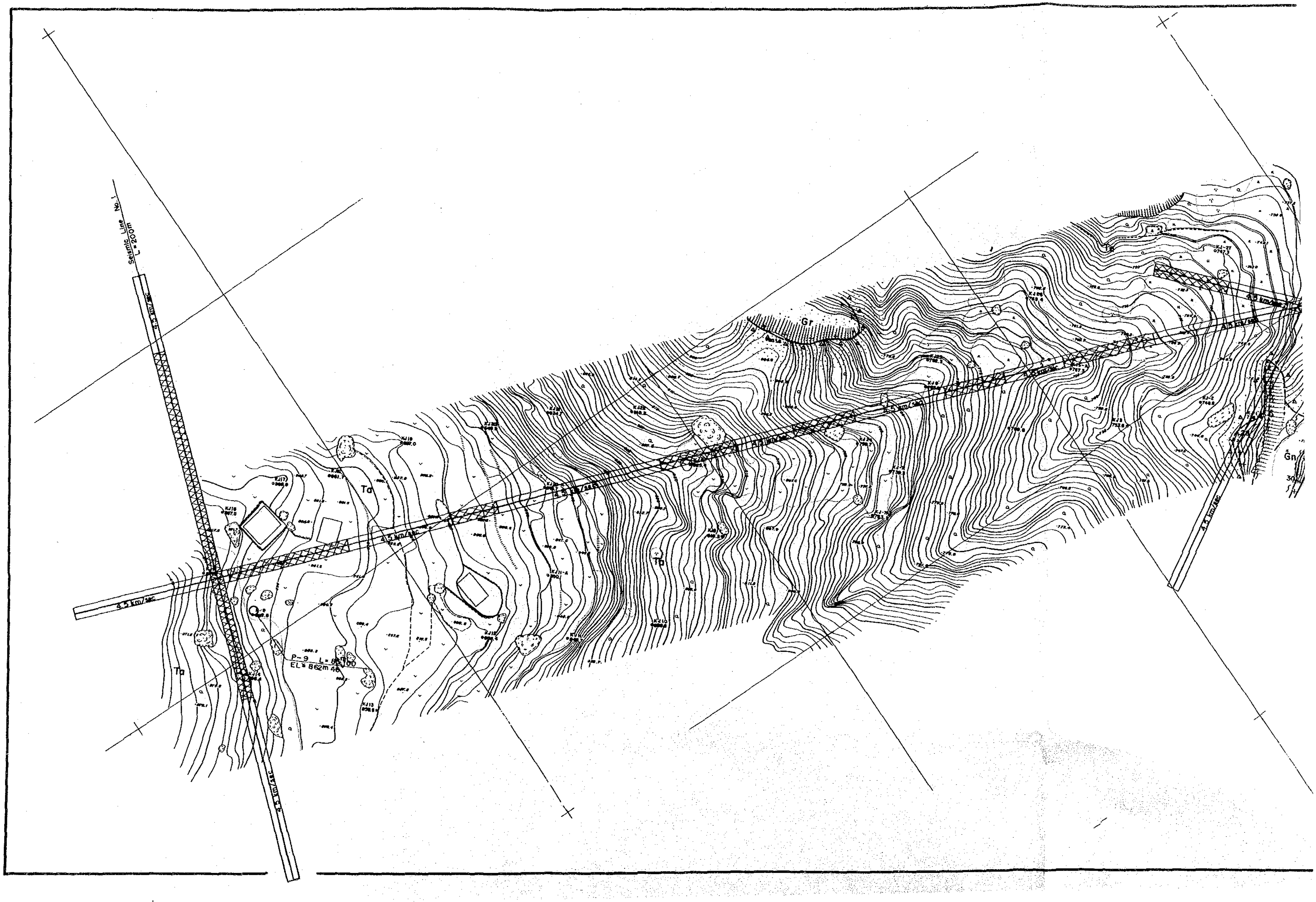
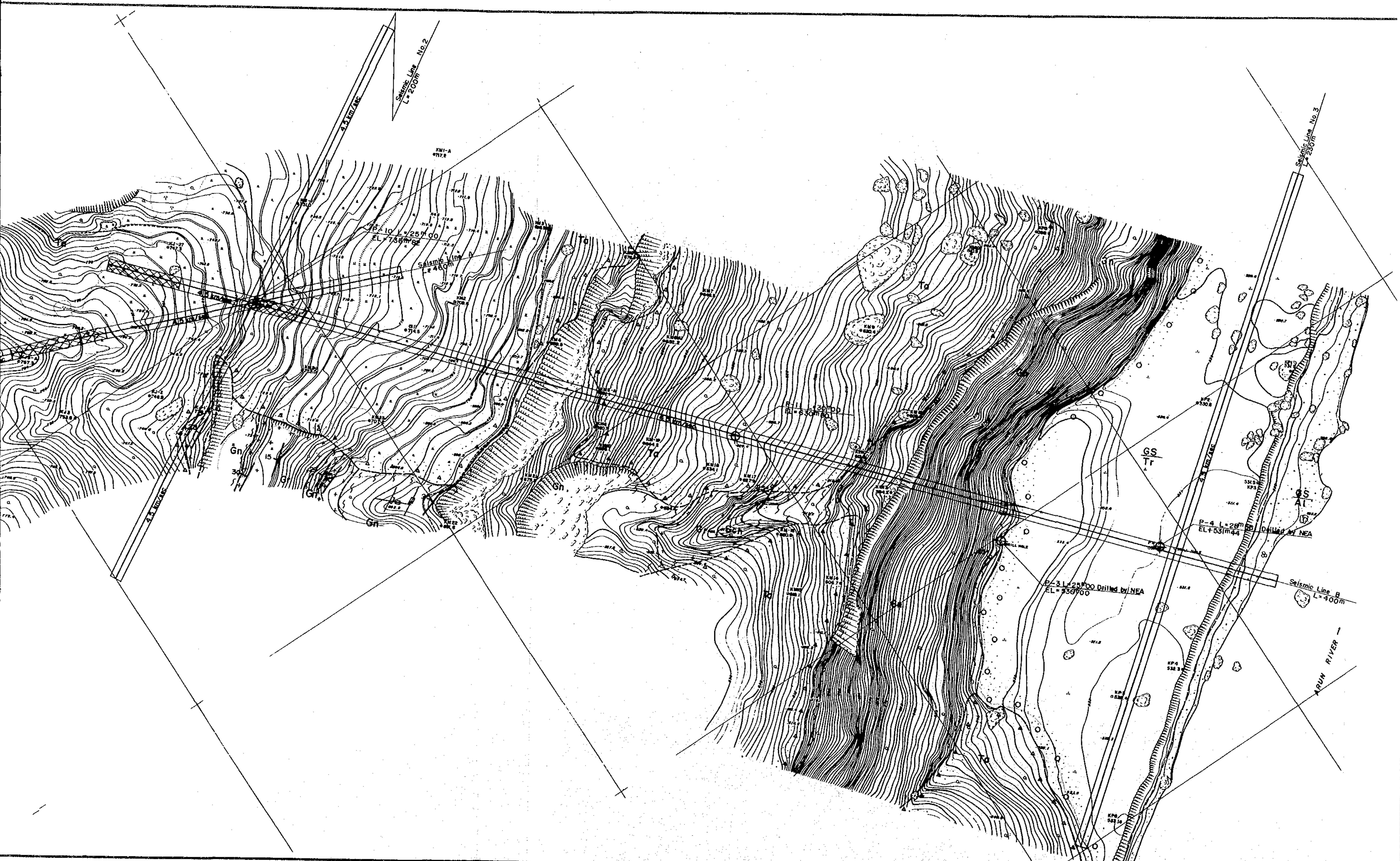
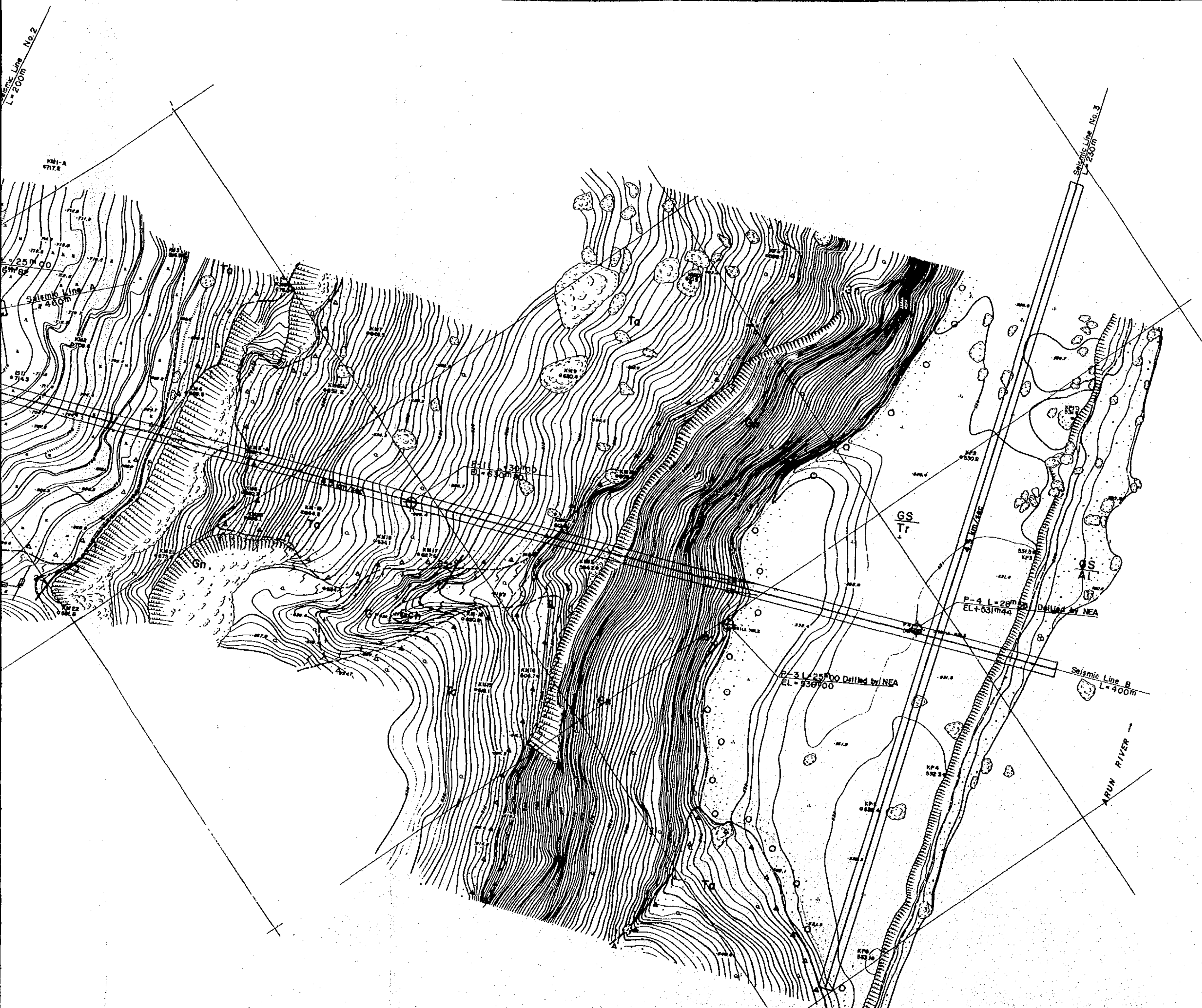
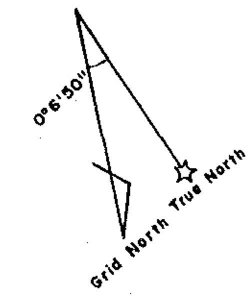

Seismic Line No.1
L = 200m
4.5 km/sec.
Ta
Gr
Gn


Seismic Line No.2
L=200m
Seismic Line A
L=460m
Seismic Line No.3
L=230m
Seismic Line B
L=400m
P-1 L=30m00
EL=630m80
P-4 L=28m50 Drilled by NEA
EL+531m44
P-3 L=25m00 Drilled by NEA
EL=539m00
GS
Tr
GS
Al
ARUN RIVER
Gn
Ta





Legend.

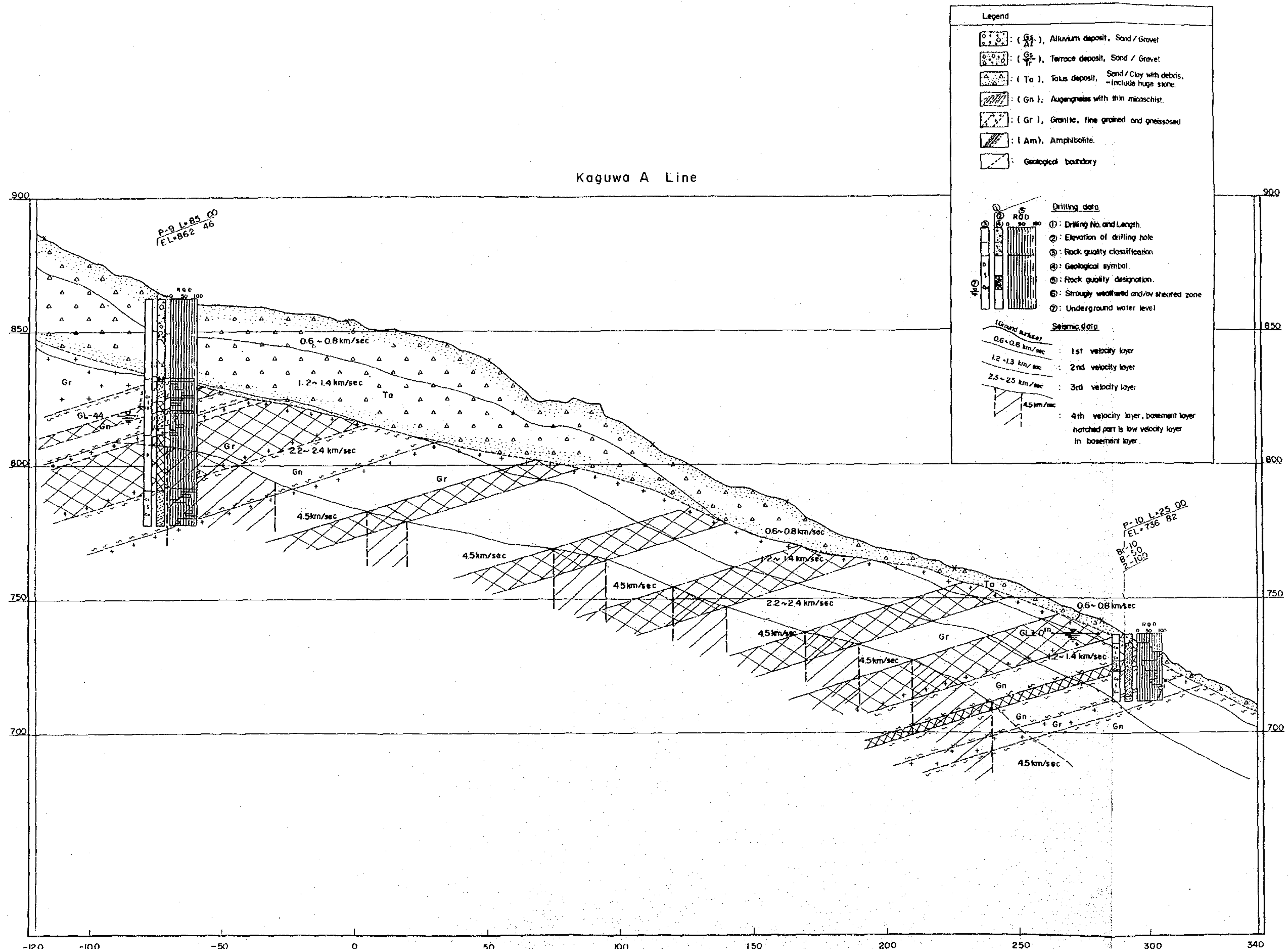
GS / Al	Alluvium river deposit, Sand / Gravel.
GS / Tr	Terrace deposit, — do —
Ta	Talus deposit, Sand/Clay with debris,-include huge stone.
Gn	Augengneiss with thin mica schist.
Gr	Granite fine grained and gneissosed.
Am	Amphibolite.
	Bedding, Gneissose structure.
	Joint.
	Drilling point.
4.5 km/sec.	Seismic Line No. Length.
	P- wave velocity in basement layer
	Low velocity layer in basement layer.
	Geological bundary

0 50m

ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

GEOLOGY
KAGUWA POWERHOUSE SITE
PLAN

DWG·G－13 | Date JUNE 1987



ARUN 3 HYDRO POWER
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GEOLOGY
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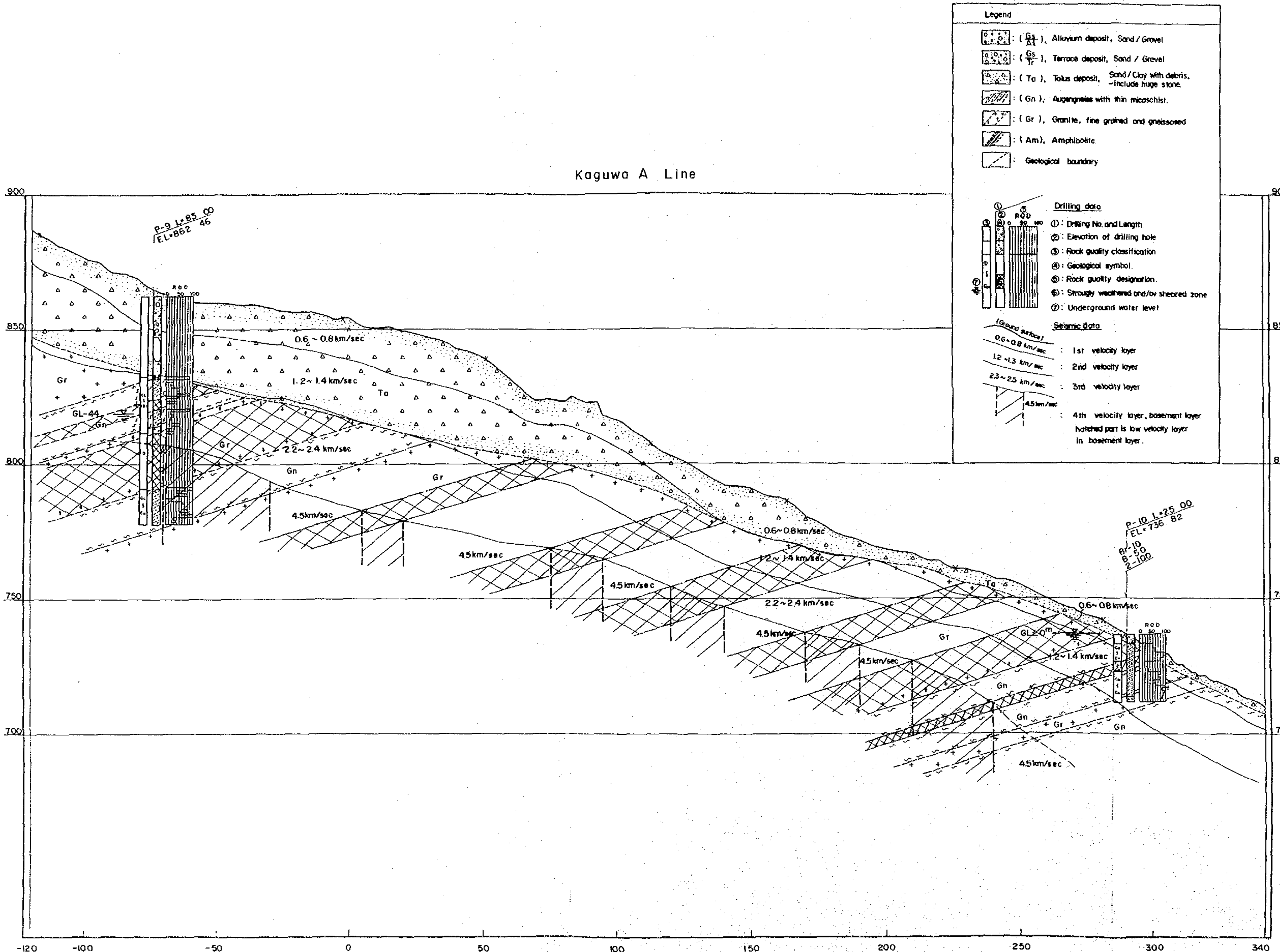
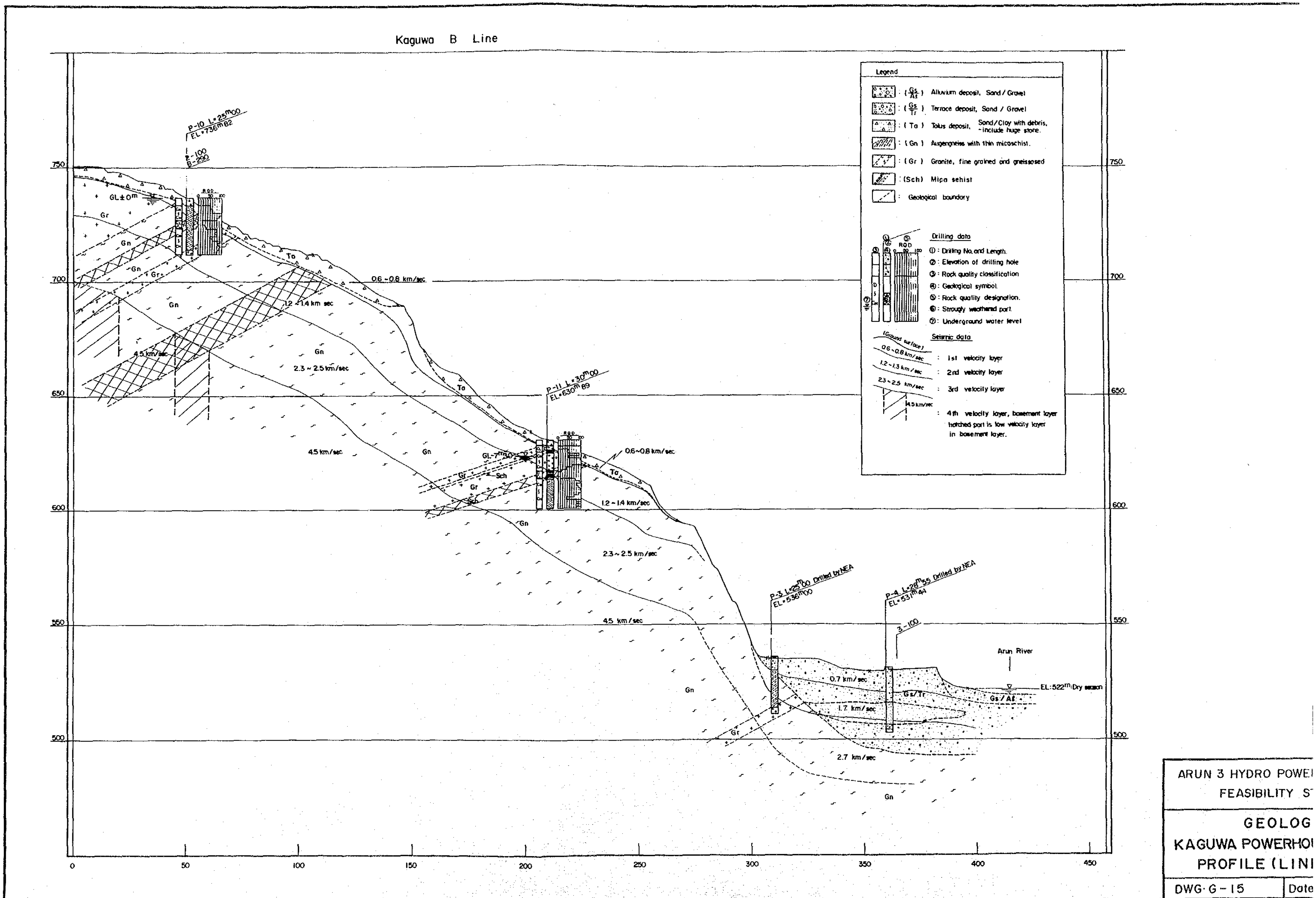


ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

GEOLOGY
KAGUWA POWERHOUSE SITE
PROFILE (LINE A)

DWG·G-14 | Date JUNE 1987



Kaguwa B Line
Legend
(Gs/At) Alluvium deposit, Sand / Gravel
(Gs/Tr) Terrace deposit, Sand / Gravel
(Ta) Talus deposit, Sand/Clay with debris, -include huge stone.
(Gn) Augengneiss with thin micaschist.
(Gr) Granite, fine grained and gneissosed
(Sch) Mica sehist
Geological boundary
Drilling data
①: Drilling No. and Length.
②: Elevation of drilling hole
③: Rock quality classification
④: Geological symbol
⑤: Rock quality designation.
⑥: Strongly weathered part.
⑦: Underground water level
Seismic data
(Ground surface)
0.6~0.8 km/sec : 1st velocity layer
1.2~1.3 km/sec : 2nd velocity layer
2.3~2.5 km/sec : 3rd velocity layer
4.5 km/sec : 4th velocity layer, basement layer hatched part is low velocity layer in basement layer.
P-10 L=25m00
EL=736m82
P-11 L=30m00
EL=630m89
P-3 L=25m00 Drilled by NEA
EL=536m00
P-4 L=28m55 Drilled by NEA
EL=531m44
GL±0m
Arun River
EL:522m:Dry season
0.6~0.8 km/sec
1.2~1.4 km/sec
2.3~2.5 km/sec
4.5 km/sec
0.7 km/sec
1.7 km/sec
2.7 km/sec
750
700
650
600
550
500
0
50
100
150
200
250
300
350
400
450
ARUN 3 HYDRO POWE
FEASIBILITY S
GEOLOG
KAGUWA POWERHO
PROFILE (LIN
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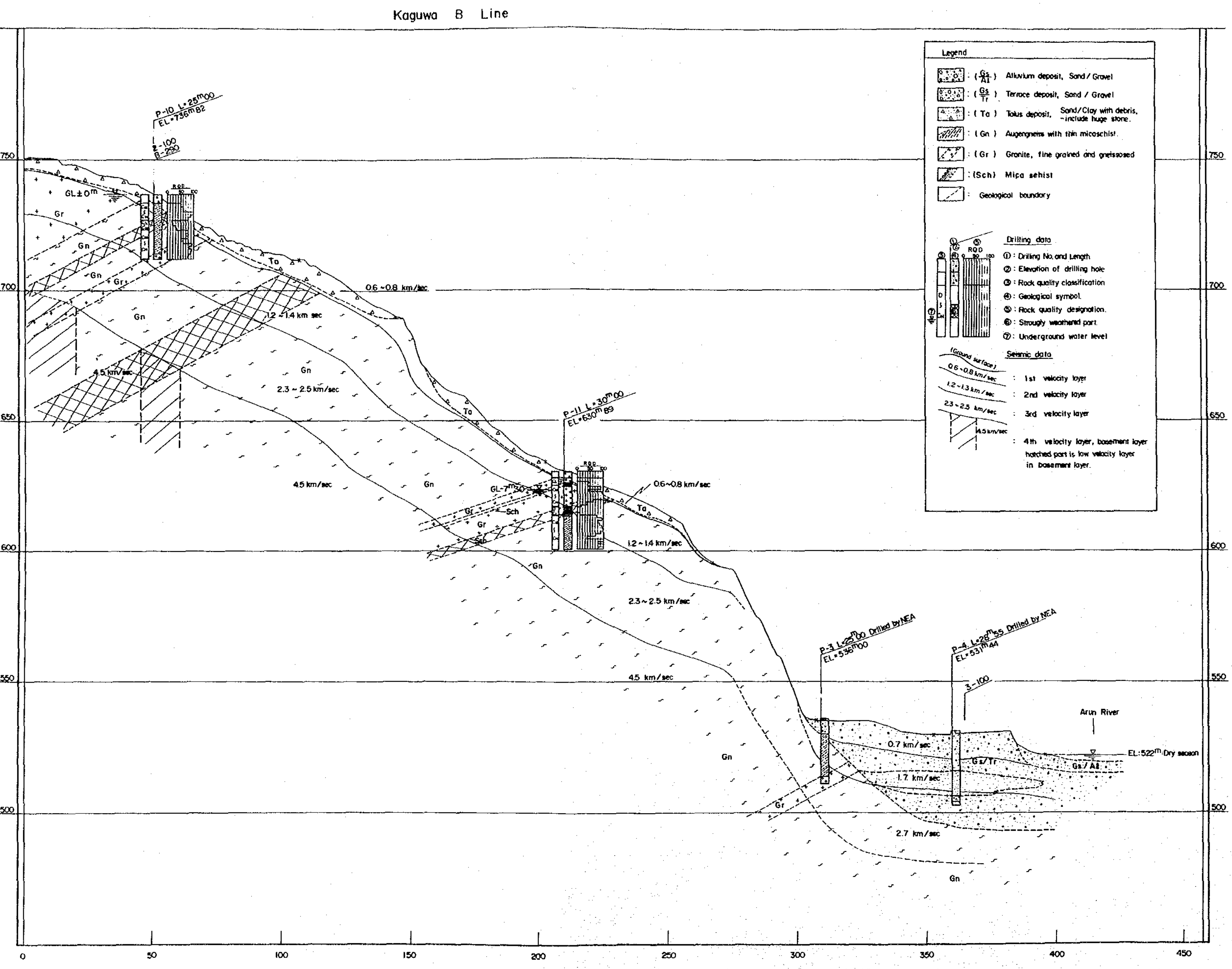
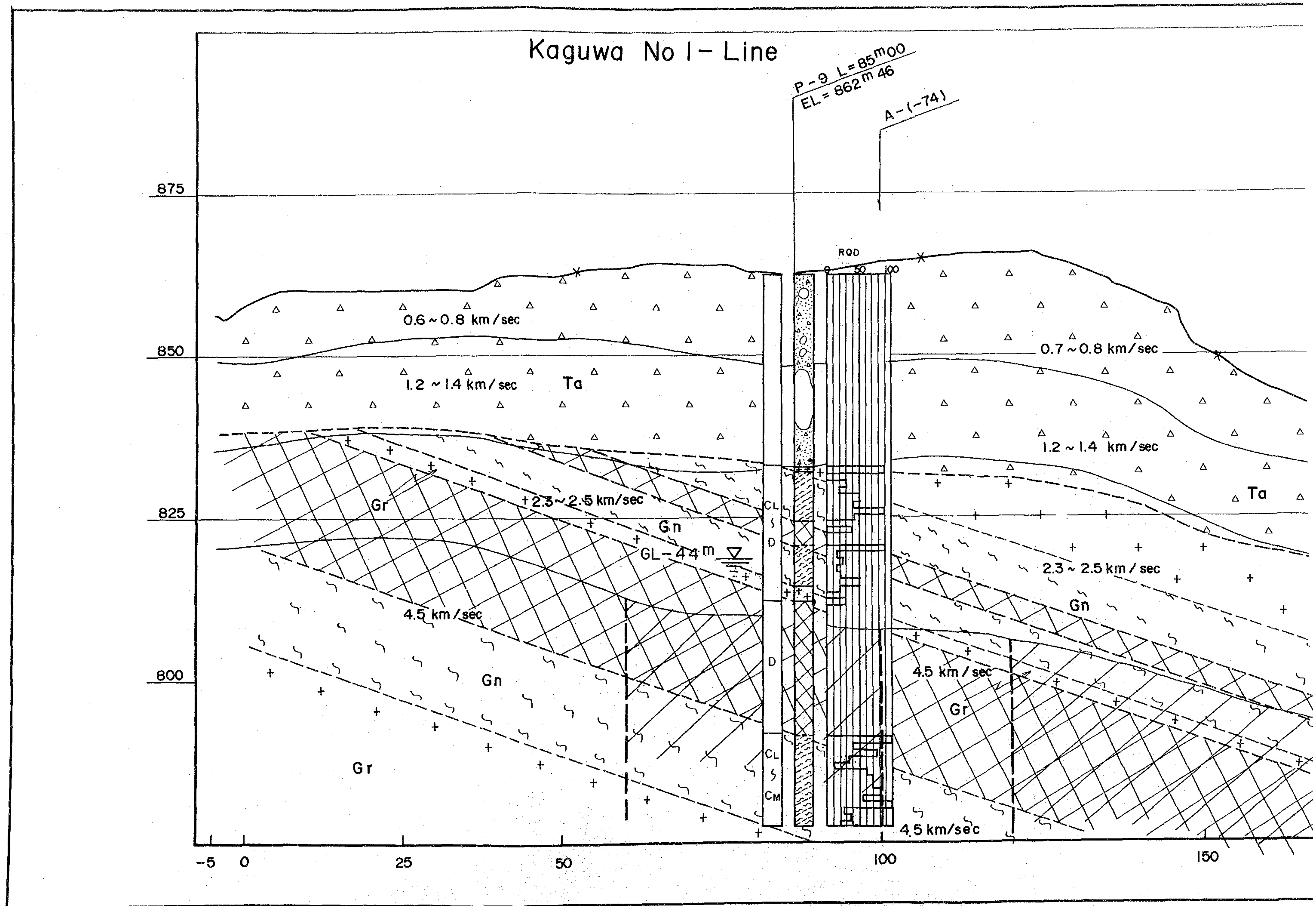


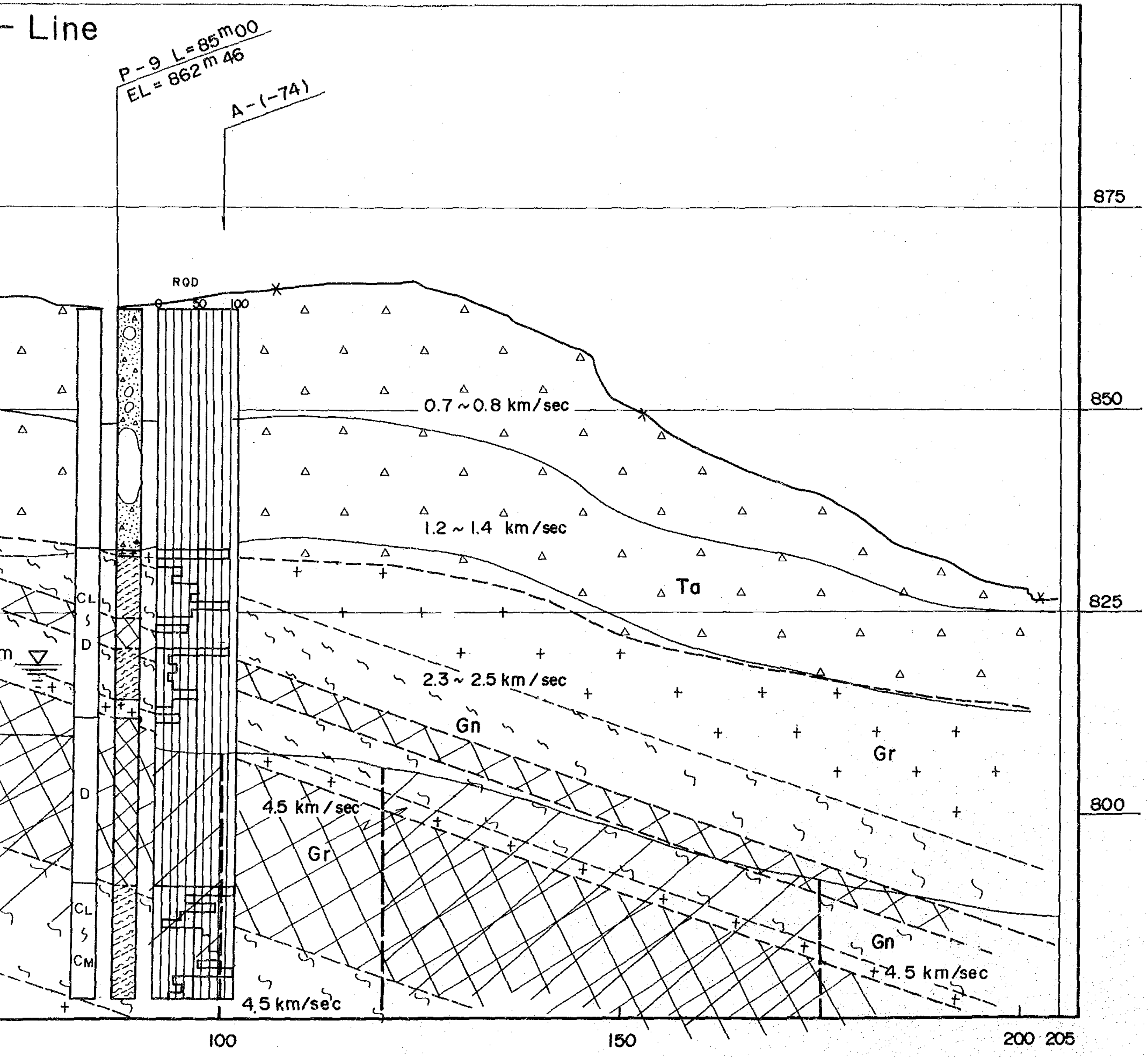
ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

GEOLOGY
KAGUWA POWERHOUSE SITE
PROFILE (LINE B)

DWG·G-15	Date JUNE 1987



Kaguwa No I- Line
P-9 L=85m00
EL=862m46
A-(-74)
RQD
0 50 100
875
850
825
800
0.6 ~ 0.8 km/sec
1.2 ~ 1.4 km/sec
Ta
0.7 ~ 0.8 km/sec
1.2 ~ 1.4 km/sec
Ta
Gr
2.3 ~ 2.5 km/sec
Gn
GL-44m
CL
D
D
CL
CM
2.3 ~ 2.5 km/sec
Gn
4.5 km/sec
Gn
Gr
4.5 km/sec
Gr
4.5 km/sec
-5
0
25
50
100
150



Legend

- (Gs/Al), Alluvium deposit, Sand/Gravel.
- (Gs/Tr), Terrace deposit, Sand/Gravel.
- (Ta), Talus deposit, Sand/Clay with debris, - include huge stone.
- (Gn), Augengneiss with thin mica schist.
- (Gr), Granite, fine grained and gneissosed
- (Am), Amphibolite
- Geological boundary

Drilling data

① : Drilling No. and Length.
② : Elevation of drilling hole
③ : Rock quality classification
④ : Geological symbol.
⑤ : Rock quality designation.
⑥ : Strongly weathered and/or sheared zone.
⑦ Underground water table

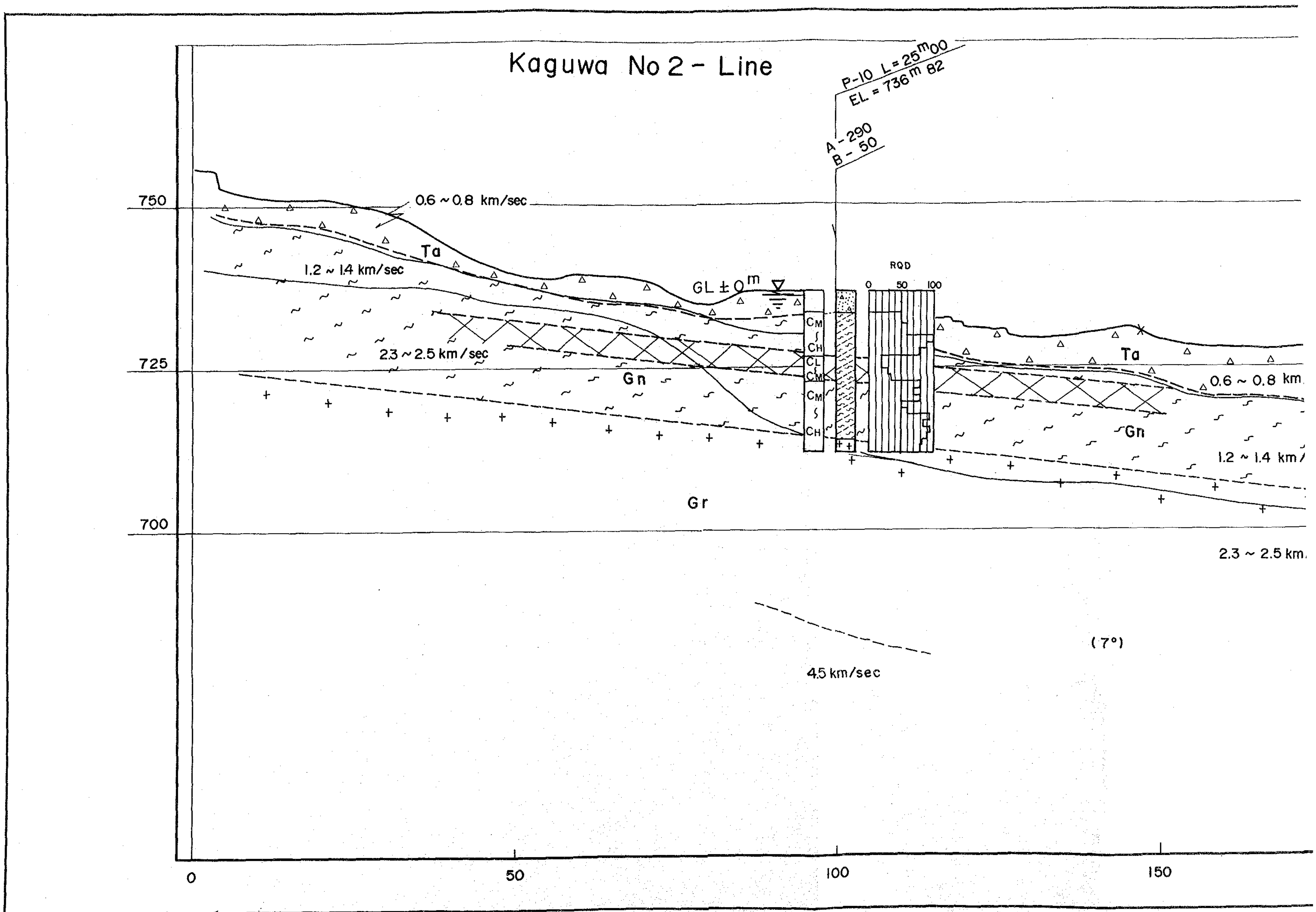
Seismic data

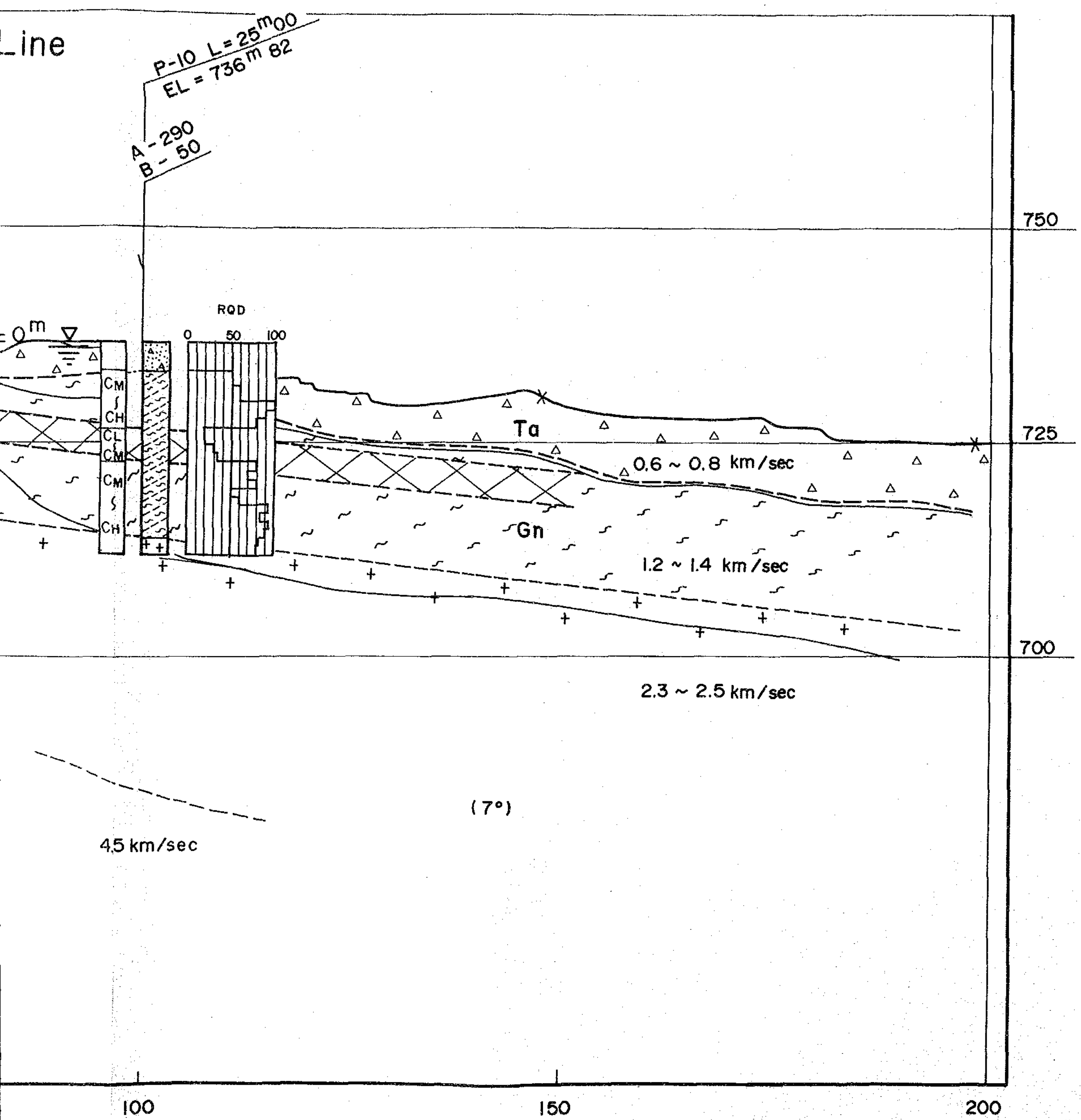
(Ground surface)
0.6 ~ 0.8 km/sec : 1st velocity layer
1.2 ~ 1.3 km/sec : 2nd velocity layer
2.3 ~ 2.5 km/sec : 3rd velocity layer
4.5 km/sec : 4th velocity layer basement layer hatched part is low velocity layer in basement layer.

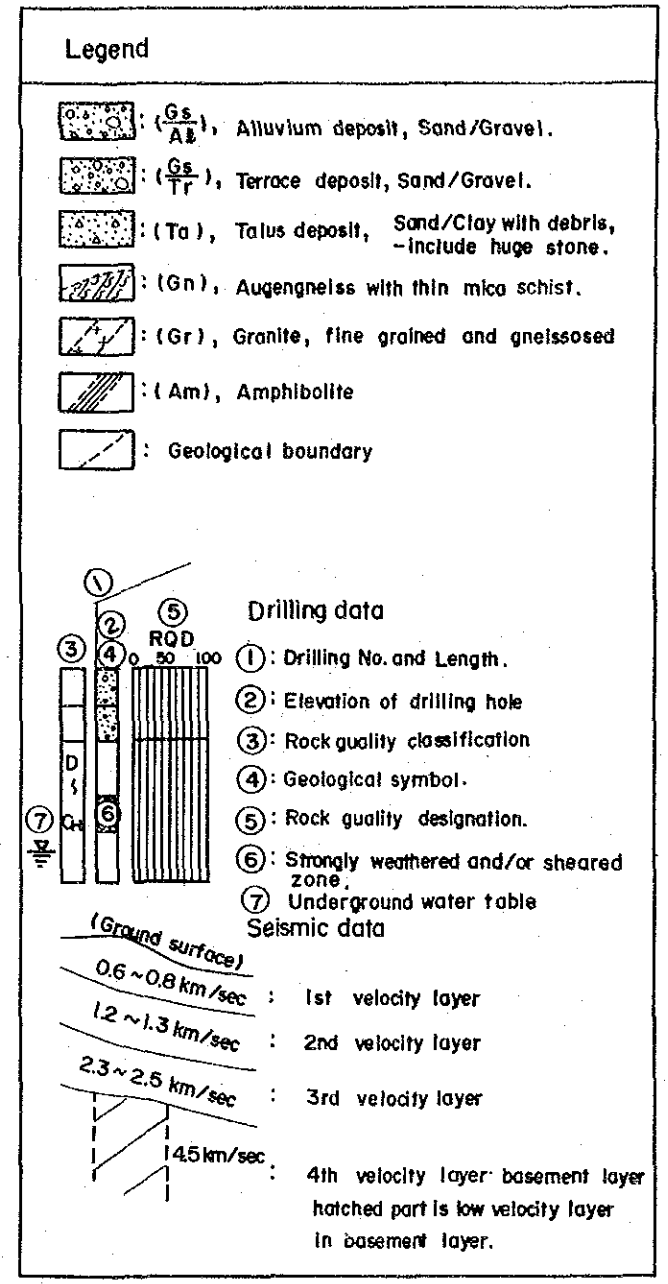
ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

GEOLOGY
KAGUWA POWERHOUSE SITE
PROFILE (LINE 1)

DWG·G-16 | Date JUNE 1987


Kaguwa No 2 - Line
P-10 L = 25m00
EL = 736m82
A - 290
B - 50
750
725
700
0.6 ~ 0.8 km/sec
Ta
1.2 ~ 1.4 km/sec
GL ± 0m
RQD
0
50
100
CM
CH
CL
CM
CM
CH
2.3 ~ 2.5 km/sec
Gn
Gr
Ta
0.6 ~ 0.8 km
Gn
1.2 ~ 1.4 km
2.3 ~ 2.5 km
(7°)
4.5 km/sec
0
50
100
150

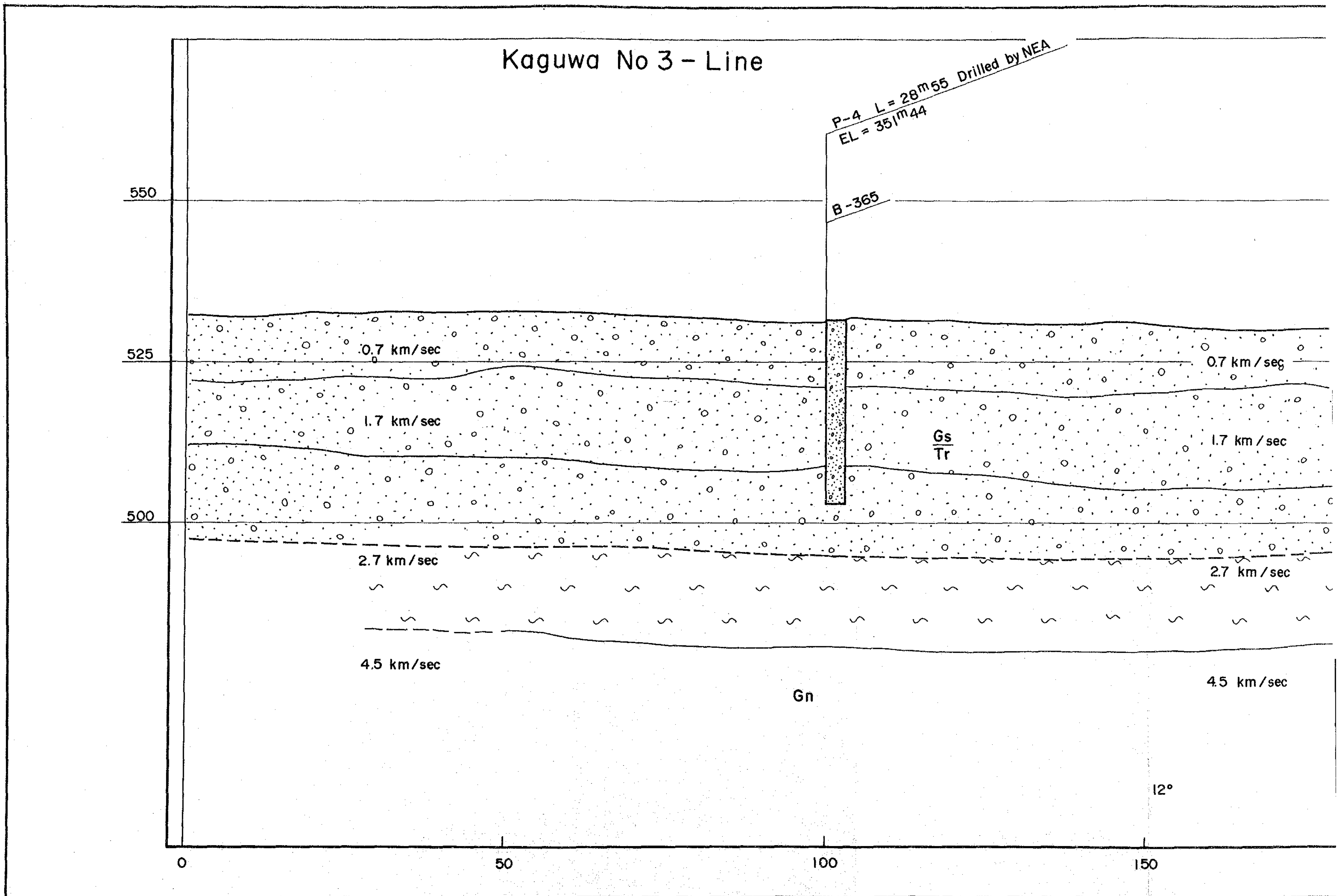




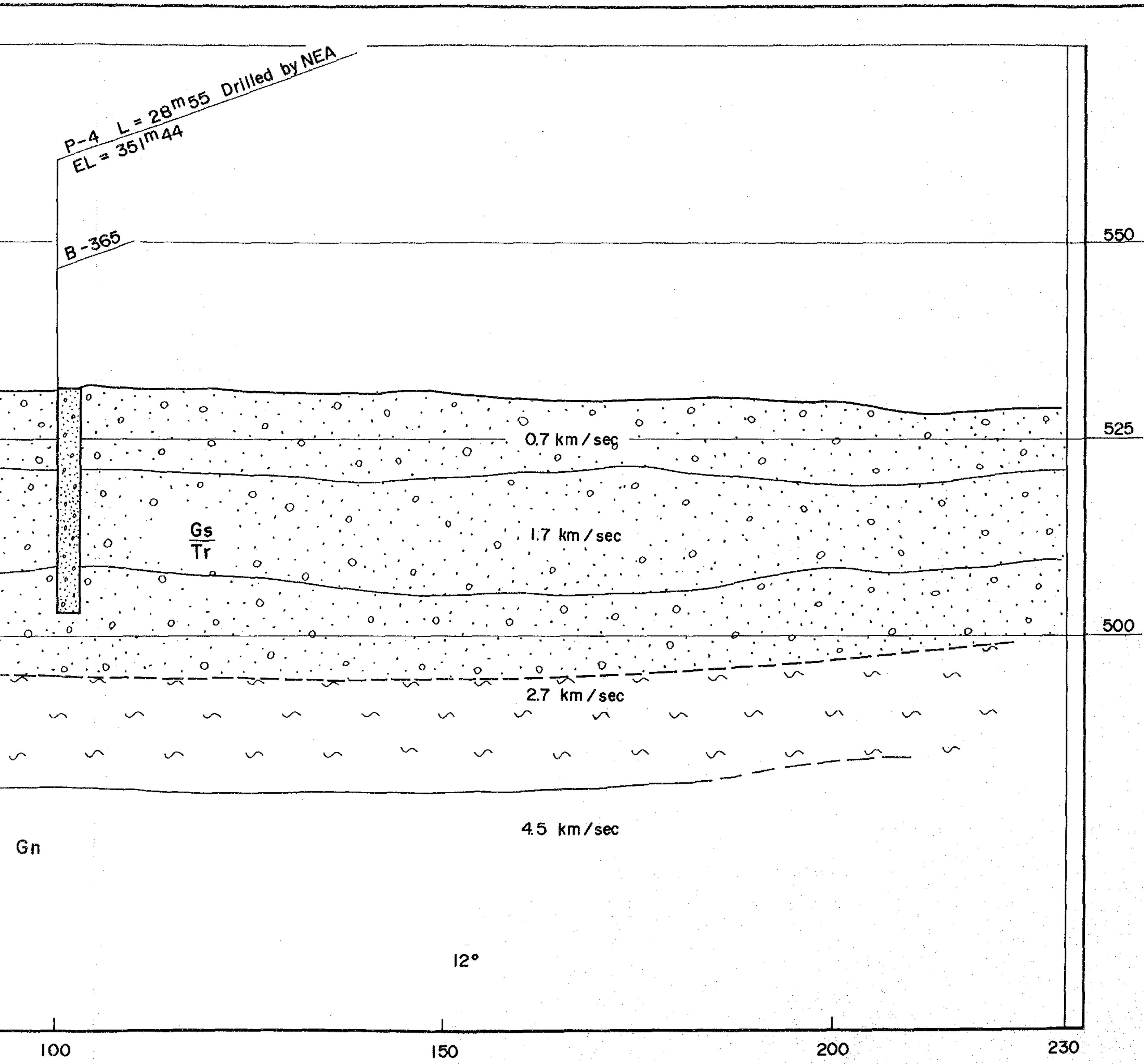
ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

GEOLOGY
KAGUWA POWERHOUSE SITE
PROFILE (LINE 2)

DWG·G-17	Date JUNE 1987



Kaguwa No 3 - Line
P-4 L = 28m55 Drilled by NEA
EL = 351m44
B-365
550
525
500
0.7 km/sec
1.7 km/sec
2.7 km/sec
4.5 km/sec
0.7 km/sec
1.7 km/sec
2.7 km/sec
4.5 km/sec
Gs/Tr
Gn
12°
0
50
100
150



Legend

- : ($\frac{Gs}{Al}$), Alluvium deposit, Sand/Gravel.
- : ($\frac{Gs}{Tr}$), Terrace deposit, Sand/Gravel.
- : (Ta), Talus deposit, Sand/Clay with debris, —include huge stone.
- : (Gn), Augengneiss with thin mica schist.
- : (Gr), Granite, fine grained and gneissosed
- : (Am), Amphibolite
- : Geological boundary

Drilling data

① : Drilling No. and Length.
② : Elevation of drilling hole
③ : Rock quality classification
④ : Geological symbol.
⑤ : Rock quality designation.
⑥ : Strongly weathered part

(RQD 0 50 100)

Seismic data

(Ground surface)

0.6 ~ 0.8 km/sec : 1st velocity layer
1.2 ~ 1.3 km/sec : 2nd velocity layer
2.3 ~ 2.5 km/sec : 3rd velocity layer
4.5 km/sec : 4th velocity layer basement layer hatched part is low velocity layer in basement layer.

ARUN 3 HYDRO POWER PROJECT FEASIBILITY STUDY	
GEOLOGY KAGUWA POWERHOUSE SITE PROFILE (LINE 3)	
DWG·G – 18	Date JUNE 1987

CHAPTER 5. HYDROLOGY AND METEOROLOGY

CHAPTER 5. HYDROLOGY AND METEOROLOGY

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CHAPTER 5. HYDROLOGY AND METEOROLOGY

5.1 General

This chapter pertains to analyses of river discharges at the dam site necessary for estimating energy generation, design flood to be applied to the civil structures, glacier lake outburst flood (GLOF) and sedimentation. Though the majority of the drainage basin upto the project site lies in the Tibetan area, practically no reliable information on Tibetan side of the catchment is available. However, the related data available in Nepal are generally well prepared and the results of analyses induced herefrom are considered to be fully satisfactory.

In connection with the design flood discharge, the analytical study on the probable maximum flood (PMF) is examined in consideration of importance of this project. Since the Arun river basin in Nepal has the typical topographic features for orographic precipitation, the estimate of flood discharge by means of PMF analysis is considered useful. As to the studies on GLOF, firstly historical events and the mechanism of GLOF are stated, and then the distribution and approximate scale of glacier lakes are indicated, and finally virtual analyses are simulated. As for sedimentation, sedimentation load in the reservoir is estimated by both the samples collected near the dam site and the records in neighboring basin, and further the shape of sedimentation is calculated.

5.2 Physiography and Climate in Project Area

5.2.1 Topography

(1) General

The Arun river is a tributary of the Sapt Kosi river running through the eastern part of Nepal and takes its rise from a glacier in the Tibetan highland north of the Himalayan range. The Arun river first runs eastward in parallel with the Himalayan range and in this section, the river gradient is rather gentle ranging from 1/600 to 1/100 and the width of valley is also wide. The Arun river thereafter makes abrupt turn to south changing the whole situation of surroundings, runs with average gradient of 1/50 forming deep gorge of V shape, crosses the Himalayan range to Nepal and joins with the Sapt Kosi river at Tribeni taking in many tributaries on its way. As stated above, the Arun river runs through two territorial sections; the Tibetan section and the Nepal section, having quite different topographic and meteorological characters divided by the Himalayan range. More than 90% of the total drainage basin upto the dam site is on Tibet side. Topographically, the Tibetan part of the basin is generally formed with soft highland, while, the Nepalese part of the basin is mountainous area with varied elevation. Meteorologically, the Tibetan section belongs to a cold zone with less precipitation due to shadow by the Himalayan range, while the Nepal section belongs to a mild zone with much precipitation due to monsoon except the extremely high land along the Himalayan range.

As to the hydrological and meteorological data, the related data collected so far in the Tibetan basin are only the monthly average records at Tingri in the upper reach of the Arun river, while in the Nepal basin, the substantial data have been collected. The information in the Tibetan part of the basin that can be used for hydrological analysis of the Arun river is quite limited. Hence the information does not contribute much in calculating various discharges. But it is believed that the flood analysis based on the various data available in Nepal will be still of high accuracy since the major component of flood discharge originates practically from the southern slope of the Himalayan range.

(2) Drainage Area

(i) Dam site

As two different drainage areas are indicated in the "Master Plan Study" and "Prefeasibility Study", the drainage areas at the dam site and at the Tumlingtar gauging station are again reviewed as shown in Table 5-1 on the basis of 1/50,000 topographic map. But the Tibetan part of the basin is not checked due to lack of reliable small scale topographic map.

Table 5-1 Basin Area

Item Case	(1) M/P	(2) Pre-F/S	(3) F/S
Tumulingtar G.S	-	30,762	-
Tumling.G.S - Dam Site	Not Indicated		1,452
Dam Site	32,332	30,031	29,310
Dam Site - Boundary	Not Ind.	1,381	Not Ava.

(ii) Gauging stations

Following drainage areas employed by NEA are used for the study.

Tumlingtar (No. 604.5) : 30,762 km^2
Sabhaya (No. 602) : 375 km^2
Hinwa (No. 602.5) : 110.44 km^2

5.2.2 Meteorology

(1) Tibetan Basin

In the whole Tibetan basin, much precipitation in the eastern region has been observed with trend to decrease to the west, and the mean annual precipitations of less than 100 mm are recorded at some places. As the Arun river basin in Tibet is shadowed by the Himalayan range, it is situated in a low-rain area of whole Tibet and the mean annual precipitation in 5 years from 1971 to 1975 is reported to be only 322 mm at Tingri located at the center of the Arun river basin in Tibet. As to the annual rainfall distribution, more than 90% of total precipitation concentrates in summer (June to September) similarly to that in the area south of the Himalayan range. On the other hand, evaporation is extremely high and the mean annual evaporation of 2,569 mm in 5 years from 1971 to 1975 is reported at Tingri stated above. This may be owing to large number of days with fine weather, low humidity, high solar radiation at highland, etc. in spite of relatively low temperature in the Tibetan basin. It is noted that the mean annual temperature at Tingri is recorded as 0.7°C and the mean monthly temperature ranges from -11.3°C to 10.9°C and is below zero between November and March.

(2) Nepal Basin

The Arun river basin in Nepal includes all climatological elements between the subtropical zone and alpine zone and the meteorological phenomena in this area are subject considerably to topographic locality, especially to altitude, as charactered by the wide range of mean annual precipitation from 1,200 mm to 3,500 mm. The specific features of rainfall distribution in the eastern region of Nepal are that (1) the highest precipitation belts lie east and west along southern slopes of the Mahabharat range and the Himalayan range and (2) the low precipitation zone is formed at the lowland between the above two ranges. The above high precipitations are caused by the southeasterly moist air current in the monsoon season which send rain first on the southern slope of the Mahabharat range of about 2,000 m high and then on the southern slope of the Himalayan range forming rapid ascending current. Num near the dam site is situated in the area with the highest precipitation in this region and its precipitation amounts sometimes to 5,000 mm in wet years. Based on the isohyetal map of the drainage basin in Nepal at the dam site, the mean annual precipitation is estimated at 2,650 mm. Fig. 5-1 shows the typical rainfall distribution in the whole Arun river basin and Table 5-2 indicates the rainfall data at the representative weather observatories.

5.3 Hydro-meteorological Network

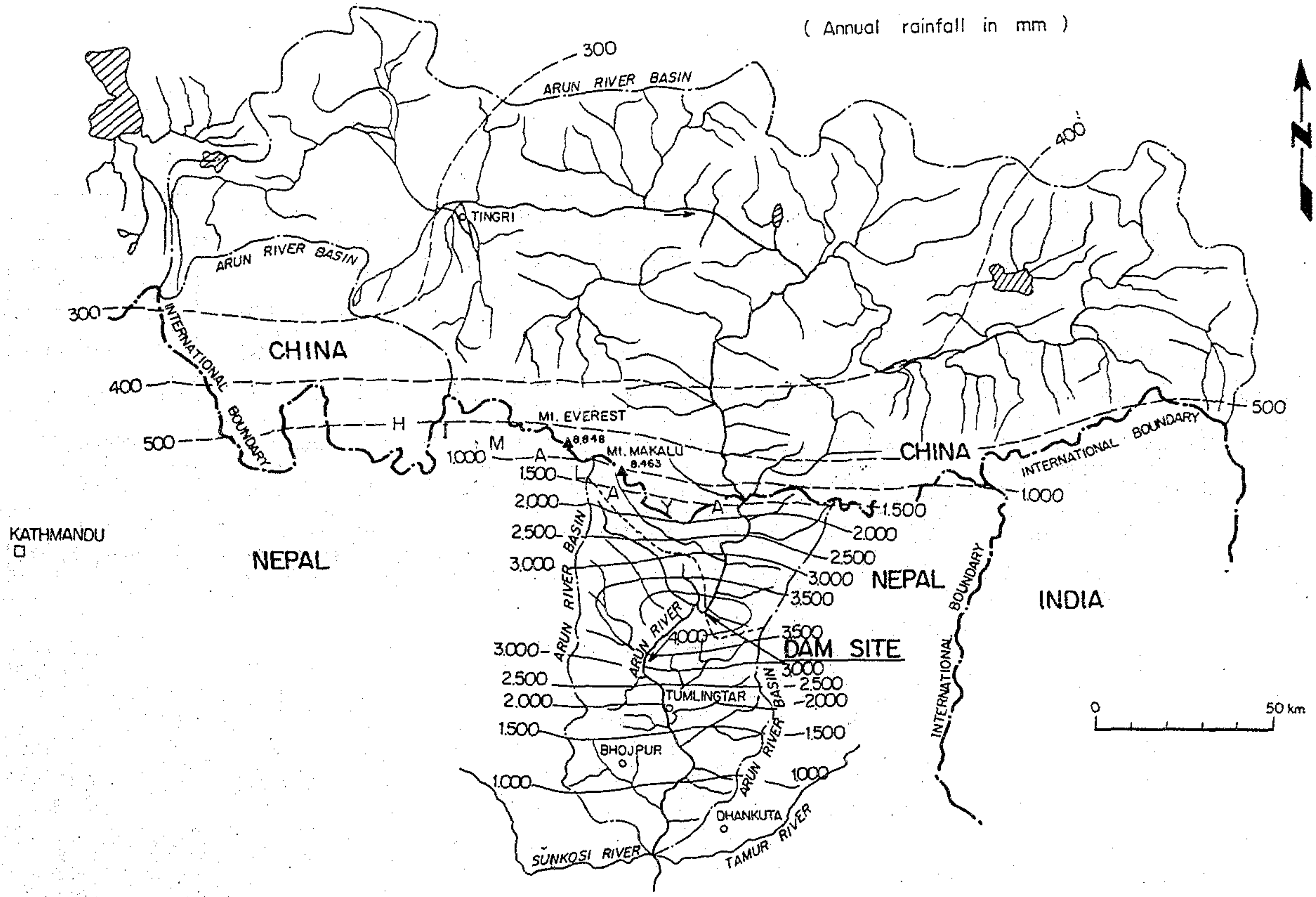
The location of meteorological stations and gauging stations in the vicinity of the project are shown in Dwg. 1. Out of these stations,

Table 5–2 Rain Fall Data

Station Number	Station Name	Altitude (EL.m)	Periods of Observation	Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Data	N o t e
	Tingri	4300	1970~1975	5	0.0	0.1	0.4	0.8	1.9	14.7	28.9	37.6	12.9	2.4	0.3	0.0	322.2	Tibet area
1201	Namche Bazar	3450	1949~1980	32	31.5	17.2	29.8	24.9	41.9	136.3	227.8	221.3	146.3	65.3	9.7	16.2	968.2	Outside Arun Basin
1202	Chaurikhark	2619	1949~1980	32	14.7	17.9	44.8	48.2	103.2	322.3	592.6	574.1	329.5	84.3	15.0	9.1	2154.7	Outside Arun Basin
1301	Num	1497	1960~1983	24	32.3	43.5	83.3	233.1	474.2	741.7	672.1	593.8	518.8	279.2	64.8	22.0	3758.8	
1303	Chainpur	1329	1948~1983	36	14.5	12.2	23.9	79.0	167.9	215.0	315.3	279.4	181.0	63.0	15.5	4.2	1370.9	
1317	Chepuwa	2591	1960~1983	21	43.4	68.9	130.4	140.6	235.6	414.0	510.6	442.8	347.2	144.0	48.6	15.4	2541.5	
1325	Dingla	1190	1957~1983	27	14.2	12.0	28.9	74.1	168.5	297.4	394.4	396.1	338.0	106.9	10.7	6.5	1847.7	

Fig. 5–1 Typical Isohyetal Map of Arun Basin

(Annual rainfall in mm)



only the Num and Chepuwa stations lie within the drainage basin upto the dam site. However, others are also referred to as the valid information sources for estimation of river discharge at the dam site. As to river discharge measurement on the main Arun river, there is only the Tumlingtar gauging station located about 50 km downstream of the dam site. Observation period of this station is 11 years from 1975 upto present which is considered not long enough, still the data can be used for estimating the energy generation with satisfactory accuracy. Observation period at the above stations are shown in Table 5-3.

5.4 Data Analysis

5.4.1 Uniformity of Rainfall Data

Uniformity analysis of the rainfall data available at meteorological stations Num, Chepuwa, Chainpur and Dingla, is examined by double mass curve method as these stations are located in the Arun river basin and have comparatively long observation periods. Fig. 5-2 gives the result of analysis which shows the reliability of data in view of their linear distributions.

5.4.2 Hydrologic Cycle

It is considered that the hydraulic data will show a certain hydraulic cycle in the long term observation and this hydraulic cycle will be useful for scheduling the operation rule curve as well as estimate of energy generation. The moving average method and power spectral analysis are examined for the purpose. As the river discharge data are only for 11 years, the rainfall data at Kathmandu (62 years), Num (23 years) and Chainpur (37 years) are used.

(1) Moving Average Method (5 years)

Fig. 5-3 shows the result of analysis by the moving average method. No hydraulic cycle is obtained at Num, however, that of 20 to 26 years can be observed at Kathmandu and Chainpur. As the trends of curves at Kathmandu and Chainpur resemble comparatively, it is assumed that hydraulic cycle around Kathmandu looks like that of Arun river basin.

Table 5–3 Hydrological and Meteorological Data List

Meteorologic Station	Station Number	Location Lat.N	Location Long.E	Elevation (m)
Arun River Basin				
Chepuwa	1317	27°46'	87°25'	2,591
Num	1301	27°33'	87°17'	1,497
Tumlingtar	1321	27°17'	87°13'	303
Dingla	1325	27°22'	87°09'	1,676
Chainpur	1303	27°17'	87°20'	1,329
Legua Ghat	1305	27°08'	87°17'	305
Dudh Kosi River Basin				
Syangboche	1225	27°49'	86°43'	3,700
Khumjung	1217	27°49'	86°43'	4,340
Namche Bazar	1201	27°50'	86°43'	3,450
Chaurikhark	1202	27°42'	86°44'	2,438
Tamur River Basin				
Olangchung Gola	1401	27°41'	87°47'	1,720
Lung Thung	1403	27°33'	87°47'	1,780
Taplethock	1404	27°29'	87°47'	1,372
Kathmandu				
Kathmandu I.E.	1030	27°42'	85°20'	1,324

Runoff Gauging Station	Station Number	Name of River	Drainage Area (km²)
Tumlingtar	604.5	Arun	30,762
Legunaghat	604	Arun	34,904
Mulghat	690	Tamur	5,640
Barahk Shetra	695	Sapta Kosi	59,550
Sabhaya	602	Sabha Khola	375
Hinwa	602.5	Hinwa Khola	110.4

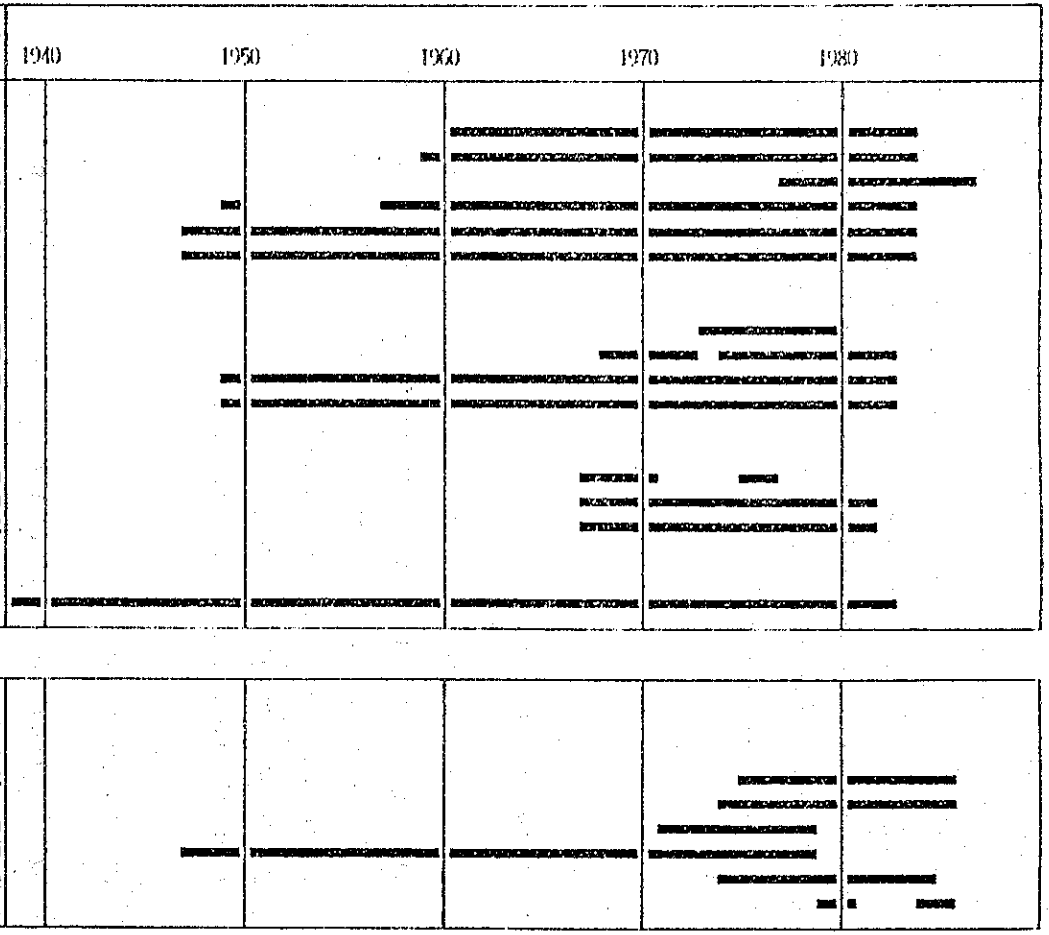


Fig. 5–2 Double Mass Curve Method

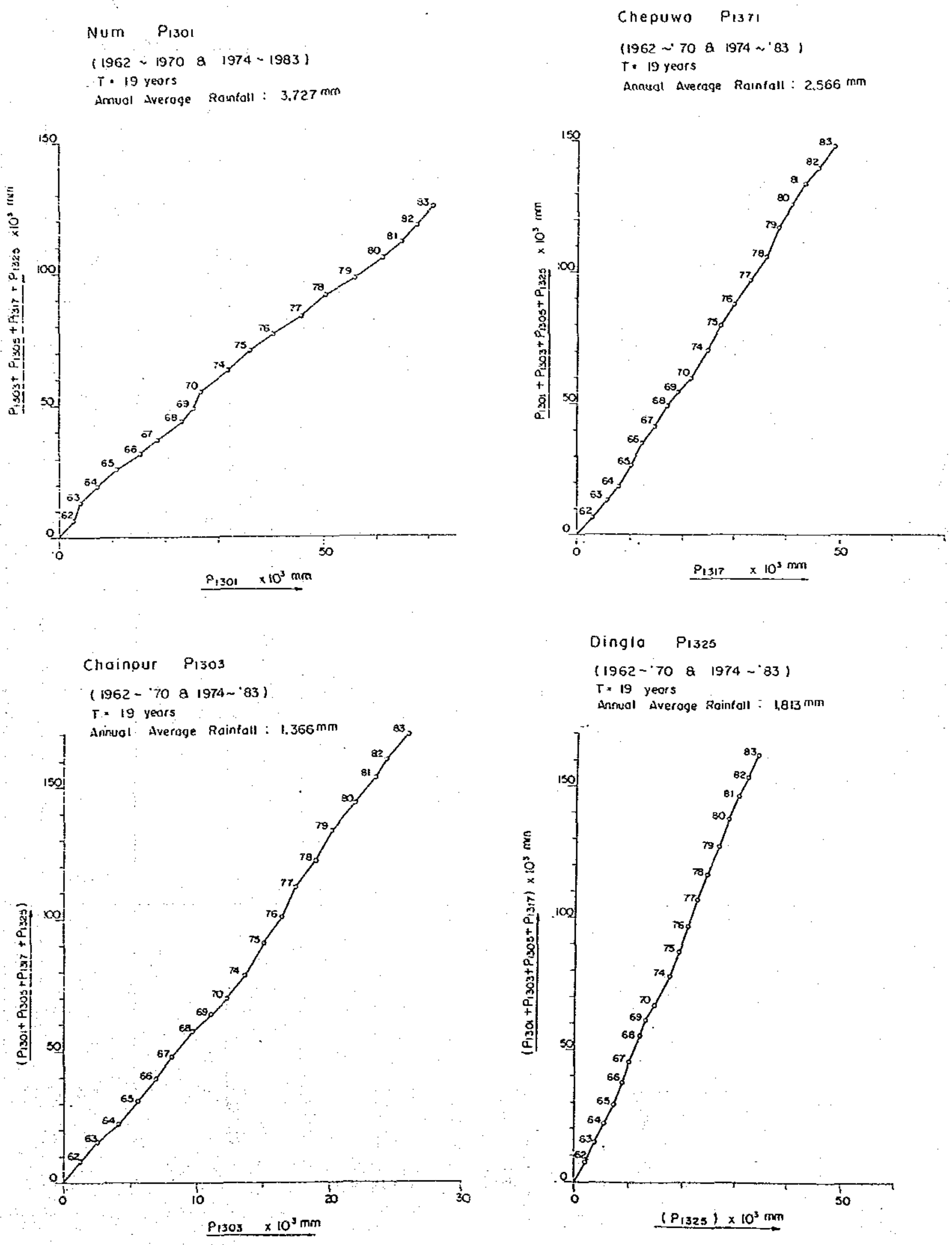
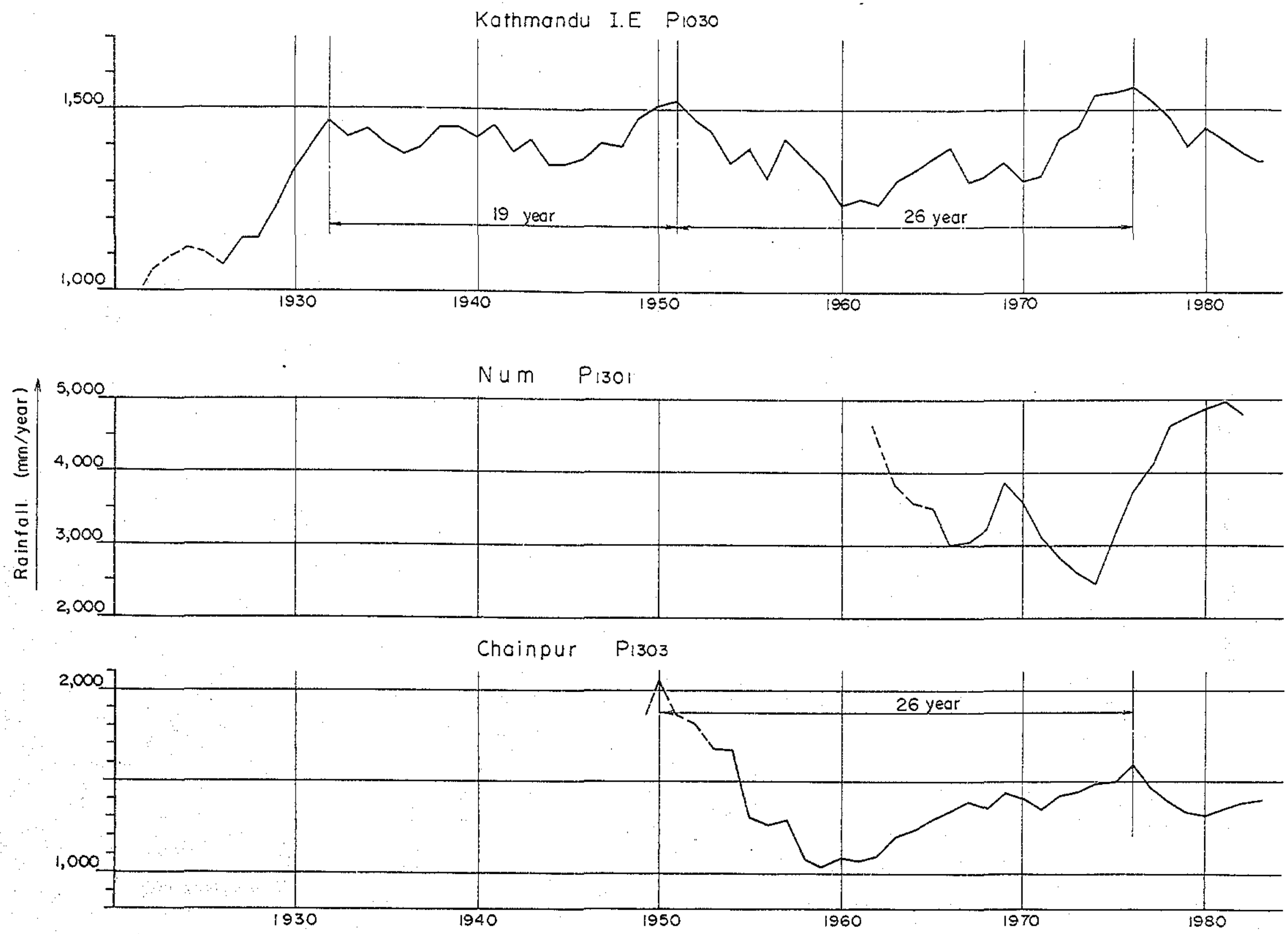


Fig. 5–3 Moving Average Analysis (T = 5 year)



(2) Power Spectral Analysis

The power spectral analysis is undertaken on the basis of data at Kathmandu according to the result of (1) above. Firstly, the variation in annual rainfall X(t) (mm) is broken down into waves (f) according to each frequency component by the Fourier transform of equation (1) and the power spectrum of frequency (average energy of each frequency) is analyzed by equation (2).

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi ft} dt \qquad (1)$$

$$Sx(f) = \lim_{T \to \infty} \left[\frac{1}{T} |X(f)|^2 \right] \qquad (2)$$

The hydraulic cycle of 20 to 30 years can be observed by the smoothed line shown in Fig. 5-4.

Results of the above studies (1) and (2) indicate that the period of discharge data for more than 20 years will be preferable for calculating energy.

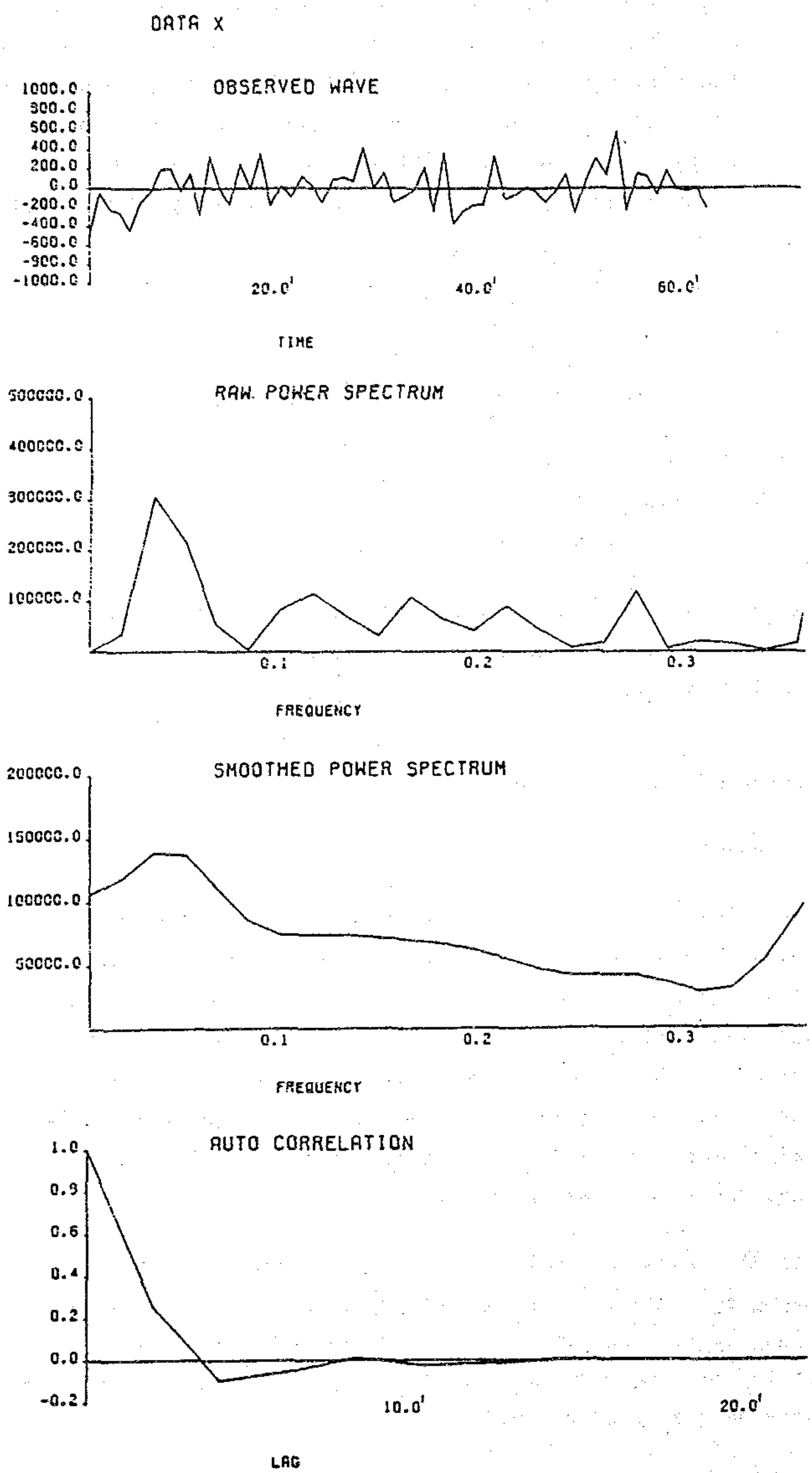
5.5 Generated Discharge at Dam Site

5.5.1 Methodology

The river discharge at the dam site is to be calculated by deduction of discharge out of the drainage basin between the dam site and Tumlingtar gauging station from that observed at the Tumlingtar gauging station. It is considered not realistic to estimate the river discharge at the dam site by sole conversion from drainage areas at the dam site and the Tumlingtar gauging station owing to significant difference of meteorological conditions in the Tibetan and Nepal parts of the basin.

In the previous study, the river discharge records at the Mulghat gauging station were applied together with those at the Tumlingtar gauging station, while, those at the Sabhaya and Hinwa gauging stations are applied to this study. The reasons of such substitution are as described below.

Fig. 5–4 Spectral Analysis



(1) The drainage basins at the Sabhaya and Hinwa gauging stations are close by that at the Tumlingtar gauging station, and the meteorological and topographic conditions resemble better than that at the Mulghat gauging station.

(2) The rating curves generated based on the actual measurement records at these two stations can stand comparison with that at the Tumlingtar gauging station and reliable.

5.5.2 River Discharges at Gauging Stations

The river discharges at each gauging station are calculated on the basis of field measurement records of water levels and discharges.

(1) Rating Curve

(i) Tumlingtar Gauging Station (No. 604.5)

Item	Gauging Height H < 4.0 m	Gauging Height H ≥ 4.0 m
Before 14 Aug.'80	$Q = 40 H^2+150 H+50$	
15 Aug.'80 - 11 Aug.'81	$Q = 85 H^2-45 H -160$	$Q = 85 H^2-115 H +120$
After 12 Aug.'81	$Q = 85 H^2-115 H +120$	

(ii) Sabhaya Gauging Station (No. 602)

Item	Gauging Height H < 1.65 m	Gauging Height H ≥ 1.65 m
Before 1 Jun.'76	$Q = 16.24H^2-4.84 H +0.36$	$Q = 34.6H^2 -42.9 H +13.3$
	Gauging Height H < 1.40 m	Gauging height H ≥ 1.40 m
1 Jul.'76 - 1 Jun.'82	$Q = 14.8H^2-6.15 H +0.64$	$Q = 34.6H^2 -42.9 H +13.3$
	Gauging Height H > 0	
After 1 Jun.'82	$Q = 34.6H^2- 42.9 H +13.32$	

(iii) Hinwa Gauging Station (No. 602.5)

$$Q = 21.53 H^2-13.92 H +2.25 m^3/s$$

(2) Correlation between Stations

Correlations among three gauging stations are as shown below.

Item	Sample	Equation of Correlation	Coeff.
(1) Tumlingtar and Sabhaya			
Monthly Average Data	114	Q602=0.05.Q604.5+1.14	0.915
Daily Average Data	3,523	Q602=0.05.Q604.5+1.20	0.781
(2) Tumlingtar and Hinwa			
Monthly Average Data	39	Q602.5=0.02.Q604.5-0.81	0.900
Daily Average Data	1,257	Q602.5=0.01.Q604.5+0.32	0.808
(3) Sabhaya and Hinwa			
Monthly Average Data	25	Q602=3.55.Q602.5+2.88	0.936
Daily Average Data	862	Q602=3.34.Q602.5+3.42	0.816

Ref. Q604.5 : Tumlingtar Gauging Station

Q602 : Sabhaya Gauging Station

Q602.5 : Hinwa Gauging Station

The results of calculation indicate that,

(i) Correlation coefficients of cases (1) and (2) are lower than that of case (3), and

(ii) Correlation coefficient of case (1) is higher than that of case (2) on the monthly level and vice versa on the daily level.

5.5.3 Discharge at Dam Site

(1) Discharge from Drainage Basin between Dam Site and Tumlingtar Gauging Station

Discharge from the drainage basin between the dam site and Tumlingtar gauging station is estimated based on the discharge records and rainfall distribution at the Sabhaya and Hinwa gauging stations as shown below.

$Qt = (Q602 + Q602.5) \times C.At/(C.A602+C.A602.5) \times Pt/Pav.$

Qt	: Runoff between Tumlingtar and dam site
Q602	: Runoff at Sabhaya gauging station
Q602.5	: Runoff at Hinwa gauging station
C.At	: Drainage area between Tumlingtar and dam site ($1,452\ km^2$)
C.A602	: Drainage area of Sabhaya gauging station ($375\ km^2$)
C.A602.5	: Drainage area of Hinwa gauging station ($110.4\ km^2$)
Pt	: Average rainfall in the drainage area between Tumlingtar and dam site (1975 - '81) Dry season from Oct. to Apr. (721 mm) Monsoon season from May to Sep. (2,652 mm)
Pav	: Average rainfall in the drainage areas at Sabhaya and Hinwa gauging stations (1975 - '81) Dry season from Oct. to Apr. (535 mm) Monsoon season from May to Sep. (2,142 mm)

$Qt = 4.03\ (Q602 + Q602.5)$ ----- Dry season

$Qt = 3.70\ (Q602 + Q602.5)$ ----- Monsoon season

The river discharges estimated by the above equations are on daily basis, however, they will not exactly correspond to the calendar days because of the following reasons.

- Though the Sabhaya and Hinwa drainage basins are located adjacent to that of the Tumlingtar gauging station, the discharges therefrom are not included in that at the Tumlingtar gauging station.
- There will be time lag in discharges from different drainage basins due to movement of rainfall zone.

(2) River Discharge at Dam Site

The river discharge is calculated by deduction of the discharge in the drainage basins between the dam site and the Tumlingtar gauging station from that recorded at the Tumlingtar gauging station. The daily discharge corresponding to calendar days for the above-mentioned deduction is calculated by the following equation.

QDnth. = Q604.5nth. -QTnth.

QDnth. : Discharge at dam site at n-th day in a certain monthly duration

Q604.5nth.: Discharge at Tumlingtar gauging station at n-th day in a certain monthly duration

QTnth. : Discharge from the drainage basin between dam site and Tumlingtar gauging station at n-th day in a certain monthly duration

The monthly average discharges and duration curves calculated based on the above considerations are as shown in Table 5-4 and Fig. 5-5. The daily discharges are indicated in Appendix-B. Flow duration curves are used for calculating energy generation and the definition of the firm discharge is described in Chapter 7.

The correlation of discharges between the dam site and the Tumlingtar will be expressed in the following linear equations.

Monthly discharge : Q(Dam) = 0.77 x Q604.5-4.07 (γ= 0.99)

Daily discharge : Q(Dam) = 0.76 x Q604.5+0.25 (γ= 0.99)

5.6 Design Flood Discharge

5.6.1 General

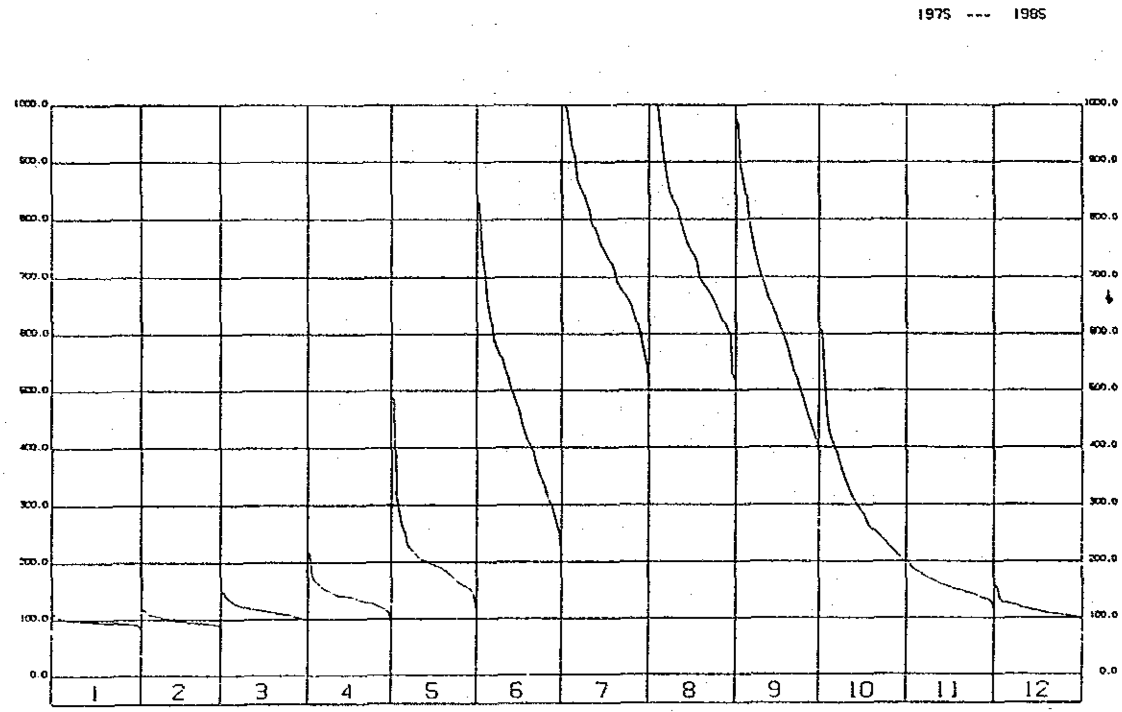
As it is considered that the Arun 3 project will play a very important role for economical and social development of Nepal, it will be appropriate to adopt the probable maximum flood (PMF) in the design of the Arun dam. PMF is defined as the flood that may be caused under the theoretical combination of the most adverse meteorological and hydrological conditions. For application of PMF in this study, preliminary conditions stated below are taken into consideration.

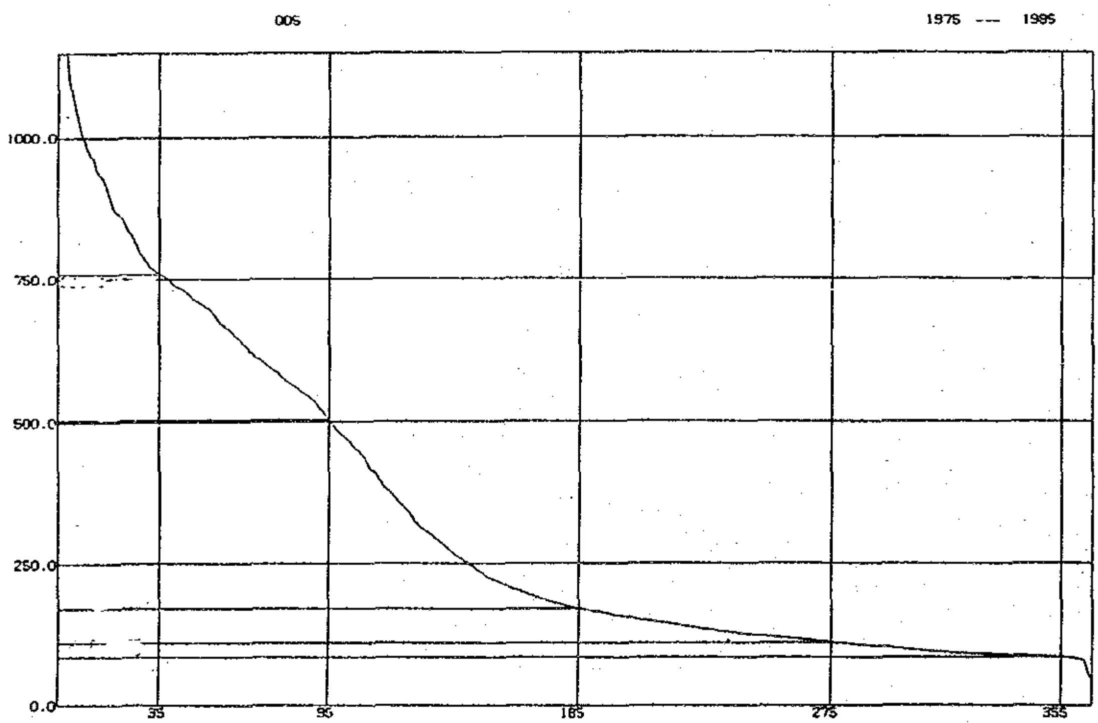
(1) Total drainage area of the Arun river is divided into two portions at the Himalayan border; the northern Tibetan area and the southern Nepalese area.

Table 5–4 Monthly Discharge Data at Dam Site

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1975	94.03	72.82	58.91	60.68	221.49	452.25	727.42	671.39	760.09	365.03	167.45	105.72	314.57
1976	78.88	78.54	91.03	108.89	167.50	588.20	680.54	728.80	517.27	275.74	178.75	125.88	302.38
1977	100.87	106.21	129.64	144.06	170.78	439.45	792.85	872.37	563.40	384.64	213.20	147.57	340.65
1978	120.92	123.24	143.84	184.31	297.06	580.97	654.12	795.39	571.54	334.56	186.36	128.73	344.82
1979	93.90	93.95	110.20	153.50	219.02	323.54	876.65	787.40	493.68	403.65	191.69	155.58	327.51
1980	120.53	127.66	155.59	198.32	216.81	469.43	798.15	1270.62	1032.87	443.08	204.59	130.53	431.84
1981	100.98	119.26	137.24	188.22	277.09	603.38	975.98	991.12	649.92	238.78	138.62	104.59	379.02
1982	95.61	99.48	130.34	160.97	181.40	487.61	679.70	556.37	373.95	135.88	83.67	65.48	255.23
1983	59.68	62.85	84.84	93.84	163.84	300.86	666.13	555.01	765.25	320.46	130.02	104.84	276.87
1984	91.54	93.09	116.40	96.93	139.92	427.89	740.56	616.57	602.98	233.10	109.17	94.57	280.93
1985	89.32	95.33	109.37	115.59	142.93	479.00	712.98	553.74	590.58	254.86	107.85	84.18	278.98
Ave.	95.11	97.49	115.22	136.85	199.80	468.42	755.01	763.53	629.23	308.16	155.58	113.42	321.16

Fig. 5-5 Duration Curve of Monthly and Annual Discharge





(2) There are few information of the Tibetan area available for this study. As indicated by the mean annual rainfall of approximately 300 mm, there is very small precipitation in this area and it is hardly considered to have storm that may cause flood. The outflow of this area is, therefore, considered to form the base flow component.

(3) For the area south of the Himalayan range, river discharge resulted from the probable maximum precipitation is considered to form the direct runoff, and PMF is estimated by adding this direct runoff to the base flow described in (2) above.

(4) Snow melting is sometimes considered to be an important factor causing PMF. However, in consideration that the flood season from July to September in the Arun river basin does not fall on the snow melting season and further, the precipitation (snow fall) in the winter is greatly smaller than that in the rainy season, snow melting will have practically no concern with PMP. Hence, it is assumed that the river flow due to snow melting will be included in the base flow stated in (2) above.

Apart from the above, probability analysis was also performed. The results are considered to have less accuracy because of short observation period of 11 years and presented for reference only. The results are, however, applied for estimating flood discharge during construction period.

5.6.2 Probable Maximum Precipitation (PMP)

PMP is generally classified as non-orographic and orographic precipitations. The form of precipitation in the Arun river basin is considered to have typical orographic characters, as it is observed that much precipitation is caused by monsoon from Bay of Bengal in the south, precipitation is concentrated at the southern slope of the Himalayan range and rainfall in the flatland area as well as the area north of the Himalayan range is extremely small. Following are the process of estimating PMP in this study.

(1) Preparation of ground profile (Fig. 5-6, 5-7)

The principal ground profiles at southern slope of the Himalayan range in the Arun river basin are prepared dividing 1/500,000 maps into meshes. Elevation therein is changed into the atmospheric pressure (mb) for convenience of succeeding calculation.

(2) Setting of air streamlines

Air streamlines are figured at intervals of 50 mb and the model surface which will not be affected by the topographic conditions is set at 300 mb. Precipitation between streamlines is given by the following formula.

$$R = \frac{\overline{V}_1 \cdot \Delta p_1 (\overline{q}_1 - \overline{q}_2)}{Y} \cdot \frac{1}{g\rho}$$

R : Precipitation (cm/sec)

$\overline{V}1$: Mean inflow wind speed (cm/sec)

Δp_1: Inflow pressure difference (mb)

$\overline{q}1,\overline{q}2$: Mean specific humidities at inflow and outflow (g/kg)

Y : Horizontal distance (cm)

g : Acceleration of gravity (cm/sec^2)

ρ : Density of water (g/cm^3)

When mixing ratio (w) in place of mean specific humidity and dimensions indicated in respective data are applied, the above formula will be modified as follow.

$$R = \frac{0.8813 \times \overline{V}_1 \cdot \Delta p_1 (\overline{w}_1 - \overline{w}_2)}{Y}$$

R : Daily precipitation (mm/day)

$\overline{V}1$: Mean inflow wind speed (m/sec)

Fig. 5–6 Analyzed Area in Arun River Basin

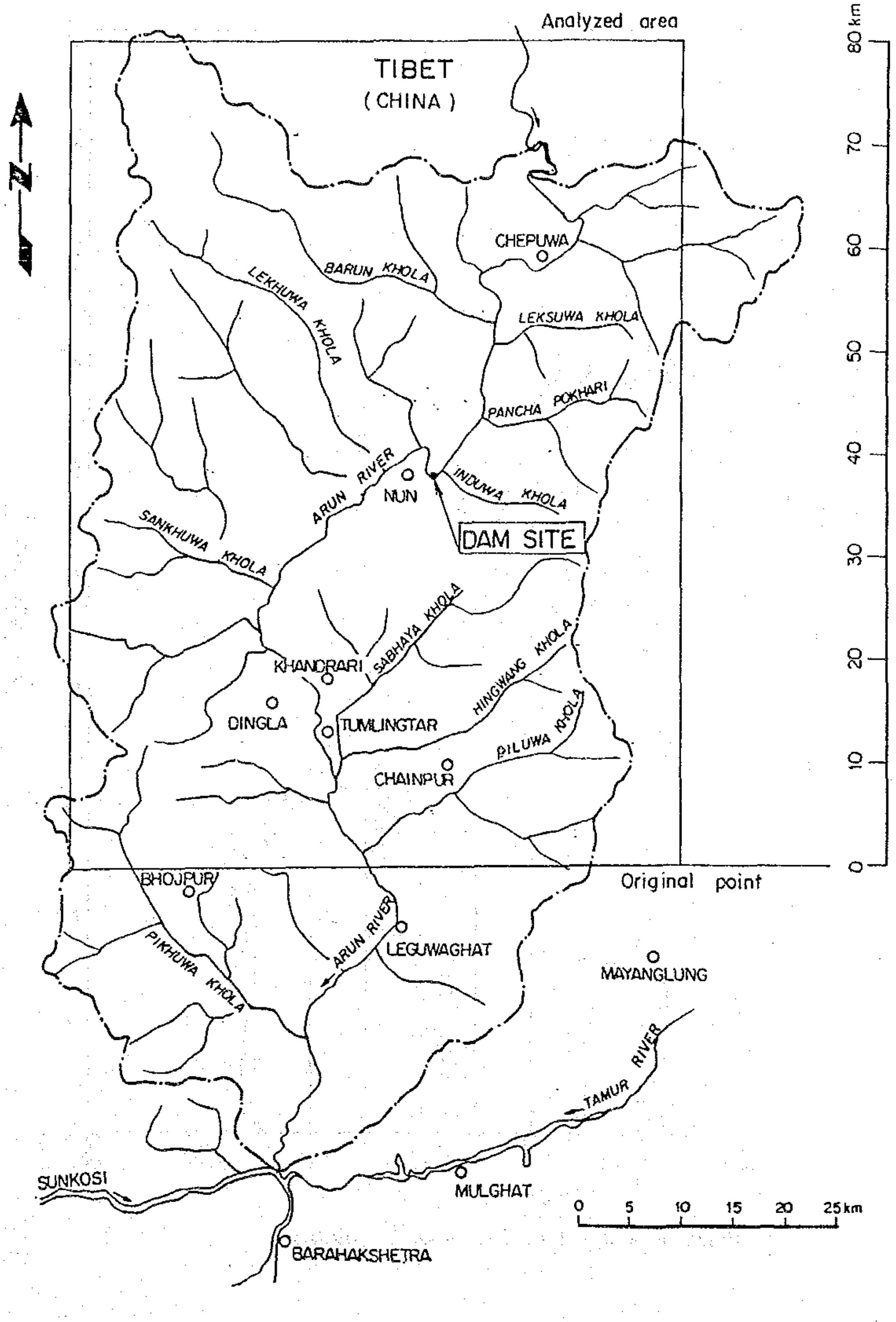
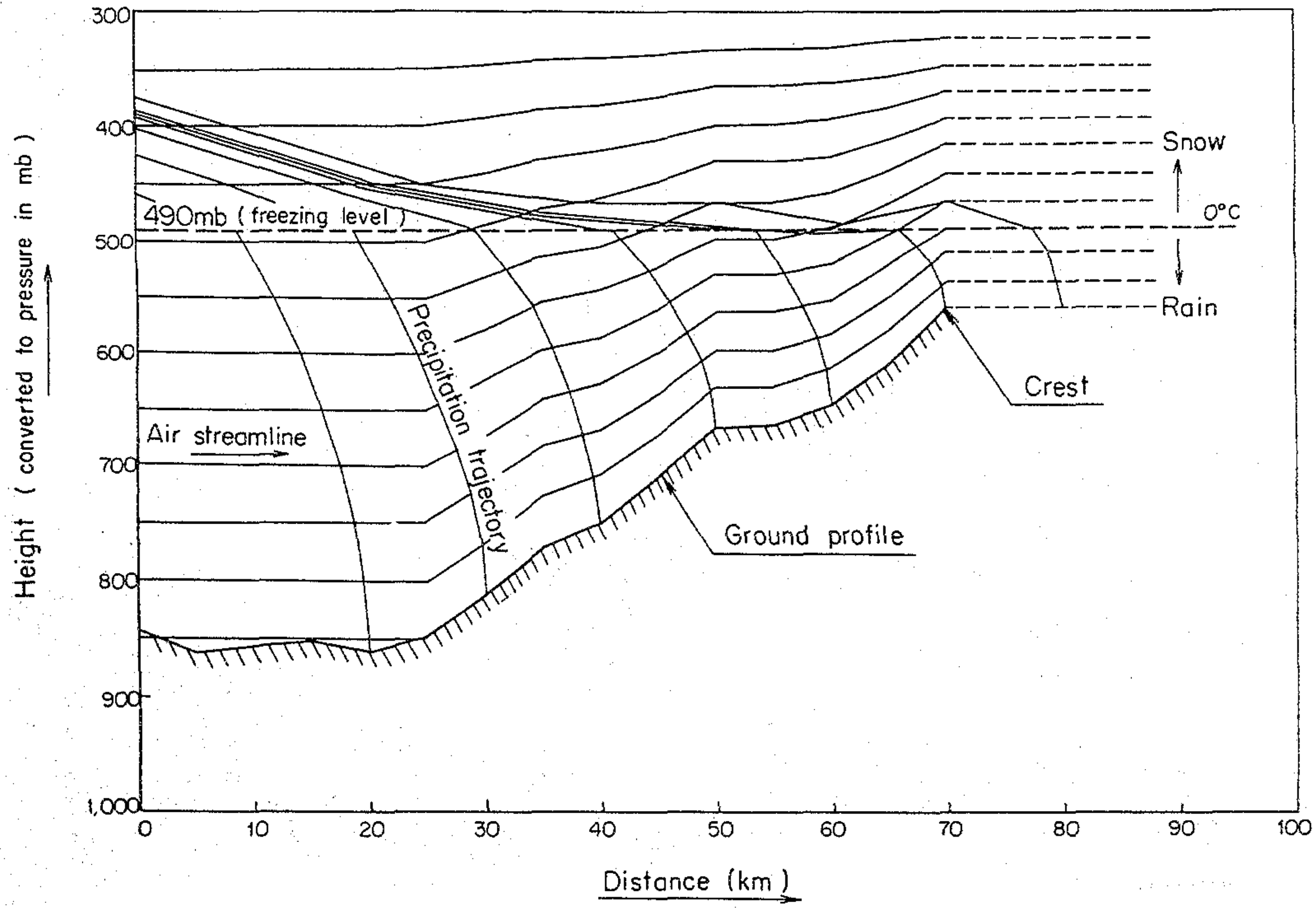


Fig. 5–7 Ground Profile, Air Streamlines and Precipitation Trajectories for PMP Estimation



Δp_1 : Inflow pressure difference (mb)

$\bar{w}1$, $\bar{w}2$: Mean mixing ratio at inflow and outflow (g/kg)

Y : Horizontal distance (km)

(3) Selection of meteorological data (at 0 km point)

Atmospheric temperature and relative humidity recorded in 12 years (1971 - 1982) at Bhojpur (EL. 1,595 m) and wind velocity at Kathmandu are applied. As the data available at present is indicated in daily values, PMP is also to be estimated at daily basis. The representative values of respective meteorological data are assumed as follows.

Temperature (T):

The maximum value of 25°C is adopted referring to envelope curve for monthly average value of daily maximum temperature. Decrement of temperature by altitude is estimated at -0.6°C/100 m.

Relative humidity (RH):

The lower value of humidities between two records observed each day is selected as daily representative humidity and the maximum value (93%) of these representative humidities is adopted. Variation of humidity by altitude is assumed to be linear upto 50% at 300 mb referring to measurement records in Japan.

Wind velocity (V):

Since wind velocity records at Bhojpur are not available, the maximum value of 6.7 knot (3.4 m/sec) is adopted referring to the daily mean velocities recorded at Kathmandu during five years from 1971 to 1975. Variation of wind velocity by altitude is also assumed to be linear upto 50 m/sec at 300 mb referring to measurement records in Japan.

(4) Setting of Freezing Level

Based on decrement of temperature by altitude previously stated, the freezing level is set at 490 mb. Above or below this level, it snows or rains.

(5) Preparation of Precipitation Trajectories

Precipitation trajectories are to be prepared at every 10 km as shown in Fig. 5-7.

(6) Calculation of Precipitation

Precipitation between each trajectory is to be calculated with the formula previously stated and the results are shown in Table 5-5 (1) - (6). Based on the above, the daily average value of PMP on the southern slope of the Himalayan range in the drainage area at dam site is estimated to be 434 mm/day.

5.6.3 Preparation of Unit Hydrograph

As no hydrographs about the past flood are available, basin lag, peak flow, etc. of unit hydrograph are estiamted by the Snyder method in this study. The shape of unit hydrograph is expressed in a function of $t^{2.4}$ at ascending portion and exponential function at descending portion, and is graded in every 6 hours and rainfall density of 1 cm as shown in Fig. 5-8 (1).

5.6.4 Hourly Distribution and Effective Precipitation

Since unit hydrograph is graded in every 6 hours, it is required to distribute the PMP values previously estimated in every 6 hours also. The following formula showing the relationship between time and precipitation for the world's greatest observed point rainfalls are applied for this purpose (ref. WMO, 1973: Manual for Estimation of Probable Maximum Precipitation).

$$R = 16.6\ H^{0.475}$$

The results of calculation are shown in Fig. 5-9, in which "arrange" means the arrangement so as to cause the maximum discharge and the

Table 5–5 (1) Computation of PMP between 20 km and 30 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	500	5.28	500	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	550	7.00	550	7.00	6.14	6.14	6.14	0.00	0	0.00	0
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	600	9.25	600	9.25	8.12	8.12	8.12	0.00	0	0.00	0
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	650	11.31	645	11.31	10.28	10.28	10.28	0.00	0	0.00	0
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	700	12.71	685	12.71	12.01	12.01	12.01	0.00	0	0.00	0
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	750	15.72	725	15.72	14.21	14.21	14.21	0.00	0	0.00	0
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	800	19.58	770	19.5	17.65	17.65	17.65	0.00	0	0.00	0
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	850	22.32	815	22.0	20.95	20.95	20.79	0.00	0	0.16	46

TOTAL= 0 46
24hr volume (mm(km))=0.8813×TOTAL= 0 41
Unit horizontal area (km)= 20 30
24hr average rainfall(mm)= 0.0 1.3
24hr average rainfall over last leg= (41- 0) / (30.0- 20.0) = 4mm

Table 5–5 (2) Computation of PMP between 30 km and 40 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	500	5.28	490	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	550	7.00	525	7.00	6.14	6.14	6.14	0.00	0	0.00	0
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	600	9.25	555	9.25	8.12	8.12	8.12	0.00	0	0.00	0
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	645	11.31	595	11.00	10.28	10.28	10.12	0.00	0	0.15	174
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	685	12.71	635	12.50	12.01	12.01	11.75	0.00	0	0.26	240
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	725	15.72	670	14.00	14.21	14.21	13.25	0.00	0	0.96	684
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	770	19.5	710	17.5	17.65	17.65	15.75	0.00	0	1.90	960
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	815	22.0	750	20.0	20.95	20.79	18.75	0.16	46	2.20	643

TOTAL= 46 2704
24hr volume (mm(km))=0.8813×TOTAL= 41 2383
Unit horizontal area (km)= 30 40
24hr average rainfall(mm)= 1.3 59.5
24hr average rainfall over last leg= (2383- 41) / (40.0- 30.0) = 234mm

Table 5–5 (3) Computation of PMP between 40 km and 50 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	490	5.28	480	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	525	7.00	500	6.50	6.14	6.14	5.89	0.00	0	0.25	388
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	555	9.25	530	8.50	8.12	8.12	7.50	0.00	0	0.62	834
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	595	11.00	560	10.00	10.28	10.12	9.25	0.15	174	1.03	1161
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	635	12.50	585	11.00	12.01	11.75	10.50	0.26	240	1.51	1396
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	670	14.00	610	12.50	14.21	13.25	11.75	0.96	684	2.46	1745
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	710	17.5	635	15.0	17.65	15.75	13.75	1.90	960	3.90	1970
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	750	20.0	665	18.0	20.95	18.75	16.50	2.20	643	4.45	1301

TOTAL= 2704 8798
24hr volume (mm(km))=0.8813×TOTAL= 2383 7754
Unit horizontal area (km)= 40 50
24hr average rainfall(mm)= 59.5 155.0
24hr average rainfall over last leg= (7754- 2383) / (50.0- 40.0) = 537mm

Table 5–5 (4) Computation of PMP between 50 km and 60 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	480	5.28	475	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	500	6.50	485	6.00	6.14	5.89	5.64	0.25	388	0.50	776
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	530	8.50	500	7.50	8.12	7.50	6.75	0.62	834	1.37	1835
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	560	10.00	530	8.50	10.28	9.25	8.00	1.03	1161	2.28	2570
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	585	11.00	560	10.00	12.01	10.50	9.25	1.51	1396	2.76	2553
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	610	12.50	590	12.00	14.21	11.75	11.00	2.46	1745	3.21	2276
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	635	15.0	620	14.5	17.65	13.75	13.25	3.90	1970	4.40	2223
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	665	18.0	650	17.5	20.95	16.50	16.00	4.45	1301	4.95	1447

TOTAL= 8798 13683
24hr volume (mm(km))=0.8813×TOTAL= 7754 12058
Unit horizontal area (km)= 50 60
24hr average rainfall(mm)= 155.0 200.9
24hr average rainfall over last leg= (12058- 7754) / (60.0- 50.0) = 430mm

Table 5–5 (5) Computation of PMP between 60 km and 70 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	475	5.28	475	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	485	6.00	485	6.00	6.14	5.64	5.64	0.50	776	0.50	776
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	500	7.50	490	7.50	8.12	6.75	6.75	1.37	1835	1.37	1835
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	530	8.50	490	7.00	10.28	8.00	7.25	2.28	2570	3.03	3416
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	560	10.00	505	8.00	12.01	9.25	7.50	2.76	2553	4.51	4171
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	590	12.00	520	9.50	14.21	11.00	8.75	3.21	2276	5.46	3868
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	620	14.5	540	12.5	17.65	13.25	11.00	4.40	2223	6.65	3359
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	650	17.5	560	15.0	20.95	16.00	13.75	4.95	1447	7.20	2106

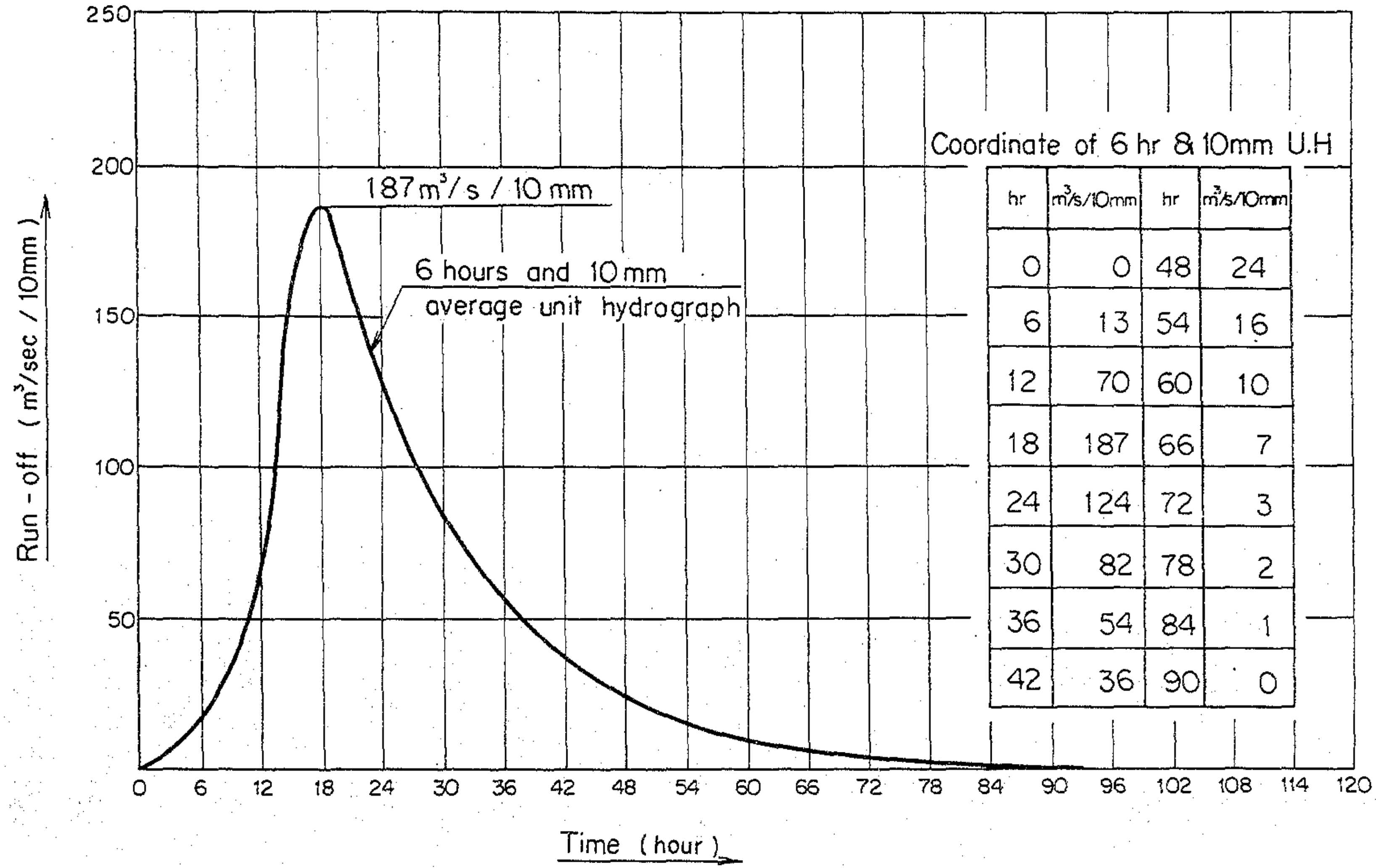
TOTAL= 13683 19533
24hr volume (mm(km))=0.8813×TOTAL= 12058 17215
Unit horizontal area (km)= 60 70
24hr average rainfall(mm)= 200.9 245.9
24hr average rainfall over last leg= (17215- 12058) / (70.0- 60.0) = 515mm

Table 5–5 (6) Computation of PMP between 70 km and 80 km

P (mb)	γ (°C)	R.H (%)	V (m/s)	Vav (m/s)	VavΔp	Ws (g/kg)	WI	Pc (mb)	γc (°C)	PLT	WLT	PUT	WUT	WIav	WLTav	WUTav	ΔWLTav =WIav-WLTav	VavΔp·ΔWLTav	ΔWUTav =WIav-WUTav	VavΔp·ΔWUTav
350	-15.8	54	46.0			3.2	1.72	310	-25.0	350	1.72	350	1.72							
400	-9.6	58	41.9	43.95	2197	4.8	2.78	360	-17.5	400	2.78	400	2.78	2.25	2.25	2.25	0.00	0	0.00	0
450	-4.2	62	37.0	39.45	1972	6.5	4.03	415	-11.0	450	4.03	450	4.03	3.40	3.40	3.40	0.00	0	0.00	0
500	0.6	66	33.2	35.10	1755	8.0	5.28	460	-6.0	475	5.28	470	5.28	4.65	4.65	4.65	0.00	0	0.00	0
550	5.0	70	28.9	31.05	1552	10.0	7.00	515	-2.0	485	6.00	470	5.80	6.14	5.64	5.54	0.50	776	0.60	931
600	9.0	74	24.5	26.70	1335	12.5	9.25	555	3.5	490	7.50	485	7.40	8.12	6.75	6.60	1.37	1835	1.52	2035
650	12.7	78	20.6	22.55	1127	14.5	11.31	610	8.0	490	7.00	470	6.70	10.28	7.25	7.05	3.03	3416	3.23	3641
700	16.1	82	16.4	18.50	925	15.5	12.71	650	11.0	505	8.00	490	8.00	12.01	7.50	7.35	4.51	4171	4.66	4310
750	19.3	85	11.9	14.15	707	18.5	15.72	720	15.0	520	9.50	510	9.50	14.21	8.75	8.75	5.46	3868	5.46	3868
800	22.2	89	8.3	10.10	505	22.0	19.58	775	20.0	540	12.5	540	12.5	17.65	11.00	11.00	6.65	3359	6.65	3359
850	25.0	93	3.4	5.85	292	24.0	22.32	830	23.0	560	15.0	560	15.0	20.95	13.75	13.75	7.20	2106	7.20	2106

TOTAL= 19533 20253
24hr volume (mm(km))=0.8813×TOTAL= 17215 17849
Unit horizontal area (km)= 70 80
24hr average rainfall(mm)= 245.9 223.1
24hr average rainfall over last leg= (17849- 17215) / (80.0- 70.0) = 63mm

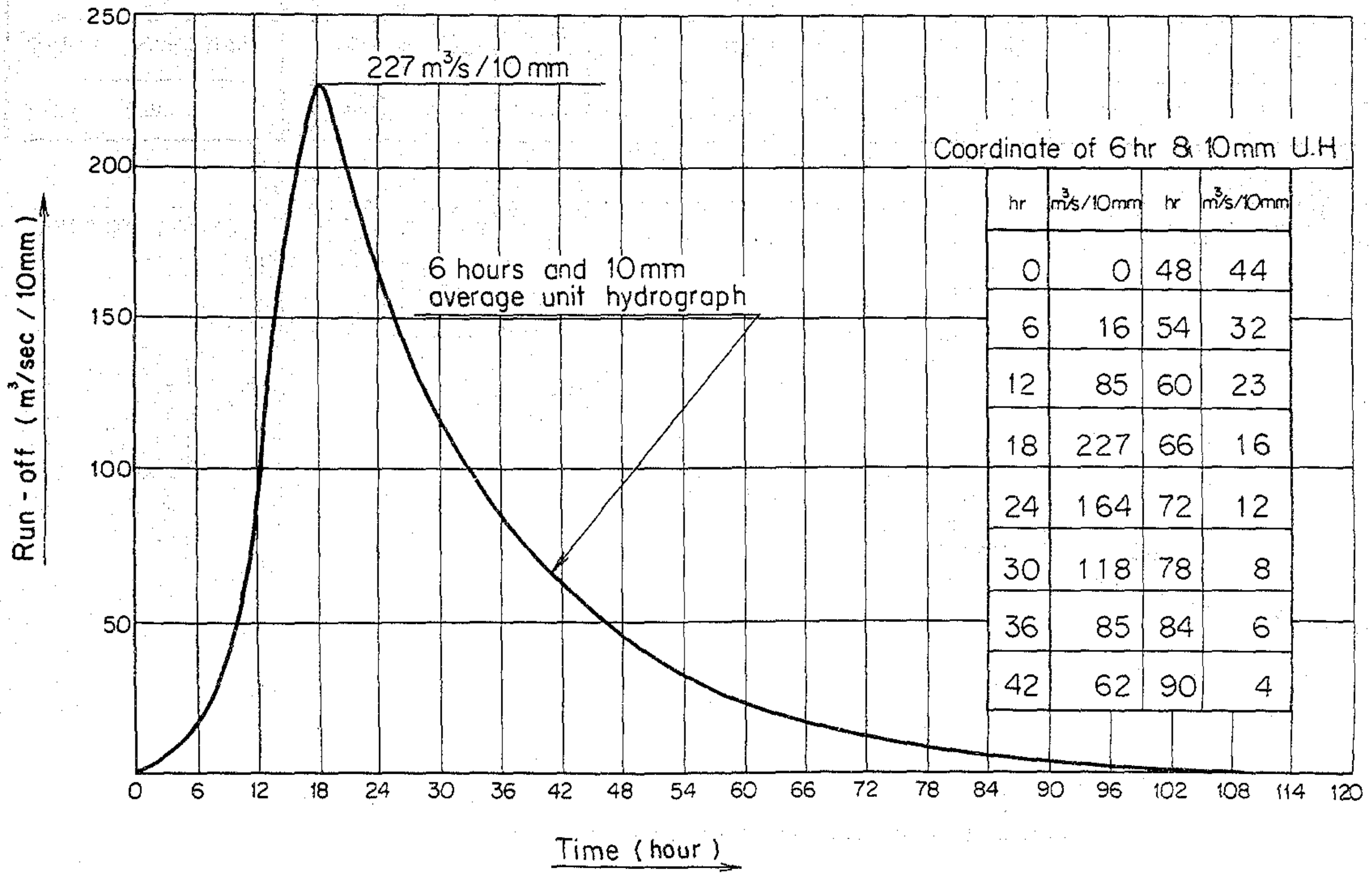
Fig. 5–8 (1) Unit Hydrograph at Arun Damsite



Coordinate of 6 hr & 10mm U.H

hr	$m^3/s/10mm$	hr	$m^3/s/10mm$
0	0	48	24
6	13	54	16
12	70	60	10
18	187	66	7
24	124	72	3
30	82	78	2
36	54	84	1
42	36	90	0

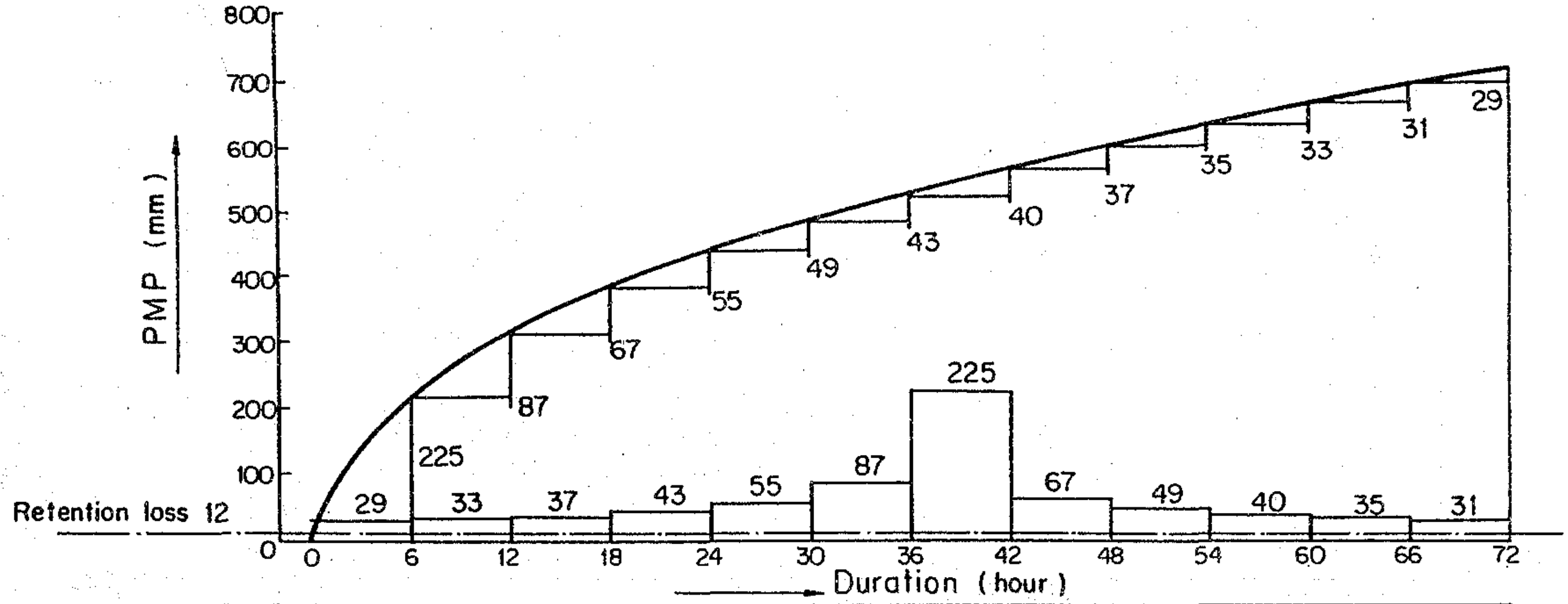
Fig. 5–8 (2) Unit Hydrograph at Powerhouse



Coordinate of 6 hr & 10mm U.H

hr	$m^3/s/10mm$	hr	$m^3/s/10mm$
0	0	48	44
6	16	54	32
12	85	60	23
18	227	66	16
24	164	72	12
30	118	78	8
36	85	84	6
42	62	90	4

Fig. 5–9 Time Distribution of Rainfall Increment Six-Hour Period



PMP (mm)	225	312	379	434	483	526	566	603	638	671	702	731
6-hour increments	225	87	67	55	49	43	40	37	35	33	31	29
Arrange	29	33	37	43	55	87	225	67	49	40	35	31
Effective precipitation	17	21	25	31	43	75	213	55	37	28	23	19

effective precipitation is the value so arranged minus hourly retention loss of 2 mm/hr.

5.6.5 Flood Hydrograph of PMP

The flood hydrograph synthesized with the effective precipitation and unit hydrograph is as shown in Table 5-6 (1).

5.6.6 Flow Component from Tibetan Area

Due to lack of hydrological data in Tibetan area which forms a greater part of the Arun river drainage basin, it is impossible to make hydrological analysis for the Tibetan area. However, from the fact that the mean annual precipitation in the Tibetan basin is only 300 mm, it is confidently considered that there will be no heavy storm causing floods. Then the flow component from the Tibetan area is assumed to form the majority of the base flow component. In order to estimate the base flow component, the following two methods are applied for 8 years from 1976 to 1983.

(1) Flow component in the area south of the Himalayan range is first calculated on the basis of river discharge at the Sabhaya gauging station and the ratio of drainage areas and flow component from the Tibetan drainage basin is to be estimated by deducting the above from the river discharge measured at the Tumlingtar gauging station.

$$Q\ (\text{Tibet}) = Q\ (\text{Tumlingtar}) - \frac{2,833}{375} \times Q\ (\text{Sabhaya})$$

(2) Based on rainfall data recorded at 4 stations located south of the Himalayan range, flow analysis by means of the tank model method is performed and flow component from the Tibetan drainage area is calculated deducting the discharges so analysed from the river discharge at the Tumlingtar gauging station.

Table 5–6 (1) Synthetic Unit Hydrograph of PMP

(at the Dam Site)

Time (hr)	Rainfall (cm)	Time	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	Discharge (m³/s)
		Unit	0	13	70	187	124	82	54	36	24	16	10	7	4	3	2	1	0	0	
0	0.0		0																		0
6	1.7		0	0																	0
12	2.1		0	23	0																23
18	2.5		0	29	121	0															150
24	3.1		0	34	153	320	0														507
30	4.3		0	42	177	404	213	0													836
36	7.5		0	59	220	468	269	141	0												1157
42	21.3		0	101	311	580	311	179	94	0											1576
48	5.5		0	286	533	821	385	207	119	63	0										2414
54	3.7		0	74	1508	1406	546	256	137	79	42	0									4048
60	2.8		0	50	390	3983	935	363	170	91	53	28	0								6063
66	2.3		0	38	263	1030	2649	622	241	113	61	35	18	0							5070
72	1.9		0	31	200	696	685	1761	414	161	75	40	23	12	0						4098
78				26	163	529	463	456	1171	275	107	50	27	15	8	0					3290
84					137	430	352	308	303	779	183	71	33	18	10	5	0				2629
90						361	286	234	205	201	518	122	47	22	12	7	4	0			2019
96							240	190	156	136	134	344	81	31	15	8	5	2	0		1342
102								160	126	103	90	89	229	54	21	10	5	3	2	0	892
108									106	84	69	60	59	152	36	14	7	3	2	1	593
114										71	56	46	40	39	101	24	9	4	2	1	393
120											47	37	30	27	26	67	16	6	3	2	261
126												31	25	20	18	17	45	11	4	2	173
132													21	16	13	12	12	30	7	3	114
138														14	11	9	8	8	20	5	75
144															9	7	6	5	5	13	45
150																6	5	4	3	3	21
156																	4	3	3	2	12
162																		3	2	2	7
168																			2	1	3
174																				1	1
180																					
186																					
192																					
198																					
204																					
210																					
216																					
222																					

Table 5–6 (2) Synthetic Unit Hydrograph of PMP (at the Powerhouse)

Time (hr)	Rainfall (cm)	Time	0	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	Discharge (m³/s)
		Unit	0	16	85	227	164	118	85	62	44	32	23	16	12	8	6	4	3	2	
0	0.0		0																		0
6	1.7		0	0																	0
12	2.1		0	28	0																28
18	2.5		0	35	146	0															181
24	3.1		0	41	185	388	0														614
30	4.3		0	50	214	490	281	0													1035
36	7.5		0	71	265	568	355	203	0												1462
42	21.3		0	122	376	704	410	256	147	0											2015
48	5.5		0	345	644	997	509	297	186	106	0										3084
54	3.7		0	89	1823	1707	721	368	215	134	77	0									5134
60	2.8		0	60	472	4835	1235	521	266	155	97	56	0								7697
66	2.3		0	46	318	1251	3497	893	377	193	112	70	40	0							6797
72	1.9		0	37	242	844	905	2529	646	273	139	81	51	29	0						5776
78				31	197	642	611	654	1829	467	197	101	59	37	21	0					4846
84					165	522	465	442	473	1323	338	143	73	42	27	15	0				4028
90						438	378	336	319	342	957	244	103	53	31	19	11	0			3231
96							317	273	243	231	248	692	177	75	38	22	14	8	0		2338
102								229	198	176	167	179	501	128	54	28	16	10	6	0	1692
108									166	143	127	121	129	362	92	39	20	12	7	4	1222
114										120	103	92	87	94	262	67	28	14	8	5	880
120											87	75	67	63	68	189	48	20	10	6	633
126												63	54	48	46	49	137	35	15	8	455
132													45	39	35	33	35	99	25	11	322
138														33	28	25	24	26	72	18	226
144															24	20	18	17	19	52	150
150																17	15	13	12	13	70
156																	12	11	10	9	42
162																		9	8	7	24
168																			6	6	12
174																				5	5
180																					
186																					
192																					
198																					
204																					
210																					
216																					
222																					

Q (Tibet) = Q (Tumlingtar) - Q (R(Dingla, Num, Chainpur, Chepuwa))

Since deduction is made for the different flow conditions, the results of the above calculations are considered to have fair noises and accordingly, the results are smoothened by 5 day moving average method. Fig. 5-10(1), (2) show the envelope curves of hydrographs for 8 years so prepared. Both curves show similar tendency, though the curve given by the calculation (1) above is giving larger values, hence the maximum value of 1,600 m^3/s given in (1) is taken as the maximum flow component from the Tibetan drainage basin.

5.6.7 Probable Maximum Flood (PMF)

From the above calculation, PMF at dam site is estimated by adding the maximum flow component from the Tibetan drainage basin to the flow component calculated on the basis of PMP as shown in Fig. 5-11(1), the maximum flood discharge of which is observed to be 7,700 m^3/sec.

5.6.8 Probable Flood Discharge

Based on the discharge records at the Tumlingtar gauging station for 11 years from 1975 to 1985, the results of probable flood discharge calculations by the Log Pearson III and Gumbel methods are shown in Table 5-7, 5-8.

In the table, both results analysed on the basis of the annual maximum value and monthly maximum value respectively are indicated.

Further, since the above calculation is made on the basis of the mean daily flood discharge, it is necessary to take into account some surcharges in addition to proportional conversion by drainage areas for estimation of the instantaneous peak discharges at dam site. As to proportional conversion by drainage areas, the linear relation between discharges at dam site and the Tumlingtar gauging station is to be applied (ref. sec. 5.5.3), while, peaking ratio is to be assumed referring to unit hydrograph obtained in 5.6.3 above.

Table 5–7 Probable Flood Discharge at Tumlingtar by Log Pearson III Method (Daily)

Return Period	Annual Flood	Monthly Probable Flood Discharge											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2	1768	134	143	177	233	492	1116	1593	1528	1326	805	279	172
5	1990	152	169	218	287	606	1328	1856	1837	1701	1088	336	239
10	2123	164	183	243	319	676	1454	2039	2025	1915	1231	366	304
20	2245	174	197	266	348	740	1566	2220	2195	2099	1342	391	387
50	2394	186	213	295	384	820	1702	2463	2406	2312	1455	418	531
100	2502	196	225	316	409	877	1798	2653	2558	2458	1523	437	673
200	2607												
500	2743												
1000	2845												
10000	3179												

Table 5–8 Probable Flood Discharge at Tumlingtar by Gumbel Method (Daily)

Return Period	Annual Flood	Monthly Probable Flood Discharge											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2	1,774	134	142	177	232	490	1,106	1,613	1,520	1,302	774	273	193
5	2,048	157	174	227	298	632	1,370	1,941	1,904	1,763	1,106	345	301
10	2,229	172	195	260	343	726	1,544	2,157	2,158	2,069	1,326	393	373
20	2,402	187	215	292	385	816	1,712	2,365	2,402	2,362	1,537	439	442
50	2,627	206	240	332	440	933	1,929	2,634	2,717	2,741	1,810	498	531
100	2,796	220	260	363	481	1,020	2,092	2,835	2,954	3,025	2,015	543	597
200	2,963												
500	3,185												
1,000	3,352												
10,000	3,908												

Fig. 5–10 (1) Enveloping of Estimated Base Flow (Contains the Flow from Tibet Basin) by Areal Conversion Method

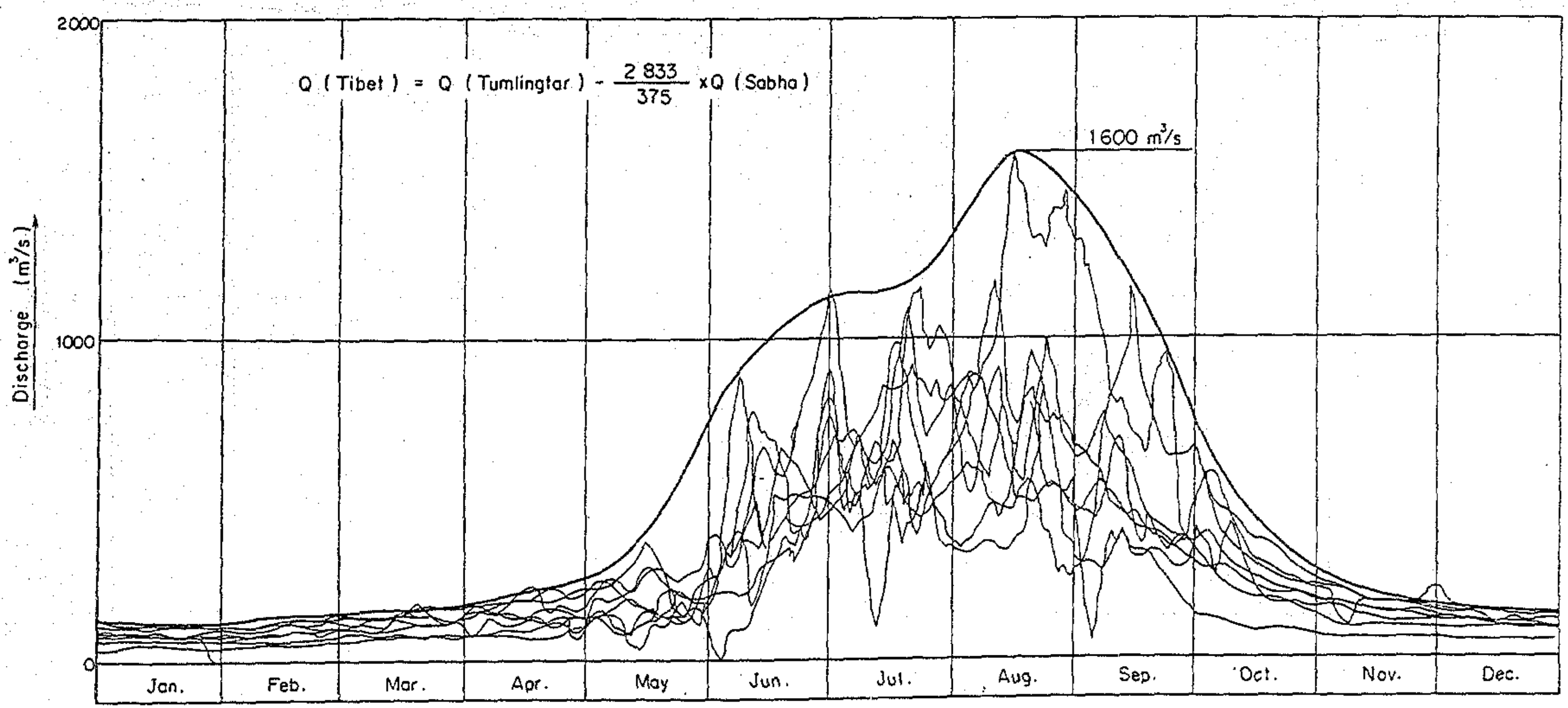


Fig. 5–10 (2) Enveloping of Estimated Base Flow (Contains the Flow from Tibet Basin) by Tank Model Method

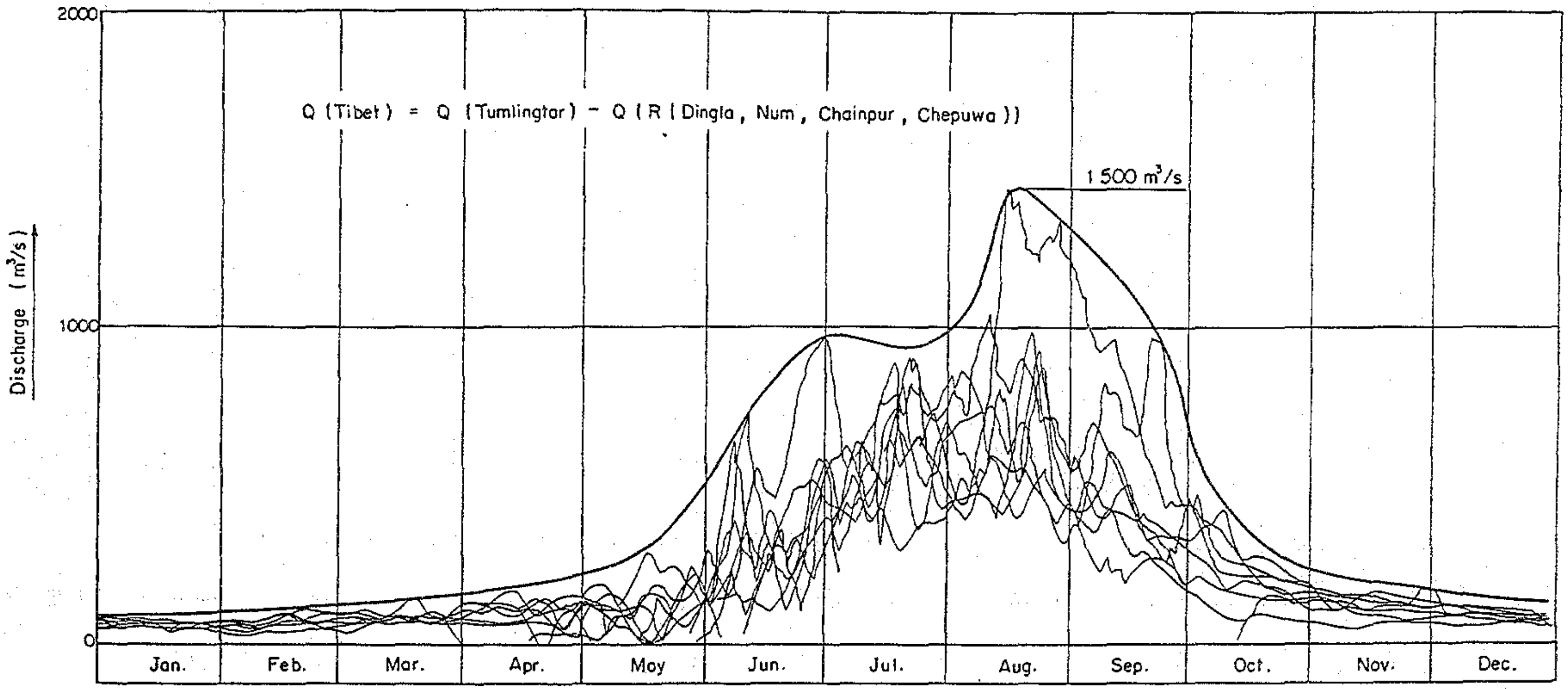


Fig. 5–11 (1) Probable Maximum Flood at Arun Damsite

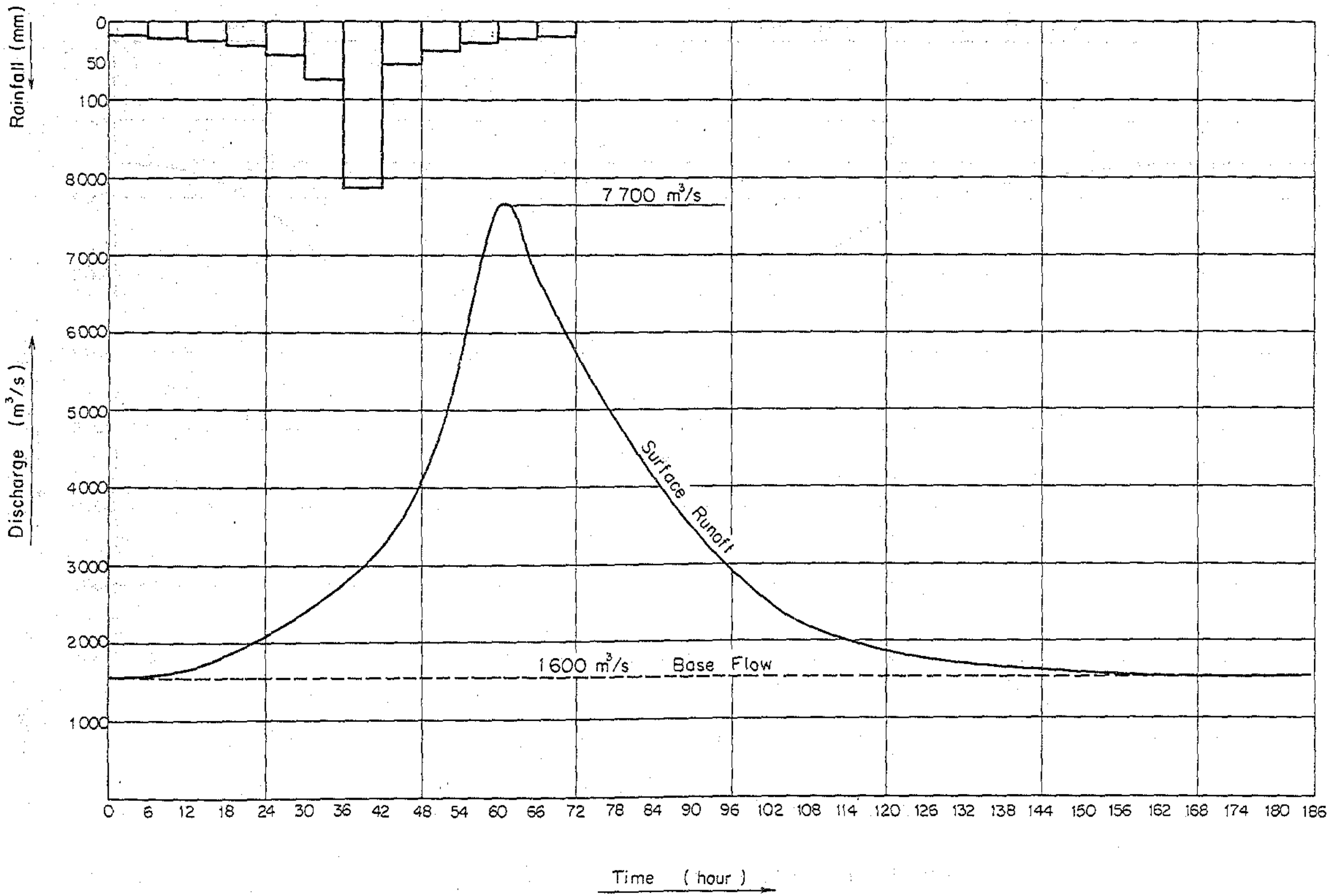
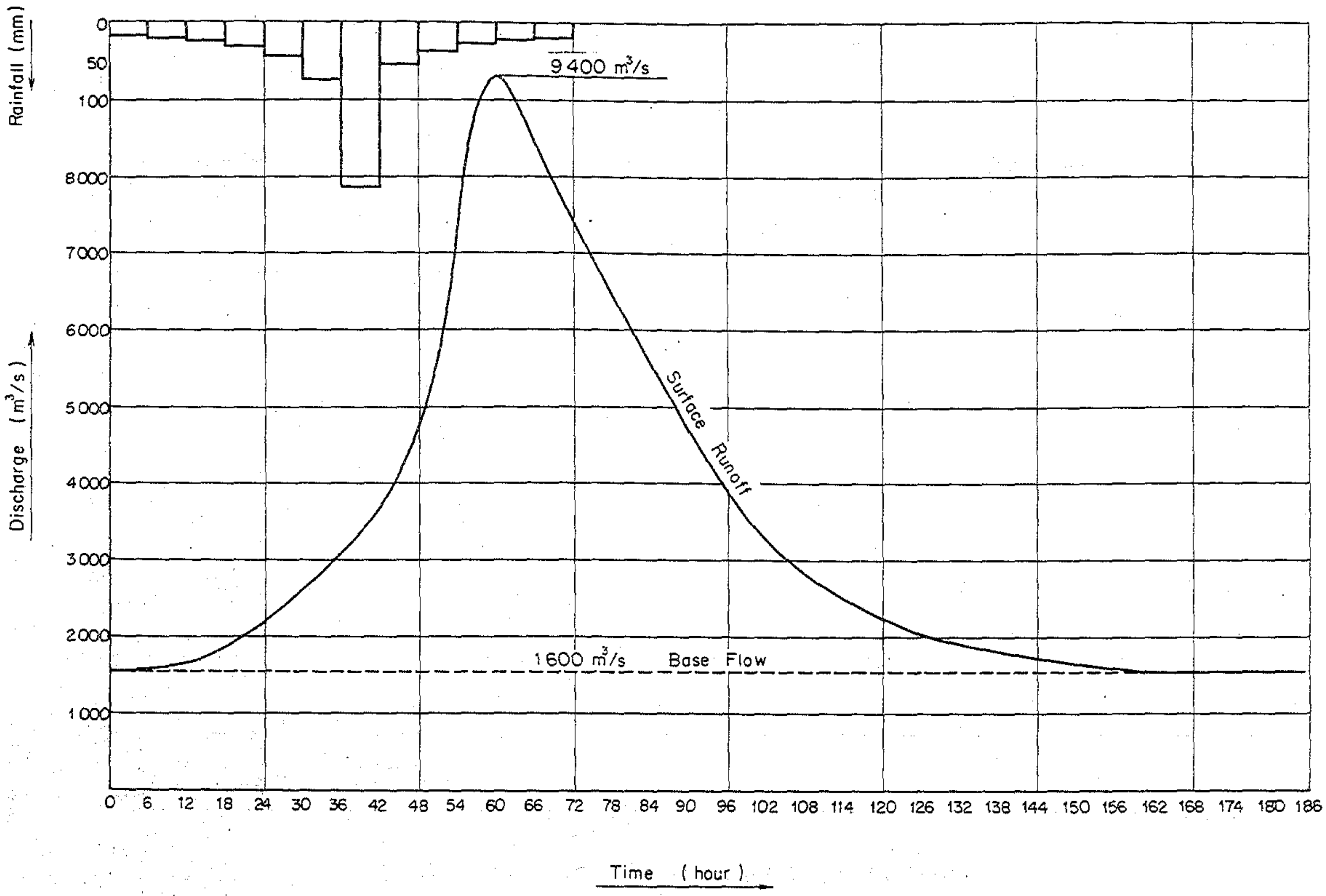


Fig. 5–11 (2) Probable Maximum Flood at Powerhouse



Conversion factors for the above are estimated to be 0.76 and 1.64 respectively and the peak discharges calculated with these factors at dam site are shown in Table 5-9, 5-10.

Fig. 5-12(1), (2) indicate the result of annual maximum value by frequency analyses.

5.6.9 Flood Discharges Applied to Design

(1) Design Flood Discharge at the Dam Site: 7,700 m^3/s

As for the design flood discharge for the concrete dam like the Arun project, frequency analysis is usually adopted. But in this study, PMF is selected as the design flood discharge even though PMF is the largest flood theoretically, considering that it will well cover all the indistinct factors stated below.

(i) As the observation period at the Tumlingtar gauging station is only 11 years, the accuracy of the result by means of frequency analysis is doubtful especially for large return period of more than 1000 years.

(ii) Though the Tibetan area is the majority of the drainage basin upto the dam site, the meteorological information in this area is very scattered and it is difficult to properly estimate the flood discharge from the Tibetan area.

(iii) One of the important components of flood is GLOF. But up to this time the details of GLOF such as volume, cause, frequency, etc. are unknown.

(2) Design Flood Discharge at the Powerhouse: 9,400 m^3/s

According to the same reason as (1), design flood discharge at the powerhouse is calculated by means of PMF method. In this case, the calculation procedure is the same as that of dam site (Table 5-6(2), Fig. 5-8(2), Fig. 5-11(2)). Owing to the difference of catchment area of 593 km^2 the magnitude of the synthetic unit hydrograph is larger than that of dam site by about 1.3 times. Then, as the base flow component, 1,600 m^3/s,

Table 5–9 Probable Flood Discharge at Arun Dam Site by Log Pearson III Method (Instantaneous Peak)

Return Period	Annual Flood	Monthly Probable Flood Discharge											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2	2,204	167	178	221	290	613	1,391	1,986	1,904	1,653	1,003	348	214
5	2,480	189	211	272	358	755	1,655	2,313	2,290	2,120	1,356	419	298
10	2,646	204	228	303	398	843	1,812	2,541	2,524	2,387	1,534	456	379
20	2,798	217	246	332	434	922	1,952	2,767	2,736	2,616	1,673	487	482
50	2,984	232	265	368	479	1,022	2,121	3,070	2,999	2,882	1,814	521	662
100	3,118	244	280	394	510	1,093	2,241	3,307	3,188	3,064	1,898	545	839
200	3,249												
500	3,419												
1,000	3,546												
10,000	3,962												

Table 5–10 Probable Flood Discharge at Arun Dam Site by Gumbel Method (Instantaneous Peak)

Return Period	Annual Flood	Monthly Probable Flood Discharge											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2	2,211	167	177	221	289	611	1,379	2,010	1,895	1,623	965	340	241
5	2,553	196	217	283	371	788	1,708	2,419	2,373	2,197	1,379	430	375
10	2,778	214	243	324	428	905	1,924	2,688	2,690	2,579	1,653	490	465
20	2,994	233	268	364	480	1,017	2,134	2,948	2,994	2,944	1,916	547	551
50	3,274	257	299	414	548	1,163	2,404	3,283	3,386	3,416	2,256	621	662
100	3,485	274	324	452	600	1,271	2,607	3,534	3,682	3,770	2,511	677	744
200	3,693												
500	3,970												
1,000	4,178												
10,000	4,871												

Fig. 5–12 (1) Probable Flood Discharge (Log Pearson III)

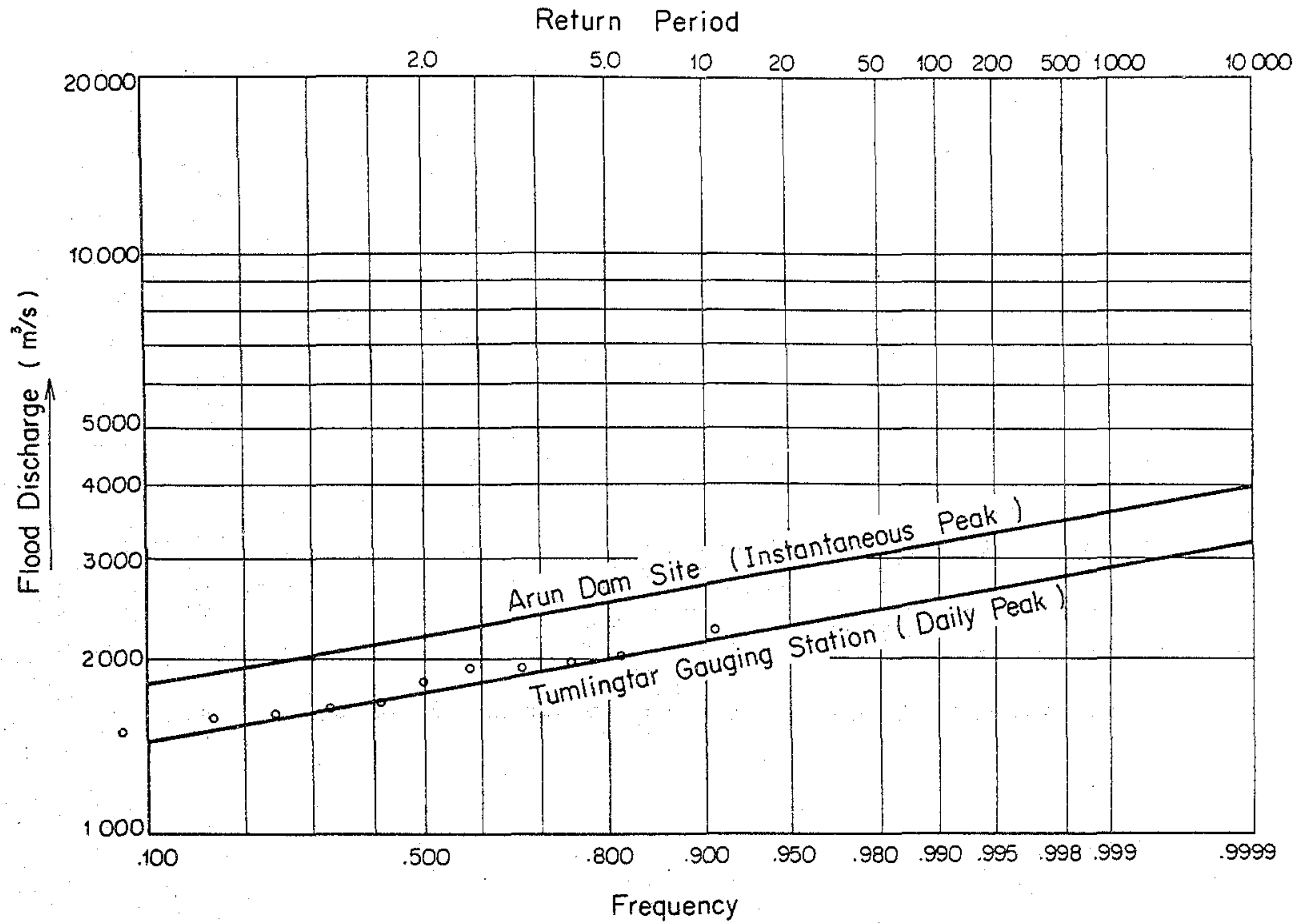


Fig. 5–12 (2) Probable Flood Discharge (Gumbel Method)