INSTITUTO DE APROVECHAMIENTO DE
AGUAS Y FOMENTO ELECTRICO
REPUBLIC OF COLOMBIA

REPORT OF PRELIMINARY STUDIES

RIO PATIA HYDRO-ELECTRIC POWER DEVELOPMENT SCHEME

(NOTE)

JULY 1967

GOVERNMENT OF JAPAN

CONTENTS

I. ESTIMATION OF RUN-OFF

I. ESTIMATION OF RUN-OFF

1. Method of Estimation

The run-off records available of the main stream of the Rio Patia were recorded at the Pusmeo Gaging Station on the main stream in March through December 1966 (July records missing). However, in 1966, the precipitation characteristics throughout Colombia differed from normal years and in the Rio Patia catchment area the records at Pusmeo Gaging Station show a great amount of run-off in November and December. Especially, the run-off in December was abnormally great. In addition, the data recorded at Pusmeo Gaging Station are not continuous for one year, and therefore, it is not appropriate to formulate the scheme of development based only on the 1966 records obtained at Pusmeo. A method to estimate the long-term run-off of the project site to supplement this deficiency should be studied. In this case, two methods are conceivable.

One is to estimate the run-off at the project site from the specific run-off based on the run-off records of several gaging stations on tributaries with data over periods of 3 to 7 years. The other is to estimate the run-off at the project site from rainfall data obtained at precipitation observation stations within the catchment area using run-off coefficients.

Of the two methods, in the case of the former, the gaging stations are one-sidedly located and it becomes necessary to estimate the run-off at the project site, with a catchment area of 9,000 km^2, from the run-off records of Canada Gaging Station on a tributary, the Rio Mayo, with a catchment area of 616 km^2. Since the extrapolation ratio is extremely great and hardly to confirm correlationship among the run-off in above-mentioned two sites, the accuracy

of the estimate will be lowered.

As for the second method, since there are precipitation observation stations at various locations with records covering comparatively long periods of time as described before, if consideration is given to selection of the run-off coefficient, it is thought a run-off of considerably high reliability can be obtained. The run-off coefficient may be obtained from the correlation between the average precipitation within the catchment area and the run-off records of Pusmeo Gaging Station on the main river. The year 1966 for which run-off records of Pusmeo Gaging Station are available was an exceptional hydrologic year both in terms of rainfall and run-off, but since there could have been no fundamental change in the run-off mechanism, it is thought possible to estimate the run-off coefficient as a function of the precipitation. Therefore, in this Report, the basic run-off to be considered from the project is estimated on a monthly basis from the precipitation. The catchment area in question is that of the Pusmeo Gaging Station which is immediately downstream of the Patia No. 1 Power Station.

2. Average Monthly Rainfall within Catchment Area

2.1 Representative Precipitation Observation Stations

Of the 23 precipitation observation stations in the Patia catchment area, when those stations with only short observation periods and those with similar rainfall trends are eliminated the 4 stations listed below remain to represent the main stream and major tributaries.

The average precipitation within the catchment area is obtained from the weighted average using the records of these 4 precipitation observation stations.

Table N. I. 1 Representative Precipitation Observation Stations of Main River and Tributaries

Observation Station	River	Catchment Area	Period of Observation
Sajandi	Main river	6,000 km^2	1955 - 1966
La Cruz	Mayo	1,100	1960 - 1966
Buesaco	Juanambu	2,100	1959 - 1966
Imues	Guaitara	4,500	1957 - 1966
Total		13,700	

Note: Pusmeo Gaging Station included in the catchment area of the main river.

Table N. I. 2 Precipitation Record of Major Observation Stations in Rio Patia Catchment Area

(Average for 1962 - 1966) (mm)

Observation Station	River	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly Total
Sajandi	Main river	115	158	137	247	212	148	63	38	72	258	428	322	2,198
La Cruz	Mayo	94	107	81	152	130	48	27	43	28	181	267	249	1,407
Buesaco	Juanambu	80	87	78	157	102	78	16	27	42	163	206	151	1,187
Imues	Guaitara	78	115	135	133	155	107	22	37	41	137	318	256	1,534
Weighted Average		95.6	128.6	122.4	187.0	169.3	115.6	39.5	36.6	53.4	196.5	343.4	267.3	1755.2

2.2 Examination on Representative Precipitation Records

The precipitation records of Sajandi Precipitation Observation Station from 1959 to 1961 are abnormally low in comparison with the records of Sajandi Gaging Station. Taking the data of Imues and Buesaco Precipitation Observation Stations for the three years between 1959 and 1961, and comparing them with data of other years, it is not conceivable that this 3-year period was exceptionally dry. Therefore, it may be considered the records of Sajandi Precipitation Observation Station for these 3 years should be eliminated in present study because they are lacking in reliability.

The average monthly precipitation of the catchment area with Pusmeo Gaging Station as the downstream end for the abovementioned 5-year period obtained by the previously mentioned method is as given below.

Table N.I.3 Rio Patia Catchment Area Average Monthly Precipitation

Month / Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total
1962	165.0	130.4	182.4	128.7	158.5	80.5	4.5	64.1	68.0	152.3	220.5	142.0	1,496.9
1963	133.2	321.7	86.2	173.5	139.5	109.6	82.5	7.2	28.7	161.6	259.7	162.6	1,666.0
1964	41.2	125.5	8.8	215.8	105.5	278.3	54.9	54.2	50.3	211.7	238.7	349.0	1,773.9
1965	108.0	32.0	80.7	240.7	183.2	2.2	5.0	33.3	90.1	231.8	515.5	190.1	1,712.6
1966	30.4	33.4	213.9	176.5	259.8	107.5	50.4	24.3	29.7	225.0	482.8	492.9	2,126.6
Average	95.6	128.6	122.4	187.0	169.3	115.6	39.5	36.6	53.4	196.5	343.4	267.3	1,755.2

3. Run-off Coefficient

Concerning the relation of run-off actually recorded monthly at Pusmeo Gaging Station from March through December 1966 (July records missing) and the average precipitation of the catchment area estimated as abovementioned, taking the run-off characteristics of the catchment area into consideration and employing the trial and error method, it is judged appropriate to assume that the precipitation of the preceding 7 months will result in the run-off of that particular month according to the run-off coefficient given below.

Table N. I. 4 Run-off Coefficient of Precipitation of Preceding 7 months

Month Precipitation Conditions	Particular Month	1 Month Previous	2 Months Previous	3 Months Previous	4 Months Previous	5 Months Previous	6 Months Previous	7 Months Previous	Total
Normal Cases	0.11	0.08	0.05	0.04	0.03	0.02	0.01	0.01	0.35
Particular Month 250 Preceding Month 250	0.21	0.08	0.05	0.04	0.03	0.02	0.01	0.01	0.45
Particular Month 250 Preceding Month 250	0.50	0.20	0.05	0.04	0.03	0.02	0.01	0.01	0.86

Table N. I. 5 Comparison of Monthly Observed Run-off and Estimated Run-off at Pusmeo Gaging Station

(March - December 1966) (m3/sec x days)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Mar. - Dec.
Estimated Run-off	9101	7240	9041	9358	10678	9360	6938	5215	4123	6810	20721	57581	139825
Observed Run-off	-	-	11492	8951	10136	6687	-	5504	4104	6819	24081	58217	143611

4. ESTIMATION OF MONTHLY RUN-OFF AT PUSMEO GAGING STATION

The monthly run-off at Pusmeo Gaging Station was estimated from the monthly average precipitation within the catchment area during the beforementioned 5 year period from 1962 through 1966 and the run-off coefficient mentioned in preceding paragraph.

The monthly average run-off at Pusmeo Gaging Station thus obtained is given below. For the periods from March through June and August through December 1966, the run-off actually recorded at this station are used. The monthly run-off below are to be used as basic values for the present study.

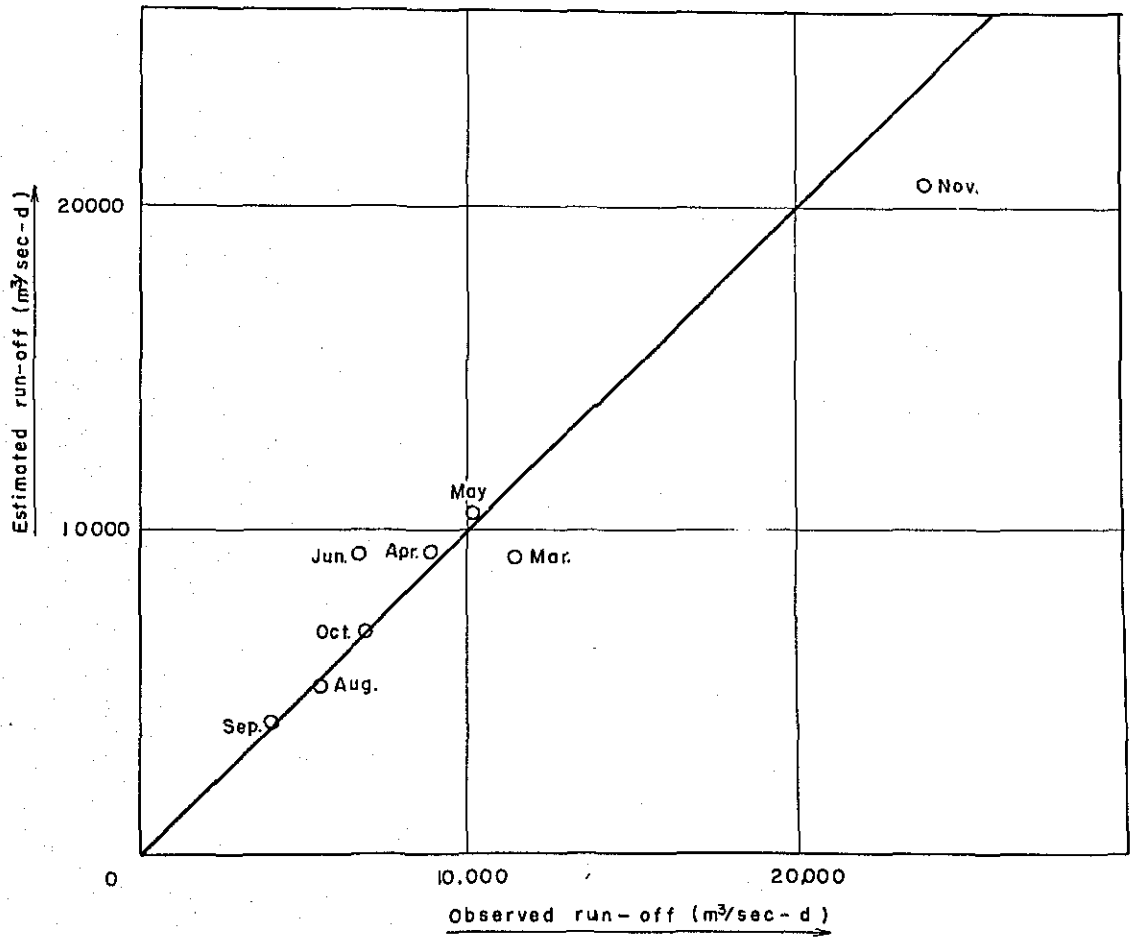
Table N.I.6 Estimated Average Monthly Run-off at Pusmeo Gaging Station

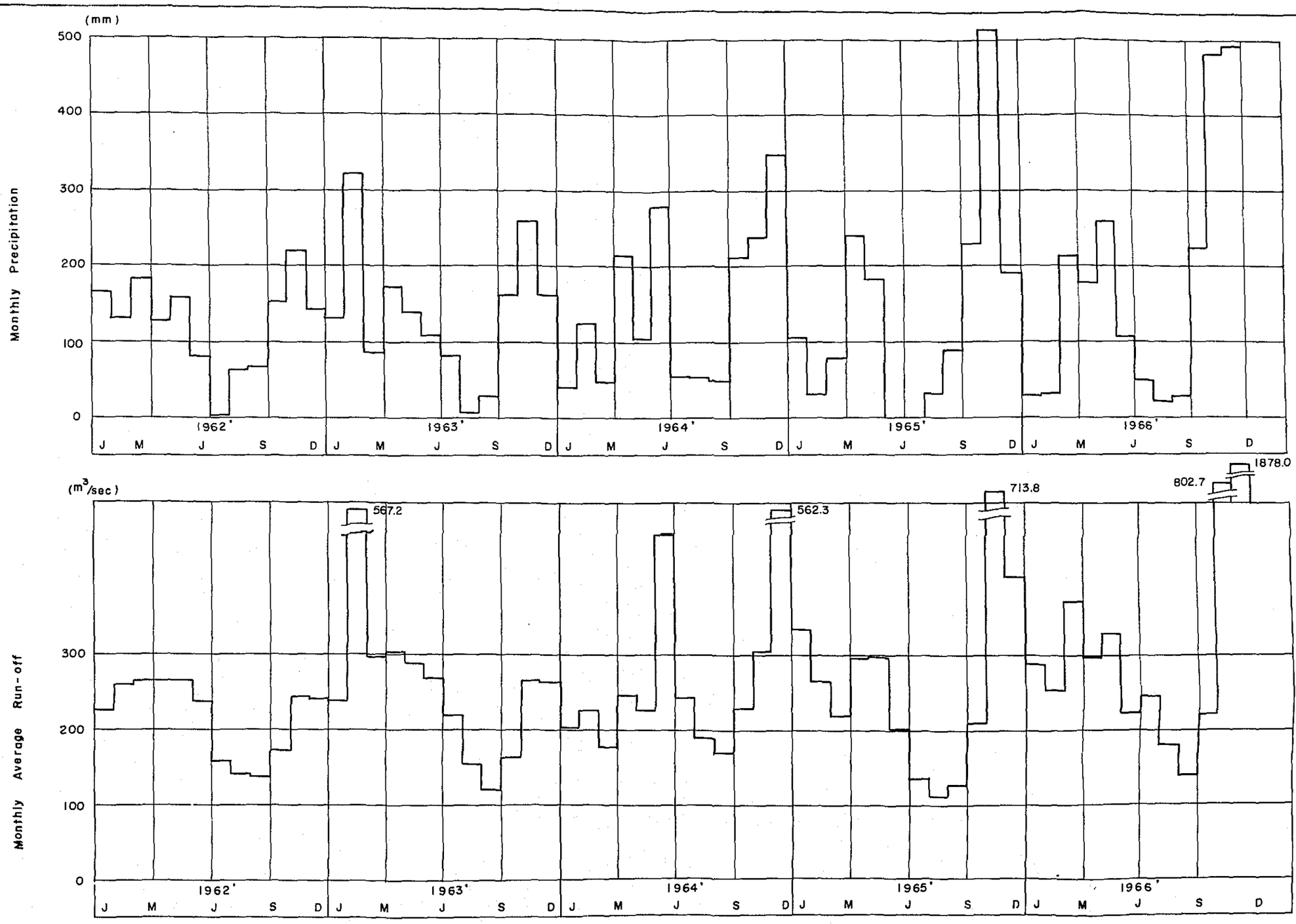
Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
1962	231.5	266.0	270.9	272.4	271.1	243.6	159.0	145.4	141.0	176.3	250.1	247.0	222.9
1963	243.4	574.1	301.3	309.9	293.3	272.7	224.0	154.0	124.5	166.8	271.3	269.0	267.0
1964	205.4	230.8	180.6	251.9	231.2	469.9	247.8	193.3	175.2	233.2	310.1	574.2	275.3
1965	340.3	271.3	222.6	301.6	302.8	205.6	139.7	113.8	129.5	213.6	728.9	275.5	270.4
1966	293.5	258.5	370.7	298.4	327.0	222.9	245.8	177.5	136.8	220.0	802.7	1,878.0	436.0
Average	262.8	320.1	269.2	286.8	285.1	282.9	203.3	156.8	141.4	202.0	472.6	648.7	294.3
Average (Excl. 1966)	255.2	335.6	244.0	284.0	274.6	298.0	192.6	151.6	142.6	197.5	390.1	341.4	258.9

5. FLOOD

The peak flood at the time of the December 1966 which is said to have been the greatest in several decades is estimated to have been approximately 4000 m^3/sec. Based on this data and taking into consideration other factors necessary, the design flood for the Patia No. 1 and Patia No. 2 sites will be taken at 10,000 m^3/sec.

Correlation between estimated and observed run - off




(mm)
Monthly Precipitation
500
400
300
200
100
0
1962'
1963'
1964'
1965'
1966'
J M J S D
(m³/sec)
Monthly Average Run-off
567.2
562.3
713.8
802.7
1878.0
300
200
100
0

II. STUDY OF SCALE OF PATIA NO. 1 RESERVOIR CAPACITY

II. STUDY OF SCALE OF PATIA NO. 1 RESERVOIR CAPACITY

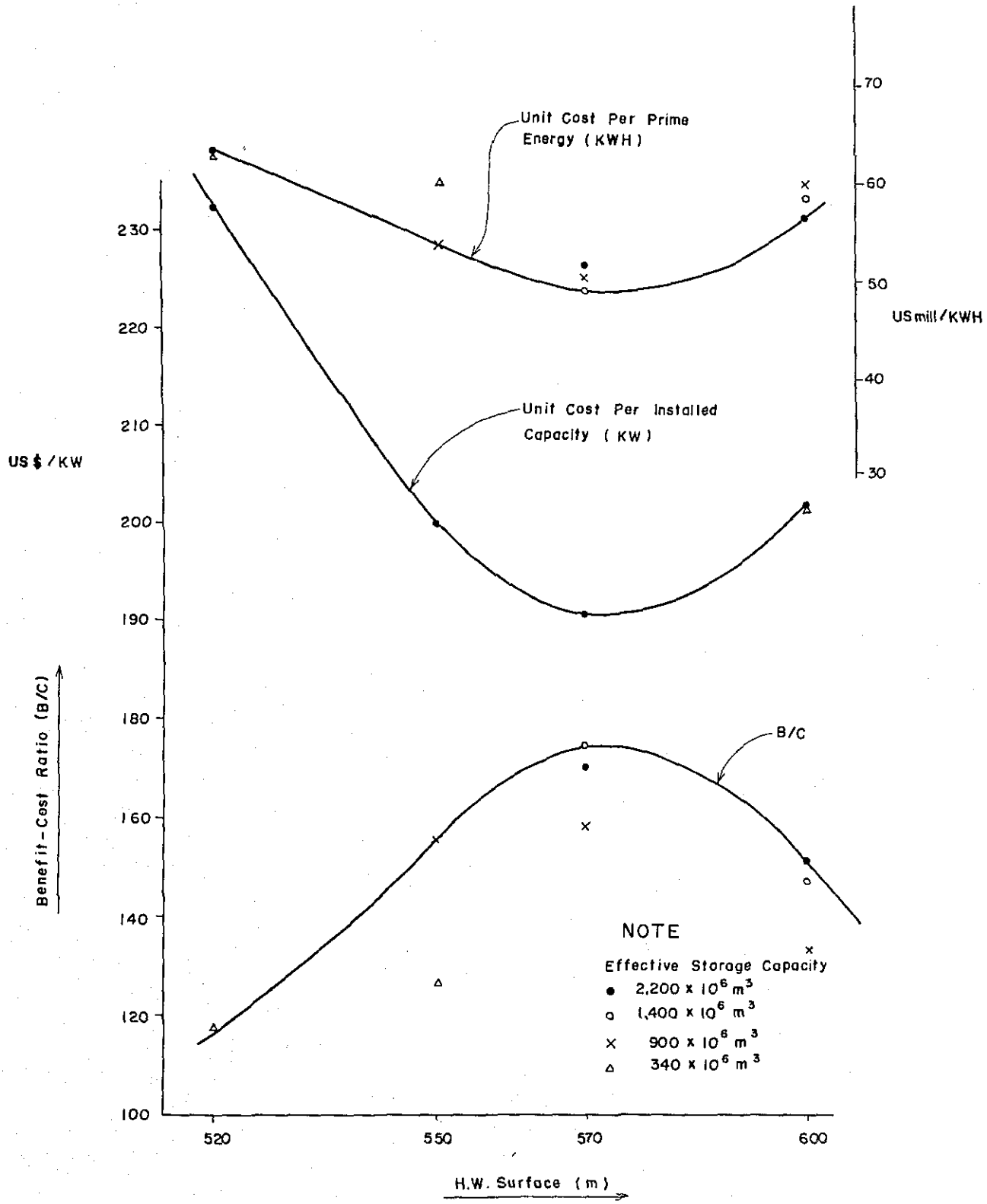
Comparison of Various Reservoir Capacity

Case	High Water Level	Effective Storage	Max. Discharge	Effective Head	Max. Output	Annual Energy Production	Prime Energy	Total Construction Cost	Construction Cost per kw	Construction Cost per kwh	Benefit-Cost Ratio
	m	$10^6 m^3$	m^3/sec	m	mw	10^6kwh	10^6kwh	10^6US$	US$	US mill	
1	600	2,200	560	206.0	980	3,970	3,880	218.3	222.8	55.0 (56.3)	1.52
2	600	1,400	540	207.0	950	3,990	3,770	215.6	226.9	54.0 (57.2)	1.48
3	600	900	470	208.0	830	4,010	3,440	205.0	247.0	51.1 (59.6)	1.34
4	570	2,200	560	167.0	800	3,210	3,000	155.0	193.8	48.3 (51.7)	1.71
5	570	1,400	540	174.0	800	3,321	3,130	152.2	190.3	45.8 (48.6)	1.75
6	570	900	470	177.0	708	3,420	2,880	145.0	204.8	42.4 (50.3)	1.59
7	550	900	470	149.0	600	2,893	2,240	120.0	200.0	41.5 (53.6)	1.56
8	550	340	350	155.0	468	3,010	1,820	108.6	232.1	36.1 (59.7)	1.26
9	520	340	350	122.0	364	2,380	1,350	85.3	243.3	35.8 (63.2)	1.17

(Note) 1. Benefit-cost ratio is based on annual costs of U.S. $23.20 per kw, energy cost of 3.04 U.S. mills and annual cost ratio of 10.41%.

2. Value of benefit-cost ratio at generating end.

3. Figures in parentheses in column for construction cost per kwh are for prime energy


Unit Cost Per Prime Energy (KWH)
Unit Cost Per Installed Capacity (KW)
B/C
US $ / KW
US mill / KWH
Benefit-Cost Ratio (B/C)
H.W. Surface (m)
NOTE
Effective Storage Capacity
2,200 x 10^6 m^3
1,400 x 10^6 m^3
900 x 10^6 m^3
340 x 10^6 m^3
100
120
140
160
180
190
200
210
220
230
30
40
50
60
70
520
550
570
600

III. MICROSCOPIC DESCRIPTION OF ROCK SAMPLE AT PATIA PROJECT

III. MICROSCOPIC DESCRIPTION OF ROCK SAMPLE AT PATIA PROJECT

Sample No. 1

Locality: Road side between Agroyaco and Guasca bridge.

Macroscopically reddish-brown in color, somewhat phyllitic. The original rock is considered to be tuff.

Microscopically, the rock is constituted with the following minerals; hematite, muscovite, chlorite and quartz. Because of very fine grained nature of the rock, the exact constituent minerals are not certain except those listed above.

Sample No. 2

Locality: At Patia No. 1 dam site.

Macroscopically, fine grained massive green rock with numerous scattered black spots (titan-augite).

The constituent minerals are twinned titan-augite (relic), chlorite, calcite, zoisite, garnet and quartz. From the textural evidences such as aphitic distribution of altered minerals, the original rock is considered to be basalt.

Sample No. 3

Locality: At Patia No. 1 dam site.

Macroscopically, a little fissible red-green tuffaceous rock with scattered large black pyroxene-amphibote minerals.

The constituent minerals are relic titan-augite, relic pale brown colored hornblende, epidite, calcite, prehnite chlorite, sphene, opaque mineral. Relic glassy texture is observable.

Sample No. 4

Locality: At the Pusmeo bridge site.

Macroscopically, pelitic phyllite with abundant small carbonate lenses.

The constituent minerals are calcite, muscovite, chlorite, opaque minerals, quartz, plagioclase and sphene.

The preferred orientation of constituent minerals is very conspicuous. The sedimentary texture, however, is recognizable throughout the rock. Therefore, the phyllitic texture may mainly be due to the sedimentary structure, and not to metamorphic, which only modifies the original.

Sample No. 5

Locality: At the Pusmeo bridge site.

Macroscopically massive green rock with white veinlets. From the textural evidences, this rock must be originated from clastic rock or at best from tuff.

The constituent minerals are chlorite, pumpellyte(?.....too fine grained to determine only with microscope. Since this mineral is very important, further investigation is required.), sphene, with quartz vein.

Sample No. 6

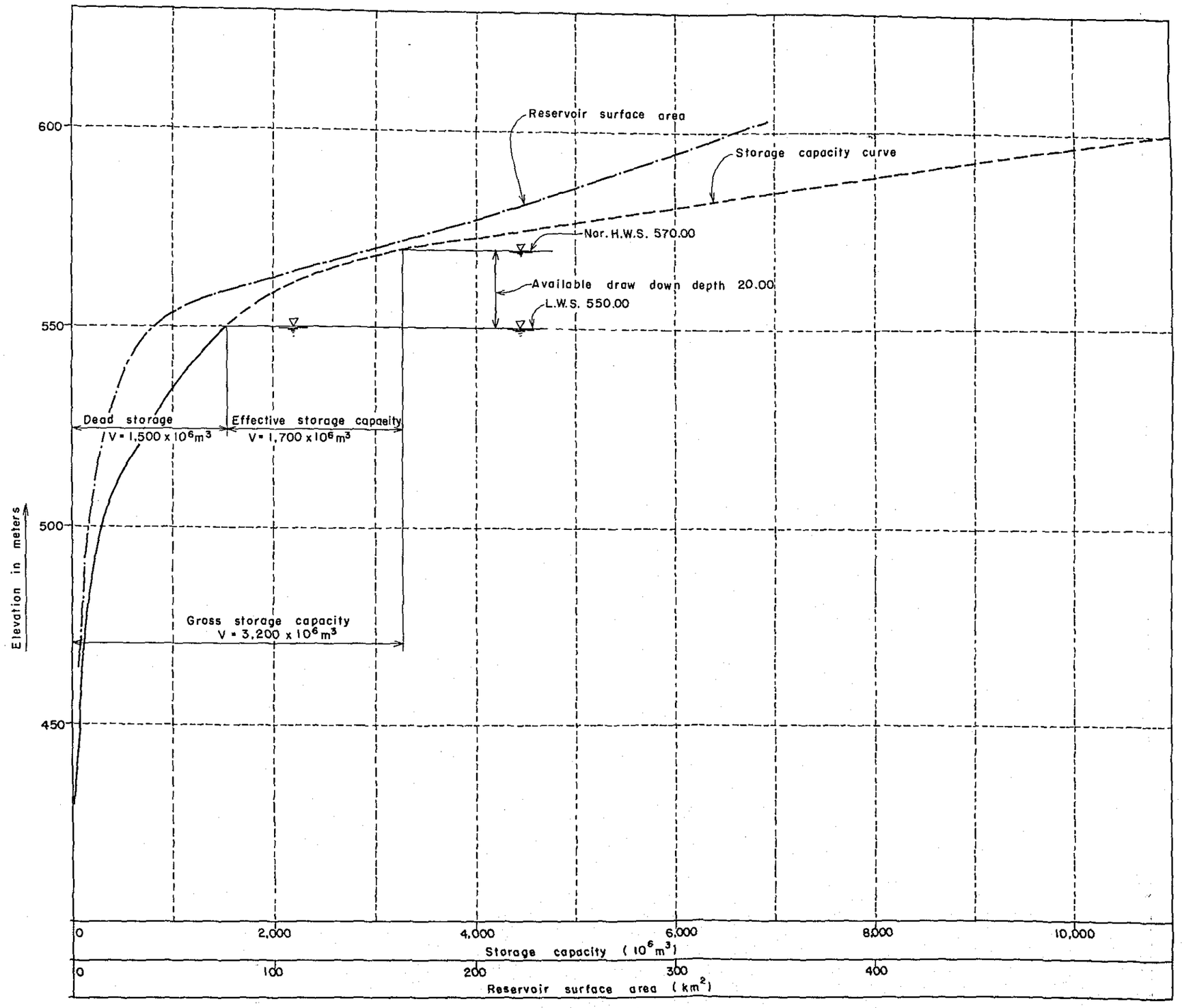
Locality: Outlet of tailrace.

Thin alternation of black and white siliceous rock (chert). Very fine grained. The constituent minerals are quartz, oligoclase, calcite and opaque minerals.

Sample No. 7

Locality: Near the Patia No. 2 dam site.

Black phyllitic slate with chert inclusion. The rock is constituted of quartz, plagioclase, chlorite, calcite, muscovite, graphite and pyrite. Clastic grains, sand-silt sized are scattered. Recrystallization is very weak or non-existant.



EL. (m)	A (km²)	V (10⁶m³)
408	0	0
425	0.21	2
450	2.13	31
500	8.02	285
550	41.7	1,530
575	185	4,360
600	330	10,800

Note : A : Reservoir surface Area
V : Gross storage capacity

Reservoir area is estimated on the base of the aerophotograph map of scale 1:25,000, but the area of the upper stream than the confluence of *Rio SAN JORJE* is estimated by using the aerophotograph. And since the map of the main tributaries are not available, the reservoir area of these parts is not included.

OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO-JAPAN

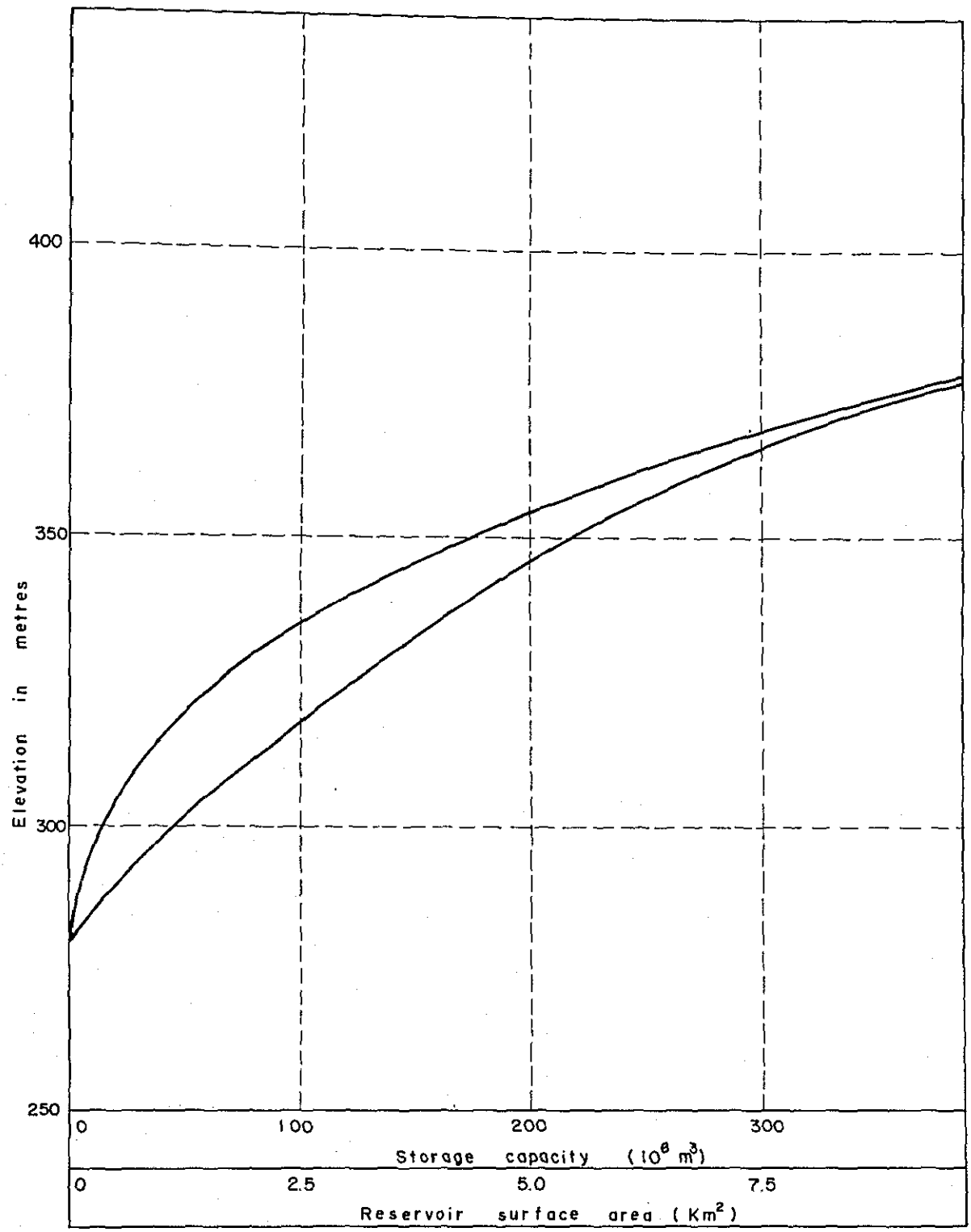
INSTITUTO DE APROVECHAMIENTO DE AGUAS Y FOMENTO ELECTRICO BOGOTA - COLOMBIA

PATIA HYDROELECTRIC SCHEME

PATIA NO. 1 RESERVOIR
AREA AND CAPACITY

E.P.D. CONSULTANTS
(ELECTRIC POWER DEVELOPMENT CO.)

FIG: N-1 | DATE JUN. 20, 1967



S.M.L (M)	A (Km^2)	V($10^6 m^3$)
280	0	0
300	1.13	11.3
350	5.33	172
375	9.13	353
380	10.20	401

OVERSEAS TECHNICAL COOPERATION AGENCY
TOKYO - JAPAN

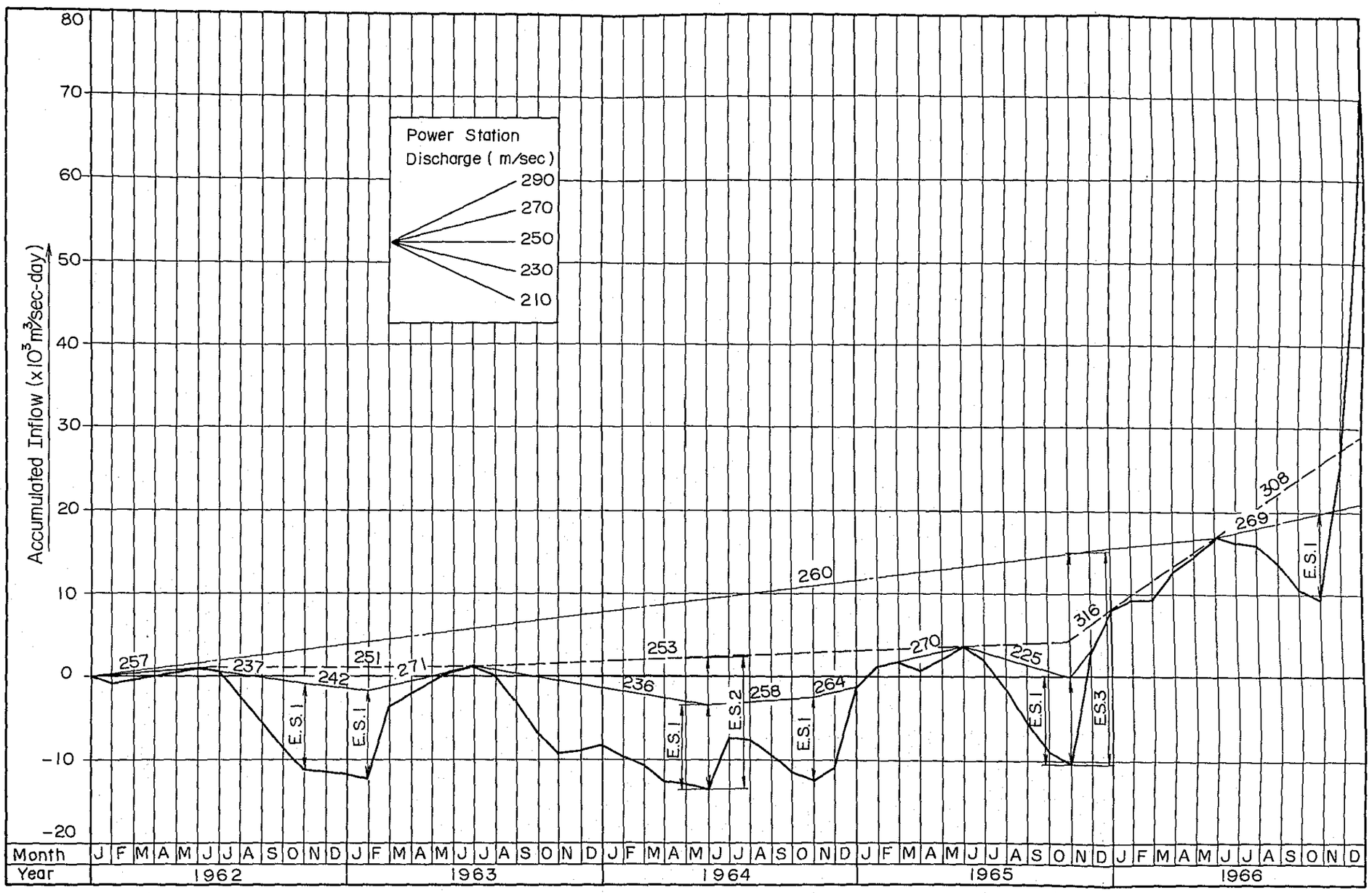
INSTITUTO DE APROVECHAMIENTO DE AGUAS Y FOMENTO ELECTRICO BOGOTA - COLOMBIA

PATIA HYDROELECTRIC SCHEME

PATIA NO.2 RESERVOIR AREA AND CAPACITY

E.P.D. CONSULTANTS
(ELECTRIC POWER DEVELOPMENT CO.)

FIG: N-2 | DATE: JUN.20.1967



Note : Effective Storage (E.S.I) ..... $900 \times 10^6 m^3$ (10,417 m/sec-day)
" (E.S.2) ..... $1400 \times 10^6 m^3$ (16,200 m/sec-day)
" (E.S.3) ..... $2200 \times 10^6 m^3$ (25,400 m/sec-day)

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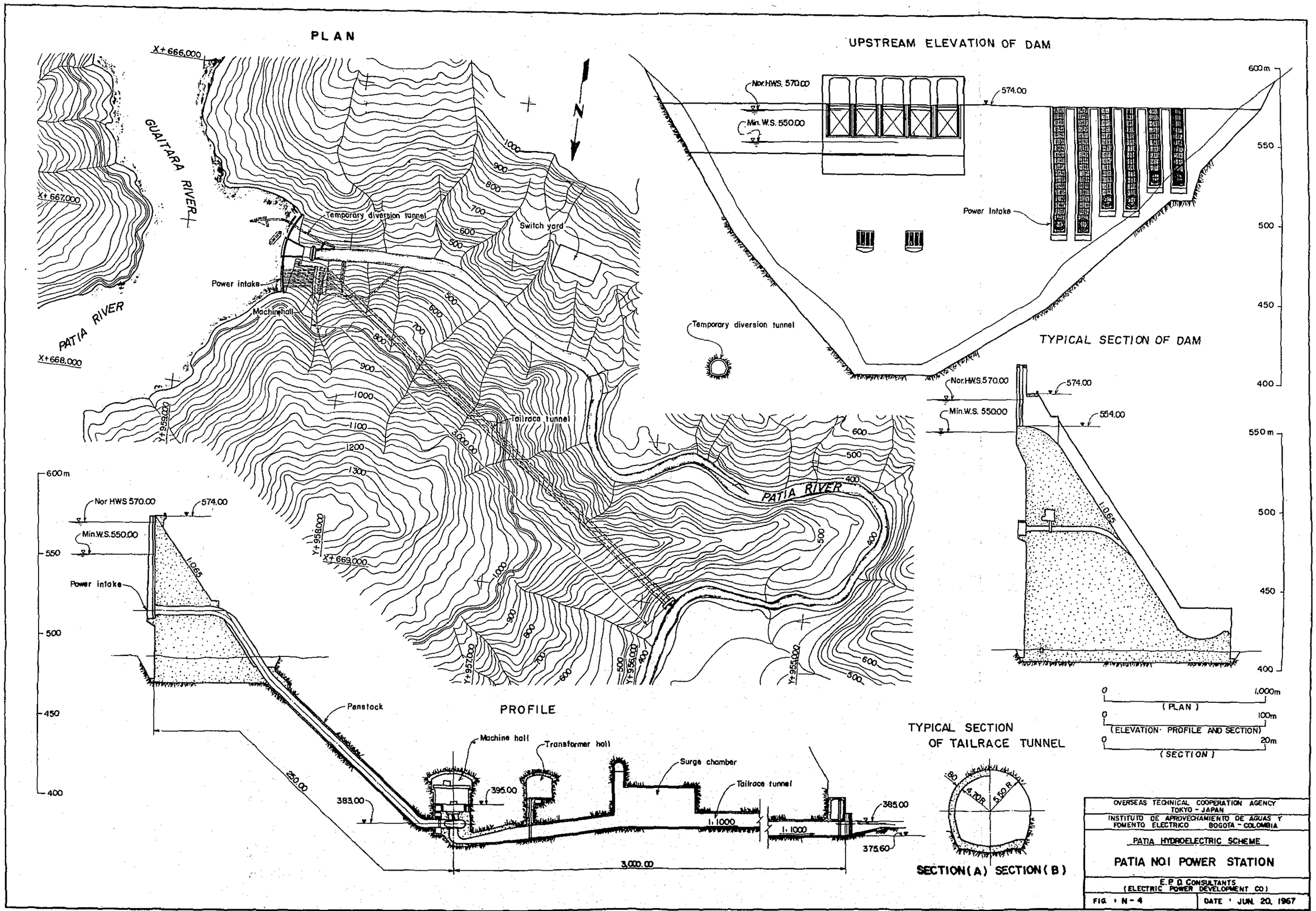
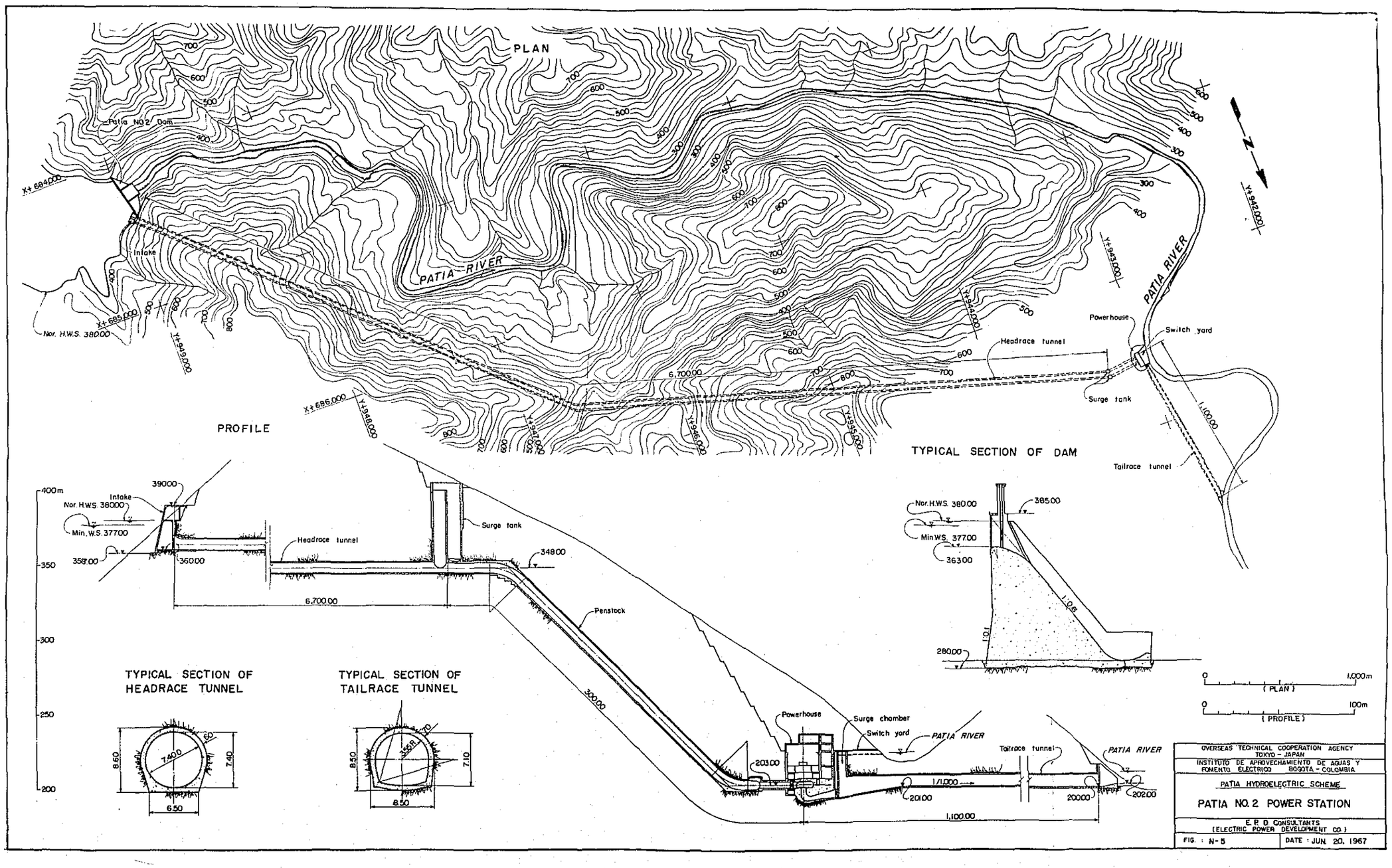
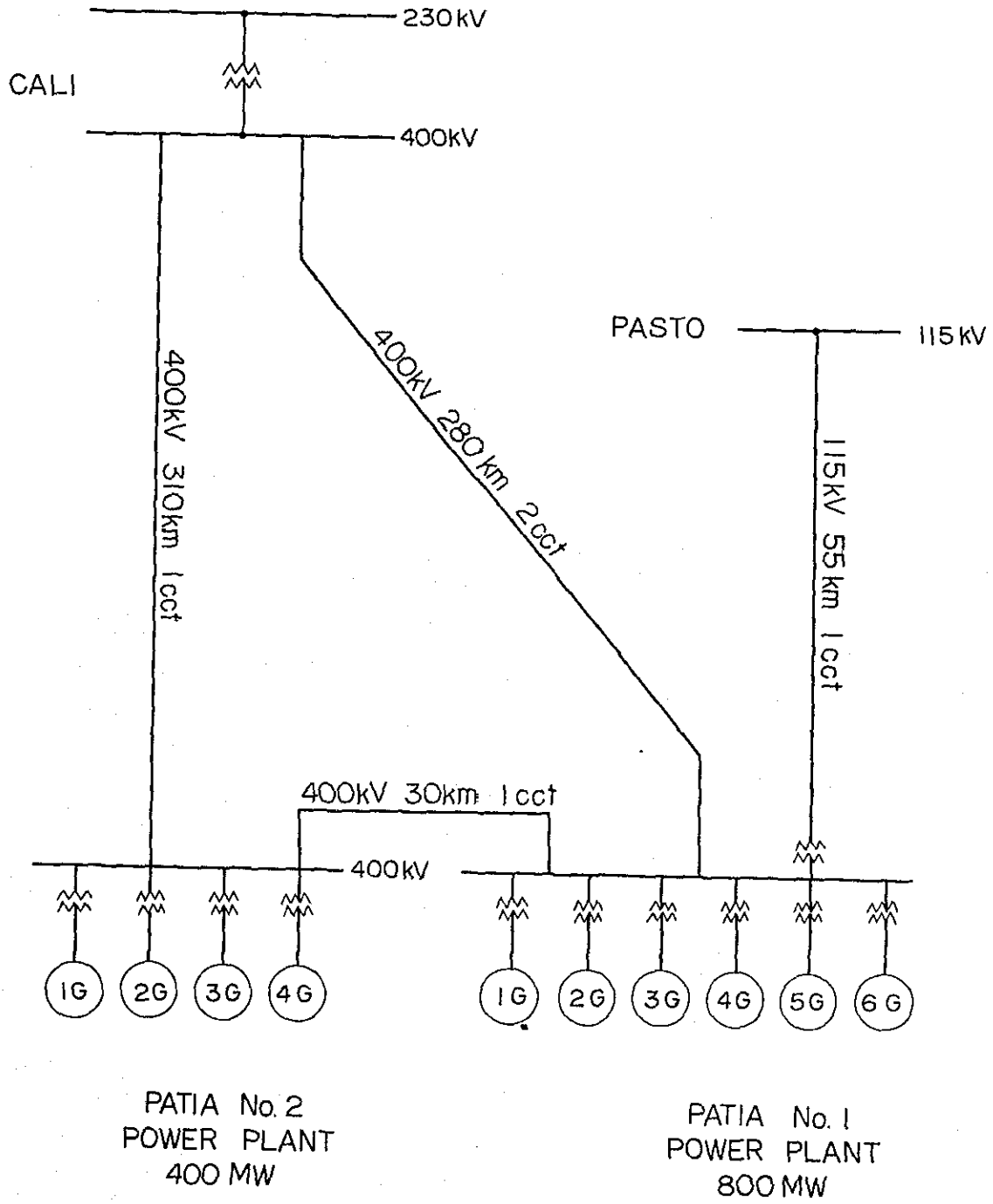
PATIA HYDROELECTRIC SCHEME	
PATIA NO.I RESERVOIR MASS CURVE	
E.P.D. CONSULTANTS (ELECTRIC POWER DEVELOPMENT CO.)	
FIG: N - 3	DATE JUN. 20, 1967


PLAN
X+666,000
X+667,000
X+668,000
GUAITARA RIVER
PATIA RIVER
Temporary diversion tunnel
Switch yard
Power intake
Machinehall
Tailrace tunnel
Y+958,000
X+669,000
Y+957,000
Y+956,000
Y+955,000
UPSTREAM ELEVATION OF DAM
Nor.H.W.S. 570.00
Min.W.S. 550.00
574.00
Power Intake
Temporary diversion tunnel
TYPICAL SECTION OF DAM
554.00
1.065
PROFILE
Penstock
Machine hall
Transformer hall
Surge chamber
Tailrace tunnel
395.00
383.00
385.00
375.60
250.00
3,000.00
TYPICAL SECTION OF TAILRACE TUNNEL
4.70R
5.50R
SECTION(A) SECTION(B)
(PLAN)
(ELEVATION· PROFILE AND SECTION)
(SECTION)
OVERSEAS TECHNICAL COOPERATION AGENCY TOKYO - JAPAN
INSTITUTO DE APROVECHAMIENTO DE AGUAS Y FOMENTO ELECTRICO BOGOTA - COLOMBIA
PATIA HYDROELECTRIC SCHEME
PATIA NO.1 POWER STATION
E.P.D. CONSULTANTS (ELECTRIC POWER DEVELOPMENT CO)
FIG. : N-4
DATE : JUN. 20, 1967


PLAN
Patia No.2 Dam
Intake
PATIA RIVER
Nor. H.W.S. 380.00
Powerhouse
Switch yard
Headrace tunnel
Surge tank
Tailrace tunnel
PROFILE
TYPICAL SECTION OF DAM
Nor.H.W.S. 380.00
Min.W.S. 377.00
385.00
363.00
280.00
1:0.8
1:0.1
Min. W.S. 377.00
358.00
360.00
348.00
6,700.00
Penstock
300.00
Surge chamber
203.00
201.00
202.00
1/1,000
1,100.00
TYPICAL SECTION OF HEADRACE TUNNEL
TYPICAL SECTION OF TAILRACE TUNNEL
7.40
8.50
6.50
7.10
0 1,000m (PLAN)
0 100m (PROFILE)
OVERSEAS TECHNICAL COOPERATION AGENCY TOKYO - JAPAN
INSTITUTO DE APROVECHAMIENTO DE AGUAS Y FOMENTO ELECTRICO BOGOTA - COLOMBIA
PATIA HYDROELECTRIC SCHEME
PATIA NO. 2 POWER STATION
E. P. D CONSULTANTS (ELECTRIC POWER DEVELOPMENT CO.)
FIG. : N-5
DATE : JUN. 20, 1967



OVERSEAS TECHNICAL COOPERATION AGENCY TOKYO - JAPAN	
INSTITUTO DE APROVECHAMIENTO DE AGUAS Y FOMENTO ELECTRICO BOGOTA - COLOMBIA	
PATIA HYDROELECTRIC SCHEME	
TRANSMISSION LINE SYSTEM	
E.P.D. CONSULTANTS (ELECTRIC POWER DEVELOPMENT CO.)	
FIG: N-6	DATE: JUN.20.1967