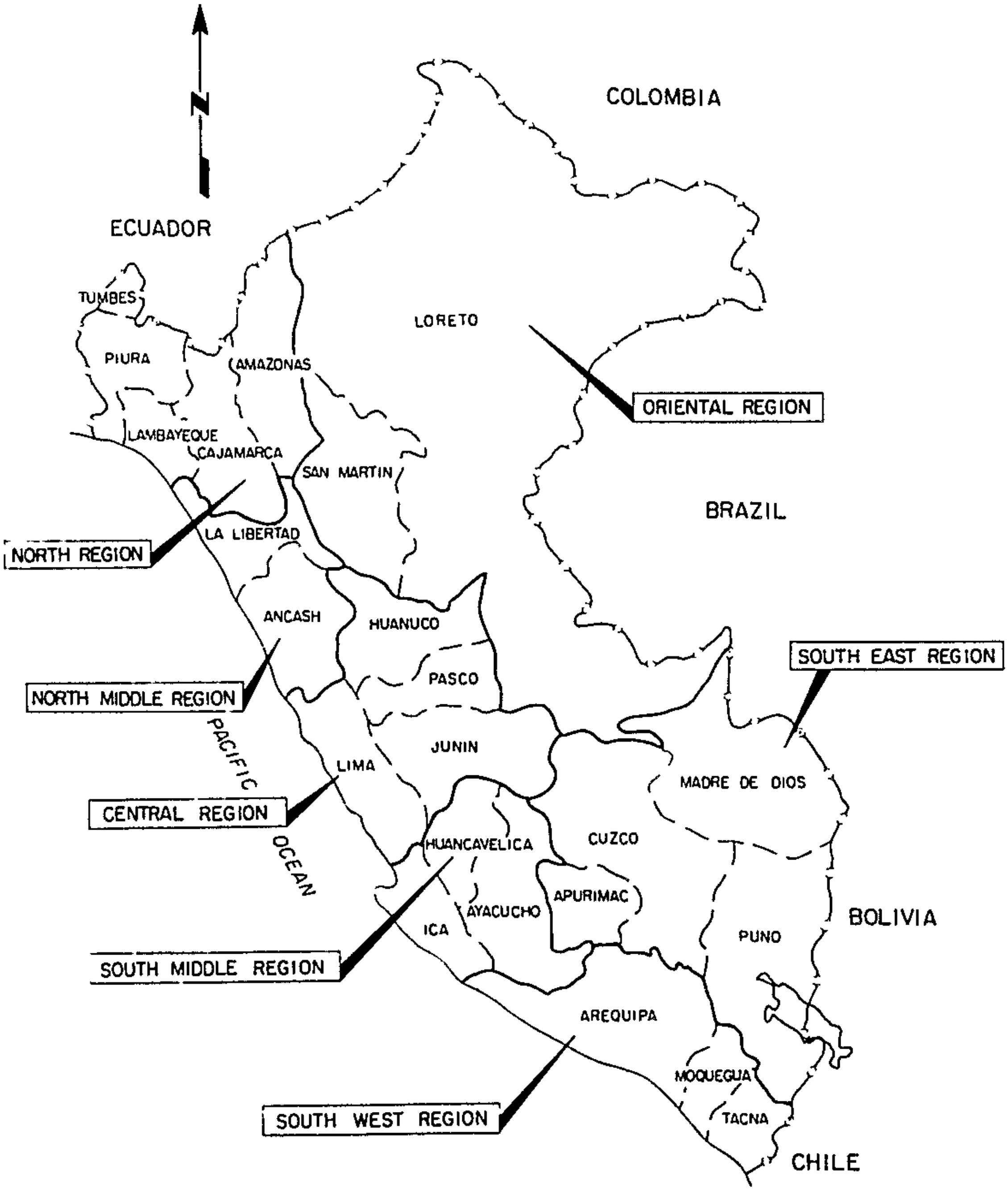


Table 4-3 Energy Production and Installed Capacity of ELECTROPERU in 1982

Region	Type	Energy Production (GWh)	(%)	Installed Capacity (MW)	(%)
North and North middle	Hydro	615.2		157.8	
	thermal	178.5		193.6	
	Sub-total	793.7	17.1	351.4	25.0
Central and South middle	Hydro	3,214.4		811.0	
	thermal	56.4		54.4	
	Sub-total	3,270.8	70.6	865.4	61.4
South east	Hydro	196.5		45.1	
	thermal	39.1		35.8	
	Sub-total	235.6	5.1	80.9	5.7
Oriental	Hydro	-		-	
	thermal	141.8		63.3	
	Sub-total	141.8	3.0	63.3	4.5
South west	Hydro	178.2		36.2	
	thermal	14.5		11.2	
	Sub-total	192.7	4.2	47.4	3.4
Total	Hydro	4,204.3		1,050.1	
	thermal	430.3		358.3	
	total	4,634.6	100	1,408.4	100

Source: ELECTROPERU: GERENCIA DE OPERACION

Table 4-4 Breakdown of Energy Sold of South West Region in 1982

Item	Energy Sold (GWh)	Rate (%)
Public Use		
Street Lamp	6.01	4.2
Residencial	30.60	21.3
Minor Industry	1.06	0.7
Commercial	6.29	4.4
General	6.86	4.8
Pump	14.86	10.3
Sub-total	65.68	45.7
Major Industry	78.18	54.3
Total	143.86	100

Source: GRENCIA DE DISTRIBUCION COMMERCIALIZATION
by ELECTROPERU

4.2.2 SPCC-ARICOTA SYSTEM

The SPCC-Aricota System, from its electric power supply set-up, can be divided into the SPCC System supplied by privately-operated power generation facilities owned by Southern Peru Copper Corporation (SPCC) which is an enterprise established with U.S. capital, and the Aricota System being supplied with electric power by ELECTROPERU.

Although power interchange is being done between the SPCC and Aricota power systems, fundamentally, the present situation is that the demands of the respective systems are being supplied by their own power generating facilities.

The power generating facilities of the SPCC-Aricota System in 1983 were shown in Table 4-5, and the total effective installed capacity was 145.2 MW. Of this capacity, the power generating facilities owned by ELECTROPERU consist of Aricota No. 1 Power Station and Aricota No. 2 Power Station, totalling 35.7 MW.

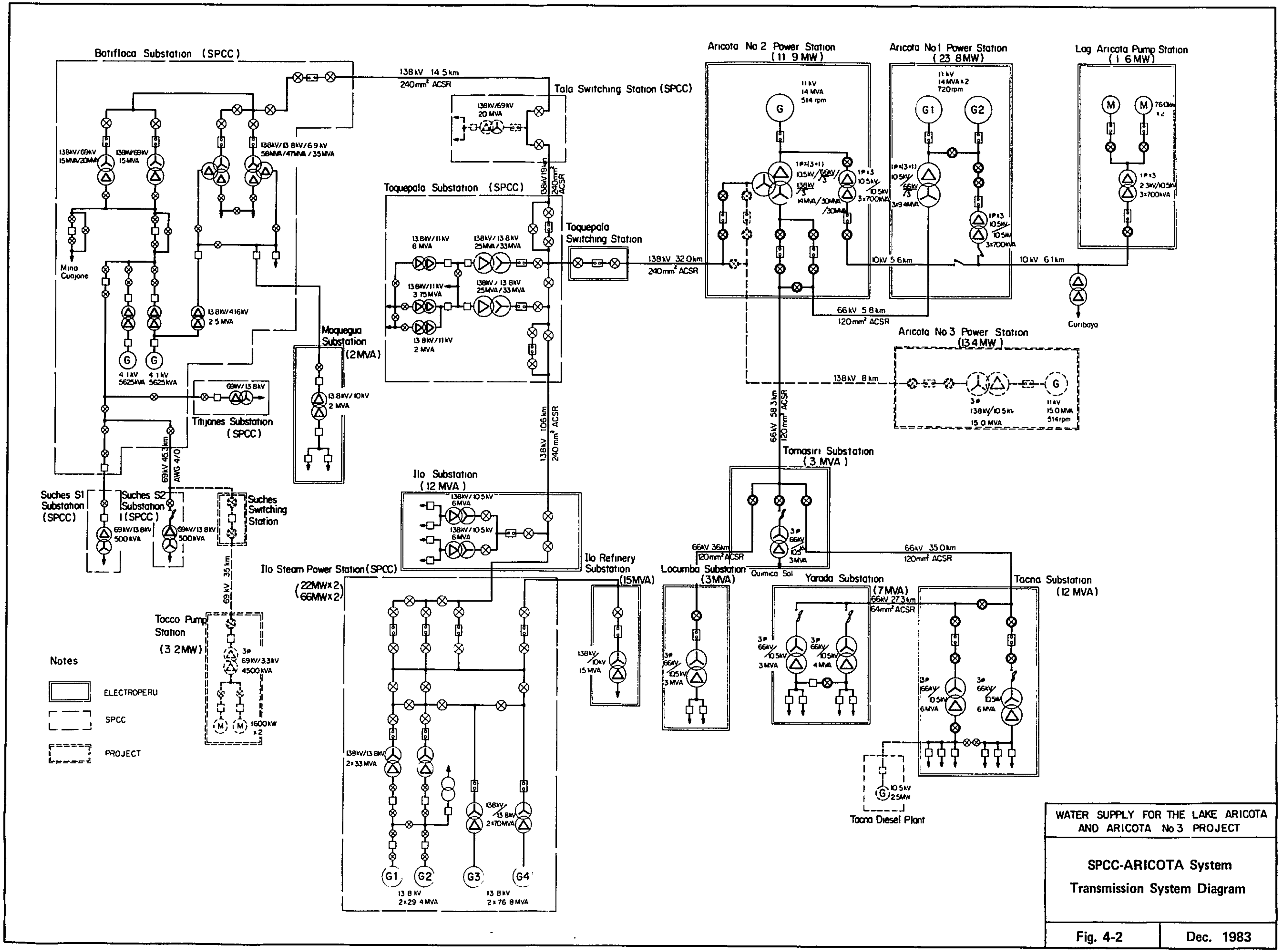
Table 4-5 Generating Facilities of SPCC-Aricota System

Power Station	Type	Unit x installed capacity (MW)	Effective output (MW)	Commence-ment	Fabricator	Owner
Aricota No. 1	Hydro	2 x 11.9	23.8	1966	Toshiba	ELECTROPERU
Aricota No. 2	Hydro	1 x 11.9	11.9	1967	Fuji	"
Ilo	Thermal	2 x 22 2 x 66	105	1959 1970,1979	BB GE	SPCC "
Botiflaca	Hydro	1 x 4.5	4.5	1978	GE	"
Rumipunco	Hydro	1 x 4.5		1978	GE	"
*Toquepala	Diesel	5 x 1	-	1959	-	"

* Diesel plant of Toquepala is for emergency use and then it is not usually operated.

Next, the actual energy productions and maximum demands from 1971 to 1982 in the service area of this Project are shown in Table 4-6 and Table 4-7. The maximum demand of the Aricota System in 1982 was 30.75 MW, the annual energy production 147.05 GWh, and the load factor 54.6%.

Transmission diagram in SPCC-Aricota system is shown in Fig. 4-2.



WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT

SPCC-ARICOTA System Transmission System Diagram

Fig. 4-2 Dec. 1983

Table 4-6 Energy Demand of SPCC-Aricota System

Unit: GWh

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Increase (%)
Aricota System													
Tacna Substation	9.65	11.14	12.63	14.03	16.60	19.67	21.16	22.92	23.90	27.11	30.88	34.00	12.1
Yarada Substation	-	-	-	6.94	7.69	8.56	9.88	10.14	13.08	19.56	21.60	21.22	15.0
Locumba Substation					1.02	3.58	7.25	9.09	9.54	9.03	9.12	10.27	19.2
Tomasiri Substation					0.34	0.26	0.23	0.30	0.30	0.42	0.42	0.46	4.4
(Tacna System Total)	(9.65)	(11.14)	(12.63)	(20.97)	(25.65)	(32.07)	(38.52)	(42.45)	(46.82)	(56.12)	(62.02)	(65.95)	(19.1)
Ilo Substation	13.85	15.20	9.51	14.24	12.46	13.67	10.85	14.35	16.35	18.54	22.99	17.65	2.2
Copper Refinery Substation					10.54	39.42	50.63	46.75	51.00	51.89	48.92	54.54	5.6
Moquegua Substation				-	3.69	4.62	6.01	6.13	6.62	7.36	7.72	8.91	11.6
(Ilo System Total)	(13.85)	(15.20)	(9.51)	(14.24)	(26.69)	(57.71)	(67.49)	(67.23)	(73.97)	(77.79)	(79.63)	(81.10)	(17.4)
Aricota System Total	23.50	26.34	22.14	35.21	52.34	89.78	106.01	109.68	120.79	133.91	141.65	147.05	18.1
SPCC System Total	-	-	-	-	-	416.29	649.17	647.35	649.06	656.96	609.49	677.98	8.5
Total	-	-	-	-		506.07	755.18	757.03	769.85	790.87	751.14	825.03	8.5

Table 4-7 Maximum Power Demand of SPCC - Aricota System

Unit: MW

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Increase (%)
Aricota System													
Tacna Substation	2.18	2.42	2.87	3.09	3.87	4.02	4.46	4.74	6.48	6.74	7.70	8.70	13.4
Yarada Substation	1.13	1.23	-	1.97	1.87	1.97	2.05	2.15	2.79	3.62	4.60	4.14	12.5
Locumba Substation					-	0.85	0.99	1.64	1.19	1.90	1.90	1.60	11.1
Tomasiri Substation					-	0.25	0.53	0.53	0.53	0.53	0.53	0.53	0
(Tacna System Total)	(3.31)	(3.65)	(2.87)	(5.06)	(5.74)	(7.09)	(8.03)	(9.06)	(10.99)	(12.79)	(14.73)	(14.97)	(14.7)
Ilo Substation	5.20	5.80	5.80	5.20	4.95	4.80	4.50	5.00	5.20	5.30	6.70	6.00	1.3
Copper Refinery Substation					-	6.80	7.90	7.81	7.20	7.20	7.20	7.38	1.4
Moquegua Substation				1.06	-	1.20	1.80	1.75	1.80	1.95	2.20	2.40	12.2
(Ilo System Total)	(5.20)	(5.80)	(5.80)	(6.26)	(4.95)	(12.80)	(14.20)	(14.56)	(14.20)	(14.45)	(16.10)	(15.78)	(10.6)
Aricota System Total	8.51	9.45	8.67	11.32	10.69	19.89	22.23	23.62	25.19	27.24	30.83	30.75	12.4
L. F (%)						51.5	54.4	53.0	54.7	56.1	52.4	54.6	
SPCC System Total	-	-	-	-	-	88.0	111.0	106.0	106.0	117.0	110.0	106.0	3.2
Total	-	-	-	-	-	107.89	133.23	129.62	131.19	144.24	140.83	136.75	4.0
L. F (%)	-	-	-	-	-	53.5	64.7	66.5	67.0	62.3	60.9	68.9	

4.2.3 SERVICE AREA

(1) Tacna District

The population of Departamento de Tacna in 1981 was 130,000. The city of Tacna is the capital of the department, and is the largest load center. Supply of electric power to this district is through distribution from Tacna Substation. The capacity of Tacna Substation was increased in 1979 by one bank of transformers of 6 MVA, for a total installed capacity of two banks, 12 MVA. The electric power demand in 1982 was maximum demand of 8.7 MW, and the annual energy of 34 GWh, and the growth rates in the 11-year period from 1971 to 1982 were annual rates of 13.4% for maximum demand and 12.1% for electric energy.

This district is being supplied by a transmission line of 66 kV, 1 cct, 120 m^2 ACSR, 94 km from Aricota No. 2 Power Station to Tacna Substation. The total of the maximum demands of Tacna, Yarada, Tomasiri, and Locumba Substations was 15 MW in 1982. In step with such increases in demand, there is a necessity for a reactive power equipment (condenser) to be provided at Tacna Substaiton for maintaining transmission line voltage and alleviating transmission losses, and plans for this have already been made by ELECTROPERU.

Meanwhile, in order to meet the future growth in power demand in the Tacna district, a plan has been made by ELECTROPERU for construction of a Calana Substation in the Tacna district with a transmission line of 138 kV, and legnth of 102.5 km between Aricota No. 2 Power Station and Calana Substation, and a study on this has already been completed.

(2) Yarada District

The power demand in the Yarada district mainly consists of the pump load for pumping up groundwater to irrigate farmland. The maximum demand in 1979 was 2,790 kW, and annual energy consumption was 13.08 GWh. In 1982, the cultivated land area had reached 3,200 ha, maximum demand 4,140 kW, and annual energy consumption 21.22 GWh. Because of this growth in power demand, one transformer bank, 4 MVA, was added to the facilities of Yarada Substation, and the total installed capacity became 7 MVA.

The growth rates in power demand during the 11 years from 1971 to 1982 were 12.5% annually in maximum demand and 15% annually in energy consumption. However, it is thought that hereafter as the water level is lowered, it will become necessary to secure irrigation water for the cultivated land by increasing pump capacities and it is expected that power demand increases in response to this situation.

(3) Locumba District and Tomasiri District

Locumba Substation and Tomasiri Substation were constructed in 1975. Tomasiri Substation was previously a switchyard, but in order to meet an industrial load caused by the development of factories and the general loads of the surrounding area, a transformer capacity of 3 MVA was installed. Accompanying electrification of the Locumba district, transmission line of a 66 kV, 1 cct, 36 km was newly constructed from Tomasiri Substation, and a transformer bank of capcity of 3 MVA was installed to supply electric power to meet general loads of this district.

The growth in power demand during the 6-year period from 1976 to 1982 was at an annual rate of 11.1% in terms of maximum demand, and annually 19.2% in terms of energy consumption. In the Tomasiri district there is hardly any growth in maximum demand, but there is an annual growth of 4.4% in energy consumption.

(4) Ilo Distrit, Copper Refinery and Moquegua District

The power demand in the Ilo district consists of residential lighting loads in Ilo city and fishing industry loads. The copper refinery was constructed by Peruvian Government in 1975 adjacent to Ilo Thermal Power Station of SPCC, which is an electric copper refining plant for processing anode copper of SPCC facility at Ilo. The electric power demand in the Moquegua district mainly consists of the residential lighting load in Moquegua city. These three districts are all located the inside area of the SPCC System, with the Ilo district and the copper refinery supplied by a 138 kV transmission line of SPCC, and the Moquegua district by a 13.8 kV transmission line from Botiflaca Substation of SPCC, but the responsibility for supplying electric power rests with ELECTROPERU. For this purpose ELECTROPERU is transmitting from the Aricota System electric power to SPCC equivalent to the electric energy supplied to these districts by SPCC, through a 138 kV transmission line between Aricota No. 2 Power Station and Toquepala substation, and this power interchange is adjusted at Toquepala Substation in a manner that the electric energy amounts of the two will be mutually balanced.

The growth in power demand at the Ilo district during the 11-year period of 1971 to 1982 was at annual rates of 1.3% in terms of maximum demand and 2.2% in terms of energy consumption. The growth at the copper refinery during the 6-year period from 1976 to 1982 was at annual rates of 1.4% in terms of maximum demand and 5.6% in terms of energy consumption. The annual growth rates in the Moquegua district were 12.2% in maximum demand and 11.6% in energy consumption.

(5) SPCC System

SPCC is a U.S.-capital enterprise engaged in development of Toquepala Mine and Cuajone Mine which meets its power demands through private generation at Ilo Thermal Power Station and two hydroelectric power plants. The installed capacity of Ilo Thermal Power Station consists of two 22 MW generators and two 66 MW generators, or a total of four generators for 176 MW, but the output at present is restricted to 105 MW because of the capacities of steam generating facilities of boilers. The two hydroelectric power plants of Botiflaca and Rumipunco in the vicinity of the Cuajone Mine have installed capacities totalling 9 MW with two units, but operation is restricted to 4.5 MW or one half because of reutilization of water used at the mine. As for the Toquepala Mine, it has generating facilities of 5 MW with five 1,000 kW diesel generators, but these are antiquated facilities which started operation in 1959 and are now used only in emergencies.

The SPCC System was interconnected with the Aricota System in 1967 by a 138 kV, 1 cct transmission line between Toquepala Substation and Aricota No. 2 Power Station, and as described in (4) above, power demands at the Ilo district, the copper refinery, and the Moquegua district in the SPCC System service area are being supplied from ELECTROPERU through a 138 kV transmission line of SPCC. Also, power interchanges are carried out between the Aricota and SPCC systems at times of faulting or during inspections, and adjustments are made so that interchange quantities will be balanced on an annual basis.

The proportion of the power demand of the SPCC System in SPCC-Aricota system in 1982 was 77.5% in terms of maximum demand

and 82.2% in terms of annual energy consumption.

4.3 ELECTRIC POWER DEMAND FORECAST

4.3.1 BASIC CONDITIONS

For making a load forecast in concrete terms, in view of the features of the power systems in the object area already mentioned, it was decided to consider only the SPCC-Aricota System, one of the systems being operated independently in the South West Region.

Further, since the two subsystems of the SPCC-Aricota System, or the Aricota System and the SPCC System, are meeting their respective demands with their own power generating facilities, the loads to be considered in the electric power demand forecast for this Project are those of Tacna city and vicinity, Ilo city Moquegua city, and the copper refinery at Ilo which comprise the service area of the Aricota System of ELECTROPERU.

The scale of the demand in this service area is a small one which was a maximum of 30 MW as of 1982. With such a situation, attention should be paid to the fact that power demand would be influenced greatly by local economic policies such as regional electrification programs and commissioning of individual projects. On performing analyses based on the records of actual demand in 1971 through 1982, and the results of investigations of actual situations in the field, it is judged that the most recent load forecast made by ELECTROPERU (Ref. 3) is quite reasonable, and this can be adopted as data for the load forecast.

4.3.2 DATA INVESTIGATED AND PERIOD OF FORECAST

Regarding the electric power demand forecast for the project area, ELECTROPERU has analyzed on several occasions in the past, and evaluated actual performances in power demand and made forecasts of future loads.

(Ref. 1) Planeamiento del Sistema Electrica Interconectado Sur Oeste

Periodo: 1981 - 1990
November , 1981

(Ref. 2) Sistema: Sur Oeste

Mensaje: Energia (GWh) Plan Maestro D.G.E./D.D.E.
Potencia (MW) Plan Maestro D.G.E./D.D.E.

Periodo: 1982 - 2006
10/2/1983

(Ref. 3) Sistema: Sur Oeste

Mensaje: Energia (GWh) Plan Maestro D.G.E./D.D.E.
Potencia (MW) Plan Maestro D.G.E./D.D.E.

Periodo: 1983 - 2007
29/4/1983

The Survey Mission, during the Third Field Investigations of August 1983, obtained the latest data (Ref. 3) reviewing the electric power demand forecast for the South West Region from the Planning Department of ELECTROPERU. These data review the growth in power demand in the South West Region considering the economic situations in recent years, grasp the actual states of demand and supply at the various load centers, and take into account load forecasts based on local electrification programs and individual agricultural or industrial projects, and the period of forecast is from 1983 to 2007.

Here, the period of load forecast was taken to be the 15 years from 1983 to 1998. The reason for adopting this period was that it was judged 10 to 15 years which are lengths for short-range load forecasts would be reasonable as the forecast period since the scale of this Project is small, and start-up of the interconnecting transmission line project between the Arequipa-Cerro Verde System and the SPCC-Aricota System cannot be considered because of the delay in construction, and that even if Aricota No. 3 Power Station were to be added, it would be necessary for a new power source to be commissioned in 1993.

The electric power demand forecast data for the South West Region prepared by ELECTROPERU (Ref. 3) and the power demand data for the service area of the Project are given in Appendix IV.

4.3.3 LOAD FORECAST

The method of forecasting power demand is as described in 4.3.1. The results of comparisons of the growth rates in actual demands in the past and in forecasts for the service area of this Project are shown in Table 4-8.

Table 4-8 Comparison of Demand Growth Rate of Aricota System

	Past (%)		Forecast (%)	
	1971-1982 (11 years)	1977-1982 (5 years)	1983-1988 (5 years)	1983-1998 (15 years)
Maximum Demand (MW)				
Tacna System	14.7	13.3	6.0	5.7
Ilo System	10.6	2.1	4.5	5.3
Total	12.4	6.7	5.2	5.5
Energy (GWH)				
Tacna System	19.1	11.4	5.9	6.1
Ilo System	17.4	3.7	3.7	5.4
Total	18.1	6.8	4.7	5.7

The above-mentioned results of growth rates show large increases of 12.4% annually in maximum demand and 18.1% annually in energy consumption during the 11 years from 1971 to 1982. However, on looking at the most recent 5-year period, the growth rates are lower, being 6.7% annually in maximum demand, and 6.8% annually in energy consumption. The forecast values of ELECTROPERU are 5.2% annually in maximum demand and 4.7% annually in energy for the 5-year period from 1983 to 1988, and 5.5% annually in maximum demand and 5.7% annually in energy for the 15-year period from 1983 to 1998, and these may be judged reasonable assuming that the economic situation will not change greatly in consideration of the actual growth rates of the most recent 5 years.

Regarding the maximum demand obtained as the forecast value, since the value of maximum demand in the load forecast of ELECTROPERU is the sum of the maximum demands at substations in the various districts, this sum divided by the diversity factors of the performance of the Aricota System during the 5 years from 1978 to 1982 (sum of individual maximum demands/synthetic maximum demand by month) were taken as maximum demands and shown in Table 4-9.

Table 4-9 Power Demand Forecast for Aricota System

Year	Tacna System Maximum Demand (MW)	Tacna System Energy (GWh)	Ilo system Maximum Demand (MW)	Ilo system Energy (GWh)	Maximum Demand (a) (MW)	Maximum Demand (b) (MW)	Energy (GWh)	Annual L. F (%)	Diversity Factor (a)/(b) (%)	
1971	3.31	9.65	5.20	13.85	8.51					
72	3.65	11.14	5.80	15.20	9.45					
73	2.87	12.63	5.80	9.51	8.67					
74	5.06	20.97	6.25	14.24	11.32					
75	5.74	25.65	4.95	26.69	10.69					
76	7.09	32.07	12.80	57.71	19.89					
77	8.03	38.52	14.20	67.49	22.23					
78	9.06	42.45	14.56	67.23	23.62	21.78	109.68	57.5	108.4	
79	10.99	46.82	14.20	73.97	25.19	23.17	120.79	59.5	108.7	Mean
1980	12.79	56.12	14.45	77.79	27.24	23.82	133.91	64.2	114.4	Diversity
81	14.73	62.02	16.10	79.63	30.83	29.28	141.65	55.2	105.3	Factor
82	14.97	65.95	15.78	81.10	30.75	28.89	147.05	58.1	106.4	= 108.6(%)
83	16.2	70.8	17.6	88.2	33.8	31.1	159.0	58.4	108.6	
84	17.1	75.1	18.2	90.3	35.3	32.5	165.4	58.1	108.6	
85	18.5	80.5	18.9	92.6	37.4	34.4	173.1	57.4	108.6	
86	19.5	85.2	19.5	94.8	39.0	35.9	180.0	57.2	108.6	
87	20.6	90.3	20.2	97.2	40.8	37.6	187.5	56.9	108.6	
88	21.7	94.4	21.9	106.0	43.6	40.1	200.4	57.0	108.6	
89	22.6	98.4	23.3	113.7	45.8	44.5	221.1	57.2	108.6	
1990	23.5	102.7	24.8	121.0	48.3	44.5	223.7	57.4	108.6	
91	24.5	107.4	25.5	124.6	50.0	46.0	232.0	57.6	108.6	
92	25.6	112.1	26.1	127.1	51.7	47.6	239.2	57.4	108.6	
93	27.4	122.1	28.2	139.4	55.6	51.2	261.51	58.3	108.6	
94	29.4	131.4	30.1	149.4	59.5	54.8	280.8	58.5	108.6	
95	31.1	141.0	31.9	159.9	63.0	58.0	300.9	59.2	108.6	
96	33.0	151.0	34.0	170.8	67.0	61.7	321.8	59.5	108.6	
97	35.1	161.5	36.2	182.0	71.3	65.7	343.5	59.7	108.6	
98	37.2	172.3	38.2	193.8	75.4	69.4	366.1	60.2	108.6	

4.3.4 DEMAND AND SUPPLY BALANCE

A study of the demand and supply balance of the Aricota System when Aricota No. 3 Power Station is developed was made based on the following conditions:

(1) Regarding the total output of the Aricota No. 1 and No. 2 power stations, it will be possible for operation at maximum output of 35.7 MW to be done in the future as a result of the water supply scheme.

(2) A diesel power station is at present being constructed in the vicinity of Tacna Substation, with one 2.5 MW diesel generator scheduled to be commissioned in November 1983, and this is to be incorporated in the demand and supply balance. Further, in view of demand and supply balance, addition of one more unit of 2.5 MW in 1986 is considered.

(3) Operation of Aricota No. 3 Power Station, is to be started in December 1987, considering the work period, and the output of 13.4 MW is to be considered.

(4) The electric power of Aricota No. 3 Power Station will be transmitted to Aricota No. 2 Power Station by a 138 kV, 1 cct transmission line and, from there it will be transmitted to the Tacna System by a 66 kV, 1 cct transmission line, and to the Ilo System by a 138 kV, 1 cct transmission line. However, at the time that the transmission capacity of the 66 kV line becomes exceeded because of increase in the power demand of the Tacna System, a new 138 kV, 1 cct transmission line is to be constructed at the Tacna district (Calana Substation) in order to cope with the increase in power demand of the Tacna System.

(5) The water pump-up facilities with installed capacity of 1.6 MW at laguna Aricota, are also to be operated in the future

for securing water to be used at the Aricota No. 1, No. 2 and No. 3 power stations. Further, from July 1987, the electric power for the water pump-up facilities with installed capacity of 3.2 MW constructed at Tocco Dam in accordance with the water supply scheme is also to be supplied from the Aricota System, and this is to be deductred from the supply capability.

(6) From 1993, there will be a shortage in power supply capability because of increase in the power demand of the Aricota System, and it was assumed that the No. 1 power station with output of 4MW will be completed in 1993, the No. 2 power station with output of 7.1 MW in 1994, and further, the No. 3 power station with output of 19.2 MW in 1996 of the No. 1 to No. 5 power stations planned by CORDETACNA in comprehensive development of the Rio Villavillane. The particulars of the power stations planned on the Río Villavillanes are as follows.

	Effective Head (m)	Available Discharge (m^3/sec)	Power Station Output (MW)
No. 1 PS	201	2.5	4
No. 2 PS	350	2.5	7.1
No. 3 PS	950	2.5	19.2
No. 4 PS	393	2.5	8
No. 5 PS	408	2.5	8.3

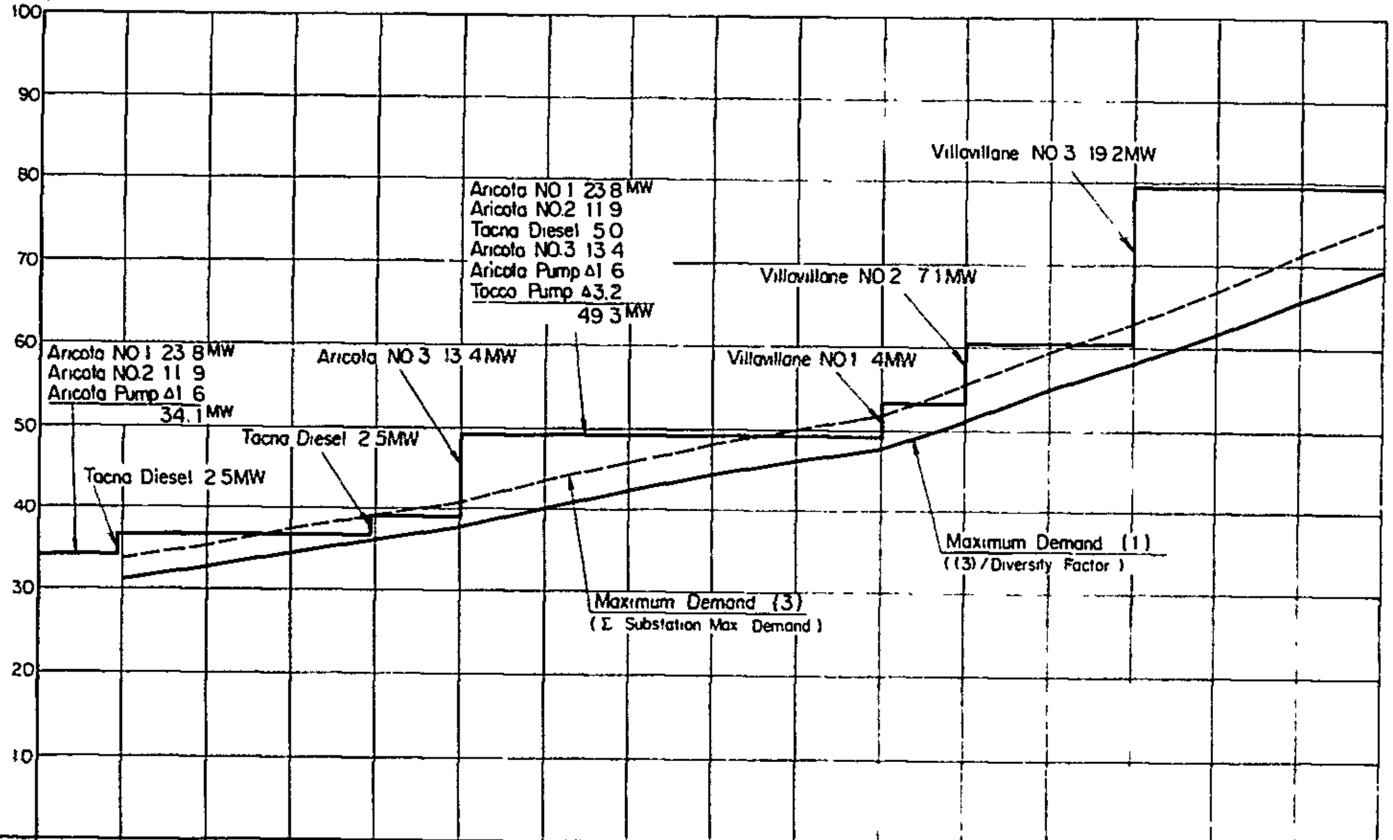
With the above as the basis, the demand and supply balance calculated will be as shown in Table 4-10 and Fig. 4-2, and from 1988 to 1992 a balance between demand and supply can be achieved with the Aricota No. 3 Power Station Scheme . As for the period after 1992, although plans are to be made in accordance with the progress made in the interconnected power transmission plan for the SPCC-Aricota system and the Arequipa system, it was assumed here that the No. 1, No. 2 and No. 3 power stations in line with the Rio Villavillane Comprehensive Development Plan would be completed in 1993, 1994, and 1996, respectively, for meeting power demands up to 1998.

Table 4-10 Demand and Supply Balance of Aricota System

Year	Maximum Demand (MW) (1)	L. F (%)	Project (MW)	Installed Capacity Hydro (MW)	Installed Capacity Diesel (MW)	Installed Capacity Accumulated (MW)	Maximum Available Capacity (MW) (2)	Balance (MW) (2) - (1)
1983	31.1	58.4		35.7		35.7	34.1	3.0
84	32.5	58.1	2.5 2.5x1*1	35.7	2.5	38.2	36.6	4.1
85	34.4	57.4	0	35.7	2.5	38.2	36.6	2.2
86	35.9	57.2	2.5 2.5x1*2	35.7	5.0	40.7	39.1	3.2
87	37.6	56.9	0	35.7	5.0	40.7	39.1	1.5
88	40.1	57.0	13.4 13.4x1*3	49.1	5.0	54.1	49.3	9.2
89	42.3	57.2	0	49.1	5.0	54.1	49.3	7.0
90	44.5	57.4	0	49.1	5.0	54.1	49.3	4.8
91	46.0	57.6	0	49.1	5.0	54.1	49.3	3.3
92	47.6	57.4	0	49.1	5.0	54.1	49.3	1.7
93	51.2	58.3	4 4x1*4	53.1	5.0	58.7	53.3	2.1
94	54.8	58.5	7.1 7.1x1*5	60.2	5.0	65.2	60.4	5.6
95	58.0	59.2	0	60.2	5.0	65.2	60.4	2.4
96	61.71	59.5	19.2 19.2x1*6	79.4	5.0	84.4	79.6	17.9
97	65.7	59.7	0	79.4	5.0	84.4	79.6	13.9
98	69.4	60.2	0	79.4	5.0	84.4	79.6	10.2

Note -
*1: Commissioning of Tacna Diesel Plant
*2 Expansion of Tacna Diesel Plant
*3: Commissioning of Aricota No. 3
*4: Commissioning of Villavillane No. 1 PS
*5: Commissioning of Villavillane No. 2 PS
*6: Commissioning of Villavillane No. 3 PS

Fig. 4-3 Estimated Demand and Installed Capacity in Aricota System



Year		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Maximum Demand (1) (MW)		31.1	32.5	34.4	35.9	37.6	40.1	42.3	44.5	46.0	47.6	51.2	54.8	58.0	61.7	65.7	69.4
Installed Capacity (MW)		35.7	38.2	38.2	40.7	40.7	54.1	54.1	54.1	54.1	54.1	58.1	65.2	65.2	84.4	84.4	84.4
Maximum Available Capacity (2) (MW)		34.1	36.6	36.6	39.1	39.1	49.3	49.3	49.3	49.3	49.3	53.3	60.4	60.4	79.6	79.6	79.6
Balance (MW)	(2)-(1)	3.0	4.1	2.2	3.2	1.5	9.2	7.0	4.8	3.3	1.7	2.1	5.6	2.4	7.9	13.9	10.2
	(2)-(3)	0.3	1.3	-0.8	0.1	-1.7	5.7	3.4	1.0	-0.7	-2.4	-2.3	0.9	-2.6	2.6	8.3	4.2
Maximum Demand (3) (MW)		33.8	35.3	37.4	39.0	40.8	43.6	45.9	48.3	50.0	51.7	55.6	59.5	63.0	67.0	71.3	75.4

CHAPTER 5

METEOROLOGY AND HYDROLOGY OF BASINS

CHAPTER 5 METEOROLOGY AND HYDROLOGY OF BASINS

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 5 METEOROLOGY AND HYDROLOGY OF BASINS

5.1 BASIC CONSIDERATIONS

The hydrological data required for this Project are the runoff data to be utilized so as to calculate quantity of water intake availabe for the water supply scheme and runoff discharge availabe for the power generation, flood discharge data necessary for the designing of civil structures such as dam, and data on water quality related to environmental assesment in connection with dilution and drainage of Laguna Loriscota.

The Survey Mission carried out a selection of the data obtained, prior to arrangement of the above hydrological data, and fundamental analyses were performed on these observation data.

For computing the runoff at the individual intake sites, it was endeavored to adopt measured records as much as possible, but since hydrological data were nil for the Loriscota Basin, upon considering the topographical characteristics of this basin, the inflow was computed from the viewpoint of water budget using the data of neighboring observation stations in the surroundings.

Regarding the Aricota basin, water budget calculations were made concerning the period for which inflow and outflow data were fully available, and the relation between water level and seepage was obtained. The period of 1974 and thereafter for which there are no inflow data, inflow was calculated based on outflow data and lake water level.

Basic hydrological data required for flood analyses are extremely scarce with only the data recorded at Pasto Grande gauging station being available. Report containing flood analyses made by using these data were obtained and the Survey Mission reviewed the flood analyses described in this report.

Investigation on was quality as well as on quantity is important because, by implementing the Project, discharge is reutilized as irrigation water for Locumba Vally and Ite Norte.

The water quality in the project area and its sarroundings are described in Chapter 10 as well predictive study on the influence due to treatment by diluting and draining unsuatable water for irrigation, which is held in Laguna Loriscota.

5.2 OUTLINE OF METEOROLOGY AND HYDROLOGY

The area considered in this Project is centered at Departamento de Tacna in the southern part of Peru and straddles Departamento de Moquegua and Departamento de Puno. The area of water collection belongs to the Altiplano of the Andes mountain range, and is a low-temperature, humid. The area in which the water used by power generation is utilized for irrigation is located along the Pacific Coast, west of the water collection area and this coast is featured by a dry, tropical climate.

The precipitation in the Andes mountainland is larger in quantity as a whole compared with the Costa and is greatly affected by cold fronts and pressure variations. During the period from April to November, the front recedes, the country is covered by a high-pressure cell, and fair weather prevails. During the period from December to March a front sets in, the atmospheric pressure is low with uninterrupted cloudy weather, and there is much rain.

Annual precipitation generally increases as the elevation becomes high and the distance toward inland becomes short, and in the vicinity of the projected power station site under

EL. 2,000 m, the precipitation is approximately 50 mm, while at EL. 3,000 to 3,500 m in the vicinity of Laguna Aricota it is about 150 to 250 mm. Further, in the Altiplano of elevation about 4,500 m which is the water collection area for the water supply scheme, the precipitation is approximately 400 to 600 mm. Snowfall is seen during the period from December to March.

The temperature differs according to elevation. The annual mean temperature at Candarave with elevation of approximately 3,400 m is about 9°C, while at Pasto Grande of elevation of approximately 4,550 m it is about 3°C. However, a large temperature differential is produced between the daytime and nighttime, and especially, at high land of about EL. 4,500 m, whereas the temperature in the daytime is around 14 to 20°C, it drops to -5°C to -19°C in the nighttime.

The trend of discharge in the water collection area is greatly influenced by the trend of rainfall, and there is a sharp difference between the runoff in the dry season and that in the rainy season. The months in which there are the largest amounts of runoff are February-March with 1.6 to 3.1 times as much as the annual average runoff, while the months with the smallest amounts of runoff are October - November with 0.2 to 0.7 times as much as the annual average runoff.

Data on hydrology are not available in the Loriscota Basin which is to be the main water source for the water supply scheme, but according to the results of the present study, it is estimated that the present Laguna Loriscota is maintaining a balanced condition through inflow and outflow averaging around 1.4 m^3/sec. As for the inflow at the Tocco intake site, it is estimated to be approximately 0.50 m^3/sec.

In the Aricota Basin, since water intake is being carried out for irrigation mainly at the Río Callazas, it is thought approximately 2.0 m^3/sec is entering Laguna Aricota as inflow not including the above intake.

5.3 RUNOFF AND METEOROLOGICAL GAUGING STATIONS

The hydrometeorological data for this project are mainly on the Andean Altiplano connected with the water supply scheme, on the Aricota Basin, and on the surrounding area which it is estimated will be influenced by the Project.

The locations of the major gauging stations are as indicated in Fig. 5-1, with the periods of observation shown in Table 5-1 and Table 5-2. These data were obtained by agencies such as SENAMHI, ELECTROPERU, SPCC, EICTM, and the Ministerio de Agricultura. However, the observation periods are not uniform and data which can be directly used for the Project are limited. The Survey Mission selected data to be adopted from the viewpoints of geography and the periods covered by the data with regard to the overall applicability of the data based on the hydrological and meteorological observation data obtained insofar as possible.

General descriptions will be given below regarding the principal observation stations.

(1) Meteorological Gauging Stations

a) Tacalaya Meteorological Gauging Station

This gauging station is located approximately 15 km south of laguna Suches at the most upstream part of the Rio Locumba, at EL. 4,500 m, and has been under the administration of SPCC since 1953.

b) Suches Meteorological Gauging Station

This gauging station is located at the shore of Laguna Suches at EL. 4,452 m, and has been under the administration of SPCC since 1956.

c) Pasto Grande Meteorological Gauging Station

This gauging station is located at EL. 4,550 m along the Río Viscachas, a tributary of the Río Tambo. The upstream side of this site is a vast pampa of approximately 130 km^2. This gauging station has been under the administration of SPCC since 1952.

d) Vilacota Meteorological Gauging Station

This gauging station is located at EL. 4,390 m near Laguna Vilacota upstream of the Rio Maure and has been under the administration of SENAMHI since 1964.

(2) Runoff Gauging Stations

a) Candarave Runoff Gauging Station

This gauging station is located in the vicinity of the mouth of the Río Callazas, one of the principal rivers flowing into Laguna Aricota, and is 3 km upstream from the lake, at an elevation of 2,850 m. The river gradient at the site of this runoff gauging station is approximately 1/100, and the catchment area is 637 km^2. However, there are 17 places where irrigation intake is being carried out on large and small scales upstream of this gauging station. Particularly, a maximum of 1.9 m^3/sec is being drawn at a point immediately downstream of Coranchay Gauging Station, while furthermore, half of the above amount is being conducted outside the Aricota basin to Cairani and Huanuara. Consequently, the runoff at this gauging station is not that of the natural stream, and is considered to be comprised of overflow from the abovementioned intake facilities sites, recharge water from the above, and runoff from the residual catchment area.

This gauging station had been under the administration of ELECTROPERU since 1963, but observations have not been carried out since 1973.

b) Coranchay Runoff Gauging Station

This gauging station is located on the middle stretch of the Río Callazas at an elevation of 4,200 m. The river gradient in the vicinity of the gauging station is approximately 1/70, and the catchment area is 438 km^2. The station has been under the administration of SPCC since 1955.

c) Aricota Runoff Gauging Station

This gauging station is located on the Río Salado, one of the principal rivers flowing into Laguna Aricota, 2 km upstream from the lake at an elevation of 2,800 m. The catchment area is 349 km^2. The river gradient in this vicinity is approximately 1/100.

Administration of the station has been under ELECTROPERU since 1963, but observations have not been made since 1973.

d) Pasto Grande Runoff Gauging Station

This gauging station is located at EL. 4,510 m on the Río Viscachas, a tributary of the Río Tambo, and has a catchment area of 560 km^2. With the gauging station as the dividing line, the upstream side is a broad pampa and the downstream side is a canyon, and the river gradient becomes steep.

The administration of this station has been under SPCC since 1953.

e) Tocco Runoff Gauging Station

This gauging station is located upstream of Pasto Grande at EL. 4,547 m and has a catchment area of 85 km^2. This station has been under the administration of SPCC since 1970.

f) Vilacota Runoff Gauging Station

The gauging station is located at EL. 4,400 m, 5.5 km upstream of laguna Vilacota, and has a catchment area of 76 km^2. The river gradient in this vicinity is approximately 1/100.

The administration of this station has been by SENAMHI since 1964.

g) Chucarapi Runoff Gauging Station

This gauging station is located at EL. 135 m on the downstream part of the Río Tambo where the Tambo Valley opens up, and the catchment area is a vast one which spreads out to parts of the three departments of Puno, Moquegua and Arequipa. The catchment area is 12,855 km^2, but the area estimated to comprise runoff sources is 8,924 km^2 of the whole catchment area.

Records have been obtained since 1933 with the station under the administration of the Ministerio de Agricultura.

(3) Other Valid Data

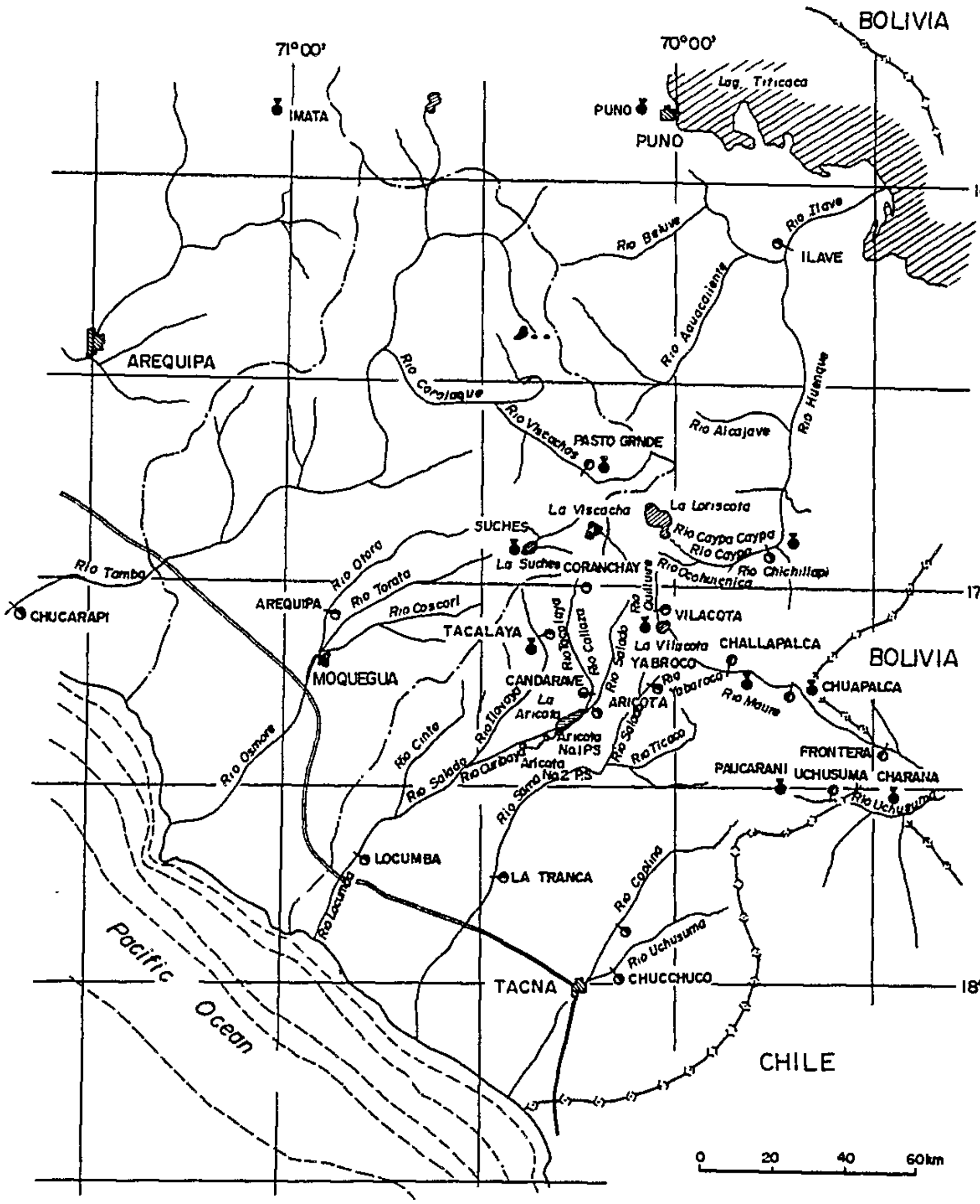
a) Aricota Pumping Station

This pumping station was provided to pump up the water of Laguna Aricota for conduction of water to Aricota No. 1 Power Station constructed on the Rio Curibaya and for supply of irrigation water to Curibaya site. The administration and operation is by ELECTROPERU and the pump-up quantities and lake water levels since 1967 have been recorded.

b) Existing Aricota No. 1 and No. 2 Power Stations

The two power stations, since start of power generation in 1967, have been administrated and operated by ELECTROPERU. Based on the power generation performance data of these stations, it is possible to estimate the amount of water used for power generation with relatively high accuracy. At the No. 1 power station, comparison with the quantity of pump-up, and at the No. 2 power station, comparison with the discharge from the No. 1 power station and the runoff from the Curibaya site direction including seepage from Laguna Aricota are valid.

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



Run-off Gauging Station

Meteorological Gauging Station

Table 5-1 Existing Meteorological Data

Station	River	Location			Control	Observation Period (57–81)
		La (S)	Lon (E)	Height (msnm)		
Pasto Grande	Tambo	16°43'	70°14'	4,500	SPCC	52
Quellaveco	Osmore	17°06'	70°36'	3,550	SPCC	52
Tacalaya	Locumba	17°03'	70°25'	4,500	SPCC	52
Suches	Locumba	16°56'	70°23'	4,452	SPCC	56
Yabroco	Sama	17°20'	70°07'	3,200	SEN	
Candarave	Locumba	17°16'	70°15'	3,415	SEN	
Curibaya	Locumba	17°23'	70°20'	2,350	SEN	
Vilacota	Maure	17°07'	70°03'	4,390	SEN	
Camilaca	Locumba	17°16'	70°23'	3,300	SEN	
Cairani	Locumba	17°17'	70°22'	3,205	SEN	
Locumba	Locumba	17°37'	70°46'	559	SEN	
Puno	Ilave	15°52'	70°02'	3,875	SEN	33
Ilabaya	Locumba	17°25'	70°31'	1,425	SEN	
Toquepala	Locumba	17°15'	70°35'	3,600	SPCC	52

SPCC: Southern Peru Copper Corporation

SEN : Servicio Nacional de Meteorologia e Hidrologia (SENAMHI)

Table 5-2 Existing Run-off Data

Station	River	Location			Area (Km^2)	Control	Observation Period
		La (S)	Lon (E)	Height (msnm)			58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81
Pasto Gronde	Vizcachas	16°43'	70°14'	4,510	551	SPCC	56
Tacalaya	Cotana	17°03'	70°25'	4,500	42	SPCC	52
Laguna Sches	-	16°56'	70°23'	4,452	371	SPCC	
Coranchay	Callazas	17°07'	70°17'	4,100	439	SPCC	56
Vilacota	Quilvire	17°04'	70°02'	4,400	76	SEN	
Chichillapi	Chichilla	16°56'	69°45'	4,150	286	EICTM	
Aricota	Salado	17°20'	70°14'	2,825	349	ELP	
Candarave	Callazas	17°18'	70°13'	2,850	637	ELP	
Tocco	Tocco	16°49'	70°08'	4,547	85	SPCC	
Chucarapi	Tambo	17°03'	71°42'	135	12,390	M.de A.	33
Yabroco	Yabroco	17°21'	70°07'	3,200	180	SEN	

SPCC : Southern Peru Copper Corporation
SEN : Servicio Nacional de Meteorologia e Hidrologia (SENAMHI)
M.de A. : Ministerio de Agriculture
ELP : Electro Peru

5.4 ANALYSES ON OBSERVED DATA

5.4.1 VERIFICATION OF UNIFORMITY

The uniformity of hydrological data collected in relation to this project was investigated by the double mass curve method.

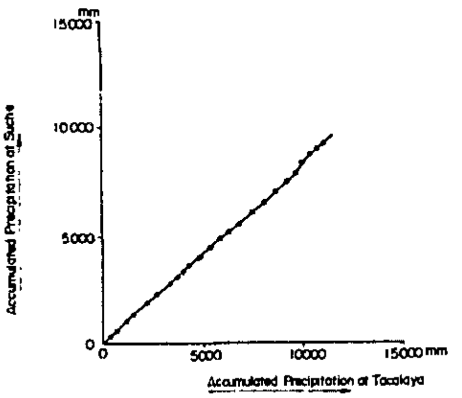
In general, precipitation and runoff are said to have a correlation including a time differential. The gradient of the time curve drawn by the double mass curve will indicate the average correlation between corresponding values. In such case, if the gradient changes during the elapse of time, it may be estimated that a change of relation between the both occurred from the year of the breaking point. The factors that can be considered as the causes are due to environmental conditions and observation conditions. In general, it is said that with the former the gradient varies gently, while with the latter, the breaking point is comparatively distinct, after which a more or less constant trend is indicated.

Analyses were made from the above viewpoints, and in cases of data for which abnormalities were recognized, the causes were estimated and judgments were made of whether corrections of the data would be required.

(1) Precipitation

a) Tacalaya and Suches

Fig. 5-2 W-Mass Curve of Precipitation of Suches and Tacalaya

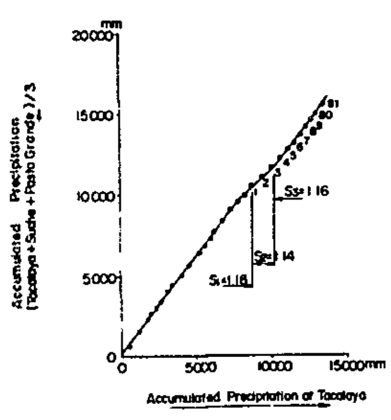


The corresponding period for the two gauging stations is the 25 years from January 1957 to August 1981. The annual average precipitations for this period are 465 mm at Tacalaya and 386 mm at Suches.

As shown in Fig. 5-2, the gradients show roughly constant trends.

b) Tacalaya and Pasto Grande

Fig. 5-3 W-Mass Curve of Precipitation of Pasto Grande and Tacalaya



The corresponding period for the two gauging stations is the 29 years from January 1953 to December 1981. The annual average precipitations for this period are 467 mm at Tacalaya and 534 mm at Pasto Grande.

The relation is shown in Fig. 5-3. Whereas the gradient for the 19-year period until 1972 is Si = 1.18, for the 2-year period of 1972 and 1973, Tacalaya shows a trend of being 3.4% higher than Suches, while in the 8-year period after that, the difference is only 1.8%.

Consequently, it may be judged that the trends between the two sites roughly coincide.

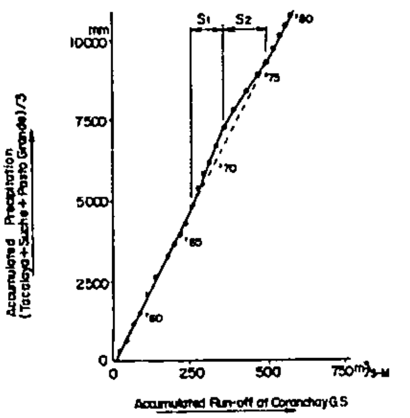
Regarding the abovementioned three precipitation data, as a result of analysis of the relations with Tacalaya which, because observation conditions were relatively complete, was used as the nucleus, it was judged that the observation data of both Suches and Pasto Grande were uniform. Assuming that average values would be used for the above three precipitation data concerning relation between runoff and precipitation, it will hereafter be called the normal precipitation.

(2) Runoff and Precipitation

a) Coranchay Runoff Gauging Station and normal precipitation

Analysis was made of the 24-year period from January 1957 to December 1980 for which there is correspondence between the two data. The average runoff at Coranchay Runoff Gauging Station is 1.98 m^3/sec (original data) and the annual average precipitation of the abovementioned three precipitation gauging stations is 451 mm.

Fig. 5-4 W-Mass Curve of Precipitation and Run-off at Coranchay G.S



The results are shown in Fig. 5-4. The trend of the 11-year period from 1957 to 1967 and the trend in the 5 years after 1976 are practically the same. In contrast, the 5-year period from 1966 through 1971 shows runoff is approximately 25% smaller than precipitation, while the five years until 1976 show it is conversely about 24% greater.

Next, the cases in dividing the runoff according to rainy season and dry season are shown in Figs. 5-5 and 5-6. The trend for the rainy season is roughly the same as in Fig. 5-4 for the whole year. Therefore, from the facts that the change point in the gradient is relatively distinct and that factors to cause changes in landform and vegetation at the catchment area and changes in the state of land use cannot be seen, it was judged that the rainy-season runoff from 1966 to 1976 were abnormal values due to difference in the observation conditions.

Fig. 5-5 W-Mass Curve of Precipitation and Run-off at Coranchay G.S (Rainy Season: Nov.~May)

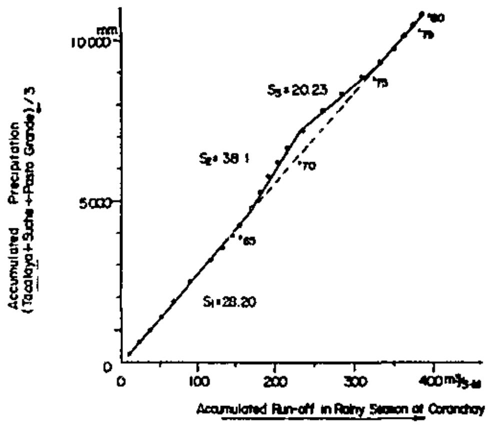
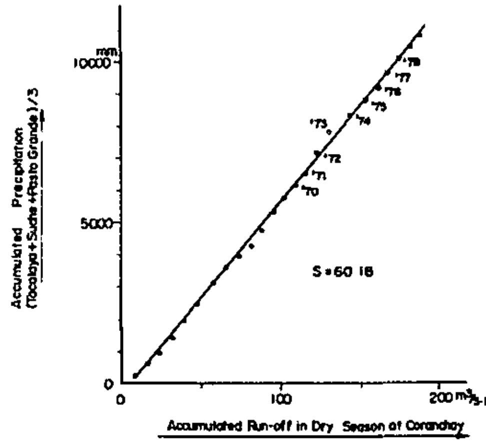


Fig. 5-6 W-Mass Curve of Precipitation and Run-off at Coranchay G.S (Dry Season: Jun~Oct.)



On the other hand, regarding the dry season, a more or less constant trend was indicated except for several years, and abnormalities as in the rainy season cannot be seen. The dry-season runoff is almost completely from outflow of groundwater, and in general, the form of discharge does not change abruptly. Consequently, it is judged that dry-season runoff records are roughly uniform.

b) Candarave Runoff Gauging Station and Normal Precipitation

This gauging station is located on the Río Callazas approximately 25 km downstream of Coranchay Runoff Gauging Station, at the mouth of the river at laguna Aricota. However, a maximum of 1.9 m^3/sec is drawn off from the runoff at Coranchay Gauging Station immediately downstream of the Coranchay station for irrigation purposes. Downstream of this station, a maximum of 0.95 m^3/sec is further being drawn at 16 other intakes in total. In these intake facilities there is no sign of restriction on intake of water. This can be verified also by the examples of the hydrographs for the two gauging stations shown in Fig. 5-7. Consequently, although intake of the runoff at this gauging station is being done, the trend with elapse of time is constant as shown in Fig. 5-8, and it may be judged that the data have uniformity.

Fig. 5-7 Hydrograph at Coranchay and Candarave G.S (1967 ~ 1971)

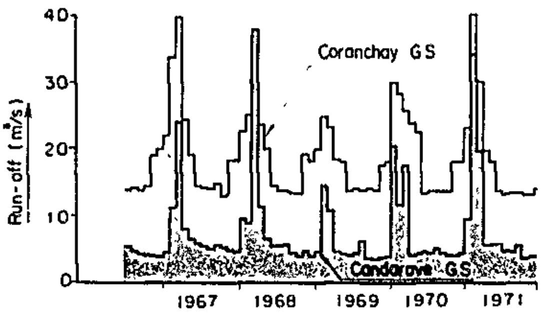
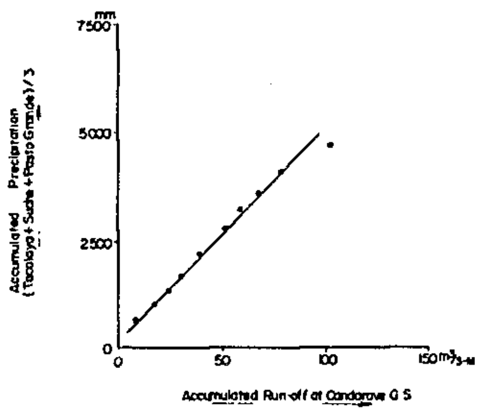
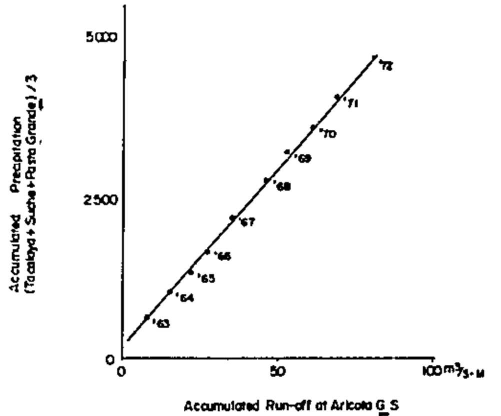


Fig. 5-8 W-Mass Curve of Precipitation and Run-off at Candarave G.S



c) Aricota Runoff Gauging Station and normal precipitation

Fig. 5-9 W-Mass Curve of Precipitation and Run-off at Aricota G.S



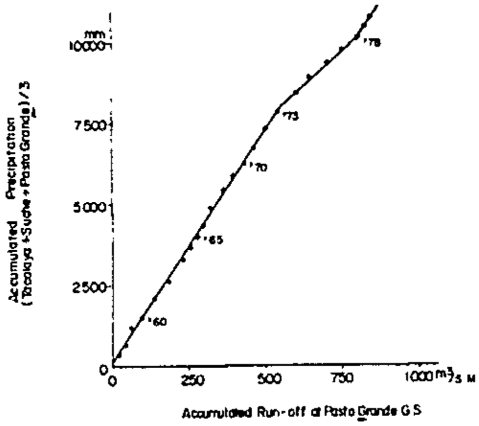
The relation between the two during the 10 years from 1963 to 1972 are shown in Fig. 5-9.

The gradient is roughly constant throughout the entire period and abnormalities are not recognized. Consequently, it is judged that the runoff data for this runoff gauging station are uniform.

d) Pasto Grande Runoff Gauging Station and normal precipitation

Analyses were performed on the 24 years from 1957 to 1980 for which the periods of the two data correspond. The average runoff (original) at Pasto Grande Runoff Gauging Station is 2.91 m^3/sec, while the normal precipitation is 451 mm.

Fig. 5-10 W-Mass Curve of Precipitation and Run-off at Pasto Grande G.S



As shown in Fig. 5-10, the gradient for the period from 1973 to 1978 is approximately 30% gentler compared with other periods, and the results is that runoff is large for the precipitation.

Next, with regard to runoff, the case distinguished according to rainy season and dry season is shown in Figs. 5-11 and 5-12. In the abovementioned 5-year period, large differences in gradients can be seen for the rainy seasons and dry seasons. Whereas in the rainy season the runoff coefficient is approximately 1.4 times higher compared with that of before 1973, that of the dry season becomes approximately 3.3 times higher. The precipitation at this site in the dry season, similarly to other neighboring catchment areas, makes up only a small proportion of the annual precipitation and is about 8%. Consequently, the greater part of the discharge during this period comes from springing of groundwater and snowmelt.

Fig. 5-11 W-Mass Curve of Precipitation and Run-off at Pasto Grande G.S (Rainy Season: Nov.~May)

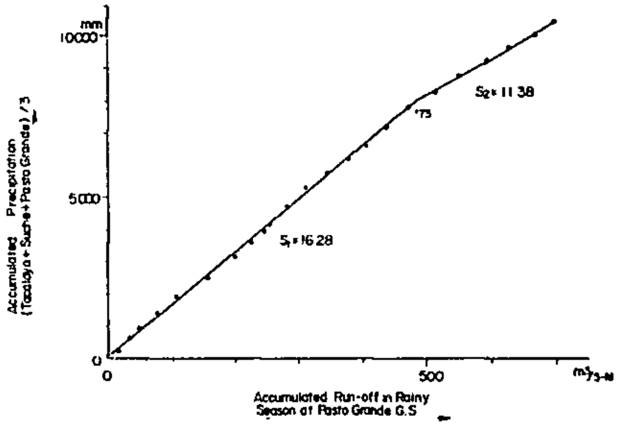
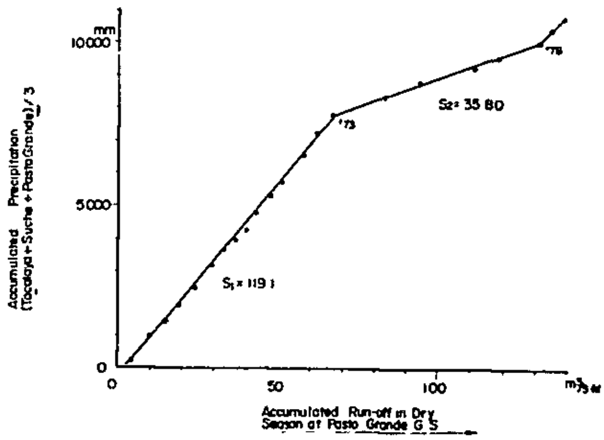


Fig. 5-12 W-Mass Curve of Precipitation and Run-off at Pasto Grande G.S (Dry Season: Jun.~Oct.)



If it were assumed that the original data are correct, it would be due to factors other than precipitation such as evapotranspiration peculiar to the Pasto Grande catchment area. The reasons are that abnormalities were not seen in the previously-mentioned dry-season runoff at Coranchay Runoff Gauging Station, and that abnormalities were not seen either at Vilacota Runoff Gauging Station which has a relatively broad pampa in its catchment area.

In general, the runoff variation in the dry season should be gentle, but whereas in case of the original data the average runoff from June to October in the dry season in 1973 was 0.93 m^3/sec, it was 3.45 m^3/sec in 1974 and approximately five times larger. As for monthly variations, during the 5 years from 1974 to 1978, in comparison with an average of 2.51 m^3/sec for September, that of October was 0.73 m^3/sec for an abrupt reduction.

With regard to the above values, there are no factors to bring about large changes from a meteorological standpoint.

Next, investigations were made regarding the observation conditions.

Water level observations at this runoff gauging station are being carried out every year. However, regarding the relation between water level and runoff, as pointed out by ONERN, no observation was made during this period. Appendix Fig. A.V-1 is the rating curve used for calculation of runoff. As can be seen by the figure, whereas the runoff is approximately 1 m^3/sec in case the water level is 44 cm, at 45 cm with only a rise of 1 cm in the water level the runoff becomes approximately 3.5 m^3/sec.

Assuming that the original data has been over-evaluated, the causes that can be considered are due to river-bed changes and water level rise in accordance with reduction in flow velocity.

In case of the former, it is amply possible in general for the river-bed in a natural stream to change about several centimeters. In case of the latter, even though there may not be a change in the cross section at the gauging station, the phenomenon can be produced if a change occurs in the river channel in the vicinity. Although a definite statement cannot be made regarding this matter within the scope of the present investigation, signs were recognized in field reconnaissances suggesting that there had been changes in the river channel immediately downstream of the gauging station.

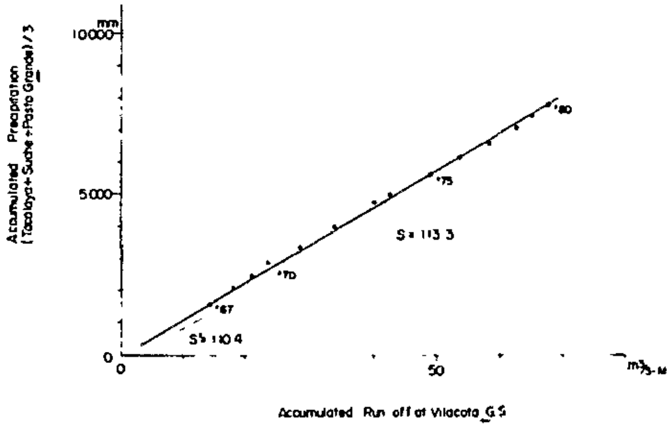
In addition to the above, when the accuracy of water level observations in a condition of flowing water was superposed and considered, it was judged that the runoff records for this site were abnormal values in compliance with the observation conditions.

e) Vilacota Runoff Gauging Station and precipitation observation data for Pasto Grande and Vilacota

Analysis was performed for the 17 years from 1964 to 1980 during which there was correspondence between the two data period. The average runoff at Vilacota Runoff Gauging Station is 0.34 m^3/sec, and the annual average precipitation of the abovementioned precipitation gauging stations is 481 mm.

The trend seen between the two is shown in Fig. 5-13.

Fig. 5-13 W-Mass Curve of Precipitation and Run-off at Vilacota G.S



Although the values for 1967 show that the increase rate for discharge is low compared with the increase rates for precipitation in other years, the trend as a whole is of rough consistency. Consequently it is judged that there is more or less uniformity.

5.4.2 CORRECTION OF DATA

As a result of the verifications made in the preceding clause, corrections are carried out on the runoff data of the Coranchay and Pasto Grande gauging stations.

(1) Coranchay

The rainy season (November - May) runoff from 1966 to 1976 are to be corrected. The average gradient (S_1 = 28.2) for the 15 years excluding the period for correction is to be used as the basis. The monthly runoff are given in Appendix Table A.V-12 (1) & (2).

a) 1966 - 1972

$$Q_M = Q_0 \times \alpha_1$$

where, Q_M : corrected value

Q_0 : original value

α_1 : correction factor

$$\alpha_1 = \frac{SO_1}{S_1} = \frac{38.10}{28.20} = 1.35$$

b) 1973 - 1976

$$Q_M = Q_0 \times \alpha_2$$

$$\alpha_2 = \frac{SO_2}{S_1} = \frac{20.23}{28.20} = 0.72$$

(2) Pasto Grande

The runoff from November 1973 to October 1978 are to be corrected.

a) Rainy season (November - May)

The average gradient (S_1 = 16.28) for the period from 1957 to 1973 is to be used as the basis.

$$Q_M = Q_0 \times \alpha_R$$

$$\alpha_R = \frac{S_R}{S_1} = \frac{11.38}{16.28} = 0.70$$

b) Dry season (June - October)

The average gradient (S_1 = 119.12) for the period from 1957 to 1973 is to be used as the basis.

$$Q_M = Q_0 \times \alpha_D$$

$$\alpha_D = \frac{SD}{S_1} = \frac{35.80}{119.12} = 0.30$$

The monthly runoffs are shown in Appendix Table A.V-14 (1) & (2).

5.4.3 EXAMINATION OF HYDROLOGIC CYCLE

(1) Hydrologic Cycle

The period covered by the hydrological data used in planning must be a standard-type which can serve to represent the entire period.

The longest periods for which runoff data were obtained by the Survey Mission were 25 to 26 years with which it is difficult to estimate long-term cycle. In general, it is considered that long-term runoff cycle has the same trend as that of rain. In the case here, it was decided to make a study by the moving average method using data of the four precipitation gauging stations below.

Site	Period	
Puno	1940 - 1982	43 years
Tacalaya	1953 - 1981	29 "
Suches	1957 - 1981	25 "
Pasto Grande	1953 - 1981	29 "

The technique is effective for grasping the trend of average-type variation excluding short-time fluctuations in time-series samples.

Fig. 5-14 shows the time-series diagrams for the various sites in case the length of time to be averaged is taken as 60 months.

For the most recent 24-year period, for which data are complete, the trends of the various gauging stations, including Puno outside the catchment area, are seen to indicate more or less the same waves. Accordingly, it will be possible to estimate the trends in the project catchment area prior to this period from the values for Puno.

a) Puno

The trends for the 36-year period from 1946 to 1981 can be broadly divided into three waves: that is, the 15-year period from 1946 to 1960, the 10-year period from 1960 to 1970 and the 11-year period from 1970 to 1981. It is to be noted, however, that the long-term variation trend shows a tendency rises gradually as increasingly recent years are approached. This suggests the possibility for a cycle longer than the 43 years used in calculations exists.

b) Tacalaya

The cycles are roughly similar to those of Puno, and are 9 years and 12 years in length. However, whereas the value in 1981 for Puno is approximately 15% larger than that in 1970, that of Tacalaya is conversely 13% smaller. Accordingly, so long as these values are compared, there is no trend for the average precipitation to increase gradually in recent years as in the case of Puno.

c) Suches

The cycle is roughly the same as for Tacalaya and Puno, and 12 years. The value for 1970 is roughly the same as that for 1981.

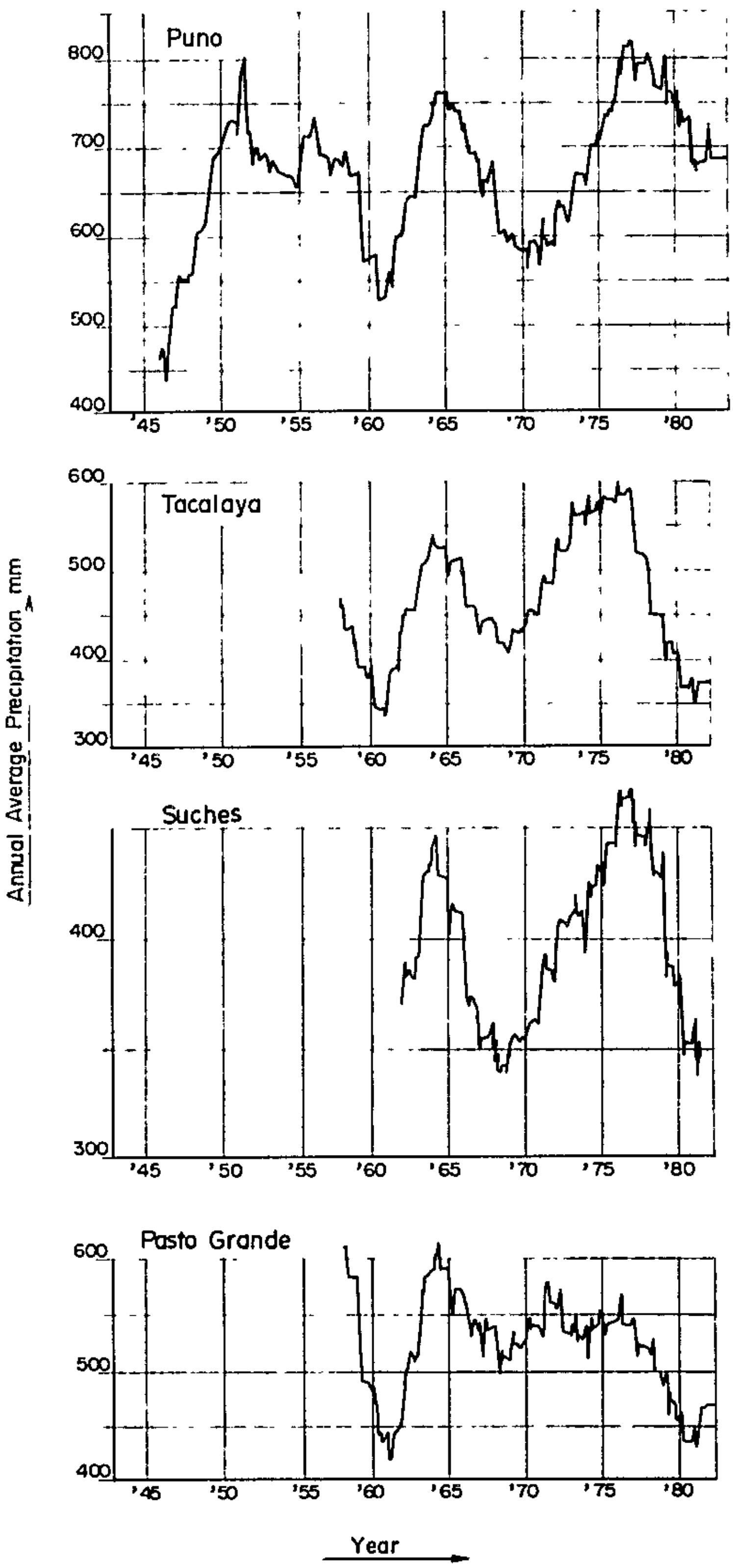
d) Pasto Grande

The cycle is not indicated as distinctly as for the other gauging stations. For the 9-year period from 1960 to 1968 it is the same as for Puno and Tacalaya, but the wave from 1969 to 1981 is low. In the case of this site, there is a possibility that the above period can be considered as a single wave.

As a result of analyses regarding the hydrologic cycle at the various gauging stations mentioned above, it is estimated that the periods with the strongest cyclic properties in the 42-year period from 1940 to 1981 are approximately 10 to 15 years.

Fig. 5-14 Moving Average Analyses

Period of Moving Average ; n= 60month



(2) Period of Hydrologic Data Used for Calculation of Value

For this Project, the 15 years from 1966 to 1980 are to be adopted as the period to satisfy the hydrologic period determined above. The reasons for this are given below.

a) Although it is desirable for original data to be used insofar as practicable, it is the 18 years from 1963 to 1980 in which data are relatively complete.

b) The average value for the period adopted is roughly intermediate in the range of variation in case of the moving average for 15 years. Consequently, this can be considered as an average-type value from a quantitative standard also.

Table 5-3 Average Precipitation

Unit: mm/Year

Observatory	Moving Average (T=15 years)	Average Precipitation of Adopted Period	Average Precipitation of Obtained Period
Tacalaya	437 - 513	470	467
Suche	383 - 405	390	384
Pasto Grande	510 - 563	510	534

5.4.4 RUNOFF CHARACTERISTICS

In general, the runoff at any point of a stream without inflow and outflow of groundwater from other river basins is the precipitation in the river basin less the losses within the basin. In this case, if the unit of time for calculations is taken to be a long period such as one water year, the losses will be roughly equal to evapotranspiration. It was decided to analyze the quantitative outflow characteristics regarding these relationships in the various catchment areas.

Fig. 5-15 to 5-18 indicate the losses per 100 km^2 of catchment area using the annual inflow and annual precipitations at the gauging stations of Coranchay, Pasto Grande, Tocco and Vilacota. The equation used for the calculations was as follows:

$$q_{LOSS} = \frac{1}{CA \times 10^{-2}} (P \times CA/86,400 - \Sigma Q_{IN}) \quad m^3/s.d/100\ km^2$$

where, q_{LOSS}: loss per 100 km^2, $m^3/s.d/100\ km^2$
CA: catchment area, km^2
P: annual precipitation, mm/year
ΣQ_{IN}: total annual inflow, $m^3/s.d/year$

However, in case there is inflow and outflow of groundwater from other river basin, the value obtained by the above equation will not be a true loss. Therefore, based on values obtained tentatively, comparisons were made between the various catchment areas, and taking into account the results of field reconnaissances, examinations were made of whether or not inflow and outflow of groundwater exist.

The results of calculations are shown in Table 5-4.

Table 5-4 Relation between Annual Precipitation and Loss

Basin	Sample	Equation of Correlation	Coefficient of Correlation
Coranchay	18	$q = 2.593 \times 10^{-3} P - 0.190$	0.99
Pasto Grande	25	$q = 2.4181 \times 10^{-3} P - 0.074$	0.93
Villacota	16	$q = 2.651 \times 10^{-3} P - 0.198$	0.99
Total	59	$q = 2.594 \times 10^{-3} P - 0.176$	0.98
Tocco	12	$q = 2.601 \times 10^{-3} P - 0.317$	0.96

Fig. 5-15 Relation Between Precipitation and Loss in Coranchay Basin

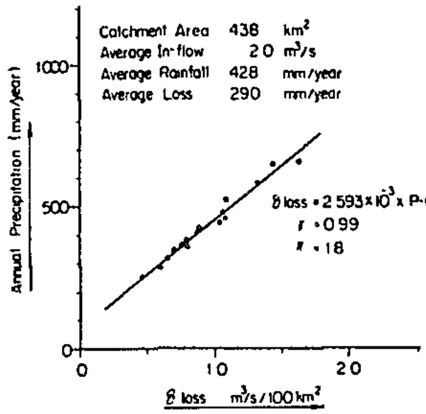


Fig. 5-16 Relation Between Precipitation and Loss in Pasto Grande Basin

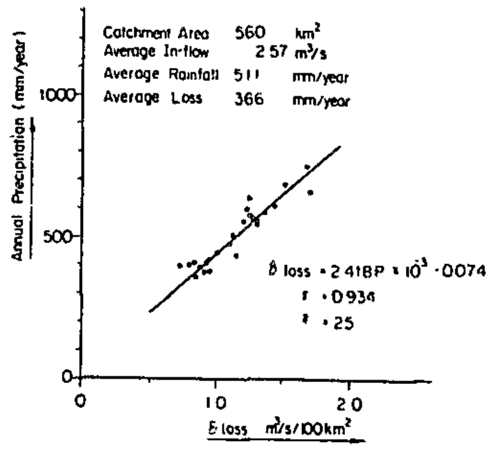


Fig. 5-17 Relation Between Precipitation and Loss in Tocco Basin

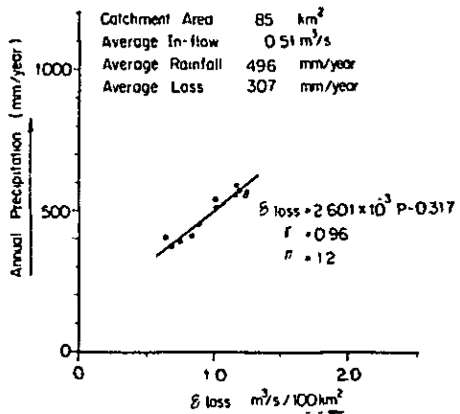


Fig. 5-18 Relation Between Precipitation and Loss in Vilacota Basin

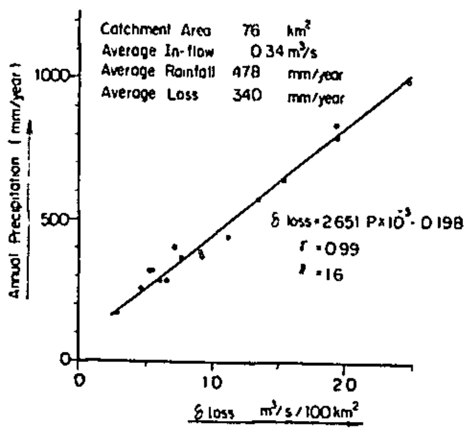
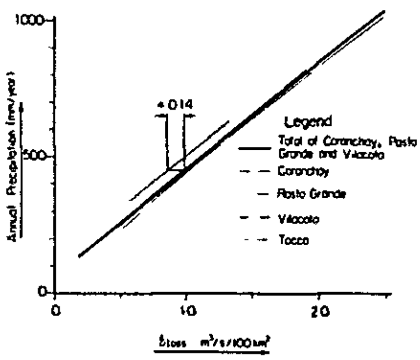


Fig. 5-19 Relation Between Precipitation and Loss in Project Area



The points described below were found as results mentioned above.

(1) The loss is roughly proportional to precipitation and gradients are roughly equal for all of the catchment areas. That is, the values observed at the various gauging stations are extremely diverse, large and small, but the losses converted to quantities per unit area are thought not to be greatly different from those of the various catchment areas.

(2) The loss in the Tocco catchment area is approximately 0.14 $m^3/s.d/100\ km^2$ smaller than those of other catchment areas regardless of variation in precipitation. This suggests that the source of the spring at Copapujo confirmed by field reconnaissance is from another river basin. That is, the loss indicated in Fig. 5-19 has been estimated to be smaller than that of other catchment areas by that amount, and it will be suitable to consider that supplementation by groundwater from another river basin is occurring.

However, the accuracies of these correlations are in units of annual level. That is, the properties of the rainy season when outflow is large are strongly evident. Consequently, it is not possible to discern variations between seasons from these correlation diagrams.

5.5 SITE RUNOFF

5.5.1 PASTO GRANDE SITE

For the runoff at this site, the runoff at the Pasto Grande Runoff Gauging Station as corrected in 5.2.2 was used since the site is the same as for the gauging station. The average inflow from 1966 to 1980 was 2.53 m^3/sec. The monthly average runoff is shown in Appendix Table A.V-14 (2).

5.5.2 TOCCO SITE

For the runoff at this site, the runoff at the Tocco Runoff Gauging Station was used without alteration since the site is the same as for the gauging station and abnormalities are not seen in the data. The average inflow from 1970 to 1980 was 0.50 m^3/sec. The monthly average runoff is shown in Appendix Table A.V-15.

5.5.3 LORISCOTA BASIN

This catchment area is topographically a closed basin, and in addition, the only data which can directly be of any information are the results of depth measurements of the lake made by CORDETACNA in 1982, and hydrological data on items such as precipitation, evaporation, outflow, etc., do not exist at all.

Consequently, it was decided that the inflow to Laguna Loriscota would be computed by the method indicated below using the outflow characteristics and hydrological and meteorological data of neighboring catchment areas.

i) The average precipitation in the basin is calculated by the Thiessen Method based on the data of the neighboring Pasto Grande Precipitation Gauging Station and the Vilacota Precipitation Gauging Station.

ii) The total annual inflow to Laguna Loriscota is determined by computing the loss in the Loriscota Basin based on the relation between annual precipitation and loss calculated previously in 5.4.4.

iii) The total annual evaporation from Laguna Loriscota is estimated from the data of neighboring gauging stations and sounding maps.

iv) With Laguna Loriscota as the basis, water budget calculations are made by using the values calculated by the above technique, and verifications are made of the individual values.

v) The total annual inflow verified is applied to the outflow patterns of the neighboring gauging stations, and monthly inflow is calculated.

vi) The monthly inflow is further separated into surface inflow and sub-surface inflow directly flowing in at the lake bottom.

vii) Using the values obtained by the above, the variations in the Loriscota lake surface estimated to have occurred from 1966 to 1980 are computed, and the relevancies and proprieties are comprehensively evaluated.

(1) Precipitation

The precipitation was calculated by the Thiessen method using the data of the Pasto Grande and Vilacota precipitation gauging stations.

$$P_L = P_P \times 0.756 \times P_V \times 0.244$$

where, P_L : precipitation in Loriscota Basin
P_P : precipitation at Pasto Grande Precipitation Gauging Station site
P_V : precipitation at Vilacota Precipitation Gauging Station site

The annual average precipitation from 1966 to 1980 was 504 mm/year. The average monthly precipitations are shown in Appendix Table A.V-9.

(2) Calculation of Total Annual Inflow

It was found from the results of analyses of outflow characteristics in 5.4.4, that the relations between loss and precipitation per 100 km^2 of catchment area in the basins adjacent to the Loriscota Basin indicate more or less the same trend. That is, this signifies that extreme differences do not exist between various catchment areas in environmental conditions such as topography, geology, vegetation, etc., comprising the catchment areas.

In this catchment area also, except for the fact that Laguna Loriscota is topographically a closed lake, it may be judged that the environmental conditions of the basin which are the supply sources of inflow are not different from those of the neighboring catchment areas.

Consequently, it was decided to calculate the inflow into this lake based on the results of studies on precipitation and outflow characteristics described in 5.4.4.

a) Loss from Loriscota Basin

The evapotranspiration from this basin is calculated using the correlation formula for precipitation and evapotranspiration in the catchment areas of the Pasto Grande, Coranchay and Vilacota runoff gauging stations.

$$q_{LOSS} = 2.594 \times 10^{-3} \times P - 0.176 \ m^3/sec/100\ km^2$$

$$n = 59$$

$$\gamma = 0.98$$

$$E_v = 315.4\ q_{LOSS}\ mm/year$$

The average annual loss from this basin excluding Laguna

Loriscota for the period of 1966 to 1980 is 357 mm/year.

b) Inflow into Laguna Loriscota

The inflow into this lake may be shown by the equation below.

$$Q_{IN} = \frac{P \times A_L + (P - E_v) \times (CA - A_L)}{365 \times 86.4}$$

where, P : annual precipitation, mm/year

E_v : loss (mainly evapotranspiration), mm/year

CA : catchment area, 234 km^2

A_L : lake surface area, 30 km^2

The above lake surface area A_L should be handled as a variable, but it was assumed to be 30 km^2 here for the reasons below.

Although variations in the surface area of this lake will be dealt with in the section on verification of the water budget, the range of fluctuations in the lake surface area during the last 15 years is estimated to have been 25 to 35 km^2 as a result of simulations. However, in obtaining inflow by the above-mentioned method, the fluctuation in the surface area is not a major factor. To elaborate, assuming that in a certain year there was an error of 5 km^2 in the lake surface area versus the average area, the error in the value in calculation results is of the degree of $\pm 5\%$, and small. Such errors are mutually offset to an extent by taking 15 years as the period of calculations.

Hence, in view of the accuracies of the basic data, it was judged that this would be amply permissible.

The average inflow into this lake from 1966 to 1980 was calculated to have been 1.40 m^3/sec. (See Appendix Tables A.V-22)

(3) Evaporation from Laguna Loriscota Surface

Since this lake is topographically a closed lake, it may be said that the greater part of the outflow is caused by evaporation from the lake surface.

According to the soundings map prepared by CORDETACNA based on the survey made in December 1982, the lake surface area was approximately 31 km^2, the maximum depth was 4 m, and the storage of water approximately 74 x 10^6 m^3.

As data on evaporation from a lake surface, there is the report, "Evaporation and Evapotranspiration at Pasto Grande Reservoir," prepared in 1967 by Dr. Zane Spiegel at the request of SPCC. According to this report, evaporation from the reservoir surface is calculated to be 1,625 mm/year. However, this value does not expressly give the exact year.

The average annual evaporation at Pasto Grande Gauging Station based on evaporation dish data from 1966 to 1980 is 1,517 mm/year. According to this, it may be estimated that the evaporation from the lake surface in this area is about 1,500 mm.

Assuming here that the lake surface area is 30 km^2 and the average annual evaporation is 1,500 mm/year, the evaporation from the lake surface will be 1.43 m^3/sec.

Meanwhile, it is estimated that the average lake surface area during the 15 years from 1966 to 1980 was roughly about 30 km^2. That is, if the area hypothetically were to be taken as 35 km^2, the evaporation would be 1.7 - 1.8 m^3/sec, and in view of the inflow, it would not be possible to maintain the lake surface area.

Data on lake surface area consist of results of aerial photographic surveys made in 1955 and the values from a survey made in 1960 by the Ministerio de Fomento, Dirección de Irrigación, Departamento de Proyectos, and the former gives approximately 32 km^2, and the latter approximately 25 km^2. According to precipitation observation data from Pasto Grande, the average precipitation for the period from 1953 to 1955 is approximately 1.5 times as much as the average precipitation for the entire period for which data were obtained, and it is estimated that in 1955 it was at the end of a period when wet years had consecutively occurred. As for the 5-year average precipitation during the period from 1956 to 1960, it was 0.8 times, and it may be considered that dry years occurred in succession.

Consequently, both of these values are not average-type values, and rather, are judged to be values indicating upper and lower limits.

(4) Verification of Inflow by Water Budget

The inflow and outflow in case of using Laguna Loriscota as the basis are verified using the values obtained by the previously-mentioned methods.

a) Water budget

When the 15-year period from 1966 to 1980 is taken as the object of the water budget study, contrasted to the average inflow of 1.40 m^3/sec obtained in (3) above, the evaporation from the lake surface among outflow factors is esimtaed to be around 1.4 m^3/sec. Consequently, the following can be considered with regard to inflow and outflow of groundwater.

i) There is extremely little possibility of inflow of groundwater from another catchment area.

ii) Although the possibility of outflow to other catchment areas in the form of groundwater cannot be ignored, quantity-wise it will be little.

Based on the above, it was judged that the inflow into Laguna Loriscota calculated by this method is more or less reasonable.

(5) Computation of Monthly Inflow

Inflow by month is computed by applying the total annual inflow verified to the outflow patterns of neighboring runoff gauging stations.

The runoff gauging stations in catchment areas adjacent to this basin are pasto Grande, Tocco, and Vilacota. Here, the outflow pattern of the Vilacota Runoff Gauging Station site was applied considering the results of the studies described above and the results of field reconnaissance.

The monthly inflows from 1966 to 1980 are given in Appendix Table A.V-22 (1).

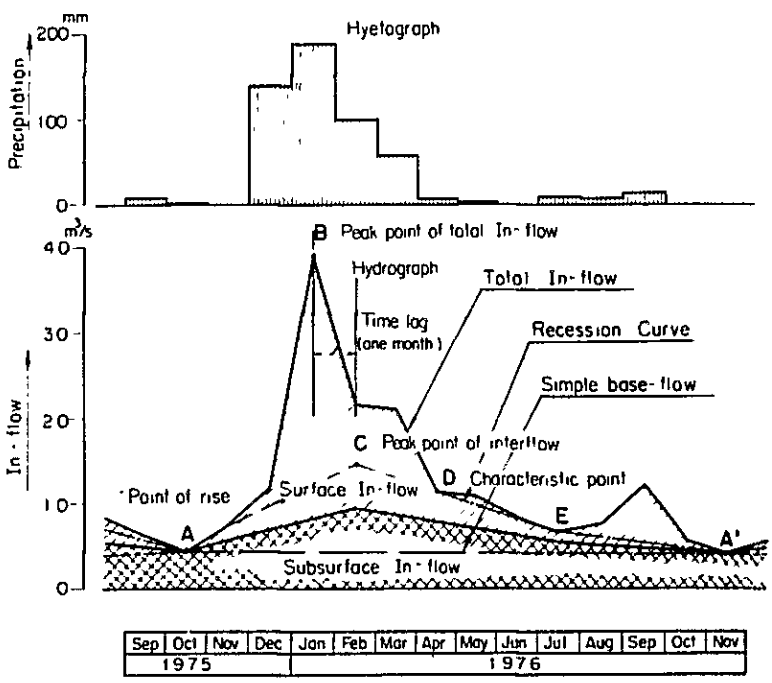
(6) Separation of Surface Inflow and Sub-surface Inflow

It is thought that the inflow into laguna Loriscota obtained above is made up of surface inflow and sub-surface inflow. It is estimated from the field reconnaissances made by the Survey Mission and information from persons concerned that the dry-season surface runoff of the Río Lorisa and the Río Putijane, which are the major streams in this basin, are practically non-existent. Therefore, these two rivers may be said to be intermittent streams. From this, it may be estimated that there is at least influent seepage corresponding to base flow.

Considering the above background, and based on the hypotheses below, the inflow into this lake was separated into surface and sub-surface inflows using hydrographs and hyetographs.

An example of separation is shown in Fig. 5-20.

Fig. 5-20 Assumed In-flow Model of Lake Loriscota



Hypothesized Conditions

1) All of the components of base runoff flow into Laguna Loriscota as direct influent seepage. (A-A')

ii) All of the components of direct runoff flow in from streams such as the Río Lorisa and Río Putijane. (A-B-D-C-A)

iii) 50% of the components of interflow (A-C-D-E-A'-A) flows directly in at the bottom of Laguna Loriscota as influent seepage, while the other 50% is surface inflow.

iv) The time lag between the peak point of direct runoff and the peak point of interflow is one month. (B - C)

The average surface inflow during the 15 years from 1966 to 1980 is 0.63 m^3/sec, and the sub-surface inflow 0.77 m^3/sec.

The monthly quantities of the two are given in Appendix Table A.V-22 (2) & (3).

(7) Estimation of Lake Surface Variation

Fig. 5-21 shows the lake surface variations assumed to have occurred during the period from 1966 to 1980.

The conditions for calculation were as follows:

a) The hydrologic cycle is the 15 years as previously mentioned with periods being continuously repetitive.

b) The monthly inflow previously described is used for inflow.

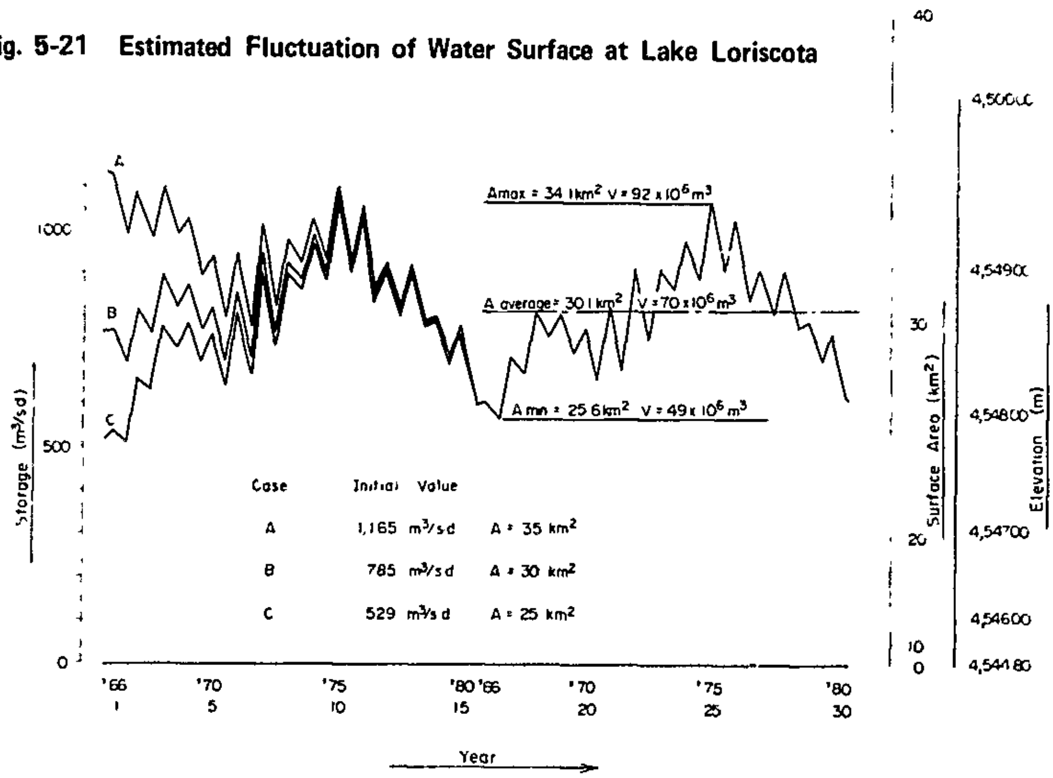
c) Outflow in the form of groundwater is disregarded.

d) The evaporation values used for computing evaporation from the lake surface are the monthly averages in Pasto Grande Meteorological Gauging Station.

e) The configuration of the lake bottom is due to the sounding map prepared by CORDETACNA.

With the above as the conditions, calculations were made based on initial lake surface areas from 25 km^2 to 35 km^2.

Fig. 5-21 Estimated Fluctuation of Water Surface at Lake Loriscota



As a result, the following may be said:

a) The lake surface variations by differences in the initial values disappear in about 7 to 8 years, after which the same trends are indicated.

b) Lake surface variations, broadly divided, occur between seasons, and between years.

c) The variation between seasons is about 20 to 50 cm in terms of water level.

d) The average lake surface area excluding the error in the initial value is 30.12 km^2.

e) The time when the surface area of the lake is thought to have been the largest was in 1975, the last year in which wet years had continuously occurred, and it was calculated to have been 34.1 km^2.

f) The time when the surface area of the lake is thought to have been the smallest began with the end of the dry season of 1966 which was a dry year, and was calculated as being 25.6 km^2.

Based on the above, it is judged that the various values on the Laguna Loriscota inflow computed in this chapter are more or less balanced.

5.5.4 RIO CHILA, RIO COYPACOYPA BASINS

Both of these rivers are located at the most upstream part of the Río Ilave, and are adjacent to each other. As runoff data of the river system there are those from Chichillapi Runoff Gauging Station at a point of approximately 10 km downstream from the confluence of the two rivers. However, observations were made at this runoff gauging station only until 1973.

As data on a runoff gauging station to be used for this Project, it was decided that the runoff at the Vilacota site was computed, and that the runoff at the planned site would be calculated by the catchment area ratio.

The average inflow data from 1966 to 1980 were as indicated below.

Chila site	CA = 102 km^2
	Q = 0.41 m^3/sec
Coypacoypa site	CA = 107 km^2
	Q = 0.43 m^3/sec

The monthly inflow data are shown in Appendix Table A.V-23 & 24.

5.6 ARICOTA BASIN

5.6.1 FUNDAMENTAL CONDITIONS

The data available for inflow to Laguna Aricota are those of the Aricota and Candarave runoff gauging stations. However, these observation data are those up to 1973. Meanwhile, at laguna Aricota, water level data since 1964 have been observed, while as outflow performances, the pump-up records since 1966 and the power generation performances of the existing Aricota No. 1 and No. 2 power stations are available.

The inflow into the lake was calculated by the following method employing the above data.

(1) Water budget calculations are made concerning periods for which inflow and outflow data are complete, and the relation between water level and seepage quantity is determined.

(2) Outflow data such as power station performance records and pump-up records are used to cary out case studies. Taking the results of these into account, selection of the data to be used in calculation of inflow is made, and the value judged to be the most reasonable is adopted as the inflow into the lake.

5.6.2 SEEPAGE FROM LAGUNA ARICOTA

The purposes of calculating the quantity of seepage in this Project are to ascertain the inflow into the lake and to estimate the seepage after implementation of the Project.

Topographically, Laguna Aricota is in the form of a closed lake, but the greater part of the outflow is supplied by seepage to the Río Curibaya. That is, the outflow of Laguna Aricota in a natural state is considered to be comprised of evaporation from the lake surface and seepage, and the water level fluctuation at that time is estimated to be due to the influence of the hydrologic cycle. However, there are no observation data with which direct quantitative verification can be made of these phenomena.

Consequently, in this Report, water budget calculations were made of this lake concerning the period for which measured inflow data exist on Aricota Runoff Gauging Station and Candarave Runoff Gauging Statin, and seepage was decided to be calculated.

The conditions for calculations are indicated below.

(1) Data Used

Aricota Runoff Gauging Station Site
Runoff, Appendix Table A.V-13.

Candarave Runoff Gauging Station Site
Runoff, Appendix Table A.V-11.

Laguna Aricota Measured Water Level,
Appendix Table A.V-19.

Suches Runoff Gauging Station Evaporation,
Appendix Table A.V-1.

Aricota Pumping Station Pump-up Records,
Appendix Table A.V-18.

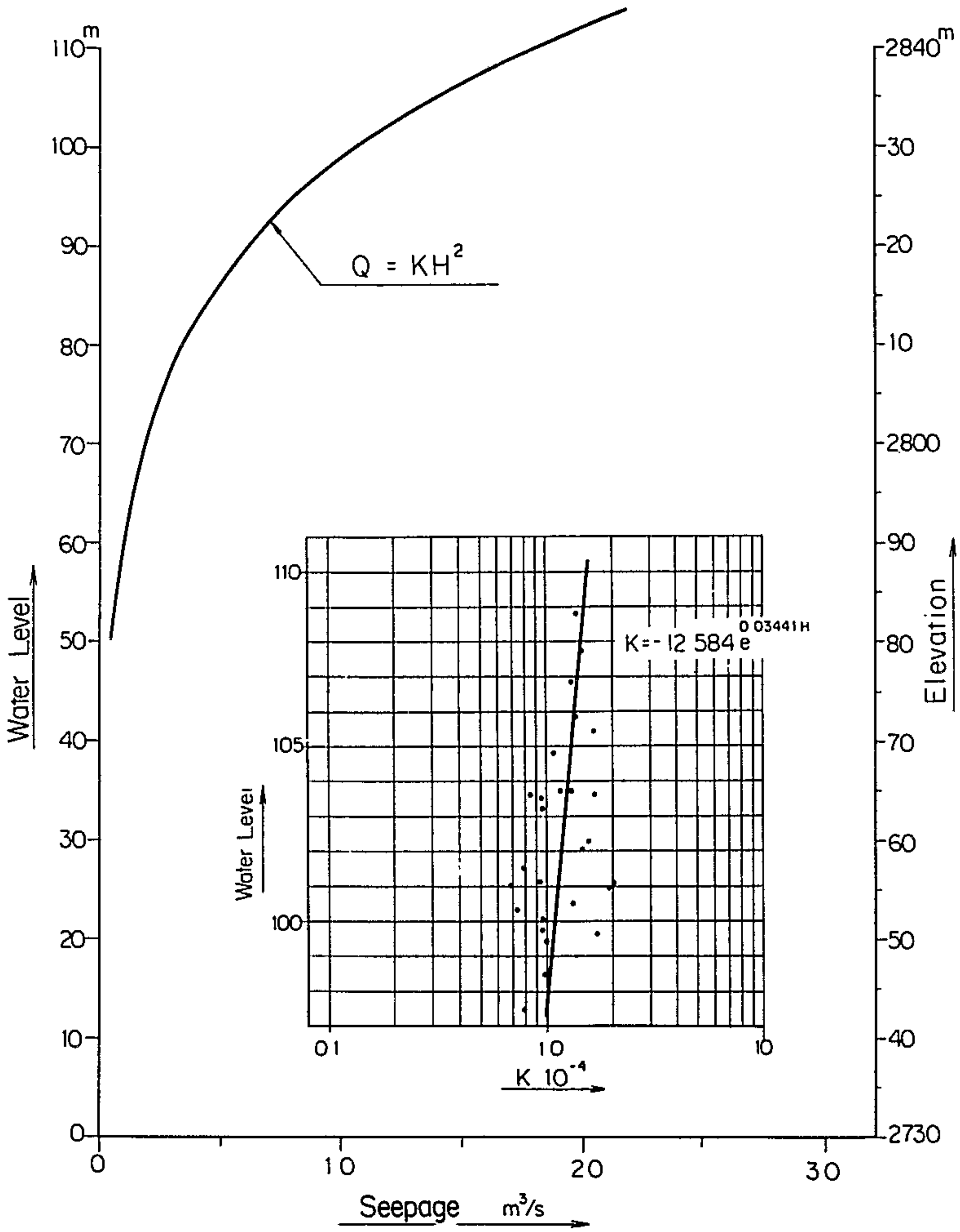
Energy Production at Aricota No. 1 Power Station,
Appendix Table A.V-20.

Energy Production at Aricota No. 2 Power Station,
Appendix Table A.V-21.

(2) Period of Calculation: October 1964 - June 1973

The relation between water level and seepage at Laguna Aricota calculated based on the above conditions is shown in Fig. 5-22.

Fig. 5-22 Seepage Curve at Lake Aricota



5.6.3 INFLOW TO THE LAGUNA ARICOTA

The period for calculation of runoff data adopted for this Project is the 15 years from 1966 to 1980 described in the study of 5.4.3, Hydrologic Period. Of this, up to 1973, it is possible to calculate based on the data of Aricota Runoff Gauging Station and Candarave Runoff Gauging Station. Regarding the inflows after 1973, data such as pump-up records, the power generation performances of Aricota No. 1 and No. 2 Power Stations were used for case studies, and the value judged to be the most reasonable was taken as the inflow into the lake.

(1) January 1966 - December 1972

The inflow into the lake is the sum of the runoffs at Aricota Runoff Gauging Station and Candarave Runoff Gauging Station.

(2) January 1973 - December 1980

The inflow during this period was obtained through calculations by month for the three cases indicated below.

Case 1 : Method of Determination from Pump-up Records

$$QA\text{-}1 = BA + EVA + QF + DM$$

where,
- QA: Laguna Aricota inflow
- BA: pump-up record
- QF: seepage
- DM: monthly variation in storage
- EVA: evaporation from lake surface

Case 2 : Method of Determination from Aricota No. 1 Power Generation Performance

$$QA\text{-}2 = QU1 + EVA + QF + DM + Q_{IR1}$$

where, QU1: Aricota No. 1 Power Station available discharge

Q_{IR}: discharge to Curibaya village, 0.139 m^3/sec, according to survey by CORDETACNA

However, calculations are made assuming no overflow from the spillway in control of generation.

Case 3 : Method of Determination from Aricota No. 2 Power Generation Performance

$$QA\text{-}3 = QU2 + EVA + DM + Q_{IR1} + Q_{IR2}$$

where, QU2: Aricota No. 2 Power Station available discharge

Q_{IR2}: discharge from intake site, 0.15 m^3/sec, according to survey by CORDETACNA

However, calculations made assuming no overflow from spillway in control of generation.

The annual average inflows calculated for the 3 cases above are shown in Table 5-5.

Table 5-5 Annual Average Inflow in Each Case

Unit: m^3/sec

Case	1973	1974	1975	1976	1977	1978	1979	1980	Average
1	3.17	2.73	3.21	2.61	2.82	2.07	1.63	1.33	2.44
2	3.31	2.96	3.50	2.85	3.25	2.31	1.21	1.24	2.58
3	3.10	2.46	3.05	2.49	2.86	1.83	0.91	1.06	2.22

The following may be said from the results of calculations:

a) The time-dependent trends are the same for the various cases.

b) The value for Case 3 obtained based on the performance at the No. 2 power station is the smallest, but the overflow from the spillway in control of generation is not included. Therefore, there is an underevaluation by that amount. Since it is judged that this power station takes a peak operation mode to meet load variations in the aspect of power demand and supply, it may be considered there were frequent overflow at this power station.

c) The value for Case 2 obtained from the performance at the No. 1 power station also does not include the overflow from the spillway in control of generation. However, the quantity is considered to be small compared with the No. 2 power station. It is judged, therefore, that the No. 1 power station takes the operation mode of meeting base load.

On the other hand, a factor for overevaluation is that seepage from Laguna Aricota springing into the headrace is contained in the available discharge for power generation, and it is thought this amount has been calculated in duplicate.

d) The value in Case 1 obtained from pump-up records is not inconsistent compared with other cases from the standpoint of the numerical expression.

Based on the above, it was decided that the inflow of Case 3 determined from pump-up records would be adopted as the data to be used for this Project. It may be added that the accuracy of the inflow calculated by this technique will be increased more the longer the unit of time is and as a result, there were months when negative values were indicated.

However, since this project site is to have a water storage function, it is thought the error will be abosrbed in a period of several months. Consequently, it was judged that the inflow by month calculated here adequately had accuracy required for the Project.

The monthly inflow data for the 15 years from 1966 to 1980 are given in Appendix Table A.V-25.

5.7 DESIGN FLOOD DISCHARGE

5.7.1 GENERAL

As described in 5.3, there are seven runoff gauging stations and four meteorological gauging stations in the catchment area of the Project, but hardly any hydrological observations required for making flood analyses are being carried out at these stations. The hydrological data obtained in this present survey are all monthly precipitation and runoff data, and data necessary for flood analyses are extremely scarce.

The only useful data are the precipitation and water level records obtained at Pasto Grande Runoff Gauging Station. There is an existing report in which these data were used to study the design flood discharge of the Pasto Grande site, and it was decided to review the flood analyses given in that report.

Firstly, in addition to determining the design flood discharge of the Pasto Grande site, the flood discharges of other sites were obtained by catchment area ratios. However, with regard to flood discharge at the Chintari intake dam site, since concrete studies have not been made at all up to this time, and valid hydrological data do not exist, it was decided that an estimate would be made based on traces of past floods in the surroundings of that site.

5.7.2 PASTO GRANDE SITE

Regarding the design flood discharge at the Pasto Grande site, in (i) "Afianzamiento Hídrico de Aricota," prepared by INAF in 1981, the 1,000-year return period flood is taken to be 400 m^3/sec, while in (ii) "Estudio Hidrológico del Río Viscachas en Pasto Grande," prepared by ONERN in 1983, the 1,000-year return period flood is said to be 42 m^3/sec.

The flood discharge of INAF of (i) was calculated from precipitation, but the water storage effect of the vast marshland of Pampa Pasto Grande spread over an area of 130 km^2 upstream of this project site has not been reflected. The result of a brief examination of the storage effect of this pampa shows that although the effect would differ depending on the flood discharge pattern and reservoir size, the peak discharge indicates a trend of being greatly reduced. However, at the present time when the flood discharge pattern and the river basin characteristics are still unknown, it is thought to use the flood discharge obtained from the quantity of precipitation only as a reference.

In the data of (ii), ONERN first determined runoff using the rating curve from the water level records of the Pasto Grande site, following which flood discharge was obtained by probability calculations using the runoff. However, the high water level portion of the rating curve used is very low compared with the rating curve computed based on the river gradient and roughness coefficient which can actually be assumed. Therefore, with regard to the high water level portion, the topography and vegetation of the site were taken into consideration and modifications were made by the Manning formula. The flood discharge was reexamined using this modified rating curve.

The results are as given below.

Table 5-6 Probable Flood Discharge

Unit: m^3/sec

Return Period	Revised	INAF	ONERN
1000	190	400	42
100	150	-	33.5

5.7.3 TOCCO INTAKE DAME SITE

Tocco Runoff Gauging Station is located at this site, and runoff observations have been made since 1970. Observations of peak runoff have also been made for 7 years since 1975, but the observation period is too short for examining design flood discharge, and the data must be said to be inadequate.

Consequently, as was mentioned in 5.7.1, it was decided to determine the design flood discharge of this site by catchment area ratio based on the design flood discharge at the Pasto Grande site. The design flood discharge at Tocco is the flood discharge of the Tocco catchment area itself plus the flood discharge of the Loriscota Basin, and may be obtained by the following equation:

$$Q_T = Q_{PG} \cdot \left(\frac{A_T + A_L}{APG}\right)$$

$$= 190 \ m^3/sec \times \left(\frac{85 \ km^2 + 234 \ km^2}{551 \ km^2}\right)$$

$$= 110 \ m^3/sec$$

where, QT: design flood discharge at Tocco site
Q_{PG}: flood discharge at Pasto Grande site
A_T: catchment area of Tocco site
AL: catchment area of Laguna Loriscota
A_{PG}: catchment area of Pasto Grande site

In accordance with the above, the design flood discharge for the Tocco site is taken to be 110 m^3/sec.

As previously mentioned, peak runoff observations have been carried out for 7 years at Tocco Runoff Gauging Station, and when these runoff records have become further accumulated in the future, it will be necessary for the above design flood discharge to be examined.

5.7.4 CHINTARI INTAKE DAM SITE

Flood discharge at Chintari site is estimated by check of traces due to flood water at valley.

In this area, in Quebrada Chintari and in other valleries for example, traces of mudflow (Hudico) are recognized.

According to the observations at the trench which has been excavated along the Quebrada Chintari, having 2 to 2.5 m in depth, it is known that mudflow occurred several times.

Upon a measuring result of absolute area for organic fragment (piece of plant) which was taken at the top part of the second mudflow layer from the surface, it appears to be 470 $\pm$120 years prior to 1950 A.D.

This shows that the mudflow occurred once 350 to 590 years as the frequency.

It is seemed to be 50 mm as annual precipitation around this region (Curibaya, about 87% of that is within the period of January to March).

And 23 mm of precipitation equivalent to about 45% of annual one occurs in February.

Catchment area of the valley (Quabrada Chintari) is about 50 km^2 and is approximately equal to the one for Rio Curibaya at Chintari.

It has not been made clear at the moment that what magnitude of rainfall cuase a mudflow, however a design flood discharge of 10 m^3/s is set up for this site based on the annual precipitations and design floods at Andes plateau area.

5.8 SEDIMENTATION

There is extremely little information regarding sedimentation with only mentioned in "Afianzamiento Hidrico de la Laguna Aricota," prepared by ELECTROPERU in 1979. According to this, little sedimentation occurs in this project area with hardly any effect on service lives of reservoirs.

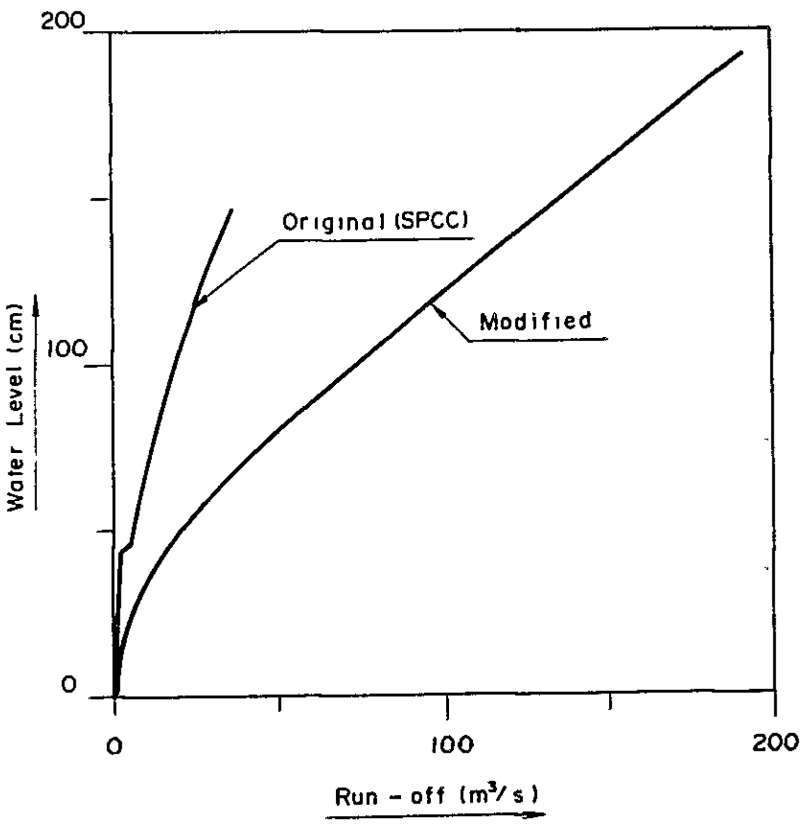
As a reason for such a situation, the fact that most of the runoff in this project area is nurtured by groundwater and snowmelt is cited. Further, this project area is topographically stable, and the forms of the catchment areas are such that suspended load sand and traction load sand which constitute the principal elements of sedimentation are not easily produced.

The Tocco catchment area is small, being 85 km^2 and almost all of the area is pampa with little relief, and collapses of ground cannot be seen. Also, there is no rainfall of localized severe rain type, and it may be judged that catchment area characteristics are such that there will be little sediment.

As a result of consideration of the above, it is estimated that sedimentation at the Tocco site will have almost no effect on the service life of the reservoir.

It may be said that there will be practically no sedimentation at the intake dam site for Aricota No. 3 Power Station. The reason is that all of the water to be drawn at this site will be power generation discharge from Aricota No. 2 Power Station with no residual catchment area water of the Rio Curibaya.

Fig. 5-23 Rating Curve at Pasto Grande Gauging Station



CHAPTER 6

GEOLOGY AND MATERIALS

CHAPTER 6 GEOLOGY AND MATERIALS

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 6 GEOLOGY AND MATERIALS

6.1 BACKGROUND OF GEOLOGICAL INVESTIGATIONS

6.1.1 PAST INVESTIGATIONS

Geologic maps of 1/100,000 scale prepared by Comision Carta Geologica Nacional are available on the southern part of Peru, and these carry explanations on geological outlines. These geologic maps contain the Water Supply Scheme and Aricota No. 3 Hydroelectric Power Scheme areas and were the most effective basic data for the investigations reported here.

In the diversion project area fairly numerous boring investigations had been carried out by the Southern Peru Copper Corporation from the past, and the conditions of groundwater had been surveyed. At the Pasto Grande Dam site, 5 boreholes and 2 test pits were excavated by INAF and the geology of the dam site had been approximately clarified. Furthermore, 3 boreholes have been drilled in the reservoir area of the dam. In the surroundings of Laguna Loriscota, 6 boreholes were drilled by CORDETACNA, and the conditions of groundwater investigated. In addition, water quality analyses have been made by the Ministerio de Agricultura y Alimentacion on lake and stream water from the water supply scheme area and its surroundings.

The results of rough investigations have been given in "Report on Modified Second Stage Development of Plan Tacna," while with regard to Aricota No. 1 and No. 2, reports and explanations are given in "Final Plan for First Stage of Comprehensive Development of Tacna Department, General Information."

Further, the results of investigations on the geological outline of this project area are given in the "Republic of Peru

Aricota Lake Water Supply Scheme and Aricota No. 3 Hydroelectric Power Scheme Preliminary Report" prepared by JICA.

6.1.2 INVESTIGATIONS BY THE SURVEY MISSION

With regard to the water supply scheme area, surface geological reconnaissances were made on the various intake dam sites and the waterways, and for investigation works seismic prospecting was performed and test pit excavations were made. seismic prospecting was done at the Chila site on two measuring lines, a total length of 960 m, at the Coypacoypa site on two measuring lines, a total length of 960 m, and at the west shore of Laguna Loriscota on two measuring lines, a total of 1,440 m. Excavation of test pits consisted of a total of 3 pits, 6.96 m, at the north shore of Laguna Loriscota to investigate the conditions of surface deposits and of groundwater. The results of these investigations are analyzed in the sections below, while drawings and work quantities are given in an Appendix-VI.

Concerning Aricota No. 3, surface geological reconnaissances were carried out on intake dam, waterway, surge tank, penstock, powerhouse and tailrace, and the investigation works consisted of seismic prospecting, test pit excavation, and borehole drilling. The seismic prospecting was done on two measuring lines, total length of 960 m at the intake dam, one measuring line, 1,080 m, at the penstock, and three measuring lines, 1,140 m, at the powerhouse. Test pit excavation consisted of three locations totalling 7.5 m in order to investigate the conditions of the soft surface layers at the penstock route. Drilling of boreholes was done at four points totalling 72.65 m at the intake dam, and four points, 78 m, at the powerhosue. The results of these investigation works are analyzed and studied in the sections below, while drawings and work quantities are given in an Appendix-VI.

6.2 GEOLOGICAL OUTLINE OF PROJECT AREA

6.2.1 GENERAL

The project area is situated in the middle of the Andes Mountain Range (Late Cenozoic upheaval) at roughly the southern end of Peru near the border with Chile. Topographically, the project area straddles a plateau area (4,000 - 4,600 m) and the western slope (1,500 - 4,000 m) of the Andes which is a transition zone from the coastal area.

The intake sites and waterway routes for supplying supplementary water to Laguna Aricota are mainly located at a plateau area. The basement consists of the Puno Group deposited in the Early Tertiary Period. In the middle of the period, the Huaylillas Formation chiefly consisting of tuff, and the Llallahui Volcano chiefly consisting of andesite lava were active. Further, in the late part of the period, the Maure Formation and the Capillune Formation composed of conglomerate and siltstone from lacustrine deposits were distributed, during which time, there were eruptions of Sencca Volcano chiefly consisting of tuff breccia. Subsequently, from the Late Tertiary to the Quaternary, the Barroso Volcano (Andesite of calcalkali rock series, rhyolite) erupted over a wide area, while further, glacial deposits and fluvial deposits were distributed covering flat areas.

Aricota No. 3 Power Station is located on the western slope of the Andes Mountain Range where the Toquepala Formation consisting of andesite and tuff breccia produced by Volcanic activity which occurred between the Late Mesozoic and Early Tertiary periods is widely distributed. Also, there can be seen diorite (thought to be a part of the Andes batholith) penetrating through the above layers. The Toquepala Formation as a whole has a northwest strike and a south west dip, and it is thought to have been subject to folding due to the Incapuquio Fault passing through Chiuntari and intrusive rock (diorite).

6.2.2 OUTLINE OF COMPONENT GEOLOGY

The outline of the principal formations distributed in the survey area are described below in the order of age.

(1) Toquepala Formation

This formation is found in a broad area to the southwest in the Tarata geologic map, and is the basal rock widely distributed and exposed in the Aricota No. 3 scheme area. However, direct outcrops corresponding to this formation cannot be seen.

The formation is composed of andesitic, dacitic and rhyolitic effusive materials and pyroclastic materials, and the total thickness is slightly under 2,000 m.

The formation covers the Yura Group or the Chulluncane conglomerate formation in angular unconformity, while it is similarly overlain by the Tarata, Huilacollo, Moquegua, and Hualillas formations.

The Toquepala Formation has been subjected to structural deformation and metamorphism due to intrusions of diorite and granodiorite.

This formation may be divided into two members, but the boundaries are not distinct.

It is considered that the age of formation was from Late Cretaceous to Early Tertiary.

(2) Moquegua Formation

This overlies the Toquepala Formation in angular unconformity and is situated on the erosion surface of diorite of the

Andes batholith. The distribution in the present survey area is small, and there is no direct involvement with structures.

This is a heterogeneous coarse conglomerate which has been consolidated to a medium degree and is coarsely stratified. The component gravels are volcanic rock and intrusive rock with small amounts of limestone contained. The gravel diameters are from 5 to 50 cm, with high contents of 10 to 20 cm. The thickness of the formation is about 200 m.

The age of formation is considered to have been Miocene to Pliocene.

(3) Tacaza Group

In the Andes plateau area the formations which are comparable to the Moquegua Formation mentioned above are the Huaylillas Formation and the Llallahui Formation.

The underlying formation is a continental sediment, the intermediate consists of tuff and rhyolite, while the overlying comprises volcanic rocks.

The formation covers the Puno Formation in angular unconformity, and is covered similarly by the Maure Formation. The age in which this formation was produced is considered to be the Miocene Epoch.

(4) Maure Formation

The formation consists of slightly loose sedimentary rocks of breccia, conglomerate, sandstone, tuff, siltstone and clay, and is thought to have been deposited in a lacustrine environment on having been transported down by swift streams.

The bottom is unknown in this area, but it is thought that the thickness of the formation is more than 140 m, and that it was produced from the Pliocene to the Later Miocene.

There is folding with dips about 15 to 20 degree toward the northeast.

(5) Sencca Formation

This formation consists of pyroclastic volcanic rocks. The thickness of the formation is small (80 m and under) and the deposits are horizontal with gentle slopes. It is chiefly rhyolitic, but changes to andesitic and dacitic at the sides and vertically. The rock is a light, porous lithic tuff containing coarse-grained quartz crystals. There is much content of lava, pumice, and rock pieces, with intercalations of lenses of agglomerate and tuff breccia which in some cases are of considerable thickness.

The Sencca Formation overlies the Maure Formation in weak unconformity, and is covered by the Capillune Formation in erosion unconformity or conformity, and contacts the Barroso Formation in unconformity.

It is estimated that the Sencca Formation was produced in the Late Pliocene Epoch.

(6) Capillune Formation

This formation is composed of mudstone, siltstone, sandstone, conglomerate, and pyroclastic rocks.

The sandstone is gray to yellowish gray in color, is fine-grained to coarse-grained, and the matrix varies between clayey, tuffaceous, and conglomeratic. Consolidation has been inadequate and there are some parts which are not dense at all. The conglomerate is yellowish gray to greenish gray, contains rounded to subrounded volcanic gravels whose sizes are greatly varied. The matrix is sandy or tuffaceous, and of medium density. The pyroclastic rocks constitute an intercalation mainly consisting of a resedimentary tuff containing a large quantity of angular ot subangular lithic material, while further, there are thin lenses of rhyodacitic tuff, and intermediate layers of tuff breccia containing lava and pumice.

The formation may be divided into the three strata of lower member (sediment), andesitic member, and Tichijones member (sediment) in order from the bottom.

The Capillune Formation overlies the Tacaza Group in erosion unconformity (basal conglomerate can be seen at the Rio Viscachas), and lies on the Sencca Formation with slight unconformity to conformity. The top is covered with the Barroso Group in erosion unconformity.

The formation thickness is from several meters to 195 m, and there is no major structural deformation.

It is thought the formation was in the late Pliocene Epoch with prominent glacial erosion having occurred after deposition.

It is said that the Capillune Formation serves as an aquifer and contains a large quantity of groundwater. In the vicinity of Loma del Azufre located between Candarave and Pasto Grande, outcrops of this formation mainly consisting of sandstone may be observed at slopes next to a road. The sandstone is fairly well-consolidated and hard, and since there are few fissures, it is not thought to be permeable. On the Capillune Formation in the vicinity there is an artificial waterway down which a large quantity of water flow. This formation is further distributed at the south fringe of Pampa Pasto Grande, where the rock is well-consolidated, and cannot be thought to be permeable. However, the formation is broadly divided into three strata with the upper two considered as being aquifers. It is thought the part observed through outcrops was probably the bottommost stratum.

(7) Barroso Group

This group is broadly divided into the three volcanic strata of Chila, Barroso, and Purupurini. It is composed of trachyandesitic lava containing a small amount of andesite and pyroclastic rocks, and forms an irregular volcanic cone and cupolas.

The mountain body has been considerably destroyed by glacial erosion.

The Barroso lava overlies older formations in erosion unconformity or angular unconformity. The Purupurini volcanic rocks ocver underlying strata in erosion unconformity.

The Barros volcanic stratum is further subdivided into two members. The lower member is mainly a lava flow which comprises the central structure of the volcanic cone. The components are dark gray, light gray, blue or reddish brown andestite to trachyandesite which are of coarse-grained to medium-grained porphyritic textures and porous, with maximum stratum thickness of 970 m. The upper member comprises the outermost part of the volcanic cone and is distributed irregularly filling depressions. This is a crystalline tuff of porphyritic texture, the constitution is trachyte to trachyandesite, and the maximum thickness is 850 m.

(8) Gracial Deposits

a) Till

This is seen in small quantities limited to isolated locations at the sides of the volcanic cone or high areas. The components are volcanic boulders with striations and angular detritus, while the matrix is fine- to coarse-grained, with varved clay existing in part. The layer thickness is 40 to 50 m at maximum.

b) Fluvio-glacial Deposits

These are deposits transported by water melted from glaciers and distributed at lowlands adjacent to slopes. The rocks are volcanic and of diverse compositions, with insufficiently sorted granules and sand being main although boulders and large detritus are also contained. The maximum layer thickness is 50 m.

The boundary between the above two deposits is not always distinct.

(9) Recent Detrital Deposit

Alluvium, colluvial deposits, pyroclastic cones, fluviatile deposits, and aeolian deposits are contained, and these cover the ground surface in succession.

The alluvium comprises the greater part of the flat land and pampa, consists of volcanic gravel, sand and clay, and is featured by indistinct bedding and lenses.

Fluviatile deposits are distributed limited to the beds of river valleys, and thicknesses are small. These are conglomerates, sand-gravel, and sand layers of inadequate stratification, and lenses of silt and clay are contained.

Aeolian deposits are distributed only in small quantities and are thin. They exist scattered at foots of slopes and cliffs in small depressions and plains.

The stratum called Bofedales is a clayey sand layer containing humus of marshland.

(10) Intrusive Rocks

Of the intrusive rocks in the Toquepala Formation, diorite, granodiorite, and granite, the one mainly having a connection with the Project is diorite, with distribution above a part of the Aricota No. 3 headrace tunnel route. This diorite is of a greenish gray color, is medium- to fine-grained holocrystalline, and is hard, but joints are developed. The age during which the intrusion occurred is thought to be from the Late Cretaceous to Early Tertiary periods.

6.3 GEOLOGY OF WATER SUPPLY SCHEME AREA

6.3.1 PASTO GRANDE DISCTICT

(1) Damsite

The dam site is planned near the entrance of the canyon where the Pampa Pasto Grande suddenly narrows to form the Rio Viscachasa. The topography is that of a gently-sloped inverted trapezoid with the left-bank side slightly steep (approximately 38 degree) near the river bed, but otherwise gentle. The right bank is similar except that there is a little canyon cutting in toward the southwest slightly downstream to present a small mountain body which at a glance has the appearance of a triangular pyramid.

The right bank has exposures of andesite, tuff breccia, and tuff, and these rocks have parts which are slightly soft with a large number of cracks.

The left bank is covered with an unconsolidated surface layer of about 4 m, and there is no outcrop of bedrock which can be seen directly. However, outcrops of tuff breccia and agglomerate can be seen slightly downstream. The deposit at the surface layer consists of talus breccia, a tuffaceous sand layer which shows bedding planes, and a surface sand-gravel layer. According to boring data (PG-1) of INAF, strata from a depth of 3 m to 26.16 m consist of agglomerate, sandstone, and siltstone of the Capillune Formation. The core from the borehole was collected in stick form and is well-consolidated.

The present river deposits at the river bed are thin and it is estiamted that they are less than 2 m even if the rocks with loose parts are included. According to boring data (P.G-2.3) of INAF, the foundation comprises conglomerate, sandstone, and silt stone of the Cappillune Formation in the lower layer.

As the foundation for the dam, the bed rock will pose no problem either in watertightness or bearing capacity if water cut-off treatment of cracks is performed. The unconsolidated strata at the left bank will need to be excavatead.

In the case of dams with the height of about 7 or 8 meters, it is thought possible for either a fill-type or a concrete-type dam to be constructed.

With regard to the basal stratun, according to a 1/100,000 geologic map (INGEMMET, 1975), it consists of the Llallahui volcanic rocks of the Tacaza Group of the Middle Tertiary Period, but in the survey reports of SPCC (1974) and INAF (1983), it is identified as the Capillune Formation of the Late Tertiary, so that a discrepancy exsits. A conclusive statement cannot be made concerning this because of the lack of reconnaissance data.

(2) Reservoir

The bed rock is estimated to consist of the Capillune Formation and underlying strata. According to boring (PG-5, 6, 7) performed by INAF, brittle fragments of tuff breccia were barely collected below 52 m at PG-7. Core recoveries were extremely poor down to 25 m at PG-5 and 23.62 m at PG-6. This is in sharp contrast with the boring at the dam site. It is necessary to clarify whether this is because the strata in the vicinity consist of poorly-consolidated conglomerate and sandstone layers even though of the Capillune Formation, or whether fluvio-glacial deposits and recent detrital deposits exist in large quantities. If it is found to be a poorly consolidated part of the Capillune Formation, the distribution and continuity will pose an imporatant problem for watertightness of the reservoir.

It has been pointed out that a fault in almost a north-south direction and an outgrowth group of minor faults exist between the dam site and the reservoir. This may be related to the difference in geologies between the dam site and the reservoir mentioned above.

There is evidence that the Pampa Pasto Grande may have been a lake in the past. To elaborate:

a) At the left-bank slope of the dam site talus deposits are covered by a sand stratum with horizontal bedding planes. This cannot be explained unless the existence of water in the past is considered.

b) Analyses of diatoms were performed on deposits at the pampa. As a result, it was learned that large quantities of diotomaceous fossils of the following varieties were contained.

Navicular mutica, Pinnularia borealis, Hantzschia amphioxys, Cocconeis placentula, Synedra parasitica.

These diatoms are all of fresh water origin, and it is surmised that the environment in which they lived was a watery area such as a lake where there was not much flow of water.

If the Pampa Pasto Grande had been lake for the reasons given above, it at least possessed watertightness at that time. That the water is gone today and it has beocme a plain pampa can be considered to be due to one of the following two causes:

The first is that the Rio Viscachas had been blocked somewhere, but the blocking medium was cut by overtopping at some time and the water was therefore drawn off.

The second is that a hole was formed in the Capillune Formation comprising the pampa and the lake dried up due to leakage through the hole.

If the leakage had not been through a hole, but by seepage, a lake would not have been formed in the first place. If a hole had been formed and it had sucked in the water, there still should be a hole to suck in water even now, but no such hole can be seen at present. As for the Rio Viscachas, it presently has a flow of water and it cannot be explained what the condition in the days of the lake was like.

That the Rio Viscachas may have been blocked off somewhere is highly probable since such closed lakes can be seen elsewhere in the project area, while large-scale landslide areas can be seen here and there.

If the disappearance of the lake was due to the first cause, the reservoir at Pampa Pasto Grande would have good watertightness, but definite proof of this has not been obtained as yet.

(3) Investigation of Reservoir Watertightness

It is necessary for a study to be made drilling several boreholes in the Capillune Formation at locations several meters above the normal water surface level of the reservoir, and comparing the groundwater levels in the boreholes with the normal water surface level.

6.3.2 SURROUNDINGS OF LAGUNA LORISCOTA

(1) Southwest Shore District

Seismic prospecting was done at the lakeshore facing Co. Jancotie at the southwest part of Laguna Loriscota. According to the prospecting, divisions can be made into an upper stratum (thickness about 20 m) of V_p = 480 - 1,250 m/sec, a lower stratum of V_p = 1,670 - 2,220 m/sesc, and a rock mass of V_p = 2,940 m/sec, and these will be as described below when correlated geologically.

The upper stratum is tuff breccia according to the outcrops seen around the measuring line, and there is a correlation with the Barroso volcanic rocks. That there is variation in velocity is thought to be ude to the Barroso volcanic rocks being a mixture of ejecta of tuff breccia, tuff, and lava. The rock mass of V_p = 2,940 m/sec may be lava. The lower stratum cannot be seen from the ground surface, but continues on to the bottom of Laguna Loriscota. This is estimated to correspond to the Capillune Formation based on the entries in the general geologic map (1/100,000), comparisons of V_p-values with those of strata in other areas, and the fact that velocity variations are small in the lateral direction.

It is thought there will be no problems about physical properties such as bearing capacity of the stratum as the foundation for a pumphouse and penstock in view of the scales of these structures.

(2) Vicinities of Mouths of Rio Putijane and Rio Lorisa

The surface layer consists of river deposits (granules, sand, silt), organic soil, and glacial deposits (sand, silt, coarse detritus). It appears that the facies of these surface deposits vary depending on the locations of the rivers flowing into Laguna Loriscota (see geologic profiles of trenches).

The basal rock, according to boring data from two boreholes drilled by CORDETACNA, consists of andesite of the Barroso Group, but the thickness is unknown. The thicknesses of the unconsolidated deposits of the surface layer are 10 m at SA-1 (Rio Lorisa right bank), and 13 m at SA-5 (Rio Putijane left bank).

Regarding the thickness and distribution of the Barroso Group, it is comparatively thin, being roughly several tens of meters and estimated to become thinner in the direction of Laguna Loriscota. This is because the Barroso Group is not found very much in the upstream area, while the underlying Capillune Formation is widely exposed, and in boreholes at other points along the lake shore the Barroso Group is not seen.

Although the groundwater level is high (within 1 m), the permeability of the ground strata will differ in correspondence with the variations in the facies according to location, and there is much still unknown concerning the groundwater quantity.

(3) Hydrogeology of Surroundings of Laguna Loriscota

The topography is flat except where the Quaternary Borroso volcanic rocks are exposed at the southwestern end of Laguna

Loriscota to form a small hill. Other than this the topography is gentle and is covered by fluvio-glacial deposits and recent detrital deposits.

At the north to northeast shore of the lake there are detrital deposits spread out centering on the two streams of the Rio Lorisa and Rio Putijane, and a good aquifer is formed. The deposit at the surface layer is a sand-gravel layer of about 13 m according to boring (SA-5), and in a simple pumping test by trench a value of $K = 4.3 \times 10^{-4}$ cm/sec was obtained. In the vicinity of the Rio Lorisa the sand-gravel layer is about 10 m (Borehall SA-1), slightly coarse, and in pumping tests at a trench the value was $K = 2.9 \times 10^{-2}$ cm/sec. The basal rock is andesite of Barroso volcanic rocks which is hard and watertight. Furhter, it is thought the Capillune Formation exists underlying the Barroso volcanic rocks, but the properties are unknown, and it is necessary to investigate whether artesian water is formed as the supply route of water to Laguna Loriscota.

Although streams cannot be seen at the south to southwest shore of the lake, there are springs seen near the lake shore. These springs are thought to have resulted from rainwater on the Barroso volcanic rocks seeping underground and emerging from parts of the Capillune Formation and the Barroso Group.

The east shore of the lake comprises a gentle hill area which is probably the Barroso volcanic rocks covered with fluvio-glacial deposits. According to Borehole SA-2, the surface layer down to 20 m is a sand-gravel deposit, 20 m to 70 m is a gravel deposit and correlated with the Capillune Formation or the Maure Formation. Although the underground structure is difficult to estimate by just this information, it is thought there is a possibility of a part of the water of Laguna Loriscota seeping to the Rio Chila.

At the west shore of Laguna Loriscota a valley is formed where two small mountain bodies of Barroso volcanic rocks meet, and from a topographical standpoint, when the water level of Laguna Loriscota rises, it is thought there will be overflow into the Rio Pasto Grande, but further according to Borehole SA-4, sand-gravel and gravel deposits continue down to 90 m suggesting that there is continuous leakage from underground.

Regarding the geology of the lake bottom it is thought to consist of Barroso volcanic rocks or the Capillune Formation judging by the surrounding geology. The existence of springs or thermal spring from the lake bottom is unknown at present.

(4) Origin of Dissolved Salts in Laguna Loriscota Water

Laguna Loriscota is a closed lake with only the two streams of Rio Lorisa and Rio Putijane flowing in and none flowing out. Consequently, the origin of the abnormally high salt content simplistically could be thought to be due to concentration through evaporation of the river water which had supplied the salts. However, the following can be pointed out as conflicting with this thinking.

a) Evaporation residue of lake water exists at a level several meters higher than the present lake surface, and therefore, it is estimated that the lake surface was several meters higher in the not too distant past. That the lake surface is now several meters lower is thought to suggest that even though there is no outflowing surface stream there is an underflow river. If an underflow river exists, the lake is not a bona fide closed lake, but a seepage lake. As previously mentioned, the boreholes drilled by CORDETACNA, SA-2 and SA-4, suggest the existence of an underflow river.

b) One feature is the high content of boron in the dissolved solids. The source of boron in almost all cases is either seawater or volcanic thermal spring. Since seawater cannot be a source at such a high elevation as 4,500 m, there is a strong possibility of volcanic thermal spring being the source.

c) The dissolved boron in the water of the Rio Lorisa and Rio Putijane flowing into Laguna Loriscota is of very low concentration, and this is incongruous with the fact that the Laguna Loriscota water is of high salt content.

d) The dissolved boron content of the water of the Rio Maure is of very high concentration, and at present there is inflow of thermal spring into the river. If there should be a thermal spring at the bottom of Laguna Loriscota, then the two data are in harmony concerning boron.

Accordingly, there is an extremely great possibility that the origin of the dissolved salts in Laguna Loriscota water lies in thermal spring which is rising or had risen from the lake bottom.

Upon examination of the evaporation residue at the lake shore, it is found that the component substances are mainly diatom, with small amounts of hornblende, plagioclase, quartz, chlorite and sericite, and there are no indications of thermal springs. Probably, volcanic ash had been mixed into diatom. Since the evaporation residue is exposed to rainwater, compounds containing boron probably have been leached out by water.

6.3.3 RIO TOCCO BASIN

(1) Rio Tocco Intake Dam

The river bed is narrowed down where the Rio Pasto Grande becomes the Rio Tocco, and the gentle slopes of the skirts of Co.

Quesllampo and Co. Pacchiauqui are close by. The river-bed protion has fluvi-glacial deposits (sand - granules, silt) and recent river deposits (granules, sand, silt), while the surface layer consists of grassland or is marsh. It is thought the basement consists of Barroso volcanic rocks (lava of andesitec to trachyandesitic compositions and tuff), but outcrops cannot be seen directly. A canyon dissecting the left-bank mountain body extends to the vicinity of the dam site, and topographically, it is thought the left bank is covered with deposits from this canyon.

The thicknesses and properties of the fluvio-glacial deposits and recent river deposits at the river bed are not clearly known. Even if it should be possible to remove the recent river deposits, it may not be possible to remove the fluvio-glacial deposits for reasons of thickness. In the event removal cannot be done, water cut-off by grouting would be difficult, and it may be required to consider some other method. For this purpose, it will be necessary to investigate the properties and thicknesses by excavating test pits at several locations.

(2) Copapujo (Extreme Upstream Rio Tocco)

Copapujo is the name of springs where a fairly large volume of water continuously rises and the Rio Pasto Grande is formed by these springs.

Only glacial deposits (sand - granules) can be seen at the surface.

The basement is thought to be the Capillune Formation or the Barosso Group. The source of the spring water is rainfall (snowfall) at Co. Viscachas and Co. Quonual which seeps through fissures in the mountain body, part of which has emerged at the ground surface.

That the volume of spring water is stable suggests that it is not coming out directly from fissures in the Barroso volcanic rocks, but is first retained in the Capillune Formation or other formation, after which a part emerges at the ground surface.

In general, a pampa forms a marshy land because of an impermeable stratum at a shallow depth so that it appears to have a high groundwater level as a whole, but the routes of groundwater flow, and locations of permeable strata may be surprisingly irregular and complex.

6.3.4 RIO CHILA AND RIO COYPACOYPA BASINS

(1) Rio Chila

The site of the intake dam is in a valley of a gently-sloped inverted trapezoid shape, slightly upstream of where the broad marshy area upstream on th Rio Chila narrows down and the river gradient becomes slightly steep.

The two banks are the skirts of volcanic rock mountain bodies of Co. Curahuara and Co. Antajave, and andesite and trachyandesite of Barroso Group are exposed. The rock masses themselves are hard, but there are numerous cracks.

The river-bed portion (width about 65 m) is thinly covered (about 4 m) with fluvio-glacial deposits (sand, coarse detritus) and recent river deposits (sand, gravel, and humus).

Both banks become gently sloped at relative heights of about 30 m. Seismic wave velocities at the surface layer portion are scattered, being V_p = 310 - 1,430 m/sec. This is thought to be because although there are exposed rocks at both banks they are in the form of loose blocks. At the bottom part the velocities vary between 2,120 and 3,850 m/sec, with low values at the river-bed portion due perhaps to cracks formed during glacial movement.

There is ample bearing capacity as a foundation for the structures considering what the scale of the dam would be, but thorough water cut-off work must be done on cracks in the foundation.

(2) Rio Coypacoypa

The river-bed portion of the intake damsite holds fluvio-glacial deposits and recent deposits, with a surface layer (about 4 m) of gravel, sand, and clay. The basement is thought to consist of the Capillune Formation (tuffaceous sandstone, clay and conglomerate), and there are places at the gradual slope on the right bank where the Capillune Formation is directly exposed.

The topography is that of a gently-sloped depression produced by glacial erosion action. Surface water meanders widely, and the flow is around 200 ℓ/sec. The vicinity is a broad marshland.

A problem which would arise as the site for an intake dam is the permeability of the basal Capillune Formation, and judging by the vegetation and other factors in the surroundings, it is thought there is a fair amount of underflow water. Therefore, preventing loss of water underground and not merely damming up surface water will result in effective intake of water.

Hydrogeologic details are unknown at present and only seismic prospecting data are available. Accordingly, the thicknesses and properties of fluvio-glacial deposits at the river bed and of the Capillune Formation are unknown at the present stage. Water cut-off treatment by grouting these for a dam foundation may be difficult and other method may need to be considered. For this, it will be necessary for test pits to be excavated at several locations to investigate properties and thicknesses.

6.3.5 WATERWAY

(1) General

The formations distributed along waterway routes in the various schemes are the following:

1) Fluvio-glacial deposits
2) Barroso Group
3) Capillune Formation

The fluvio-glacial deposits are highly permeable and it is thought necessary for some kind of pavement to be provided. Since they comprise a weak stratum which is inadequately consolidated, flat, and stable places should be selected for waterways, and slopes of steep gradients should be avoided.

The Barroso Group mainly consists of volcanic rocks or pyroclastic rocks and there is no problem of stability for a waterway, but permeability is high because of a large number of cracks. Consequently, this also requires pavement with mortar or other material.

The Capillune Formation is divided into three strata, the upper two being highly permeable, but the bottom one is said to be of low permeability. In fact, in the vicinity of Loma del Azufre, there is an artificial waterway which has been constructed on the Capillune Formation without any pavement, and a large volume of water flows down this waterway. Therefore, in the case of the bottom layer of the Capillune Formation, merely excavating would suffice and no pavement would be needed, but in case of the two upper strata a pavement would be required. Particularly, with regard to the uppermost layer, since its consolidation is inadequate, it is thought necessary to exercise care concerning stability also. In effect, a location at a place of steeply-sloped topography should be avoided.

(2) Geology of Waterway from Laguna Loriscota to Tocco Intake Dam

The waterway to cause the water of Laguna Loriscota to flow into the Rio Tocco, in terms of topography, passes a small canyon of relatively gentle slope sandwiched by the mountain masses (Barroso valcanic rocks) of Co. Quesllampo and Co. Ichipata.

Geologically, the vicinity of the ground surface consists of Bofedares and fluvio-glacial deposits.

Three boreholes (SA-3, SA-4, SA-9) have been drilled in this vicinity by CORDETACNA, and particularly, according to the entry concerning SA-4 located near the project routes, the section from the ground surface to a depth of 32 m is mainly an unconsolidated sand layer, and the groundwater level is shallow at 1.46 m. Moreover, to a depth of 90 m it is a gravel layer (including huge rock masses and sand), and sound bedrock is not reached. At borehold SA-3, to a depth of 15 m, it is a layer of medium- to coarse-grained sand, while from 15 m to 110 m is a gravel layer, with a volcanic rock bed reached at 110 m. At this borehole there is springing of water at around 110 m, with artesian flow of water in the hole.

Inferred based on the above, in the event the water-way is made an open channel, since a loose, gravelly sand layer is passed and the groundwater level is high, it is estimated that there will be seepage out of groundwater from slopes so that it will be necessary to pay thorough attention to handling of groundwater and stabilization of slopes in carrying out construction, and it is expected that the work will be fairly difficult.

6.4 GEOLOGY OF ARICOTA NO.3 SCHEME AREA

6.4.1 INTAKE DAM

Two boreholes (B-2, B-3) have been drilled and seismic prospecting performed on two measuring lines at the project site of the intake dam.

According to the results of these investigations, river-bed sand-gravel is of a thickness of 8 to 9 m in the vicinity of Borehole B-2 at the right bank of the Rio Curibaya, thickening to 22 to 23 m in the vicinity of Borehole B-3 at the left bank, while it appears that the thickness is increased even more toward the middle of the valley. This river-bed sand-gravel contains boulders, with angular to subangular gravels conspicuous, but the interstices of the gravels are filled by granules and silt for relatively good tightness.

The basement consists of andestitic to rhyolitic volcanic rocks, with jointing slightly developed, but the rocks are hard.

When considered as a dam foundation, since this river-bed sand-gravel has relatively low contents of clay and silt, and comparatively few rounded gravels, while moreover, the gravels are mostly hard volcanic rocks, it is considered there will be adequate bearing capacity in view of the scale of the dam, and little possibility of occurrence of uneven settling. However, the problem is great regarding permeability and it is thought advisable for surface shielding to be provided both the waterway and regulating pond.

There are two large canyons which open up from the east-southeast and west-northwest directions at Chintari. These normally have no water flows and are dry, but there is a possibility of debris flows* and mud flows being produced in case of heavy rain, which would greatly affect the intake dam and waterway. Therefore, it would be advisable for the dam axis to be selected upstream as much as possible in order to avoid these flows.

Also, it is estimated that a tectonic line exists passing through the abovementioned two canyons and crossing Chintari, but it cannot be directly confirmed at the ground surface.

* It appears debris flows have occurred several times. Upon dating by the carbon-14 method of plant fragments interjected between the uppermost debris flow and the immediately subjacent one, it was found to be 470 $\pm$ 120 years prior to 1950 A.D.

6.4.2 HEADRACE TUNNEL ROUTE

The geology of the route is composed of andesite to rhyolitic volcanic rocks and intruded diorite. The major structure is that of distribution in the north-south direction with overlaying strata exposed more the farther downstream, but the upstream part has been subjected to the influence of the tectonic line in the west-northwest direction crossing Chintari, while the downstream part has been subjected to structural deformation and alteration due to intrusion of the diorite.

The upstream part consists of dacite (rhyolite), andestite, and rhyolitic pyroclastic rocks, and although joints are developed, the rocks are hard. The middle- and downstream parts have alternations of tuff breccia and porphyritic ejecta (andesitic - rhyolitic), and especially, the downstream part has pyroclastic rocks with distinct bedding planes, and the rocks are slightly soft.

Although only partial outcrops of diorite are seen, they are thought to be parts of a rock mass occupying a considerably wide area underground, and alteration of the country rock and development of metalliferous veins of quartz, gypsum, and calcite thought to be effects of intrusion are conspicuous.

These are thought to be strata corresponding to the middle or top parts of the Toquepara Formation which was produced in the Late Mesozoic to Early Tertiary periods.

In carrying out tunnel excavation, that the upstream part is hard but joints are developed, and that the middle- and downstream parts have diorite which is hard but the country rock has been subjected to alteration, has development of joints, and lithologic character varies incessantly, will be points requiring attention. It is expected that there will be hardly any springing of water.

6.4.3 HEAD TANK AND PENSTOCK

The Geology consists of andesitic and rhyolitic pyroclastic rocks with distinct bedding planes, the strike is N20°E and the dip about 30°W, which in relation to the penstock route would be a sidelong direction. Seismic prospecting was performed here on one measuring line while pits were excavated at three places.

Outcrops of bedrock cannot be seen on the ridge for a distance of about 400 m at the slope below the head tank, but judging by the conditions of the slopes in the surroundings and the geological conditions in the pits, it is thought basal rock exists within 6 m. The talus of the surface layer, as judged by the topography and conditions of deposits, shows little movement, is in block form, is an aggregation of rock masses due to mechanical weathering, and is stable (average gradient less than 23 degrees).

As a whole the rocks are tuffaceous, and the rock character is slightly soft compared with the geologies at Aricota No. 1 and

No. 2, but the thickness of covering and seismic wave velocity of the basal rock are about the same. Outcrops of tuff breccia can be seen at the steep slope below an elevation of about 1,630 m. This part is hard but slightly irregular cracking can be seen at the surface, and loosening due to tension is estimated to exist. It is thought there is a possibility that these cracks are minor faults of structural nature produced in an ancient time (in view of similarity of direction with minor faults in the vicinity).

The bedrock is tuffaceous with development of bedding planes, and there is fear of creep since the inclination of the bedding planes is close to the direction of the slope, but seen topographically, it is estimated that this mountain body will be stable if no further dissecting occurs.

6.4.4 POWERHOUSE

Four boleholes have been drilled and seismic prospecting performed on three measuring lines at this site.

The boreholes reached rock at 9.65 m in case of P-2, 26.9 m in case of P-3, and 4.1 m in case of P-4. The basal rocks are tuff and tuff breccia, which are well-consolidated, but slightly cracky. The seismic wave velocities in the basal rocks are V_p = 2,940 - 4,170 m/sec, and there is adequate bearing capacity as the foundation for the powerhouse.

From the ground surface to the bedrock consists of an unconsolidated sand-gravel layer, which contains boulders, and deposited material of poor sorting exists in large quantity. As a whole, there is a large proportion of fine-particled components (granules, sand), and the material is close to being a mud-flow deposit. Clay and silt are contained but are small in quantity. Permeability is high, but bearing strength is possessed, and it is thought there is little possibility of uneven settlement.

The seismic wave velocities of the surface deposits range between Vp = 230 and 1,250 m/sec, while for underlaying deposits, loosened portions and severely weathered portions of the bedrock, V_p = 1,490 - 2,170 m/sec.

For Borehole P-3, a question remains whether bedrock or a block had been reached, but even if bedrock is deeper down, it is thought the depth to bedrock in the vicinity of the project site will be such that construction can be amply done.

In case of Borehole P-1, deposits existed down to a depth of 20 m, and bedrock has not been confirmed.

There is a ravine at the right-bank side immediately downstream of the investigation site, and it is feared debris flow may affect the powerhouse. However, since the ravine is narrow and it meanders in a complex manner, energy will be dissipated even if a debris flow were to be produced, while a natural levee is formed at the mouth of the stream, so it is estimated there will be no adverse effects on the project site which is located slightly upstream.

6.5 CONSTRUCTION MATERIALS

6.5.1 WATER SUPPLY SCHEME AREA

(1) Fill Dam Materials

If it is decided that the various dams planned in the Ands plateau region are to be fill types, rock materials, filter materials, core materials, and aggregates for appurtenant concrete structures will be required.

Regarding Pasto Grande Dam, since there are andesite and tuff breccia which are fairly hard at the right and left banks, it will be possible for these to be used as rock materials and concrete aggregates. As for fine aggregate for concrete, there are glacial deposits in the vicinity and it is thought they can be used.

It will be possible for fluvio-glacial deposits to be utilized as filter material. However, there is practically no outlook for obtaining core materials in the vicinity. Consequently, the dam will need to be a special type or a concrete type.

With regard to Tocco Dam, volcanic rocks of the Barroso Group are available in the vicinity, and of these, andesite and trachyte which are hard are thought can be used as rock materials or concrete aggregates. It will be possible for fluvio-glacial deposits to be used as sand and filter materials. However, similarly to Pasto Grande Dam, there is nothing to be utilized as a core material. Consequently, a special type will need to be considered for the dam. It will be necessary for all of the materials to be thoroughly tested to confirm whether they can actually be used.

(2) Waterway Pavement Materials

If the waterways are to be stone-lined, it is thought andesite and trachyte of the Barroso Group which are hard can be used. If the waterways are to be concrete-lined, these rocks can still be used for aggregates. It will be possible for fluvio-glacial deposits to be used as fine aggregate. These materials also will need to be thoroughly tested.

6.5.2 ARICOTA NO.3 SCHEME AREA

The principal construction materials would be as follows:

(1) Rock materials for the intake dam

(2) Aggregate for concrete to line the headrace tunnel

(3) Aggregate for concrete from the penstock to the powerhouse.

It is thought that the volcanic rocks comprising the nearby mountain body can be used as rock materials for the intake dam. Although it is thought excavation muck from the headrace tunnel could be used also, a study will be required to determine whether the construction schedule will allow use of the muck.

Parts of the excavation muck from the headrace tunnel which are hard are thought can be used as aggregate for the concrete lining of the headrace tunnel. The volcanic rocks composing the mountain mass in the vicinity can also be considered. As for fine aggregates, it should be possible to use naturally deposited material or selected material from excavation muck.

The same conditions as for aggregate for headrace tunnel lining concrete will apply to aggregates for concrete needed from the penstock to the powerhouse.

6.6 EARTHQUAKES

In the Aricota No. 3 scheme area, there are several places which can be pointed out as being of colluvial topographies produced by severe earthquakes.

For example, the mountain body at the right bank of the Rio Curibaya upstream of the No. 3 Power Station site has collapsed massively to present a landslide topography. Further, it is considered that Laguna Aricota is a natural dammed lake formed when the mountain body at the right bank of the Rio Curibaya collapsed on a large scale and the debris and rock masses from the collapse blocked the Rio Curibaya. To the northwest of Candarave Village, the mountain body has collapsed extensively leaving an area of barren condition.

Further, there are indications that Pampa Pasto Grande in the diversion project area had been a dammed lake in the past formed by blockage somewhere of the Rio Vizcachas. It is considered that these topographical features were produced throughout the project area in general by severe earthquakes which occurred in the past.

Although there are no data available to determine in what geological age these severe earthquakes occurred, it can be considered that the earthquakes accompanied the activities of Sencca Volcano or Barroso Volcano which were prominent from the Late Tertiary to the Quaternary.

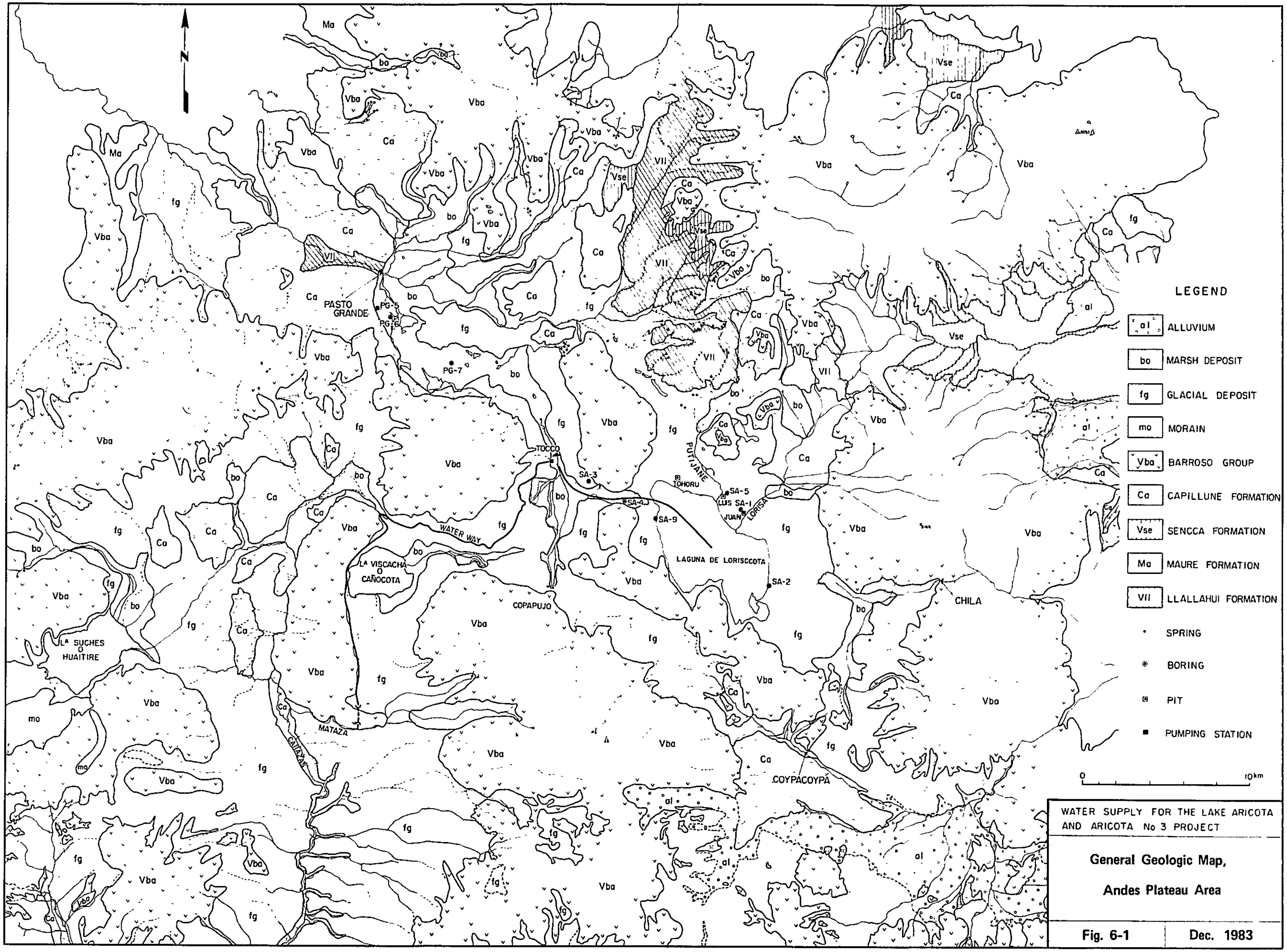
According to a report on earthquake classification (Chavez, J., y Huaco, D., 1973), the area under study is situated in Zone No. 3, and is an area where strong earthquakes occur. In recent times, in 1948, an earthquake of magnitude 7.5 was recorded at a depth of 60 km with the epicenter at a point 60 km south of Tacna City at the center of Departamento de Tacna.

Based on preliminary-level study material, the risk of an earthquake of a scale of magnitude 8.0 occurring in the next 100 years is seen to be 99%.

Consequently, thorough consideration on earthquakes must be given in carrying out design of structures.

Table 6-1 Stratigraph Sequence

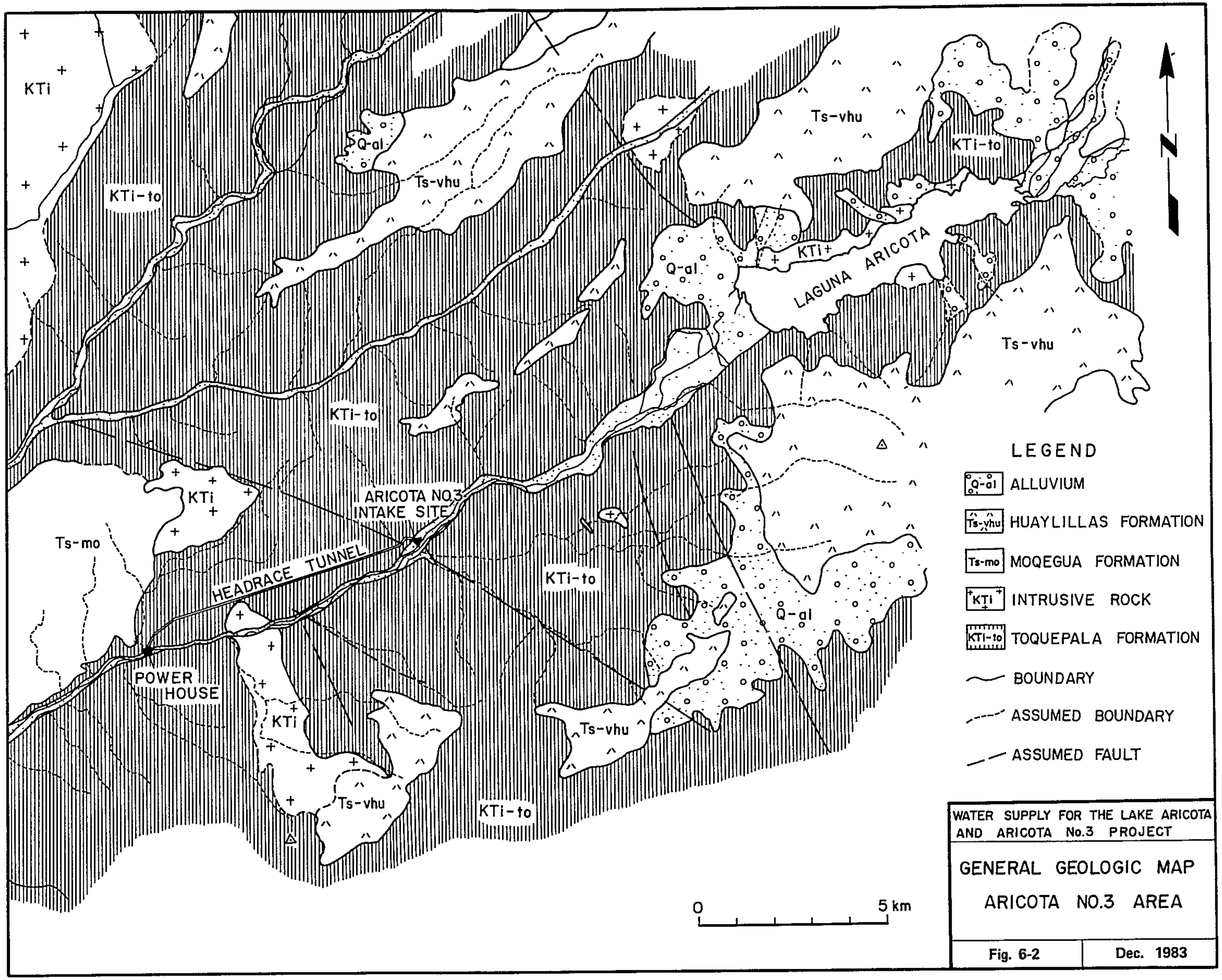
A G E		TARATA HOJA 35-v (Aricota No. 3)		HUAITIRE HOJA 34-v (Pasto Grande & Lorisccota)		MAZO CRUZ HOJA 34-x (Chila & Coypacoypa)	
Quaternary	Holocene		alluvium		alluvium		alluvium
					Bofedales		Bofedales
	0.01x10^6		fluvio-glacial deposit		fluvio-glacial deposit		fluvio-glacial deposit
	Pleistocene						Maraine
			Barroso volcanic rocks		Barroso volcanic rocks		Barroso group
	1.6-1.8x10^6						
Tertiary	Superior		Capillune formation		Capillune formation		Capillune formation
			Sencca volcanic rocks		Sencca volcanic rocks		Sencca volcanic rocks
			Huaylillas volcanic rock		Maure formation		
	Middle		Moquegua formation	Tacaza group	Llallahui volcanic volcanic rocks	Tacaza group	Llallahui volcanic rocks
				Tacaza group	Huaylillas tuff	Tacaza group	
	Inferior	Toquepala group	Huilacollo volcanic rocks	Puno group	Pichu formation	Puno group	Pichu formation
	66 x 10^6	Toquepala group	Tarata formation	Puno group	Puno formation	Puno group	Puno formation
Gretaceous	Superior	Toquepala group	Toquepala formation				



WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT

General Geologic Map, Andes Plateau Area

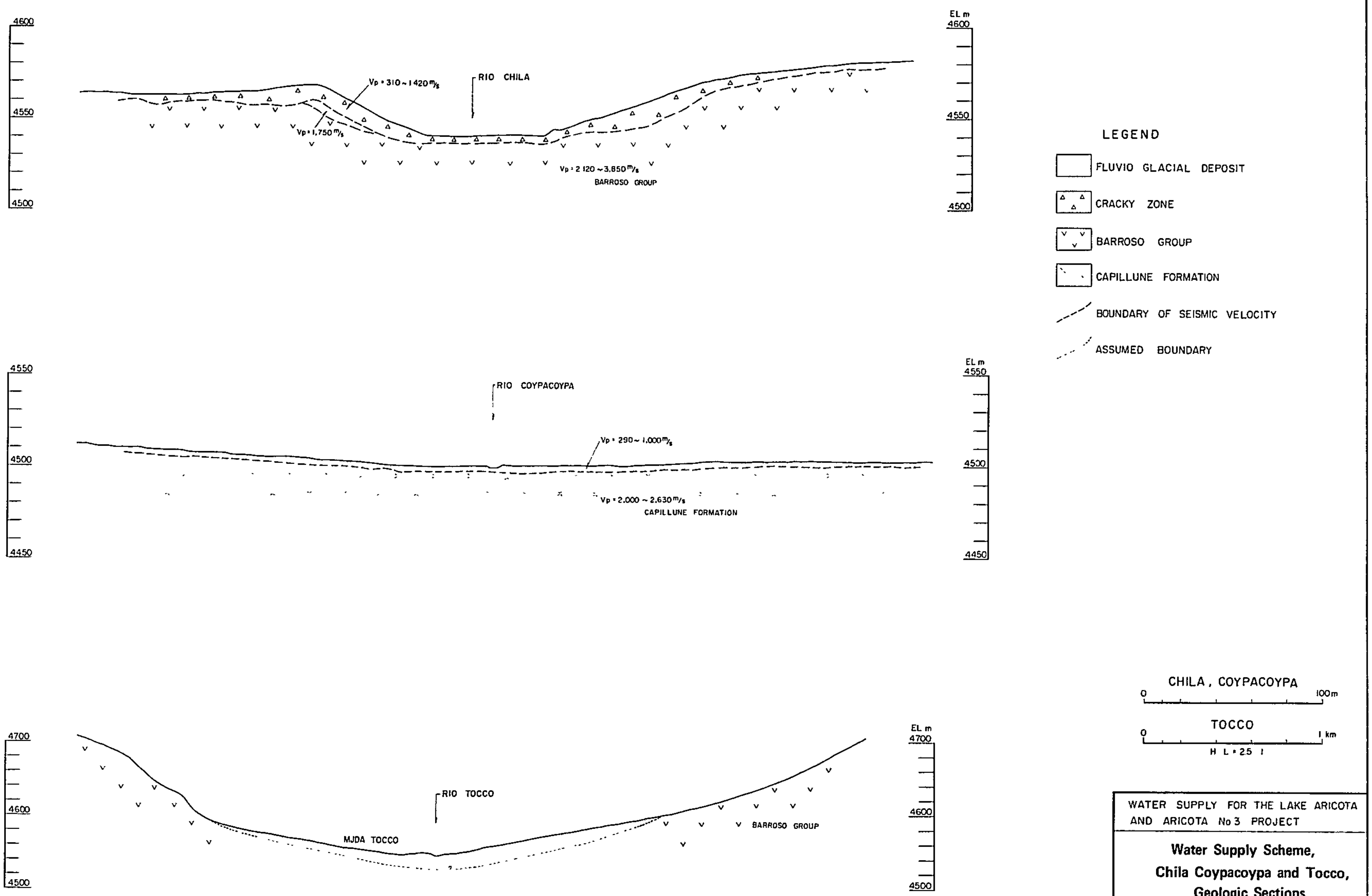
Fig. 6-1 | **Dec. 1983**



WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No.3 PROJECT

GENERAL GEOLOGIC MAP
ARICOTA NO.3 AREA

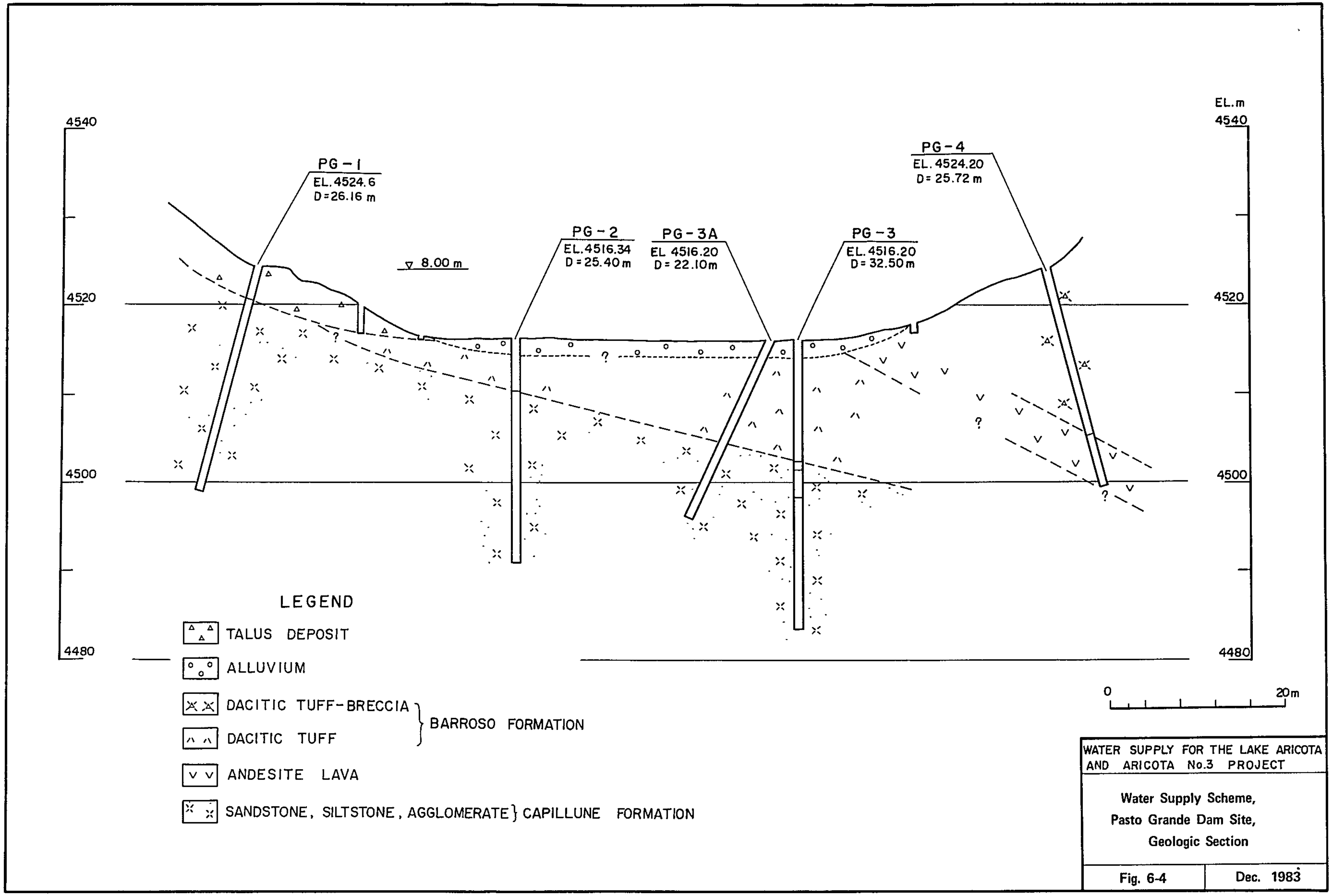
Fig. 6-2	Dec. 1983



WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT

Water Supply Scheme, Chila Coypacoypa and Tocco, Geologic Sections

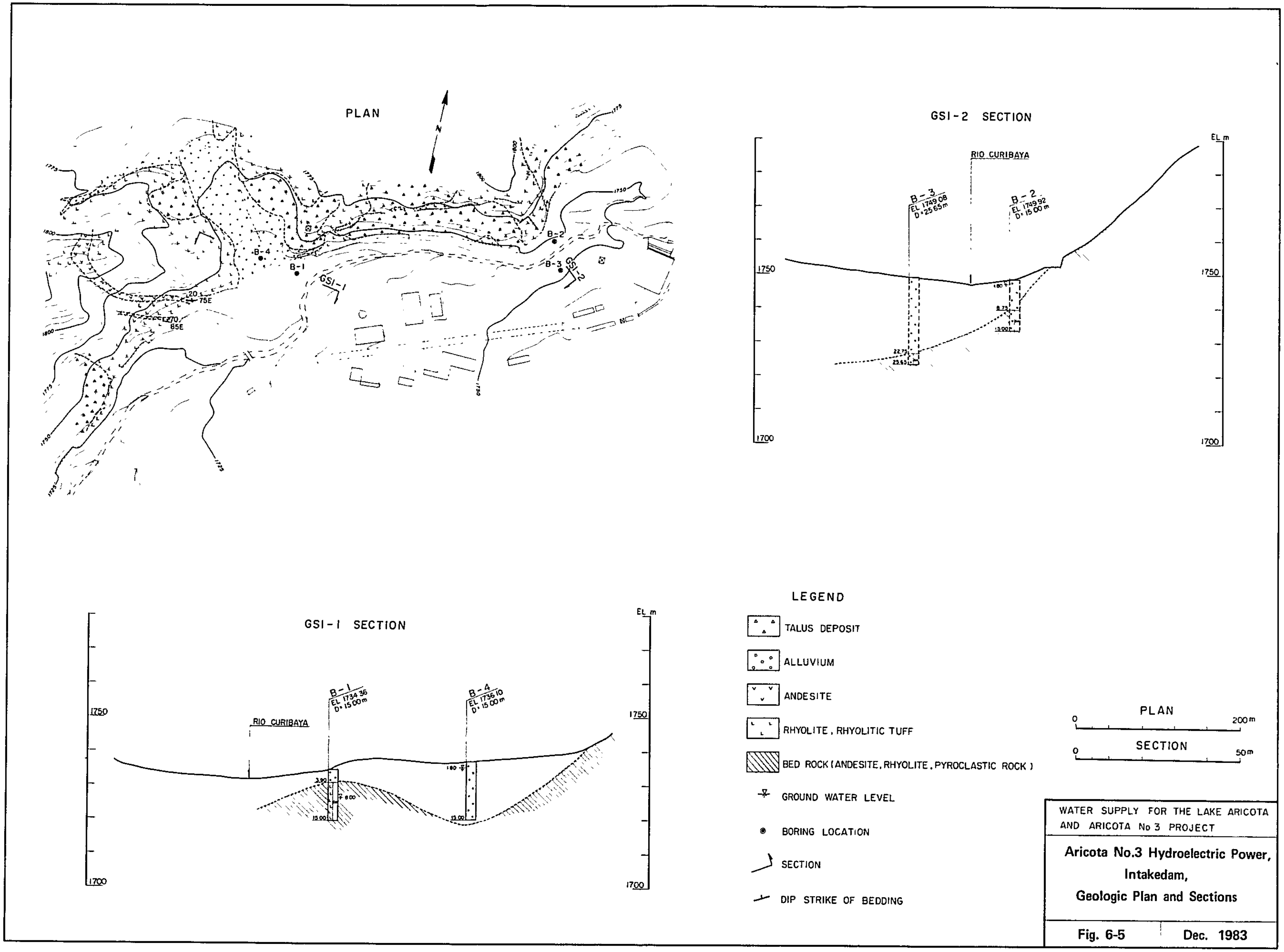
Fig. 6-3	Dec. 1983

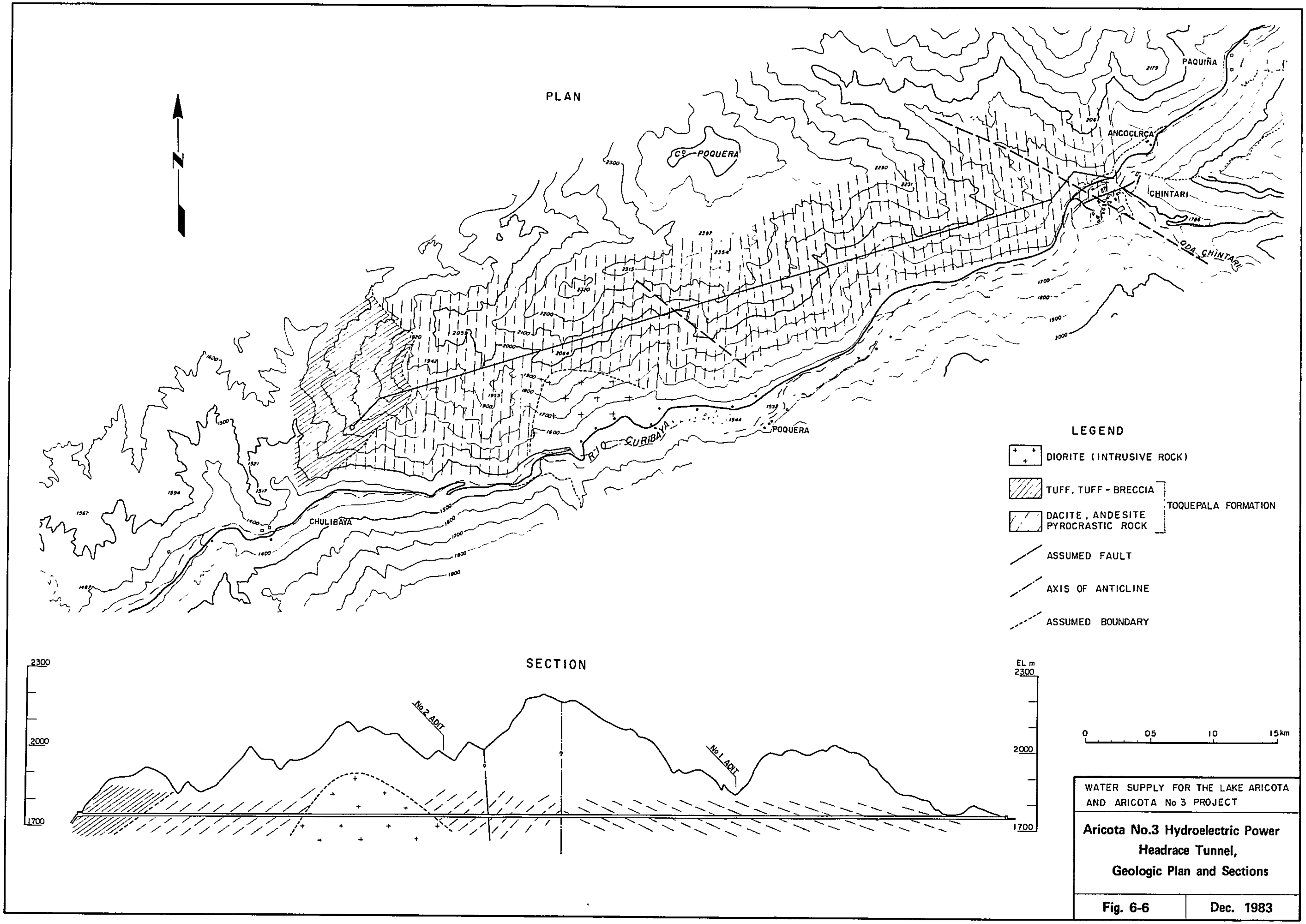


WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No.3 PROJECT

Water Supply Scheme,
Pasto Grande Dam Site,
Geologic Section

Fig. 6-4 | Dec. 1983

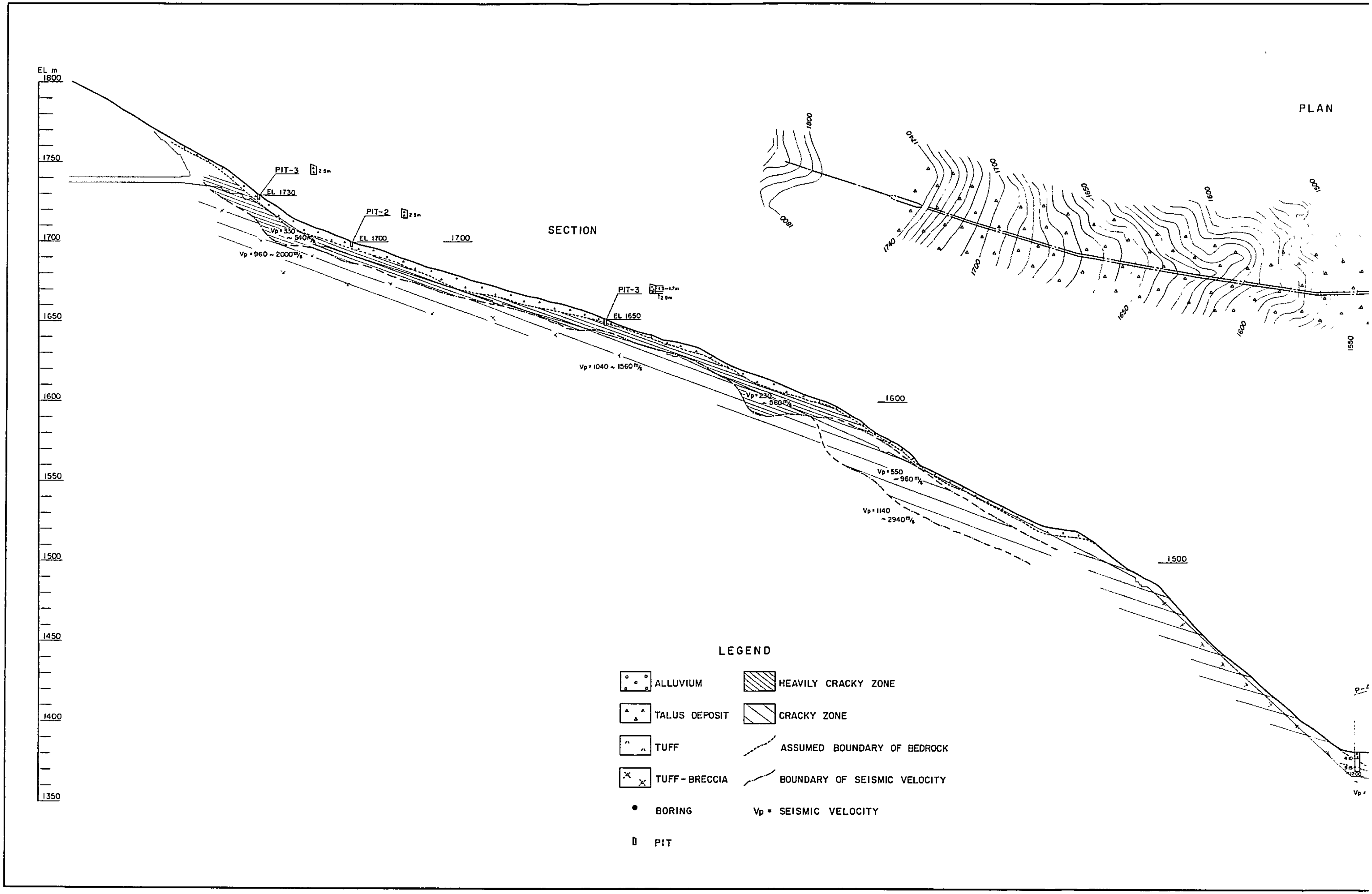

PLAN
N
B-4
B-1
GSI-1
B-2
B-3
GSI-2
20
75E
E270
85E
1800
1775
1750
1725
GSI-2 SECTION
RIO CURIBAYA
B-3
EL 1749.08
D=25.65m
B-2
EL 1749.92
D=15.00m
EL m
1750
1700
GSI-1 SECTION
RIO CURIBAYA
B-1
EL 1734.36
D=15.00m
B-4
EL 1736.10
D=15.00m
LEGEND
TALUS DEPOSIT
ALLUVIUM
ANDESITE
RHYOLITE, RHYOLITIC TUFF
BED ROCK (ANDESITE, RHYOLITE, PYROCLASTIC ROCK)
GROUND WATER LEVEL
BORING LOCATION
SECTION
DIP STRIKE OF BEDDING
PLAN
0
200m
SECTION
0
50m
WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT
Aricota No.3 Hydroelectric Power, Intakedam, Geologic Plan and Sections
Fig. 6-5
Dec. 1983



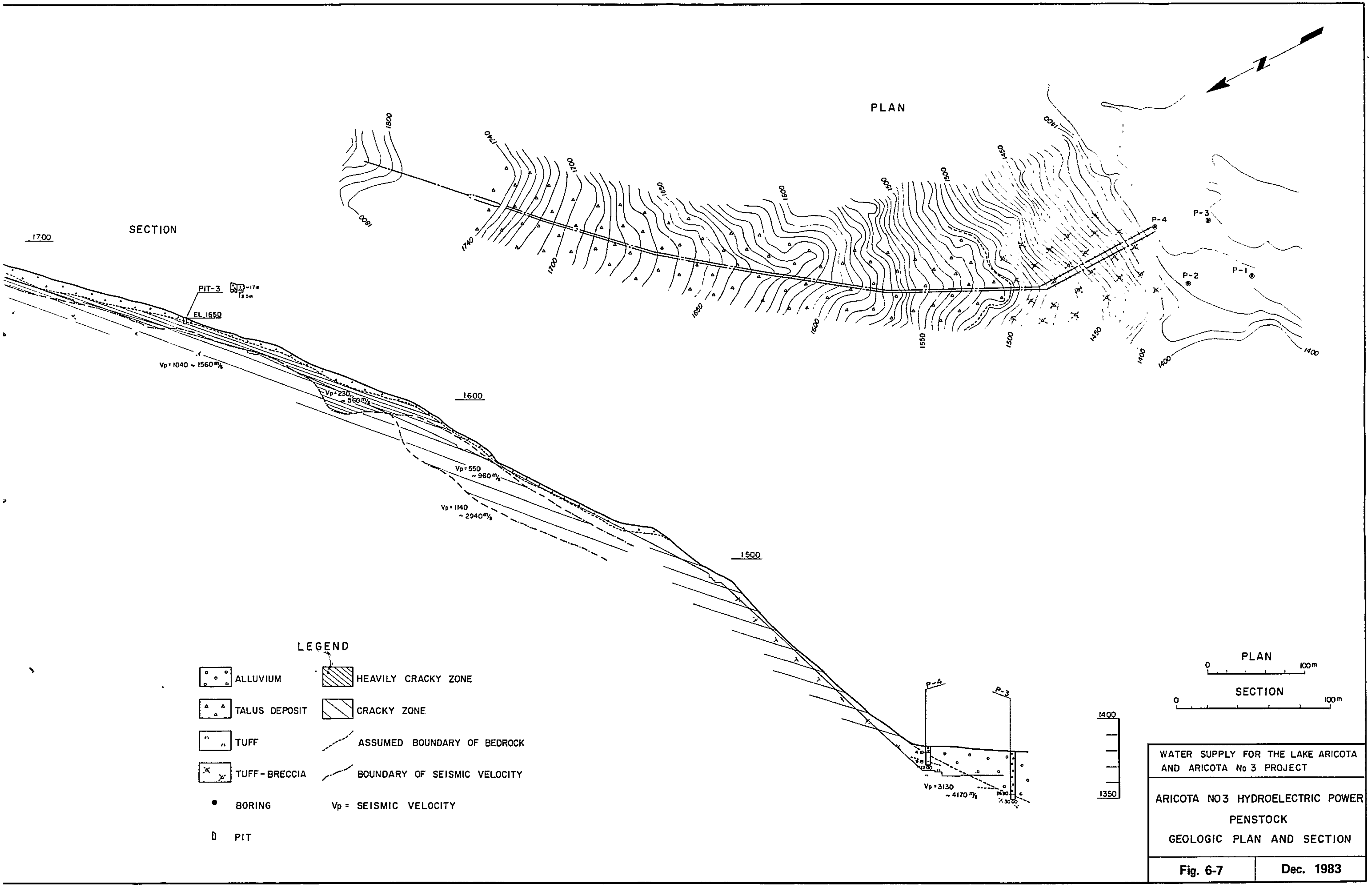
WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT

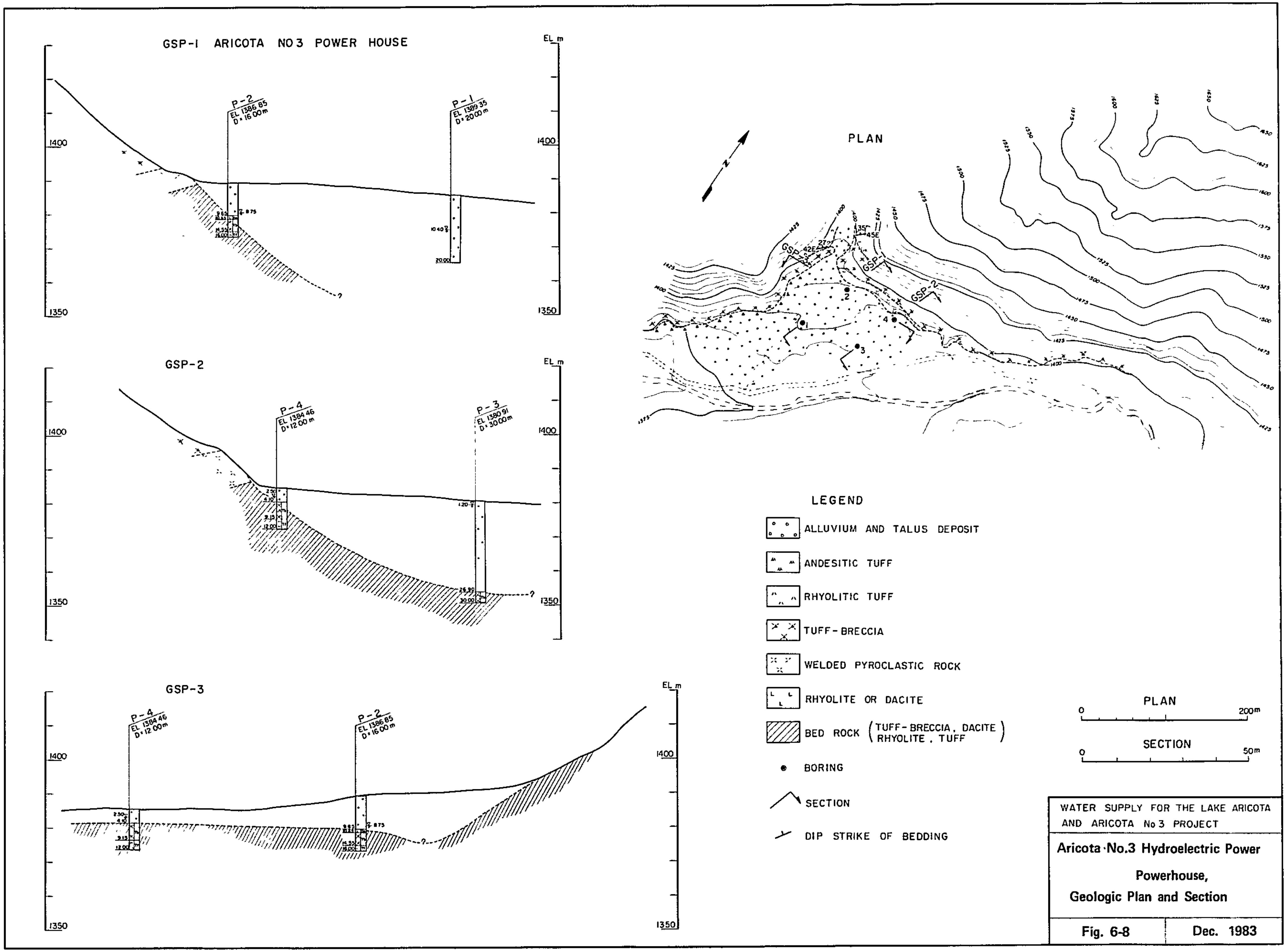
Aricota No.3 Hydroelectric Power Headrace Tunnel, Geologic Plan and Sections

Fig. 6-6 | **Dec. 1983**



SECTION
PLAN
EL m
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
PIT-3
EL 1730
PIT-2
EL 1700
PIT-3
EL 1650
Vp = 330 ~ 540m/s
Vp = 960 ~ 2000m/s
Vp = 1040 ~ 1560m/s
Vp = 230 ~ 560m/s
Vp = 550 ~ 960m/s
Vp = 1140 ~ 2940m/s
LEGEND
ALLUVIUM
TALUS DEPOSIT
TUFF
TUFF-BRECCIA
BORING
PIT
HEAVILY CRACKY ZONE
CRACKY ZONE
ASSUMED BOUNDARY OF BEDROCK
BOUNDARY OF SEISMIC VELOCITY
Vp = SEISMIC VELOCITY


PLAN
SECTION
PIT-3
EL 1650
Vp=1040 ~ 1560 m/s
Vp=230 ~ 560 m/s
Vp=550 ~ 960 m/s
Vp=1140 ~ 2940 m/s
Vp=3130 ~ 4170 m/s
1700
1600
1500
1400
1350
P-1
P-2
P-3
P-4
LEGEND
ALLUVIUM
TALUS DEPOSIT
TUFF
TUFF-BRECCIA
BORING
PIT
HEAVILY CRACKY ZONE
CRACKY ZONE
ASSUMED BOUNDARY OF BEDROCK
BOUNDARY OF SEISMIC VELOCITY
Vp = SEISMIC VELOCITY
PLAN 0 100m
SECTION 0 100m
WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT
ARICOTA NO3 HYDROELECTRIC POWER
PENSTOCK
GEOLOGIC PLAN AND SECTION
Fig. 6-7
Dec. 1983



WATER SUPPLY FOR THE LAKE ARICOTA AND ARICOTA No 3 PROJECT

Aricota No.3 Hydroelectric Power Powerhouse, Geologic Plan and Section

Fig. 6-8 | **Dec. 1983**