CENTRALES ELECTRICAS DEL CAUCA S. A.

REPUBLIC OF COLOMBIA

FEASIBILITY REPORT
ON
JULUMITO HYDRO-ELECTRIC PROJECT

APPENDIX

AUGUST 1972

OVERSEAS TECHNICAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

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APPENDIX I

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FOR DEFINITE STUDIES

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I FIELD INVESTIGATION WORKS REQUIRED FOR DEFINITE STUDIES

As recommended in Chapter 2, "CONCLUSION AND RECOMMENDATION", in order to carry out definite design of the Julumito Hydroelectric Project, further detailed investigations and testing must be conducted for the project site.

The contents of the various investigations which will be necessary to complete prior to start of definite design are described below.

It should be added that it would be desirable for these investigations to be carried out in accordance with the schedule of Fig. I-1.

I-1 TOPOGRAPHIC SURVEY

I.1.1 General Map of Project Area

In regard to maps covering the entire area of the Julumito Project including the sites of structures, reservoir, etc., there is presently available a 1/10,000-scale aerial photographic survey map with contour line intervals of 25 m: this should be supplemented and modified to prepare a general map of the project area with contour line intervals of 5 m.

I.1.2 Datum Point Surveying (See Fig. I-2)

Surveying should be carried out to establish a datum triangulation network for the entire project area, especially to interconnect the sites at which civil structures will be provided. Triangulation stations should be provided and the respective coordinates established.

The coordinates of the above datum points must be the criteria for the general map of the project area (1/10,000) of I.1.1, and for the river profile levelling and topographical surveying described below.

I.1.3 River Profile Levelling (See Fig. I-3)

River profile levelling of the rivers mentioned below should be carried out.

(1) Rio Cauca

Approximately 30 km starting from the junction of the Rio Cauca and Rio Sate to the Rio Cauca Diversion Dam site approximately 500 m above the upstream Cauca Bridge.

(2) Rio Palacé

2 kilometers both upstream and downstream of the Rio Palacé Diversion Dam site or a total of 4 km.

(3) Rio Blanco

2 kilometers both upstream and downstream of the Rio Blanco Diversion Dam site or a total of 4 km.

(4) Rio Sate

Approximately 10 km from the dam site and upstream.

I.1.4 Topographical Survey (See Fig. I-2)

Topographical surveys should be carried out for the construction sites of the civil structures tabulated below.

Place	Scale	Contour Line Interval (m)	Area (km^2)
Reservoir Area	1/10,000	2.0	5.40
Rio Cauca Diversion Dam Site	1/500	2.0	0.51
Rio Palacé Diversion Dam Site	1/200	2.0	0.83
Rio Blanco Diversion Dam Site	1/200	1.0	0.56
Cauca Diversion Waterway	1/2,000	2.0	1.21
Palacé Diversion Waterway	1/2,000	2.0	6.00
Dam Site	1/500	2.0	0.81
No. 1 Dike Site	1/500	2.0	0.16
No. 2 Dike Site	1/500	1.0	0.24
Waterway	1/2,000	2.0	0.48
Powerhouse Site	1/500	2.0	0.14
Quarry Site	1/1,000	5.0	0.10
Borrow Area	1/1,000	5.0	0.33

I-2 HYDROLOGIC AND METEOROLOGIC INVESTIGATION WORKS

I.2.1 Hydrologic Investigations

(1) Observation data should continue to be collected and compiled for Julumito Gaging Station on the Rio Cauca, Malvasa Gaging Station on the Rio Palacé and the gaging station on the Rio Sate.

(2) Gaging stations should be installed in the neighborhoods of the diversion dam sites on the Rio Palacé and the Rio Blanco to observe run-offs daily and the data therefrom should be compiled.

(3) The hourly discharges during floods should be observed at the various abovementioned gaging stations and the data therefrom should be compiled.

(4) Besides the above, run-off data from gaging stations on the main stream and tributaries of the Rio Cauca in areas neighboring the project area should be collected and compiled for periods as long as possible.

I.2.2 Meteorologic Investigations

(1) Precipitation Data

(a) Observation records of daily precipitation at the meteorological observation stations of Popayan, Puracé, Coconuco and Florida in the project catchment area should continue to be collected and compiled.

(b) A meteorological observation station should be installed in the catchment area of the Rio Palacé for daily observation of precipitation and the data therefrom should be compiled.

(c) At times of heavy precipitation, hourly precipitations should be observed at the various abovementioned observation stations and the data therefrom should be compiled.

(d) Besides the above, precipitation observation records of meteorological observation stations on the main stream and tributaries of the Rio Cauca in areas neighboring the project area should be collected and compiled for periods as long as possible.

(2) Temperature, Humidity and Evaporation

Daily observation data on temperature, humidity and evaporation at Popayan Meteorological Observation Station should be collected and compiled for periods as long as possible.

I-3 GEOLOGIC INVESTIGATION WORKS

I.3.1 Julumito Dam Site

The investigations and tests indicated below are for the purposes of determining consolidation settlement of the valcanic ash and of confirming the bearing capacities and watertightness of the volvanic ash and weathered andesite.

A. Core Boring

(1) Work quantities (8 holes, total 220 m) are given in Table I-3-1 and the locations of the holes in Fig. I-4.

(2) Geologic logs and daily reports on boring operations will be prepared.

(3) Standing water level should be measured daily prior to start of drilling.

B. Test Pit

Test pits are to be dug in the vicinity of the proposed dam crest (Table I-3-1 and Fig. I-4) for geological surveys, and besides preparing geologic sketches of test pits, loading tests are to be carried out. At every 1-m depth, samples will be taken for the purpose of soil tests.

C. Field Permeability Test

These tests would be conducted by the single packer method utilizing bore holes. With every 5 m of drilling, a packer is to be installed at a point 3 m from the bottom of the hole and water injected at a predetermined pressure. The injection pressure would be a maximum of about 1.5 times the water pressure of the stored water at the test location and would be fluctuated in stages between these limits. Namely, pressure rise and pressure drop will be in accordance with the following.

Pressures in bore holes at river bed

$3\ kg/cm^2 - 5\ kg/cm^2 - 10\ kg/cm^2 - 5\ kg/cm^2 - 3\ kg/cm^2$

Pressures in bore holes at wings of dam

$1\ kg/cm^2 - 3\ kg/cm^2 - 1\ kg/cm^2$

In carrying out the tests, considerations should be given to prevent excessive pressures acting near the mouths of the holes and the pressure down to 5 m from the mouths should be held to $1\ kg/cm^2$ or lower.

D. Field Loading Test

These tests will be carried out to estimate the bearing capacities of the volcanic ash and the weathered andesite lava. The tests are to be made utilizing trenches, test adits and test pits from which load-settlement curves are to be prepared and yielding loads calculated.

The locations for testing would be as tabulated below.

Test point of "in situ" loading test utilized test adit and test pit

Name of test adit or test pit		Test point	Number of test point	Remark
		(From portal in meter)		
Adit	A - 1	2, 5 and 10	3	
	A - 2	do	3	
	A - 3	do	3	
	A - 4	do	3	
Test		1, 3 and 5m deep	3	
adit		do	3	

E. Tests Using Undisturbed Samples

The items of test would be as follows:

(1) Permeability test

(2) Direct shearing test; consolidated undrained shearing tests to be carried out and displacement-stress curves during consolidation and shear to be prepared.

(3) CBR test; correlations with direct shearing tests, triaxial compression tests and consolidation tests to be determined and used as part of data for evaluation of the dam foundation.

(4) Triaxial compression test; consolidated, undrained shearing tests and consolidated drained shearing tests will be conducted.

(5) Consolidation test

Accompanying the above tests to be carried out in order to consider the permeability, consolidation settlement and shear strength of the basement, the following tests and measurements should be conducted on the same sample.

(i) Natural water content

(ii) Field density

(iii) Dry density

(iv) Specific gravity of soil particles

(v) Gradation analysis; particularly, distribution of particles of 0.074 mm and under.

(vi) Relative consistency; to be tested at natural water content insofar as possible and the water content at time of test to be measured. When testing at liquid limit, the sample to be thoroughly kneaded.

(vii) Calculation of degree of saturation and void ratio on site

I.3.2 Dike No. 1 Site

The following investigations are to be carried out to study the bearing capacity and watertightness of foundation of Dike No. 1.

A. Core Boring

Work quantities (3 holes, total 75 m) are given in Table I-3-1 and the locations of the holes in Fig. I-6.

B. Test Pit

(1) Work quantities (4 pits, total 20 m) are given in Table I-3-1 and the locations of the pits in Fig. I-6.

(2) Undisturbed samples are to be collected at depths of 1 m, 3 m and 5 m and the same tests as for samples from the Julumito dam site are to be performed.

C. Field Permeability Test

Permeability tests are to be carried out utilizing boring holes by the same methods as at the Julumito dam site.

I.3.3 Dike No. 2 Site

The following investigations are to be carried out to study the bearing capacity and watertightness of foundation of Dike No. 2.

A. Test Pit

(1) Work quantities (5 pits, total 25 m) are given in Table I-3-1.

(2) Undisturbed samples are to be collected at depths of 1 m, 3 m 5 m and permeability tests, consolidation tests and CBR tests are to be carried out. The test procedures are to be the same as for those of the Julumito dam site.

B. Field Permeability Test

Tests will be made by the method of constant head utilizing test pits.

I.3.4 Intake and Surge Tank Sites

Core borings will be carried out to clarify the geological conditions of the intake and surge tank foundations. The quantities would be 1 hole, 50 m, at the intake site and 1 hole, 70 m, at the surge tank site.

I.3.5 Rio Cauca Diversion Dam Site

Core borings and permeability tests utilizing bore holes will be carried out to determine the states in which river deposits and terrace deposits exist for obtaining information with regard to foundation excavation and foundation treamtent.

A. Core Boring

Work quantities (3 holes, total 150 m) are given in Table I-3-1 and the locations of the holes in Fig. I-8.

B. Field Permeability Test

Permeability tests would be conducted setting single packers at 3 m from the bottom of a hole with every 5 m of drilling. In case packers cannot be set well in sand-bravel layers, cementation will be carried out for the top 2 m of the 5-m depths and the packers set at these portions. The pressure to be used in water injection is to be a maximum of about 3 kg/cm^2, but near the ground surface, the pressure should be reduced to prevent leakage of the injected water to the ground surface.

I.3.6 Construction Materials

(1) Quarry Site

The investigation site is comprised of andesite lava flowed more or less horizontally. Although investigations by test adits are desirable, it was decided that surveys by core boring would be made as the topography is rugged and the rock is in the form of a horizontal layer.

1) Work quantities (2 holes, total 330 m) are given in Table I-3-1 and the locations of the holes in Fig. I-9.

2) Density and absorption tests will be carried out utilizing the cores sampled. It is desirable for unconfined compressive strengths to be measured.

(2) Borrow Area

The material which can be utilized for the impervious core of the dam is limited to volcanic ash. Since this material is fine-grained, the imperviousness is good, but because of the high water content, there are various problems involved such as consolidation settlement, occurrence of pore pressure during embankment and trafficability of construction equipment.

Therefore, the characteristics of the volvanic ash should be studied and the results reflected in engineering technologies such as construction methods and embankment quality control.

A. Core Borings

1) Work quantities (2 holes, total 80 m) are given in Table I-3-1 and the locations of the holes in Fig. I-9.

2) The procedures in investigations and operations would follow those for the Julumito dam site, but cores collected are to be used as necessary as samples for soil tests.

B. Test Pits

1) Work quantities (4 pits, total 60 m) are given in Table I-3-1 and the locations of the pits in Fig. I-9.

2) Samples for soil tests are to be collected at every meter of depth. The samples may be disturbed, but wet densities and water contents are to be measured on site at the places of sampling.

C. Soil Tests

The items of soil tests are as follows with brief comments added for items requiring special attention:

1) Field wet density

2) Natural water contents

3) Gradation analysis: Analyses to be made of -0.074-mm sized to clarify silt and clay components

4) Consistency; to be carried out for liquid limits and plastic limits. Samples to be used in conditions close to natural water contents and water immediately before testing to be clearly noted in data

5) Classification; according to Unified Classification System (USBR) and Revised PR System (AASHO)

6) Density of soil particle

7) Void ratio in natural state

8) Degree of saturation in natural state

9) Large-scale compaction permeability test; method of compaction to be based on Modified Proctor, Large Scale (AASHO)

Remarks:

The sample for this test should be air-dried. Sample oven-dried and then added with water should not be used. However, when there is need for hurry, it would be permissible to oven-dry at temperatures below $60^{O}C$ for preparation of samples.

In compaction tests, samples prepared at various water contents should be used and repeated utilization of the same sample must be avoided.

10). Small-scale compaction permeability test; method of compaction to be based on Modifed Proctor, Small Scale (AASHO)

Remarks:

Refer to coefficient of permeability in large-scale compaction permeability test of 9).

11) CBR test; use samples compacted at optimum water content

12) Triaxial compression test; consolidated drained test and consolidated undrained test to be carried out

13) Consolidation test

14) Direct shearing test; conduct consolidated undrained shearing test. Clearly note displacements and stresses during consolidation and shear processes

15) Collection of information and study regarding dam embankment method the core material to be used is volcanic ash which is fine-grained and moreover of high water content and possesses characteristics differing from ordinary soil materials. For example, in case compaction tests are made of the material close to the natural water content, the specimen may indicate fluidity before the specified number of rammer blows is reached to make further compaction impossible. This behavior has a connection with deterioration phenomena of soil materials due to excessive kneading and overcompaction in actual construction. Therefore, since strength and trafficability of the soil will differ according to the work quantity of compaction even at the same optimum water content, it is necessary for the optimum work quantity to be calculated. In order to gain an outlook on this matter, the degrees of saturation and air void ratios of samples varying the number of rammer blows in the compaction test (Modifed Proctor, Small Scale (AASHO)) should be calculated. Also, the relationships, between number of rammer blows and strengths such as in cone tests, Proctor penetration tests or CBR tests are to be graphically expressed. It is thought suitable for the degree of saturation of the soil at which maximum strength is produced to be calculated using such data as references with this degree of saturation to be used as a measure of embankment quality control of the core. Further, the compaction work quantity showing the optimum degree of saturation may be used as a reference for the rolling method in execution of construction.

Table I-3-1 List of Proposed geological investigation works (sheet 1 of 2)

(1) Core boring

Site	Nate of hole	Location	Angle of hole	Length of hole (m)	Remarks
Julumito dam (main dam)	DH-206	left bank	vertical	30	final size of hole, BX.
	DH-207	do	do	40	do
	DH-208	right bank	do	30	do
	DH-209	do	do	40	do
	DH-210	river bed	do	20	do
	DH-211	do	do	20	do
	DH-212	do	do	20	do
	DH-213	do	do	20	do
	Total	8 holes,	220m long.		
Dike No. 1	DDH-101	left bank	vertical	25	final size of hole, NX.
	DDH-102	right bank	do	25	do
	DDH-103	river bed	do	25	do
	Total	3 holes,	75m long		
Intake Surge tank	DH-8		vertical	50	final size of hole, BX.
	DH-9		do	70	do
Rio Cauca diversion dam	CDH-1	left bank	vertical	30	final size of hole, BX
	CDH-2	right bank	do	30	do
	CDH-3	do	do	30	do
	CDH-4	river bed	do	30	do
	CDH-5	do	do	30	do
	Total	5 holes	150m long.		
Borrow area	BDH-1		vertical	40	final size of hole, NX.
	BDH-2		do	40	do
	Total	2 holes	80m long		
Quarry	QDH-1		vertical	150	final size of hole, NX.
	QDH-2		do	180	do
	Total	2 holes	330m long.		
	Grand total	22 holes	975m long.		

The schedule of proposed works is indicated in Table I-1-2.

Table I-3-1 List of proposed geological investigation works (sheet 2 of 2)

(2) Test pit

Site	Name of pit	Location	Depth of pit pit (m)	Remark
Julumito dam (main dam)	TP-201	left bank	7	
	TP-202	do	7	
	TP-203	right bank	7	
	TP-204	do	7	
	Total	4 pits	28m long	
Dike No. 1	DTP-101	left bank	5	
	DTP-102	do	5	
	DTP-103	right bank	5	
	DTP-104	do	5	
	Total	4 pits	20m long	
Dike No. 2	DTP-201		5	
	DTP-202		5	
	DTP-203		5	
	DTP-204		5	
	DTP-205		5	
	Total	5 pits	25m long	
Borrow area	BTP-101		15	
	BTP-102		15	
	BTP-103		15	
	BTP-104		15	
	Total	4 pits	60m long	
	Grand total	17 pits	133m long	

The schedule of proposed works is indicated in Table I-1-2.

Fig. I-1-(1) Schedule of Field Investigation Works for Definite Study (1)

Items	Quantity	1973 Oct.	Nov.	Dec.	1974 Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	1975 Jan.	Feb.	Mar.	Apr.	May	Jun.
Triangulation and Leveling	Station of Triangulation (24 pointe)	—	—	—	—	—	—	—														
River Profile and Leveling	Rio Cauca 30.0 km Rio Palace 4.0 Rio ; 4.0 Rio Sate 10.0							—	—	—												
Topographical Survey	(km²)																					
Reservoir Area (1/10.000)	5.40							—	—	—												
Diversion Dam Site																						
Rio Cauca (1/500)	0.51										—	—										
Rio Palacé (1/200)	0.83											—	—									
Rio Blanco (1/200)	0.56												—									
Diversion Waterway																						
Cauca (1/2.000)	1.21													—	—							
Palacé (1/2.000)	6.00															—	—	—				
Dam Site (1/500)	0.81									—	—	—										
No.1 Dike Site (1/500)	0.40												—									
No.2 Dike (1/500)													—	—								
Waterway (1/2.000)	0.48															—	—					
Powerhouce Site (1/500)	0.14													—	—	—						
Quarry Site (1/1.000)	0.10																	—	—			
Borrow Area (1/1.000)	0.33																			—		
Check of Existing Aerial Topographical Map																			—	—	—	—
Preparation of Hydrogic Data		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Preparation of Meteorological Data		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→

Fig. I-1-(2) Schedule of Field Investigation Works for Definite Study (2)

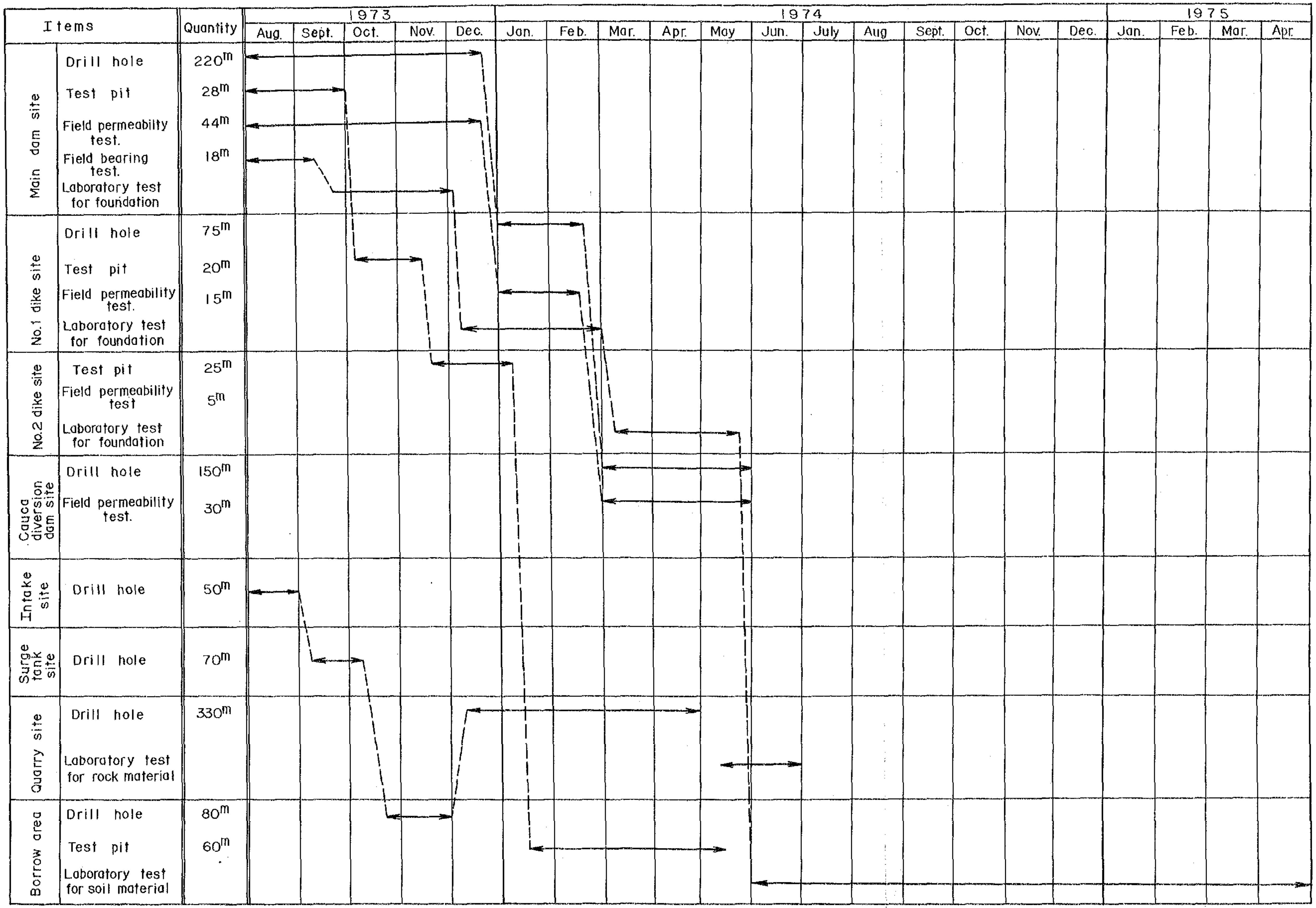
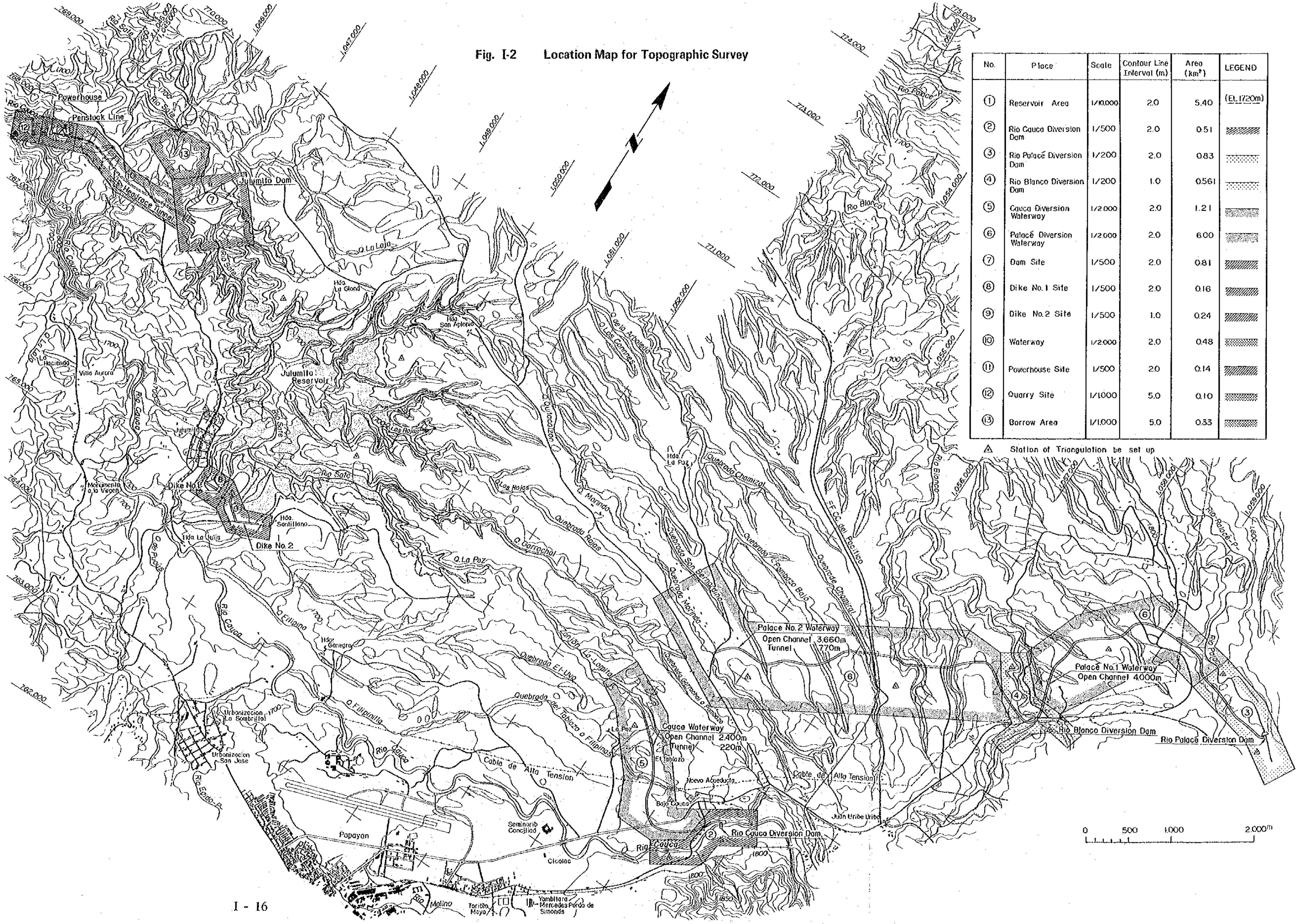


Fig. I-2 Location Map for Topographic Survey



No.	Place	Scale	Contour Line Interval (m)	Area (km²)	LEGEND
①	Reservoir Area	1/10,000	2.0	5.40	(EL.1720m)
②	Rio Cauca Diversion Dam	1/500	2.0	0.51	
③	Rio Palacé Diversion Dam	1/200	2.0	0.83	
④	Rio Blanco Diversion Dam	1/200	1.0	0.561	
⑤	Cauca Diversion Waterway	1/2,000	2.0	1.21	
⑥	Palacé Diversion Waterway	1/2,000	2.0	6.00	
⑦	Dam Site	1/500	2.0	0.81	
⑧	Dike No.1 Site	1/500	2.0	0.16	
⑨	Dike No.2 Site	1/500	1.0	0.24	
⑩	Waterway	1/2,000	2.0	0.48	
⑪	Powerhouse Site	1/500	2.0	0.14	
⑫	Quarry Site	1/1,000	5.0	0.10	
⑬	Borrow Area	1/1,000	5.0	0.33	

△ Station of Triangulation be set up

Fig. I-3 Route Map of River Profile Levelling

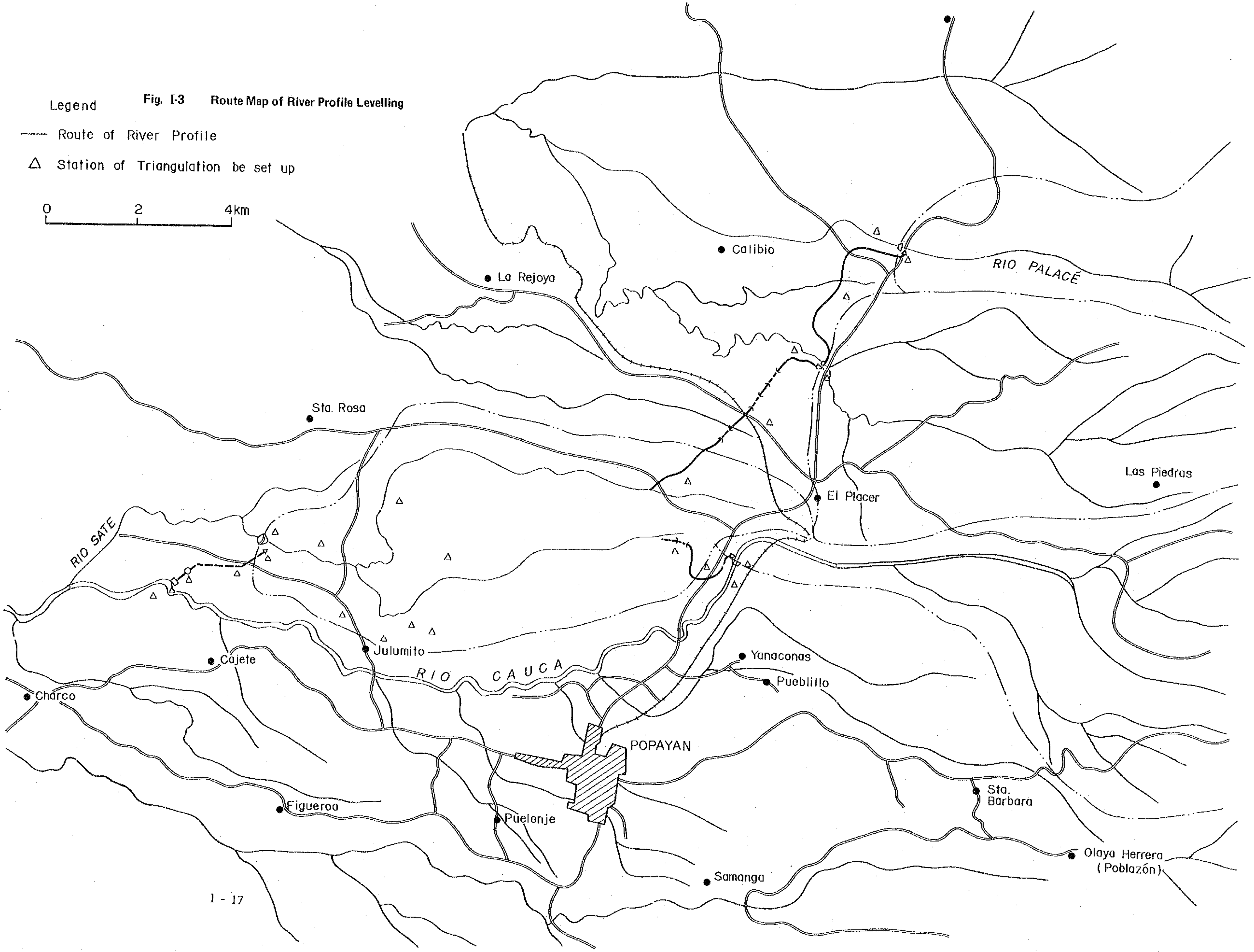


Fig. I-4 Location Map for Recommended Geological Investigation Works at Dam Site (Plan)

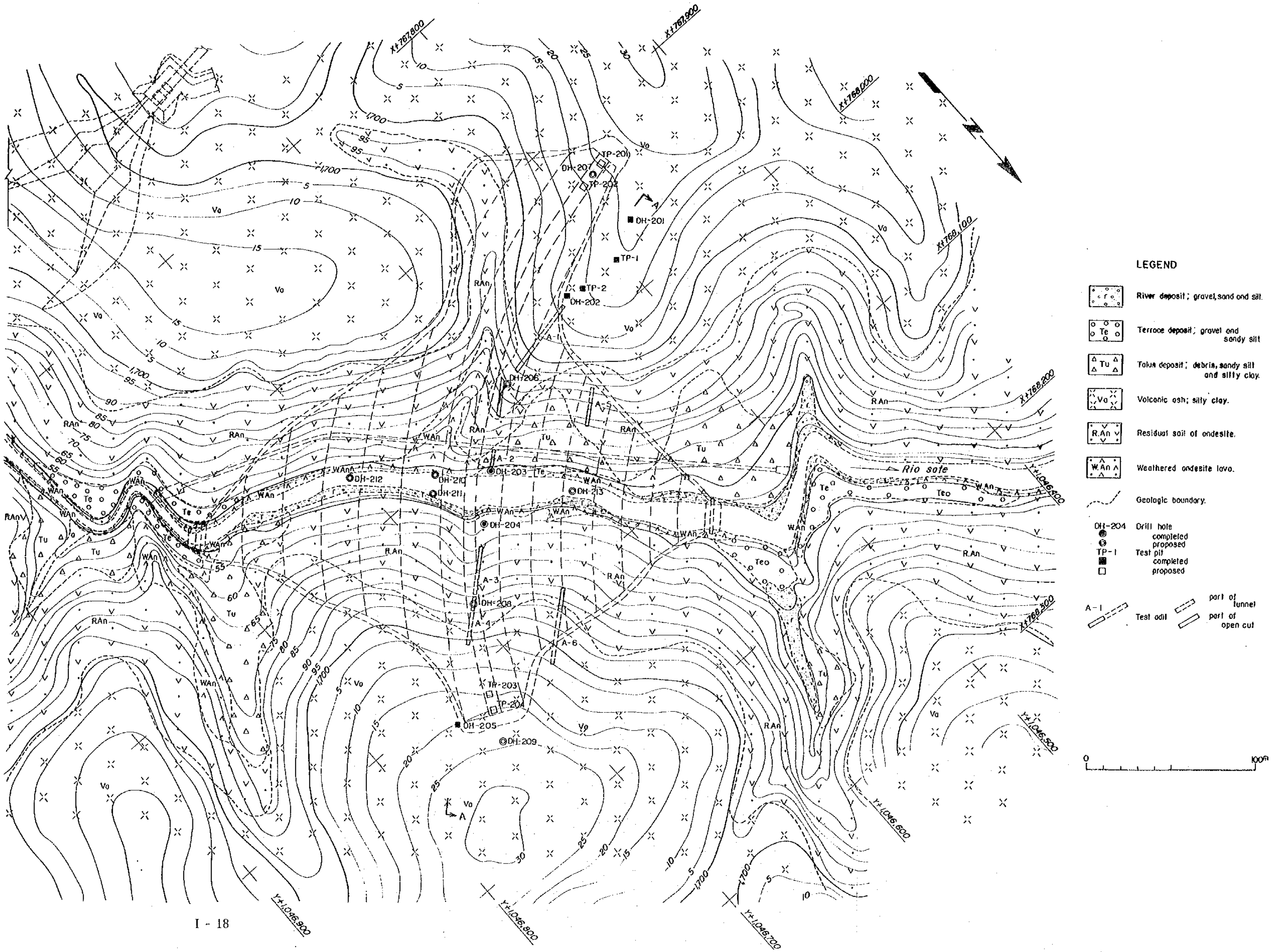


Fig. I-5 Location Map for Recommended Geological Investigation Works at Dam Site (Section)

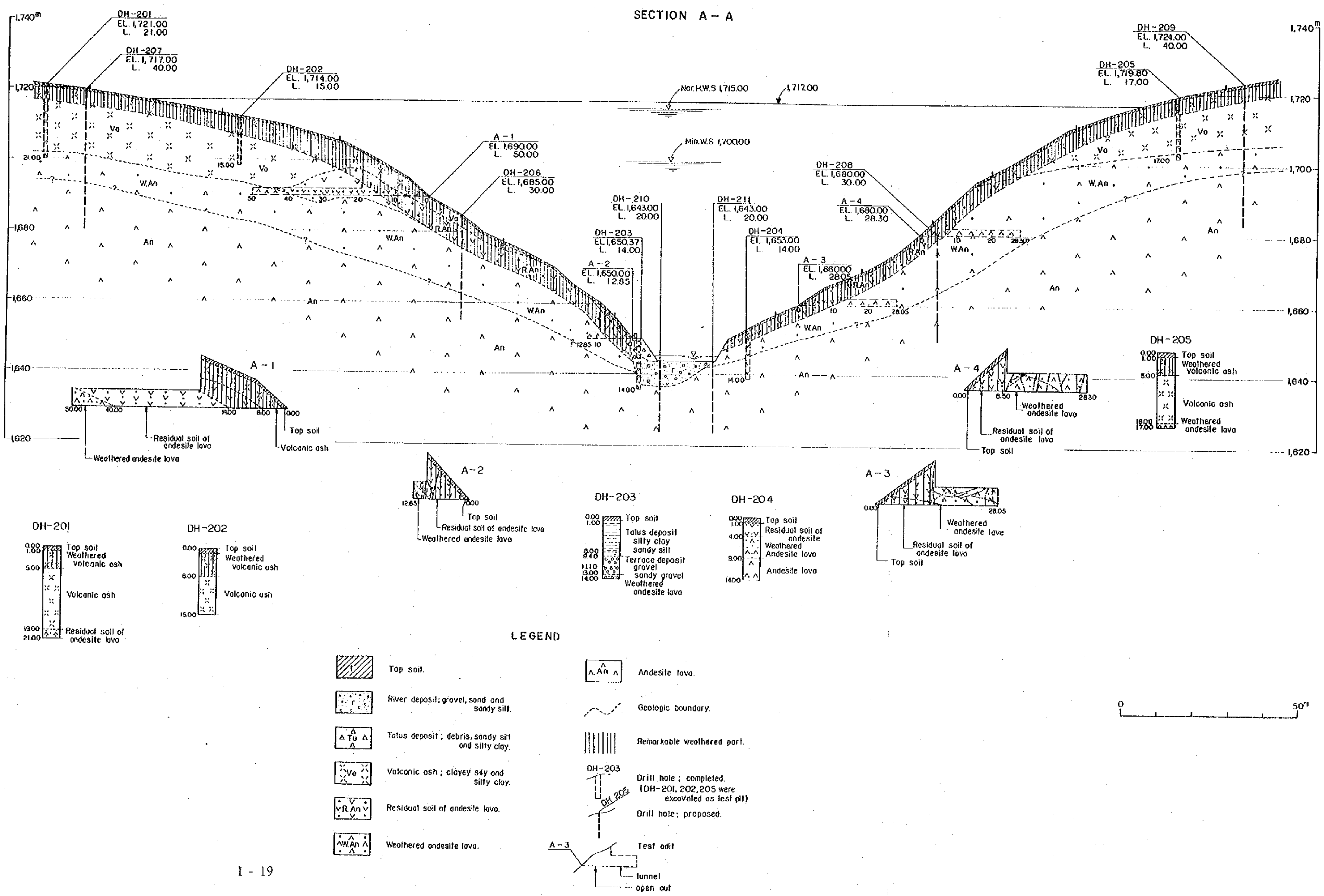


Fig. I-6 Location Map for Recommended Geological Investigation Works at Dike No. 1 Site (Plan and Section)

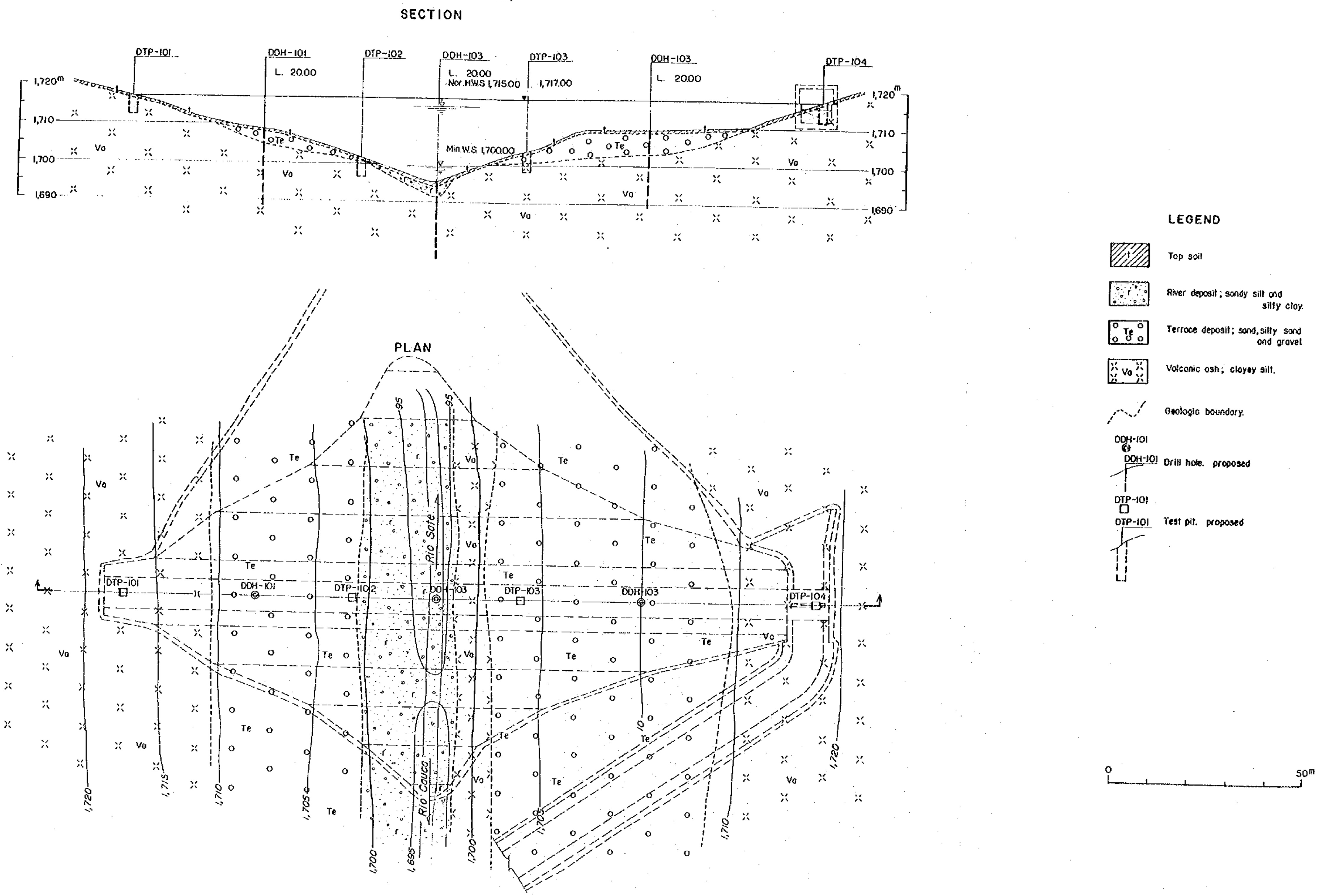


Fig. I-7 Location Map for Recommended Geological Investigation Works at Waterway and Powerhouse Site (Plan and Section)

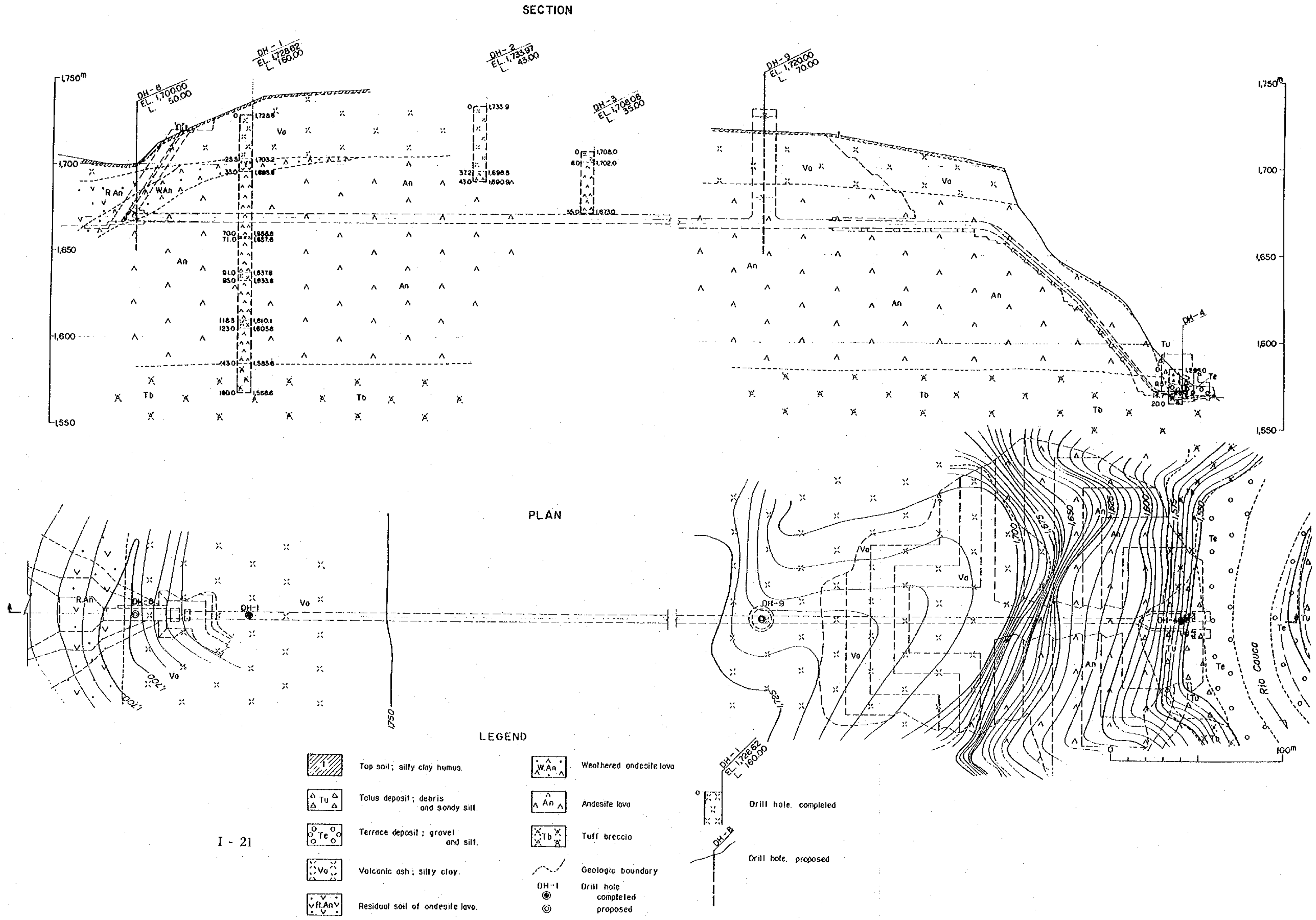


Fig. 1-8 Location Map for Recommended Geological Investigation Works at Rio Cauca Diversion Dam Site (Plan and Section)

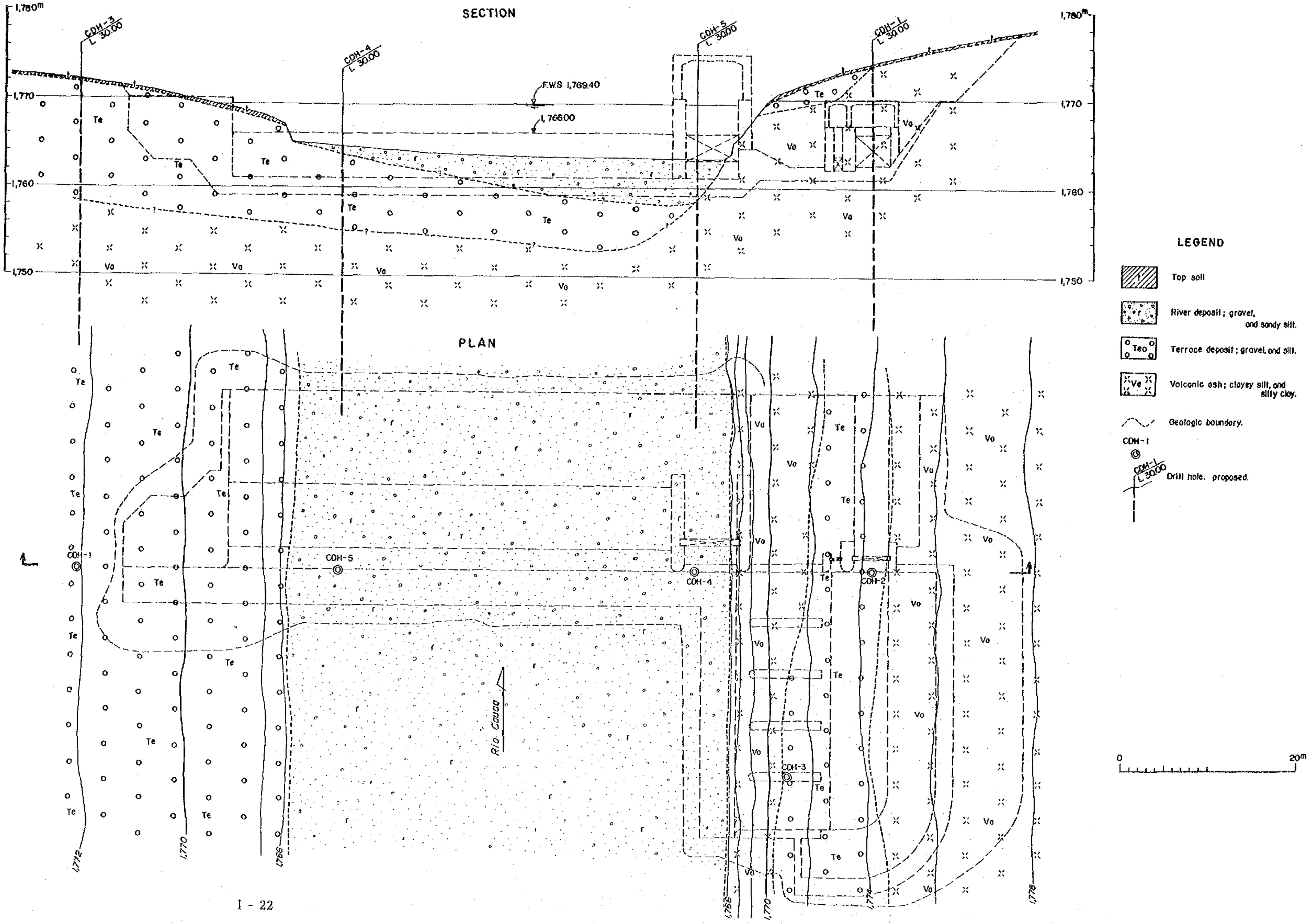


Fig. I-9 Location Map for Recommended Geological Investigation Works at Borrow Area and Quarry Site (Plan)

APPENDIX II

STUDY OF CEDELCA-CEDENAR SYSTEM

AS AFFECTED BY JULUMITO HYDROELECTRIC PROJECT

APPENDIX II STUDY OF CEDELCA-CEDENAR SYSTEM AS AFFECTED BY JULUMITO HYDROELECTRIC PROJECT

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II STUDY OF CEDELCA POWER SYSTEM AS AFFECTED BY JULUMITO HYDROELECTRIC PROJECT

Julumito Hydroelectric Power Station (26.5 MW x 2) is to be interconnected into the CEDELCA System to fill the increase in demand of the southern region of Colombia going through the substations of Popayan, Rio Maya, Pasto and Ipiales.

In the present examination of the electric power system, power flow and voltage regulation calculations, transient stability calculations and short-circuit capacity calculations were made using a digital computer (IBM-360-5061) and the necessary conditions for operation of the power system were obtained.

II.1 PREMISES

In examination of the CEDELCA System the following premises were established.

(a) The existing power system consists of the Transmission Line, 115 kV, extending over a distance of 400 km from Pance Substation (CVC) to Ipiales Substation in Southern Colombia and 33 kV feeders spreading out from the various substations. The CEDELCA System as related to the Julumito Project is shown in Fig. II-1.

(b) Julumito Power Station is to be connected to CEDELCA System at Popayan Substation at the end of 1981 by a 115 kV, single circuit transmission line having a length of 10 km.

(c) The load forecast up to 1985 for the substations are projected to be as shown in Table II-1. Load at off-peak hours are assumed from present and forecasted daily load curves.

(d) The supply capability consists of the existing Rio Mayo Power Station (21 MW), small hydro stations parallel to the 33 kV, and Florida II Power Station (24 MW) to be commissioned in September, 1973, while any deficiencies can be expected to be filled from Pance Substation to which an interconnection will be made. In 1982, Julumito Power Station (53 MW) will start operation to meet the increased demand of these areas.

(e) The diesel power plant connected in the secondary, 33 kV system of Pasto Substation is to be used as reserve capacity from 1976 and after.

II.2 CALCULATIONS OF POWER FLOW AND VOLTAGE REGULATION

As mentioned above, Julumito Power Station will be connected to interconnecting line at Popayan Substation along with Florida II Power Station from where power must be transported to meet the load of the Pasto and Ipiales districts by the transmission line which is as much as 250 km in length. Power flow and voltage regulation were calculated for the 5 years of 1976, 1978, 1980, 1982 and 1985 to find a way to operate the system easily and to insure economical investment, and the studies made included selecting of voltages of various substations and taps of transformers, taking into consideration the investments for the installation of phase modifying facilities (static condensers) and addition of transmission line which will become necessary in the future. The impedance map used in power flow calculations is given in Fig. II-2.

The results of calcualtions are as indicated in Fig. II-3 ~ Fig. II-7. The following conditions were assumed for the power flow calculations:

(a) The load factor was taken to be 0.90 based on the present load factor and the future demand structure.

(b) The voltage at the interconnecting point of Pance Substation where an interconnection is to be made to a 220 kV system was taken to be 100%.

(c) The substation transformers of 30 MVA units will be added corresponding to loads as shown in Table II-3. However, at Ipiales Substation, a 10 MVA unit is to be added as the demand growth rate there will be small.

(d) Transformers at major substations such as Popayan are equipped with LRT, but those of other substations were assumed to have no-voltage taps ± 5%.

In voltage regulation calculations, it was considered that Popayan Substation, since it would have a major supply power station, would maintain voltages of about 105% (120.75 kV) at peaks. Also, it was considered there would be a voltage regulation of 10% (11.5 kV) to Pasto and Ipiales Substations which are 200 ~ 250 km away from each other and necessary static condensers will be installed at these substations. Further, at off-peak hours, the condition will approach flat regulation.

(1) Voltage Fluctuation

Based on the power flow calculation results, the voltage fluctuations at the various substations are rearranged and given in Table II-4, provided however, that necessary static condensers are considered to be installed at Pasto and Ipiales Substations. The voltage fluctuations at Pasto and Ipiales Substations between peak and off-peak hours would be about 1% in 1976 and 4% in 1985. The voltage fluctuations of other substations will be more of less the same. Further, if Popayan - Pasto were to be made into a double circuit around 1984, the voltage fluctuation would be about 8%. For no-voltage taps of transformers without LRT, 100.0 ~ 102.5% can be used at Popayan Substation and 95% at Pasto and Ipiales Substations. As for the time after Popayan - Pasto becomes double circuit, it would be appropriate for transformer taps of substations lying to the west to be about 97.5%.

In order to supply good quality powr to the CEDELCA System with only the existing transmission lines, it is desirable for LRT of ±10% to be installed at the transformers along with voltage regulating facilities at Pasto and Ipiales Substations which are especially distant load ends.

(2) Installation of Static Condensers

The necessary capacity of static condensers computed from the power flow calculation results of Fig II-3 ~ Fig II-7 and other factors are indicated in Table II-5. The total capacity of static condensers at Pasto and Ipiales Substations will increase from 2.6 MVA in 1976 to 25.5 MVA in 1982 and in 1985 it will be 44 MVA. However, if by 1985 Popayan - Pasto were to be double-circuited, the amount of installation would be reduced to 23.5 MVA.

The static condensers would have relations with the beforementioned transformer tap ranges and would be installed at the secondary side of transformers. The capacities of condensers would be 5 to 10 MVA. Large-scale voltage regulations will be made with the static condensers and minute regulations with transformer taps. The substation voltage fluctuations in this system will not be very large because of these static condensers.

(3) Transmission Line Addition Scheme

The power losses at peak hours of the entire CEDELCA System are shown in Table II-6 both before and after Popayan - Pasto line is made double-circuit.

The 187 km long line between Popayan and Pasto are presently provided with double-circuit steel towers with one circuit strung and it would be a comparatively easy to add the second circuit. From 1980 and after when the load of the Pasto and Ipiales districts will increase, the system loss will be 4.3 MW which will reach 9.5 MW in 1985 and double-circuiting of this line should be considered.

Table II-6 gives comparisons of losses according to the year if double-circuiting is carried out. Savings in peak kW due to the installation of second circuit would be 1.3 MW in 1982 and as much as 4.1 MW in 1985.

(4) Synthesizing the above from the power flow and voltage regulation calculations, it is recommended for the following to be carried out:

(a) Adopt 10% voltage regulation for Popayan - Pasto - Ipiales.

(b) The transformer taps of Julumito Power Station should be 102.5-105.0-107.5%.

(c) The interconnecting transformer to be installed at Pance Substation, in consideration of outage of the largest-unit of the CEDELCA System up to 1985, should be of capacity of around 50 MVA equipped with LRT.

(d) It is desirable for transformers of the various substations to be equipped with ±10% LRT from the standpoint of system operation, and a stable and good quality power supply should be carried out.

(e) Pasto and Ipiales Substations which are at especially distant load areas should hereafter have LRT equipped transformers installed, but further, in consideration of utilization of existing transformers, static condensers should be installed for voltage regulation. The capacities of condensers to be installed after 1976 should be 5 MVA ~ 10 MVA. A total capacity of condensers to be installed at the two substations will reach 25 MVA by 1982.

(f) The capacities of static condenser will have a relation with double-circuiting of the Popayan-Pasto line and should be determined taking this into consideration.

(g) Based on the above, secondary voltages can be adequately maintained stable without problem in the case of LRT ±10% being installed at the transformers of each substation, but also through suitable selection of no-voltage taps for existing transformers.

(h) As Popayan - Pasto is equipped with double-circuit steel towers, additional stringing will be comparatively easy and in consideration of the fact that more than half of the southwestern part of the CEDENAR System is supplied through this transmission line and in view of the items below, the line should be made into a double circuit from 1980.

- o Securing the reliability of power in the southwestern Pasto and Ipiales districts.
- o Reduction in peak kW losses.
- o Savings in static condensers in the southwestern districts.

II.3 STUDY OF SYSTEM STABILITY

The voltage phase difference according to the power flow calculations will be approximately 30 degrees between the busbars of Pance and Ipiales in 1985 when this will be a maximum, but if Popayan - Pasto were to be double-circuit, this will be about 17 degrees and there will be no problem in regard to steady state stability.

As for transient stability, Fig. II-8 shows the result of a comparatively severe fault of 3 LG, 0.14 sec. open at the closest end to Popayan Substation on the Popayan-Cali line. Although the Popayan Power Station as a whole will not be separated or step out from the 220 kV CVC System and is stable, it was learned that around the time of start up of Julumito Power Station, Rio Bobo Power Station and other small hydro power stations parallel to the 33 kV secondary side of Pasto Substation would step out in all cases. As a countermeasure it will be necessary either to separate the secondary 33 kV system at Pasto Substation or to provide stepout relays at each power station.

II.4 SHORT-CIRCUIT CAPACITY

The results of short-circuit capacity calculations are indicated in Figs. II-9-1 and II-9-2. The maximum short-circuit capacity of the Popayan System is 540 MVA or under at Popayan Substation and considering 1985 or an even more future year, it will suffice to adopt CB of 1,000 MVA for Popayan Substation, not more than 1,000 MVA for others and about 1,000 MVA for Julumito Power Station also.

Table II-1 Projected Power Flow

Unit: MW

		1976		1978		1980		1982		1985	
		peak	night	peak	night	peak	night	peak	night	peak	night
Santander	Ⓐ	3.3	1.1	3.9	1.3	4.6	1.6	5.4	1.8	6.8	2.3
Small PS	Ⓑ	2.1	0.7	2.5	0.9	3.0	1.1	3.4	1.1	4.3	1.4
Popayan	Ⓒ	15.7	5.3	18.6	6.3	22.0	7.5	25.7	8.7	32.4	11.0
Pasto	Ⓓ	25.0	5.5	31.4	6.7	37.2	8.0	43.4	9.3	54.7	11.7
"	Ⓔ	1.7	0.4	2.1	0.5	2.5	0.6	2.9	0.6	3.6	0.8
Ipiales	Ⓕ	6.8	1.4	8.4	1.8	10.0	2.1	11.6	2.4	13.7	3.1
Total		54.6	14.4	66.9	17.5	79.3	20.9	92.4	23.9	115.5	30.3

Table II-2 Years of Power Flow and Voltage Regulation Calculation

(1976～1985 10 Case)

Case No.	Year	Peak Night	No. of circuit of Transmission Line between Popayan and Pasto
1	1976	Peak	
2	"	Night	
3	1978	Peak	1 cct
4	1980	Peak	
5	1982	Peak	
6	"	"	2 cct
7	1985	Peak	1 cct
8	"	Night	
9	"	Peak	2 cct
10	"	Night	

Table II-3 Projected Capacity of Transformer

		Transformer Capacity (MVA)					
		1976	1978	1980	1982	1985	
Santander	Ⓐ	10.0	10.0	10.0	10.0	10.0	
Small PS	Ⓑ	5.0	5.0	5.0	5.0	5.0	
Popayan	Ⓒ	26.25	26.25	56.25	56.25	56.25	Addition 30 MVA x 1 in 1980
Pasto	Ⓓ	56.25	56.25	56.25	56.25	86.25	Addition 30 MVA x 1 in 1975 Addition 30 MVA x 1 in 1983
"	Ⓔ	5.0	5.0	5.0	5.0	5.0	
Ipiales	Ⓕ	12.75	12.75	12.75	22.75	22.75	Addition 10 MVA x 1 in 1981

Table II-4 Calculation Results of Voltage Regulation at Each Substations

Unit: %

	Year	1976		1978	1980	1982		1985			
	Transmission Line Poparan-Pasto	1 cct		1 cct	1 cct	1 cct	2 cct	1 cct		2 cct	
	Peak · Night	peak	night	peak	peak	peak	peak	peak	night	peak	night
Primary Side (115 kV) Bus	Cali (Base)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Santander	100.9	100.0	100.7	100.5	101.3	101.3	100.9	100.0	100.9	100.7
	Popayan	103.6	99.7	102.5	101.9	104.6	104.6	103.7	99.8	103.9	102.1
	Rio Mayo	102.6	99.3	101.9	101.0	101.7	102.2	99.5	99.5	100.9	103.5
	Pasto	97.2	97.1	96.6	96.0	95.9	97.9	94.6	97.3	96.5	102.8
	Ipiales	95.7	96.3	94.9	94.1	94.0	95.3	92.8	96.6	94.0	102.1
Secondary Side Bus	Santander	99.4	98.9	99.0	98.4	98.9	98.8	97.7	99.0	97.8	99.7
	Popayan	100.3	97.7	99.2	100.1	102.6	102.6	101.1	99.0	101.3	101.2
	Rio Mayo	106.6	99.1	105.9	105.0	105.6	106.2	103.6	99.3	104.9	103.4
	Pasto	95.0	96.1	95.0	95.0	95.0	95.0	95.0	96.7	95.0	102.2
	Ipiales	95.0	95.2	95.0	95.0	95.0	95.0	95.0	95.9	95.0	101.5

Table II-5 Required Capacity of Static Condenser

Target Voltage: 95% at peak time

Unit: MVA

Transmission Line Popayan-Pasto	1 cct			2 cct		
Installation Point	Pasto	Ipiales	Total	Pasto	Ipiales	Total
1976	–	2.6	2.6	-8.5	1.2	–
1978	6.2	4.4	10.6	-2.3	2.9	–
1980	13.4	6.5	19.9	3.9	4.8	8.7
1982	17.1	8.4	25.5	5.2	5.3	10.6
1985	31.6	12.4	44.0	14.1	9.4	23.5

Table II-6 Transmission Line Loss

(In the case of Static Condenser is installed)

Unit: MW

Transmission Line Popayan-Pasto	1 cct	2 cct	Difference
1976	2.4	2.0	0.4
1978	3.0	2.4	0.4
1980	4.3	3.0	1.3
1982	5.9	4.0	1.9
1985	9.5	5.4	4.1

Fig. II-1 Diagram of CEDELCA-CEDENAR System

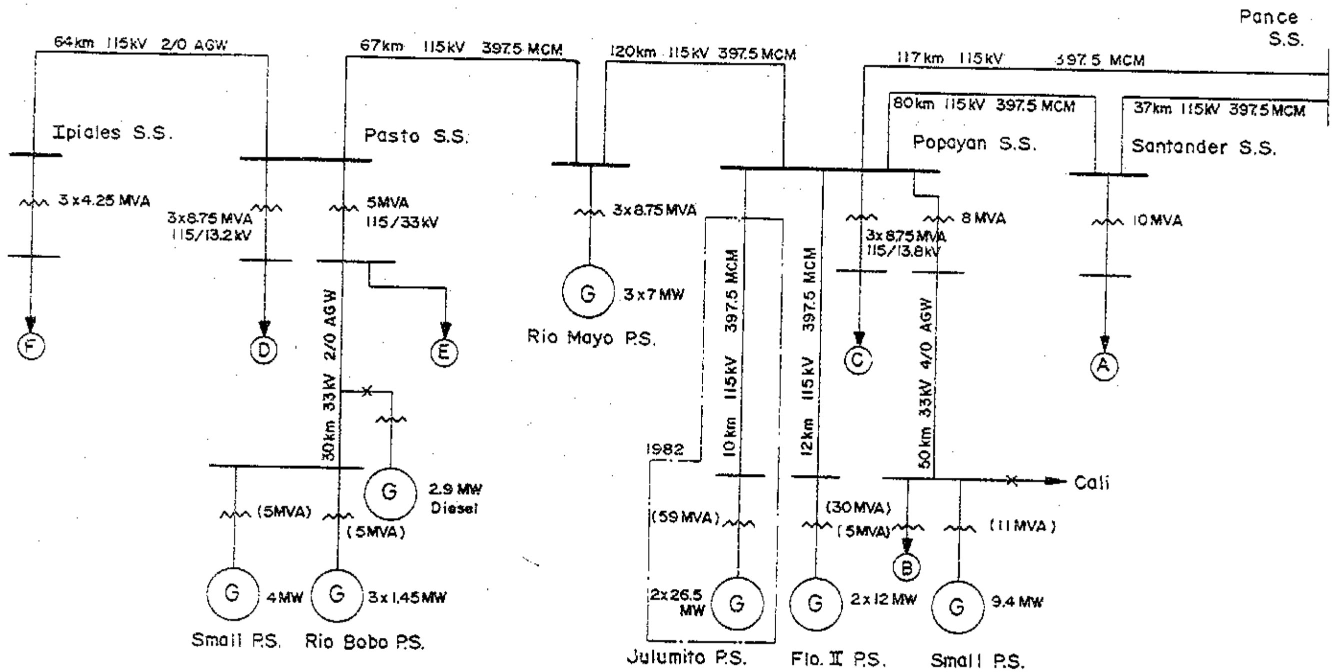

Fig. II-2 Impedance Map

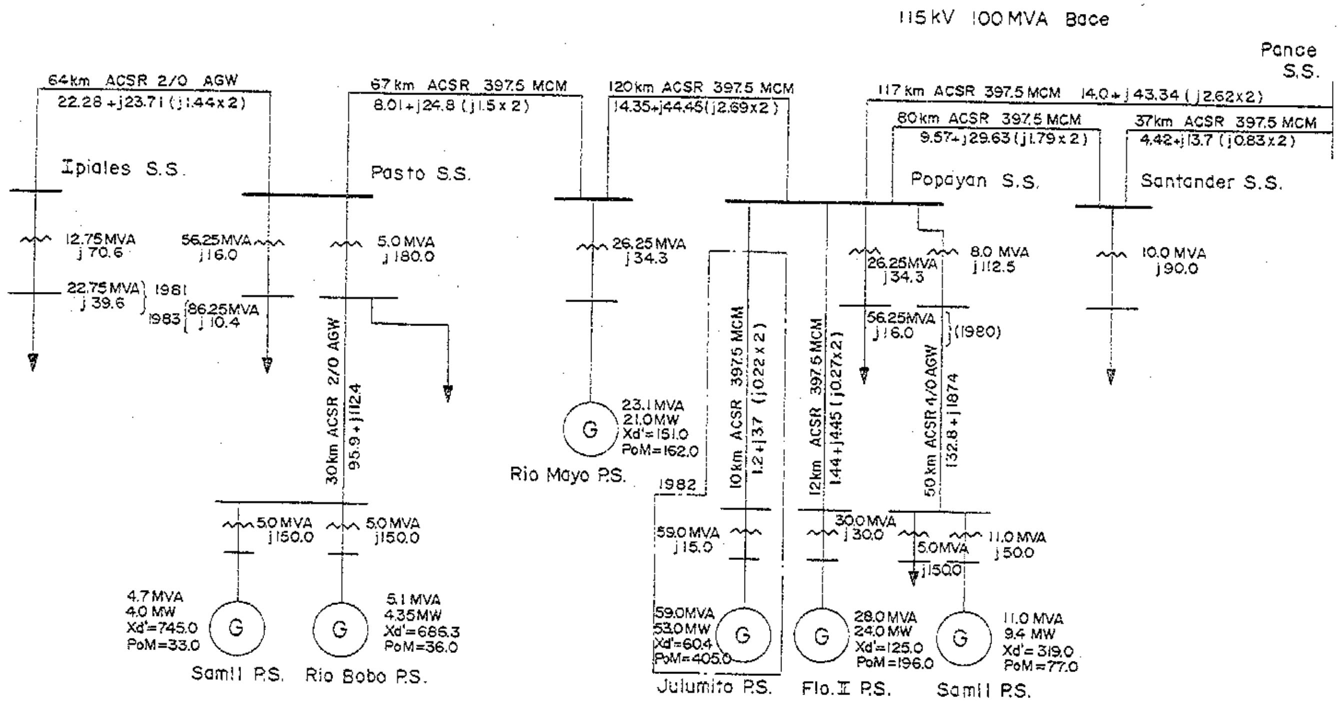

Fig. II-3-1 Power Flow and Voltage Regulation (Peak, 1976)

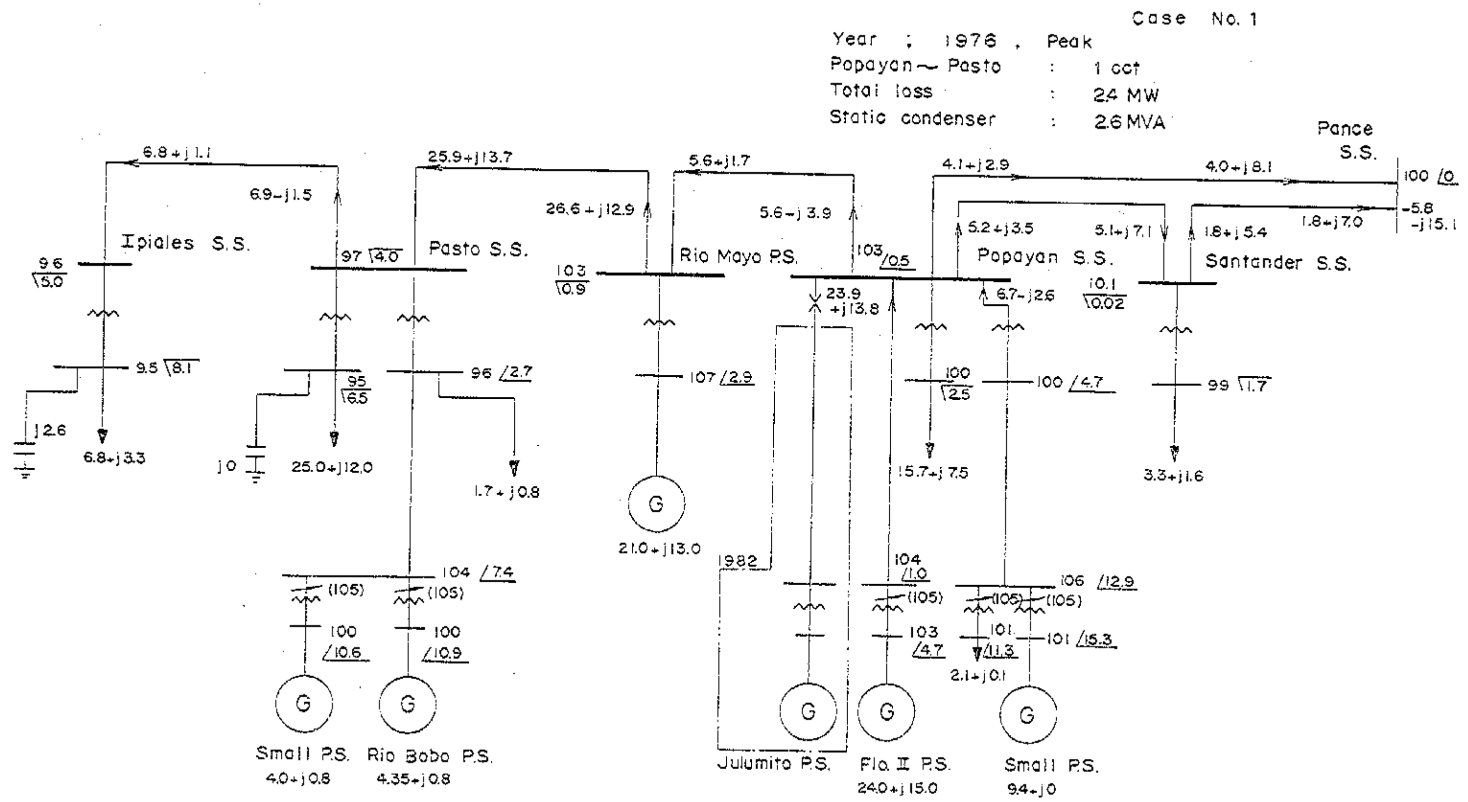

Fig. II-3-2 Power Flow and Voltage Regulation (Night, 1976)

Case No. 2

Year : 1976 , Night
Popayan～Pasto : 1 cct
Total loss : 1.5 MW
Static condenser : — MVA

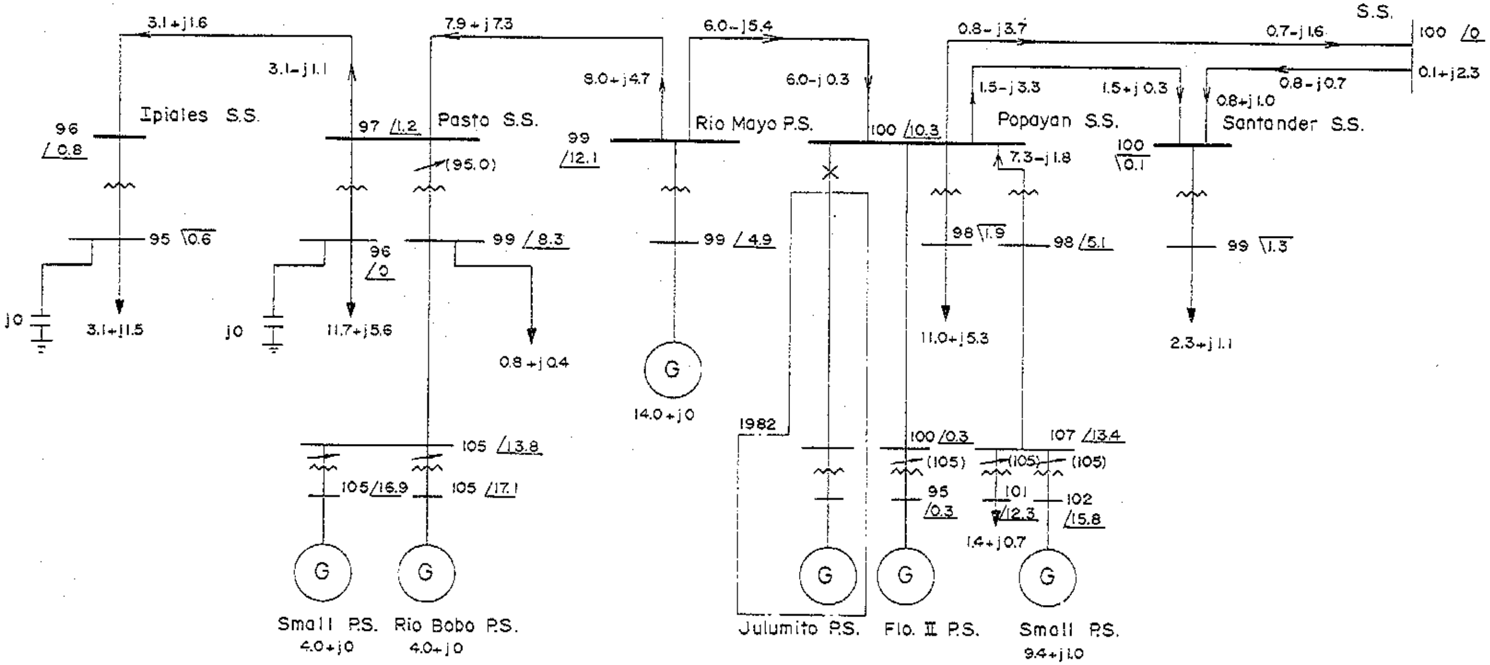

Fig. II-4 Power Flow and Voltage Regulation (Peak, 1978)

Case No. 3

Year : 1978 , Peak
Popayan ~ Pasto : 1 cct
Total loss : 3.0 MW
Static condenser : 10.6 MVA

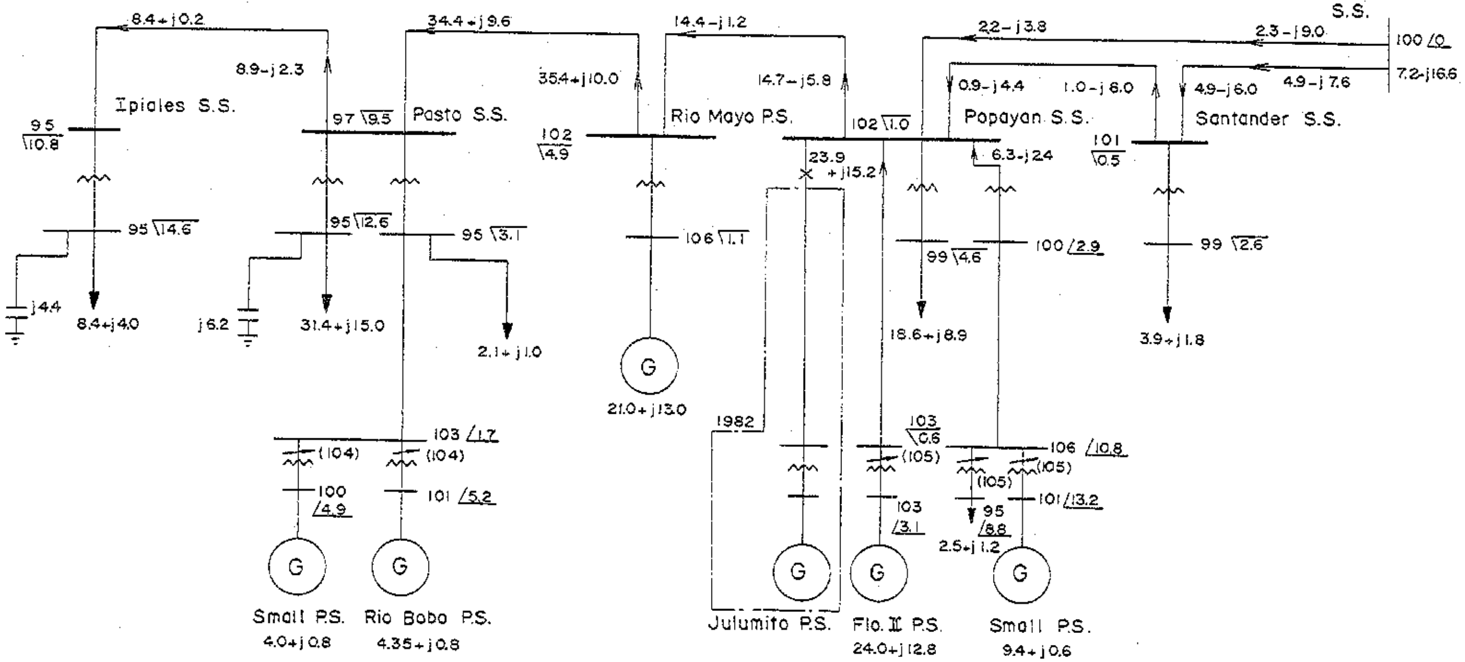

Fig. II-5 Power Flow and Voltage Regulation (Peak, 1980)

Case No. 4

Year : 1980, Peak
Popayan ~ Pasto : 1 cct
Total loss : 4.3 MW
Static condenser : 19.9 MVA

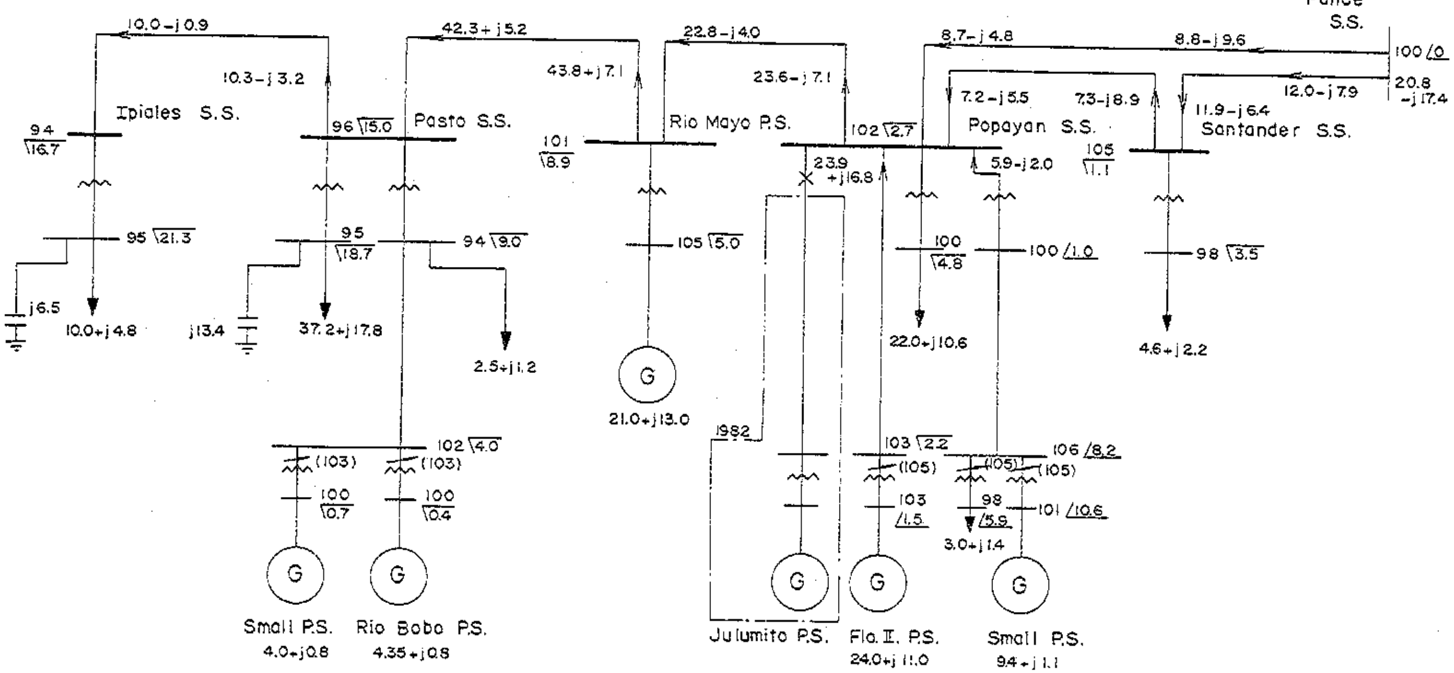

Fig. II-6-1 Power Flow and Voltage Regulation (Peak, 1982)

Case No. 5

Year : 1982 , Peak
Popayan ~ Pasto : 1 cct
Total loss : 5.9 MW
Static condenser : 25.5 MVA

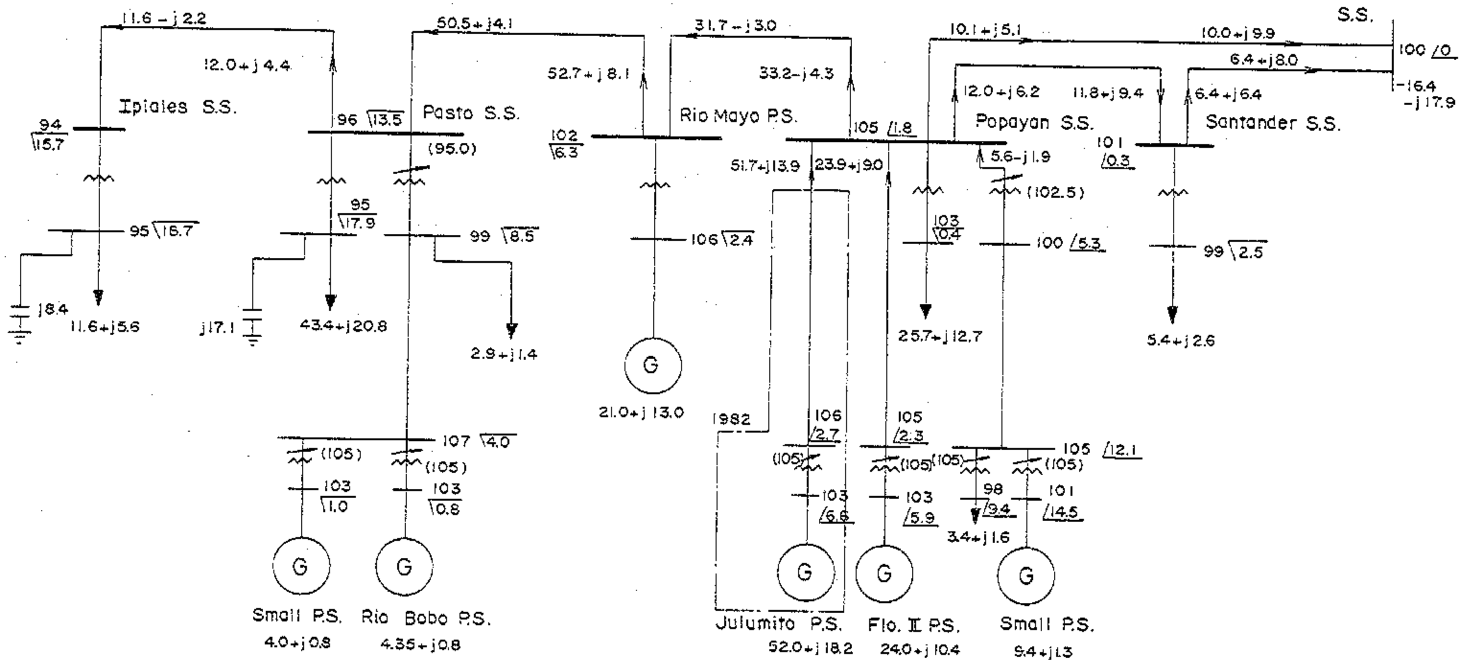

Fig. II-6-2 Power Flow and Voltage Regulation (Peak 1982, in case additional Popayan - Pasto Line is strung.)

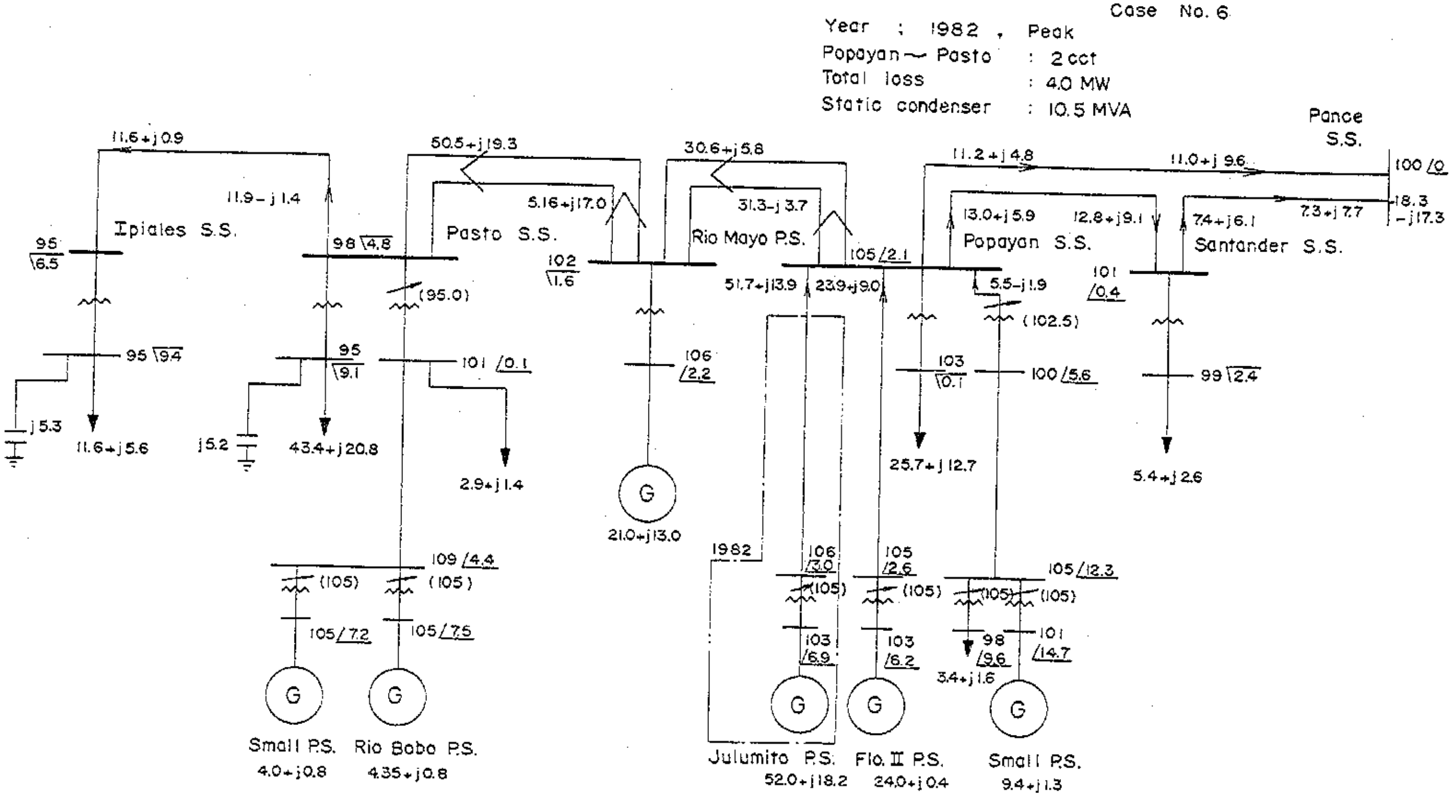

Fig. II-7-1 Power Flow and Voltage Regulation (Peak, 1985)

Case No. 7

Year : 1985 , Peak
Popayan～Pasto : 1 cct
Total loss : 9.5 MW
Static condenser : 44.0 MVA

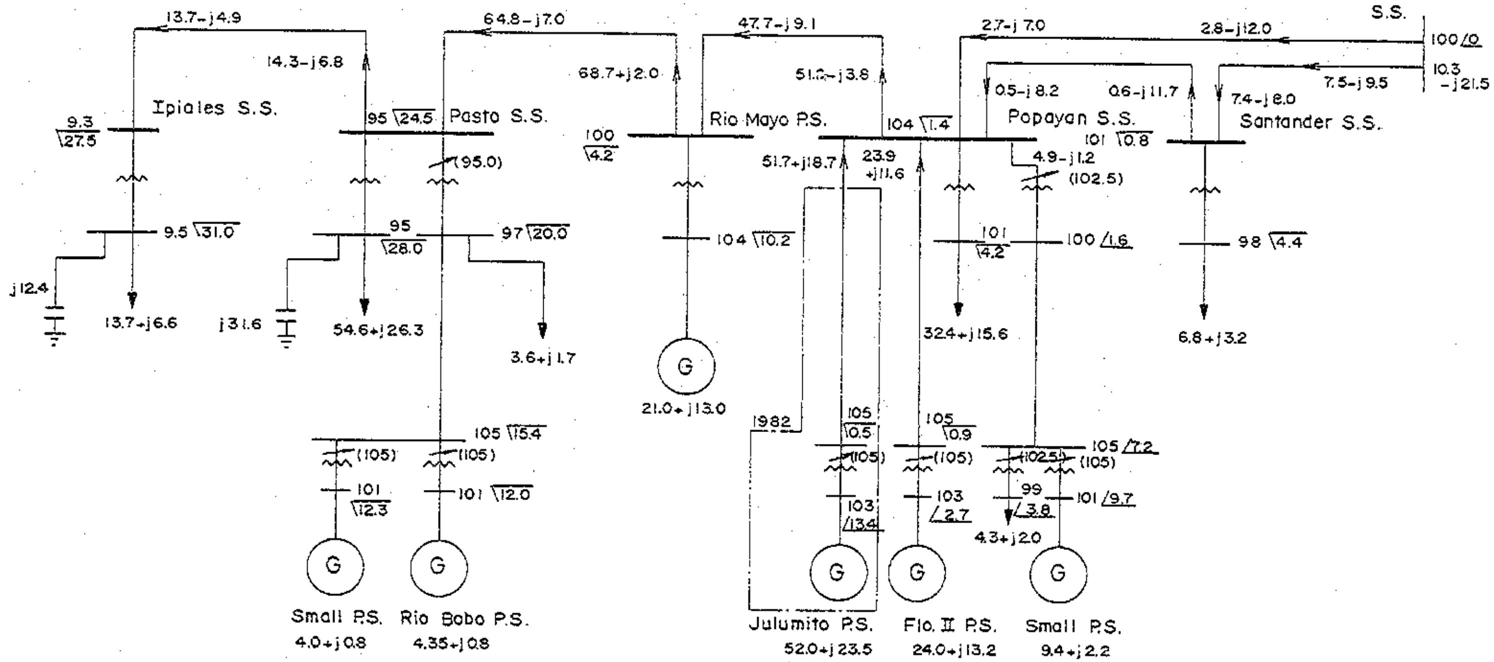

Fig. II-7-2 Power Flow and Voltage Regulation (Night, 1985)

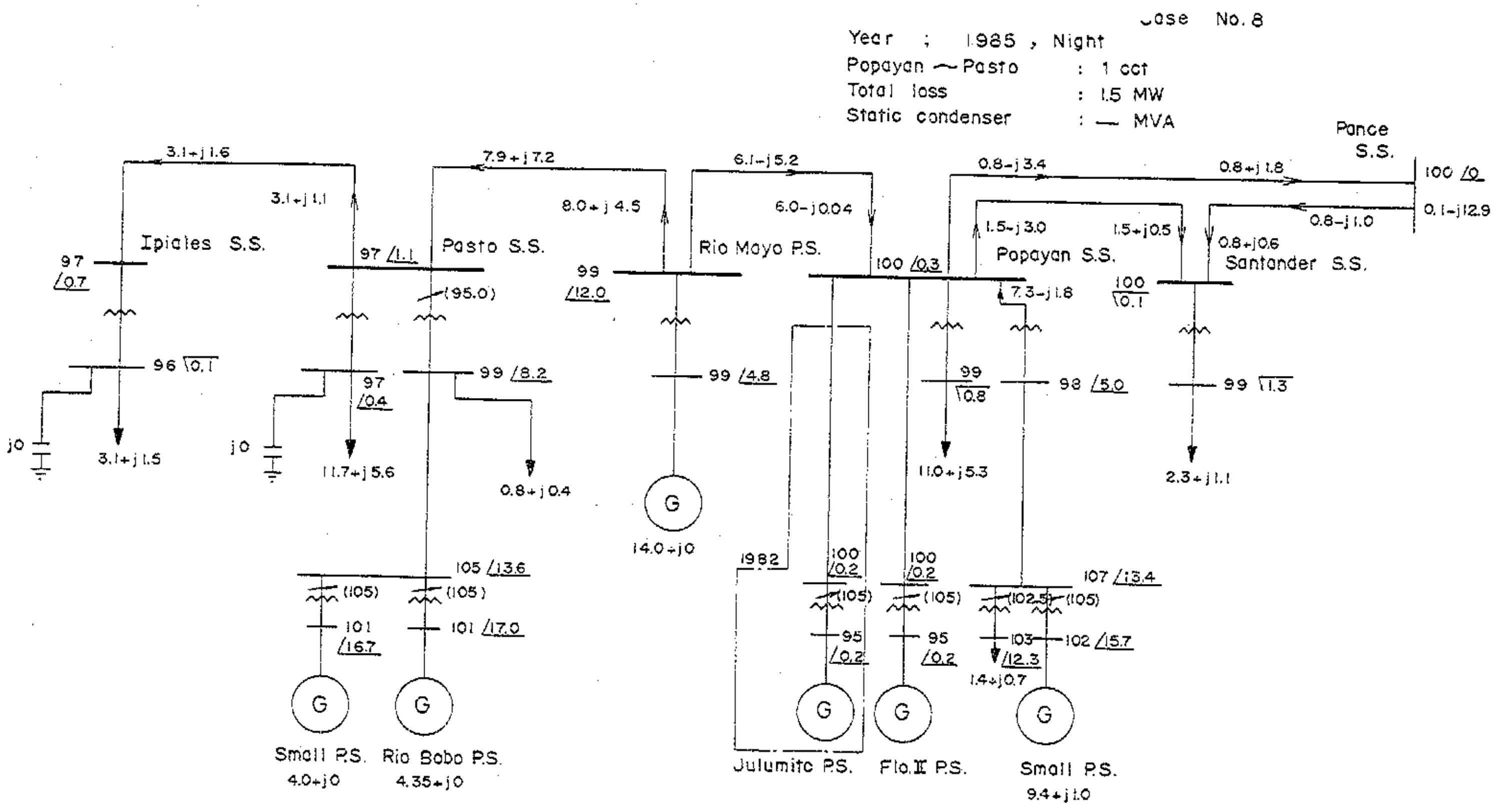

Fig. II-7-3 Power Flow and Voltage Regulation (Peak, 1985, in case additional Popayan - Pasto Line is strung.)

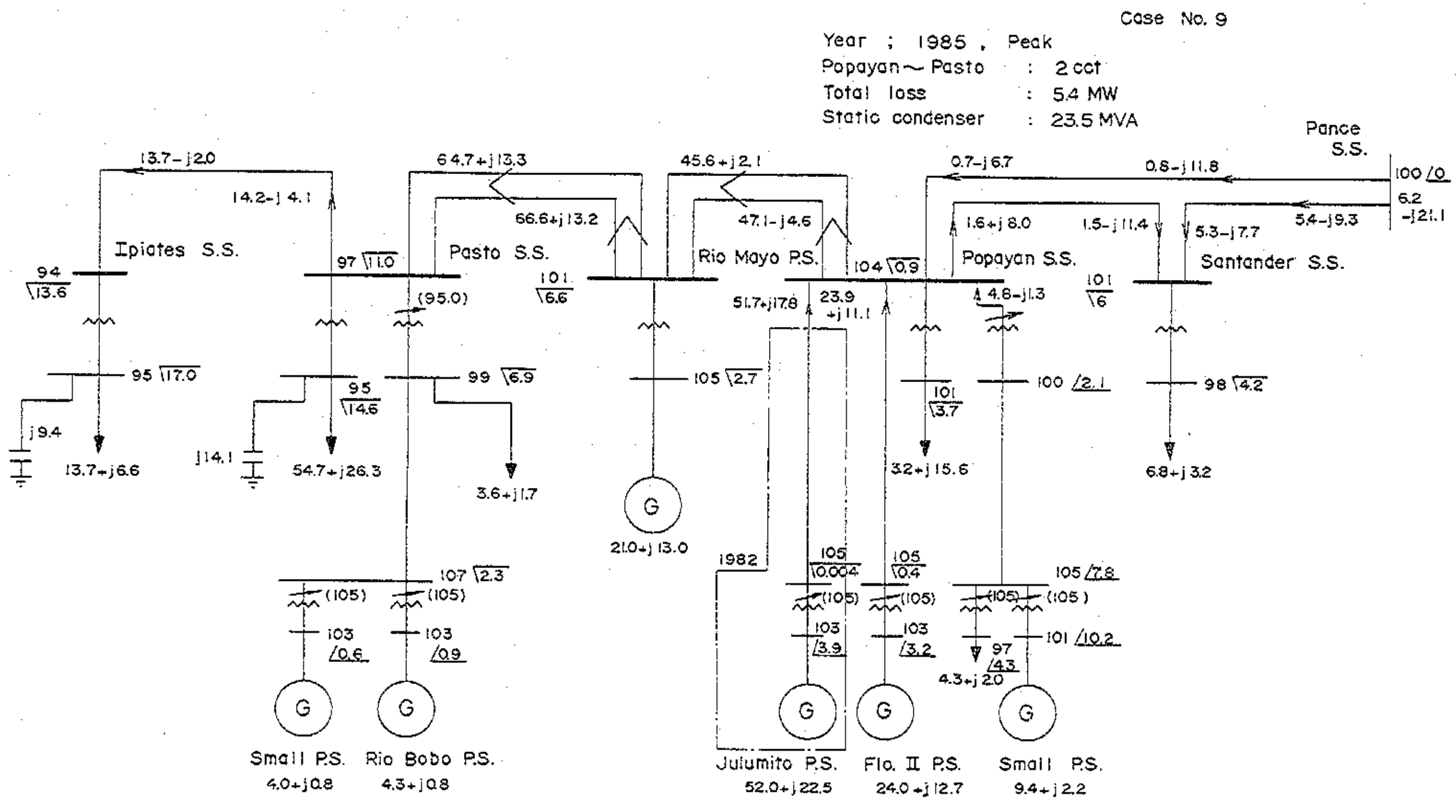

Fig. II-7-4 Power Flow and Voltage Regulation (Night, 1985, in case additional Popayan - Posto Line is strung.)

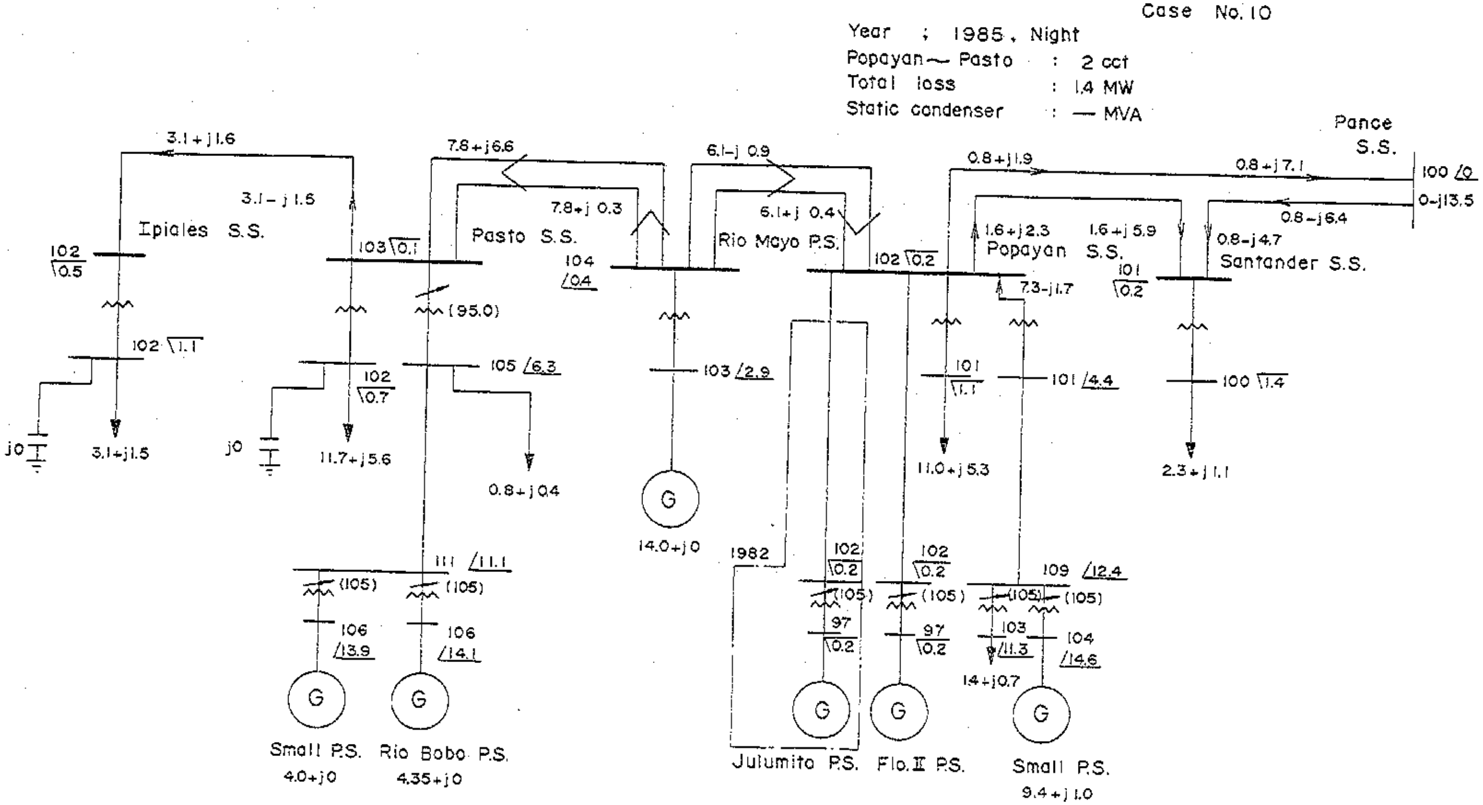

Fig. II-8-1 Calculation Recording Chart of Transient Stability (3LG-open, 1980)

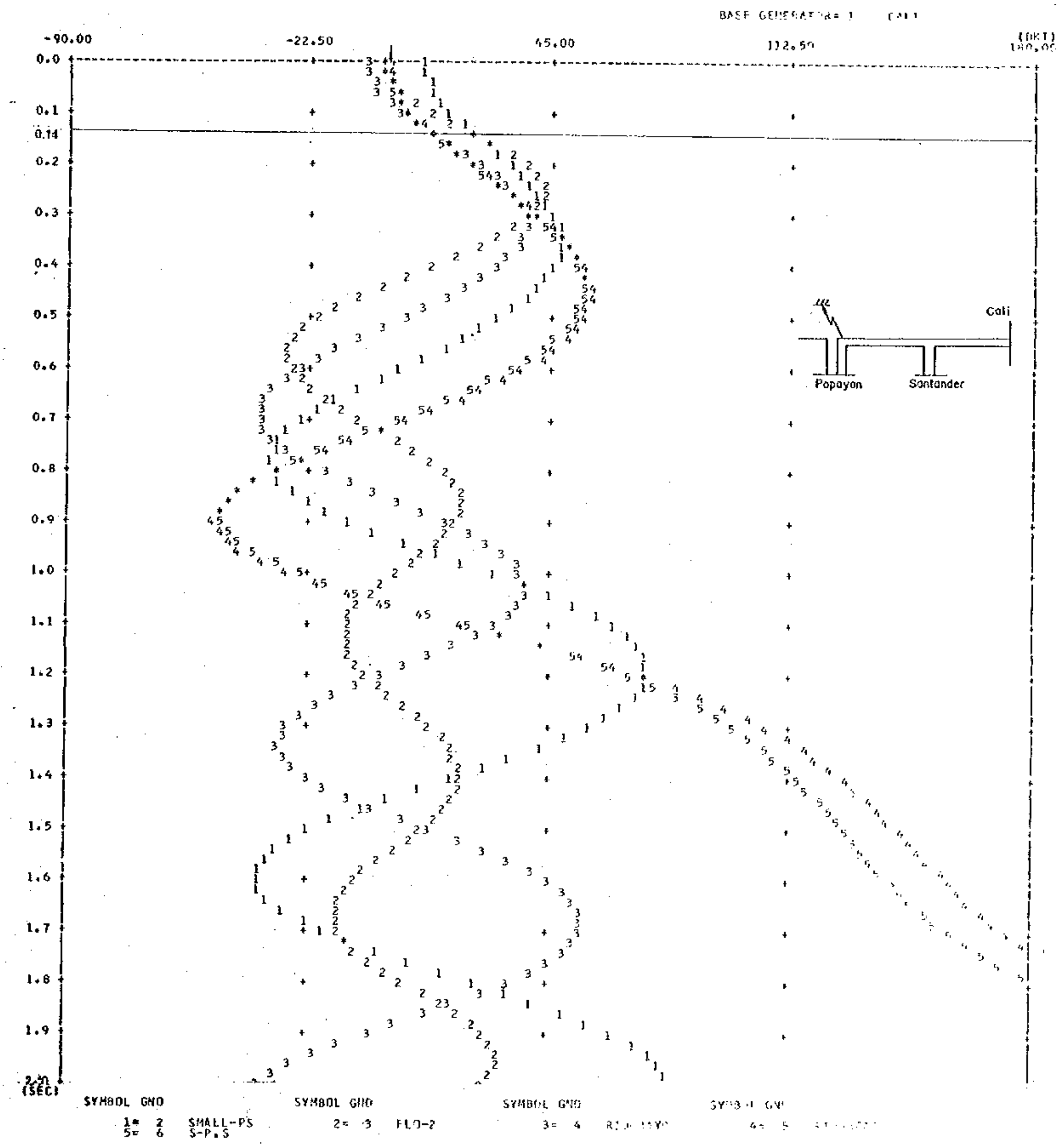

Fig. II-8-2 Calculation Recording Chart of Transient Stability (3LG-open, 1985)

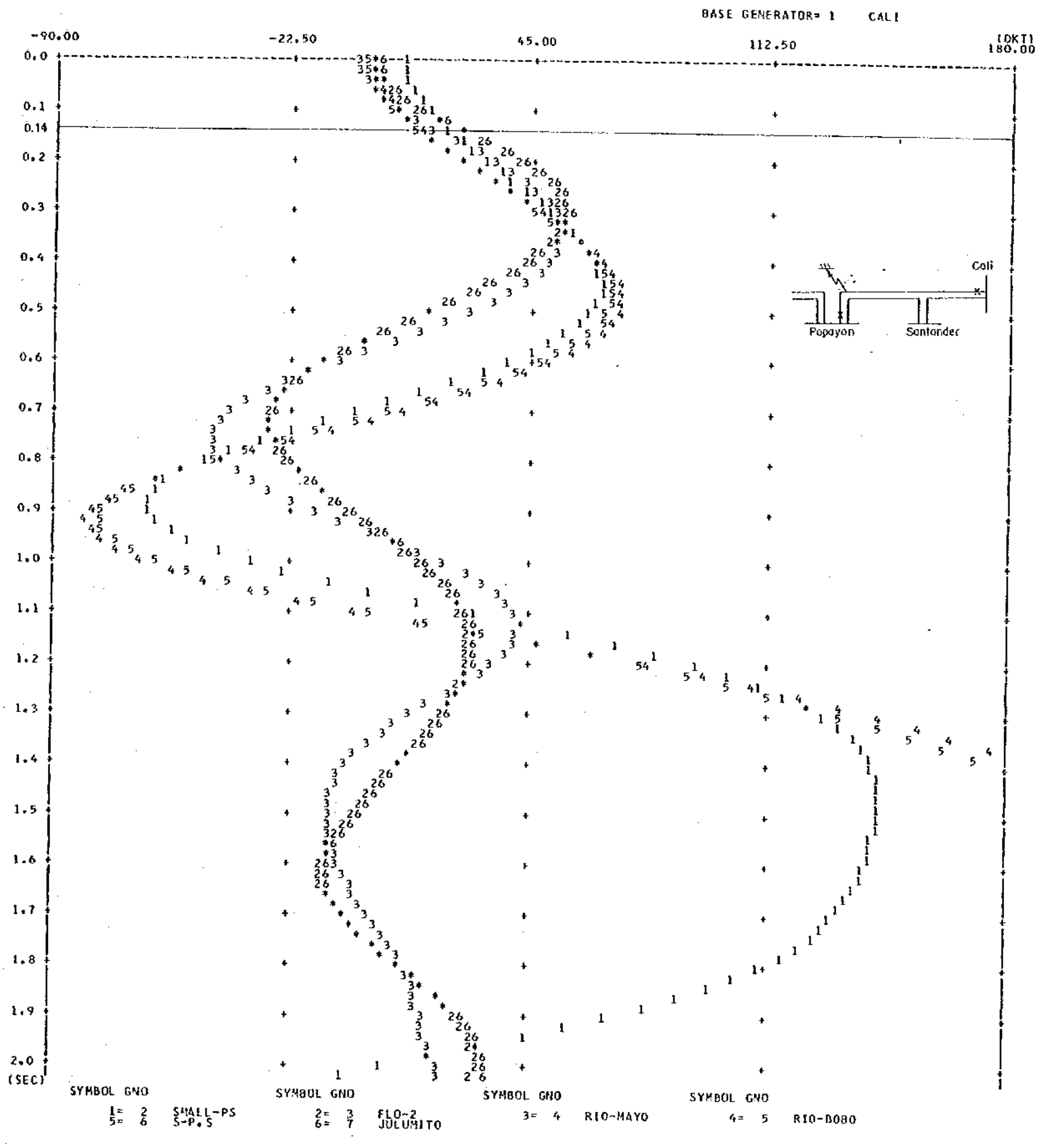

Fig. II-9-1 Short Circuit Capacity (1982)

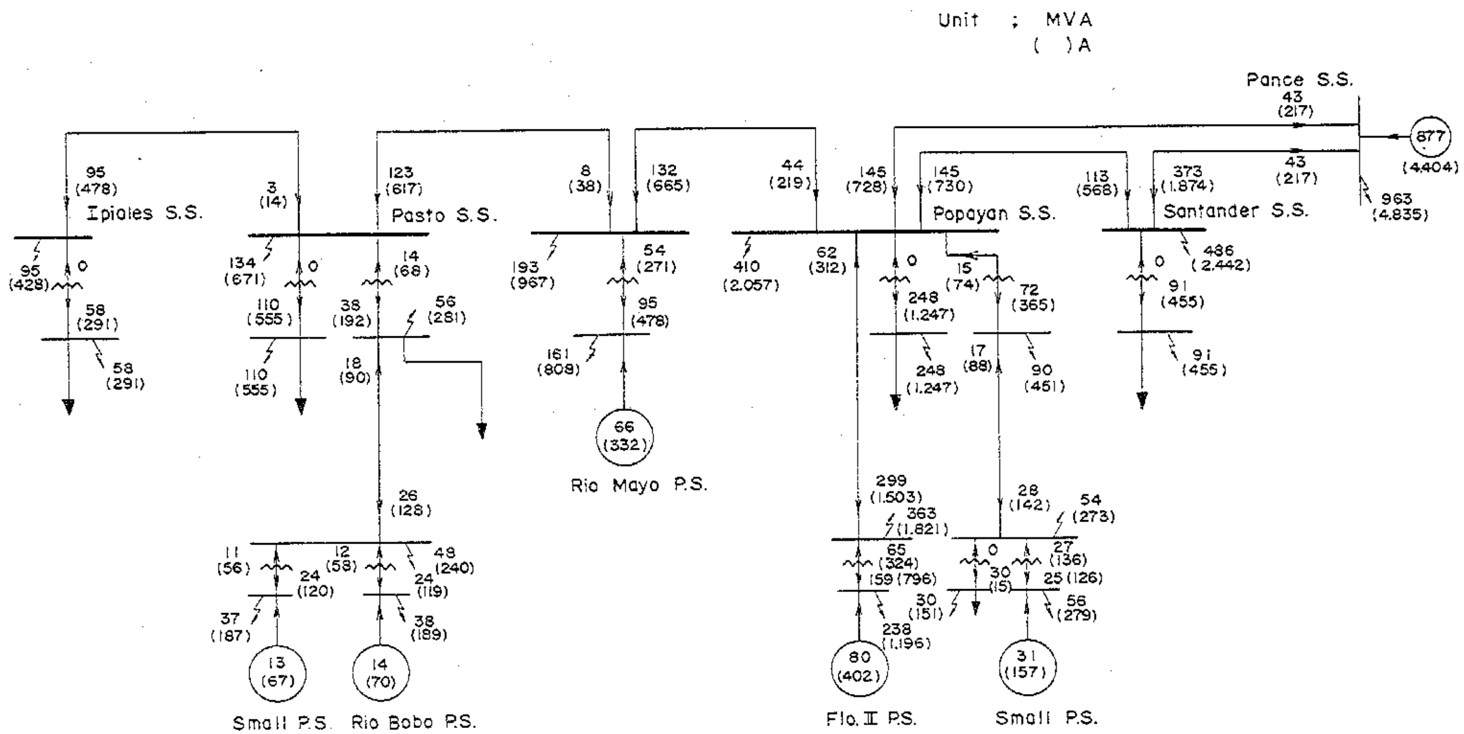

Fig. II-9-2 Short Circuit Capacity (1985)