CHAPTER 3.

WEATHER AND HYDROLOGY

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3.1 Meteorological Outline in the Area

The project area belongs to a tropical monsoon region, and the annual climate undergoes the strong effect of monsoons. Namely, in the season of May to October, during which south-west monsoon from the Bay of Bengal is strong, there is a large amount of rainfall in the area, forming the rainy season, and on the contrary, in the season of November to April, during which northeastern monsoon coming from the continent blows strongly makes the dry season. The annual average total precipitation is approximately 1,300mm.

Temperature is high through the year, about 27°C on an average. Particularly, in April which is just before the rainy season, the daily highest temperature reaches almost 40°C. December and January which are in the dry season is the lowest temperature period in the year, and the daily lowest temperature goes down to 10°C or so.

Humidity is also high through the year. It is about 85% in the plain at midstream of the basin and over 90% in the southern mountaineous region of the basin. March and April in the end of the dry season are the least humid months through the year, and it is 60% or so sometimes. In other months, humidity is almost constant.

Annual average evaporation in the basin is about 1,300mm measured by Class A Pan. It is large in the midstream area and northern area of the basin and small in the southern area thereof. Evaporation is largest in March and April, the end of the dry season.

3.2 Gauging Station and Weather Observatory Station

1) Gauging station

Gauging stations in the area are located at four different positions, as shown in Fig. 3-1. Out of the stations, Mae La Luang gives the water level data alone and is located at a tributary of the Yuam River Therefore, it was omitted in the study. Meanwhile, the gauging data of the Moei River at Tha Song Yang are taken into account for reference although it lies out of the catchment area. At the above four stations, the daily discharge has been measured. Also, the measurements of hourly discharge have been made in Ban Tha Rua and Sop Han.
Gauging stations' catchment area and gauging periods are noted in Tables 3-1 and 3-2. At the four stations, daily sediments also have been measured. The measuring periods are shown in Table 3-3.

2) Weather observatory stations

Five weather observatories are in the area, as shown in Fig. 3-1. Meteorological parameters measured at those observatories are indicated below.

	Recipi-tation	Evapora-tion	Relative humidity	Tempera-ture	Wind movement
Mae La Luang	○	○			
Sop Han	○	○	○	○	
Chom Chaeng	○				
Ban Tha Rua	○	○	○	○	
Mae Sariang	○				○

Precipitation has been measured for 10 years or so at the above observatories except Mae Sariang where 31 years precipitation data are available. The measurement of evaporation at Sop Han and Ban Tha Rua has been conducted by the method of Class A Pan. As for the data of wind movement, those measured at several spots out of the basin were also taken into account for reference. Spots and periods of measurement were shown according to meteorological factors in Tables 3-4, 3-5, 3-6, 3-7 and 3-8.

3.3 Precipitation

Precipitation has been measured at five stations, and the three out of the five stations, Sop Han, Chom Chaeng and Mae Saeriang, are close to each other so that these three stations can be regarded as one station practically. Considering the size of the catchment area (approximately 6,000km^2) and the localization of precipitation, observation of precipitation could not be sufficient.

The precipitation pattern for one year in the area is shown according to months in Fig. 3-2, and the values are shown in Table 3-13. As seen in these illustrations, rainfall in the catchment area shows a conspicuous contrast between a rainy and a dry season, due to the effect of tropical periodic winds. The rainy season will start around May and continue until the latter half of October, while the dry season will continue from November to the following April. The annual total precipitation in the basin is approximately 1,300mm on average, but about 90% of it is distributed in the six months of the rainy season. During the dry season the remaining 10% or so falls, but it normally falls only for several days in an intensive way. Therefore, non-rainfall days continue practically for several weeks or months.

Precipitation in April and May which is the transit phase from dry to rainy season varies from year to year. Typically, rain starts falling from the latter half of April, and during early days rain falls once a week or 10 days with precipitation amount varying largely; occasionally falls a large amount. Following this, the interval of rainfall will shorten gradually, and as it enters the latter half of June, rain falls almost every day. The amount will reduce slightly in June and July and increase again in the latter half of August, and it will gradually reduce again from October and go down to almost none in November. As noted in Section 3.1, "Meteorological Outline", monsoon blows from the Bay of Bengal in the rainy season, conveying rain-laden clouds, nimbi, from south. As the result, rainfall in the rainy season is created by travelling rain clouds and concentrated into some hours during a day at a place, while rainfalls in the dry season seem localized by strong solar radiation.

Rainfall is in general originated by the phenomenon that rain-laden clouds are blocked with mountains and elevated high. In this project area too, precipitation is heavy, about 1,600mm annually, at Ban Tha Rua which is located in mountaineous area in the southern part and also close to the sea, while precipitation at Sop Han and Mae Sariang located in plain area at midstream is less, about 1,200mm per annum. Mae La Luang located in the mountain area but in the northern part gives relatively less annual precipitation, about 1,300mm.

The heaviest daily precipitation during measured period is 131.0mm recorded at Mae Sariang in May 23, 1980.

Variation of the annual total precipitation in years during the recorded period is shown in Fig. 3-3.

3.4 Temperature

Temperature has been measured at two stations; Sop Han and Ban Tha Rua. The period of measurement is shown in Table 3-7. Additionally, the monthly list of daily highest and lowest temperature is shown in Fig. 3-4 and Table 3-16. The annual averages of daily highest and lowest temperature are about 33°C and 22°C respectively, as shown in the table.

The daily lowest temperature goes down to the lowest, 13°C or so, in February. It went down to 10°C or less in some days, and 6°C was recorded at Ban Tha Rua in January, 1974. As it comes closer to the rainy season the temperature goes up, and during the rainy season it is nearly constant at 23°C or so.

Meanwhile, the daily highest temperature becomes highest, 38°C or so, in April, right before beginning of the rainy season. The temperature had exceeded 40°C in some days, and the highest was recorded for 44.5°C at Sop Han in April, 1981. It will start decreasing as a rainy season begins, and go down to 30°C or so in August. After that, it again rises slightly until towards October. As entering a dry season, it again decreases down to 30°C or so.

The difference between daily highest and lowest temperature becomes largest in March which is in the latter half of a dry season, reaching 21°C or so. As it enters a rainy season, the difference is getting smaller, reaching 7°C or 8°C in July or August.

3.5 Relative Humidity

In the project area, the relative humidity has been measured at Sop Han and Ban Tha Rua, and the duration of measurement is shown in Table 3-6. Also, the monthly list of daily average relative humidity is shown in Fig. 3-5 and Table 3-15. The annual average humidity was 86% at Sop Han and 94% at Ban Tha Rua, indicating that it is higher by about 10% at Ban Tha Rua which is in mountaneous area than at Sop Han. The reason for this is that precipitation is heavier at Ban Tha Rua while evaporation there is less as described in the next section. The variation during one year is similar at both the two spots; Sop Han and Ban Tha Rua, and the relative humidity becomes lowest in April and May, right before the rainy season, while it is almost constant throughout the rest of one year.

3.6 Evaporation

Evaporation in the project area has been measured at three stations; Mae La Luang, Sop Han and Ban Tha Rua. The duration of measurement thereof is given in Table 3-5, and the average of monthly evaporation is shown in Fig. 3-6 and Table 3-14. As indicated in this table, the annual total evaporation is approximately 1,400mm at Sop Han and Mae La Luang and 1,200mm at Ban Tha Rua. Ban Tha Rua is located in southern mountaneous area, having heavy precipitation and less evaporation. The variation during one year shows the trend similar to temperature, and the annually-highest evaporation has been experienced in April, just before the rainy season. Following this, evaporation reduces continuously until August, and it again increases in September and October, then again decreases in the following dry season. In April, during which evaporation becomes largest during a year, the daily evaporation becomes as much as 6.0mm.

<u>Estimation of Evapotranspiration and the Water Balance</u>

In present state, evaporation from the river and evapotranspiration from the flora has been taking place, and the runoff measured at Ban Tha Rua is the resultant of precipitation subtracted by these evapotranspiration. When a reservoir is created due to completion of the dam construction, in the area covered by this reservoir the existing evapotranspiration from the flora, etc. is replaced by sole evaporation from the reservoir. Therefore, it is required to estimate the alteration in available water volume associated with this change.

Reservoir evaporation has been calculated by multiplying 0.7 [2(1)] to the record at Ban Tha Rua and Sop Han (by Class A Pan method).

On the other hand, estimation of the evapotranspiration from the existing flora was carried out by two methods; Thornthwaite Method, and Blaney and Criddle Method. The basic equation is as follows:

[Thornthwaite Method]

$$Ept = 0.533 \quad Do \left(\frac{10tj}{J}\right)^{a}$$

where $a = (6.75 \times 10^{-7} J^{3}) - (7.71 \times 10^{-5} J^{2}) + (1.79 \times 10^{-2} J) + 0.49$

$$J = \sum_{j=1}^{12} \left(\frac{tj}{5}\right)^{1.514}$$

Ept = Monthly average of daily evapotranspiration (mm/day)

Do = Daytime ratio i.e. daily daytime/12hrs.

t = Monthly average temperature (°C)

j = Month (1-12)

J = Indicator of month

[Blaney and Criddle Method]

$$Ept = K \cdot C \cdot t$$

where Ept = Monthly average evapotranspiration (inch/month)

C = Ratio of monthly daytime to annual daytime

t = Monthly average temperature (°F)

K = Coefficient corresponding to kind of flora

When the unit is converted to the meter system, the equation is;

$$Ept = K \cdot C \quad (45.72t + 812.8)$$

where [Ept] = mm/month

[t] = °C

The factors required in the above two methods were determined as follows.

[Thornthwaite Method]

Do (Daytime ration): The value at 18° North Latitude where the project site is located was calculated.

[Blanney and Criddle Method]

C: same as the above Do, rough value for 18° N Lat.

K: factor depending on the kind of flora; 0.70 for deciduous trees.

The results of calculation are given in Table 3-17 and 3-18.

Seeing from the results, the evapotranspiration calculated by the Thornthwaite Method shows larger estimated values than by the Blaney and Criddle Method.

By the Thornthwaite Method, evapotranspiration based on the data of Ban Tha Rua is larger than evaporation, while evapotranspiration based on Sop Han is less than evaporation. However, according to the Blanney and Criddle Method, the values of evaporation were larger at both Ban Tha Rua and Sop Han. Neither the two methods offer any convincing quantitative proof, but, judging qualitatively, the evaporation generated when the reservoir will have been filled up with water in future is larger than the existing evapotranspiration, and reduction of an available water volume can thus be anticipated.

Based on the above knowledge, calculation of power in this study has been conducted under such adverse condition that evapotranspiration from the existing flora in the reservoir area impounded in future is not taken into account and that evaporation from the reservoir which will take the place of the present evapotranspiration is treated as full reduction of the available water volume. In this moment, the reduction of available water due to evaporation from the reservoir was obtained from the measured evaporation at Ban Tha Rua and the area of reservoir in the following way:

Annual average evaporation obtained from the recorded data at Ban Tha Rua for 11 years is 3.40mm which is calculated by the observed value itself by the Pan method but not by the value multiplied by 0.7. The annual total evaporation calculated is approximately 1,240mm. For the whole reservoir,

$$1,240\text{mm} \times 20.2\text{km}^2 \text{ (at HWL-170.0m)} = 25.0 \times 10^6 \text{m}^3$$

This corresponds to 0.9% of the total inflow 2,800 x $10^6 m^3$, and must be reduced from the annual inflow for power generation.

3.7 Discharge

1) Measured discharge

In the project area, daily discharges have been measured at four stations; Ban Tha Rua, Sop Han, Chom Chaeng and Mae La Luang, and hourly discharges have been measured at two stations; Ban Tha Rua and Sop Han. Out of the above four gauging stations, stations located on the main stream of the Yuam River are two of Ban Tha Rua and Sop Han. Sop Han and Ban Tha Rua are located at the midstream and downstream, respectively in the basin. Particularly, Ban Tha Rua is located about 15km away in the upstream of the planned damsite A, and for analysis of discharge in this study, the records at the Ban Tha Rua gauging station have been mainly adopted.

The period of measurement at each gauging station and the catchment area are given in Tables 3-1 and 3-2. Additionally, the monthly average of daily runoff at Ban Tha Rua is given in Fig. 3-7, and the annual total runoff is given in Fig. 3-8.

The alteration of annual average runoff occurs in reflection of the meteorological conditions of tropical monsoons, thereby runoff during the dry season is very contractive to that during the rainy season; the seasonal total runoff in the rainy season (May to October) is nearly 80% of the annual total runoff. The annual total runoff averaged over the recorded 11 years (1970-1980) is approximately 2,800 x $10^6 m^3$, and the annual average runoff is $88.8 m^3/sec$. The monthly list of daily average runoff is given in Table 3-9. In addition, the duration curve averaged over the 11 years is shown in Fig. 3-9. According to this, $88.8 m^3/sec$ corresponds to the about 120-day runoff.

2) Reasonability of runoff data

The runoff data at Ban Tha Rua is recorded for 11 years, but it is required to review whether or not this record for 11 years is necessary and enough as basic information for studying the power generation plan. This review was carried out by using the Tank Model method.

Observation of the precipitation in the area has been made at five stations, out of which four stations have the recording period of only 10 years or so, which is in parallel with runoff measurement at Ban Tha Rua, but Mae Sariang alone has the data for a full 31 years. This review, employing a tank model, is pursued by the following way: inputting the precipitation at Mae Sariang, extend the runoff at Ban Tha Rua from the actually recorded 11 years to further 20 years in the past, and make qualitative judgement for the 11 year period of the measured records.

Tank Model is one of techniques for analyzing the runoff, and at present it is widely proven in the world for its effectiveness. Tank Model includes many models with various structures, but in principle it has a structure connecting vertically in series or in parallel some tanks with outlets in the side and bottom corresponding to discharge to a river and seepage to ground. Taking precipitation as input, the model enables to estimate run-off of the river. This study employed the so-called soil-moisture type of tank model composed of four tanks combined vertically in series with soil moisture function provided at the first top tank, which is widely said appropriate for the region having a long dry season. The conceptional model is shown in Fig. 4-10. (for details, refer to Appendix.)

In employing this Model, parameters were first determined by using the runoff and precipitation data recorded for 11 years at Ban Tha Rua and Mae Sariang, respectively, and afterwards runoff was estimated retracing the past to 1950, i.e. for further 20 years. The precipitation data employed here as the input is only of one station of Mae Sariang. In other words, the precipitation over the catchment area of approximately 6,000km^2 is represented by the data at one station. This representation entails some problems, but the correlation between the precipitation at Mae Sariang and the arithmetical average precipitation at other four stations within the recorded 11 years, can be assured to some extent as shown in Fig. 3-11 where the correlation factor is 0.826, so that the representation is reasonably justified.

The estimated runoff by using this Model is given in Fig. 3-12 along with the observed runoff at Ban Tha Rua. In the figures the solid line and broken line show the observed and estimated runoff, respectively. Furthermore, the monthly comparison of daily runoff is given in Tables 3-19 and 3-20.

Against the estimated runoff during the past 31 years which was extended in a time series in a way mentioned above, the power spectrum as shown in Fig. 3-13 was obtained by taking the unit time lag of one month. From the viewpoint of the long period exceeding one year, this result shows that the runoff has one period of 11 years. The periodic feature for a longer duration, say 30, 50 or 100 years, is not clarified with the available data of this time. The above-mentioned 11-year periodical characteristic is correspondent to the tendency of runoff on the Quae Yai River having the meteorological condition similar to that in this project area, and thus it is conceived to be reasonable. Reference is to be made to Fig. 3-14. Very long periodic feature, i.e. 50 or 60 years can be recognized to some extent in the rainfall data at Bangkok seen in Fig. 3-14. The above analysis, thus, convinces that the runoff adopted this time, forming one cycle of period of 11 years, is adequate to be utilized with the average thereof to determine the development scale.

3) Inflow into the damsite

The inflow into the damsite was calculated as follows, by adopting the data over the recorded period of 11 years at Ban Tha Rua and taking into account the catchment area and evapotranspiration:

For damsite A,

$$Q_{IN} = Q_{BAN\ THA\ RUA} \times \frac{5,920km^2}{5,770km^2} \times (1-\frac{25x10^6m^3}{2,798x10^6m^3})$$

$$= 1.017\ Q_{BAN\ THA\ RUA}$$

The inflow is calculated by multiplying the above ration uniformly to the measured runoff.

For damsite C,

$$Q_{IN} = Q_{BAN\ THA\ RUA} \times \frac{5,810km^2}{5,770km^2} \times (1-\frac{18x10^6m^3}{2,798x10^6m^3})$$

$$\simeq Q_{BAN\ THA\ RUA}$$

Here, the runoff at Ban Tha Rua was adopted without modification.

3.8 Sedimentation

Sediments have been measured at three stations in the area; Ban Tha Rua, Sop Han and Chom Chaeng. The duration of measurements is given in Table 3-3. Out of them, two stations of Ban Tha Rua and Sop Han measure the main stream. To observe the condition of sediments in the similar basin, the data at Tha Song Yang along the Moei river were also referred to, although it is out of the basin of concern. The measured records at stations are given in Tables 3-10, 3-11 and 3-12.

Measurement has been done for suspended sediment in terms of weight and in these tables the volume calculated by the unit weight obtained with the equation below is also given.

The unit weight of suspended sediment after settling down in the reservoir was obtained with the following equation: [2(3)]

$$W_{av} = W_1 + 0.434\,K\left[\frac{t}{t-1}(\ln t - 1)\right]$$

where W_{av} : average unit weight of sediment after t years (gr/cm^3)

W_1 : unit weight of initial sediment (gr/cm^3)

K : coefficient

t : number of years

This yields $W_{av} = 1.30 gr/cm^3$.

As mentioned above, measurement has been conducted for suspended material, and thus, for actual sediment, bed load must additionally be taken into account. Referring to various reports,[2(2), 2(4)] bed load have been assumed for 20% in terms of the volume ratio.

The estimated sediment obtained is as follows:

Ban Tha Rua	($5,700km^2$)	: $109.6m^3/km^2/yr$
Sop Han	($2,496km^2$)	: $136.2m^3/km^2/yr$
Tha Song Yang	($8,360km^2$)	: $196.9m^3/km^2/yr$

$140m^3/km^2/yr$ which was slightly modified one to be larger than that of at Sop Han was adopted as design sediment. Then, the calculated total sediment for 100 years amounts to $82.9 \times 10^6 m^3$. This corresponds to 18.7% of the total storage volume of the reservoir. At this volume, the sediment level of the reservoir is 129.0m, on the assumption that the sediment lies in horizontal.

3.9 Flood Analysis

The hourly runoff measured at two stations, Ban Tha Rua and Sop Han, were adopted as the basic data of flood analysis. Their measurement periods are given in Table 3-2. However, at both the stations, measurement has not been carried out at night (18:00 to 06:00 hrs) and even daytime measurement has been often carried out only in every three or six hours, and thus peak runoff have not always been caught in the measurement. Therefore, some of peak runoffs had to be estimated from the runoff recorded right before or after in the sequence. The maximum flood in each year measured at Ban Tha Rua is given in Fig. 3-15.

1) Flood analysis by probability

The peak runoffs of the max. flood mentioned above are plotted in the Log Normal distribution and Gumbel distribution as shown in Figs. 3-16 and 3-17. According to the figure, the flood of 1,000 return period is:

Log Normal Distribution: $1,900m^3/sec$

Gumbel Distribution : $2,200m^3/sec$

However, these are rather small compared with flood in other projects in Thailand.

2) Creager's Method

The Creager curve which was referred to in the U.Q.Y.F.S. Report has been adopted. The Creager curve is shown in Fig. 3-18. The factor C is assumed to be 40 taking into account the topological feature of the area in this plan as well as distance from the sea. Then, the peak of flood yields:

$$Q_F = 6,150 m^3/sec$$

3) P.M.F. (Probable Maximum Flood)

(i) Determination of P.M.P. (Probable Maximum Precipitation), Choice of adequate Storm and its maximization:

Looking over all the concerning precipitation data recorded at stations in the catchment area, 24 cases of a typical pattern of precipitation, which seems adoptable for the whole basin, have been selected. The 24 cases of precipitation have been screened to the following nine cases, knowing the average precipitation during the period, daily totals of precipitation at every station, etc.:

1970	5/15 to 5/18,	1971	7/16 to 7/22
1974	8/8 to 8/13,	1977	9/4 to 9/8
1978	8/12 to 8/16,	1978	9/10 to 9/23
1979	8/11 to 8/17,	1980	5/20 to 5/25
1980	9/6 to 9/9		

The above nine cases of storms which are point precipitations are converted to area precipitations through DAD operation. The isohyetal maps needed in that conversion have been represented by the one isohyetal map indicated in Fig. 3-19, in consideration of the distribution of precipitation of the past data, and the isohyetals have been assumed fixed irrespective of storms. In other words, the rainfalls measured at stations has been regarded as the average in the area enveloped by its hypothetical isohyetals. In addition, the value of precipitation on the fixed isohyetals were given an appropriate value in every storm and day taking into account the observed precipitations.

Following this, the nine cases of storms, to which the above-mentioned DAD analysis had been applied, have been maximized by ratio of precipitable water obtained from their dew point. In general, in the PMP analysis, elevation adjustment, barrier adjustment and moisture adjustment are taken into account if necessary. But in this study the elevation adjustment is not needed since the analysed data is itself in the project area and the barrier adjustment has been decided omissible considering the height of neighbouring mountains, while the moisture adjustment is in itself included into procedure of maximization. The dew points have been obtained from the relative humidity and temperature at Ban Tha Rua, and the precipitable water (total moisture amount involved in the vertical column standing on the unit area of ground surface to the sky) corresponding to their dew point has been taken from the figure publicized by the U.S. National Weather Service. The maximized precipitation of storms is given in Fig. 3-20 with the duration time on the abscissa. As seen in this figure, the storm of No. 21 (1), 1980, 5/20 - 5/25, is extremely huge and this sequence of precipitation has, thus, been adopted as P.M.P.

(ii) Determination of daily runoff generated by PMP

While PMP has been obtained as described above, the relation between the sequence of precipitation and the resulted runoff has been studied, using the past data of daily rainfalls and daily runoffs. The sequence of precipitation here is the one that considerable daily precipitation continued for two or three days and thereby large runoffs arose in the following days. In this study, sequences of precipitation which are relatively eminent among records and the resultant runoffs have been extracted, and then the relation between the precipitation and the resultant maximum runoff (daily runoff) has been studied. When the unit precipitation is 10mm, the maximum runoff is $93m^3$/sec on the average and $128m^3$/sec in the maximum, and it takes place with time lag of one day or so from the last day of the sequence of precipitation. The runoff per unit precipitation largely varies depending on the rainy or dry season, i.e., depending on the amount of soil moisture storaged in the catchment area. Since the PMP is now conceived to occur in July and August which is in the middle of the wet season, the runoff per unit precipitation is assumed the largest of $128m^3$/sec.

Considering the basin retention for 5% against the PMP 4-day sequence studied in the above (i), the effective precipitation becomes 257mm. Thus, the maximum generated daily runoff becomes 3,290m^3/sec. On the other hand, storm and the resultant flood are experienced intermittently in the wet season of July and August, and thus such condition must be involved in the study. When the past largest discharge (Q = 925m^3/sec, August 30, 1971) is considered as the precedent runoff and the time lag is taken for three days, the above daily runoff due to PMP is amounted to 3,790m^3/sec.

(iii) Determination of P.M.F. hydrograph

It is notable that the above analysis has been conducted on the daily basis, and the maximum runoff obtained therefrom is also the daily average runoff. However, in practice the runoff remarkably varies in hours, and the actual peaks are conceived to rise up more sharply. In fact, the ratio of daily runoff against hourly runoff was found to be 1.17 on the average and 1.64 in maximum through the study using recorded data at Ban Tha Rua.

In this study, the maximum ratio was adopted for 1.64. Thereby, the daily maximum peak runoff becomes 6,216m^3/sec rounded to 6,200m^3/sec.

4) Design flood discharge

As the result obtained through the above three methods, the peak discharge of design flood in this project has been decided to be PMF 6,200m^3/sec. The hydrograph of the design flood was drawn as a similar figure of the envelope of the recorded flood discharges which is shown in Fig. 3-15. The hydrograph of the design flood is also given in Fig. 3-21. The volume of this design flood is 1,110 x $10^6 m^3$.

Table 3 - 1 Runoff Gaging Station and Available Daily Discharge

River	Station	C.A. (km²)	Year 66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
Nam Mae Yuam	Sop Han	2,496			—	—	—	—	—	—	—	—	—	—	—			
Nam Mae Sariang	Chom Chaeng	378		—	—	—	—	—	—	—	—	—	—	—	—	—		
Nam Mae Yuam	Ban Tha Rua	5,770*					—	—	—	—	—	—	—	—	—	—	—	
Mae Nam Moei	Tha Song Yang**	8,360						—	—	—	—	—	—	—	—	—	—	

Note : * Catchment Area was measured on a 1: 250,000 map for the study.
** Record at The Song Yang was ussd for referrence

Table 3 - 2 Runoff Gaging Station and Available Hourly Discharge*

River	Station	C. A (km²)	Year 66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
Nam Mae Yuam	Sop Han	2,496	Mar. —	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nam Mae Yuam	Ban Tha Rua	5,770			May —	—	—	—	—	—	—	—	—	—	—	—	—	—

Note : * Hourly Discharger were not measured in night (18:00 to 6:00 hrs)

Table 3-3 Runoff Gaging Station and Available Suspended Sediment Discharge

River	Station	C.A. (km²)	Year 66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
Nam Mae Yuam	Sop Han	2,496						—	—	—	—	—	—	—	—		—	
Nam Mae Sariang	Chom Chaeng	378						—		—	—	—	—	—	—	—	—	
Nam Mae Yuam	Ban Tha Rua	5,770						—	—		—	—	—	—	—	—	—	
Mae Nam Moei	Tha Song Yang*	8,360							—	—	—	—	—	—	—	—	—	

Note : * Record at Tha Song Yang was used for referrence.

Table 3-4 Observatory Station and Available Daily Precipitation

Station	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Mae La Luang							Feb.													
Sop Hon						May														
Chom Chaeng							May													
Ban Tha Rua																				
Mae Sariang	50																			

Table 3-5 Observatory Station and Available Daily Evaporation

Station	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Mae La Luang																	1.0*			
Sop Hon													1.5*							
Ban Tha Rua											2.5*									

Note : *. Number of months where record was not made.

Table 3-6 Observatory Station and Available Daily Relative Humidity

Station	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Sop Hon						May					3.0									
Ban Tha Rua											Jul.						2.5			

Table 3-7 Observatory Station and Available Daily Temperature (Max. Min.)

Station	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Sop Hon						Max. Min.		3.0			3.0	7.0								
Ban Tha Rua										Max. Min.	Jul.									

Table 3-8 Observatory Station and Wind Movement (Direction, Velocity)

Station	Year																			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Solaiwin *1												—	— 2.0 —	—	—	— 3.5				
Chiang Mai *2																			—	—
– ditto – *3																		—	—	—
Mae Hong Son *4																		—	—	—
Mae Sariang *5																		—	—	—
Tak *6																		—	—	—
Kanchanaburi *7																		—	—	—
– ditto – *8	51 —	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Bangkok *9	51 —	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

Note : *1 Velocity was measured on daily basis.
*2 Velocity was measured 2,000m up in the air on daily basis.
*3 Monthly average velocity was measured 9.0 m up from the ground.
*4 Monthly average velocity was measured 12.0 m up from the ground.
*5 Monthly average velocity was measured 12.0 m up from the ground.
*6 Monthly average velocity was measured 12.5 m up from the ground.
*7 Monthly average velocity was measured 15.0 m up from the ground.
*8 Direction and monthly average max. velocity was measured.
*9 Direction and monthly average max. velocity was measured.

Table 3-9 Monthly List of Daily Average Runoff at Ban Tha Rua G.S.

(Unit: m^3/s, except for Annual Total)

Mon. / Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total ($m^3/s.day$)	Annual Average
1970	48.09	34.65	25.20	24.65	49.25	69.23	145.13	247.13	262.60	145.77	77.21	55.73	36,186	99.14
1971	35.65	25.52	20.01	14.71	29.82	83.98	323.55	359.68	268.10	142.05	76.05	47.96	43,720	119.78
1972	33.12	24.06	19.15	19.19	17.21	36.34	197.19	310.55	195.10	128.60	95.40	60.26	34,827	95.16
1973	40.03	26.55	21.92	16.05	31.63	64.09	133.28	264.52	289.13	180.16	88.30	55.34	37,004	101.38
1974	35.26	25.12	17.15	16.18	31.12	72.20	127.66	227.53	174.83	116.01	83.14	41.42	29,574	81.03
1975	38.84	25.63	21.29	15.22	24.98	71.36	140.70	205.09	274.80	182.87	85.96	50.25	34,723	95.13
1976	36.01	26.26	18.64	13.95	26.70	50.89	115.43	221.10	188.63	154.91	82.99	48.36	30,111	82.27
1977	52.73	24.76	18.37	17.57	20.02	29.29	71.02	170.48	290.53	115.72	72.43	44.48	28,265	77.44
1978	32.31	23.49	15.80	11.67	21.91	23.35	133.64	244.19	211.10	140.91	58.89	34.66	29,134	79.82
1979	24.92	19.14	13.29	12.11	18.94	23.24	58.62	241.01	116.29	108.15	47.23	28.17	21,788	56.69
1980	17.96	13.29	10.92	9.06	32.84	51.58	94.70	143.79	327.37	185.26	82.61	52.57	31,183	85.20
Average	35.9	24.4	18.3	15.5	27.7	52.3	140.1	239.6	236.2	145.5	77.3	47.2	32,410 (2,800 x $10^6 m^3$)	88.8

Table 3-10 Annual Sedimentation Observatory: SOP HAN

Year	Annual Sediment (t/year)	Annual Sediment (m^3/year)	Specific Discharge of Sediment (m^3/km^2/year)
1971	234,980	180,754	72.4
1972	187,542	144,263	57.8
1973	1,084,413	834,164	334.2
1974	245,653	188,964	75.7
1975	646,225	497,096	199.2
1976	131,278	100,983	40.5
1977	228,627	175,867	70.5
1978	313,353	241,041	96.6
1979	-	-	-
1980	241,882	186,063	74.5
Av.			113.5

Note: Specific Gravity of Soil = 1.30 gr./cm^3
Catchment Area = 2,496 km^2

Table 3-11 Annual Sedimentation Observatory: BAN THA RUA

Year	Annual Sediment (t/year)	Annual Sediment (m^3/year)	Specific Discharge of Sediment (m^3/km^2/year)
1971	465,822	358,325	62.1
1972	970,927	746,867	129.4
1973	-	-	-
1974	-	-	-
1975	10,037,791	7,721,378	1,388.2
1976	428,788	329,837	57.2
1977	398,518	306,552	53.1
1978	621,636	478,182	82.9
1979	405,887	312,221	54.1
1980	1,502,392	1,155,686	200.3
Av.			247.2 (91.3)

Note: Specific Gravity of Soil = 1.30 gr./cm^3
Catchment Area = 5,770 km^2
Average in parenthesis is a figure calculated excluding the sediment in 1975.

Table 3-12 Annual Sedimentation Observatory: THA SONG YANG

Year	Annual Sediment (t/year)	Annual Sediment (m^3/year)	Specific Discharge of Sediment (m^3/km^2/year)
1971			
1972	3,601,007	2,770,005	331.3
1973	1,604,920	1,234,554	147.7
1974	2,008,150	1,544,731	184.8
1975	1,441,015	1,108,473	132.6
1976	1,129,598	868,922	103.9
1977	669,809	515,238	61.6
1978	1,309,693	1,007,456	120.5
1979	2,935,068	2,257,745	270.1
1980	1,349,321	1,037,939	124.2
Av.			164.1

Note: Specific Gravity of Soil = 1.30 gr./cm^3
Catchment Area = 8,360 km^2

Table 3-13 Monthly List of Daily Average Precipitation at Each Obervatory Station

(Unit: mm)

Mon. / Obs. Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total	Annual Average
Mae La Luang ('67 - '80)	0.57	0.05	0.22	1.47	6.35	6.00	7.23	9.89	7.70	3.26	1.18	0.60	1,363.9	3.74
Sop Han ('66 - '80)	0.51	0.09	0.25	0.96	5.63	5.74	7.20	7.53	7.72	3.60	0.51	0.35	1,197.1	3.28
Chom Chaeng ('67 - '80)	0.47	0.05	0.30	1.01	4.91	4.53	6.33	7.53	5.52	3.29	0.37	0.35	1,068.7	2.93
Ban Tha Rua ('70 - '80)	0.78	0.07	0.30	1.37	7.61	9.25	10.39	11.07	6.97	3.92	0.95	0.35	1,624.4	4.45
Mae Sariang ('50 - '80)	0.40	0.18	0.26	1.35	5.59	6.32	6.50	8.16	7.14	3.94	0.72	0.41	1,232.8	3.38

Table 3-14 Monthly List of Daily Average Evaporation at Each Observatory Station

(Unit: mm)

Mon. / Obs. Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total	Annual Average
Mae La Luang ('70 - '80)	3.25	4.32	5.47	6.36	4.73	3.69	3.31	3.00	3.59	3.52	3.25	3.02	1,444.3	3.96
Sop Han ('67 - '80)	2.81	4.27	5.63	6.61	5.16	3.48	2.93	2.73	3.36	3.30	2.90	2.54	1,405.9	3.85
Ban Tha Rua ('67 - '80)	2.77	3.30	4.82	5.96	4.33	3.04	2.57	2.33	3.14	3.31	2.77	2.71	1,241.8	3.40

Table 3-15 Monthly List of Daily Average Relative Humidity at Each Observatory Station

(Unit: %)

Obs. Station \ Mon.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
Sap Han ('66 - '81)	88.76	88.48	84.76	78.58	81.31	85.96	87.21	87.77	87.64	87.50	88.10	88.93	86.35
Ban Tha Rua ('71 - '81)	94.83	96.06	95.51	89.84	92.53	94.71	95.40	96.14	95.41	94.76	93.75	94.52	94.55

Table 3-16 Monthly List of Daily Average Temperature at Each Obervatory Station

(Unit: degree Celcius)

Obs. Station \ Mon.		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total	Annual Average
Sop Han '67-'72 ('80,'81)	Min.	15.21	12.98	14.91	22.42	23.97	23.66	23.31	23.10	23.29	22.75	20.48	17.73	8.0	20.5
	Max.	30.43	33.46	36.40	37.40	35.62	30.89	29.97	30.22	31.60	32.54	31.86	30.34	44.5	32.9
Ban Tha Rua ('71-'80)	Min.	14.15	13.81	17.29	21.29	23.02	23.08	23.02	22.92	23.06	22.04	19.47	16.08	6.0	20.0
	Max.	31.81	35.57	38.73	39.03	35.88	33.57	32.40	31.47	33.23	34.22	33.06	31.52	43.5	34.2

Table 3-17 Estimation of Water Loss due to Evapotranspiration W/ or W/O Reservoir Monthly List of Daily Average at Ban Tha Rua

(Unit: mm/day)

	Method	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann. Total	Ann. Mean
Available Precipitation for Crop Consumption	P : Precipitation x 0.8	0.62	0.06	0.24	1.10	6.09	7.40	8.31	8.86	5.58	3.14	0.76	0.28	1,300	3.56
Evapotranspiration in Calculation	A : Thornthwaite	2.23	3.43	5.42	7.77	7.01	6.17	5.48	5.00	5.77	5.23	3.97	2.61	1,828	5.01
	B : Blaney and Criddle	3.29	3.54	4.00	4.37	4.42	4.37	4.29	4.13	4.07	3.90	3.60	3.32	1,439	3.94
Estimated Evapotranspiration (w/o Reservoir)	AP: Smaller one either A or	0.62	0.06	0.24	1.10	6.09	6.17	5.48	5.00	5.58	3.14	0.76	0.28	1,056	2.89
	BP: either B or P	0.62	0.06	0.24	1.10	4.42	4.37	4.29	4.13	4.07	3.14	0.76	0.28	841	2.31
Estimated Evaporation (w/ Resorvoir)	O : Observed Evaporation x 0.7	1.80	2.33	3.52	4.29	3.01	2.21	1.73	1.58	2.01	2.25	1.91	1.90	868	2.38
AP-O		-1.18	-2.27	-3.28	-3.19	3.08	3.96	3.75	3.42	3.57	0.89	-1.15	-1.62	188	0.51
BP-O		-1.18	-2.27	-3.28	-3.19	1.41	2.16	2.56	2.55	2.06	0.89	-1.15	-1.62	-27	-0.07

Note : 1) "-" means that evaporation from the reservoir is greater than evapotranspiration from the existing flora, when the reservoir will be filled up.

Table 3-18 Estimation of Water Loss due to Evapotranspiration W/ or W/O Reservoir
Monthly List of Daily Average at Sop Han

(Unit: mm/day)

	Method	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann. Total	Ann. Mean
Available Precipitation for Crop Consumption	P : Precipitation x 0.8	0.41	0.07	0.20	0.77	4.50	4.59	5.76	6.02	6.18	2.88	0.41	0.28	958	2.62
Evapotranspiration in Calculation	A : Thornthwaite	3.04	2.86	5.16	8.70	7.52	5.73	4.77	4.65	4.93	4.90	3.73	2.45	1,780	4.88
	B : Blaney and Criddle	3.39	3.46	3.97	4.60	4.48	4.33	4.19	4.10	3.97	3.84	3.57	3.29	1,436	3.93
Estimated Evapotranspiration (w/o Reservoir)	AP: Smaller one either A or P	0.41	0.07	0.20	0.77	4.50	4.59	4.77	4.65	4.93	2.88	0.41	0.28	871	2.39
	BP: either B or P	0.41	0.07	0.20	0.77	4.48	4.33	4.19	4.10	3.97	2.88	0.41	0.28	816	2.24
Estimated Evaporation (w/ Resorvoir)	O : Observed Evaporation x 0.7	2.11	3.40	4.37	5.18	3.96	2.54	2.08	2.06	2.62	2.56	2.10	1.92	1,059*	2.90
AP-O		-1.70	-3.33	-4.17	-4.41	0.54	2.05	2.69	2.59	2.31	0.32	-1.69	-1.64	-188	-0.51
BP-O		-1.70	-3.33	-4.17	-4.41	0.52	1.79	2.11	2.04	1.35	0.32	-1.69	-1.64	-243	-0.66

Note: 1) "-" means that evaporation from the reservoir is greater than evapotranspiration from the existing flora, when the reservoir will be filled up.
2) *.; This figure 1,059 mm (1,059/0.7 = 1,513 mm) is greater then the one in Table 4-14, because this is derived from the record 1969, 1970 and 1980 in relation to available temperature record needed in the calculation.

Table 3-19 Monthly Comparison of Daily Average Runoff, Observed & Estimated

(Unit: m^3/s, excp. Ann. Total ($m^3/s.day$))

Mon. / Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total ($m^3/s.day$)	Annual Average
1970	48.09	34.65	25.20	24.65	49.25	69.23	145.13	247.13	262.60	145.77	77.21	55.73	36,186	99.14
	30.03	23.25	16.53	12.05	26.10	43.88	54.76	163.55	258.70	219.09	111.33	64.93	31,254	85.63
1971	35.65	25.52	20.01	14.71	29.82	83.98	323.55	359.68	268.10	142.05	76.05	47.96	43,720	119.78
	40.90	33.16	29.04	20.41	14.81	18.36	154.76	181.15	230.67	133.48	64.29	39.31	29,338	80.38
1972	33.12	24.06	19.15	19.19	17.21	36.34	197.19	310.55	195.10	128.60	95.40	60.26	34,827	95.16
	31.56	24.31	17.32	13.40	13.20	12.70	24.17	116.09	129.23	159.28	92.61	55.62	21,078	57.59
1973	40.03	26.55	21.92	16.05	31.63	64.09	133.28	264.52	289.13	180.16	88.30	55.34	37,004	101.38
	32.43	26.15	19.56	13.59	16.58	22.38	51.21	147.37	196.02	136.46	65.19	36.94	23,305	63.85
1974	35.26	25.12	17.15	16.18	31.12	72.20	127.66	227.53	174.83	116.01	83.14	41.42	29,574	81.03
	28.89	22.15	15.54	12.70	12.50	30.84	87.48	191.97	142.29	116.48	70.65	40.30	23,603	64.66
1975	38.84	25.63	21.92	15.22	24.98	71.36	140.70	205.09	274.80	182.87	85.96	50.25	34,723	95.13
	41.86	28.53	22.70	15.79	13.95	36.55	83.14	113.47	132.39	94.92	51.15	31.57	20,325	55.69
1976	36.01	26.26	18.64	13.95	26.70	50.89	115.43	221.10	188.63	154.91	82.99	48.36	30,111	82.27
	25.97	20.24	14.84	12.82	12.70	14.53	44.54	112.68	104.83	75.40	46.11	26.90	15,639	42.73
1977	52.73	24.76	18.37	17.57	20.02	29.29	71.02	170.48	290.53	115.72	72.43	44.48	28,265	77.44
	31.45	20.60	15.45	15.62	12.14	15.01	30.71	77.67	174.65	119.01	63.53	39.28	18,738	51.34
1978	32.31	23.49	15.80	11.67	21.91	23.35	133.64	244.19	211.10	140.91	58.89	34.66	29,134	79.82
	30.03	24.60	19.17	13.38	13.53	13.96	83.26	133.52	184.34	171.03	82.15	44.01	24,835	68.04
1979	24.92	19.14	13.29	12.11	18.94	23.24	58.62	241.01	116.29	108.15	47.23	28.17	21,788	56.69
	32.19	24.84	17.75	12.72	12.00	27.33	32.79	129.39	144.22	130.45	59.01	32.84	20,004	54.80
1980	17.96	13.29	10.92	9.06	32.84	51.58	94.70	143.79	327.37	185.26	82.61	52.57	31,183	85.20
	25.58	19.04	13.25	12.00	66.20	47.05	69.28	110.32	279.99	197.98	106.01	63.82	30,843	84.27

Note: Upper line is observed runoff.
Lower line is estimated runoff.

Table 3-20 Monthly Comparison of Daily Average Runoff, Observed & Estimated, throughout the Period

(Unit: m^3/s, excp. Ann. Total ($m^3/s.day$))

Mon. / Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total ($m^3/s.day$)	Annual Average
Observed ('70-'80)	35.9	24.4	18.3	15.5	27.7	52.3	140.1	239.6	236.2	145.6	77.3	47.2	32,400	88.5
Estimated ('50-'80)	31.46	24.65	18.63	14.40	17.76	27.31	62.87	142.79	169.95	137.53	74.95	43.29	23,378	59.38

Fig. 3-1 Observatory and Gaging Stations with the Covering Area

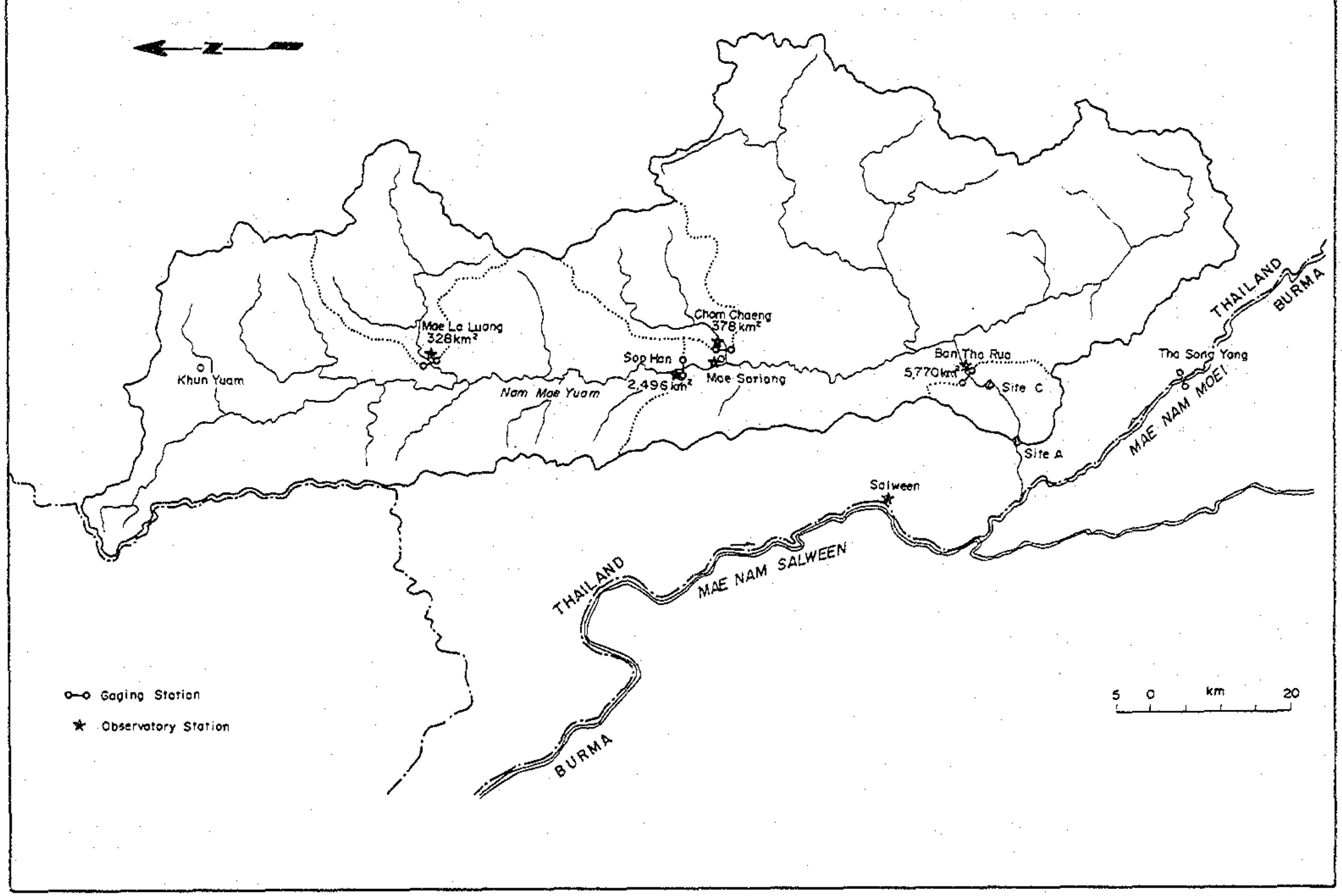


Fig. 3-2 Average of Monthly Precipitation

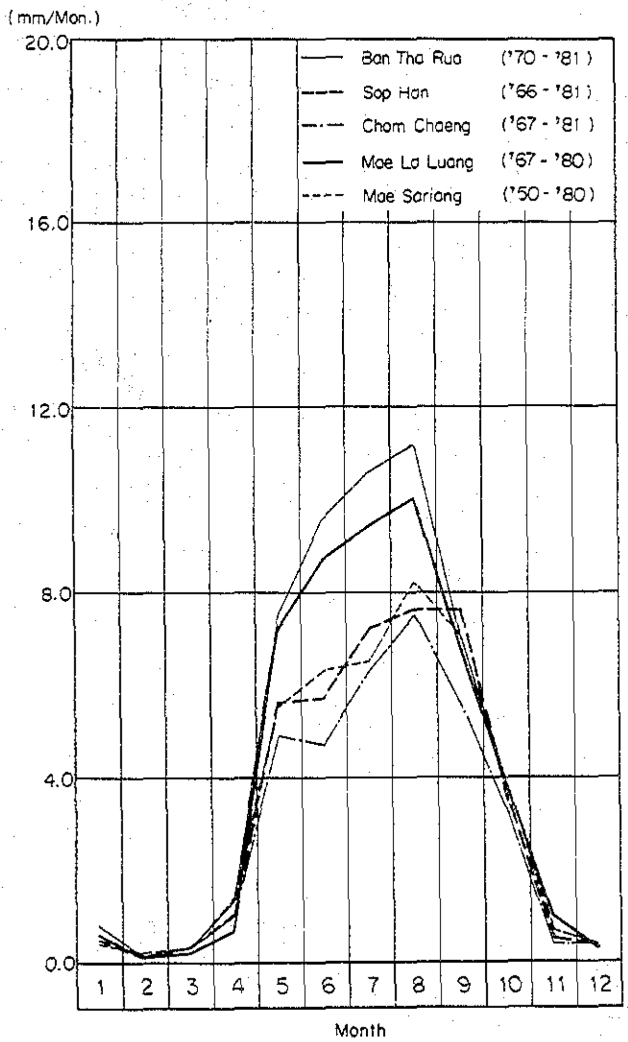


Fig. 3-4 Average of Monthly Temperature (Max. / Min.)

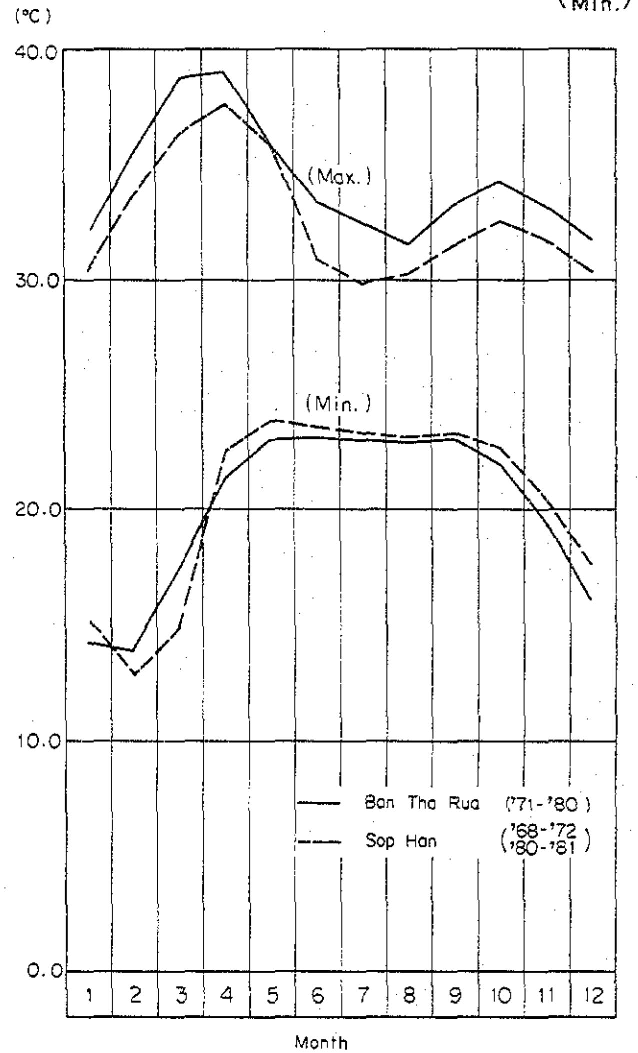


Fig. 3 − 3 Annual Total Precipitation

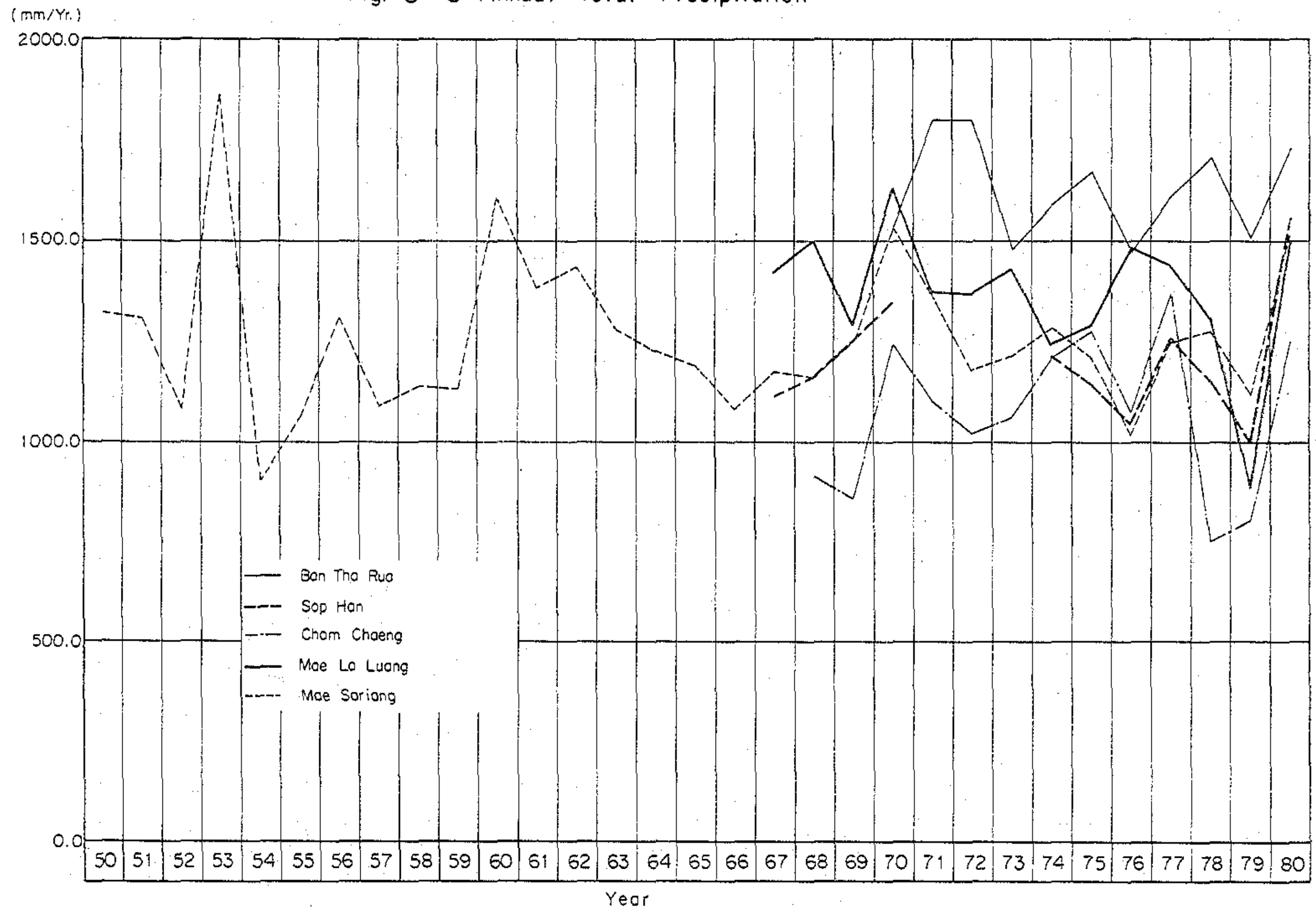


Fig. 3-5 Average of Monthly Relative Humidity

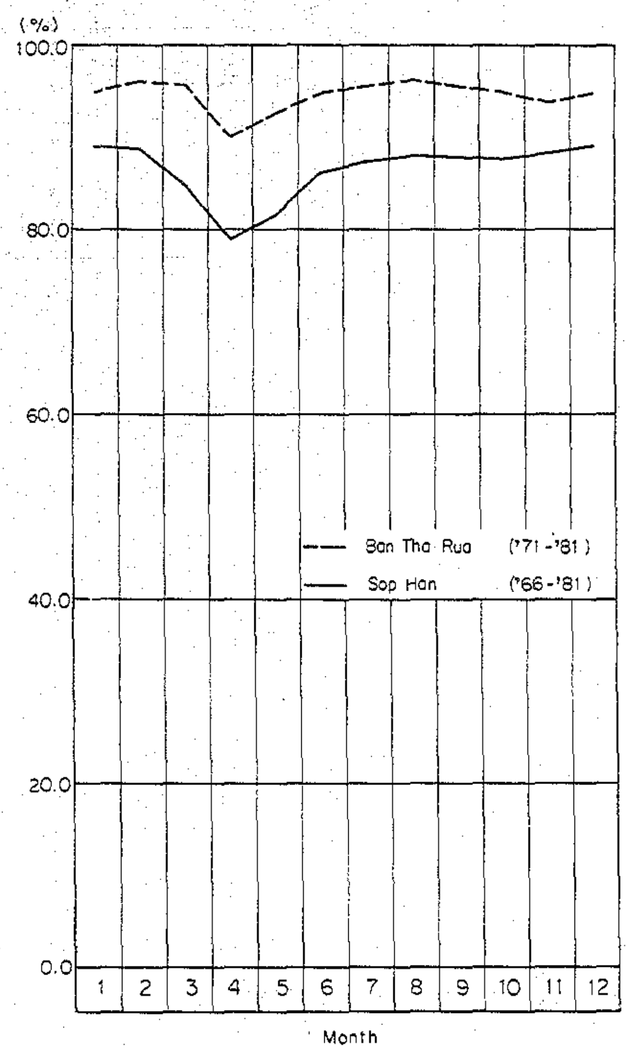


Fig. 3-6 Average of Monthly Evaporation

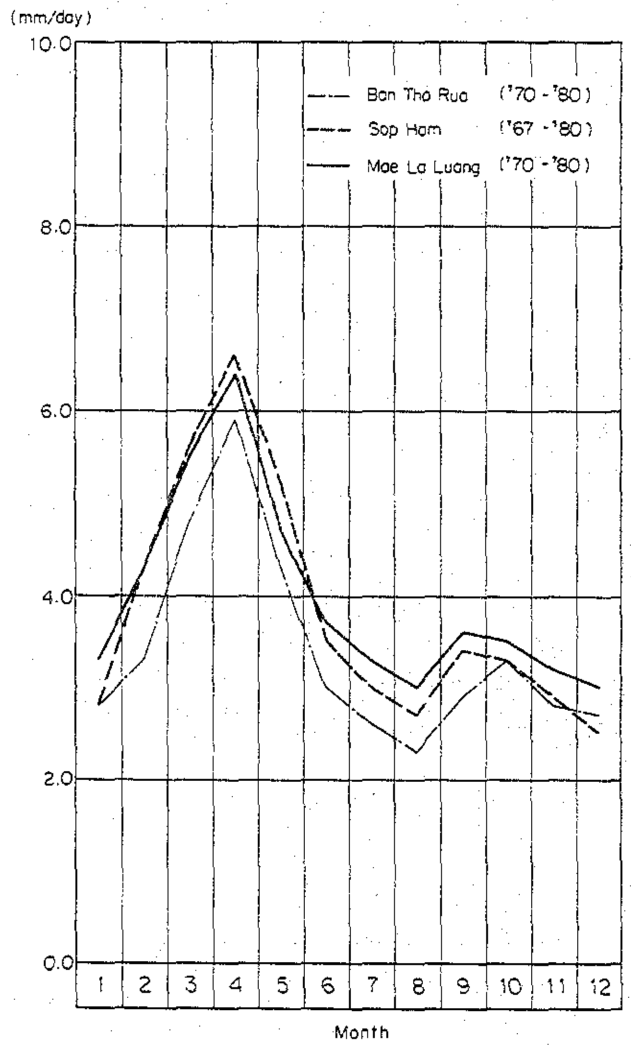


Fig. 3-7 Average of Monthly Runoff at Ban Tha Rua

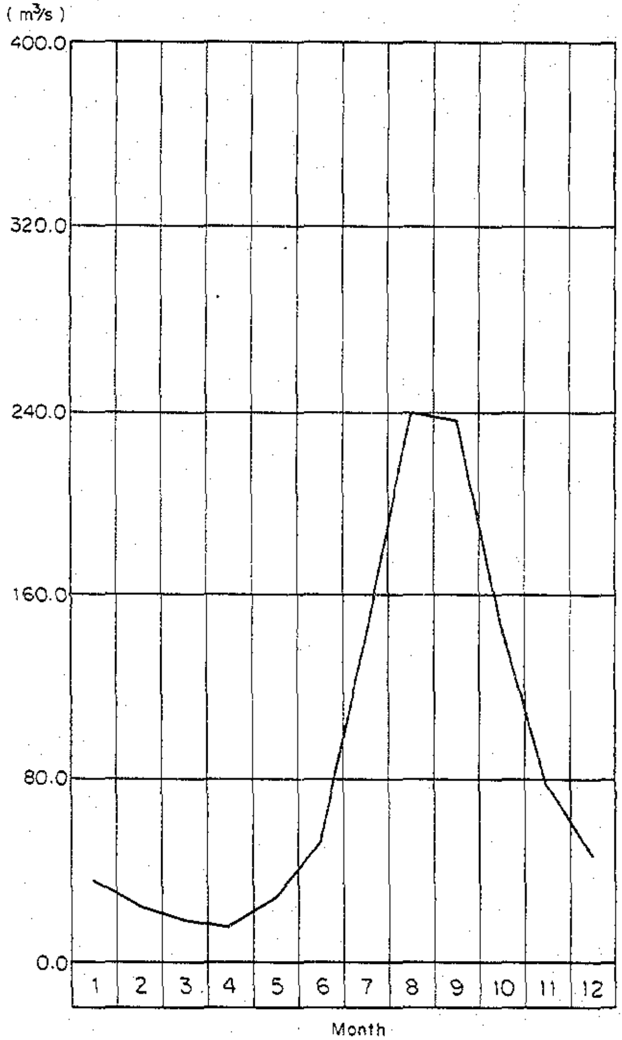


Fig.3-8 Annual Total Runoff at Ban Tha Rua

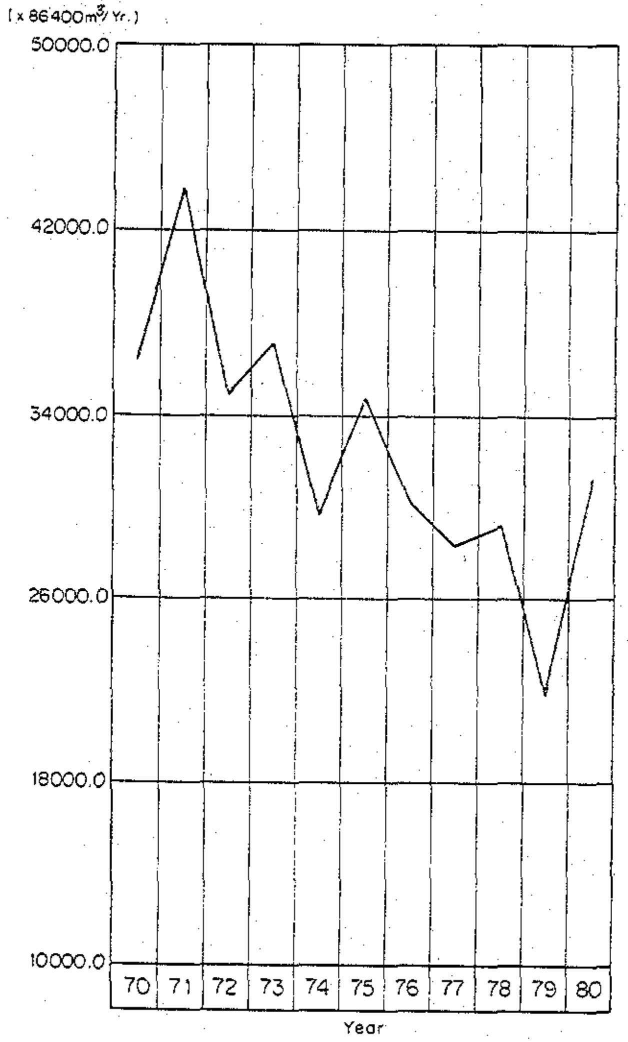
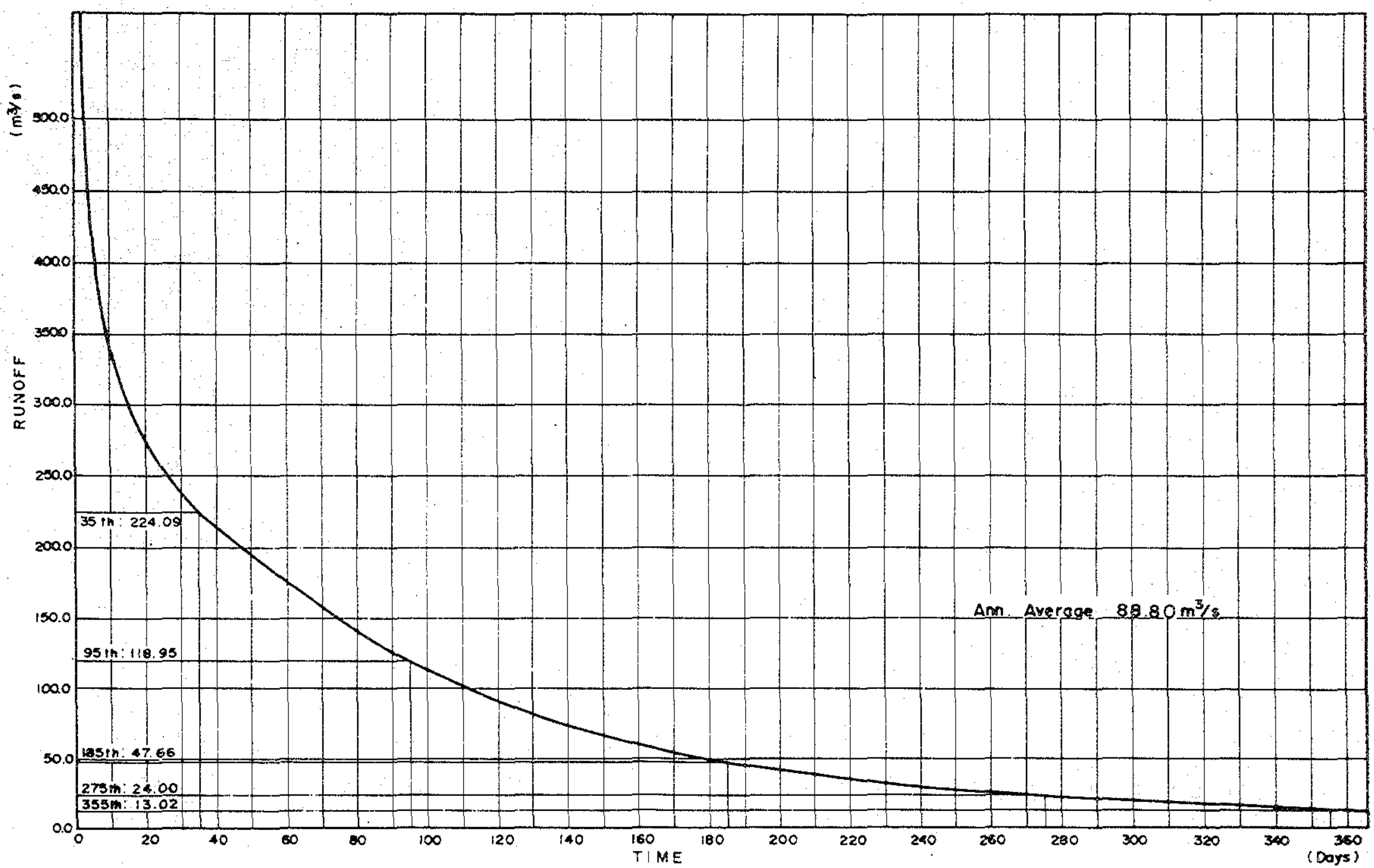


Fig. 3-9 Duration Curve of Nam Mae Yuam
at Ban Tha Rua G.S. (C.A. = 5,770 km^2)
Parallel Average of Racorded Period 1970 to 1980



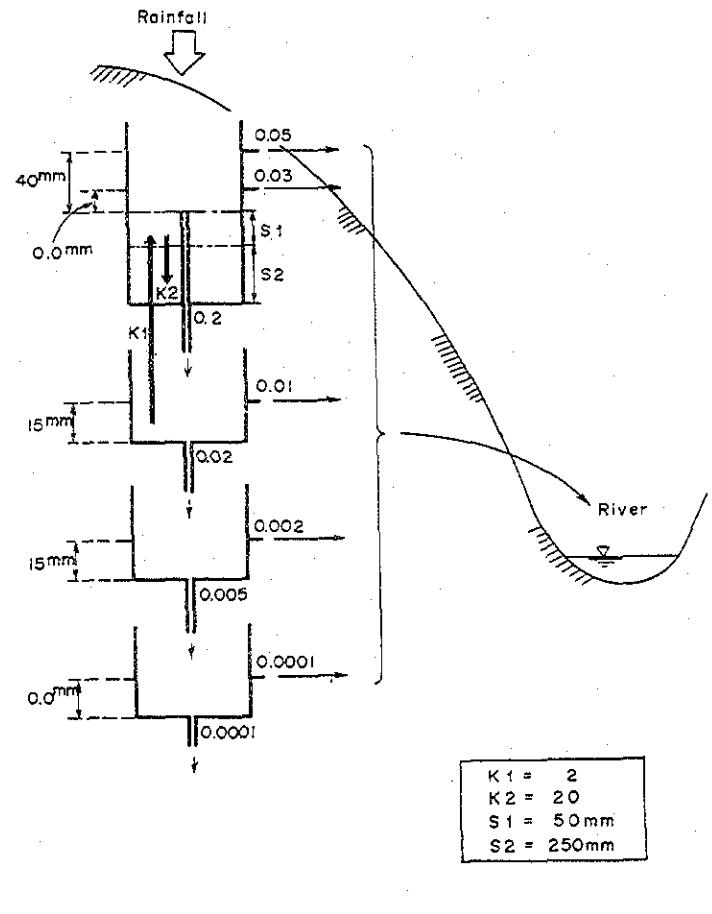


Fig. 3-10 Tank Model with Adopted Coefficients

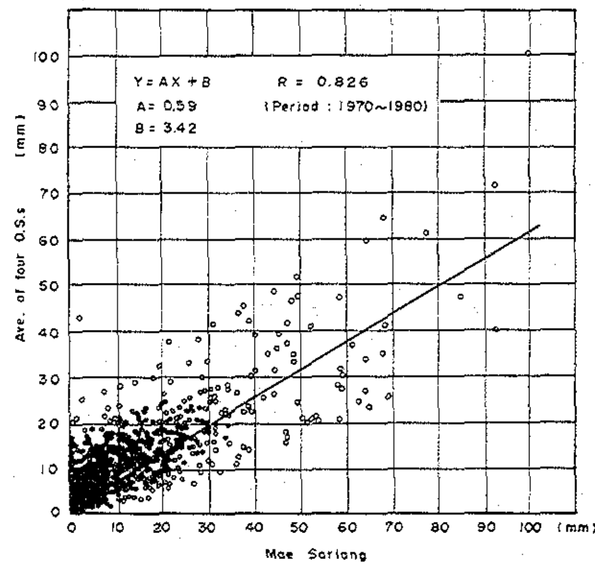


Fig. 3-11 Correlation of Daily Rainfall between Mae Sariang and Other four (4)-O.S.s (Ban Tha Rua, Sop Han, Chom Chaeng, Mae La Luang)

Fig. 3 - 12 Estimated and Observed Runoff of Yuam River

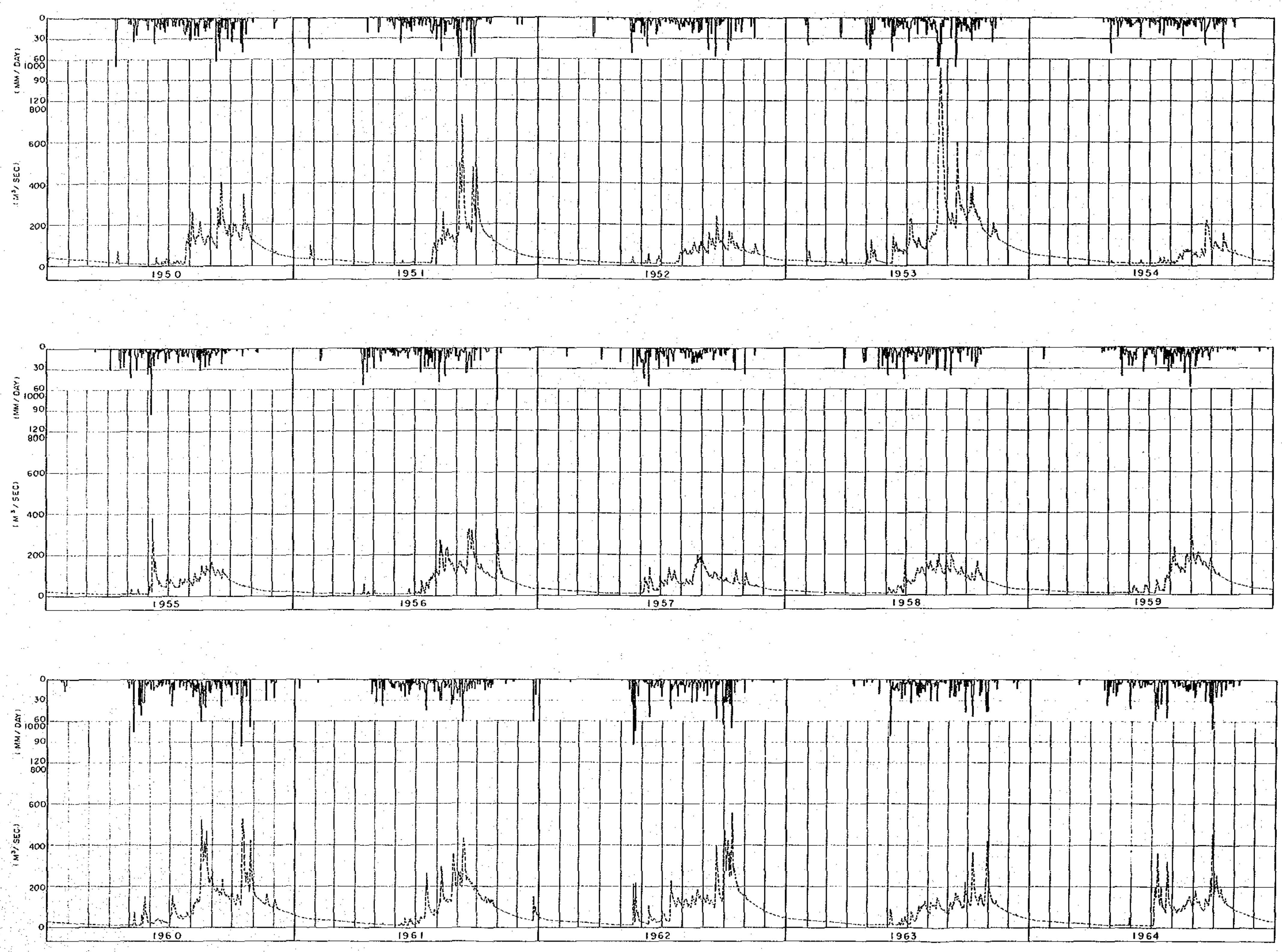


Fig. 3-12 Estimated and Observed Runoff of Yuam River (cont'd.)

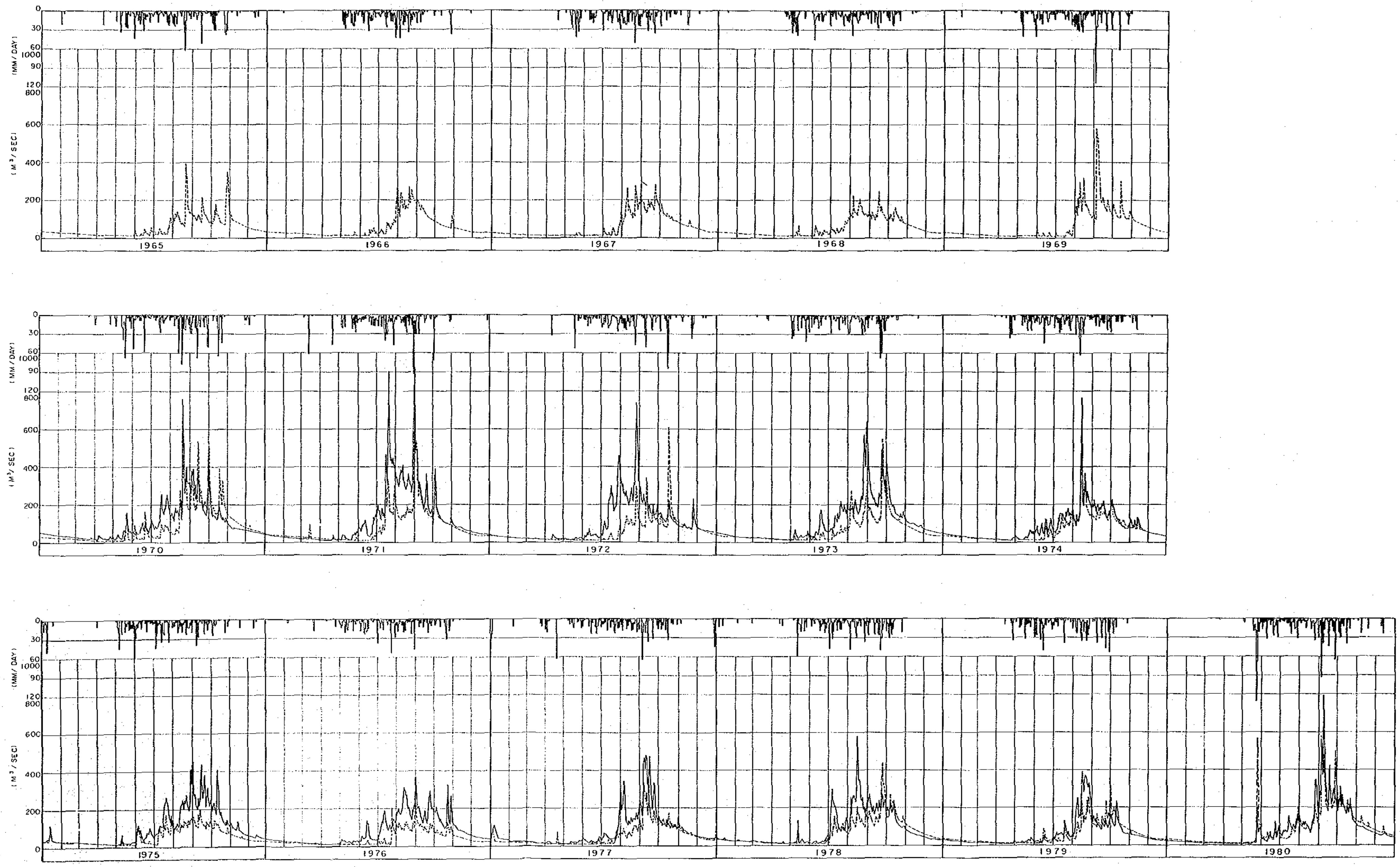


Fig. 3-13 Spectrum Analysis of Estimated Runoff

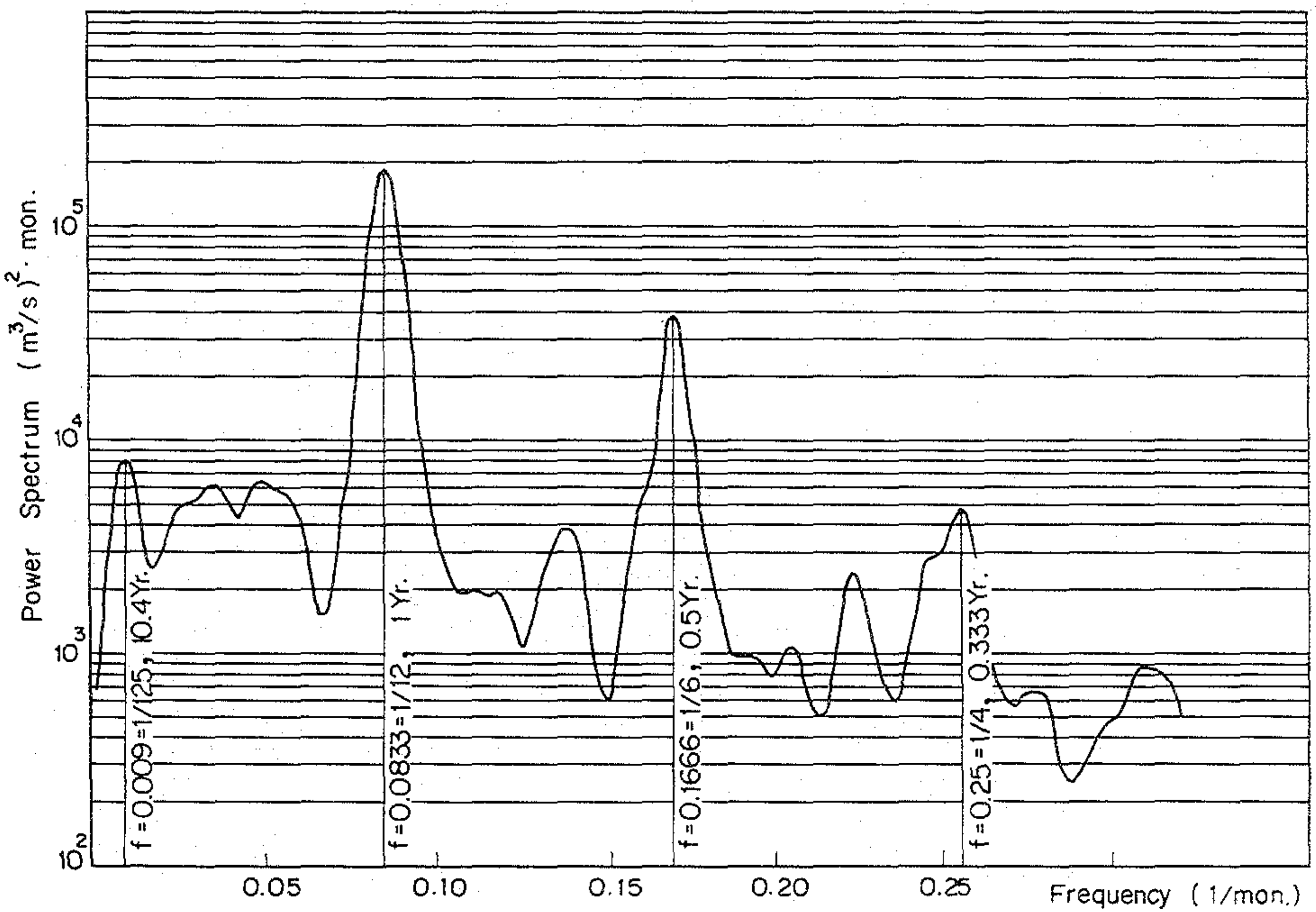
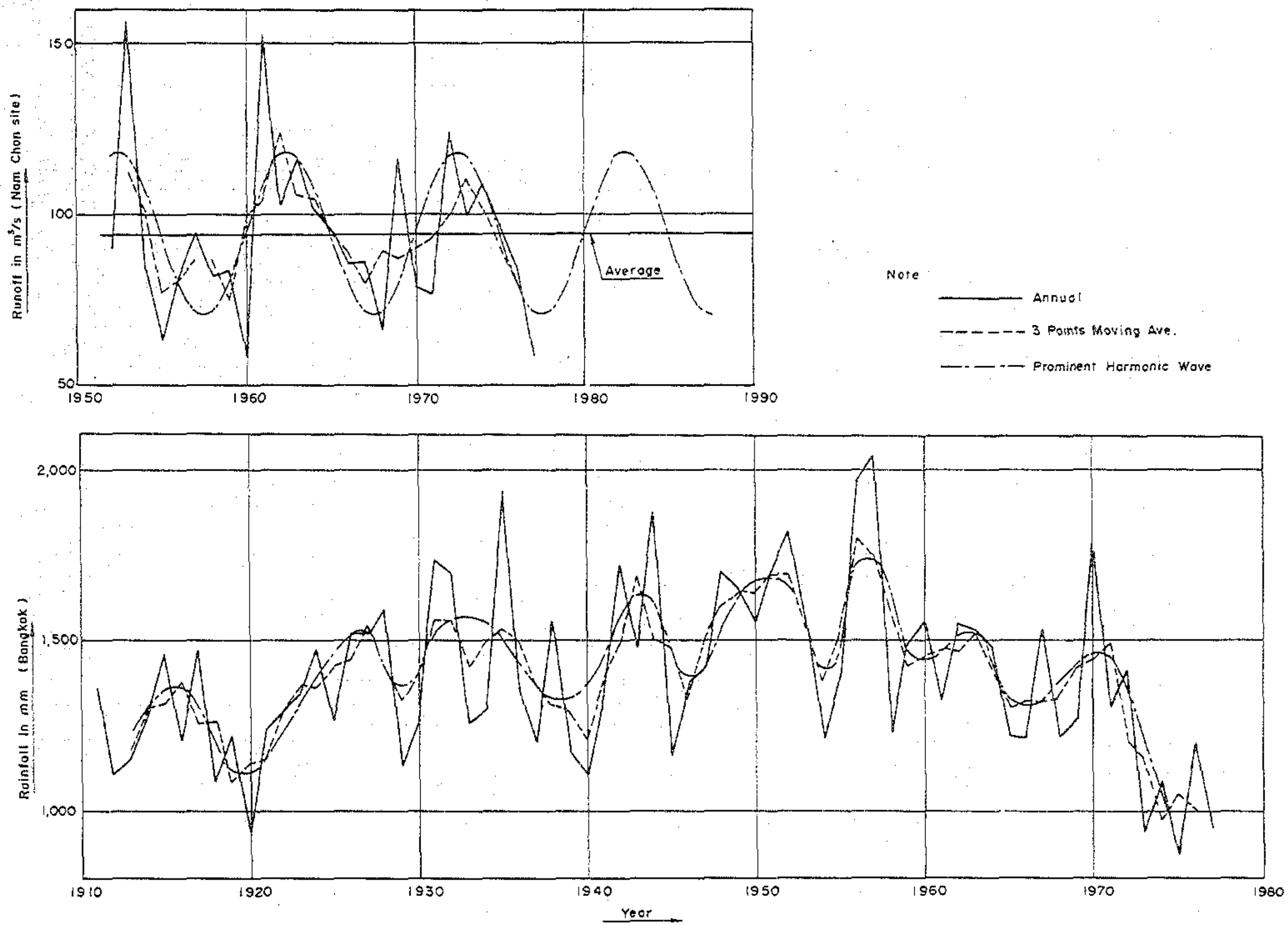


Fig. 3-14 Cycle of Runoff and Rainfall (3 Points Moving Average Method)



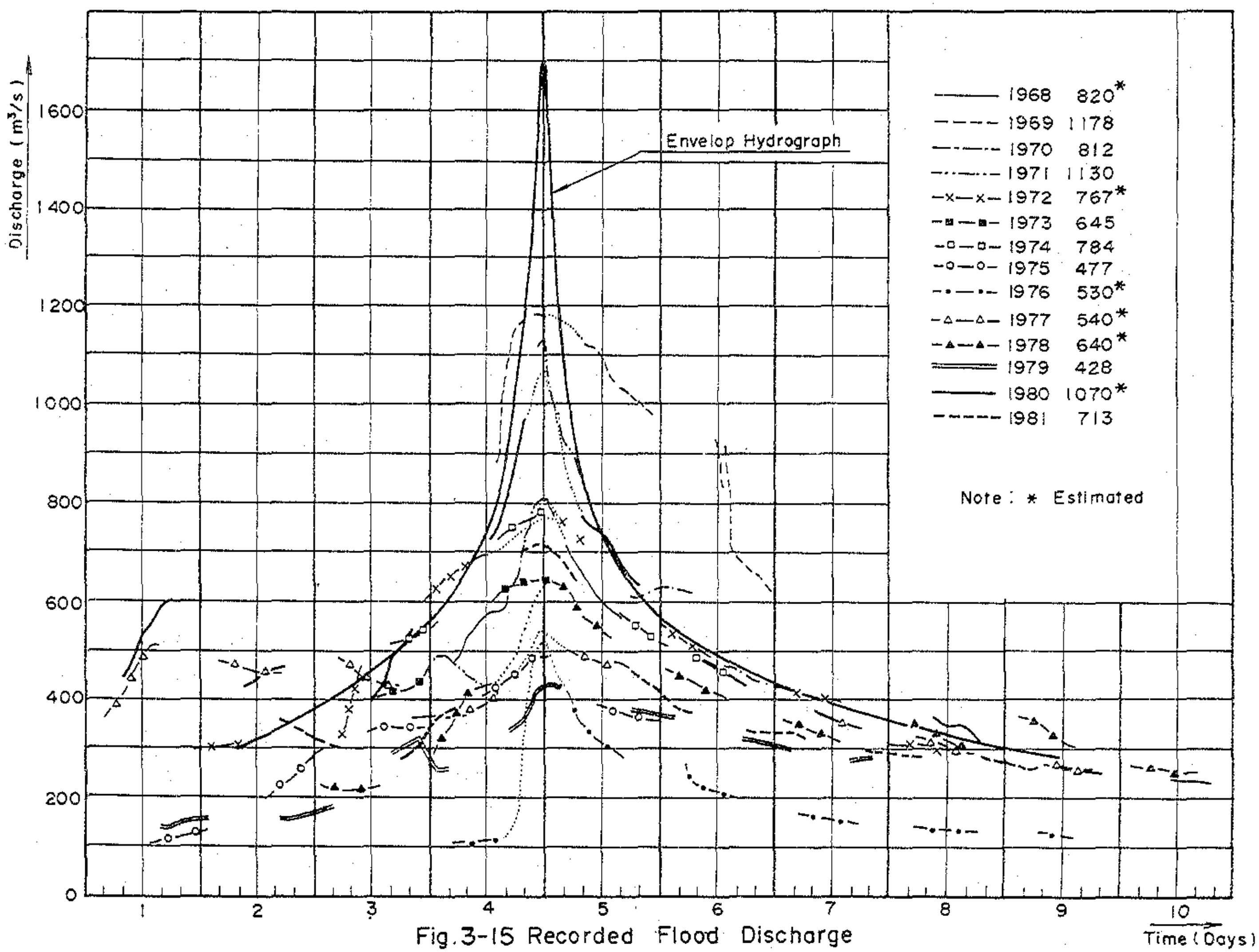


Fig.3-15 Recorded Flood Discharge

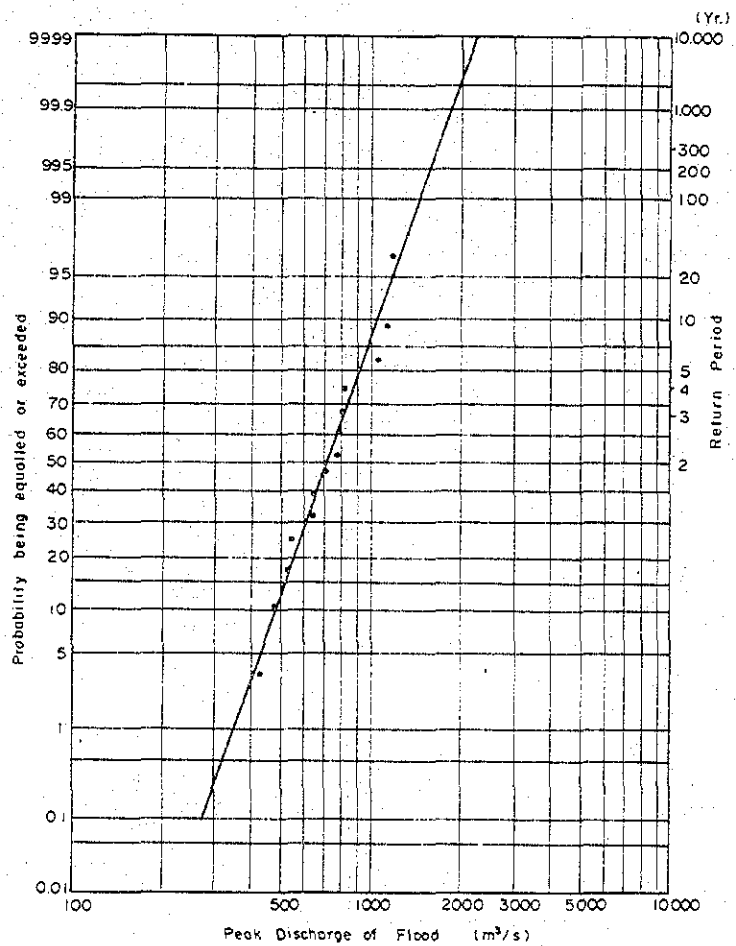


Fig. 3-16 Log Normal Distribution of Flood Peak

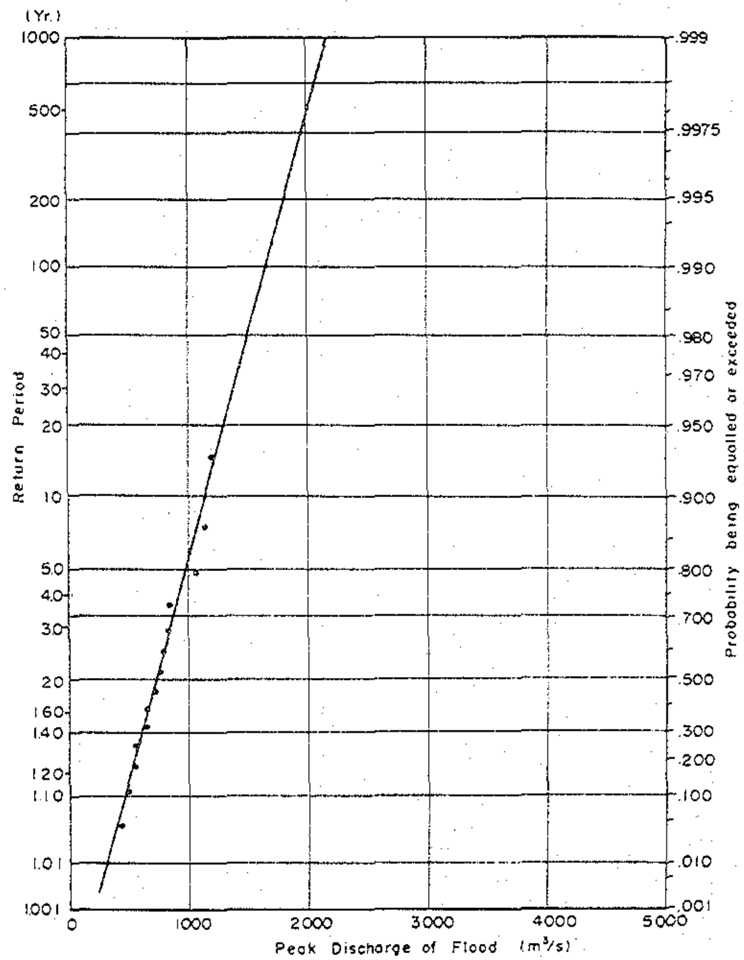
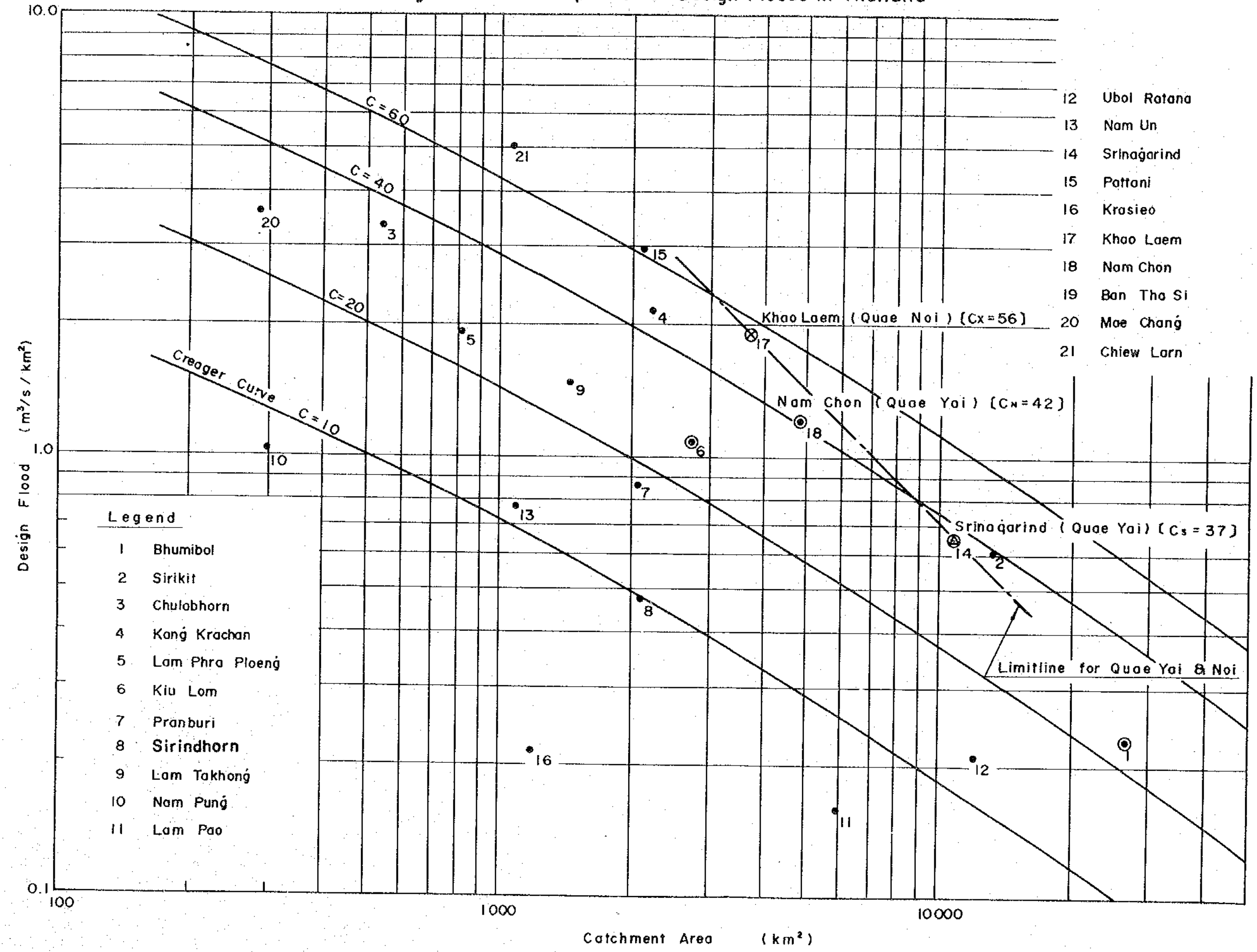
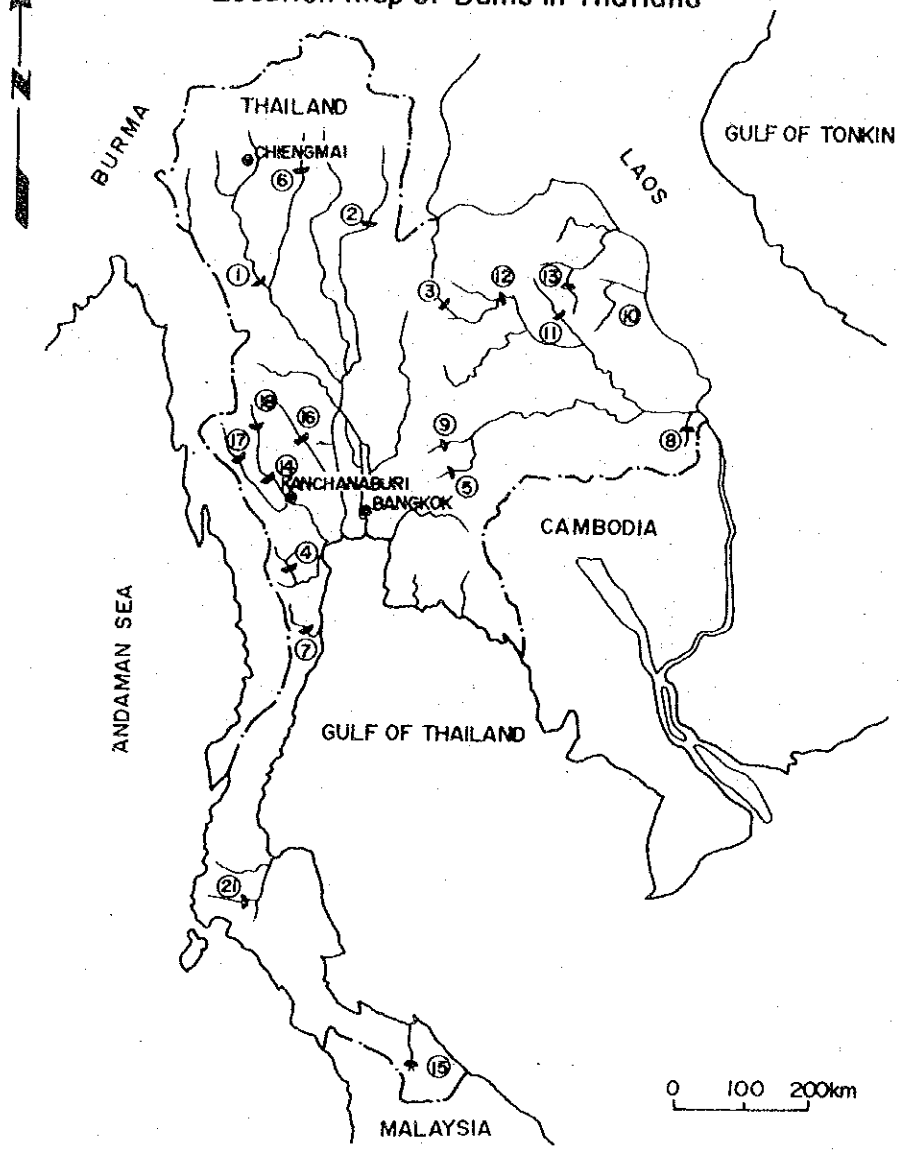


Fig. 3-17 Gumbel Distribution of Flood Peak

Fig. 3 - 18 Comparison of Design Floods in Thailand



Location Map of Dams in Thailand



Notes:

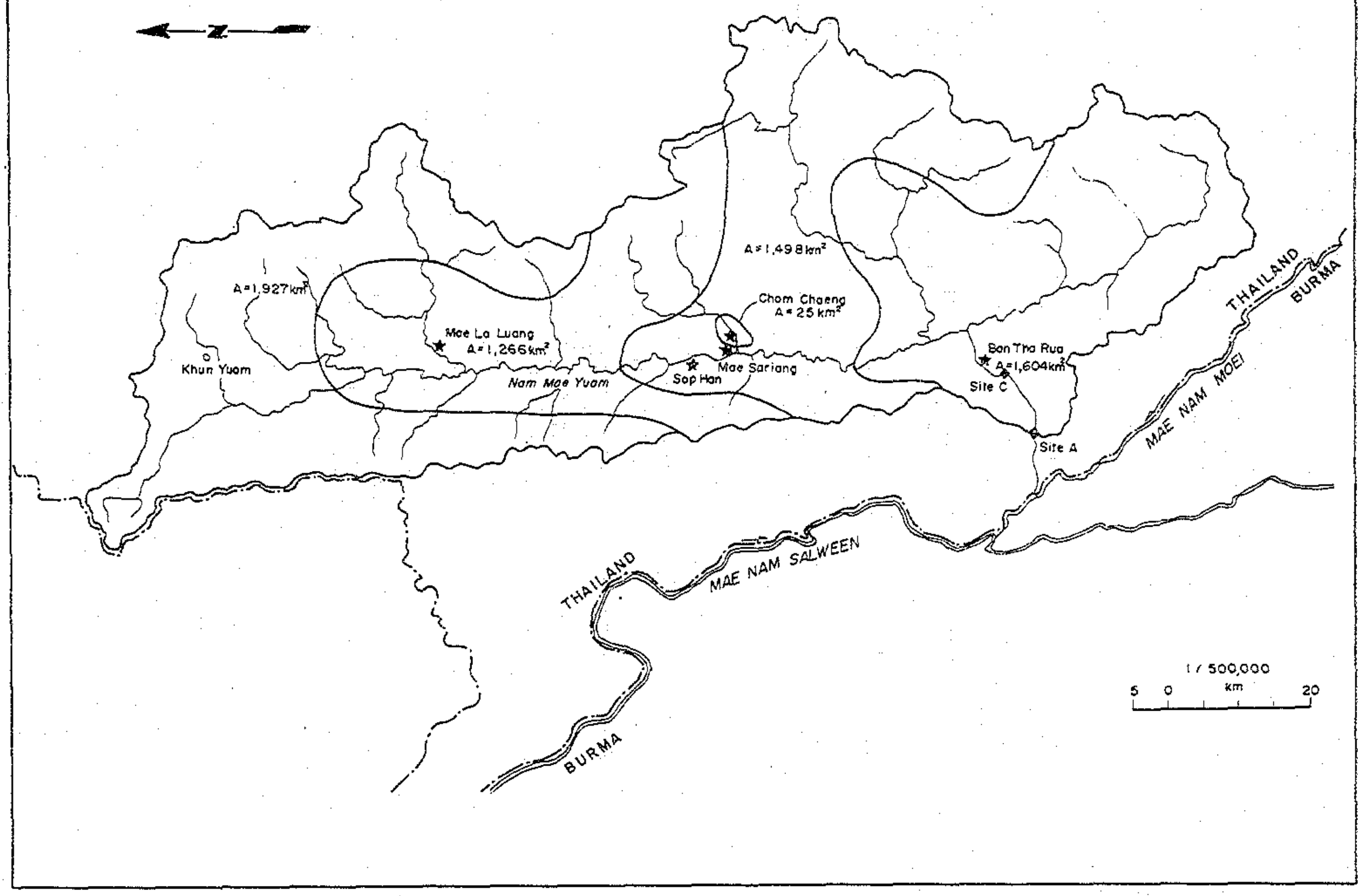
1. Creager's Eq.

(Unit in cfs-sq. Miles) $q = 46\ C.A^{(0.894 \cdot A^{-0.048} - 1)}$

(Unit in m³/s-sq. km) $q = 0.503 \cdot C.(0.3861 \cdot A)^{[0.894 \times (0.3861 \cdot A)^{-0.048} - 1]}$

2. Values in [ ] are Creager's coefficients C derived from Design PMF

Fig. 3-19 Hypothetical Isohyetal Map with Corresponding O. S.



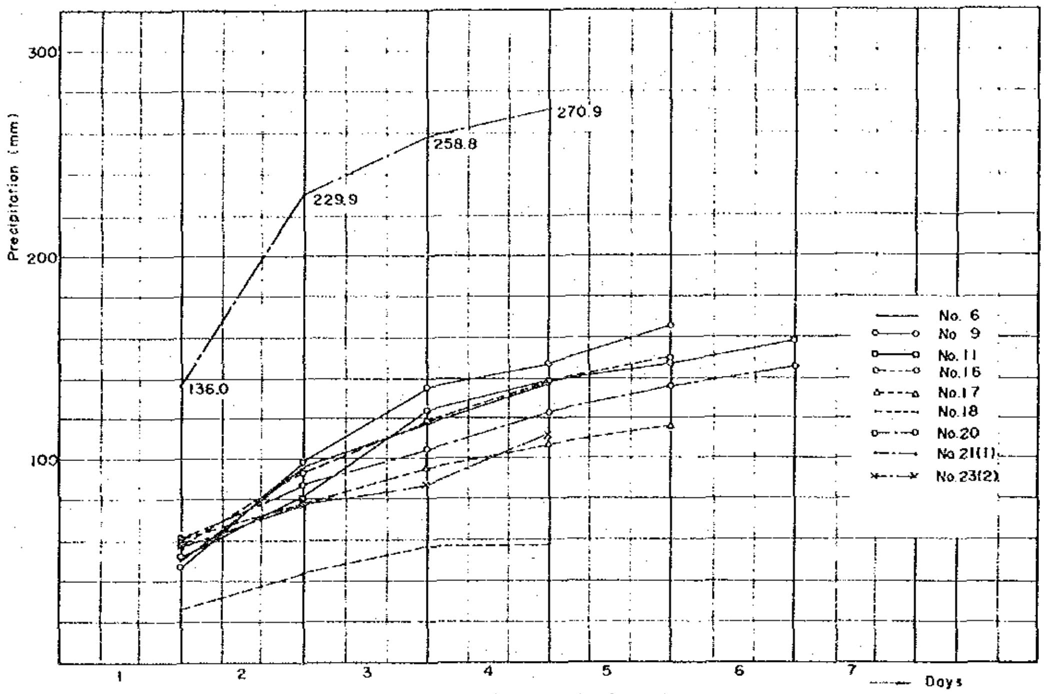


Fig.3-20 Maximised Precipitation of Storms

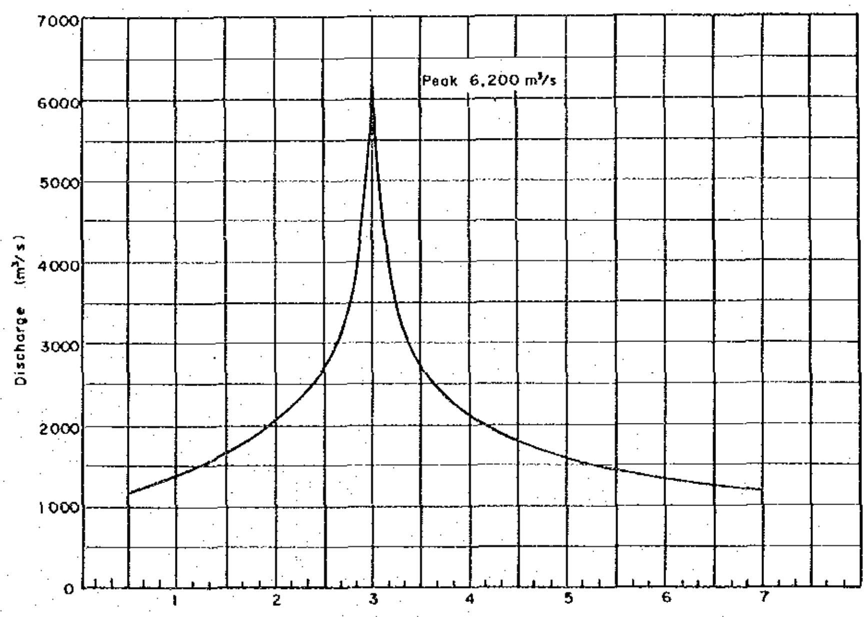


Fig.3-21 PMF Discharge

CHAPTER 4.

CONSTRUCTION MATERIALS

CHAPTER 4. CONSTRUCTION MATERIALS

4.1 Impervious Core Materials

Impervious core materials have been investigated at area A, B and C, which are located in the left bank 0.4km upstream, 0.7km upstream and in the right bank 0.8km downstream of the damsite A, respectively. The location of these areas are shown in Fig. 4-1.

The investigation has been made in these zones by digging thirteen test pits of 1m to 5m in depth. The results of the investigation revealed that materials distributed in these areas are talus deposits of calcareous sandstone and shale.

The material test has been carried out on samples collected at every one meter from the pits in every area, making physical tests and mechanical tests. Samples collected at eight pits including five pits (A-1 to A-5) in area A, one pit (B-1) in area B and two pits (C-1 and C-2) in area C, were tested by AIT (Asian Institute of Technology). On the other hand, samples collected in five pits including four pits (A-7 to A-10) in area A and one pit (C-6) in area C were tested at NEA (National Energy Administration). The location of test pits in every borrow area is given in Fig. 4-2.

1) Test items and quantity

Items and quantity of tests conducted for samples obtained at every one meter in pits digged in the bollow areas A, B and C are shown in tables below:

Test Items	Quantity			
	Area A	Area B	Area C	Total
Natural Water Content	26 (15)	2 (0)	11 (5)	39 (20)
Specific Gravity	26 (15)	2 (0)	11 (5)	39 (20)
Atterberg Limits	26 (15)	2 (0)	11 (5)	39 (20)
Maximum Grain Size	26 (15)	2 (0)	9 (5)	37 (20)
Compaction & Permeability	16 (8)	1 (0)	2 (0)	19 (8)
Strength	5 (0)	1 (0)	2 (0)	8 (0)

Note: The unit is the number of samples.
The figure in parentheses is the number of samples subject to tests conducted by NEA out of the total sample size.

2) Test results and consideration

The results of various tests conducted for samples collected in every meter in depth at every pit are shown in Table 4-1.

(i) According to the gradation analyses, the gradation of materials distributed in three areas A, B and C ranges from 19mm to 38mm in the maximum diameter, from 54% to 99% in the amount of particles passing the sieve of 4.75mm mesh and from 12% to 75% in the particle amount passing the sieve of 0.075mm, so that it is recognized finer grains are dominent for a construction material. The liquid limit (LL) is between 26.2% and 49.3%, the majority of which show 40% or so. The plasticity index (PI) is almost 10% to 20%. Such materials are classified to between clayey gravels (GC) and silty clays (CL) by Unified Soils Classification System.

(ii) The results of the compaction and permeability test indicate that the maximum dry density of the above-mentioned materials is within 1.580 to 1.990t/m^3 (for materials passing the 19.0mm sieve). The coefficient of permeability at that moment (which means that coefficient of permeability at the optimum water content) is within 7.9 x 10^{-5} to 3.1 x 10^{-8} cm/sec.

3) The angle of internal friction obtained by using the effective stress from the results of triaxial compression test is between 25.2° and 34.8°, while the adhesive strength is within 0.22 to 0.66kgf/cm^2.

In general, physical properties of a soil material depends largely upon the grain content of 0.075mm or less in the diameter. Therefore, seeing from this viewpoint, the following relations were extracted from the above-mentioned test results:

a) -0.075mm grain content ∿ Permeability
b) -0.075mm grain content ∿ Angle of Internal Friction
c) -0.075mm grain content ∿ Dry Density
d) Dry Density ∿ Angle of Internal Friction

The following correlations were obtained:

a) the permeability tends to reduce with increase of the -0.075mm grain content.
b) the dry density tends to reduce with increase of the -0.075mm grain content.
c) the dry density tends to reduce with increase of the -0.075mm grain content.
d) the angle of internal friction tends to increase with increase of the dry density.

From the above-mentioned results, the following can be considered:

(i) From the relation of the -0.075mm grain content and the permeability, it is required that the -0.075mm grain content is 35% or larger in order to assure the imperviousness of 1 x 10^{-5}cm/sec of the material. However, studying the relation between the -0.075mm grain content and the permeability in detail, it is found that the permeability varies according to an organization having performed the tests. For example, the permeability obtained by AIT for the material which has -0.075mm grain content of 44% to 75% ranges 7.9 x 10^{-5} to 3.2 x 10^{-6}cm/sec, while that obtained by NEA does 3.4 x 10^{-7} to 3.1 x 10^{-8}cm/sec. In other words there is the descrepancy of one or two order between these test results. Presuming from the test data obtained in NEA, the permeability of 1 x 10^{-5}cm/sec or so could be obtained even when the -0.075mm grain content is 25% to 30%. It is, thus, needed to carry out in the future the confirmation of permeability coefficient for further definite study.

(ii) Impervious core materials in general have a higher imperviousness in terms of permeability coefficient when the soil contains more fine particles, but taking into account the settling due to consolidation, strength, workability, etc., it is favored to use coarser soils within permissible imperviousness. Therefore, it is desirable to lay the materials temporarily in order to make the material quality uniform, and thus to improve the workability and other materials quality.

(iii) Outline of estimated available quantity of materials

According to the above-mentioned test results, rough amounts of the available core volume in areas are estimated as follows:

Area A; approximately 80,000m^3

Area B; approximately 60,000m^3

As seen above, the rough figure of available volume of impervious core materials is at present about 140,000m^3, but this figure could be increased through the process of piling. However, some lack of core materials is still foresseable to meet the whole of required amounts, so that enlargement of investigation areas is necessary for further study.

4.2 Rocks and Filter Materials

The quarry sites providing rock material have been investigated on both the banks of the Huai Uya Kra river which is the branch of the Nam Mae Yuam river flowing into the dam from the left bank at about 700m up-stream from the damsite. Rocks contained in these areas are calcareous sandstones and limestones, and the results of surface survey indicates that of good-quality materials is possibly available. On the other hand, filter materials are required to be artificially produced from materials collected in quarry sites, since bed material in the river, which has appropriate gradation, is not available around the damsite. The investigated areas are given in Fig. 4-1.

4.3 Concrete Aggregates

Since concrete aggregates, like filter materials, cannot be found as the natural material near the damsite, it is planned to produce them artificially.

4.4 Recommendation of Additional Survey

Based on results of surveys and tests conducted so far the following investigations and tests are conceived necessary for implementing further detailed design:

1) Impervious core materials

Since the relation between gradation and permeability coefficient had not been clearly grasped from the test data acquired so far, only the rough figures of the quantity have been now estimated. Therefore, through additional tests, it is required that the relation between gradation and permeability be more clearly known, so that the lower limit of gradation meeting the design permeability is determined and the more accurate collectable amounts are worked out.

(i) Additional investigation areas and the quantity

Since the rough figure of the presently-estimated available amount does not likely meet the whole quantity of impervious core materials, enlargement of investigation areas is required. The additional investigation is supposed to be impremented in borrow areas A and B surveyed this time and in borrow area D (located about 2.3km downstream of the damsite, on the left bank of the Huai Mae Lama Luang river, the branch of the Nam Nae Yuam river) which has been newly selected through the field investigation, and test pits are planned in these areas, which are located as indicated in Figs. 4-1 and 4-2. The sampling quantity is as follows:

Investigation Area	Digging Depth	Pit Number	Digging Depth in Total
Area A	5m	2	10m
Area B	5m	7	35m
Area D	5m	12	60m

(ii) Test items and quantity

Sampling specimens in every one meter in depth from the additional test pits, physical tests should be made. At the same time, both physical and dynamic test should be carried out for representative specimens at each test pit.

The objective of tests of representative specimens is to know the standard quality of materials contained in the areas under survey. In other words, it aims at finding the relation between physical and dynamic properties of materials. Accordingly, materials involved in these areas should be classified into three groups corresponding to the -0.075mm grain content and three representative specimens should be obtained in every group. The three groups referred to here should be as follows:

a) Fine grain materials; the -0.075mm content is 40% or more
b) Medium grain materials; the -0.075mm content is 20% or more and less than 40%.
c) Coarse grain materials; the -0.075mm content is less than 20%.

Test items and the quantity of representative specimens involved in physical and dynamic tests are given in the following table.

	ITEMS	Area A		Area B			Area D			TOTAL	STANDARDS
		MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE		
Physical Tests	Water Content	2	1	2	2	2	3	3	3	18	ASTM D2216
	Specific Gravity Water Absorption	2	1	2	2	2	3	3	3	18	ASTM D854, C127
	Gradation	2	1	2	2	2	3	3	3	18	ASTM D422
	Liquid L.	2	1	2	2	2	3	3	3	18	ASTM D423
	Plast. L.	2	1	2	2	2	3	3	3	18	ASTM D424
Dynamic Tests	Compaction	2	1	2	2	2	3	3	3	18	Note 1
	Permeability	2	1	2	2	2	3	3	3	18	Note 2
	3-ax. Compaction	1	1	1	2	1	2	2	2	12	Note 3

Note 1: It should be conducted according to ASTM D698 Method C, provided that the specimen once employed for test cannot be used again. The test should be normally conducted for five water contents per specimen.

Note 2: It should be carried out by the falling-head permeability test, and for specimens produced in the compaction test.

Note 3: Isotropic consolidated-undrained triaxial test (CIU) associating measurement of the pore water pressure should be made. The shearing method at this occasion is conducted by the strain control method. The water content of the speciment under test takes the optimum water content obtained by the compaction test.

2) Rock and filter materials

As for the rock and filter materials, no tests have been conducted so far. Investigations and tests necessary for further study are considered as follows:

First, test boring should be performed in the area to be investigated and the boring core obtained should be examined. When they will reveal the area good for quarry site, test adits should be provided so as to collect samples and to conduct various tests.

The number of test boring and test adit are as follows:

Test borings; eight holes (The location is shown in Fig. 4-1)
Test adits; four adits (The detail is determined from the results of test borings.)

The test items to be carried out on specimens obtained from the test adits are as follows:

Test Items	Filter Material	Rock Material
Specific gravity and Water absorption	○	○
Gradation	○	○
Large-size compaction	○	○
Large-size permeability	○	——
Large-size triaxial compression	○	○

The marking "○" denotes the test to be conducted.

3) Concrete aggregates

The tests to be conducted for concrete aggregates are as follows: First, the crashing test should be conducted for aggregates of the maximum diameter (80mm), and the following tests should be made for specimens thereby.

- o Specific gravity and water absorption (for fine and coarse aggregates)
- o Gradation (for fine and coarse aggregates)
- o Abrasion (for coarse aggregates)
- o Stability (for fine and coarse aggregates)
- o Alkahli reaction (for fine aggregates)
- o Compression

In addition to the above tests, mixing test is desirable.

Table 4-1 Result of Soil Tests

Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PL (%)	Atterberg Limits PI	Gradation Analyses Maximum Grain Size (mm)	-38.1 mm (%)	-19.1 mm (%)	-4.75 mm (%)	-0.425 mm (%)	-0.075 mm (%)	-0.005 mm (%)	Compaction & Permeability Optimum Water Content (%)	Maximum Dry Density (t/m³)	Coefficient of Permeability (cm/sec)	Triaxial Compression Strength ($\overline{CIU}$) Total Stress C (kgf/cm²)	Total Stress ø (deg.)	Effective Stress $\overline{C}$ (kgf/cm²)	Effective Stress $\overline{ø}$ (deg.)
A-1	1	SC	2.688	8.8	28.6	18.5	10.1	25	100	97	86	48	45	30	13.0	1.850	7.9×10^{-5}	0	27.8	0.48	33.8
A-2	1	SC	2.832	14.0	39.0	23.3	15.7	19	100	100	75	50	44	19	18.2	1.695	3.2×10^{-6}	—	—	—	—
	2	ML	2.788	16.9	39.2	27.0	12.2	25	100	99	93	66	56	22	—	—	—	—	—	—	—
	3	SC	2.841	18.6	38.2	22.9	15.3	25	100	97	91	61	47	18	15.7	1.710	4.4×10^{-6}	1.10	18.4	0.56	26.4
	4	CL	2.826	22.1	43.0	23.7	19.3	19	100	100	84	64	58	23	22.4	1.580	6.7×10^{-6}	—	—	—	—
	5	CL	2.839	24.0	40.9	22.8	18.1	25	100	96	94	74	64	27	22.5	1.585	6.3×10^{-6}	1.00	18.8	0.66	25.5
A-3	1	GC	2.733	10.8	41.2	23.0	18.2	38	100	91	65	39	35	21	—	—	—	—	—	—	—
	2	GC	2.734	10.3	40.8	23.6	17.2	38	100	92	59	35	30	18	12.8	1.930	1.7×10^{-5}	1.00	19.7	0.36	33.8
A-4	1	GC	2.660	8.6	26.2	17.2	9.0	25	100	96	54	25	20	13	—	—	—	—	—	—	—
A-5	1	SC	2.687	9.0	35.2	23.5	11.7	25	100	97	74	48	45	24	—	—	—	—	—	—	—
	2	GC	2.720	8.3	32.8	21.9	10.9	25	100	96	63	31	26	17	11.7	1.990	6.5×10^{-5}	0.67	27.2	0.37	34.8
A-7	1	CL	2.694	25.6	49.3	25.8	23.5				90	78	74		—	—	—		—	—	—
	2	ML	2.612	18.6	40.4	26.2	14.2				84	61	56		15.6	1.762	3.9×10^{-7}	(15.4)	—	—	—
	3	ML	2.656	13.5	44.8	28.5	16.3				—	62	52		17.2	1.757	1.1×10^{-7}	(18.9)	—	—	—
A-8	1	GC	2.773	27.6	38.2	24.1	14.1				73	53	48		—	—	—	—	—	—	—
	2	SM	2.779	24.0	39.1	24.0	15.1				82	54	46		13.4	1.807	3.4×10^{-7}	(14.6)	—	—	—
	3	SC	2.752	10.0	37.0	23.8	13.2				79	55	50		14.8	1.803	2.6×10^{7}	(14.4)	—	—	—
A-9	1	CL	2.709	19.6	33.4	20.1	13.3				83	75	59		—	—	—	—	—	—	—
	2	CL	2.684	15.1	37.9	22.0	15.9				88	64	51		13.8	1.845	1.6×10^{-7}	(14.0)	—	—	—
	3	CL	2.752	24.2	44.2	26.4	17.8				83	66	58		—	—	—	—	—	—	—
	4	CL	2.669	21.9	44.7	23.8	20.9				88	72	65		16.8	1.762	1.4×10^{-7}	(15.8)	—	—	—
A-10	1	CL	2.610	19.1	36.5	20.8	15.7				82	62	54		—	—	—	—	—	—	—
	2	CL	2.628	29.1	38.2	21.2	17.0								—	—	—	—	—	—	—
	3	CL	2.758	25.7	37.9	21.5	16.4				95	83	71		16.1	1.779	3.1×10^{-8}	(17.1)	—	—	—
	4	CL	2.662	18.6	39.6	21.2	18.4				99	87	75		—	—	—	—	—	—	—
	5	CL	2.788	20.6	39.0	21.0	18.0				95	81	69		15.8	1.782	8.9×10^{-8}	(16.8)	—	—	—

Table 4-1 Result of Soil Tests (cont'd.)

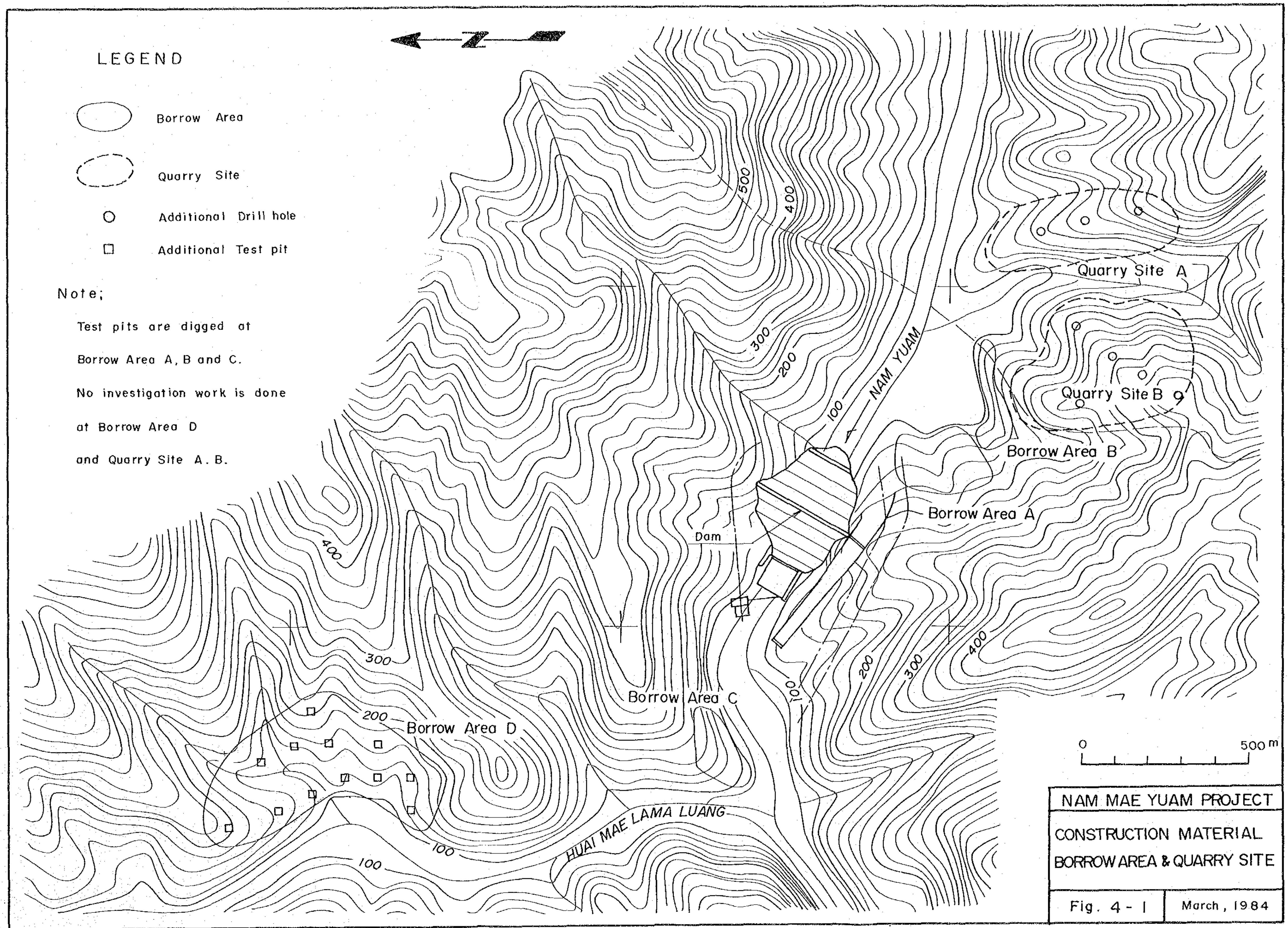
Sample No.	Depth (m)	Classification of Soils by Unified System	Specific Gravity	Natural Water Content (%)	Atterberg Limits LL (%)	Atterberg Limits PL (%)	Atterberg Limits PI	Gradation Analyses: Maximum Grain Size (mm)	-38.1 mm (%)	-19.1 mm (%)	-4.75 mm (%)	-0.425 mm (%)	-0.075 mm (%)	-0.005 mm (%)	Compaction & Permeability: Optimum Water Content (%)	Maximum Dry Density (t/m³)	Coefficient of Permeability (cm/sec)	Triaxial Compression Strength ($\overline{CIU}$) Total Stress: c (kgf/cm²)	Total Stress: φ (deg.)	Effective Stress: c (kgf/cm²)	Effective Stress: φ (deg.)
B-1	1	CL	2.763	19.3	38.8	24.3	14.5	25	100	97	88	77	68	33	—	—	—	—	—	—	—
	2	CL	2.741	20.5	39.5	23.5	16.0	38	100	87	73	62	53	27	16.8	1.680	7.1×10^{-7}	0.42	19.2	0.22	26.7
C-1	1	CL	2.794	19.4	43.6	24.1	19.5	19	100	100	79	64	61	39	—	—	—	—	—	—	—
	2	CL	2.748	13.9	40.9	22.6	18.3	38	100	84	66	54	50	27	—	—	—	—	—	—	—
	3	GC	2.795	15.4	42.4	22.4	20.0	38	100	86	69	53	48	34	16.2	1.808	6.5×10^{-7}	0.62	17.4	0.33	25.2
	4	CL	2.852	16.2	41.2	21.1	20.1	38	100	88	69	55	51	33	16.9	1.810	1.2×10^{-5}	0.42	14.0	0.28	26.8
C-2	1		2.729	8.4	—	NP	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2		2.711	19.2	—	NP	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C-6	1	SF	2.667	25.5	—	NP	—				99	95	20		—	—	—	—	—	—	—
	2	SF	2.580	6.5	—	NP	—				99	93	40		—	—	—	—	—	—	—
	3	S-F	2.647	24.0	—	NP	—				—	94	12		16.6	1.630	—	—	—	—	—
	4	SF	2.646	23.0	—	NP	—					78	30		—	—	—	—	—	—	—
	5	S-F	2.682	18.0	—	NP	—				76	53	13		11.5	1.849	—	—	—	—	—

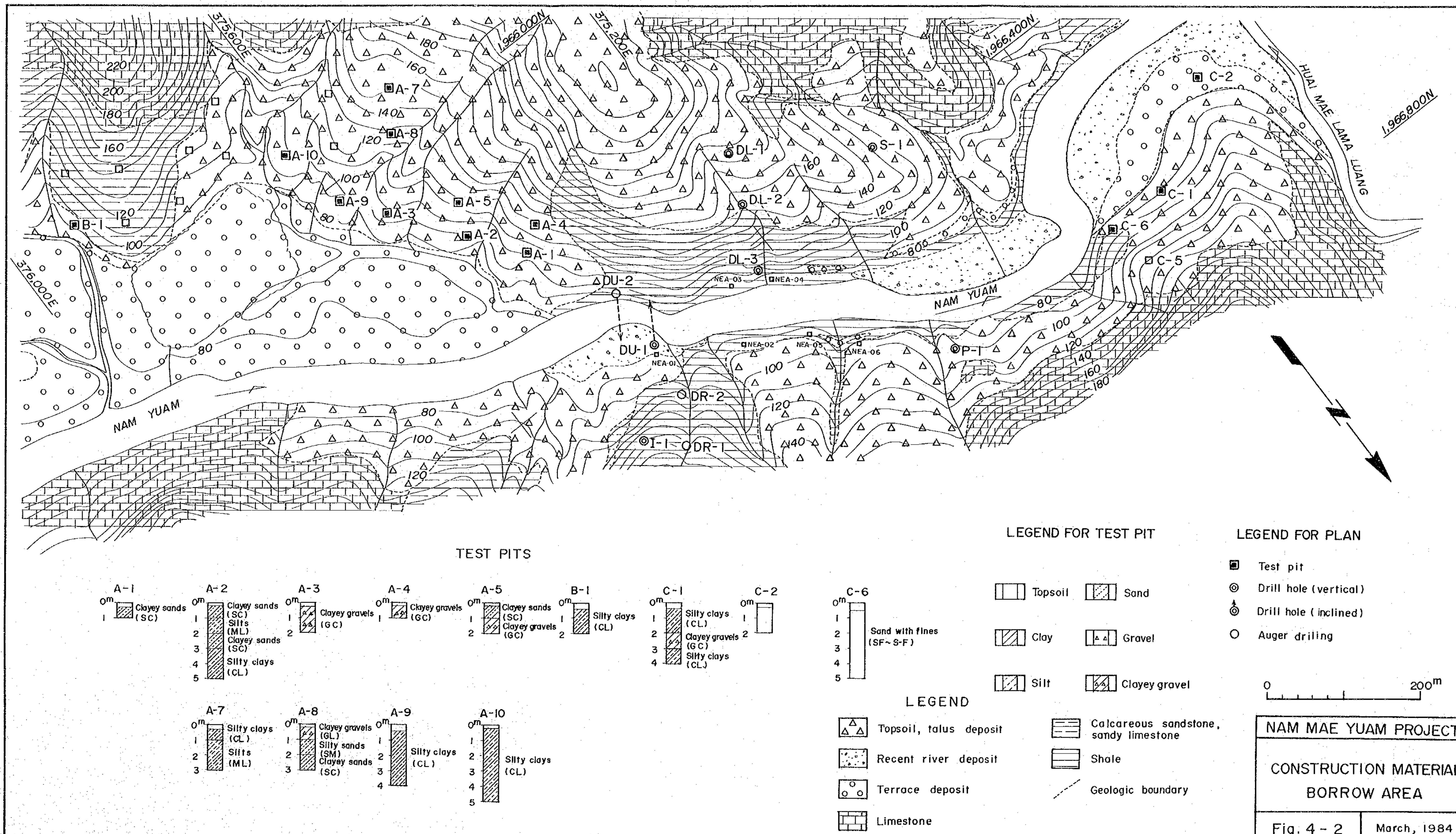
Remarks ; * The specimens for triaxial compression test were compacted to the maximum dry density at the optimum water contents.

* Cocfficient of permeability is the one at optimum water content.

* The coefficient of Permeability of the samples taken from test pits A-7 ~ 10, which were tested by NEA, were determined at only one water content. The water contents are shown in parentheses in right side of coefficient of Permeability.

* On the sample taken from the test pit. A-4 1.00m, the zero-air-void curve dose not coordinate with the test result of its compaction and permeability test. So the result is deleted from this table.


LEGEND
Borrow Area
Quarry Site
Additional Drill hole
Additional Test pit
Note;
Test pits are digged at
Borrow Area A, B and C.
No investigation work is done
at Borrow Area D
and Quarry Site A. B.
N
Quarry Site A
Quarry Site B
Borrow Area B
Borrow Area A
Borrow Area C
Borrow Area D
Dam
NAM YUAM
HUAI MAE LAMA LUANG
500
400
300
200
100
0
500 m
NAM MAE YUAM PROJECT
CONSTRUCTION MATERIAL
BORROW AREA & QUARRY SITE
Fig. 4 - 1
March, 1984



NAM MAE YUAM PROJECT

CONSTRUCTION MATERIAL BORROW AREA

Fig. 4 - 2 March, 1984

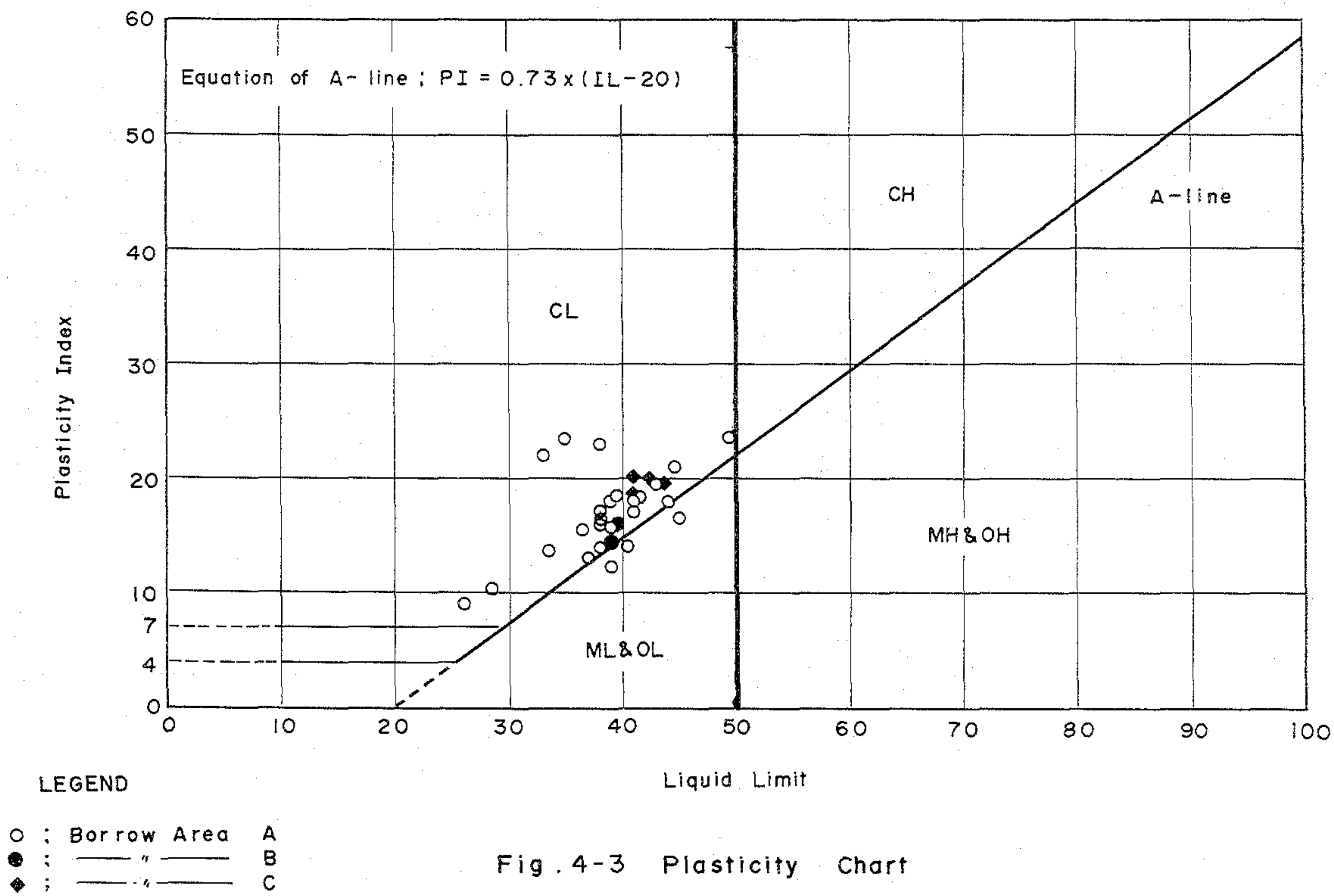


Fig. 4-3 Plasticity Chart

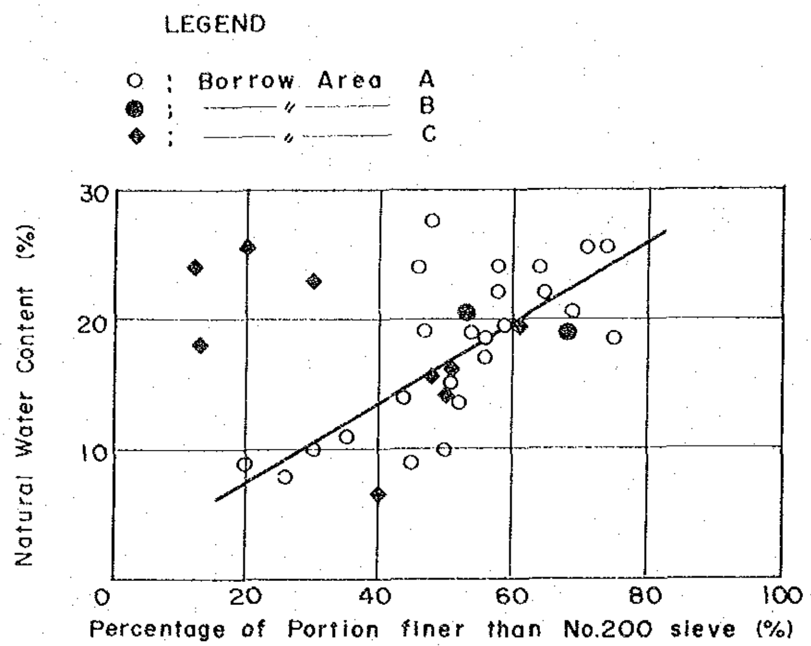


Fig.4-4 Natural Water Content of Material including All Particle-Size v.s. Percentage of Portion finer than No.200 sieve of Material including All Particle-Size

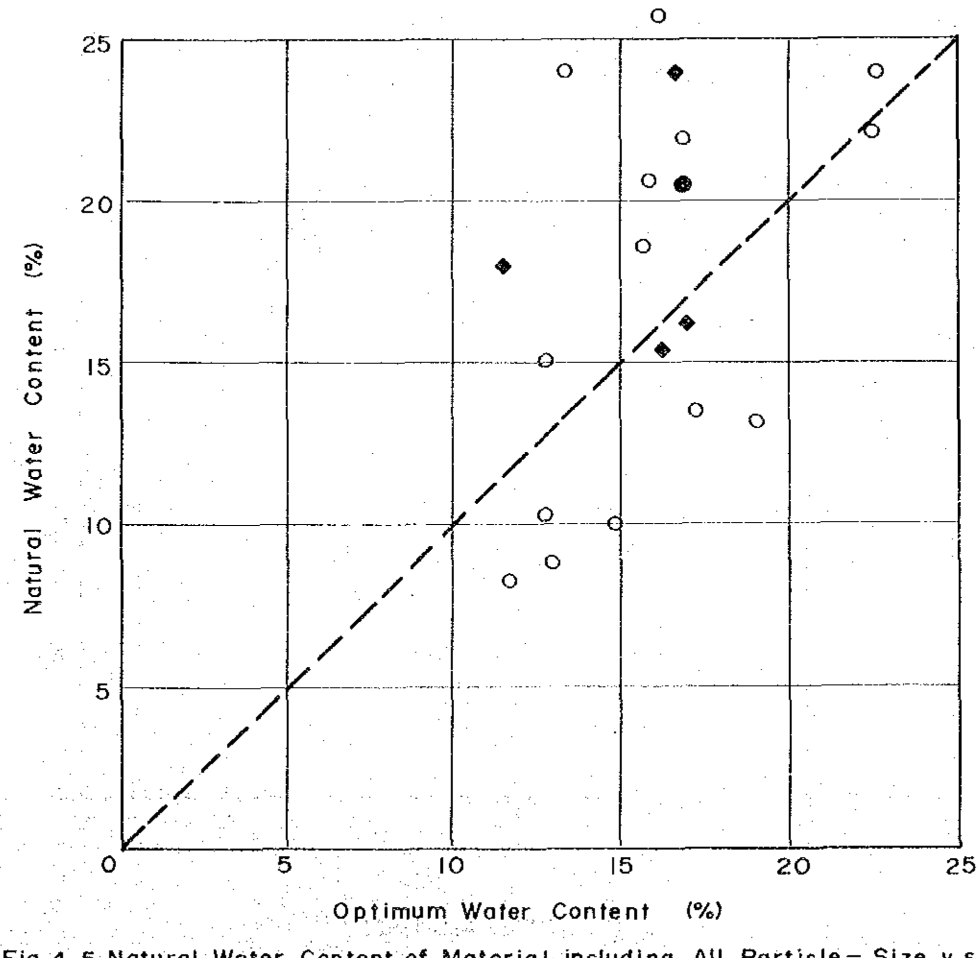


Fig.4-5 Natural Water Content of Material including All Particle- Size v.s. Optimum Water Content of Material passing 19.0mm sieve

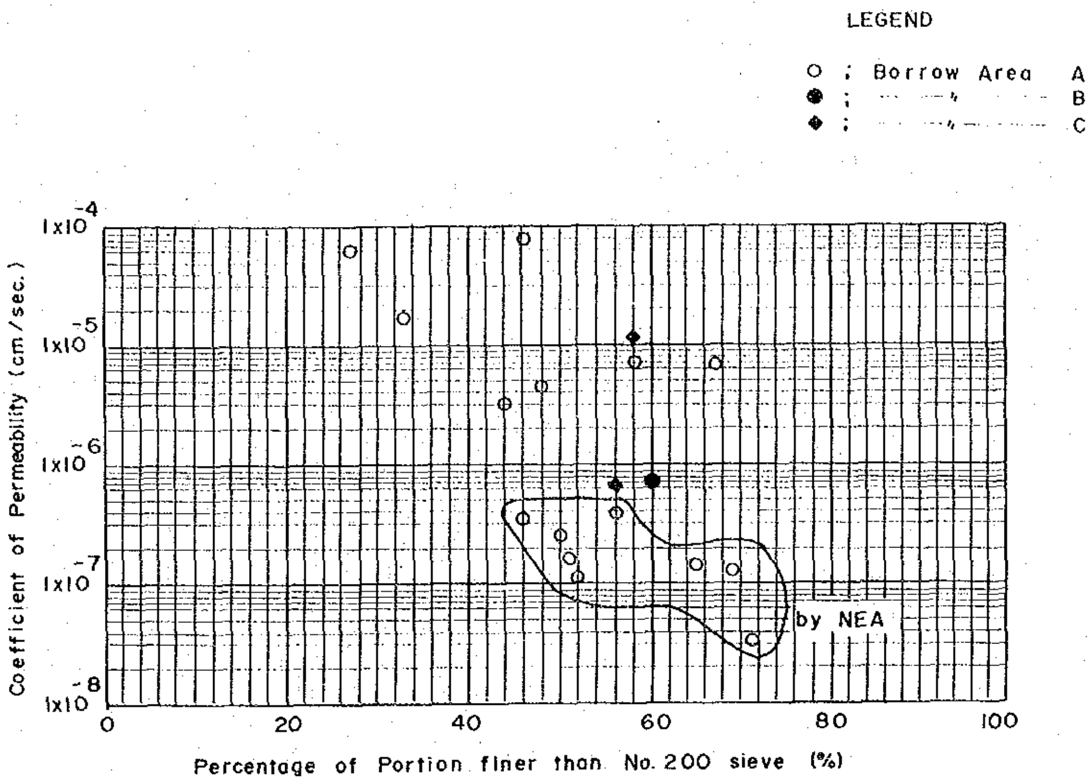


Fig. 4-6 Coefficient of Permeability v.s. Percentage of Portion finer than No. 200 sieve of Material passing the 19.0 mm sieve

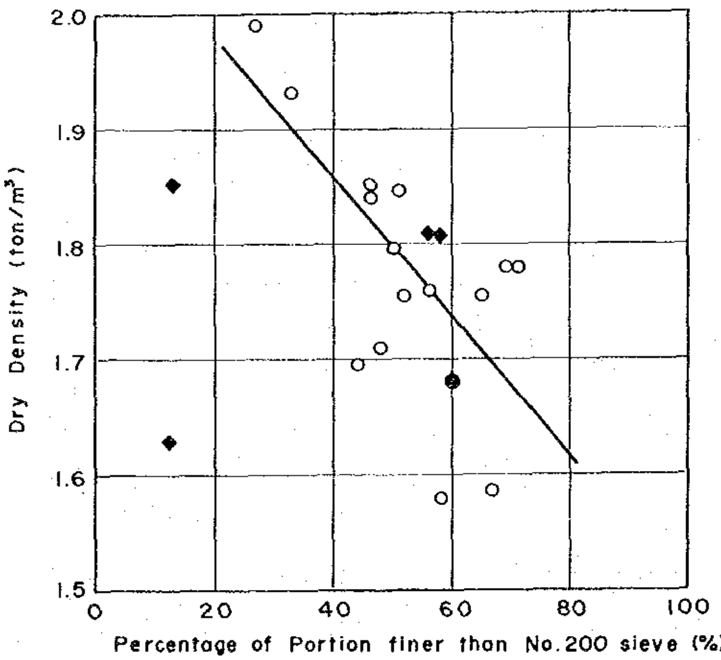


Fig. 4-7 Dry Density v.s. Percentage of Portion finer than No. 200 sieve of Material passing the 19.0 mm sieve

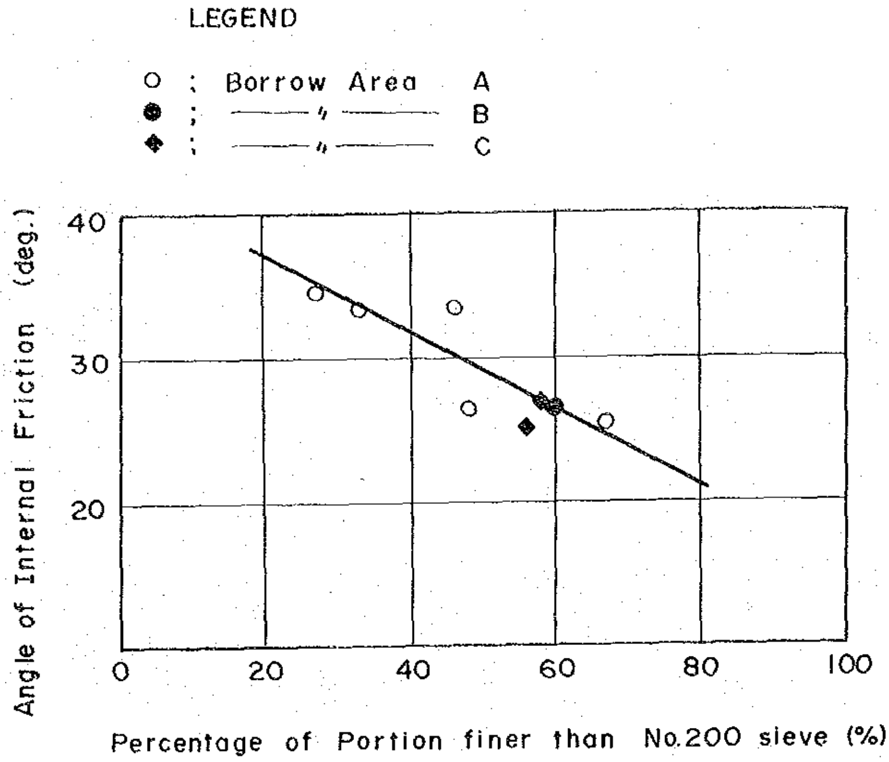


Fig. 4-8 Angle of Internal Friction v.s. Percentage of Portion finer than No.200 sieve of Material passing the 19.0mm sieve

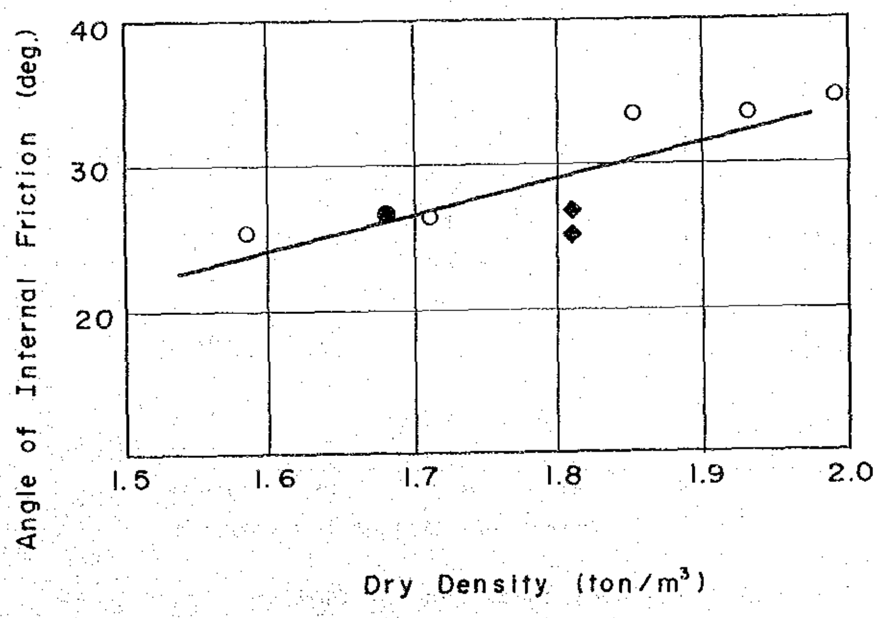


Fig.4-9 Angle of Internal Friction v.s. Dry Dencity of Material passing 19.0 mm sieve

CHAPTER 5.

PLANNING OF DEVELOPMENT

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5.1 Necessity of Development

Thailand's economic growth rate stood at 7.4% in 1970s, following Hong Kong, South Korea, Taiwan, Singapore, etc., being prominent in Asian developing nations. Particularly, the growth of its industrial sector is significant, doubling the share in the whole economy compared with in 1960.

The electricity demand in 1982 was 17,500GWh, and according to estimation by the "Load Forecast Working Group for Tariff Study Committee, 1982", the growth rate of the peak demand will likely reduce gradually from the estimated annual rate of 14% in 1983, but it will still show 6.5% in 1991, being fairly high, and even afterwards it seems likely to continue at the annual rate of 6%.

In other words, the electricity demand in 1991 can be estimated 6,200MW and 36,900GWh being more than double of 2,900MW and 17,500MW in 1982. Even after 1991, an annual increase of demand is considered 400MW to 500MW and 2,400GWh to 3,200GWh.

The oil-fired power generation shares 65% of the current electricity demand, while 78% of total energy is supplied with oil. It is, therefore, significant for economic stability to largely develop energy substitutive for oil such as natural gas, lignite, hydro and nuclear energy, suppressing the increase of oil importation as much as possible.

This Yuam hydroelectric power development plan is not only extraordinarily effective for assurance of domestic energies, but also effective for keeping the peak balance as a large-scale power source, and further, it is the plan with relatively less problems in international and environmental issues. Its effective development is, therefore, highly desirable.

5.2 Previous Plan

The previous plan achieved prior to the present feasibility study was worked out in 1976, and the damsite thereof is nearly the same as the "A site" recommended this time. That power generation scheme was a dam type as well as a storage type in its function. Table 5-1 shows both previous and presently proposed scheme.

5.3 Choice of Development Plan

1) General

Damsites A and C can be considered as a planned site along the main course of the Yuam river. The optimum plan, for A, C or these combination, can be determined through study of dam height, effective storage, output level, generating type and development time. Furthermore, comparison with Pai No. 6 and Chaem No. 5 plans is required in terms of precedence.

The optimum plan should be based on the principle to minimize the total cost of the system in forecasting the future demand and supply. This plan is, in other words, such that the saving amount due to the said plan, i.e., the resulting amount in subtracting the cost of the said plan from the cost of alternative supply plan becomes the largest.

This study should cover over the life of facilities at the site in question and also should be adaptable for the estimated demand and supply volume. However, since all possible reviewing on all thinkable comparison schemes makes the calculation complex in vain, some are disregarded experientially to the extent that no large error arises, and its accuracy is to be increased stage by stage.

A thermal power plant is reasonably the alternative power supply source, of which the cost is due saved by an electric power project in question, in such nations as Thailand where a large part of power system relies on thermal power plants. Of course, there are various kinds of thermal power plants, but the one with imported coal was employed here. However, with this supply source alone, load fluctuation such as peaking is not met, so that it is required that a gas turbine thermal power sustains about 14% of the peak demand. General description of the employed gas turbine and imported-coal thermal power plant are given in Table 5-2.

2) Operation of reservoir

To study operation of a reservoir and an output capacity, it should be first obtained the 95%-firm discharge. Herein, the mass curve of runoff is first drawn, then on the assumption that past actual runoff is reproduced exactly the same way and that the future figures are completely foreseeable, the 95%-firm discharge was obtained from the probability distribution of the firm discharge of each year, with operation of the reservoir made most effectively. Reference is to be made in Fig. 5-1 and Fig. 5-2.

The reservoir operation rule was set up in trying calculation on a mass curve to keep overflow as less as possible with assuring this firm discharge and also to keep the water level of reservoir as high as possible. The rule curve is shown in Fig. 5-3. The energy was computed based on the rule curve given in the Figure. The energy calculation, however, involves slight error as the first stage of computation where runoff data at the gauging station was used without modification for the energy calculation and the all calculation was manually conducted.

3) Choice of damsite A or C or their combination and of the high water level and available drawdown

For the first stage, parameters indicated in this caption were examined. Compared cases are shown in Table 5-3. Simplified river profile is illustrated in Fig. 5-4.

The marking "○" in the table indicates cases examined in the study. The case (marking *) of damsite A, NHWL 119m is of the combination with damsite C, and the maximum discharge thereof is the same as in damsite C.

In cases where the NHWL is not more than 155m in damsite A and not more than 170m in damsite C, a pondage type is required, instead of a storage type, due to the sedimentation level and variation of head.

In the first stage of the study, examination was focused on the cases of storage type which enabled to generate power of in peak where power capacity was derived from the 95%-firm discharge with five hour peak duration in weekdays at low water level (LWL).

In an aspect of demand-supply matching, the supply from the presently examined scheme was assumed well-balanced with the demand irrespective of the magnitude of the firm power. Therefore, as indicated in Fig. 5-6, the present scheme was supposed to share 24% of the maximum load of partial load in a heavy load day with a load factor of 74%.

In cases of pondage type, the average droughty discharge 13.0m^3/sec over the past 11 years was taken as the 95%-firm discharge, while the effective storage volume was determined by accumulating supplementary volume to the 95%-firm discharge, necessary volume for peaking in weekday-basis and daily regulating volume. Firm discharge in this case is $88m^3$/sec. However, increase of the power capacity has been tried by increase of available turbine discharge so as to examine the balance between increases of the secondary energy and construction cost, although any firm power increase is expected.

In the case of damsite C, the tailwater level right downstream of the damsite is some 127m, but by extending the headrace by 1.2km, the tailwater level comes to 119m, providing the additional head of 8m. Thus, the headrace was extended to that distance. In the farther downstream, the river gradient is smaller than 1/300, so the examination is meaningless.

Designing in this stage is a rough work, but comparisons were made for each damsite on the dam type, i.e. rock fill type or concrete gravity type, on the dam axis, and on the layout of spillway, power station, etc.

Results of the above-mentioned study in this stage revealed, as shown in Fig. 5-7 and Table 5-4, that damsite A, storage type of HWL 175m is the best in terms of both B-C (Benefit-cost) and Baht/kWh and followed by the damsite A of HWL 170m and the combination of the damsite C of HWL 180m and damsite A of HWL 119m. The cases such as damsite C alone, damsite A of HWL less than 165m or of pondage type, give the minus of B-C and also the high Baht/kWh.

Although it seems to be favored in this examination to take the HWL at 170m or higher at both damsite A and C, the number of houses to be inundated and portion of existing road to be relocated is sharply increased, while the impact on environment around the area will be drastically remarkable. Therefore, the case of damsite A, HWL 170m and effective storage 261 x $10^6 m^3$ was judged as optimum, keeping well-favorable B-C and Baht/kWh.

4) Review of reservoir operation

Most of the values indicated in Fig. 5-3 "Reservoir Operation Rule in the 1st Study Stage" can be rationally decided, but v_6, i.e. the storage target to be assured in the end of June, should be determined in comparison of the two aspects; preventing overflow in the following flood periods and keeping high energy conversion factor of discharge by the reservoir level kept as high as possible. In general, in the case where several power plants are located in a sequence on one river system, it is more adequate that, in the upper stream reservoir, overflow is reduces to a possible extent, i.e., $v_6 = v_7$, in the case of Fig. 5-3, but in the case where, like this case, no power plant is projected or located in the downstream and where head of the power plant in question is relatively small, it would be significant to keep the water level high. In this context, study was made, varying the value of v_6 diversely as shown in Table 5-5. Of course, the maximum turbine discharge should be correspondingly taken in the study.

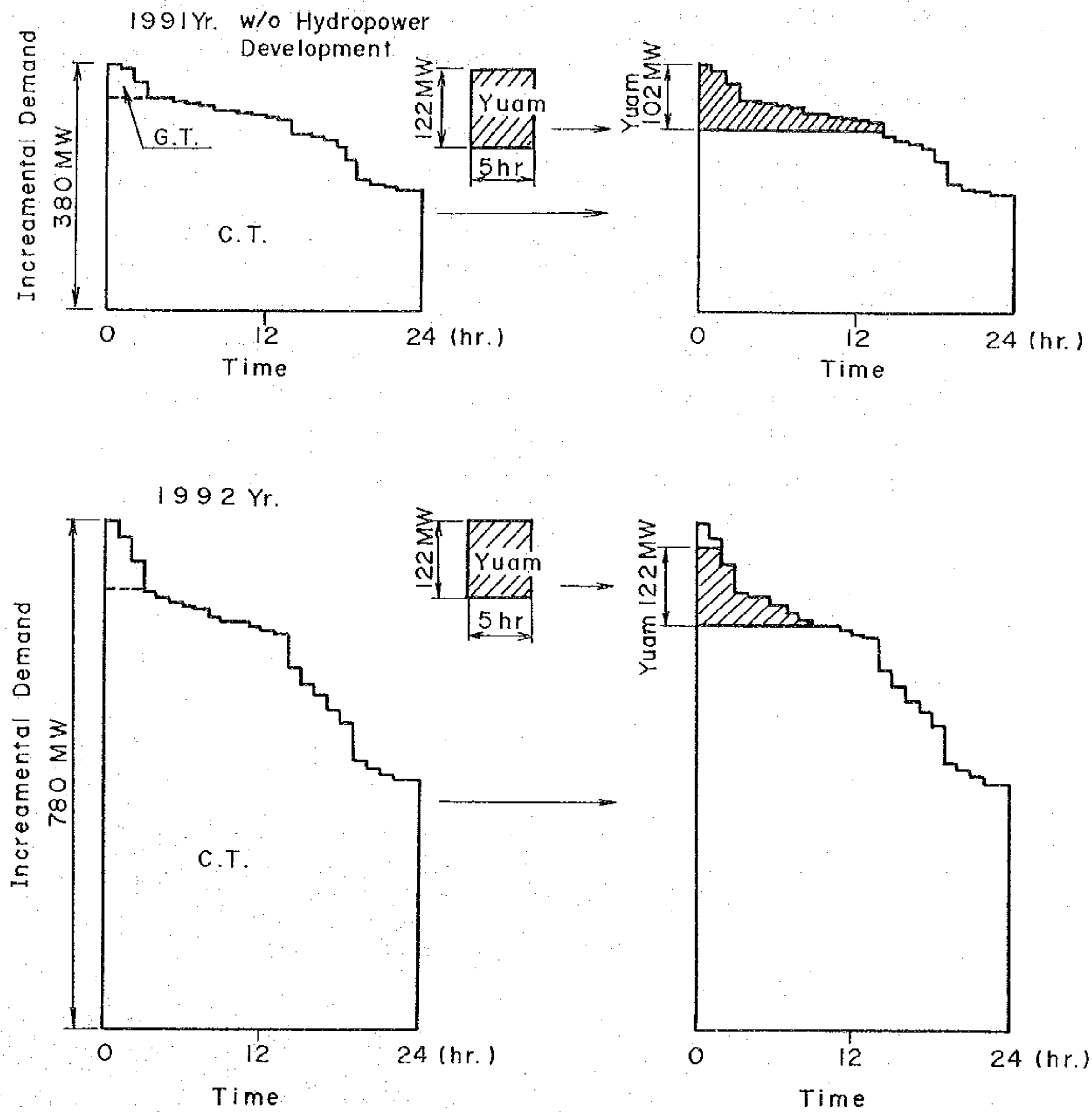
5) Choice of capacity

In subclause 3), comparison was made on the assumption that the equivalent peak duration time on a heavy load day is about five hours, but the maximum capacity must be determined by reviewing the demand and supply match in an implementation year and afterwards.

For the second stage, an assumption was employed that the demand/supply balance had been matched before the year of project implementation. On the said assumption, study was made in terms of such aspects that how will the output of the project be involved and matched to the increase of the power demand in the years following the project implementation, and how will be the net present value B-C which is converted to a value in a certain basic year.

The discount rate was to be 10%, the demand growth rate be at about 6% year and 3% year and the output capacity be of about 5 hrs, 6 hrs and 8 hrs in the equivalent peak duration time, i.e., 162MW, 137MW and 103MW in the maximum installed capacity, respectively. The operation start year was to be 1991 to 1996, the six cases, and the basic year for calculating the net present value was 1991. An example of the cases studied is shown in the figure below, and their results are shown in Table 5-6.

Example : Discount Rate 10% Demand Growth Rate 6% / Yr
Equivalent Peak Duration 5hr. Implementation Time 1991 Yr.
Basic Year in Discounting 1991 Yr. Max. Installed Capacity 162MW
Effective Power 122MW Effective Energy 522 GWh



The operation start year was resulted best in 1991 for any cases. In other words it is more favorable to start operation as soon as possible. The reason why 1991 was taken in this study as the earliest year of starting is the length of the period of further investigation and preparation and the construction of the project, which would practically be needed.

Regarding the output capacity, the case of 162MW where the equivalent peak duration time is shortest and the output is thus the largest is considered most favorable due to smaller increment of project cost against increment of output, although the output will partially be latent for the first one or two years after operation start.

In the said context, a concept to make the output much larger may come out, but it is not considered very favorable because of increase in size and weight of turbines and generators. In the case of 162MW largest in the study, two units of turbine and generator were employed, where weight of the turbine is estimated nearly 30t. If larger output, i.e. heavier turbine and generator will be considered, transportation of such equipment will be remarkably hampered due to long bridges located on the way to the site. In addition, increase of the number of units to cope with the larger output is nor very favorable because of increase of the construction cost.

It may, further, be considered that the second unit is installed one or two years later in partial construction. However, it is disadvantageous because the interest due to the initial investment for construction of a dam and other facilities is adversely large.

Upon these examination, the case of installed capacity 162MW was regarded optimum. Based on this optimum capacity, power generation computation has been conducted for the eleven year where runoff data is available. The resulted monthly average of available turbine discharge and output, reservoir water level at the end of each month, etc. are shown in Fig. 5-8, Table 5-7, 5-8 and 5-9.

6) Comparison among Yuam, Pai No. 6 and Chaem No. 5 projects

Comparison of these projects was made according to the procedures described in subclauses 3) and 5), as shown in Table 5-10. General features of Pai No. 6 and Chaem No. 5 projects are the same as indicated in the master plan "The Pai and Chaem River Hydroelectric Power Generation Development Project, Vol. 1, July, 1981", provided that the construction cost thereof is recalculated as of December, 1982 which is the same time as the Yuam project.

The Chaem No. 5 project does not hold its economic merit in its present study level, so that the detail calculation was omitted. If benefit other than power generation is largely included, it must be reconsidered.

The Pai No. 6 project is superior to the Yuam project even with the present features thereof. However, since the unit cost is expensive, problems could come out if initial potentialization of the output continues long.

Following this, studies were done which project should be implemented earlier the Yuam or the Pai No. 6 project and how much of time lag should be best between the two projects. The result is shown in Fig. 5-9. The Figure shows it is better in case of 6% of annual demand growth rate that Pai No. 6 should be started earlier with the Yuam implemented two or three years later. When the demand growth is low, this relation is inversed.

However, the feasibility study was not yet performed for the Pai No. 6 project, and the project features described in the master plan cannot be admitted optimum. It is, thus, expected that the project becomes better if reviewed to more competent plan.

Table 5-1 Comparison of Project Features between Previous and Presently Proposed Schemes

	Unit	Previeus (1976)	Presently Proposed
H.W.L	m	170	170
Total Storage Capacity	10^6m^3	450	444
Avilable Drowdown	m	30	20
Effect. Storage Capacity	10^6m^3	375	261
Max. Discharge	m^3/s	160	215
Normal Effect. Head	m	88	87.3
Installed Capacity	MW	120	162
Annual Energy	GWh	578	565

Table 5-3 Cased examined in the Study

Damsite / N.H.W.L (m)		A					C			
		175	170	165	155	119	180	175	170	155
Reservoir Type	(10^6m^3)									
	Eff. Storage 319	○	○				○			
	- ditto - 290	○	○	○			○			
	- ditto - 261	○	○	○			○			
	- ditto - 232	○	○	○			○	○		
Pondage Type	(m^3/s)									
	Max. Disc. 88			○	○			○	○	○
	- ditto - 106			○	○			○	○	○
	- ditto - 123			○	○			○	○	○
	- ditto - 140			○		*○		○	○	

Note: "*" indicates combination of damsite A, N.H.W.L. 119 m, and damsite C

Table 5-2 Benefit and Cost Rate for Studying Optimum Scale of Development

Interest Rate: 10%
1982 Price level

		Gas Turbine	Coal-fired Thermal
Ther-mal	Construction Cost ฿/kW	6,200	19,300
	Fuel Price at Plant (%)	8.17 (B/l)	70 (US$/t)
	Annual Cost Rate (%)	14.0	14.0
	Station Service Power Use (%)	6.0	6.0
	Forced Outage Rate (%)	4.0	4.0
	Overhaul Rate (%)	12.0	-
	Unit kW benefit (฿/kW)	1,100	3,000
	Unit kWh benefit (฿/kWh)	3.21	0.68
Hydro	Annual Cost Rate of Hydro (%)	11.6	
	Annual Cost Rate of Transmission Line (%)	11.7	
	Annual Plant Factor of Hydro (%)	97.0	
	Transmission line Loss Rate (%)	4.8	

Table 5-4
Planning Study in the 1st Stage in case of Storage Type

Dam Site, Dam Type		A, Rock Fill											C, Concrete Gravity					A C.G.	C C.G.	A+C	C C.G.	A+C
N H W L	m	175				170				165			180				175	119	180		175	
Total Storage	$10^6 m^3$	558				444				352			391				275	55	391		275	
Effect Storage	$10^6 m^3$	319	290	261	232	319	290	261	232	290	261	232	319	290	261	232	232	24	232		232	
Avilable Drowdown	m	18.5	17.0	14.0	12.0	30.0	24.5	20.0	16.5	43.5	33.5	26.0	25.5	17.0	14.0	12.0	20.0	1.0	12.0		20.0	
N.I.W.L.	m	168.8	169.3	170.3	171.0	160.0	161.8	163.3	164.5	150.5	153.8	156.3	171.5	174.3	175.3	176.0	168.3	118.5	176.0		168.3	
Normal Effect Head	m	92.8	93.3	94.3	95.0	84.0	85.8	87.3	88.5	74.5	77.8	80.3	49.5	51.3	52.3	53.0	45.3	42.5	53.0		45.3	
Normal Max Discharge	m^3/s	238	224	208	190	254	233	215	196	268	234	206	278	238	218	198	218	198	198		198	
Installed Capacity	MW	190	180	168	156	184	172	162	150	172	156	142	118	105	98	90	85	73	90	163	85	158
Firm Power	MW	155	149	145	140	122	126	128	124	78	94	99	59	72	72	71	47	67	71	138	47	114
Annual Energy	GWh	615	616	607	592	580	578	574	559	536	533	522	349	350	346	337	304	259	337	596	304	563
Effect. Power	MW	146	141	138	134	115	120	122	119	74	90	95	57	70	70	69	46	64	68	132	46	110
Alternative Gas T	MW	87	84	82	80	69	71	73	71	44	54	57	34	42	42	41	27			79		65
Alternative Coal T	MW	59	57	56	54	46	49	49	48	30	36	38	23	28	28	28	19			53		45
Benifit by Power	10^6 ฿	273	263	258	250	214	225	227	222	138	167	177	106	130	130	129	87			246		204
Effect. Energy	GWh	563	566	560	548	532	533	530	518	494	493	485	327	329	326	318	288	235	313	548	288	523
Alternative Gas T	GWh	63	61	60	58	50	52	53	52	32	39	41	25	31	31	30	20			57		47
Alternative Coal T	GWh	500	505	500	490	482	481	477	466	462	454	444	302	298	295	288	268			491		424
Benefit by Energy	10^6 ฿	542	539	533	519	488	494	494	484	417	434	427	286	302	300	292	246			517		471
Total Benefit	10^6 ฿	815	802	791	769	702	719	721	706	555	601	604	392	432	430	421	333			763		675
Const. Cost for Hy.	10^6 ฿	5,822	5,720	5,610	5,462	5,573	5,403	5,287	5,154	5,255	5,030	4,829	3,956	3,611	3,466	3,321	3,055	2,229	3,321	5,550	3,055	5,284
Const. Cost for Trans	10^6 ฿	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500			520		520
Annual Cost	10^6 ฿	734	723	710	693	705	686	672	657	669	642	619	518	478	461	444	413			705		674
B − C	10^6 ฿	81	79	81	76	△ 3	33	49	49	△ 114	△ 41	△ 15	△ 126	△ 46	△ 30	△ 23	△ 80			58		[illegible]
B / C		1.11	1.11	1.11	1.11	0.99	1.05	1.07	1.07	0.83	0.94	0.98	0.76	0.90	0.93	0.95	0.81			1.08		1.00
Unit Energy Cost	฿/kWh	1.30	1.28	1.27	1.26	1.33	1.29	1.27	1.27	1.35	1.30	1.28	1.58	1.45	1.41	1.40	1.43			1.29		1.29

Table 5-5 Comparison of Reservoir Water Levels in Operation Rule

Site A H.W.L. 170 cm available drawdown 20 m effective storage 261 x $10^6 m^3$ (= 3,021 $m^3/s/d$)					
(V6)		Capacity	Max. Discharge at N.H.W.L. 201 $m^3/3$ Max. Cap. 162 MW	Max. Discharge at N.H.W.L. 170 m^3/s Max. Cap. 137 MW	Max. Discharge at N.H.W.L 127 m^3/s Max. Cap. 103 MW
2121 ($m^3/s/d$)	Annual Available Discharge	$m^3/s/d$	30,219	28,873	25,280
	Annual Energy	10^6 kWh	○ 565	○ 541	479
1521 ($m^3/s/d$)	Annual Available Discahrge	$m^3/s/d$	30,274	28,939	25,661
	Annual Energy	10^6 kWh	564	540	○ 483
921 ($m^3/s/d$)	Annnual Available Discharge	$m^3/s/d$	30,291	28,983	25,802
	Annual Energy	10^6 kWh	563	539	483

Note: Calculated by computer
Optimum was marked by "○"

Table 5-6 Comparison on Capacities of the Project

		Site A, H.W.L. 170 m, Effective Storage 261 x $10^6 m^3$		
	MW	162	137	103
	m^3/s	215	182	137
Dependable Capacity	MW	128	107	80
Equivalent Peak Duration Time	hr	5.04	6.0	8.0
Annual Energy	GWh	565	541	483
Construction Cost	10^6B	5,787	5,492	5,160
Annual Cost	10^6B	672	638	600
Unit Price	B/kWh	1.29	1.27	1.32
Discount Rate 10%, Not considered implementation time. Considered pattern of demand only and not considered magnitude thereof.				
Annually Equalized Surplus Benefit	10^6B/Y	44	8	-6
Benefit Cost Ratio		1.07	1.01	0.90
Discount Rate 10%, Demand Growth Rate 6%/Y, Implementation Time 1991 Yr.				
Annually Equalized Surplus Benefit	10^6B/Y	40	10	-59
Benefit Cost Ratio		1.06	1.02	0.90
Discount Rate 10%, Demand Growth Rate 3%/Y, Implementation Time 1991Yr.				
Annually Equalized Surplus Benefit	10^6B/Y	31	4	-60
Benefit Cost Ratio		1.05	1.01	0.90

Table 5 - 7 Monthly Inflow

(Unit : m³/s)

Year \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
70	48.9	35.2	25.6	25.1	50.1	70.4	147.6	251.3	267.1	148.3	78.5	56.7	100.8
71	36.3	26.0	20.3	15.0	30.3	85.4	329.0	365.8	272.7	144.5	77.3	48.8	121.8
72	33.7	24.5	19.5	19.5	17.5	37.0	200.5	315.8	198.4	130.8	97.0	61.3	96.8
73	40.7	27.0	22.3	16.3	32.2	65.2	135.5	269.0	294.0	183.2	89.8	56.3	103.1
74	35.9	25.5	17.4	16.5	31.6	73.4	129.8	231.4	177.8	118.0	84.6	42.1	82.4
75	39.5	26.1	21.7	15.5	25.4	72.6	143.1	208.6	279.5	186.0	87.4	51.1	96.7
76	36.6	26.7	19.0	14.2	27.2	51.8	117.4	224.9	191.8	157.5	84.4	49.2	83.7
77	53.6	25.2	18.7	17.9	20.4	29.8	72.2	173.4	295.5	117.7	73.7	45.2	78.8
78	32.9	23.9	16.1	11.9	22.3	23.7	135.9	248.3	214.7	143.3	59.9	35.3	81.2
79	25.3	19.5	13.5	12.3	19.3	23.6	59.6	245.1	118.3	110.0	48.0	28.7	60.7
80	18.3	13.5	11.1	9.2	33.4	52.5	96.3	146.2	332.9	188.4	84.0	53.5	86.6
Av.	36.5	24.8	18.7	15.8	28.1	53.2	142.5	243.6	240.2	148.0	78.6	48.0	90.2

Table 5 - 8 Monthly Available Discharge

(Unit : m³/s)

Year \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
70	48.9	41.2	31.8	30.5	55.5	76.4	183.1	176.4	192.0	144.4	78.5	56.7	93.4
71	36.3	32.4	30.0	30.0	30.0	84.7	193.0	201.0	190.4	132.8	77.3	48.8	91.0
72	33.8	31.0	30.0	30.0	30.0	30.0	182.2	199.5	183.8	130.8	95.9	61.3	86.8
73	40.7	33.0	30.0	30.0	30.0	70.2	173.9	182.5	200.3	164.2	89.8	56.3	92.1
74	35.9	32.0	30.0	30.0	30.0	72.6	168.5	164.0	175.9	116.9	84.6	42.1	82.2
75	39.6	31.9	30.4	30.0	30.0	68.7	181.8	160.6	195.7	165.7	87.4	51.1	89.8
76	36.6	32.9	30.0	30.0	30.0	45.6	156.1	187.5	158.9	150.2	84.4	49.2	82.9
77	53.6	31.4	30.0	30.0	30.0	30.0	97.4	175.8	176.1	117.5	73.7	45.2	74.5
78	34.5	30.0	30.0	30.0	30.0	30.0	151.2	176.2	193.9	139.5	59.9	35.3	78.8
79	30.0	30.0	30.0	30.0	30.0	30.0	65.2	170.1	149.4	97.4	30.0	31.1	60.5
80	30.0	30.0	30.0	30.0	30.0	30.0	120.5	129.8	188.4	175.7	84.0	53.5	77.9
Av.	38.2	32.3	30.2	30.1	32.3	51.7	152.1	174.9	182.3	139.6	76.9	48.2	82.7

Table 5 - 9 Monthly Energy

(Unit : GWh)

Year \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
70	29.4	22.3	18.9	17.9	32.3	42.7	98.9	97.2	111.5	86.6	45.6	34.0	637.3
71	21.8	17.5	17.8	16.8	17.1	47.3	112.6	120.5	110.5	79.6	44.9	29.3	635.8
72	20.3	17.3	17.7	16.9	17.1	16.5	100.1	119.5	106.7	78.3	55.7	36.8	603.0
73	24.4	17.8	17.8	16.9	17.3	39.2	93.4	99.0	116.2	98.5	52.2	33.8	626.6
74	21.5	17.3	17.7	16.8	17.1	40.5	90.6	93.8	102.1	70.0	49.1	25.3	561.8
75	23.8	17.2	18.0	16.9	17.2	38.4	98.6	87.2	113.5	99.4	50.8	30.7	611.6
76	22.0	18.4	17.7	16.8	17.1	25.4	84.6	102.8	90.9	90.0	49.0	29.5	564.3
77	32.2	17.0	17.7	16.8	17.0	16.4	51.8	94.3	100.0	70.1	42.8	27.2	503.4
78	20.7	16.2	17.7	16.7	16.8	16.0	81.2	100.4	112.6	83.7	34.8	21.2	537.8
79	18.0	16.1	17.4	16.4	16.4	15.5	34.3	95.2	85.2	55.8	17.3	18.7	406.2
80	17.8	16.3	16.9	15.7	15.4	15.6	64.1	69.1	108.3	105.5	48.8	32.1	525.7
Av.	22.9	17.6	17.8	16.8	18.3	28.5	82.7	98.1	105.2	83.4	44.6	29.0	564.9

Table 5-10 Comparison among Yuam, Pai No.6 and Chaem No.5

		Yuam H.W.L.170 m Effective Storage 261 x 10^6m^3 Installed Cap. 162 MW	Pai No.6 H.W.L.400 m Effective Storage 571 x 10^6m^3 Installed Cap. 291 MW	Chaem No.5 H.W.L.430 m Effective Storage 500 x 10^6m^3 Installed Cap. 92 MW
Dependable Capacity	MW	128	273	80
Equivalent Peak Duration Time	hr	5.04	6.88	7.10
Annual Energy	GWh	565	620	258
Construction Cost	10^6B	5,748	8,897	5,971
Annual Cost	10^6B	672	1,032	692
Unit Price	B/kWh	1.29	1.77	2.82
Discount Rate 10%, Not considered implementation time. Considered pattern of demand only and not considered magnitude thereof.				
Annually Equalized Surplus Benefit	10^6B/Y	44	155	-298
Benefit Cost Ratio		1.07	1.15	0.58
Discount Rate 10%, Demand Growth Rate 6%/Y, Implementation Time 1991 Yr.				
Annually Equalized Surplus Benefit	10^6B/Y	40	134	
Benefit Cost Ratio		1.06	1.13	
Discount Rate 10%, Demand Growth Rate 3%/Y, Implementation Time 1991 Yr.				
Annually Equalized Surplus Benefit	10^6B/Y	31	87	
Benefit Cost Ratio		1.05	1.08	

Fig. 5-1 Mass Curve of Runoff in Nam Mae Yuam at Ban Tha Rua G. S.

Ve = 261 x 10^6 m^3

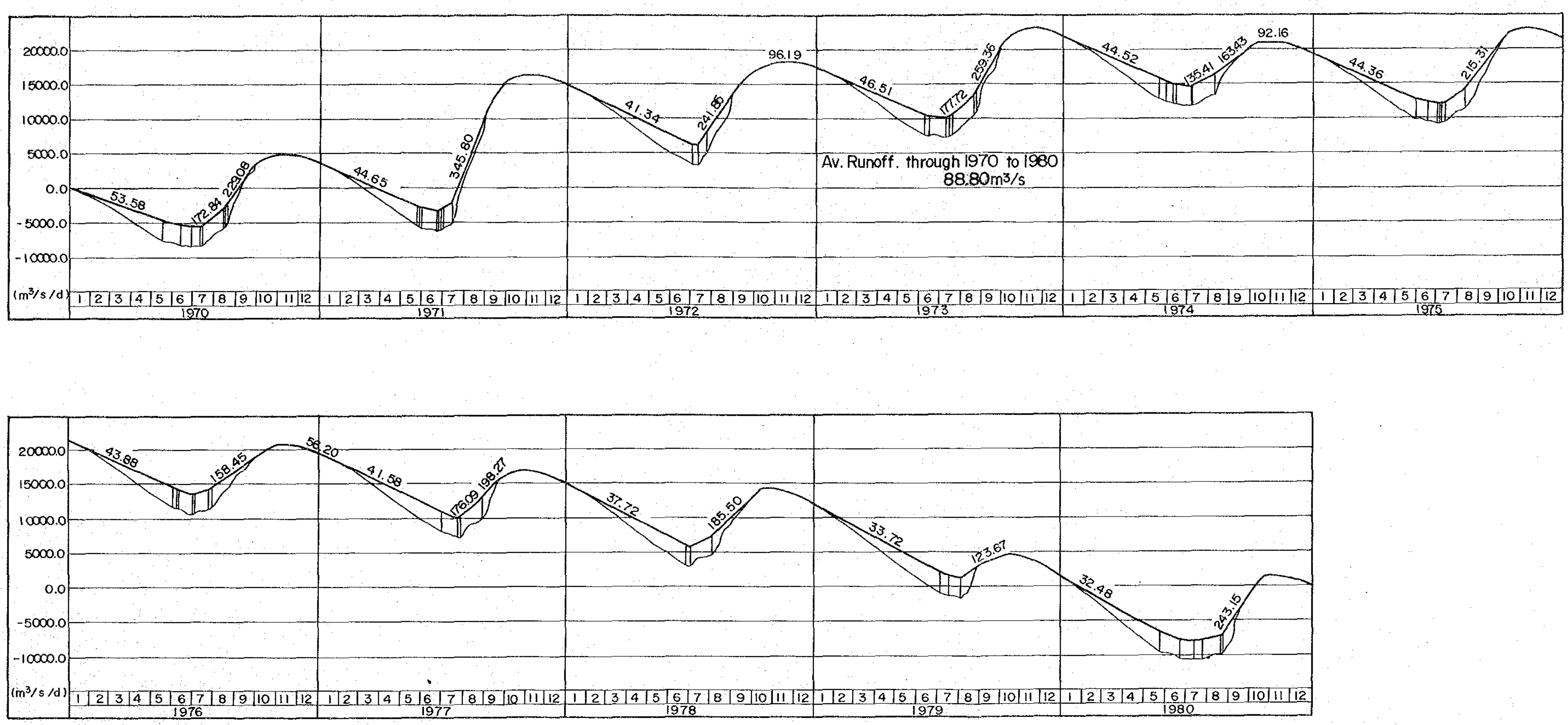


Fig. 5 – 2 Distribution of Firm Discharges Derived From Each Year

(Effective Storage $261 \times 10^6 m^3$)

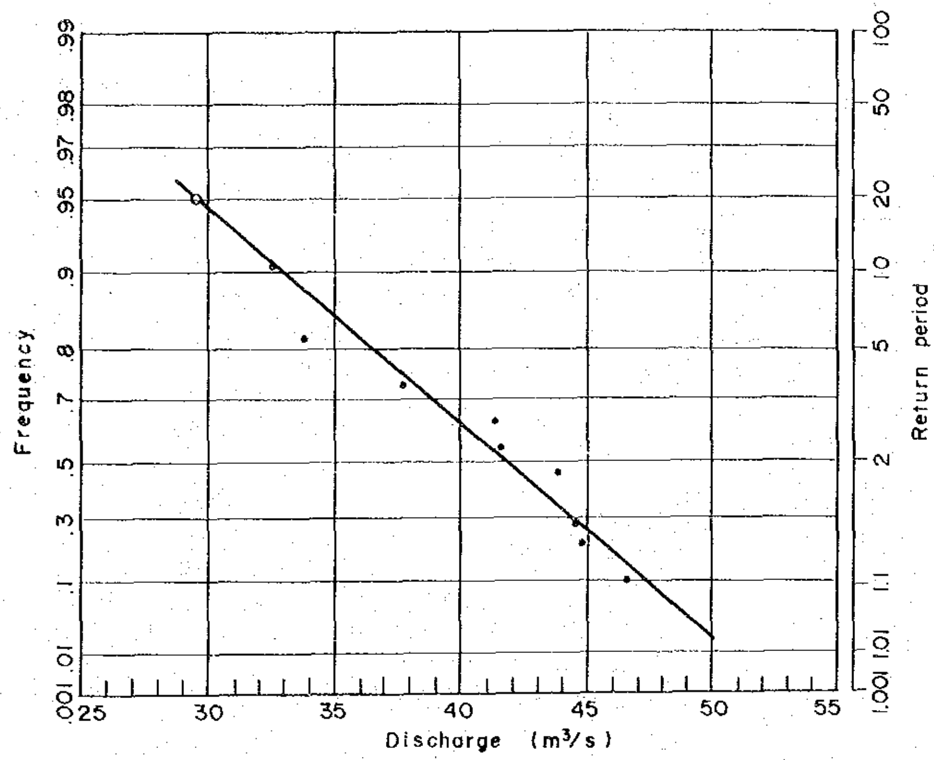
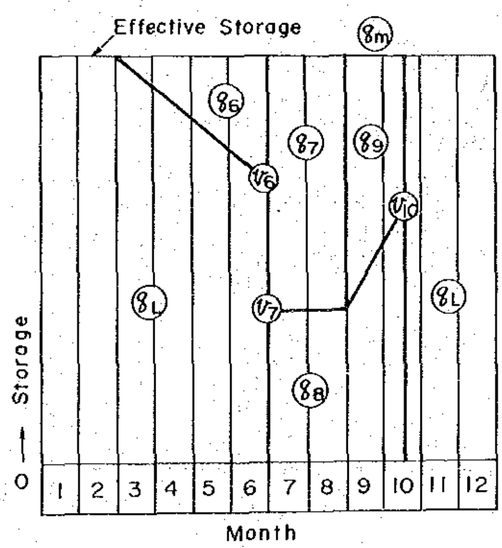


Fig.5 – 3 Reservoir Operation Rule in the 1st Study Stage



Effective Storage $10^6 m^3$		319	290	261	232
	$m^3/s/day$	3,692	3,356	3,021	2,685
q_L = 95% Firm Discharge	m^3/s	33.0	31.3	29.5	27.3
q_6	〃	148	155	175	173
q_7	〃	148	155	175	173
q_8	〃	60	60	60	60
q_9	〃	148	150	146	153
V_6	$m^3/s/day$	2,192	2,356	2,121	1,785
V_7	〃	800	800	800	800
V_{10}	〃	2,772	2,256	2,021	1,489

q_m Max. Turbine Discharge at each H.W.L.

Fig. 5 - 4 Longitudinal Section of Yuam River

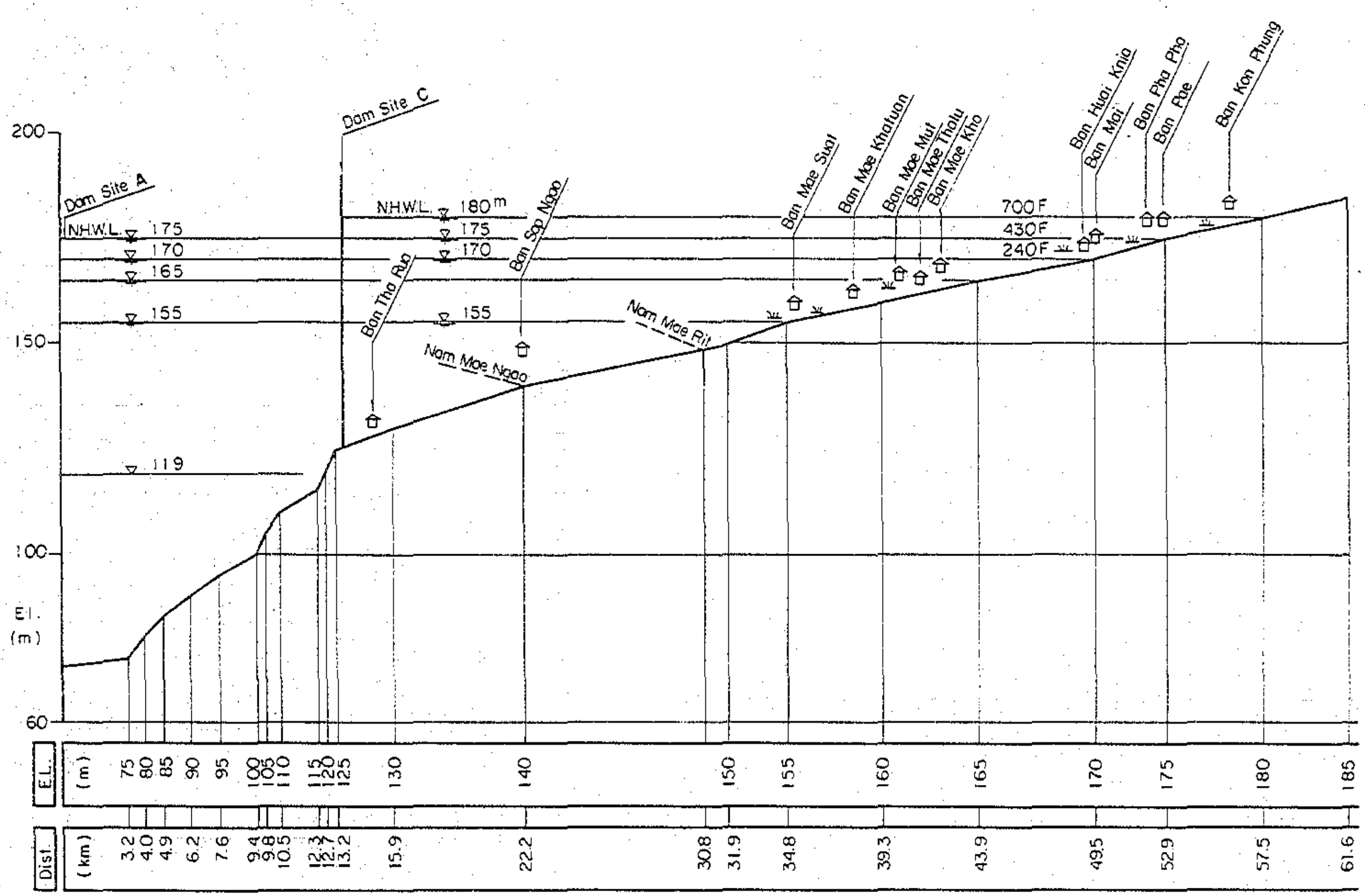
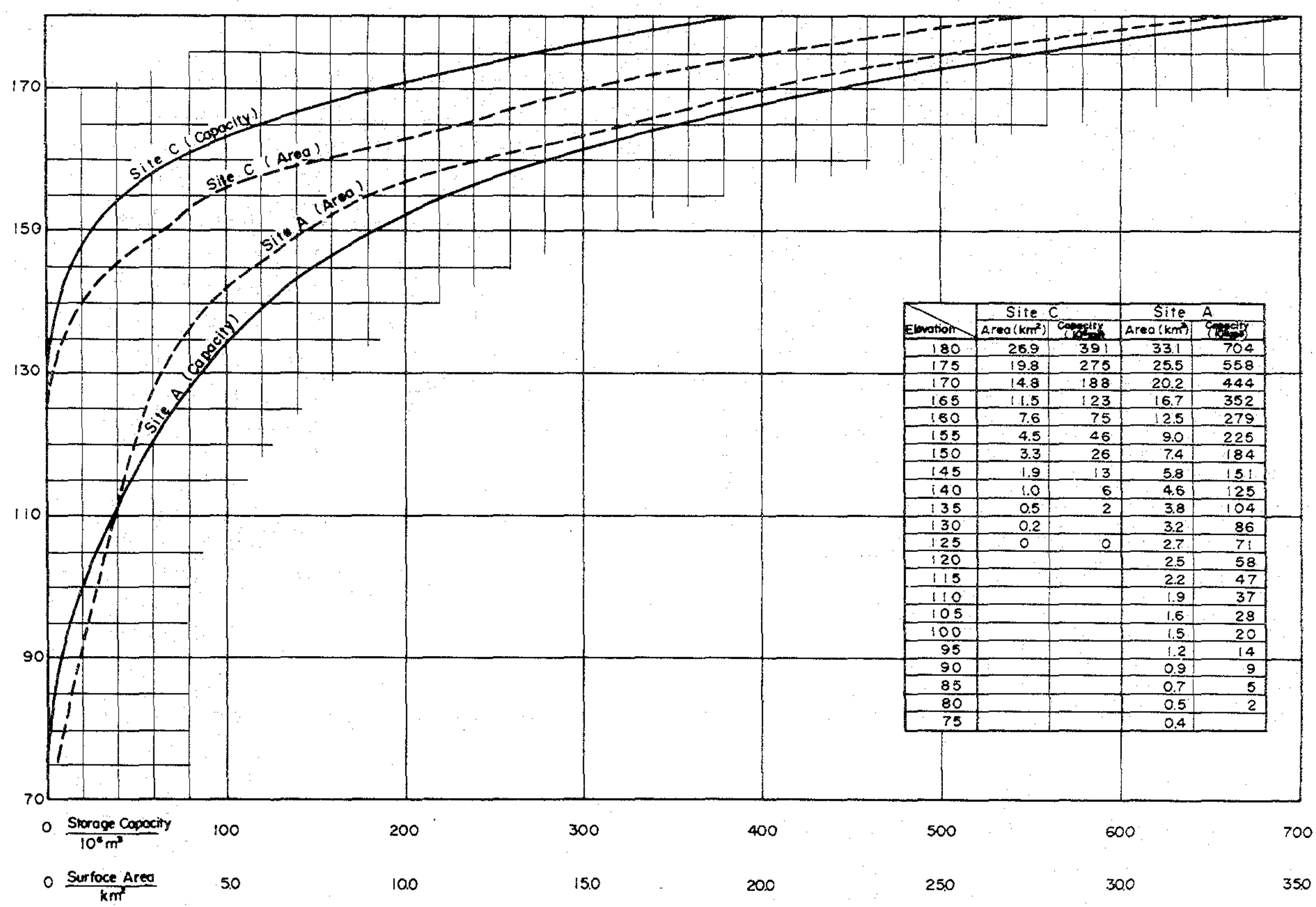


Fig. 5 – 5 Reservoir Area and Storage Capacity Curve



Elevation	Site C Area (km²)	Site C Capacity ($10^6 m^3$)	Site A Area (km²)	Site A Capacity ($10^6 m^3$)
180	26.9	391	33.1	704
175	19.8	275	25.5	558
170	14.8	188	20.2	444
165	11.5	123	16.7	352
160	7.6	75	12.5	279
155	4.5	46	9.0	226
150	3.3	26	7.4	184
145	1.9	13	5.8	151
140	1.0	6	4.6	125
135	0.5	2	3.8	104
130	0.2		3.2	86
125	0	0	2.7	71
120			2.5	58
115			2.2	47
110			1.9	37
105			1.6	28
100			1.5	20
95			1.2	14
90			0.9	9
85			0.7	5
80			0.5	2
75			0.4	

Fig.5-6 Load Duration Curve on Heavy Load Day

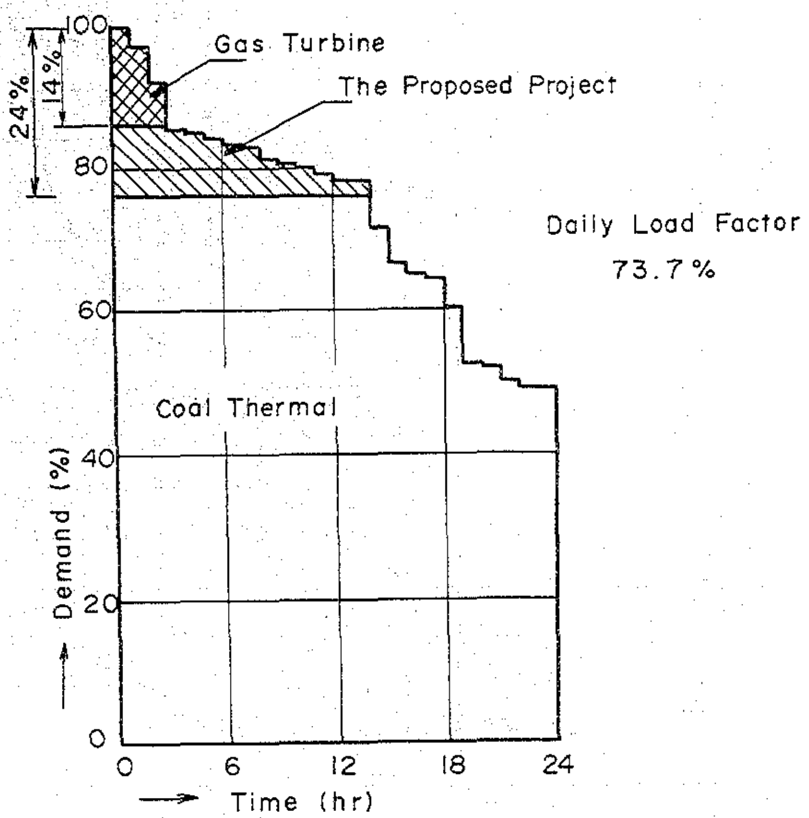


Fig. 5-9 Comparison between Yuam and Pai No.6 Project on the Implementation Priority and the Time Lag between them

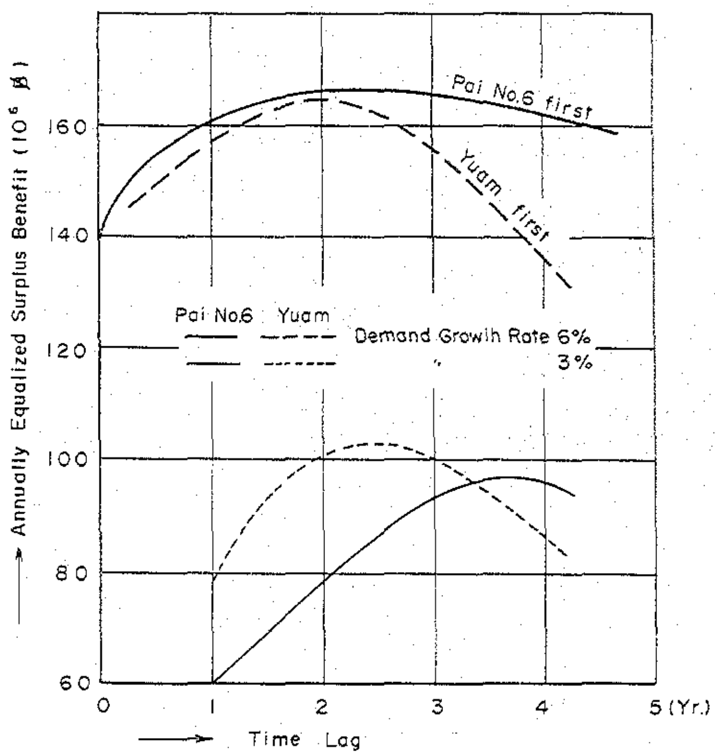


Fig. 5-7 B-C. Unit Energy Cost to Annual Cost

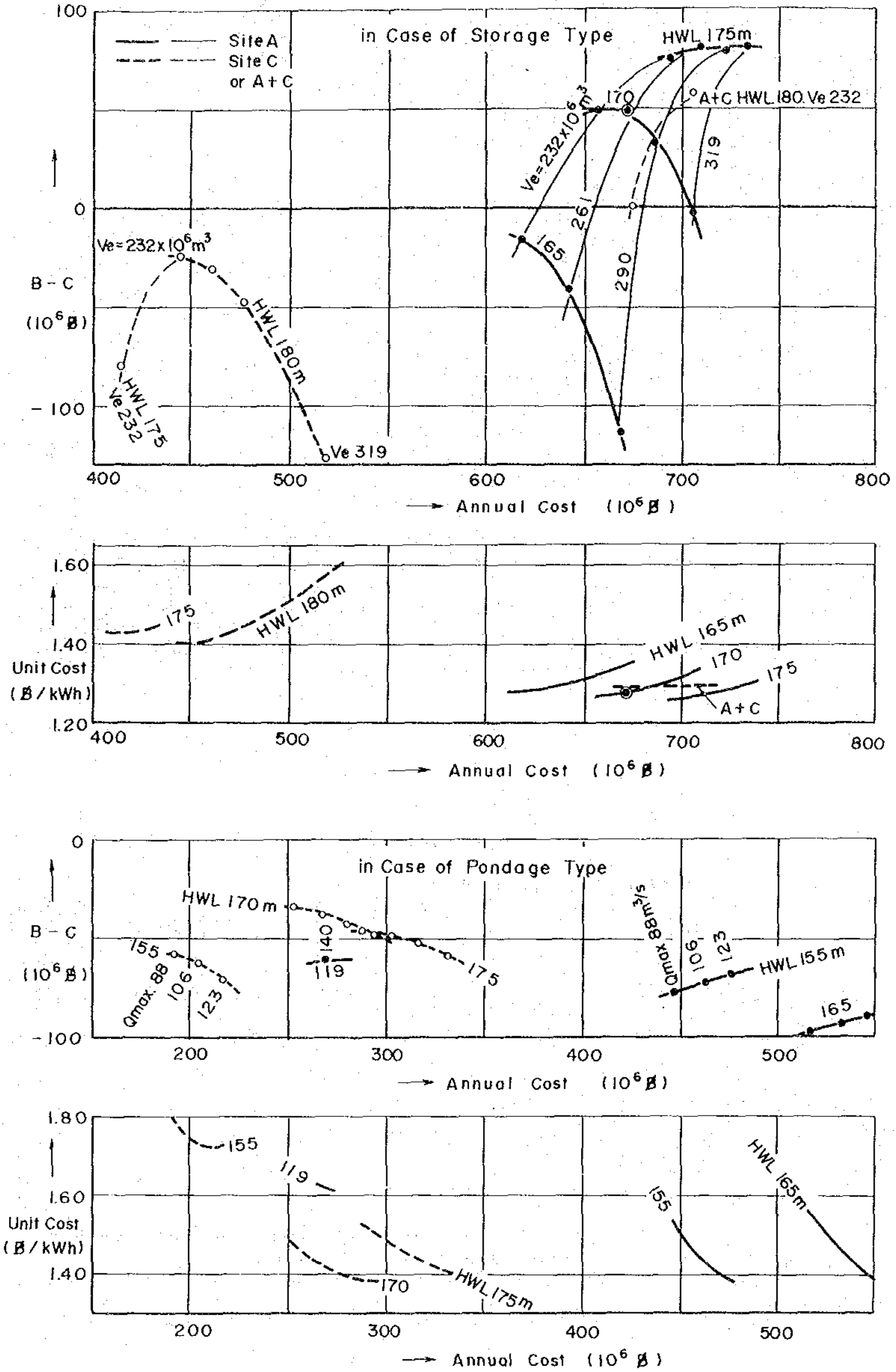
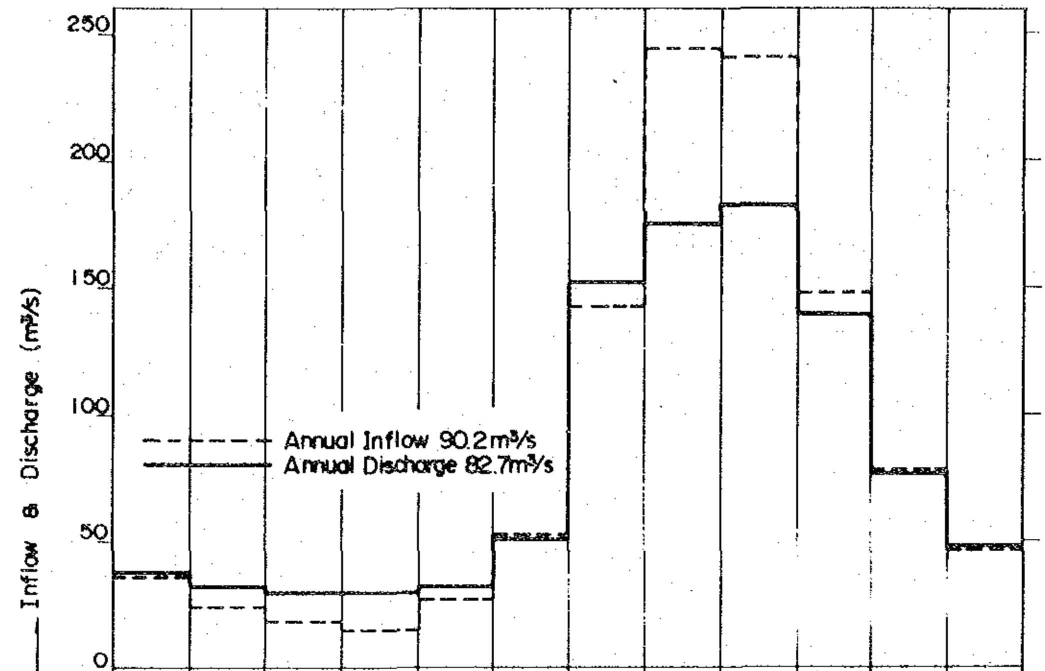
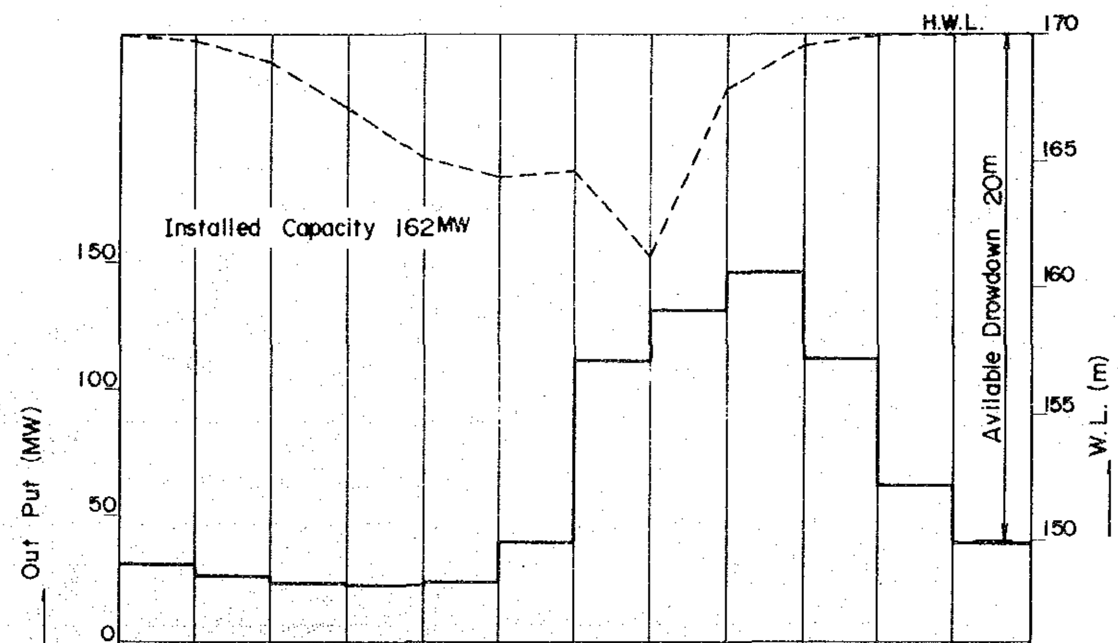


Fig. 5-8 Avg. of Inflow, Discharge, Water Level & Monthly Out Put



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Inflow	36.5	24.8	18.7	15.8	28.1	53.2	142.5	243.6	240.2	148.0	78.6	48.0
Discharge	38.2	32.3	30.2	30.1	32.3	51.7	152.1	174.9	182.3	139.6	76.9	48.2



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Water Level at End of Month	169.8	168.9	167.1	165.1	164.4	164.6	161.2	167.8	169.6	170.0	170.0	170.0
Monthly Avg. of Out Put	30.8	26.2	23.9	23.3	24.6	39.6	111.2	131.9	146.1	112.1	61.9	39.0