CHAPTER 4

LOAD FORECAST AND POWER DEVELOPMENT PLAN

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4.1 Load Forecast

4.1.1 Load Forecast by Load Forecast Working Group

(1) Load Forecast Method

The load forecast is prepared by the Load Forecast Working Group, which consists of representatives from agencies concerned and utilities such as NESDB, NEPO, NEA, MEA, PEA, EGAT. The group includes some experts from TDRI and NIDA. The working group prepares two types of forecast, micro and macro.

The micro load forecast is prepared by region and categories of consumers. The load of each category of consumer is projected by the PEA and the MEA mainly on the historical relationships between energy demand and factors such as the consumer's component of regional GDP, electricity tariff and population. The load forecast of EGAT's direct customers is made by EGAT based on consumer's expansion programs and other relevant information. The total load forecast is obtained by summing up each projected load.

In order to cross-check the above-mentioned micro forecast, a macro forecast is prepared using regression analysis on consumer categories with the parameter of GDP or GRDP.

(2) 1988 Forecast

Since the favourable economic situation for Thailand in 1987 appeared to continue in 1988. On September 8, 1988, the maximum demand of 5,444 MW was recorded, showing a 15% increase over the previous year. Because of this, the Load Forecast Working Group updated its load forecast (PDP 88-02, February, 1989) in September, 1988. Table 4-1 shows the total EGAT generation requirement of the forecast.

4.1.2 Load Forecast by JICA

As described in the prior section, the load forecast for Thailand is prepared by the Load Forecast Working Group which consists of concerned agencies and utilities. The load is forecast by region and by customer class and the total load is obtained by summing up each load (micro forecast). Accordingly, the forecast method is considered to assure high accuracy.

In the working group, a macro load forecast is also prepared to cross-check the micro forecasts, and the accuracy of the forecast is checked.

Against this load forecast, JICA made a regression analysis of GDP/population and power demand, using the chronological data for 1979 to 1988 shown in Table 4-2, and worked out a load forecast by its own macroscopic method. As a result, the following model was obtained (see Table 4-2):

$$Y = -43099 + 3.9068\ X$$

Correlation factor, $r = 0.9791$

where, Y = Energy demand (GWh)

X = GDP/population (billions of Baht/million)

JICA made a load forecast using the aforementioned regression model and the GDP growth and population growth rates predicted by the Working Group. However, JICA assumed that the load factor will increase by 0.3% a year over the average load factor for the period from 1985 to 1987. The results of load forecast by JICA are shown in Table 4-3.

4.1.3 Comparison of Load Forecast Results

(1) Energy Demand and Maximum Power Demand

A comparison of the load forecasts made by JICA and Working Group can be summarized as follows:

Power Demand Forecast (MW)

Year	W.G (MW) (1)	JICA (MW) (2)	(2) - (1)/(1) (%)
1988	5,444.0	5,444.0	
1991	7,440.0	7,408.7	-0.4
1993	8,867.0	9,014.4	1.7
1995	10,304.0	10,786.8	4.7
1998	12,596.0	13,315.4	5.7
2001	15,112.0	15,914.1	5.3
Annual Average	8.2%/year	8.6%/year	

Energy Demand Forecast (GWh)

Year	W.G (GWh) (1)	JICA (GWh) (2)	(2) - (1)/(1) (%)
1988	31,996.94	31,996.94	
1991	45,062.0	44,256.0	-1.8
1993	54,240.0	54,172.1	-0.1
1995	63,924.0	65,211.4	2.0
1998	79,170.0	81,224.8	2.6
2001	96,373.0	97,953.2	1.6
Annual Average	8.9%/year	9.0%/year	

As can be clearly seen from the above summary results, the Working Group load forecast for 1988 to 2001 tells that the maximum power (MW) and electric energy (GWh) will grow at 8.2%/year and 8.9%/year.

Against this, the results of forecast by JICA suggest that both electric power and energy demands will grow at about the same rates as projected by Working Group. As to electric power, the difference between Working Group and JICA forecasts for the year 2001 is 802 MW, which is attributable to the difference in the estimated values of the load factor. However, this is not likely to present any significant problem as a difference that may occur in 2001 or twelve years ahead of now.

From the foregoing, it may be concluded that the Working Group forecast is reasonable.

TABLE 4-1

TOTAL EGAT GENERATION REQUIREMENT
(Base Case Load Forecast)

Fiscal Year	Peak Generation			Energy Generation			Load Factor
	MW	Increase		GMh	Increase		%
		MW	%		GWh	%	
			Actual				
1974	1,256.30	57.00	4.75	7,258.72	385.90	5.61	65.96
1975	1,406.60	150.30	11.96	8,211.57	952.90	13.13	66.64
1976	1,652.10	245.50	17.45	9,414.48	1,202.90	14.64	65.05
1977	1,873.40	221.30	13.40	10,950.62	1,536.10	16.32	66.73
1978	2,100.60	227.20	12.13	12,371.67	1,421.10	12.98	67.23
1979	2,255.00	154.40	7.35	13,964.55	1,592.90	12.88	70.69
1980	2,417.40	162.40	7.20	14,753.73	789.20	5.65	69.67
1981	2,588.70	171.30	7.09	15,959.97	1,206.20	8.18	70.38
1982	2,838.00	249.30	9.63	16,881.95	921.90	5.78	67.91
1983	3,204.30	366.30	12.91	19,066.30	2,184.40	12.94	67.92
1984	3,547.30	343.00	10.70	21,066.44	2,000.10	10.49	67.79
1985	3,878.40	331.10	9.33	23,356.57	2,290.10	10.87	68.75
1986	4,180.90	302.50	7.80	24,779.53	1,423.00	6.09	67.66
1987	4,733.90	553.00	13.23	28,193.16	3,413.60	13.78	67.99
1988	5,444.00	710.10	15.00	31,996.94	3,803.80	13.49	67.09
Average Growth 1979-1988	–	334.34	9.99	–	1,962.53	9.97	–
			Forecast				
1989	6,098.00	654.00	12.01	36,584.00	4,587.10	14.34	68.49
1990	6,759.00	661.00	10.84	40,746.00	4,162.00	11.38	68.82
1991	7,440.00	681.00	10.08	45,062.00	4,316.00	10.59	69.14
1992	8,173.00	733.00	9.85	49,793.00	4,731.00	10.50	69.55
1993	8,867.00	694.00	8.49	54,240.00	4,447.00	8.93	69.83
1994	9,578.00	711.00	8.02	58,964.00	4,724.00	8.71	70.28
1995	10,304.00	726.00	7.58	63,924.00	4,960.00	8.41	70.82
1996	11,066.00	762.00	7.40	69,065.00	5,141.00	8.04	71.25
1997	11,816.00	750.00	6.78	74,016.00	4,951.00	7.17	71.51
1998	12,596.00	780.00	6.60	79,170.00	5,154.00	6.96	71.75
1999	13,414.00	818.00	6.49	84,666.00	5,496.00	9.94	72.05
2000	14,271.00	857.00	6.39	90,568.00	5,902.00	9.97	72.45
2001	15,112.00	841.00	5.89	96,373.00	5,805.00	6.41	72.80
Average Growth							
1987-1991	–	651.82	12.22	–	4,056.49	12.71	–
1992-1996	–	725.20	8.26	–	4,800.60	8.92	–
1997-2001	–	809.20	6.43	–	5,461.60	6.89	–

Reference : Working Group Load Forecast
July 1988

Table 4-2 Parameters for Regression Model

Year	Demand (GWh)	GDP Present Price	GDP Deflator 1980=100	GDP Price at 1980	Population (Million)	GDP/POP	Load Factor (%)	Peak (MW)
1979	13,964.6	556.2	85.9	647.5	46.14	14,033.0	70.69	2,255.0
1980	14,753.7	684.9	100.0	684.9	46.50	14,729.0	69.67	2,417.4
1981	15,960.0	786.2	108.0	728.0	47.49	15,330.0	70.38	2,588.7
1982	16,881.9	846.1	111.6	758.2	48.49	15,636.0	67.91	2,838.0
1983	19,066.3	924.9	115.2	802.9	49.46	16,233.0	67.92	3,204.3
1984	21,066.4	988.9	116.7	847.4	50.40	16,813.0	67.79	3,547.3
1985	23,356.6	1,041.4	119.1	874.4	51.30	17,045.0	68.75	3,878.4
1986	24,779.5	1,098.4	121.4	904.8	52.09	17,370.0	67.66	4,180.9
1987	28,193.2	1,212.5	126.1	941.5	53.61	17,935.0	67.99	4,733.9
1988	31,996.9			1,032.5	54.48	18,952.0	67.09	5,444.0
Annual average growth rate								
79-82	6.5%			5.4%	1.7%			8.0%
82-86	10.1%			4.5%	1.8%			10.2%
86-88	13.6%			6.8%	2.3%			14.1%

Source: GDP and Population were taken from International Financial Statistics (IMF 1988)

Table 4-3 Economic Growth and Power Demand Forecast

	GDP (B.Baht)	Population (Million)	GDP/POP	Demand (GWh)	Load Factor (%)	Peak (MW)
BASE CASE						
1989	1,108.8	55.37	20,026.0	35,137.8	67.78	5,917.6
1990	1,190.8	56.27	21,161.0	39,571.9	67.98	6,644.5
1991	1,278.8	57.19	22,360.0	44,256.0	68.19	7,408.7
1992	1,368.3	57.99	23,595.0	49,080.7	68.39	8,191.9
1993	1,464.1	58.80	24,898.0	54,171.1	68.59	9,014.4
1994	1,566.5	59.62	26,273.0	59,542.8	68.80	9,878.7
1995	1,676.2	60.46	27,724.0	65,211.4	69.01	10,786.8
1996	1,793.5	61.30	29,255.0	71,192.5	69.21	11,740.9
1997	1,893.6	62.06	30,512.0	76,103.2	69.42	12,513.3
1998	1,999.3	62.82	31,823.0	81,224.8	69.63	13,315.4
1999	2,110.9	63.59	33,191.0	86,569.2	69.84	14,149.1
2000	2,228.6	64.38	34,617.0	92,140.1	70.05	15,014.6
2001	2,353.0	65.17	36,105.0	97,953.2	70.26	15,914.1
LOW CASE						
1989	1,093.2	55.37	19,743.0	34,032.2	67.78	5,731.7
1990	1,165.7	56.27	20,715.0	37,829.5	67.98	6,351.9
1991	1,242.9	57.19	21,734.0	41,810.4	68.19	6,999.3
1992	1,319.8	57.99	22,758.0	45,810.8	68.39	7,646.1
1993	1,401.3	58.80	23,831.0	50,002.7	68.59	8,320.8
1994	1,487.9	59.62	24,954.0	54,389.9	68.80	9,023.8
1995	1,579.9	60.46	26,131.0	58,988.0	69.01	9,757.4
1996	1,677.5	61.30	27,363.0	63,801.1	69.21	10,522.0
1997	1,762.2	62.06	28,395.0	67,832.7	69.42	11,153.4
1998	1,851.2	62.82	29,467.0	72,020.7	69.63	11,806.6
1999	1,944.7	63.59	30,579.0	76,364.9	69.84	12,481.3
2000	2,042.9	64.38	31,733.0	80,873.2	70.05	13,178.6
2001	2,146.1	65.17	32,930.0	85,549.5	70.26	13,898.9

Note-1: GDP and Population were taken from EGAT'S Load Forecast estimated by Load Forecast working Group

Period	Annual Average GDP Growth ratio (%)		Annual Population Growth ratio (%)
	(Base Case)	(low case)	
1987-91	7.39	6.63	1.63
1992-96	7.00	6.18	1.40
1997-2000	5.58	5.05	1.23

Note-2: Load Factor was estimated to increase at annual average rate of 0.3%.

4.2 Power Development Plan

4.2.1 Power Development Plan of EGAT

(1) Present Situation of EGAT Power Facilities

The power generation, substation and transmission line facilities owned by EGAT are as shown in Tables 3-1 and 3-2 of Chapter 3.

The output of the power generation facilities as of July, 1988 was 2,250 MW by hydraulic power generation, 3,608 MW by thermal power generation, 772 MW by combined cycle thermal power generation and 265 MW by gas turbine power generation, totaling 6,894 MW.

(2) Commissioned Projects under Construction

As of February, 1989, there are 8 power projects under construction or pending approval by the government, with total capacity of 2,355 MW as follows:

Power Plant Projects	Rating (MW)	Commissioning Date	Region
A) Projects in the Fifth Plan			
1) Khanom Second Power Plant Barge	75	February 1989	3
2) Mae Moh Lignite-Fired Unit 8	300	July 1989	4
3) Mae Moh Lignite-Fired Unit 9	300	December 1990	4
B) Projects in the Sixth Plan			
4) Srinagarind Unit 5	180	April 1991	1
5) Bang Pakong Combined Cycle Block 3	300	Jun.1990-Jun.1991	1
6) Bank Pakong Combined Cycle Block 3	300	Aug.1990-Aug.1991	1
7) Mae Moh Lignite-Fired Unit 10	300	February 1992	4
8) Bang Pakong Thermal Unit 3	600	May 1992	1
Total Capacity of Power Plants Under Construction/Implementation	2,355		

(3) Power Development Plan of EGAT

The power development plan of EGAT has been formulated by selecting a series of development projects which will involve the least-cost out of many alternative power development plans.

This EGAT's power development plan was reviewed with respect to specific conditions, including (a) the change in natural gas supply and demand, (b) the change in fuel prices, (c) the new candidate projects, (d) the project costs and implementation schedule and (e) the adoption of a Base Case load forecast for a recommended PDP study and a Low Case load forecast for a sensitivity analysis. The results of the review are summarized in the Power Development Plan (PDP 88-02), and Table 4-4 gives a list of the projects in the entire plan period from 1989 to 2001. According to the list, the capacity of the generating facilities to be added up to 2001 will be 11,950 MW, the capacity of facilities to be retired will be 435 MW. It should be noted that the policy for the formulation of PDP 88-02 will cover the 6th, 7th and the 8th National Economic and Social Development Plan (NESDP), using a minimum reserve margin of 15%.

4.2.2 Demand-Supply Balance and Nam Yuam River Basin Integrated Hydroelectric Development Project

(1) Short-term Forecast of Demand-Supply Balance of EGAT's System

The power demand-supply balance based on the load forecast by JICA in the case where the EGAT's power development plan will be implemented as expected is shown in Table 4-5 (not including the Nam Yuam River Basin Integrated Hydroelectric Development Project).

Table 4-5 indicates that there will be a shortage of supply capacity during a period of 1989 - 1990 when the reserve margin of EGAT's generating system will be lower than 15%.

It is not possible to accelerate the commissioning date of projects in the near future so as to keep pace with the growth of power demand.

To solve this problem, EGAT has decided to take the following temporary measures of demand and supply management: On the demand side, requesting cooperation in the efficient use of electricity, reduction of peak load and reduction of electricity consumption of EGAT's power plants. On the supply side, adjustment of the generation plan and maintenance schedule and overload operation of generating units. Together with these measures, the importation of electricity from Lao PDR and Malaysia will be maintained.

(2) Nam Yuam River Basin Integrated Hydroelectric Development Project

The mid-term projections of the power demand-supply situation as shown in Table 4-5 suggest that the supply capacity will become short in and after 1995, falling below the target reserve margin ratio of 15%. Especially in and after May, 1996, the reserve margin ratio is forecast to go down below 10%, necessitating a review of the power development plan.

On the other hand, the Nam Yuam River Basin Integrated Hydroelectric Development Project is a project of the conventional hydraulic power generation type among the power system of Thailand, and is basically expected to be utilized as facilities for meeting peak load requirements.

Accordingly, it is necessary to accelerate the progress of the development of the Project as far as possible.

Considering the detailed design and construction work period, however, the earliest possible timing of the commissioning date of the project will be August, 1997. The time schedule for the Project to be implemented in 1997 is as follows:

Apr., '91 - Sep., '91	Detailed design and preparation of specifications
Oct., '91 - Feb., '92	Government approval
Mar., '93 - Feb., '97	Construction work of the facilities
Aug., '97	Commissioning of Nam Ngao and Mae Lama Luang Power Plants

The demand-supply balance in the case where 140 MW of the Nam Ngao power plant and 240 MW of the Mae Lama Luang power plant, totaling 380 MW, will be commissioned into service is shown in Table 4-6 (in and after 1997).

As can be seen from this Table, if both the Nam Ngao and the Mae Lama Luang power plants are implemented in August, 1997, it may be considered that the significance of its development will be great in that the reserve margin ratio will be secured at 10% - though not at the target value of 15%.

Fig. 4-1 shows the power development plan incorporating the Nam Yuam River Basin Integrated Hydroelectric Project.

Table 4-4 LIST OF PROJECTS (1989-2001) a/
(LONG TERM PROFILE)

	Power Plant	Fuel Type	Unit Number	Rating (MW)	Total (MW)	Commissioning Date
Under Construction	Khanom 2nd PPB	Oil/Gas	2	75	75	May 1989
	Mae Moh	Lignite	8	300	300	July 1989
	2nd CSTL	-	-	(270)	(270)	February 1990
	Mae Moh	Lignite	9	300	300	December 1990
	Srinagarind	Hydro	5	180	180	April 1991
	Bang Pakong CC	Gas	3	300	300	Jun 90 - Jun 91
	Bang Pakong CC	Gas	4	300	300	Aug 90 - Aug 91
	Mae Mho	Lignite	10	300	300	February 1992
	Band Pakong thermal	Oil/Gas	3	600	600	May 1992
	Rayong Combined Cycle	Gas	1	300	300	Sep 90 - Sep 91
	Rayong combined Cycle	Gas	2	300	300	Oct 90 - Oct 91
	Nan Phong Combined Cycle	Gas	1	300	300	Nov 90 - Dec 91
	Rayong Combined Cycle	Gas	3	300	300	Jan 91 - Jan 92
	230 kV Tha Tako-Khon Kaen 3	-	-	(300)	(300)	January 1992
	Bhumibol Renovation	Hydro	1-2	70	(140)b/	March 1992
	Krabi	Lignite	4	75	75	November 1992
	Mae Moh	Lignite	11	300	300	February 1993
	Bang Pakong Theramal	Oil/Gas	4	600	600	May 1993
	North Bangkok Renovation	Oil	1-3	(2x75+87.5)	(237.5)	August 1993
	Mae Moh	Lignite	12	300	300	October 1993
	Pak Mun	Hydro	1-4	34	136	November 1993
	Mae Moh	Lignite	13	300	300	April 1994
	Mae Moh	Lignite	14	300	300	October 1994
	Kaeng Krung	Hydro	1-2	40	80	December 1994
	Mae Moh	Lignite	15	300	300	April 1995
	Mae Taeng	Hydro	1-2	18+8	26	June 1995
	Saba Yoi	Lignite	1	150	150	October 1995
	Mae Moh	Lignite	16	300	300	November 1995
	South Bangkok Renovation	Oil/Gas	1-5	(2x200+3x300)	(1,300)	December 1995
	Bhumibol	Hydro	8	178	178	January 1996
	Sirikit	Hydro	4	125	125	February 1996
	Lower Sirikit	Hydro	1	15	15	February 1996
	Saba Yoi	Lignite	2	150	150	April 1996
	Saba Yoi	Lignite	3	300	300	October 1996
	Mae Moh	Lignite	17	300	300	November 1996
	Mae Moh	Lignite	18	300	300	April 1997
	New Thermal	Coal	1	600	600	October 1997
	Mae Moh	Lignite	19	300	300	November 1997
	Lower Mae Ping	Hydro	1-2	20	40	July 1998
	New Thermal	Coal	2	600	600	October 1998
	Saba Yoi	Lignite	4	300	300	November 1998
	Nam Khek (1)	Hydro	1-2	25	50	January 1999
	Nam Khek (2)	Hydro	1-2	35	70	February 1999
	New Thermal	Coal	3	600	600	October 1999
	Nam Chern	Hydro	1-4	100	400	November 1999
	New Thermal	Coal	4	600	600	October 2000
	New Thermal	Coal	5	600	600	January 2001

Existing Capacity by 1988	=	6894.2 MW
Total Added Capacity (Up to 2001)	=	11,950.0 MW
Plant Retirement	=	435.0 MW
Total Capacity by Year 2001	=	18,409.2 MW

Notes: a/ This list is only for generation projects and inter-regional transmission projects.
b/ Rating after renovation is expected to be 2x75.4 or 150.8 MW.

Table 4-5 Power Development Plan and Power Balance

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 1988)			4,340.6	2,250.1					
1987	OCT				6,894.2	6,451.2	4,702.0	1,749.2	37.20
	NOV				6,894.2	6,479.4	4,886.7	1,592.7	32.59
	DEC				6,894.2	6,473.4	4,589.8	1,883.6	41.03
1988	JAN				6,894.2	6,461.8	5,003.2	1,458.6	29.15
	FEB				6,894.2	6,437.7	5,011.1	1,426.6	28.46
	MAR				6,894.2	6,393.8	5,210.4	1,183.4	22.71
	APR				6,894.2	6,293.3	5,249.0	1,044.3	19.89
	MAY				6,894.2	6,218.0	5,370.0	848.0	15.79
	JUN				6,894.2	6,202.7	5,242.1	960.6	18.32
	JUL				6,894.2	6,225.0	5,287.5	937.5	17.73
	AUG				6,894.2	6,250.8	5,366.8	884.0	16.47
	SEP				6,894.2	6,392.4	5,444.0	948.4	17.42
(FY 1989)			4,569.0	2,250.1					
	OCT				6,894.2	6,451.2	5,111.1	1,340.1	26.21
	NOV				6,894.2	6,479.4	5,311.9	1,167.5	21.98
	DEC				6,894.2	6,473.4	4,989.4	1,484.3	29.75
1989	JAN				6,894.2	6,461.8	5,438.5	1,023.3	18.81
	FEB				6,894.2	6,437.7	5,447.1	990.6	18.18
	MAR				6,894.2	6,393.8	5,663.7	730.1	12.89
	APR				6,894.2	6,293.3	5,705.7	587.6	10.29
	MAY	KHANOM 2ND PPB	75.0		6,969.2	6,289.3	5,837.2	452.0	7.74
	JUN				6,969.2	6,274.0	5,698.2	575.8	10.10
	JUL	MAE MOH #8	300.0		7,269.2	6,581.3	5,747.5	833.7	14.50
	AUG				7,269.2	6,607.1	5,833.7	773.3	13.25
	SEP				7,269.2	6,748.7	5,917.6	831.1	14.04
(FY 1990)			4,944.0	2,250.1					
	OCT				7,269.2	6,807.5	5,738.9	1,068.5	18.61
	NOV				7,269.2	6,835.7	5,964.4	871.3	14.60
	DEC				7,269.2	6,829.7	5,602.0	1,227.6	21.91
1990	JAN				7,269.2	6,818.1	6,106.6	711.5	11.65
	FEB	2ND CSTL			7,269.2	6,794.0	6,116.2	677.7	11.08
	MAR				7,269.2	6,750.1	6,359.5	390.6	6.14
	APR				7,269.2	6,649.6	6,406.6	243.0	3.79
	MAY				7,269.2	6,574.3	6,554.3	20.0	0.30
	JUN	BANG PAKONG CC #3 (GT)	200.0		7,469.2	6,749.0	6,398.1	350.8	5.48
	JUL				7,469.2	6,771.3	6,453.6	317.7	4.92
	AUG	BANG PAKONG CC #4 (GT)	200.0		7,669.2	6,987.1	6,550.3	436.7	6.66
	SEP	RAYONG CC #1 (GT)	200.0		7,869.2	7,318.7	6,644.5	674.2	10.14

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 1991)			5,544.0	2,250.1					
	OCT	RAYONG CC #2 (GT)	200.0		8,069.2	7,567.5	6,399.0	1,168.4	18.26
	NOV	NAM PHONG CC (GT)	200.0		8,269.2	7,785.7	6,650.4	1,135.3	17.07
	DEC	MAE MOH #9	300.0		8,569.2	8,064.7	6,246.3	1,818.3	29.11
1991	JAN	RAYONG CC #3 (GT)	200.0		8,769.2	8,243.1	6,808.9	1,434.1	21.06
	FEB				8,769.2	8,219.0	6,819.7	1,399.3	20.51
	MAR				8,769.2	8,175.1	7,090.9	1,084.2	15.29
	APR	SRINAGARIND #5 *		180.0	8,949.2	8,254.6	7,143.4	1,111.1	15.55
	MAY				8,949.2	8,179.3	7,308.1	871.2	11.92
	JUN	BANG PAKONG CC #3 (ST)	100.0		9,049.2	8,259.0	7,134.0	1,124.9	15.76
	JUL				9,049.2	8,281.3	7,195.8	1,085.4	15.08
	AUG	BANG PAKONG CC #4 (ST)	100.0		9,149.2	8,402.1	7,303.7	1,098.3	15.03
	SEP	RAYDONG CC #1 (ST)	100.0		9,249.2	8,638.7	7,408.7	1,230.0	16.60
(FY 1992)			6,744.0	2,430.1					
	OCT	RAYDONG CC #2 (ST)	100.0		9,349.2	8,792.5	7,075.5	1,717.0	24.26
	NOV				9,349.2	8,820.7	7,353.4	1,467.3	19.95
	DEC	NAM PHONG CC #1 (ST)	100.0		9,449.2	8,909.7	6,906.6	2,003.0	29.00
1992	JAN	RAYONG CC #3 (ST)	100.0		9,549.2	8,993.1	7,528.7	1,464.3	19.45
	FEB	MAE MOH #10	300.0		9,849.2	9,254.0	7,540.6	1,713.4	22.72
	MAR	BHUMIBOL RENOVATION *		10.8	9,849.2	9,220.0	7,840.5	1,379.4	17.59
	APR				9,449.2	9,119.0	7,898.6	1,220.4	15.45
	MAY	BANG PAKONG THERMAL #3	600.0		10,449.2	9,613.3	8,080.6	1,532.6	18.96
	JUN				10,449.2	9,597.9	7,888.2	1,709.7	21.67
	JUL				10,449.2	9,620.3	7,956.5	1,663.8	20.91
	AUG				10,449.2	9,646.3	8,075.8	1,570.4	19.44
	SEP				10,449.2	9,788.5	8,191.9	1,596.6	19.49
(FY 1993)			7,944.0	2,440.9					
	OCT	KARIBI #1,3 RETIRED	-40.0		10,409.2	9,809.6	7,785.9	2,023.7	25.99
	NOV	KARABI #4	75.0		10,484.2	9,909.2	8,091.7	1,817.5	22.46
	DEC				10,484.2	9,903.2	7,600.1	2,303.0	30.30
1993	JAN				10,484.2	9,891.5	8,284.6	1,606.9	19.39
	FEB	MAE MOH #11	300.0		10,784.2	10,152.3	8,297.7	1,854.6	22.35
	MAR				10,784.2	10,108.2	8,627.7	1,480.4	17.15
	APR				10,784.2	10,007.2	8,691.6	1,315.5	15.13
	MAY	BANG PAKONG THERMAL #3	600.0		11,384.2	10,501.6	8,892.0	1,609.5	18.10
	JUN				11,384.2	10,486.2	8,680.2	1,805.9	20.80
	JUL				11,384.2	10,508.6	8,755.4	1,753.2	20.02
	AUG	NB RENOVATION			11,384.2	10,534.5	8,886.7	1,647.8	18.54
	SEP				11,384.2	10,676.8	9,014.4	1,662.4	18.44

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 1994)			8,879.0	2,440.9					
	OCT	MAE MOH #12	300.0		11,684.2	11,020.9	8,532.4	2,488.4	29.16
	NOV	PAK MUN #1-4		136.0	11,820.2	11,178.5	8,867.6	2,310.9	26.06
	DEC	R2 GT RETIRED	-30.0		11,790.2	11,143.6	8,328.8	2,814.8	33.79
1994	JAN				11,790.2	11,131.2	9,079.0	2,052.2	22.60
	FEB				11,790.2	11,105.6	9,093.9	2,012.2	22.12
	MAR				11,790.2	11,058.8	9,454.9	1,603.8	16.96
	APR	MAE MOH #13	300.0		12,090.2	11,236.8	9,525.0	1,711.7	17.97
	MAY				12,090.2	11,156.5	9,744.6	1,411.9	14.48
	JUN				12,090.2	11,140.2	9,512.5	1,627.7	17.11
	JUL				12,090.2	11,164.0	9,594.8	1,569.1	16.35
	AUG				12,090.2	11,191.5	9,738.7	1,452.7	14.91
	SEP				12,090.2	11,342.3	9,878.7	1,463.6	14.81
(FY 1995)			9,449.00	2,576.0					
	OCT	MAE MOH #14	300.0		12,390.2	11,690.0	9,316.7	2,373.2	25.47
	NOV			80.0	12,390.2	11,720.0	9,682.7	2,037.2	21.04
	DEC	KAENG KRUNG #1-2			12,470.2	11,789.4	9,094.9	2,695.0	29.63
1995	JAN	R3 GT RETIRED	-90.0		12,380.2	11,691.2	9,913.5	2,777.6	17.93
	FEB				12,380.2	11,664.6	9,929.2	2,735.4	17.47
	MAR				12,380.2	11,616.3	10,324.1	2,292.2	12.51
	APR	MAE MOH #15	300.0		12,680.2	11,790.7	10,400.6	1,390.1	13.36
	MAY				12,680.2	11,707.8	10,640.3	1,067.4	10.03
	JUN	MAE TAENG #1-2		26.0	12,706.2	11,712.5	10,386.9	1,325.5	12.76
	JUL				12,706.2	11,737.3	10,476.9	1,260.4	12.03
	AUG				12,706.2	11,766.0	10,634.0	1,131.9	10.64
	SEP				12,706.2	11,923.5	10,786.8	1,136.7	10.53
(FY 1996)			9,959.0	2,682.9					
	OCT	SABA YOI #1	150.0		12,856.2	12,131.4	10,140.8	1,990.5	19.62
	NOV	MAE MOH #16	300.0		13,156.2	12,447.8	10,539.2	1,908.6	18.10
	DEC	SB RENOVATION			13,156.2	12,441.1	9,898.8	2,542.2	25.68
1996	JAN	BHUMIBOL #8		178.0	13,334.2	12,596.0	10,790.4	1,805.5	16.73
	FEB	SIRIKIT #4/LOWER SIRIKIT #1		140.0	13,474.2	12,697.8	10,807.4	1,890.3	17.49
	MAR				13,474.2	12,642.7	11,237.3	1,405.4	12.50
	APR	SABA YOI #1	150.0		13,624.2	12,659.2	11,320.5	1,338.7	11.82
	MAY				13,624.2	12,564.8	11,581.5	983.3	8.49
	JUN				13,624.2	12,545.6	11,305.6	1,240.0	10.96
	JUL				13,624.2	12,573.6	11,403.5	1,170.0	10.26
	AUG				13,624.2	12,606.0	11,574.6	1,031.3	8.91
	SEP				13,624.2	12,783.5	11,740.9	1,042.6	8.88

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 1997)			10,559.0	3,000.9					
	OCT	SABA YOI #3	300.0		13,924.2	13,142.2	10,808.0	2,334.2	21.59
	NOV	MAE MOH #17	300.0		14,224.2	13,462.5	11,232.5	2,230.0	19.85
	DEC				14,224.2	13,455.0	10,550.1	2,904.9	27.53
1997	JAN				14,224.2	13,440.5	11,500.3	1,940.1	16.87
	FEB				14,224.2	13,410.3	11,518.4	1,891.8	16.42
	MAR				14,224.2	13,355.2	11,976.5	1,378.6	11.51
	APR	MAE MOH #18	300.0		14,524.2	13,514.2	12,065.3	1,448.9	12.00
	MAY				14,524.2	13,419.8	12,343.4	1,076.4	8.72
	JUN				14,524.2	13,400.6	12,049.4	1,351.2	11.21
	JUL				14,524.2	13,428.6	12,153.8	1,274.8	10.48
	AUG				14,524.2	13,461.0	12,336.0	1,124.9	9.11
	SEP				14,524.2	13,638.5	12,513.3	1,125.2	8.99
(FY 1998)			11,459.0	3,000.9					
	OCT	NEW THERMAL #1	600.0		15,124.2	14,282.2	11,500.7	2,781.4	24.18
	NOV	MAE MOH #19	300.0		15,424.2	14,602.5	11,952.5	2,650.0	22.17
	DEC				15,424.2	14,595.0	11,226.3	3,368.6	30.00
1998	JAN				15,424.2	14,580.5	12,237.4	2,343.0	19.14
	FEB	SURAT THANI RETIRED	-30.0		15,394.2	14,521.8	12,256.8	2,264.9	18.47
	MAR				15,394.2	14,466.7	12,744.2	1,722.4	13.51
	APR				15,394.2	14,340.7	12,838.6	1,502.0	11.69
	MAY				15,394.2	14,246.3	13,134.6	1,111.7	8.46
	JUN				15,394.2	14,227.1	12,821.8	1,405.3	10.96
	JUL	LOWER MAE PING #1-2		40.0	15,434.2	14,288.6	12,932.8	1,355.7	10.48
	AUG				15,434.2	14,321.4	13,126.8	1,194.6	9.10
	SEP				15,434.2	14,501.4	13,315.4	1,186.0	8.90
(FY 1999)			12,329.0	3,040.9					
	OCT	NEW THERMAL #2	600.0		16,034.2	15,146.2	12,220.8	2,925.3	23.93
	NOV	SABA YOI #4	300.0		16,334.2	15,467.1	12,700.9	2,766.1	21.77
	DEC				16,334.2	15,459.4	11,929.2	3,530.2	29.59
1999	JAN	NAM KEK (1) #1-2		50.0	16,384.2	15,491.8	13,003.7	2,488.1	19.13
	FEB	NAM KEK (2) #1-2		70.0	16,454.2	15,525.9	13,024.2	2,501.6	19.20
	MAR				16,454.2	15,467.7	13,542.2	1,925.5	14.21
	APR				16,454.2	15,334.6	13,642.5	1,692.0	12.40
	MAY				16,454.2	15,234.8	13,957.0	1,277.8	9.15
	JUN				16,454.2	15,214.6	13,624.6	1,589.9	11.67
	JUL				16,454.2	15,244.1	13,742.6	1,501.5	10.92
	AUG				16,454.2	15,278.3	13,948.7	1,329.6	9.53
	SEP				16,454.2	15,465.9	14,149.1	1,316.8	9.30

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 2000)			13,229.0	3,160.9					
	OCT	NEW THERMAL #3	600.0		17,054.2	16,138.6	12,968.4	3,170.1	24.44
	NOV	NAM CHERN #1-4 *		400.0	17,454.2	16,551.1	13,477.8	3,073.3	22.80
	DEC				17,454.2	16,543.2	12,658.9	3,884.2	30.68
2000	JAN	LKG GT RETIRED	-45.0		17,409.2	16,485.1	13,799.1	2,685.9	19.46
	FEB				17,409.2	16,453.1	13,820.9	2,632.2	19.04
	MAR				17,409.2	16,395.0	14,370.6	2,024.4	14.08
	APR				17,409.2	16,261.8	14,477.0	1,784.8	12.32
	MAY				17,409.2	16,162.1	14,810.7	1,351.3	9.12
	JUN				17,409.2	16,141.8	14,458.0	1,683.8	11.64
	JUL				17,409.2	16,171.4	14,583.2	1,588.1	10.89
	AUG				17,409.2	16,205.5	14,801.9	1,403.6	9.48
	SEP				17,409.2	16,393.1	15,014.6	1,378.5	9.18
(FY 2001)			13,784.0	3,560.9					
	OCT	NEW THERMAL #4	600.0		18,009.2	17,041.0	13,745.3	3,295.7	23.97
	NOV				18,009.2	17,078.4	14,285.2	2,793.1	19.55
	DEC	SOUTH BANGKOK #1 RETIRED	-200.0		17,809.0	16,880.4	13,417.3	3,463.1	25.81
2001	JAN	NEW THERMAL #5	600.0		18,409.2	17,435.1	14,625.8	2,809.2	19.20
	FEB				18,409.2	17,403.1	14,648.9	2,754.2	18.80
	MAR				18,409.2	17,345.0	15,231.5	2,113.5	13.87
	APR				18,409.2	17,211.8	15,344.3	1,867.5	12.17
	MAY				18,409.2	17,112.1	15,698.0	1,414.0	9.00
	JUN				18,409.2	17,091.8	15,324.1	1,767.6	11.53
	JUL				18,409.2	17,121.4	15,456.9	1,664.5	10.76
	AUG				18,409.2	17,155.5	15,688.7	1,466.8	9.34
	SEP				18,409.2	17,343.1	15,914.1	1,429.0	8.97

Table 4-6 Power Development Plan and Power Balance (Including Mae Lama Luang, Mam Ngao Project)

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY NON-HYDRO (MW)	RATED CAPACITY HYDRO (MW)	ACCUMULATED CAPACTY INSTALLED (MW)	ACCUMULATED CAPACTY DEPENDABLE (MW)	PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN (MW)	RESERVE MARGIN (%)
(FY 1997)			10,559.0	3,000.9					
	OCT	SABA YOI #3	300.0		13,924.2	13,142.2	10,808.0	2.334.2	21.59
	NOV	MAE MOH #17	300.0		14,224.2	13,462.5	11.232.5	2.230.0	19.85
	DEC				14,224.2	13,455.0	10.550.1	2.904.9	27.53
1997	JAN				14,224.2	13,440.5	11,500.3	1.940.1	16.87
	FEB				14,224.2	13,410.3	11.518.4	1.891.8	16.42
	MAR				14,224.2	13,355.2	11.976.5	1.378.6	11.51
	APR	MAE MOH #17	300.0		14,524.2	13,514.2	12.065.3	1.448.9	12.00
	MAY				14,524.2	13,419.8	12,343.4	1.076.4	8.72
	JUN				14,524.2	13,400.6	12,049.4	1.351.2	11.21
	JUL				14,524.2	13,428.6	12.153.8	1.274.8	10.48
	AUG	Mae Lama Luang, Nam Ngao		380.0	14,904.2	13,783.6	12,336.0	1.447.5	11.73
	SEP				14,904.2	13,985.0	12.513.3	1.471.7	11.76
(FY 1998)			11,459.0	3,380.9					
	OCT	NEW THERMAL #1	600.0		15,504.2	14,638.6	11,500.7	3.137.8	27.28
	NOV	MAE MOH #18	300.0		15,804.2	14,963.8	11,952.5	3.011.2	25.19
	DEC				15,804.2	14,955.2	11,226.3	3.728.9	33.21
1998	JAN				15,804.2	14,938.7	12,237.4	2.701.2	22.07
	FEB	SURAT THANI RETIRED	-30.0		15,774.2	14,875.9	12.256.8	2.619.1	21.36
	MAR				15,774.2	14,813.5	12.744.2	2.069.2	16.23
	APR				15,774.2	14,670.5	12.838.6	1.831.8	14.26
	MAY				15,774.2	14,563.4	13.134.6	1.428.8	10.87
	JUN				15,774.2	14,541.6	12.821.8	1.719.8	13.41
	JUL	LOWER MAE PING #1-2		40.0	15,814.2	14,606.9	12.932.8	1.674.0	12.94
	AUG				15,814.2	14,644.0	13.126.8	1.517.2	11.55
	SEP				15,814.2	14,848.0	13.315.4	1.532.6	11.51
(FY 1999)			12,329.0	3,420.9					
	OCT	NEW THERMAL #2	600.0		16,414.2	15,502.7	12,220.8	3.281.8	26.85
	NOV	SABA YOI #4	300.0		16,714.2	15,828.3	12.700.9	3.127.4	24.62
	DEC				16,714.2	15,819.6	11.929.2	3.890.4	32.61
1999	JAN	NAM KOK (1) #1-2		50.0	16,764.2	15,850.1	13,003.7	2.846.4	21.88
	FEB	NAM KOK (2) #1-2		70.0	16,834.2	15,880.1	13.024.2	2.855.8	21.92
	MAR				16,834.2	15,814.5	13.542.2	2.272.3	16.77
	APR				16,834.2	15,664.4	13.642.5	2.021.8	14.82
	MAY				16,834.2	15,551.9	13.957.0	1.594.9	11.42
	JUN				16,834.2	15,529.1	13.624.6	1.904.4	13.97
	JUL				16,834.2	15,562.4	13.742.6	1.819.8	13.24
	AUG				16,834.2	15,600.9	13.948.7	1.652.2	11.84
	SEP				16,834.2	15,812.4	14.149.1	1.663.3	11.75

IN-SERVICE DATE		NAME OF POWER PLANT	RATED CAPACITY		ACCUMULATED CAPACTY		PEAK GENERATION REQUIREMENT (MW)	RESERVE MARGIN	
			NON-HYDRO (MW)	HYDRO (MW)	INSTALLED (MW)	DEPENDABLE (MW)		(MW)	(%)
(FY 2000)			13,229.0	3,540.9					
	OCT	NEW THERMAL #3	600.0		17,434.2	16,495.0	12,968.4	3,526.6	27.19
	NOV	NAM CHERN #1-4 *		400.0	17,834.2	16,912.4	13,477.8	3,434.5	25.48
	DEC				17,834.2	16,903.4	12,658.9	4,244.4	33.52
2000	JAN	LKG GT RETIRED	-45.0		17,789.2	16,843.3	13,799.1	3,044.2	22.06
	FEB				17,789.2	16,807.3	13,820.9	2,986.4	21.60
	MAR				17,789.2	16,741.7	14,370.6	2,371.1	16.50
	APR				17,789.2	16,591.6	14,477.0	2,114.6	14.60
	MAY				17,789.2	16,479.2	14,810.7	1,668.4	11.26
	JUN				17,789.2	16,456.3	14,458.0	1,998.3	13.82
	JUL				17,789.2	16,489.6	14,583.2	1,906.4	13.07
	AUG				17,789.2	16,528.2	14,801.9	1,726.2	11.66
	SEP				17,789.2	16,739.7	15,014.6	1,725.1	11.48
(FY 2001)			13,784.0	3,940.9					
	OCT	NEW THERMAL #4	600.0		18,389.2	17,397.5	13,745.3	3,652.1	26.57
	NOV				18,389.2	17,439.6	14,285.2	3,154.3	22.08
	DEC	SOUTH BANGKOK #1 RETIRED	-200.0		18,189.2	17,240.6	13,417.3	3,823.3	28.49
2001	JAN	NEW THERMAL #5	600.0		18,789.2	17,793.3	14,625.8	3,167.5	21.65
	FEB				18,789.2	17,757.3	14,648.9	3,108.4	21.21
	MAR				18,789.2	17,691.7	15,231.5	2,460.2	16.15
	APR				18,789.2	17,541.6	15,344.3	2,197.3	14.32
	MAY				18,789.2	17,429.2	15,698.0	1,731.1	11.02
	JUN				18,789.2	17,406.3	15,324.1	2,082.1	13.58
	JUL				18,789.2	17,439.6	15,456.9	1,982.7	12.82
	AUG				18,789.2	17,478.2	15,688.7	1,789.4	11.40
	SEP				18,789.2	17,689.7	15,914.1	1,775.6	11.15

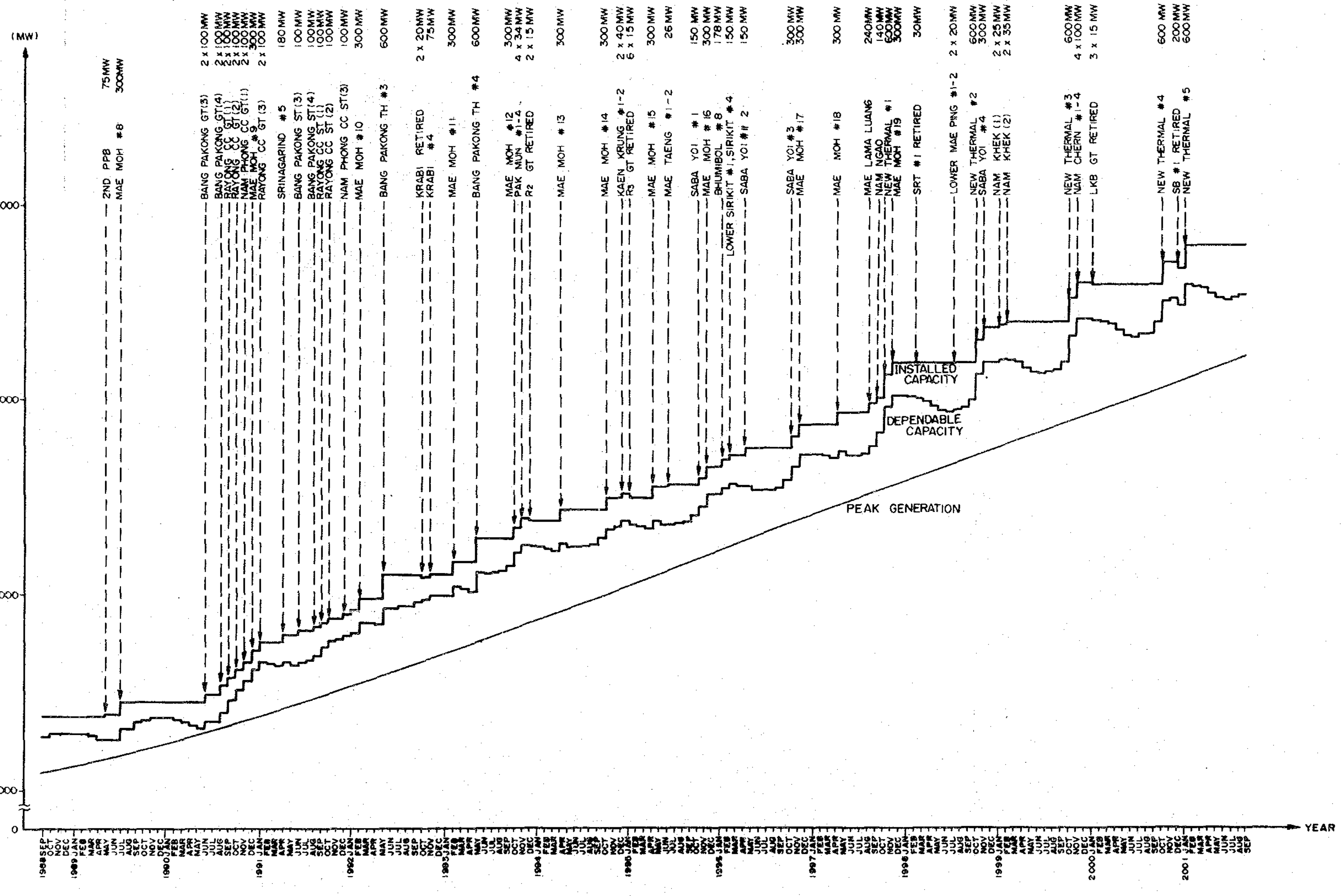

Fig. 4.1 Power Development Plan

CHAPTER 5

HYDROLOGY

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5.1 General

The Yuam river situated in the Mae Hong Son Province in the northwest of Thailand, originates in a mountain area of about 1,000 m in elevation in the northernmost part of the Mae Hong Son Province. The river flows southward while combining with several tributaries via Mae Sariang Town and combines with the Ngao river. Thereafter, the Yuam river flows westward, combines with the Moei river that flows along the border with Myanmar, combines with the Salawin river and finally pours into the Andaman Sea. The length of the Yuam river is about 180 km and the area of the basin is as large as about 6,000 km^2.

The Yuam river basin belongs to a typical tropical monsoon zone. It rains heavily over the basin between May and October due to the southwest monsoon from the Bay of Bengal. Conversely between November and April when the northeast monsoon from continent becomes stronger, it forms a dry season with almost no rainfall. The precipitation over the basin is recorded at about 1,300 mm per year on average.

The temperature is high throughout the year, i.e. about 27°C on average. It is particularly hot in April and the highest temperature of the day reaches as high as 40°C. The temperature becomes the lowest in December and January, and the lowest temperature of the day becomes as low as 10°C.

The relative humidity is high throughout the year. It is about 85% in the plain area in the middle reaches of the basin and higher than 90% in the mountains of the lower reaches. In March and April the humidity falls to about 60%, occasionally.

The average evaporation is about 1,300 mm per year on the basis of the measured value of a Class A Pan. The evaporation in the lower reaches is smaller than in the upper or middle reaches. The evaporation becomes the largest in March and April.

5.2 Meteorological Station and Stream-flow Gauging Station

There are many meteorological and stream-flow gauging stations provided by authorities such as the National Energy Administration (NEA), the Meteorology Department (MD), the Royal Irrigation Department (RID) and EGAT in the Yuam river basin. The hydrological data such as rainfall, relative humidity, evaporation, runoff and suspended sediment concentration, are being measured. Table 5-1 and Fig. 5-1 show the location of meteorological and stream-flow gauging stations.

5.2.1 Meteorological Station

The meteorological stations in the basin account for nine locations in total; five locations operated by the NEA, one operated by the MD and three operated by EGAT. The items measured at these stations are indicated in the following table. The Chom Chaeng meteorological station was closed at the end of 1985, and a total of 8 stations are now being operated.

Station		Precipitation (Daily)	Temperature (Daily Max., Min.)	Relative Humidity (Daily)	Evaporation (Daily)
NEA	Khun Yuam	o			
NEA	Mae La Luang	o			o
NEA	Sop Han	o	o	o	o
NEA	Chom Chaeng	o 1)			
NEA	Ban Tha Rua	o	o	o	o
MD	Mae Sariang	o			
EGAT	Wang Khan	o	o 2)	o 3)	o 3)
EGAT	Ban Mae Rit	o	o	o	o
EGAT	Ban Mae Ngao	o	o	o	o

1) Closed in December, 1985
2) Closed in December, 1986
3) Closed in November, 1986

Most of the meteorological stations managed by the NEA were installed in the late 1960's and in the beginning of the 1970's. Various data have been recorded over a period of between 10 years and nearly 20 years. The three stations managed by EGAT started operating between 1983 and 1984, and records have only a short period of several years. Figs. 5-2 (1) to 5-2 (5) show the period of observations and items measured at each station.

The Sop Han, Chom Chaeng and Mae Sariang stations are located near to each other and can be regarded as one location, substantially. In view of the drainage area of about 6,000 km^2 and the localized nature of the rainfall, the rainfall records are not sufficient quantitatively. The rainfall records at Mae Sariang cover the longest period among these stations.

The Khun Yuam station of the NEA, located in the uppermost reaches of the Yuam river, has been operated for over 30 years since 1952. This record was judged useful to grasp the hydrologic characteristics in the upstream region.

The daily data of both the relative humidity and the air temperature have been taken at 4 stations; Sop Han, Ban Tha Rua, Ban Mae Rit and Ban Mae Ngao. The longest records are for 20 years at Sop Han for relative humidity and for 14 years at Ban Tha Rua for air temperature.

The evaporation has been measured at the above 4 stations and at Mae La Luang. The longest records are for 17 years at Sop Han.

In addition, the monthly average value of the wind velocity at Mae Sariang and the daily wind velocity at Salawin have been recorded for about 4 years.

At EGAT's Ban Mae Rit station the hourly data of both the temperature and the relative humidity have been taken since June 1988.

5.2.2 Stream-flow Gauging Station

There are two gauging stations of the NEA; Sop Han and Ban Tha Rua, (in addition there used to be a gauging station at Chom Chaeng which was closed in 1983), and three stations of EGAT; Wang Khan, Ban Mae Rit and Ban Mae Ngao. EGAT's stations were started between 1983 and 1984. Therefore, the periods of observation are short. On the other hand, the runoff records have been kept for 19 years at Sop Han and for 18 years at Ban Tha Rua. These data can be used for a long-term runoff analysis.

Of the above 5 stream-flow gauging stations, Sop Han, Ban Tha Rua and Wang Khan are located along the Yuam river. The Sop Han station is located upstream of Mae Sariang. The Wang Khan station is located about 30 km upstream of Sop Han. The Ban Mae Rit and Ban Mae Ngao stations are located at the most downstream point of the Rit river and Ngao river, respectively.

At these five gauging stations, measurements have been taken of the hourly runoff during floods, (only during 6:00 - 18:00 hrs and no measurement is taken at night). At the same time the suspended sediment concentration has also been measured. Figs. 5-2 (6) and (7) show the observation period of each gauging station.

There is a weir for irrigation installed by the RID immediately downstream of the Sop Han gauging station, providing a maximum intake of irrigation water of 3 m^3/sec since 1976.

Table 5 — 1 Location of Runoff Gauging Stations

Station	River	Administrator	Location Longitude (E)	Location Latitude (N)	Catchment Area (km^2)
Mae La Luang	Nam Mae La Luang	NEA			328
Sop Han	Nam Mae Yuam	NEA	97° - 56.1'	18° - 12.2'	2,496
Cham Chaeng	Nam Mae Sariang	NEA	97° - 58.0'	18° - 9.8'	378
Ban Tha Rua	Nam Mae Yuam	NEA	97° - 54.8'	17° - 50.0'	5,770
Wang Khan	Nam Mae Yuam	EGAT	97° - 58.2'	18° - 23.3'	1,974
Ban Mae Rit	Nam Mae Rit	EGAT	97° - 57.8'	17° - 53.5'	1,376
Ban Mae Ngao	Nam Mae Ngao	EGAT	97° - 58.2'	17° - 51.3'	935
RID Irrigation Weir	Nam Mae Yuam	RID	97° - 56.1'	18° - 21.9'	2,617

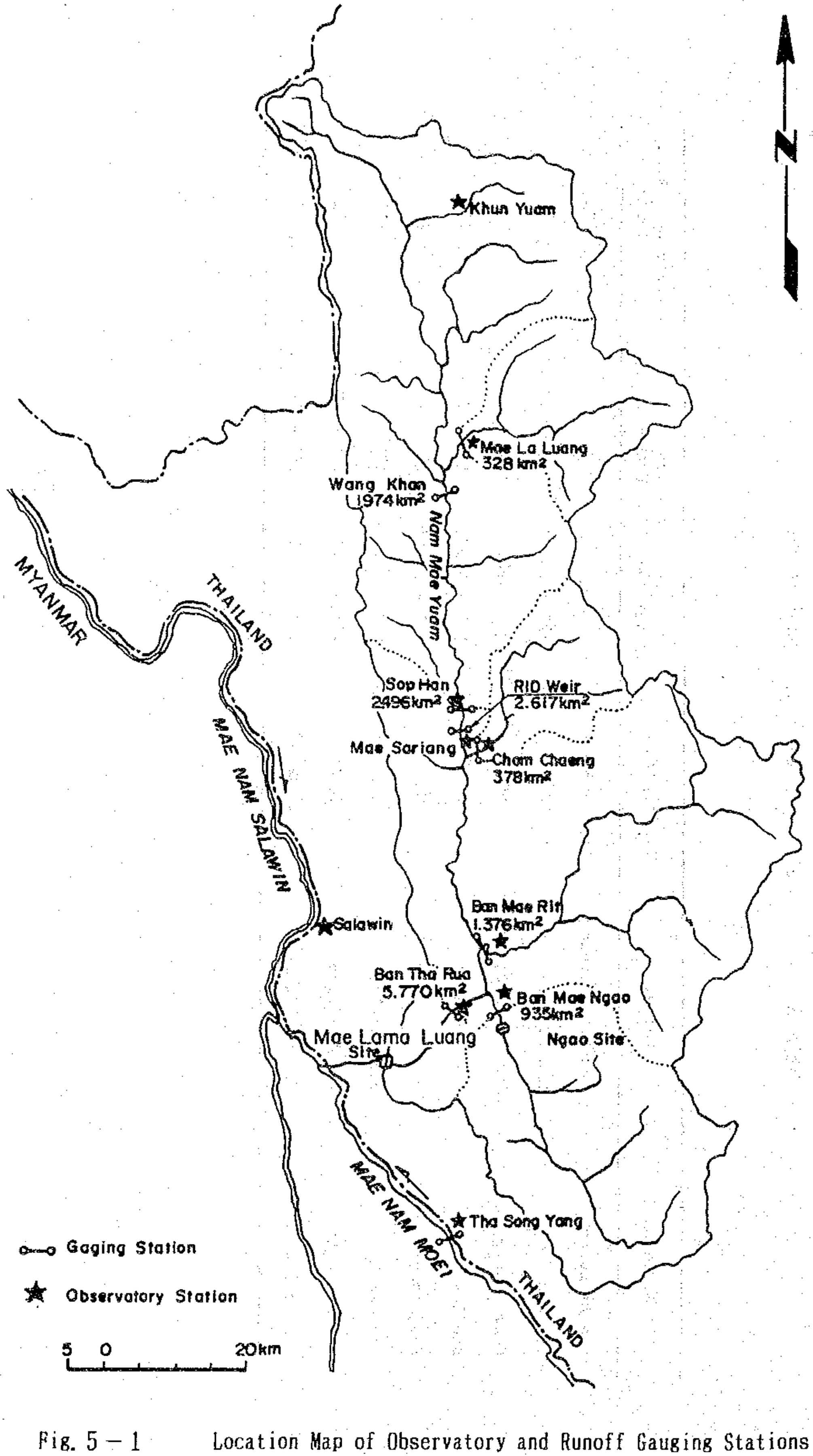


Fig. 5 − 1　　Location Map of Observatory and Runoff Gauging Stations

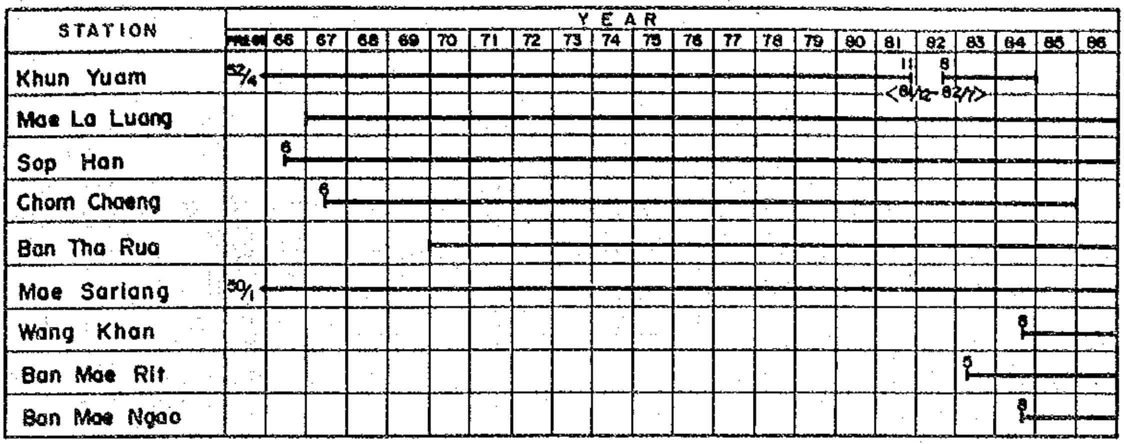


Fig. 5 − 2(1) Measurement Period of Daily Precipitation

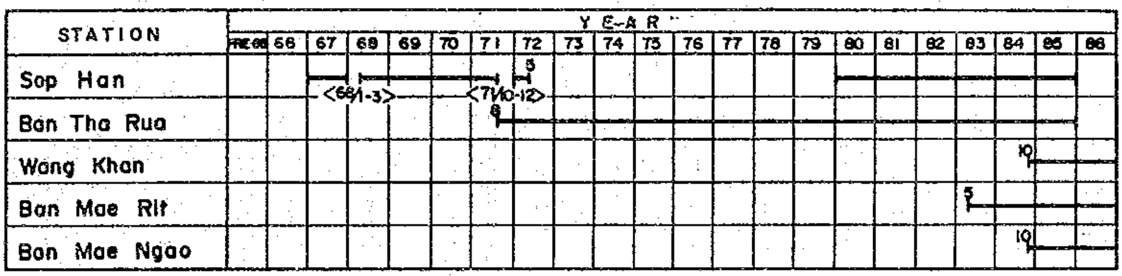


Fig. 5 − 2(2) Measurement Period of Daily Temperature (Max. and Min.)

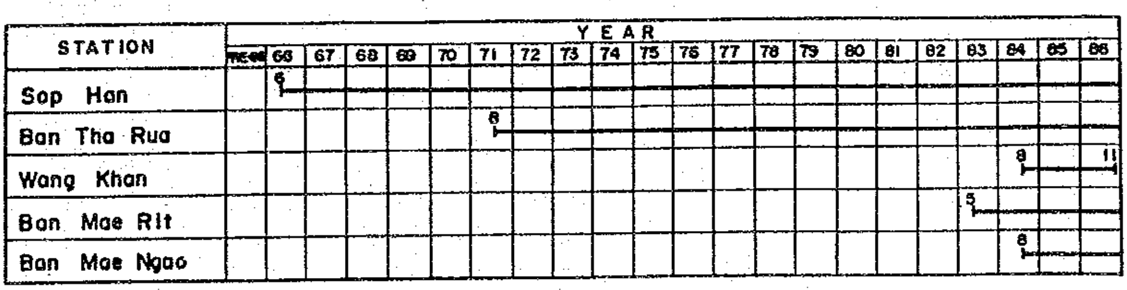


Fig. 5 − 2(3) Measurement Period of Daily Relative Humidity

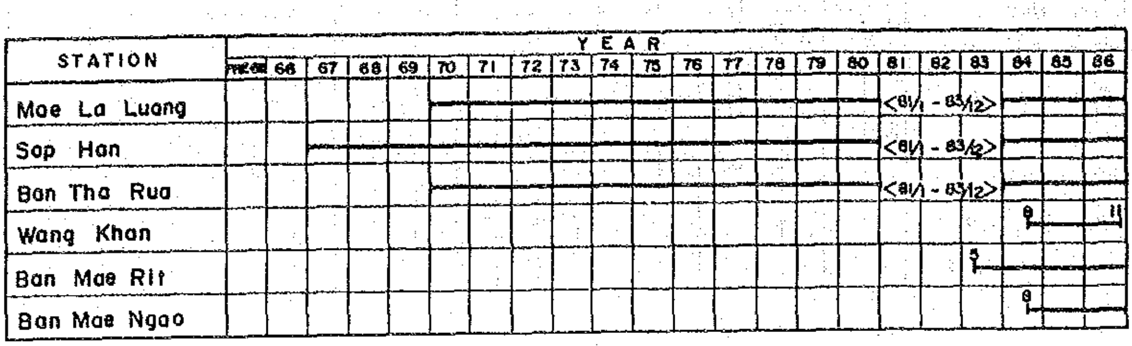


Fig. 5 – 2 (4)   Measurement Period of Daily Evaporation

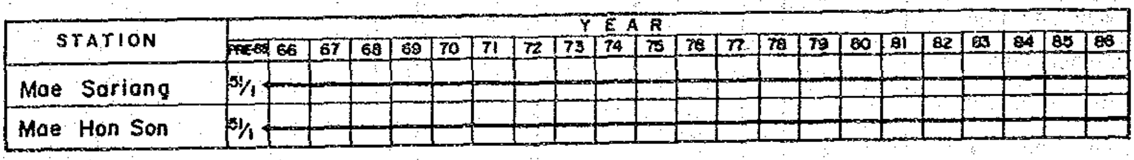


Fig. 5 – 2 (5)   Measurement Period of Wind Movement (Monthly)

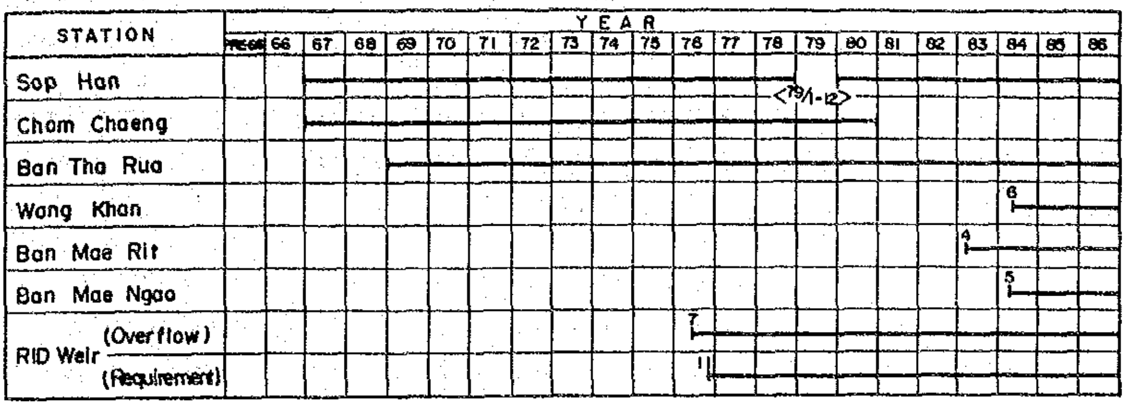


Fig. 5 — 2(6) Measurement Period of Daily Runoff

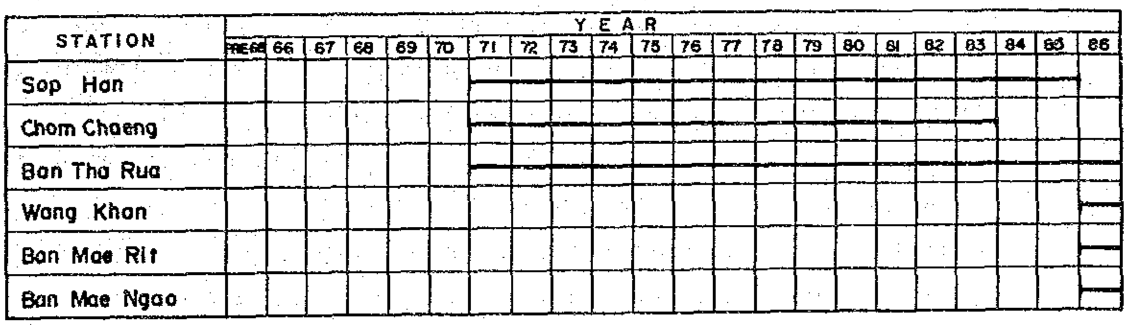


Fig. 5 — 2(7) Measurement Period of Daily Suspended Sedimemt

5.3 Hydrological Features of the Basin

5.3.1 Precipitation

The precipitation in the Yuam river basin shows a striking contrast between the rainy season and the dry season due to tropical monsoon.

The rainy season generally starts around May and continues till the end of October, while the dry season starts in the beginning of November and continues till April.

The annual total precipitation in the basin is about 1,300 mm, 90% of which is concentrated in 6 months of the rainy season. The precipitation during the dry season accounts for the remaining 10%. Table 5-2 and Fig. 5-3 show the monthly average precipitation at each meteorological station and Fig. 5-4 shows the annual precipitations.

In this basin the southwest monsoon blowing in from the Bay of Bengal dominates in the rainy season. For this monsoon, a considerable difference in the precipitation can be recognized in the basin because of its long topography to the north and south. The average annual precipitation is as much as 1,600 mm at Ban Tha Rua in the downstream reaches of the basin. While at Mae Sariang and at Sop Han etc., which are located in the middle reaches of the basin, the precipitation is only between 1,100 and 1,200 mm. At Khun Yuam located in the upstream reaches, the precipitation is as much as 1,300 mm. On the other hand, at the Tha Song Yang meteorological station in the Moei river basin which is located further south of Ban Tha Rua, the annual precipitation is as much as about 2,000 mm, nearly two times that of Sop Han (see the table below). The isohyetal map of the basin in 1984 is shown in Fig. 5-5.

The maximum recorded daily precipitation was 131.0 mm at Mae Sariang on May 23, 1980.

Observatory Station	Average Annual Precipitation (mm)	Period of Measurement
Ban Tha Rua	1,600	1970-1986
Mae Sariang	1,229	1950-1984
Sop Han	1,197	1967-1986
Khun Yuam	1,345	1959-1984
Tha Song Yang	1,981	1967-1986

5.3.2 Air Temperature

According to the records at Sop Han and Ban Tha Rua, the annual average values of the daily maximum and minimum temperatures are about 33°C and 20°C, respectively.

The daily minimum temperature is the lowest in February, i.e. about 13°C. The temperature sometimes goes down to 10°C, recording 6°C at Ban Tha Rua in January 1974. The daily minimum temperature is fairly constant at about 23°C from May to October during the rainy season.

The daily maximum temperature becomes the highest in April, i.e. about 38°C. On some days the temperature exceeds 40°C, and the recorded highest value was 44.5°C at Sop Han in April 1981.

The difference between the daily minimum and maximum temperatures becomes the largest in March, i.e. about 21°C. The difference becomes the smallest (7-8°C) in July or August.

Table 5-3 and Fig. 5-6 show the monthly fluctuation in the daily maximum and daily minimum temperatures.

5.3.3 Relative Humidity

The relative humidities in the basin show a high value of about 90% on an annual average basis.

The annual average of relative humidity at Sop Han is 86% and it is 94% at Ban Tha Rua. This difference is due to the effects of both topography (the mountains and plains) and the difference in annual precipitation.

Table 5-4 and Fig. 5-7 show the changes in the relative humidity by month at each station.

5.3.4 Evaporation

The annual evaporation in the basin is about 1,400 mm at Sop Han and about 1,200 mm at Ban Tha Rua. The maximum daily evaporation of about 6 mm occurs in April.

The monthly evaporations at two stations are shown in Table 5-5 and Fig. 5-8. The measurements were all taken using a Class A Pan.

5.3.5 River Flow

The runoff records at the Ban Tha Rua gauging station (1969 - 1986) show the average annual inflow of about 2,825 x 10^6 m^3 and the average runoff of 89.6 m^3/sec. Table 5-6 and Fig. 5-9 show the monthly runoff at Ban The Rua. The daily maximum runoff recorded at the Ban Tha Rua gauging station was 1,020 m^3/sec on August 2, 1969.

Comparing the runoff at Sop Han (catchment area = 2,496 km^2) that represents the middle and upper reaches of the Yuam river with that at Ban Mae Ngao (935 km^2) that represents the Ngao river basin, the runoff at Sop Han is less than 60% of that at Ban Mae Ngao. It is concluded that more than a half of the runoff at Ban Tha Rua is provided by runoff from the Ngao river basin having an drainage area smaller than 1/6 of the whole basin area. The specific runoff value of the middle and upper reaches of main stream basin is about 1/5 of that of the Ngao river.

Gauging Station	Drainage Area (km^2)	Average Runoff (m^3/sec)		Average Specific Runoff in Two Years ($l/sec/km^2$)
		1985	1986	
Sop Han	2,496	29.5	17.7	9.5
Ban Mae Ngao	935	51.4	30.4	43.7
Ban Tha Rua	5,770	99.1	60.5	13.8

Table 5 − 2 Monthly list of Average Daily Precipitation

(unit: mm)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total	Annual Average
Khun Yuam ('59 - '81)	0.28	0.06	0.15	1.46	5.96	5.31	7.66	9.28	8.77	3.56	1.05	0.54	1,349.9	3.70
Mae La Luang ('67 - '86)	0.40	0.06	0.16	1.53	6.13	6.17	7.15	9.45	7.20	3.62	1.35	0.52	1,339.3	3.67
Sop Han ('67 - '86)	0.36	0.11	0.19	1.02	5.16	5.99	6.79	7.13	7.09	3.71	0.78	0.31	1,166.3	3.20
Ban Tha Rua ('70 - '86)	0.50	0.08	0.19	1.43	6.88	10.97	9.68	10.89	6.55	3.65	1.13	0.34	1,600.2	4.38
Mae Sariang ('50 - '86)	0.35	0.16	0.27	1.33	5.40	6.39	6.36	7.97	7.03	3.85	0.68	0.37	1,229.1	3.37

Table 5 − 3 Monthly list of Average Daily Temperature (Max. and Min.)

(unit: degree Celcius)

Station		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
Sap Han ('68 - '72, '80, '85)	(Min.)	14.44	13.56	17.39	22.65	24.00	23.41	23.19	22.91	23.08	22.56	20.02	16.18	20.3
	(Max.)	30.65	34.19	37.33	38.30	36.05	31.12	30.30	30.17	31.66	32.35	31.62	29.99	32.8
Ban Tha Rua ('71 - '85)	(Min.)	13.54	13.97	16.66	20.86	22.65	22.91	22.59	22.70	22.79	21.82	19.22	15.48	19.6
	(Max.)	30.39	35.65	39.02	39.67	36.63	32.84	32.52	31.57	33.44	34.22	32.87	31.14	34.1

Table 5 – 4 Monthly list of Average Daily Relative Humidity

(unit: %)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
Sap Han ('66 - '86)	88.70	88.11	84.64	78.61	81.28	85.16	87.06	87.60	87.29	87.46	87.88	88.72	86.04
Ban Tha Rua ('71 - '86)	93.56	94.86	94.10	89.17	91.40	93.73	93.89	94.71	93.95	93.78	93.04	93.63	93.31

Table 5 – 5 Monthly list of Average Daily Evaporation

(unit: mm)

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Total	Annual Average
Sop Han ('70 - '86)	2.73	4.14	5.64	6.54	4.95	3.21	2.75	2.60	3.28	3.23	2.86	2.58	1,310.5	3.59
Ban Tha Rua ('70 - '86)	2.74	3.37	4.99	6.17	4.46	2.87	2.52	2.31	2.82	3.27	2.80	2.70	1,250.4	3.43

Table 5 – 6 Monthly list of Average Daily Runoff at Ban Tha Rua Gauging Station (1969-86)

(unit: $m^3/sec.$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL (x 10^6 m^3)
1969	28.53	20.95	15.05	14.01	27.91	89.17	139.81	625.23	382.50	178.19	109.70	70.98	4,501.84
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	3,126.46
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	3,777.38
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	3,009.07
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	3,197.12
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	2,555.23
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	3,000.05
1976	36.01	26.26	18.64	13.95	26.70	50.89	115.43	221.10	188.63	154.91	83.43	49.04	2,604.55
1977	53.32	25.75	19.10	18.10	20.44	30.06	73.24	172.38	291.77	117.40	74.04	44.87	2,476.56
1978	33.38	24.88	17.76	13.77	22.79	24.07	135.62	246.43	213.11	142.87	61.04	34.73	2,565.85
1979	25.12	19.14	13.29	12.11	18.94	24.30	61.69	243.89	120.97	111.32	48.55	28.73	1,927.26
1980	19.84	15.23	13.26	11.74	33.95	51.61	96.44	146.19	328.87	187.57	84.43	53.01	2,747.46
1981	33.06	19.83	14.63	12.79	15.41	58.13	138.79	263.00	151.77	110.37	76.21	46.82	2,488.86
1982	30.19	20.55	15.06	14.56	26.96	113.02	175.71	401.12	274.09	175.08	76.16	43.76	3,612.83
1983	29.20	19.56	13.84	10.68	10.48	25.94	29.19	93.62	119.29	120.40	73.82	39.76	1,544.02
1984	25.65	18.04	13.33	13.16	13.11	115.20	124.01	244.82	206.11	138.24	64.34	37.61	2,677.33
1985	24.88	18.12	13.56	11.42	22.77	91.85	151.94	208.82	249.47	200.77	118.85	71.73	3,126.21
1986	40.22	28.81	21.21	19.83	23.25	46.77	121.31	154.15	115.34	67.10	50.47	33.80	1,906.96
Average	33.91*	23.26	17.41	15.12	24.82	62.12	135.04	257.51	228.14	144.43	79.28	48.10	2,824.72

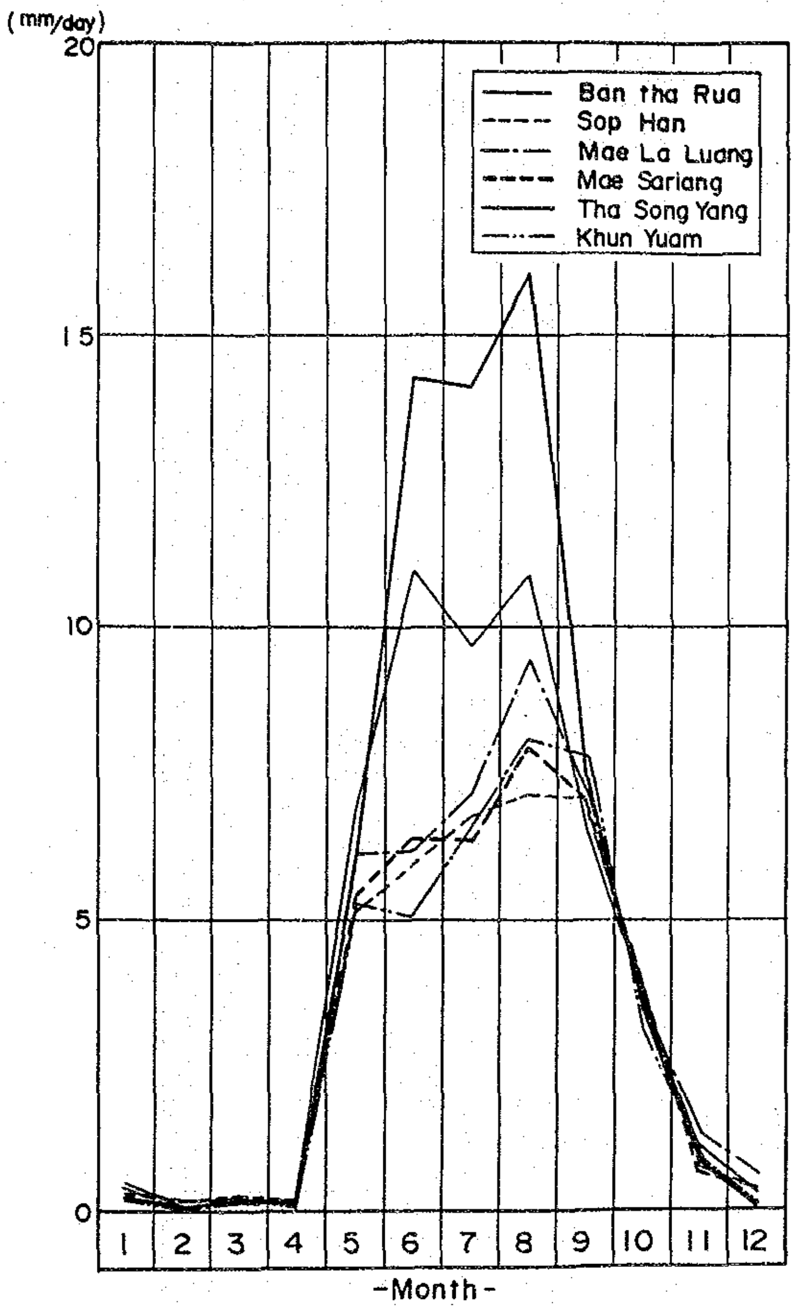


Fig. 5 − 3 Average Precipitation in Each Month

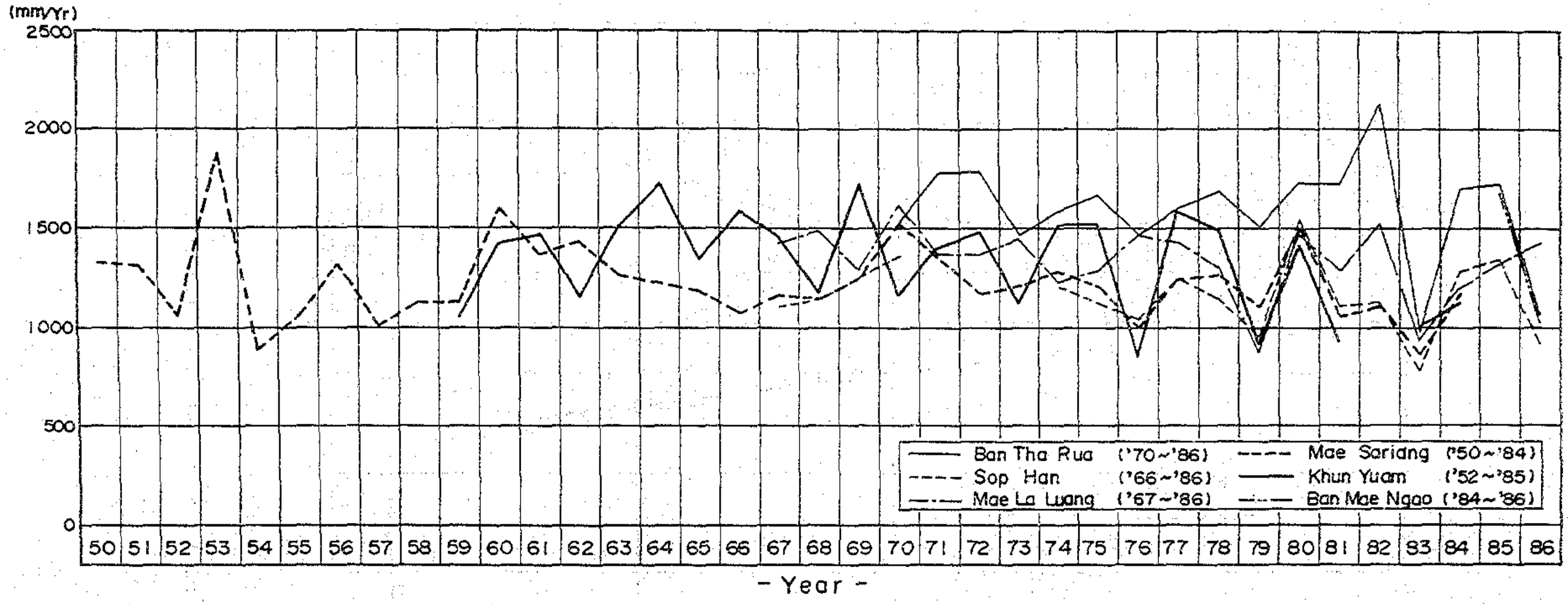


Fig. 5 − 4 Transition of Actual Annual Precipitation

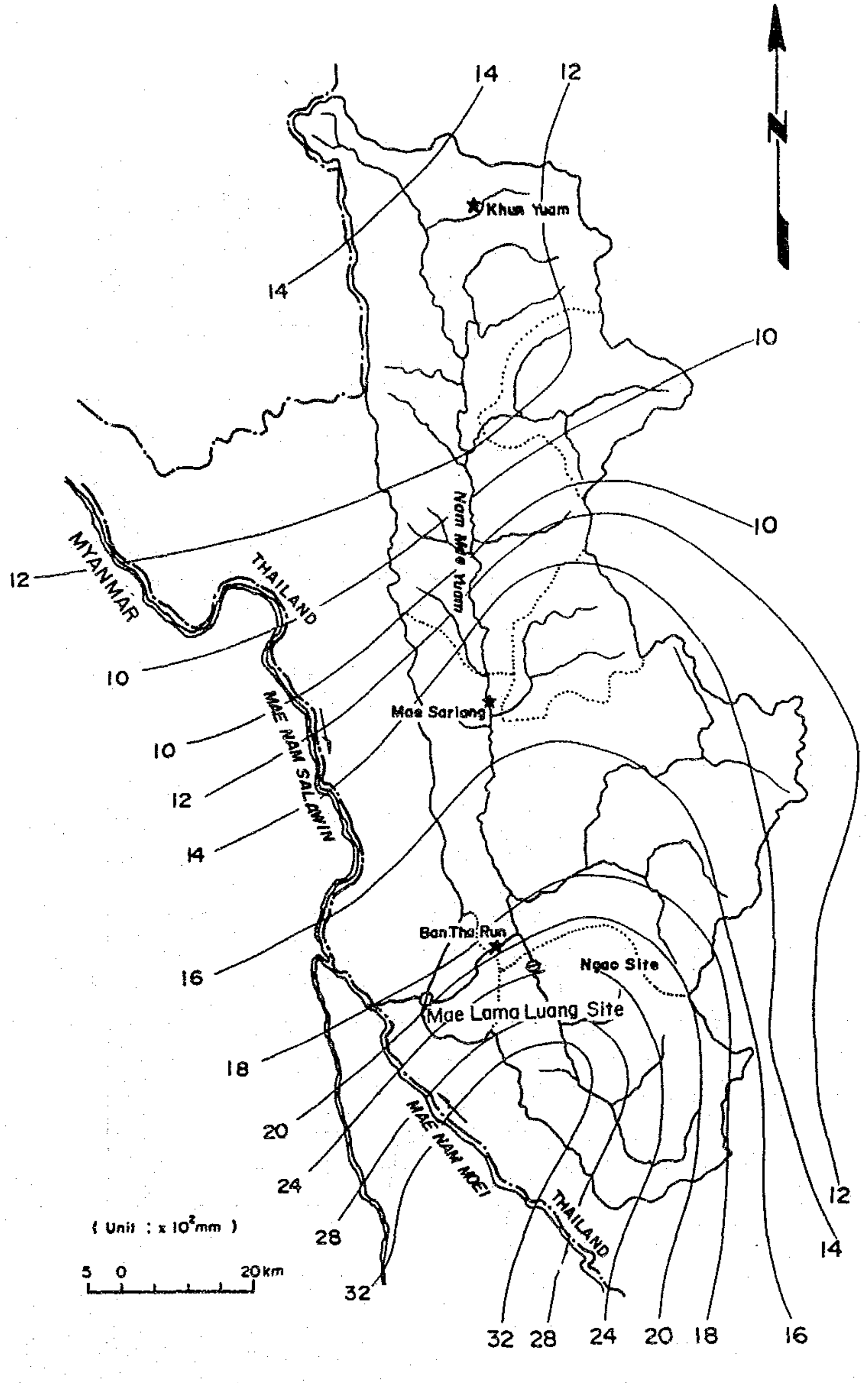


Fig. 5 — 5 Isohyetal Map of the Basin (1984)

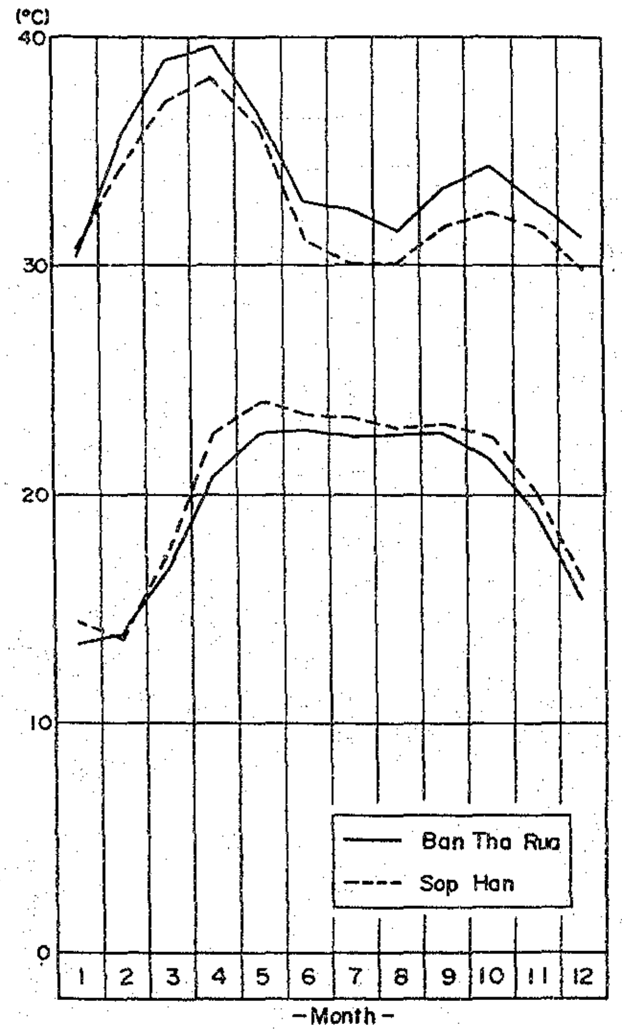


Fig. 5 — 6 Average Temperature (Max. and Min.) in Each Month

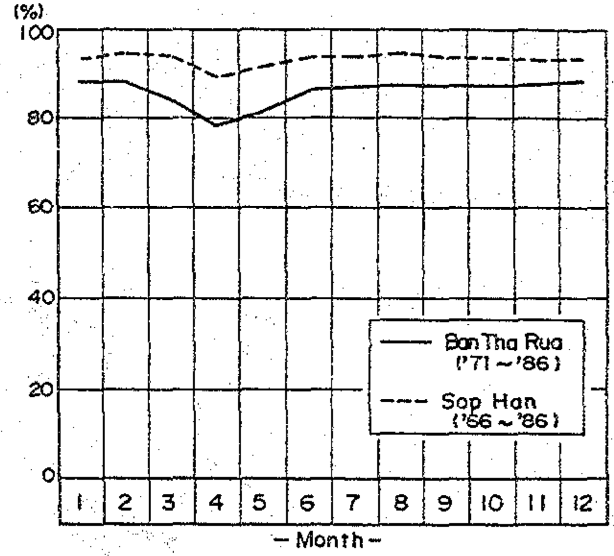


Fig. 5 — 7 Average Relative Humidity in Each Month

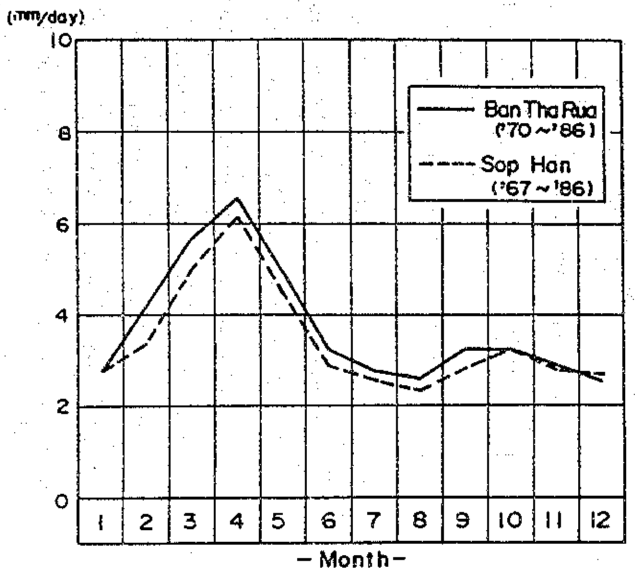


Fig. 5 − 8　　Average Evaporation in Each Month

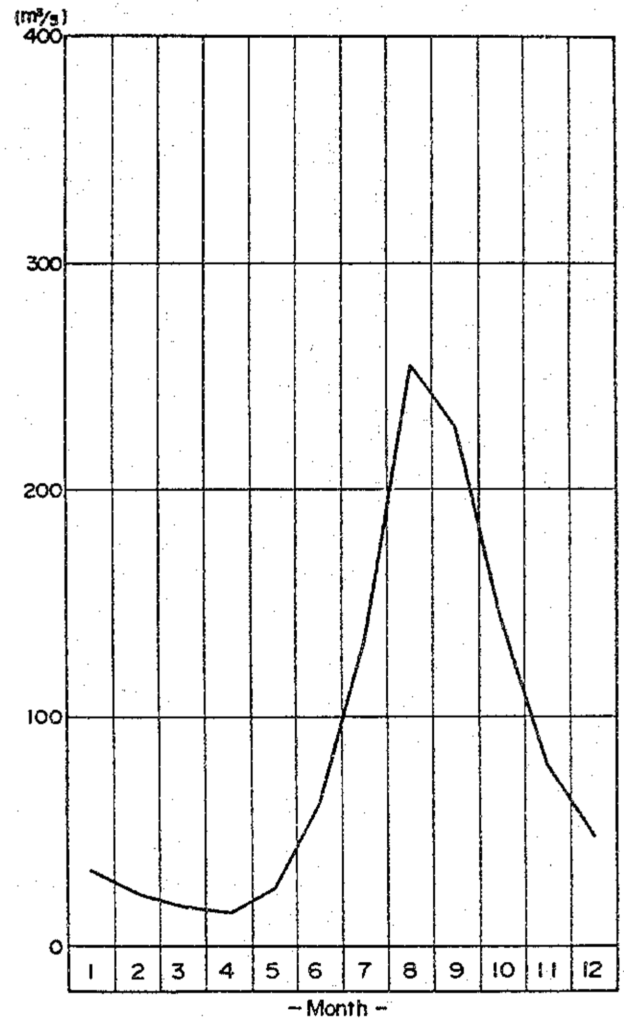


Fig. 5 − 9　　Average Runoff in Each Month at Ban Tha Rua Gauging Station

5.4 River Flow Analysis

5.4.1 Methodology

The runoff data that greatly affect the planning and economic justification of a project would be preferably available for a period approximately equal to the service life; at least about 30 years in the case of a hydroelectric power plant, 50 years in general.

The nearest gauging stations to both damsites of Mae Lama Luang and Nam Ngao, are located at Ban Tha Rua and Ban Mae Ngao respectively. Ban Tha Rua has existed only for 18 years between January 1969 and December 1986 and Ban Mae Ngao only between May 1984 and December 1986. Therefore, it is necessary to expand the runoff data using suitable methods.

Generally there are two methods to generate the runoff data. One is to introduce them from the runoff data at other stations, and the other is to estimate from the precipitation data. In this study, the expansion of the runoff data was done using the following techniques, taking into account the period of records, degree of acknowledgement and reliability of the analysis and meteorological features of the basin.

(A) Correlation Analysis

The correlation analysis is mainly applied to generate the runoff data at the Ban Mae Ngao gauging station.

(B) Tank Model Method

The tank model method is one of the methods of river flow analysis and its validity is acknolwledged widely throughout the world at present. This tank model method explains hydrological phenomena caused by precipitation such as infiltration, storage and runoff, by using several tanks having side and bottom outlets. (refer to Appendix for principle of the tank model and details of the analysis) This method was applied to the generation of runoff data for Ban Tha Rua and Sop Han.

The runoff data at both gauging stations, Ban Tha Rua and Ban Mae Ngao, were finally prepared on a daily basis for 28 years between

1959 and 1986. Natural inflow at the Mae Lama Luang dam site and at the Nam Ngao dam site were estimated from the data at the Ban Tha Rua and the Ban Mae Ngao stations respectively.

5.4.2 Preparation of Data

(1) Selection of Data

Prior to the analysis, a study on a selection of data to be used and an examination of its homogeniety and consistency was performed. In addition to the daily runoff, the daily precipitation and daily evaporation data were used in the analysis. These data shown in the table below were selected in terms of the length of the period of observation and the degree of representativeness of the basin.

Data	Station	Used Data
Daily runoff	Ban Tha Rua	1969-1986
	Sop Han	1969-1986*)
	Irrigation Weir of RID	1976-1986
	Ban Mae Ngao	1984-1986
Daily precipitation	Mae Sariang	1959-1981
	Khun Yuam	1959-1981
Daily evaporation	Ban Tha Rua	1970-1986**)
	Sop Han	1967-1986**)

*) No measurement in 1979
**) No measurement in 1981-83

The runoff data used, are the data from the weir of the RID, Sop Han, Ban Tha Rua and Ban Mae Ngao gauging stations. The intake data from the RID weir was necessary to obtain the natural runoff at Ban Tha Rua. The runoff data from Sop Han were used to estimate the runoff at the Ban Mae Ngao gauging station together with the data from Ban Tha Rua.

The data for precipitation and evaporation were used to expand the runoff data by tank model at both Ban Tha Rua and Sop Han gauging stations.

(2) Correction of Runoff Data at the Ban Tha Rua Gauging Station

The runoff data observed at the Ban Tha Rua gauging station since 1976 have not taken into account the intake quantity from the weir of the RID and it is necessary to evaluate the natural runoff at Ban Tha Rua. A correction was made by adding the intake quantity to the runoff recorded at Ban Tha Rua after 1976 when the weir was constructed to be used for intake of irrigation water. The runoff data at the Ban Tha Rua gauging station referred hereinafter means these corrected data unless otherwise noted.

(3) Supplement of Runoff Data at the Sop Han Gauging Station

The daily runoff data have been taken at the Sop Han gauging station since 1967. As there were no measurements taken in 1979, it was necessary to supplement the data in 1979 in order to use them for the river flow analysis.

Immediately downstream of the Sop Han gauging station, there is the RID weir where the intake and the overflow quantity have been measured. The natural inflow at the weir was calculated from these two values and correlation analysis using the daily runoff data from the Sop Han gauging station and the RID weir for a total of 8 years (1977-78, 1980-85) was performed.

Calculation of the correlation coefficient resulted in a value of 0.958. The regression equation was obtained, from which the runoff data at Sop Han in 1979 were supplemented. The coefficient of X, 1.05 was about the same as the catchment area ratio between both points, which can well explain the actual phenomenon. The scatter diagram and the regression line are shown in Fig. 5-10.

$$Y = 1.05X - 1.68$$

where, Y = runoff at the Sop Han gauging station
X = runoff at the RID weir

(4) Verification of Homogeniety of the Runoff Data

The obtained runoff data at both Ban Tha Rua and Sop Han were examined for its homogeniety using a double mass curve. The double mass curve of both data shows a straight line confirming the homogeniety (see Fig. 5-11).

(5) Reliability of Precipitation Data

- Moving Average and Double Mass Curve Technique

Examinations of precipitation data at the Mae Sariang and Khun Yuam stations were performed in terms of homogeneity and consistency. The Mae Hong Son station was selected as a reference station for a reason that its observation period is nearly equal to those of the Mae Sariang and Mae Hong Son stations.

Precipitation data in time series, 5-year moving average curve and annual average precipitation at the three stations are shown in Figs. 5-12 (1) - 5-12(3).

Two double mass curves are shown in Figs. 5-13(1) and 5-13(2). The double mass curve of the Mae Hong Son and Mae Sariang stations results in a linear relation, while a discontinuity is found in the double mass curve of the Mae Sariang and Khun Yuam stations between 1958 and 1959.

Annual precipitations at the Khun Yuam station for 6 years (1953 - 1958) are much lower than those for 28 years (1959 - 1986), and also lower than those of the Mae Sariang or Mae Hong Son stations for the same period (1953 - 1958).

Therefore it was judged that annual precipitations at the Khun Yuam station from 1953 to 1958 were not reliable.

- Comparison of Means and Variances

In order to check a reliability of annual precipitation at the Khun Yuam station from 1959 to 1968, for which period river runoffs are generated from tank models, comparisons were made for means and variances.

The data in the following table are annual precipitations at the Khun Yuam station for the period 1959 - 1986. This set of data was divided into two subsets: one subset from 1959 to 1968 and the other from 1969 to 1986 except 1982.

Annual Precipitations at Khun Yuam

Year	Precipitation	Year	Precipitation	Year	Precipitation
1959	1,045	1969	1,732	1979	921
60	1,412	70	1,166	80	1,424
61	1,467	71	1,402	81	939
62	1,159	72	1,482	82	-
63	1,509	73	1,122	83	1,097
64	1,742	74	1,511	84	1,119
65	1,329	75	1,512	85	1,755
66	1,595	76	874	86	1,022
67	1,447	77	1,600		
68	1,190	78	1,486		

The first subset has a mean and a standard deviation of 1,390 and 212.4 mm respectively, while the second subset has a mean and a standard deviation of 1,304 and 287.6 mm respectively.

To check whether two variances are homogeneous or not, Fisher's F-test was applied.

$$F_{cal} = \left(\frac{N_1 S_1^2}{N_1 - 1}\right) / \left(\frac{N_2 S_2^2}{N_2 - 1}\right)$$

$$= \frac{17 \times (287.6)^2}{17 - 1} / \frac{10 \times (212.4)^2}{10 - 1}$$

$$= 1.75$$

The calculated value of F_{cal} should be checked against F_{cr} for an assigned level of significance α (= 5%).

For $\gamma 1 = N_1 - 1 = 16$, $\gamma 2 = N_2 - 1 = 9$ and $\alpha = 5\%$, F_{cr} is found equal to 3.00. The value F_{cal} is less than F_{cr} and hence it is concluded that the difference between the two estimates of variances is not real and is due to chance only.

To check whether two subsets are drawn from the same population, Student's t-test was applied.

$$S_d^2 = \frac{S_1^2(N_1 - 1) + S_2^2(N_2 - 1)}{N_1 + N_2 - 2} \times \frac{N_1 + N_2}{N_1 N_2}$$

$$= 10,984$$

$$t_{cal} = \frac{1}{Sd} \mid \overline{P1} - \overline{P2} \mid$$

$$= \frac{1}{104.8}(1,390 - 1,304)$$

$$= 0.82$$

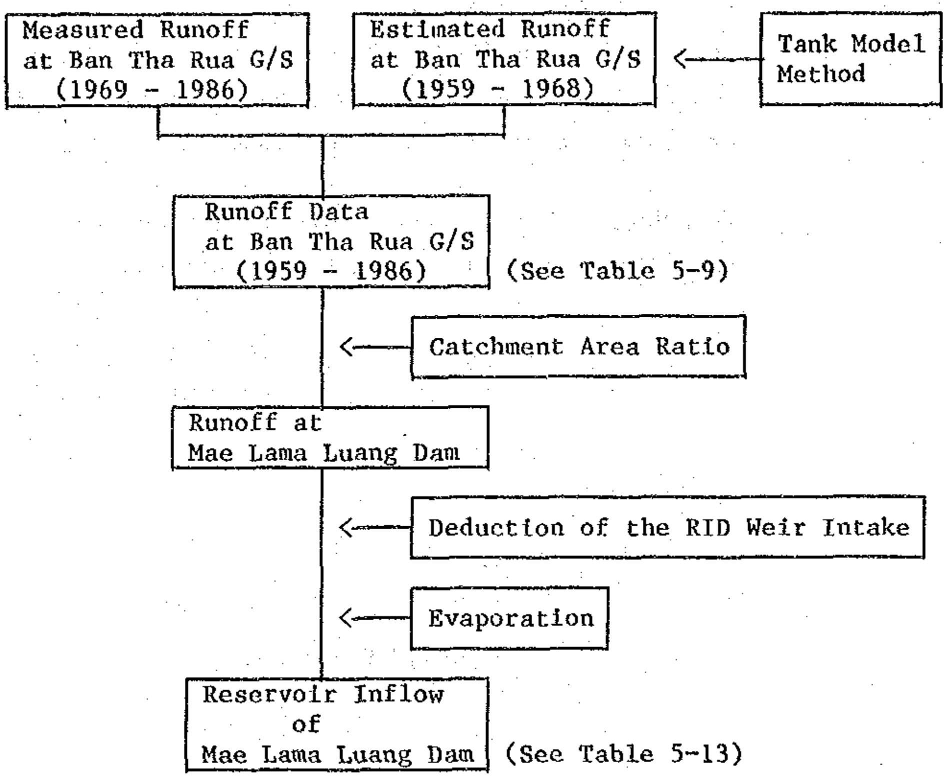
For $\alpha = 5\%$ and $\gamma = (N_1 - 1) + (N_2 - 1) = 25$, t_{cr} is found equal to 2.06. The calculated value t_{cal} is less than t_{cr} and hence the difference between the two means is not real at the assigned level of significance and is due to chance only.

Therefore it is concluded that the two data subsets are homogeneous, i.e. drawn from the same population.

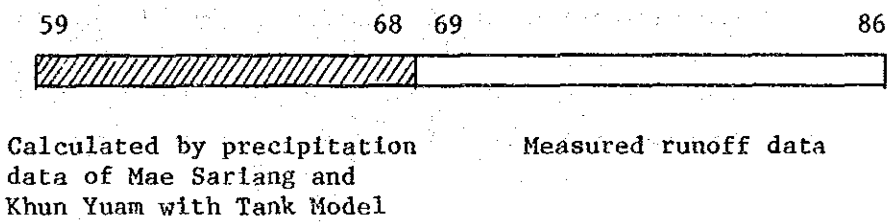
5.4.3 Estimation of Reservoir Inflow

(1) Mae Lama Luang Dam

Reservoir inflow of the Mae Lama Luang dam was estimated in the following procedure.



(Calculation Method of Runoff Data at Ban Tha Rua)



The tank model used in this study was composed of a series of four tanks having a soil moisture structure in the first tank. This model is evaluated to be suitable for runoff analysis of the region with a long dry season every year such as the Yuam river basin.

Outline of Tank Model

Site	Calibration Period	Runoff and Precipitation Data for Calibration
Ban Tha Rua G/S	1969 - 1981	Runoff: Daily runoff at Ban Tha Rua G/S Precipitation: Daily precipitation at Khun Yuam St. (x 0.3) Mae Sariang St. (x 0.7)

First the model was optimized for the 13 years between 1969 and 1981 for which both runoff data and precipitation data were available. (precipitation data at Khun Yuam not available from Dec. 1981 to July 1982) Various parameters satisfying the following conditions were established:

° The absolute accumulated difference between measured and estimated values of the annual total runoff shall be zero or negligible.

° Average ratios of the difference between actually measured (QA) value and estimated (QE) values of monthly runoff to QA shall be within 20%.

$$|QA - QE| / QA \leqq 0.20$$

In order to verify reliabilities of the tank model, compared were the observed and estimated runoffs from the tank model for the period of 1983 - 1986.

Comparison of Observed and Estimated Runoffs (10^6 m^3)

Ban Tha Rua G/S		
A	B	C
Observed Runoff	Estimated Runoff	Error (%) ((B-A)/A)x100
1,544.0	1,702.0	10.2
2,677.3	2,386.6	-10.9
3,126.2	3,190.4	2.1
1,907.0	1,481.6	-22.3

Above errors are in the range of ±30%, which corresponds to those errors between observed and estimated runoffs for calibration periods of 1969 - 1981.

Therefore this tank model is considered reliable and it can be adopted to generate runoffs at the Ban Tha Rua gauging station from daily precipitation data of the Khun Yuam and Mae Sariang stations.

After the optimum model was obtained, the daily runoff for 10 years between 1959 and 1968 was calculated using the model and the precipitation data. Finally the runoff data for 28 years (1959 - 1986) were provided together with the measured values. Fig. 5-14 shows the summary of the model used and coefficients. Observed and estimated runoff data at Ban Tha Rua during the calibration period are shown in Table 5-7 and Fig. 5-15, and all the provided data for 28 years is shown in Table 5-9.

The runoff data at the Mae Lama Luang dam site were obtained by calculating the natural runoff at the planned site from the runoff at Ban Tha Rua using the catchment area ratio and by deducting both the appropriate intake quantity at the RID weir and evapotranspiration after reservoir construction.

$$Q_{Yi} = Q_{BTR} \times \frac{C_{Yi}}{C_{BTR}} - Q_{IR} - E$$

where, Q_{Yi} = runoff at Mae Lama Luang dam site

Q_{BTR} = runoff at Ban Tha Rua

Q_{IR} = average intake at the RID weir

C_{Yi} = catchment area of Mae Lama Luang dam

Site No. 4: 6,029 km^2

Site No. 5: 6,030 km^2

Site NEA : 5,920 km^2

C_{BTR} = catchment area of Ban Tha Rua: 5,770 km^2

E = evapotranspiration after reservoir construction

- Deduction of RID Weir Intake

Monthly intakes of the RID weir, which are average intake volumes for a period of 1976 - 1986, were deducted from the reservoir inflow of the Mae Lama Luang dam from 1959 to 1986. Monthly list of intakes is shown in Table 5-12.

- Evaporation

By calculating a water balance in the drainage basin of the Mae Lama Luang dam and using Pan-values at the Ban Tha Rua station, an effect of evapotranspiration to water potential of the Mae Lama Luang reservoir was evaluated.

A water balance equation is generally represented as follows.

$$P = R + E \pm S$$

where, P: Precipitation

R: Runoff

E: Actual Evapotranspiration

S: Storage Difference (*)

(*) S can be neglected if a water balance calculation is made for a long period.

The calculation of the water balance in the basin was made for a period (1972 - 1980) with monthly precipitation data (Khun Yuam, Mae La Luang, Mae Sariang, Ban Tha Rua) and monthly runoff at the Mae Lama Luang dam.

Monthly average precipitations in the basin were estimated by Thiessen method.

Actual evapotranspirations was estimated by the above equation of water balance.

Monthly evaporation from the Mae Lama Luang reservoir were estimated multiplying a pan coefficient of 0.7. The calculation results are shown below. During a rainy season (May - September) actual evapotranspirations are larger than free-water evaporations from the reservoir. Annual total difference is 45 mm, which corresponds to about 0.05% of annual inflow into the reservoir, and hence the effect of evapotranspiration can be negligible.

Evapotranspiration After Reservoir Construction

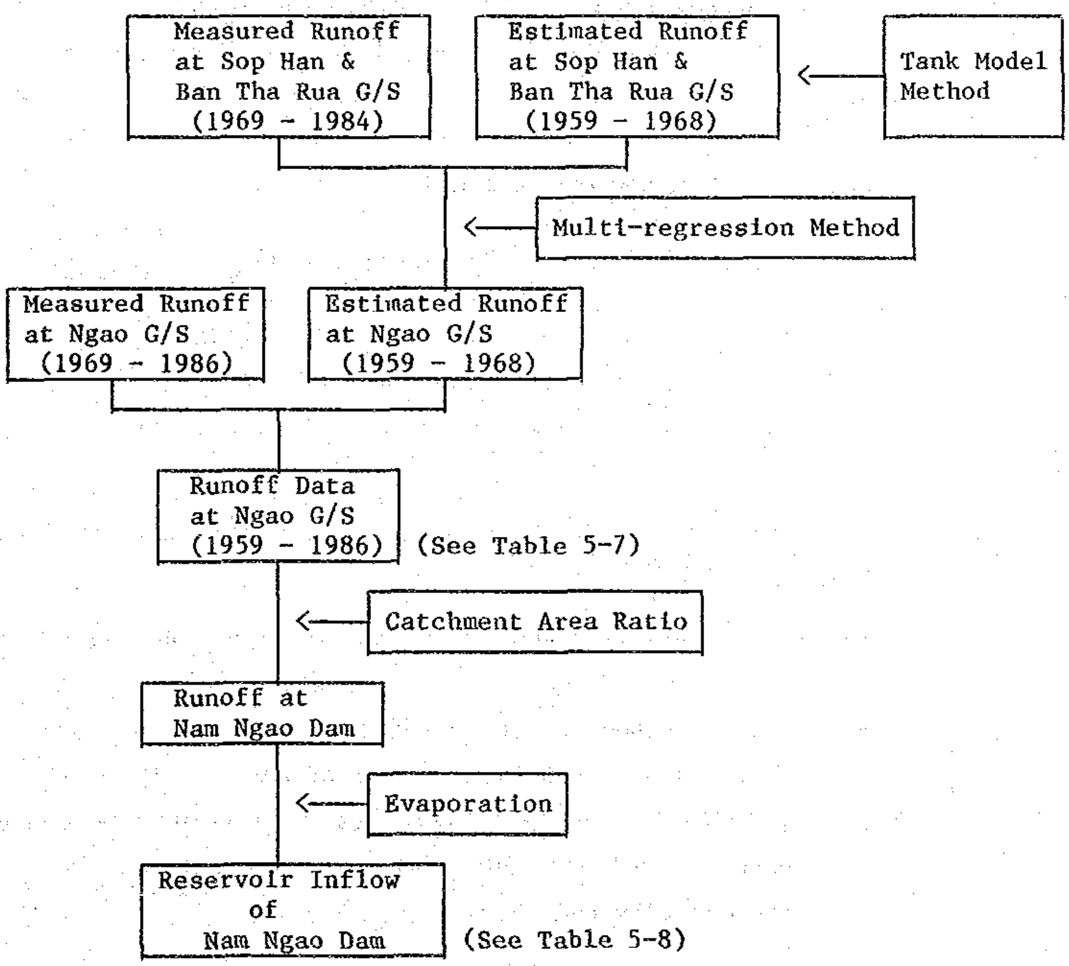
Month	A Precipitation (mm)	B Runoff (mm)	C Actual Evapotranspiration (A-B, mm)	D Free-water Evaporation (mm)	E Evaporation after Reservoir (C-D, mm)
Apr.	40.0	7.3	32.7	126.9	-94.2
May	194.5	11.8	182.7	95.2	87.5
Jun.	191.3	22.6	168.7	64.5	104.2
Jul.	242.9	55.8	187.1	40.9	146.2
Aug.	297.5	105.1	192.4	64.6	127.8
Sep.	230.3	110.7	119.6	59.4	60.2
Oct.	115.5	68.2			
Nov.	32.1	37.5			
Dec.	15.6	21.5	32.3	419.0	-386.7
Jan.	23.5	16.3			
Feb.	2.5	10.4			
Mar.	5.4	8.4			
Total	1,391.1	475.6	915.5	870.5	45.0

Table 5-13 and Table 5-14 show the monthly runoffs at the proposed Mae Lama Luang dam sites.

The average annual inflow at site No. 5 was estimated at 2,948 MCM, which yielded an average runoff of 93.5 m^3/sec. The runoff at site No. 4 was assumed to be the same as that of site No. 5 since site No. 4 is located near site No. 5 and the difference in catchment area between the two sites can be considered negligible. (about 1 km^2 on a topographical map of 1/50,000 in scale)

(2) Nam Ngao Dam

The runoff data at Ban Mae Ngao were available only for 32 months between May 1984 and December 1986. It was required to extend the data using the following procedure to prepare the runoff data for the Nam Ngao dam site:



- Establishment of Optimum Regression Model Using Correlation Analysis

To extend the data at Ban Mae Ngao, the correlation analysis was performed using actual measured data of both Ban Tha Rua and Ban Mae Ngao between May 1984 and December 1986.

The Ngao river is one of the tributaries of the Yuam river and its catchment area accounts for less than 1/6 of the entire catchment area. About 50% of the total runoff posses through the Ngao river. It is not sufficient to use only a single correlation analysis with Ban Tha Rua. Therefore, it was determined to also make use of the records from Sop Han, which has records of measured runoff for 18 years. Multiple correlation analysis was attempted, taking into account the data from 2 stations.

The correlation coefficient obtained was 0.883 for the single correlation with Ban Tha Rua and was 0.919 for the multiple correlation with Ban Tha Rua and Sop Han. It was determined to use the results of the multiple correlation analysis and the following regression model was obtained:

$$Y = 0.7722\ X_1 - 0.6422\ X_2 - 2.0660$$

Where, Y = runoff at Ban Mae Ngao gauging station
X_1 = runoff at Ban Tha Rua gauging station
X_2 = runoff at Sop Han gauging station

- Extension of Runoff Data from the Sop Han Gauging Station Using a Tank Model

To extend the runoff data from Ban Mae Ngao gauging station, the runoff data from Sop Han were extended by using a tank model. The method and the conditions for the tank model were similar to those used in the case of Ban Tha Rua. That is, the optimization of the model was made using the measured data between 1967 and 1981, followed by obtaining the runoff data between 1959 and 1966.

Outline of the tank model for the Sop Han station and the result of the verification of the tank model are indicated below.

Outline of Tank Models

Site	Calibration Period	Runoff and Precipitation Data for Calibration
Sop Han G/S	1967 - 1981	Runoff: Daily runoff at Sop Han G/S Precipitation: Daily precipitation at Khun Yuam St. (x 0.5) Mae Sariang St. (x 0.5)

Comparison of Observed and Estimated Runoffs (10^6 m^3)

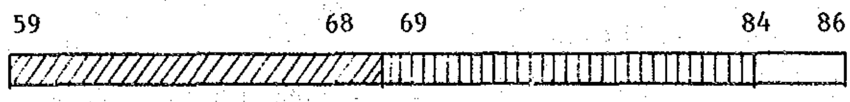
Year	Sop Han G/S		
	A	B	C
	Observed Runoff	Estimated Runoff	Error (%) ((B-A)/A)x100
1983	359.7	311.9	-13.3
1984	615.8	453.3	-26.4
1985	930.3	819.2	-11.9
1986	684.1	557.4	-18.5

Observed and estimated runoff data at Sop Han during the calibration period are shown in Table 5-8 and Fig. 5-16.

- Calculation of Runoff at Nam Ngao Dam Site

First the runoff data between 1959 and 1968 at Ban Tha Rua and between 1959 and 1966 at the Sop Han gauging stations were obtained using a tank model. Next using the regression model, the daily runoff at Ban Mae Ngao from 1959 to 1984 was calculated. Average runoff data of 28 years at the Sop Han and Ban Mae Ngao stations are shown in Table 5-10 and 5-11 respectively.

(Calculation Method of Runoff Data at Ban Mae Ngao)



Calculated using runoff data for Ban Tha Rua and Sop Han obtained by Tank Model with a regression equation	Calculated using measured runoff data from Ban Tha Rua and Sop Han with a regression equation	Measured runoff data

The runoff data at the Ngao dam site was obtained from the runoff at Ban Mae Ngao using the catchment area ratio of both points and using the following equation:

$$Q_{Ni} = Q_{BMN} \times \frac{C_{Ni}}{C_{BMN}} - E$$

Where, Q_{Ni} = runoff at Nam Ngao dam site

Q_{BMN} = runoff at Ban Mae Ngao gauging station

C_{Ni} = catchment area of Nam Ngao dam site

Site No. 1: 848 km^2

Site No. 2: 835 km^2

Site No. 3: 756 km^2

C_{BMN} = catchment area of Ban Mae Ngao gauging station: 935 km^2

E = evapotranspiration after reservoir construction (= negligible)

The average annual inflow at proposed Nam Ngao dam site No. 2 was estimated to be 1,366 MCM and an average runoff of 43.3 m^3/sec was also obtained. Monthly lists of average runoff at each proposed dam site are shown in Tables 5-15, 16 and 17.

Table 5 — 7 Comparison of Observed and Estimated Runoff at Ban Tha Rua Gauging Station (1969-81)

(unit: $m^3/sec.$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL ($\times 10^6 m^3$)
						- OBSERVED -							
1969	28.53	20.93	15.05	14.00	27.91	89.17	139.81	625.23	382.50	178.19	109.70	70.98	4,501.79
1970	48.09	34.65	25.19	24.64	49.25	69.23	145.12	247.13	262.59	145.77	77.21	55.73	3,126.40
1971	35.65	25.51	20.00	14.71	29.82	83.97	323.54	359.68	268.10	142.05	76.05	47.97	3,777.35
1972	33.12	24.04	19.14	19.20	17.21	36.33	197.19	310.55	195.10	128.60	95.41	60.26	3,009.00
1973	40.03	26.53	21.90	16.06	31.62	64.09	133.27	264.52	289.13	180.16	88.30	55.34	3,197.05
1974	35.26	25.11	17.17	16.20	31.12	72.21	127.66	227.53	174.83	116.01	83.14	41.42	2,555.38
1975	38.84	25.61	21.29	15.23	24.98	71.36	140.70	205.10	274.80	182.88	85.96	50.26	3,000.07
1976	36.01	26.25	18.65	13.96	26.70	50.89	115.43	221.09	188.64	154.91	83.43	49.04	2,604.60
1977	53.32	25.75	19.10	18.10	20.44	30.05	73.24	172.39	291.77	117.41	74.04	44.87	2,476.54
1978	33.38	24.89	17.76	13.77	22.79	24.07	135.62	246.43	213.11	142.86	61.04	34.73	2,565.87
1979	25.11	19.13	13.30	12.10	18.94	24.30	61.69	243.89	120.97	111.32	48.55	28.73	1,927.19
1980	19.86	15.22	13.27	11.74	33.96	51.60	96.44	146.19	328.86	187.57	84.43	53.01	2,747.51
1981	33.05	19.84	14.64	12.80	15.41	58.12	138.78	263.00	151.77	110.37	76.23	46.81	2,488.90
Average	35.40	24.11	18.19	15.58	26.93	55.80	140.65	271.75	241.71	146.01	80.27	49.17	2,921.36
						- ESTIMATED -							
1969	26.75	20.10	16.79	12.86	20.07	73.41	117.08	355.57	325.79	176.31	89.83	55.58	3,406.97
1970	37.71	25.79	20.77	16.21	67.82	90.23	85.00	205.91	341.31	226.53	87.34	63.22	3,342.88
1971	43.99	30.30	26.18	20.50	26.98	63.19	298.72	278.36	300.91	134.09	68.59	48.95	3,544.06
1972	33.43	26.18	21.92	17.87	14.02	22.48	71.85	268.65	190.42	185.32	121.39	73.90	2,765.25
1973	45.69	31.31	22.88	18.23	43.31	61.60	80.08	253.22	278.96	154.17	62.39	43.77	2,889.97
1974	29.04	22.73	18.75	14.34	22.19	72.98	138.52	262.11	254.34	159.35	104.13	56.90	3,050.17
1975	52.89	34.05	24.54	20.09	19.50	69.96	136.33	257.85	264.91	146.22	69.65	49.87	3,023.54
1976	35.04	26.01	21.77	17.30	14.23	24.85	76.73	165.51	140.34	106.90	56.41	36.07	1,906.40
1977	39.52	21.51	18.04	18.72	14.96	20.48	81.95	180.64	311.99	181.26	76.75	55.70	2,693.49
1978	46.69	31.18	23.05	18.73	17.36	29.47	242.20	221.55	301.19	212.28	78.14	54.27	3,372.92
1979	36.84	26.07	21.91	17.14	17.98	58.69	86.23	190.98	175.30	150.41	54.87	37.87	2,308.47
1980	24.81	19.88	16.02	13.19	75.25	115.61	148.30	170.20	387.73	222.12	84.38	62.56	3,533.84
1981	44.52	30.72	23.57	18.94	14.59	52.19	104.79	188.91	146.96	103.57	58.69	39.36	2,182.62
Average	38.22	26.60	21.24	17.24	28.33	57.93	128.29	230.73	263.09	166.04	77.89	52.16	2,924.66

Table 5 – 8 Comparison of Observed and Estimated Runoff at Sop Han Gauging Station (1969-81)

(unit: $m^3/sec.$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL ($\times 10^6\ m^3$)
- OBSERVED -													
1967	7.14	5.04	3.59	3.06	6.88	11.28	17.19	49.26	92.61	37.53	17.28	9.07	684.16
1968	6.35	4.27	3.58	4.25	8.09	13.64	25.84	52.55	43.02	45.35	18.11	9.67	621.09
1969	6.12	4.73	3.99	3.47	5.56	11.99	20.75	105.18	78.70	33.68	25.26	15.12	830.92
1970	9.92	7.03	5.36	5.60	18.83	20.14	25.50	72.47	75.87	49.16	23.56	18.56	876.60
1971	10.11	7.39	6.00	4.54	11.77	20.22	63.94	74.47	67.32	40.73	19.28	13.48	897.11
1972	8.91	6.46	4.89	5.25	4.66	8.82	23.26	69.63	35.22	27.17	26.42	11.05	612.99
1973	8.61	5.72	4.15	3.14	8.65	10.86	39.09	106.99	111.89	51.51	19.48	10.72	1,005.93
1974	10.28	7.54	5.06	4.11	8.92	11.30	17.52	43.45	50.80	28.47	29.89	12.12	604.33
1975	12.54	6.83	4.39	3.00	6.27	12.97	23.69	77.74	127.64	72.38	30.94	19.14	1,047.90
1976	11.12	7.70	5.21	3.85	5.86	6.61	14.42	36.08	52.57	45.97	22.60	16.53	603.35
1977	10.52	5.98	4.09	5.26	5.91	8.02	17.76	40.87	94.59	50.65	27.22	17.58	759.39
1978	14.03	8.50	5.53	4.18	5.65	7.07	47.09	78.32	101.70	64.54	28.91	14.02	1,002.05
1979	12.53	7.76	4.23	4.33	10.35	12.54	17.31	36.06	30.63	30.04	10.83	6.28	482.82
1980	4.34	3.16	2.35	2.25	9.90	19.52	26.32	42.69	97.58	43.33	17.97	12.72	743.27
1981	6.98	4.89	3.38	2.80	3.49	8.76	21.22	55.98	40.76	24.48	17.95	10.11	530.47
Average	9.30	6.20	4.39	3.94	8.05	12.25	26.73	62.78	73.39	43.00	22.38	13.08	753.49
- ESTIMATED -													
1967	6.51	4.51	3.13	2.40	3.10	3.25	22.14	64.75	92.18	48.33	22.85	12.95	754.73
1968	9.43	6.90	4.24	2.85	3.57	18.33	20.90	57.34	45.97	31.56	15.22	9.21	595.72
1969	6.99	4.79	3.13	2.37	5.00	11.17	37.22	112.51	93.33	51.76	28.46	15.57	984.27
1970	11.32	8.60	5.70	3.55	16.23	13.75	15.21	47.14	83.12	50.15	23.31	15.13	772.44
1971	10.48	8.16	6.09	4.08	5.13	10.26	83.25	76.97	78.16	39.20	19.56	13.01	937.34
1972	10.37	7.74	5.15	4.20	3.52	4.34	13.94	76.82	51.56	48.55	43.06	22.62	771.45
1973	12.80	9.50	6.77	4.47	13.36	7.35	15.11	74.47	75.36	38.22	17.26	10.93	753.46
1974	8.42	6.06	4.38	3.56	4.69	12.66	25.01	61.70	85.96	45.24	34.05	17.48	814.83
1975	13.61	10.08	7.36	4.69	4.66	9.51	28.94	87.10	82.20	47.23	23.67	14.41	880.16
1976	11.13	8.62	6.16	4.52	3.88	4.12	11.58	31.74	33.63	28.19	14.74	8.37	440.01
1977	9.23	5.64	3.94	3.80	3.33	3.20	14.39	48.47	93.00	54.33	25.62	16.18	740.67
1978	11.97	9.25	6.65	4.34	3.58	5.51	70.45	57.19	93.33	53.00	25.38	14.78	938.50
1979	11.43	8.77	5.90	4.24	4.51	7.96	14.61	43.49	41.05	35.46	14.40	8.97	529.67
1980	6.76	4.84	3.66	3.04	18.65	28.86	35.09	42.79	103.35	51.15	25.04	15.71	893.11
1981	11.45	8.97	6.10	3.82	3.07	8.47	15.98	47.05	34.89	23.60	14.59	8.48	491.77
Average	10.13	7.50	5.22	3.73	6.42	9.92	28.26	61.97	72.47	43.07	23.15	13.59	753.21

Table 5 — 9 Monthly List of Adopted Runoff Data at Ban Tha Rua Gauging Station

MONTHLY LIST OF DAILY TOTAL RUNOFF AT < BAN > G.S (UNIT:10**6)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1959	42.95	31.34	28.17	19.80	18.20	107.84	178.44	584.07	653.47	260.47	117.06	77.02	2118.84
1960	44.72	33.49	26.92	17.79	126.50	137.38	255.59	889.71	636.06	666.80	284.92	191.39	3311.27
1961	121.87	75.17	55.48	41.47	41.46	173.30	382.49	625.07	1007.94	395.85	189.45	162.94	3272.50
1962	109.53	66.18	56.60	42.88	181.07	172.21	421.65	562.02	555.90	794.21	215.90	147.20	3325.36
1963	99.39	61.38	54.18	39.83	30.36	220.97	417.79	495.03	555.22	644.29	334.97	163.42	3116.82
1964	115.40	70.79	56.56	42.89	69.08	63.04	697.40	498.96	826.52	602.88	202.57	148.03	3394.11
1965	101.29	64.95	58.46	44.49	36.01	135.21	212.21	590.93	452.49	466.79	343.33	146.56	2652.71
1966	104.18	63.63	54.18	40.45	71.40	212.56	438.26	995.08	604.12	221.80	145.97	104.74	3056.39
1967	70.97	50.93	45.92	35.19	55.71	67.20	250.04	728.59	776.01	438.50	179.78	130.53	2829.37
1968	88.10	56.70	49.12	39.10	72.53	243.98	286.03	616.85	429.67	334.74	145.96	106.59	2469.37
1969	76.42	50.68	40.31	36.31	74.75	231.14	374.47	1674.60	991.44	477.27	284.34	190.11	4501.84
1970	128.80	83.83	67.50	63.88	131.92	179.44	308.70	661.91	680.66	390.44	200.12	149.26	3126.46
1971	95.49	61.74	53.59	38.13	79.86	217.67	866.59	963.36	694.91	380.47	197.12	128.45	3777.38
1972	88.72	60.28	51.29	49.75	46.10	94.19	528.15	831.77	505.70	344.44	247.28	161.40	3009.07
1973	107.22	64.22	58.71	41.60	84.72	166.12	356.98	708.48	749.43	482.54	228.88	148.21	3197.12
1974	94.44	60.77	45.93	41.95	83.34	187.14	341.94	609.41	453.17	310.71	215.49	110.93	2555.23
1975	104.03	62.00	57.03	39.44	66.90	184.97	376.85	549.32	712.28	489.80	222.82	134.60	3000.05
1976	96.44	65.79	49.93	36.15	71.52	131.92	309.17	592.19	488.94	414.90	216.26	131.34	2604.55
1977	142.80	62.29	51.17	46.92	54.75	77.91	196.17	461.72	756.28	314.46	191.92	120.18	2476.56
1978	89.40	60.20	47.57	35.68	61.03	62.38	363.25	660.04	552.39	382.65	158.23	93.03	2565.85
1979	67.27	46.30	35.61	31.39	50.72	62.97	165.23	653.24	313.57	298.17	125.85	76.95	1927.26
1980	53.13	38.15	35.50	30.44	90.94	133.77	258.32	391.56	852.42	502.40	218.85	141.98	2747.46
1981	88.54	47.98	39.18	33.14	41.27	150.66	371.72	704.42	393.39	295.62	197.55	125.39	2488.86
1982	80.87	49.72	40.33	37.75	72.21	292.95	470.63	1074.36	710.43	468.95	197.42	117.21	3612.83
1983	78.22	47.32	37.08	27.67	28.07	67.24	78.18	250.76	309.19	322.47	191.33	106.50	1544.02
1984	68.70	45.20	35.71	34.12	35.12	298.59	332.15	655.72	534.24	370.27	166.78	100.73	2677.33
1985	66.63	43.84	36.32	29.60	60.99	238.06	406.95	559.30	646.62	537.73	308.06	192.12	3126.21
1986	107.72	69.71	56.81	51.41	62.27	121.23	324.92	412.88	298.95	179.73	130.82	90.52	1906.96
TOTAL	2533.24	1594.58	1325.15	1069.24	1898.81	4432.06	10050.29	19001.35	17141.41	11789.36	5859.00	3697.32	80391.79
MEAN	90.47	56.95	47.33	38.19	67.81	158.29	358.94	678.62	612.19	421.05	209.25	132.05	2871.14
MAX	142.80	83.83	67.50	63.88	181.07	298.59	866.59	1674.60	1007.94	794.21	343.33	192.12	4501.84
MIN	42.95	31.34	26.92	17.79	18.20	62.38	78.18	250.76	298.95	179.73	117.06	76.95	1544.02

Table 5－10 Monthly List of Adopted Runoff Data at Sop Han Gauging Station

(unit: m^3/sec.)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL (x 10^6 m^3)
1959	2.78	1.78	0.90	0.53	0.21	3.51	8.16	43.76	64.61	28.77	11.42	6.28	455.24
1960	4.03	2.12	0.84	0.28	5.72	3.48	15.92	93.26	63.46	61.70	27.50	17.98	785.04
1961	10.09	7.68	4.90	2.26	1.68	8.54	31.47	54.38	112.68	41.59	22.21	14.40	820.74
1962	10.24	7.84	5.14	2.89	13.28	9.47	32.46	53.83	55.91	66.72	22.72	13.03	776.31
1963	9.47	6.95	4.58	3.06	2.34	12.77	38.06	52.18	66.67	65.96	35.46	18.18	833.54
1964	11.81	9.21	6.24	3.74	6.10	3.69	66.92	52.91	120.14	60.77	27.95	16.41	1,018.52
1965	12.32	9.73	6.95	4.75	3.83	7.05	15.70	58.13	47.14	61.92	40.75	17.22	753.52
1966	11.31	8.84	6.15	4.24	9.09	18.66	48.20	115.41	74.68	31.29	18.12	12.71	948.47
1967	7.13	5.04	3.59	3.06	6.88	11.28	17.19	49.26	92.61	37.53	17.28	9.06	684.10
1968	6.34	4.28	3.58	4.25	8.09	13.63	25.84	52.55	43.02	45.35	18.11	9.66	621.06
1969	6.12	4.73	3.99	3.47	5.56	11.99	20.75	105.18	78.69	33.68	25.26	15.12	830.91
1970	9.92	7.03	5.36	5.60	18.83	20.14	25.51	72.47	75.87	49.15	23.56	18.56	876.59
1971	10.11	7.40	6.00	4.54	11.78	20.22	63.94	74.48	67.32	40.73	19.28	13.47	897.15
1972	8.91	6.47	4.90	5.25	4.66	8.82	23.26	69.63	35.22	27.17	26.42	11.05	613.07
1973	8.60	5.72	4.15	3.14	8.65	10.86	39.09	106.99	111.89	51.51	19.48	10.72	1,005.91
1974	10.28	7.54	5.06	4.12	8.92	11.30	17.52	43.45	50.80	28.47	29.89	12.12	604.35
1975	12.54	6.83	4.39	3.00	6.27	12.97	23.69	77.75	127.64	72.38	30.94	19.15	1,047.89
1976	11.12	7.71	5.20	3.85	5.86	6.61	14.42	36.08	52.57	45.97	22.60	16.53	603.37
1977	10.52	5.97	4.10	5.27	5.91	8.02	17.76	40.87	94.59	50.65	27.22	17.58	759.42
1978	14.02	8.50	5.53	4.18	5.65	7.08	47.08	78.32	101.69	64.54	28.90	14.02	1,002.03
1979	12.53	7.77	4.23	4.33	10.35	12.54	17.32	36.06	30.63	30.04	10.83	6.29	482.88
1980	4.35	3.17	2.35	2.25	9.90	19.52	26.32	42.69	97.58	43.34	17.97	12.72	743.31
1981	6.98	4.88	3.39	2.80	3.49	8.76	21.22	55.98	40.76	24.48	17.95	10.11	530.53
1982	6.36	4.23	3.08	4.13	5.56	19.22	18.50	48.74	69.42	54.86	21.12	12.38	705.79
1983	8.41	6.01	3.89	2.91	2.45	5.84	8.49	18.52	25.77	26.72	17.49	10.06	359.70
1984	6.06	4.36	2.24	3.48	3.45	15.95	26.55	52.15	51.18	41.16	16.82	9.62	615.79
1985	6.50	4.79	2.98	3.10	6.73	20.48	44.90	54.85	83.63	72.97	33.39	18.03	930.34
1986	7.13	5.04	3.59	3.06	6.88	11.28	17.19	49.26	92.61	37.53	17.28	9.06	684.10
Average	8.79	6.13	4.19	3.48	6.72	11.56	27.62	60.33	72.46	46.32	23.14	13.27	749.63

Table 5 — 11 Monthly List of Adopted Runoff Data from Ban Mae Ngao Gauging Station

(unit: m^3/sec.)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL (x 10^6 m^3)
1959	7.73	6.14	4.95	3.11	2.71	25.73	40.80	127.31	138.50	49.69	23.21	14.67	1,172.62
1960	7.40	6.22	4.65	2.71	28.36	33.97	56.62	177.92	134.39	138.10	59.66	37.99	1,821.76
1961	24.31	15.44	9.75	8.04	8.04	40.73	80.85	131.54	206.39	77.96	36.45	32.62	1,771.02
1962	20.89	12.65	9.90	8.02	38.23	39.83	90.77	114.90	116.91	169.22	43.49	29.26	1,837.72
1963	18.65	11.79	9.60	7.07	4.61	51.30	86.14	97.89	109.81	129.29	68.49	30.32	1,650.37
1964	21.47	12.42	9.17	7.48	12.64	13.13	142.99	98.49	151.05	121.46	36.42	27.31	1,731.65
1965	17.33	11.08	9.23	7.28	5.18	31.08	45.07	119.93	93.73	84.02	67.42	26.39	1,366.60
1966	18.76	11.25	8.59	6.48	11.35	45.17	85.15	192.11	118.29	37.64	26.96	18.01	1,532.92
1967	12.49	9.90	8.01	5.78	8.53	9.41	54.31	162.74	154.67	92.06	36.93	27.31	1,538.76
1968	17.61	11.53	8.88	6.10	12.29	57.15	58.46	130.50	90.01	59.07	26.97	20.47	1,319.09
1969	14.61	10.03	6.24	5.82	14.52	54.63	85.57	381.90	223.62	104.99	60.93	39.48	2,652.27
1970	26.29	18.45	12.69	12.14	21.41	34.99	86.36	129.86	138.85	71.64	38.56	26.26	1,629.69
1971	17.19	11.61	8.53	5.64	11.90	45.59	190.53	209.85	148.31	74.36	40.47	23.91	2,086.55
1972	16.13	11.16	8.62	8.42	7.37	18.51	125.40	177.48	116.21	73.35	49.86	34.35	1,713.97
1973	21.32	13.43	11.10	7.51	15.22	37.24	69.08	120.24	134.88	94.96	49.19	31.01	1,597.66
1974	16.79	11.23	7.07	6.98	14.68	42.82	78.88	134.34	91.57	63.42	38.77	20.06	1,392.00
1975	17.93	12.06	10.49	7.00	11.94	41.14	84.33	96.11	114.41	83.51	40.14	21.93	1,428.38
1976	16.79	11.95	8.05	5.53	13.46	30.44	72.03	134.43	100.40	80.28	43.67	22.73	1,428.07
1977	29.68	12.69	9.10	7.62	8.90	14.49	39.42	96.18	147.89	50.19	33.93	19.05	1,235.61
1978	13.03	10.44	7.21	5.19	10.76	10.77	65.64	125.60	86.53	59.66	23.46	14.01	1,144.27
1979	8.03	6.76	4.82	3.90	4.96	7.42	31.36	150.91	65.63	59.04	26.04	14.64	1,016.52
1980	9.47	6.90	6.00	4.97	16.10	22.66	50.68	76.09	172.76	105.56	47.36	28.05	1,441.40
1981	17.32	9.12	6.32	5.37	6.82	34.28	84.53	151.91	81.36	61.92	41.44	25.25	1,391.48
1982	15.65	10.06	6.83	5.80	13.83	67.21	112.94	256.31	151.29	89.14	39.38	21.58	2,090.61
1983	13.62	8.20	5.43	3.78	3.93	12.92	13.56	53.65	67.53	67.72	40.01	20.19	818.87
1984	12.57	8.16	6.12	5.21	6.08	72.13	77.99	152.07	100.20	58.31	29.29	17.68	1,442.61
1985	12.42	9.26	6.92	5.82	9.25	69.93	109.24	141.50	118.66	62.72	41.51	26.42	1,620.81
1986	18.09	13.11	9.57	7.43	9.22	31.03	76.28	82.66	55.98	28.47	18.54	12.31	958.27
Average	16.56	10.82	7.99	6.29	11.87	35.56	78.39	143.73	122.49	80.28	40.31	24.40	1,529.70

Table 5－12　Monthly Intakes of RID Weir

MONTHLY LIST OF DAILY TOTAL　RUNOFF AT < SHUSI >　(UNIT:10**6)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1959	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1960	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1961	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1962	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1963	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1964	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1965	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1966	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1967	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1968	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1969	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1970	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1971	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1972	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1973	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1974	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1975	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1976	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1977	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1978	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1979	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1980	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1981	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1982	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1983	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1984	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
1985	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
1986	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24
TOTAL	107.69	111.26	139.42	129.11	45.90	96.24	177.21	180.21	148.85	175.94	109.52	42.22	1463.57
MEAN	3.85	3.97	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.27
MAX	3.85	4.08	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.38
MIN	3.85	3.94	4.98	4.61	1.64	3.44	6.33	6.44	5.32	6.28	3.91	1.51	52.24

Table 5 −13　Monthly List of Adopted Runoff Data from Proposed Nam Yuam Damsite (EGAT site No.4 and No.5)

MONTHLY LIST OF DAILY TOTAL　RUNOFF AT < BAN4 > G.S (UNIT:10**6)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1959	41.04	28.82	24.47	16.08	17.39	109.26	180.15	603.95	677.60	265.92	118.42	78.99	2162.08
1960	42.89	30.92	23.15	13.98	130.56	140.14	260.78	923.37	659.40	690.57	293.85	198.50	3408.10
1961	123.52	74.61	53.01	38.73	41.69	177.67	393.39	646.80	1048.05	407.40	194.07	168.78	3367.73
1962	110.62	65.23	54.18	40.20	187.59	176.53	434.32	580.91	575.64	823.71	221.71	152.33	3422.97
1963	100.02	60.20	51.64	37.01	30.08	227.49	430.29	510.90	574.92	667.04	346.15	169.28	3205.03
1964	116.75	69.90	54.13	40.22	70.56	62.45	722.49	515.01	858.44	623.76	207.78	153.19	3494.68
1965	102.00	63.94	56.11	41.88	35.99	137.87	215.44	611.13	467.56	481.54	354.89	151.65	2720.01
1966	105.03	62.56	51.64	37.67	72.98	218.70	451.68	1033.48	626.03	225.52	148.64	107.95	3141.88
1967	70.32	49.28	43.01	32.17	56.58	66.79	254.98	754.98	805.66	451.98	183.97	134.90	2904.63
1968	88.22	55.18	46.35	36.25	74.16	251.54	292.59	638.21	443.71	343.54	148.63	109.88	2528.27
1969	76.02	49.03	37.14	33.33	76.48	238.12	385.01	1743.63	1030.80	492.50	293.24	197.16	4652.46
1970	130.75	83.67	65.56	62.15	136.22	184.09	399.89	685.30	706.01	401.75	205.23	154.47	3215.11
1971	95.95	60.59	51.02	35.24	81.82	224.04	899.31	1000.33	720.91	391.33	202.09	132.73	3895.36
1972	88.87	58.92	48.62	47.38	46.54	95.00	545.62	862.82	523.17	353.68	254.51	167.16	3092.28
1973	108.21	63.18	56.38	38.87	86.89	170.17	366.74	733.97	777.89	498.00	235.28	153.38	3288.95
1974	94.85	59.57	43.02	39.23	85.46	192.14	351.02	630.44	468.27	318.43	221.29	114.42	2618.13
1975	104.88	60.86	54.62	36.61	68.27	189.86	387.50	567.64	739.06	505.59	228.95	139.16	3083.00
1976	96.94	64.68	47.20	33.17	73.11	134.42	316.78	612.43	505.65	427.31	222.10	135.75	2669.53
1977	145.39	61.16	48.50	44.43	55.58	77.98	198.68	476.08	785.04	322.34	196.66	124.09	2535.92
1978	89.58	58.97	44.73	32.68	62.14	61.76	373.29	683.34	571.97	393.61	161.44	95.71	2629.24
1979	66.46	44.45	32.23	28.20	51.36	62.37	166.34	676.24	322.38	305.33	127.60	78.90	1961.87
1980	51.68	35.79	32.13	27.20	93.40	136.36	263.63	402.77	885.52	518.75	224.80	146.87	2818.88
1981	88.68	46.20	35.97	30.03	41.49	154.01	382.14	729.72	405.80	302.66	202.54	129.53	2548.77
1982	80.67	48.02	37.17	34.84	73.82	302.72	485.51	1116.34	737.13	483.79	202.40	120.99	3723.39
1983	77.89	45.51	33.77	24.31	27.70	66.83	75.37	255.62	317.81	330.72	196.04	109.79	1561.36
1984	67.95	43.16	32.34	31.05	35.07	308.61	340.79	678.83	553.00	380.67	170.39	103.76	2745.60
1985	65.79	41.87	32.97	26.32	62.09	245.35	418.96	578.07	670.44	555.68	318.03	199.27	3214.85
1986	108.72	68.91	54.40	49.12	63.44	123.25	333.23	425.05	307.10	181.54	132.80	93.09	1940.66
TOTAL	2539.69	1555.17	1245.44	988.30	1938.47	4535.53	10325.95	19677.35	17764.97	12144.66	6013.50	3821.70	82550.73
MEAN	90.70	55.54	44.48	35.30	69.23	161.98	368.78	702.76	634.46	433.74	214.77	136.49	2948.24
MAX	145.39	83.67	65.56	62.15	187.59	308.61	899.31	1743.63	1048.05	823.71	354.89	199.27	4652.46
MIN	41.04	28.82	23.15	13.98	17.39	61.76	75.37	255.62	307.10	181.54	118.42	78.90	1561.36

Table 5 — 14 Monthly List of Adopted Runoff Data from Proposed Nam Yuam Damsite (NEA site)

(unit: $m^3/sec.$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL ($x 10^6 m^3$)
1959	16.45	13.29	10.79	7.84	6.97	42.69	68.35	223.74	258.66	99.78	46.33	29.50	2,173.92
1960	17.13	13.71	10.31	7.04	48.46	54.38	97.91	340.82	251.77	255.43	112.78	73.31	3,397.35
1961	46.69	31.88	21.25	16.42	15.88	68.60	146.52	239.44	398.98	151.64	74.99	62.42	3,357.57
1962	41.96	28.07	21.68	16.97	69.36	68.17	161.52	215.29	220.04	304.23	85.46	56.39	3,411.81
1963	38.07	26.03	20.75	15.77	11.63	87.47	160.04	189.63	219.77	246.80	132.59	62.60	3,197.85
1964	44.21	28.99	21.67	16.98	26.46	24.95	267.15	191.13	327.16	230.94	80.18	56.70	3,482.35
1965	38.80	27.55	22.39	17.61	13.79	53.52	81.29	226.37	179.11	178.81	135.90	56.14	2,721.67
1966	39.91	26.99	20.75	16.01	27.35	84.14	167.88	381.18	239.13	84.97	57.78	40.12	3,135.85
1967	27.18	21.60	17.59	13.93	21.34	26.60	95.78	279.10	307.17	167.97	71.16	50.00	2,902.92
1968	33.75	23.22	18.82	15.48	27.78	96.57	109.57	236.29	170.08	128.23	57.78	40.83	2,533.57
1969	29.27	21.49	15.44	14.37	28.64	91.49	143.44	641.48	392.44	182.83	112.55	72.82	4,618.87
1970	49.34	35.55	25.86	25.29	50.53	71.03	148.90	253.55	269.43	149.56	79.21	57.17	3,207.74
1971	36.58	26.18	20.53	15.09	30.59	86.16	331.96	369.03	275.07	145.74	78.03	49.20	3,875.58
1972	33.98	24.68	19.65	19.69	17.66	37.28	202.32	318.62	200.17	131.94	97.88	61.82	3,087.29
1973	41.07	27.24	22.49	16.47	32.45	65.76	136.75	271.39	296.65	184.84	90.60	56.77	3,280.23
1974	36.18	25.77	17.59	16.60	31.93	74.08	130.98	233.44	179.38	119.02	85.30	42.49	2,621.65
1975	39.85	26.29	21.85	15.61	25.63	73.22	144.36	210.43	281.94	187.62	88.20	51.56	3,078.04
1976	36.94	26.94	19.13	14.31	27.40	52.22	118.43	226.84	193.54	158.93	85.16	49.63	2,669.28
1977	54.12	25.43	18.87	18.04	20.55	30.07	72.93	174.97	298.12	118.77	74.35	45.64	2,506.49
1978	33.18	24.14	16.26	12.03	22.50	23.98	137.16	250.60	216.64	144.62	60.48	35.56	2,583.90
1979	25.57	19.64	13.64	12.43	19.43	23.87	60.23	247.35	120.77	111.10	47.49	28.92	1,933.65
1980	18.47	13.69	11.26	9.36	33.72	52.92	97.20	147.59	335.92	190.13	84.80	53.95	2,765.61
1981	32.34	18.65	13.08	11.33	15.42	58.12	139.32	267.19	153.35	110.57	76.85	47.35	2,496.55
1982	29.28	19.70	13.93	13.13	26.93	114.89	177.43	409.10	278.56	177.07	76.66	44.03	3,651.22
1983	28.35	18.17	12.12	9.34	9.97	24.60	27.52	93.62	120.16	120.84	74.41	40.22	1,527.23
1984	24.89	16.28	11.18	11.50	13.08	116.59	125.38	248.59	209.42	139.28	64.47	37.79	2,690.23
1985	24.04	17.09	11.67	9.67	22.95	92.45	153.66	212.14	254.65	203.74	120.51	73.43	3,157.68
1986	39.67	27.94	20.33	18.93	23.47	46.57	122.29	155.77	116.52	67.19	50.67	34.20	1,910.56
Average	34.19	23.44	17.53	14.54	25.78	62.23	136.65	259.10	241.59	160.45	82.23	50.38	2,927.74

Table 5－15 Monthly List of Adopted Runoff Data at Proposed Nam Ngao Damsite (No.1 site)

(unit: m^3/sec.)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL ($x 10^6 m^3$)
1959	7.01	5.57	4.49	2.82	2.46	23.33	37.01	115.46	125.62	45.06	21.05	13.30	1,063.51
1960	6.71	5.64	4.22	2.46	25.72	30.81	51.35	161.37	121.88	125.25	54.11	34.46	1,652.25
1961	22.05	14.00	8.84	7.29	7.29	36.94	73.33	119.30	187.19	70.70	33.06	29.58	1,606.23
1962	18.95	11.48	8.98	7.28	34.67	36.12	82.33	104.21	106.03	153.48	39.45	26.53	1,666.73
1963	16.92	10.69	8.71	6.41	4.18	46.52	78.12	88.78	99.59	117.26	62.11	27.50	1,496.80
1964	19.47	11.27	8.32	6.79	11.46	11.90	129.69	89.32	137.00	110.16	33.04	24.77	1,570.52
1965	15.72	10.04	8.37	6.60	4.70	28.19	40.87	108.77	85.01	76.21	61.15	23.93	1,239.44
1966	17.02	10.21	7.79	5.88	10.29	40.97	77.22	174.24	107.28	34.14	24.46	16.33	1,390.29
1967	11.33	8.98	7.26	5.24	7.74	8.54	49.26	147.60	140.27	83.50	33.49	24.77	1,395.58
1968	15.98	10.46	8.05	5.53	11.15	51.84	53.02	118.36	81.64	53.57	24.46	18.56	1,196.35
1969	13.25	9.09	5.66	5.28	13.17	49.55	77.61	346.36	202.81	95.22	55.26	35.81	2,405.48
1970	23.84	16.73	11.51	11.01	19.42	31.74	78.32	117.77	125.93	64.97	34.97	23.82	1,478.05
1971	15.59	10.53	7.73	5.11	10.79	41.35	172.80	190.32	134.51	67.44	36.71	21.69	1,892.40
1972	14.63	10.12	7.82	7.64	6.68	16.79	113.73	160.97	105.40	66.53	45.22	31.16	1,554.49
1973	19.33	12.18	10.16	6.81	13.80	33.78	62.65	109.06	122.33	86.12	44.61	28.12	1,449.00
1974	15.23	10.19	6.41	6.33	13.31	38.83	71.54	121.84	83.05	57.52	35.17	18.19	1,262.48
1975	16.26	10.93	9.52	6.35	10.83	37.31	76.48	87.17	103.77	75.74	36.41	19.89	1,295.47
1976	15.23	10.84	7.30	5.02	12.20	27.61	65.33	121.92	91.05	72.81	39.61	20.62	1,295.19
1977	26.92	11.51	8.25	6.91	8.07	13.14	35.75	87.23	134.13	45.52	30.77	17.28	1,120.64
1978	11.82	9.47	6.54	4.71	9.76	9.77	59.53	113.91	78.47	54.11	21.27	12.71	1,037.80
1979	7.28	6.13	4.37	3.54	4.50	6.73	28.44	136.86	59.52	53.54	23.62	13.28	921.93
1980	8.59	6.25	5.44	4.51	14.60	20.56	45.96	69.01	156.68	95.74	42.96	25.44	1,307.28
1981	15.71	8.27	5.73	4.87	6.18	31.09	76.66	137.78	73.79	56.15	37.59	22.90	1,262.01
1982	14.20	9.12	6.20	5.26	12.54	60.96	102.44	232.46	137.21	80.85	35.71	19.58	1,896.09
1983	12.35	7.44	4.93	3.43	3.56	11.72	12.30	48.66	61.24	61.42	36.29	18.31	742.68
1984	11.40	7.40	5.55	4.72	5.52	65.42	70.73	137.92	90.88	52.88	26.56	16.04	1,308.37
1985	11.26	8.39	6.28	5.28	8.39	63.42	99.07	128.34	107.62	56.88	37.64	23.96	1,470.00
1986	16.41	11.89	8.68	6.74	8.36	28.14	69.19	74.97	50.77	25.82	16.81	11.16	869.11
Average	15.02	9.82	7.25	5.71	10.76	32.25	71.10	130.36	111.10	72.81	36.56	22.13	1,387.36

Table 5 —16 Monthly List of Adopted Runoff Data at Proposed Nam Ngao Damsite (No.2 site)

(unit: m^3/sec.)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL (x 10^6 m^3)
1959	6.90	5.49	4.42	2.77	2.42	22.98	36.44	113.69	123.69	44.37	20.73	13.10	1,047.21
1960	6.61	5.56	4.16	2.42	25.33	30.34	50.57	158.89	120.02	123.33	53.28	33.93	1,626.92
1961	21.71	13.79	8.71	7.18	7.18	36.38	72.20	117.47	184.32	69.62	32.56	29.13	1,581.60
1962	18.65	11.30	8.84	7.16	34.14	35.57	81.06	102.61	104.40	151.12	38.84	26.13	1,641.17
1963	16.66	10.53	8.58	6.31	4.12	45.81	76.92	87.42	98.06	115.46	61.16	27.08	1,473.86
1964	19.17	11.09	8.19	6.68	11.29	11.72	127.70	87.95	134.90	108.47	32.53	24.39	1,546.44
1965	15.48	9.89	8.24	6.50	4.63	27.76	40.25	107.10	83.70	75.04	60.21	23.57	1,220.44
1966	16.75	10.05	7.67	5.79	10.13	40.34	76.04	171.57	105.64	33.62	24.08	16.08	1,368.97
1967	11.15	8.84	7.15	5.16	7.62	8.41	48.50	145.34	138.12	82.22	32.98	24.39	1,374.19
1968	15.73	10.30	7.93	5.45	10.98	51.04	52.21	116.54	80.39	52.75	24.08	18.28	1,178.01
1969	13.05	8.96	5.57	5.20	12.97	48.79	76.42	341.05	199.70	93.76	54.41	35.26	2,368.60
1970	23.48	16.47	11.33	10.86	19.12	31.25	77.12	115.97	124.00	63.98	34.44	23.45	1,455.39
1971	15.35	10.37	7.61	5.04	10.63	40.72	170.15	187.40	132.45	66.41	36.14	21.36	1,863.39
1972	14.41	9.96	7.70	7.52	6.58	16.53	111.99	158.50	103.78	65.51	44.53	30.68	1,530.66
1973	19.04	12.00	9.91	6.71	13.59	33.26	61.69	107.38	120.45	84.80	43.93	27.69	1,426.79
1974	15.00	10.03	6.31	6.23	13.11	38.24	70.44	119.97	81.77	56.64	34.63	17.91	1,243.12
1975	16.02	10.77	9.37	6.25	10.67	36.74	75.31	85.83	102.18	74.58	35.85	19.59	1,275.61
1976	15.00	10.67	7.19	4.94	12.02	27.19	64.33	120.05	89.66	71.69	39.00	20.30	1,275.33
1977	26.51	11.33	8.12	6.81	7.95	12.94	35.20	85.89	132.07	44.82	30.30	17.01	1,103.46
1978	11.64	9.33	6.44	4.64	9.61	9.62	58.62	112.17	77.27	53.28	20.95	12.51	1,021.89
1979	7.17	6.04	4.30	3.48	4.43	6.63	28.01	134.77	58.61	52.72	23.26	13.07	907.80
1980	8.46	6.16	5.36	4.44	14.37	20.24	45.26	67.95	154.28	94.27	42.30	25.05	1,287.24
1981	15.47	8.14	5.65	4.79	6.09	30.62	75.49	135.66	72.66	55.29	37.01	22.55	1,242.66
1982	13.98	8.98	6.10	5.18	12.35	60.02	100.87	228.90	135.11	79.61	35.16	19.28	1,867.02
1983	12.16	7.33	4.85	3.37	3.51	11.54	12.11	47.91	60.31	60.48	35.73	18.03	731.29
1984	11.22	7.29	5.47	4.65	5.43	64.42	69.65	135.81	89.48	52.07	26.15	15.79	1,288.32
1985	11.09	8.27	6.18	5.20	8.26	62.45	97.56	126.37	105.97	56.01	37.07	23.59	1,447.46
1986	16.16	11.71	8.55	6.63	8.24	27.71	68.13	73.82	49.99	25.43	16.55	10.99	855.79
Average	14.79	9.67	7.14	5.62	10.60	31.76	70.01	128.36	109.39	71.69	35.99	21.79	1,366.09

Table 5 − 17 Monthly List of Adopted Runoff Data at Proposed Nam Ngao Damsite (No.3 site)

(unit: $m^3/sec.$)

YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	TOTAL ($\times 10^6 m^3$)
1959	6.25	4.97	4.00	2.51	2.19	20.80	32.99	102.94	111.99	40.18	18.77	11.86	948.13
1960	5.99	5.03	3.76	2.19	22.93	27.47	45.78	143.86	108.66	111.66	48.24	30.72	1,473.00
1961	19.66	12.48	7.88	6.50	6.50	32.93	65.37	106.36	166.88	63.03	29.48	26.37	1,431.97
1962	16.89	10.23	8.00	6.49	30.91	32.20	73.40	92.90	94.53	136.83	35.17	23.66	1,485.90
1963	15.08	9.53	7.76	5.71	3.73	41.48	69.65	79.15	88.79	104.54	55.38	24.51	1,334.42
1964	17.36	10.04	7.42	6.05	10.22	10.61	115.62	79.63	122.14	98.21	29.45	22.08	1,400.13
1965	14.02	8.96	7.46	5.88	4.19	25.13	36.44	96.97	75.78	67.94	54.51	21.34	1,104.97
1966	15.17	9.10	6.95	5.24	9.18	36.52	68.85	155.33	95.64	30.43	21.80	14.56	1,239.45
1967	10.10	8.00	6.47	4.67	6.90	7.61	43.92	131.59	125.06	74.44	29.86	22.08	1,244.18
1968	14.24	9.32	7.18	4.93	9.94	46.21	47.27	105.52	72.78	47.76	21.81	16.55	1,066.56
1969	11.81	8.11	5.05	4.71	11.74	44.17	69.19	308.79	180.81	84.89	49.27	31.92	2,144.51
1970	21.26	14.92	10.26	9.81	17.31	28.29	69.82	105.00	112.27	57.92	31.18	21.23	1,317.69
1971	13.90	9.39	6.89	4.56	9.62	36.87	154.05	169.67	119.92	60.12	32.72	19.34	1,687.09
1972	13.04	9.02	6.97	6.81	5.96	14.97	101.39	143.51	93.96	59.31	40.32	27.78	1,385.84
1973	17.24	10.86	8.97	6.07	12.31	30.11	55.85	97.22	109.05	76.78	39.77	25.07	1,291.80
1974	13.58	9.08	5.72	5.64	11.87	34.62	63.78	108.62	74.04	51.28	31.35	16.22	1,125.51
1975	14.50	9.75	8.48	5.66	9.66	33.26	68.19	77.71	92.51	67.52	32.46	17.73	1,154.93
1976	13.58	9.66	6.51	4.47	10.88	24.61	58.24	108.69	81.18	64.91	35.31	18.38	1,154.67
1977	24.00	10.26	7.36	6.16	7.19	11.71	31.87	77.76	119.58	40.58	27.43	15.40	999.06
1978	10.54	8.44	5.83	4.20	8.70	8.71	53.07	101.55	69.96	48.24	18.96	11.33	925.21
1979	6.49	5.47	3.89	3.15	4.01	6.00	25.36	122.02	53.06	47.73	21.06	11.84	821.91
1980	7.66	5.58	4.85	4.02	13.01	18.33	40.98	61.53	139.68	85.35	38.30	22.68	1,165.46
1981	14.00	7.37	5.11	4.34	5.51	27.72	68.35	122.83	65.79	50.06	33.51	20.42	1,125.09
1982	12.66	8.13	5.52	4.69	11.18	54.35	91.32	207.24	122.32	72.08	31.84	17.45	1,690.38
1983	11.01	6.63	4.39	3.05	3.17	10.44	10.96	43.38	54.60	54.76	32.35	16.32	662.11
1984	10.16	6.60	4.95	4.21	4.92	58.32	63.06	122.96	81.02	47.14	23.68	14.30	1,166.43
1985	10.04	7.48	5.60	4.71	7.48	56.54	88.33	114.41	95.94	50.71	33.56	21.36	1,310.51
1986	14.63	10.60	7.74	6.01	7.46	25.09	61.68	66.83	45.26	23.02	14.99	9.95	774.82
Average	13.39	8.75	6.46	5.09	9.60	28.75	63.38	116.21	99.04	64.91	32.59	19.73	1,236.85

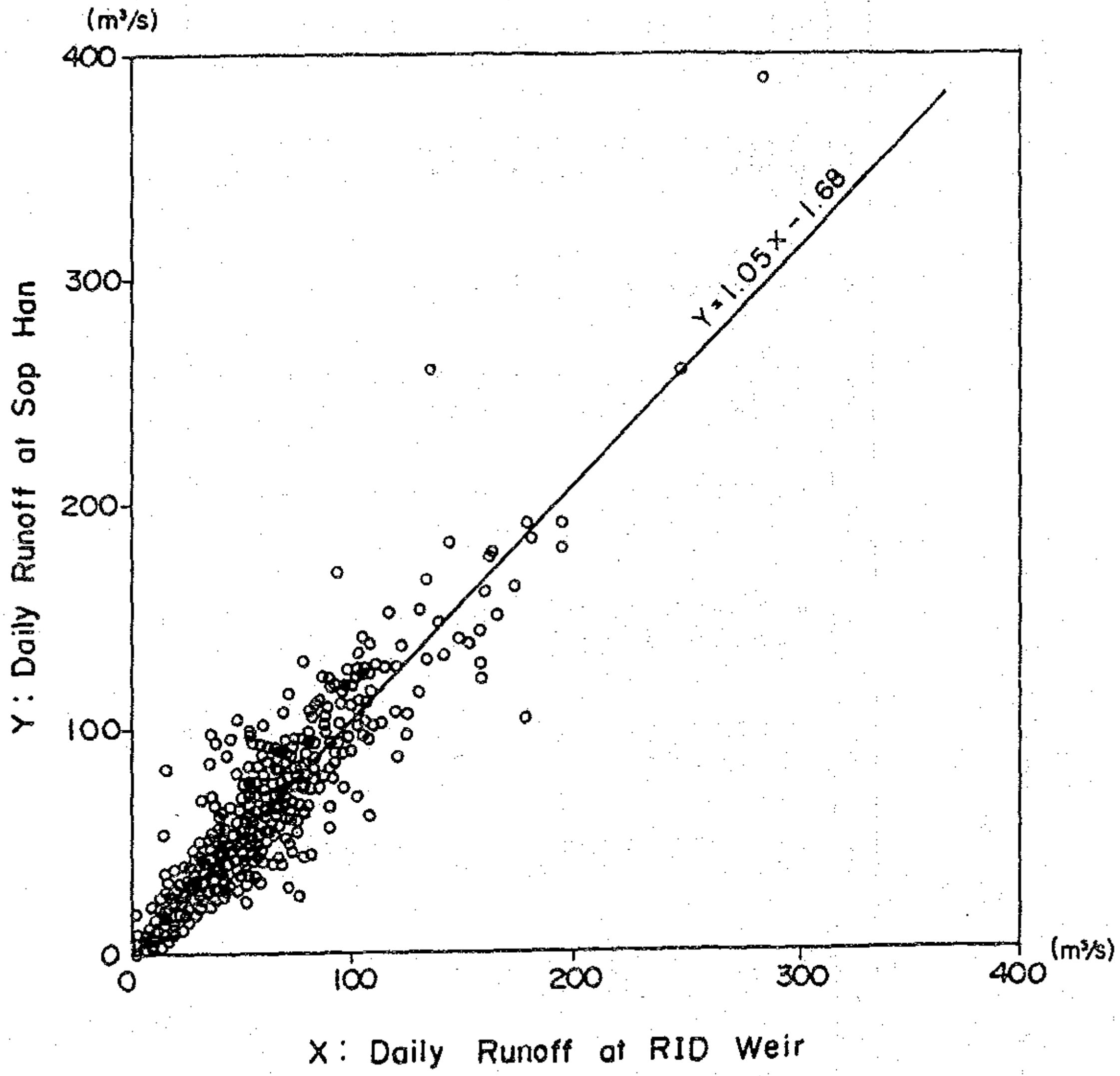


Fig. 5－10 Scattergram and Regression Line
(with daily runoff at Sop Han and RID Weir)

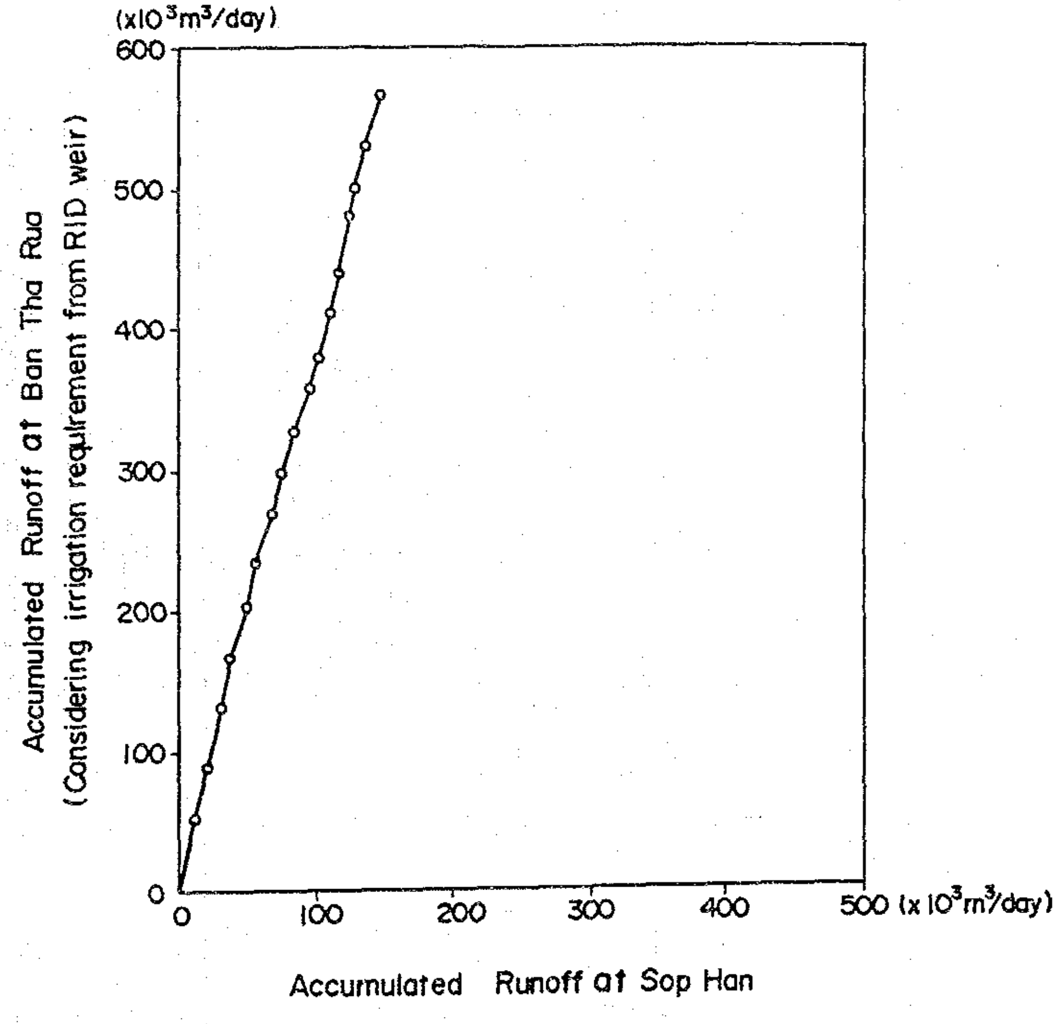


Fig. 5－11 Double Mass Curve
(with annual runoff at Sop Han and Ban Tha Rua)

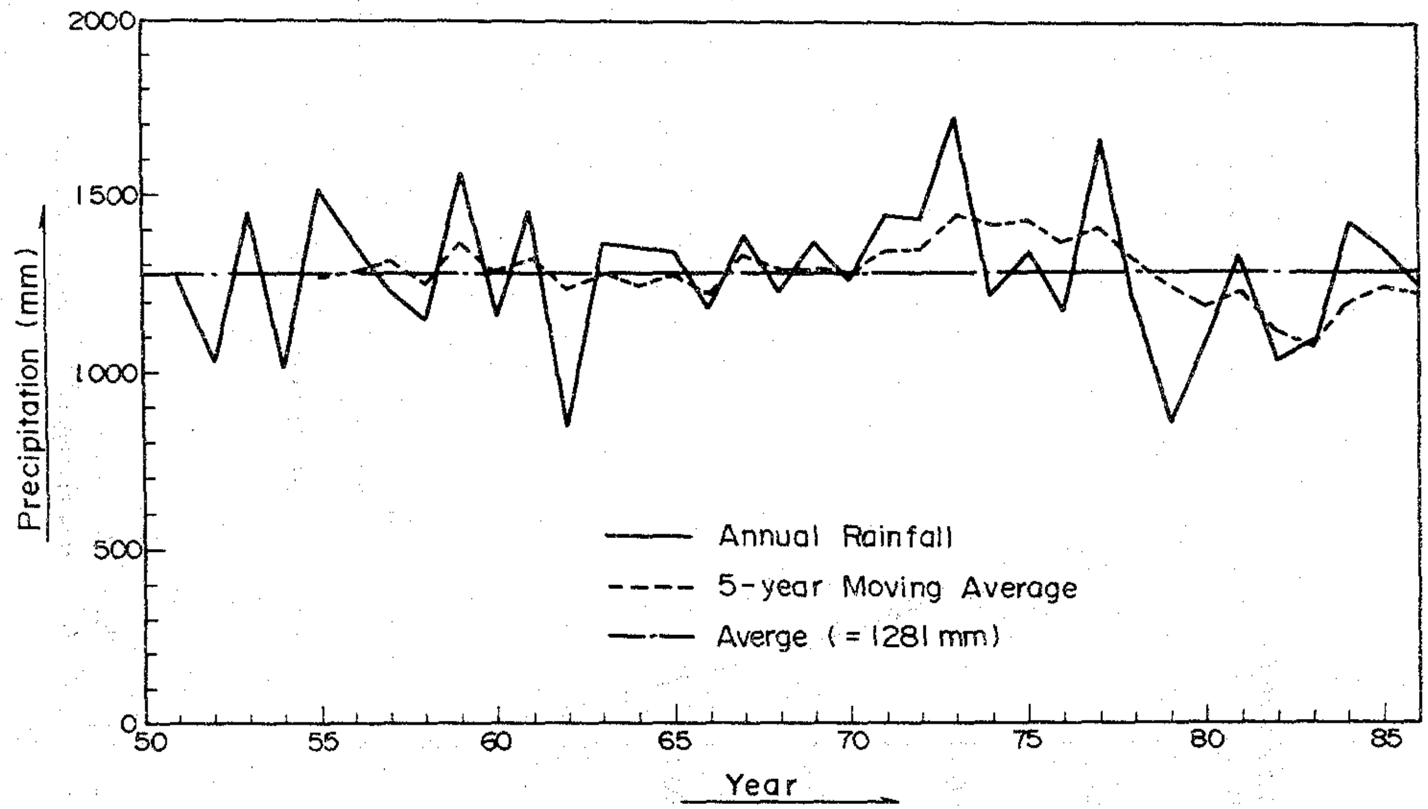


Fig.5-12(1) Precipitation at Mae Hong Son Station

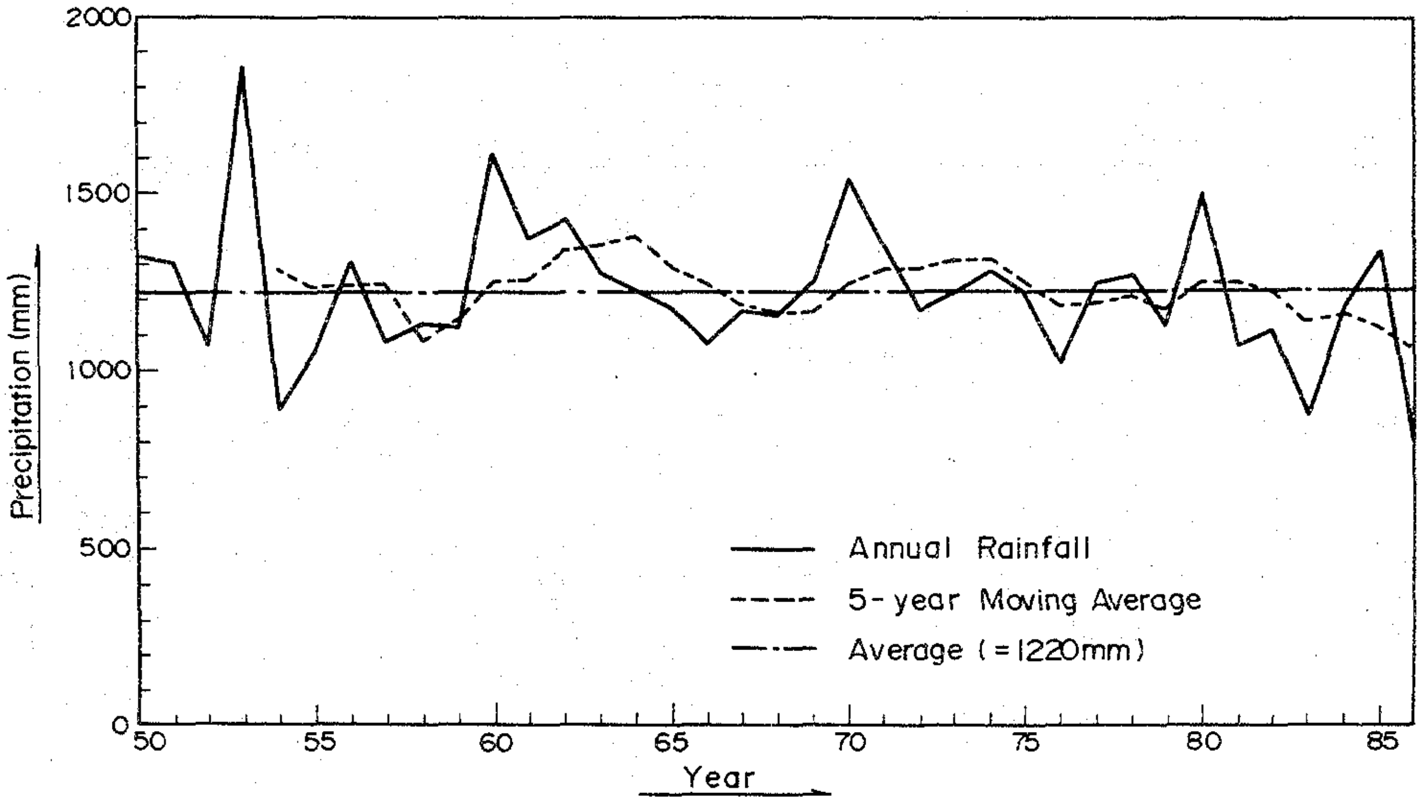


Fig.5-12(2) Precipitation at Mae Sariang Station

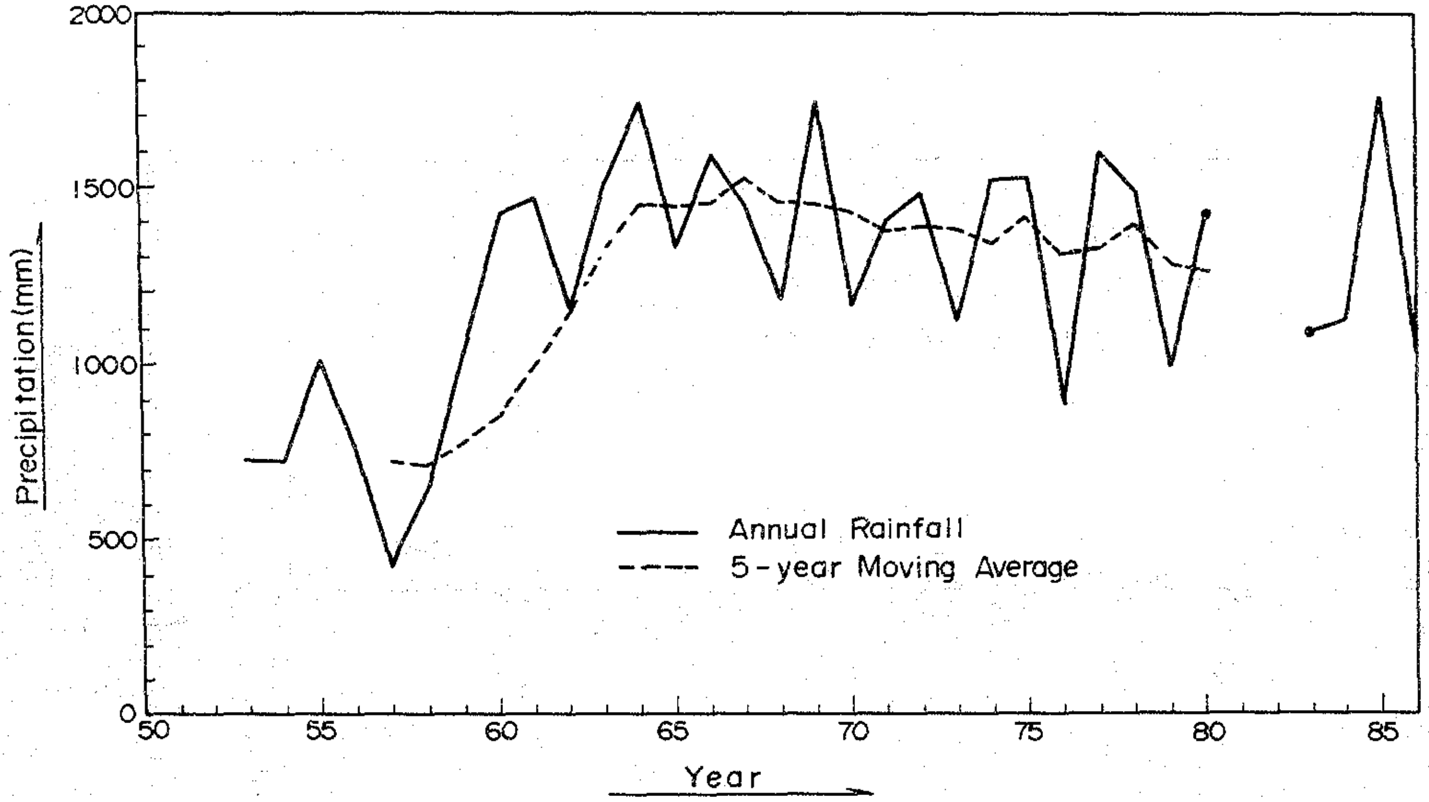


Fig.5-12(3) Precipitation at Khun Yuam Station

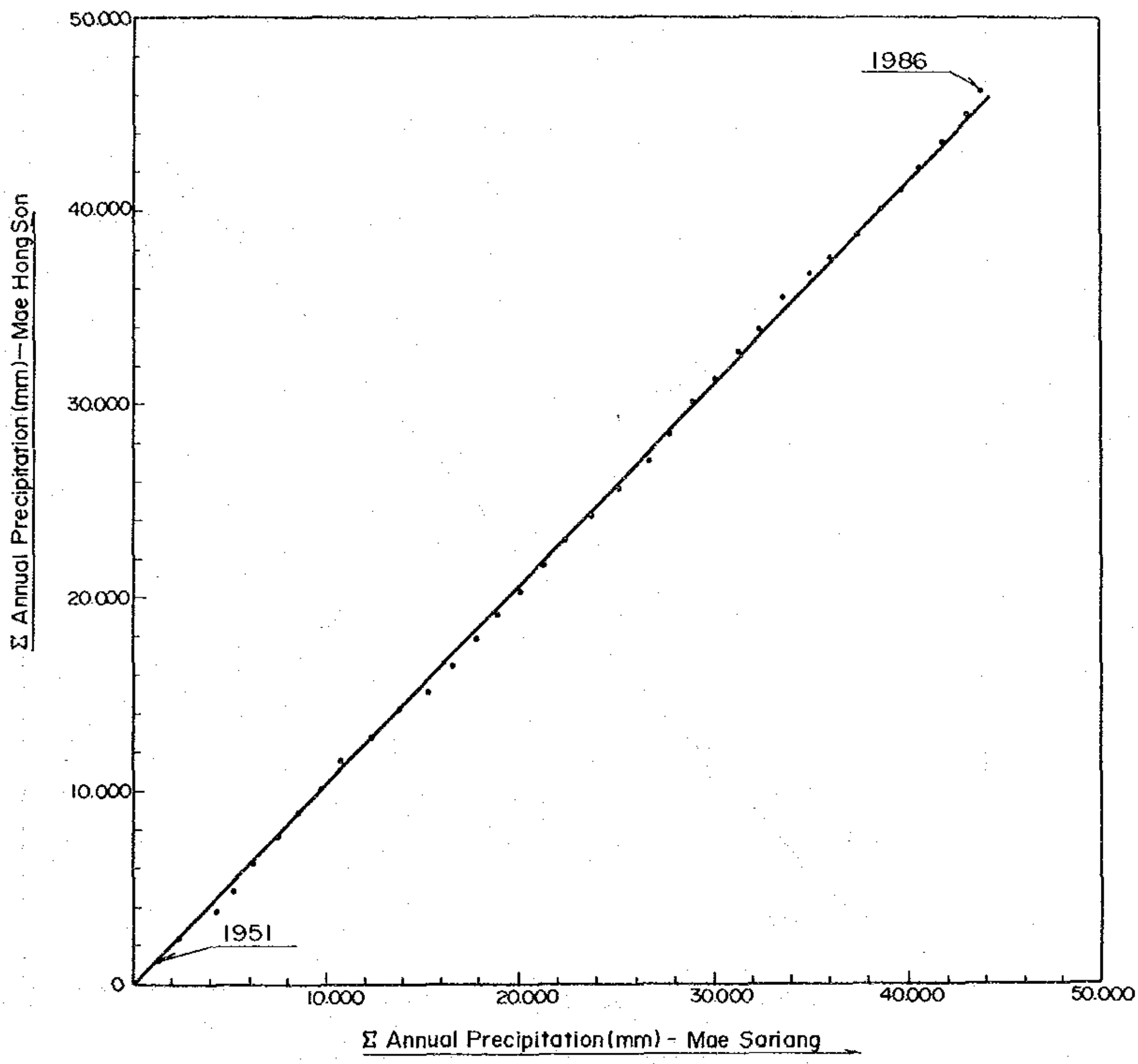


Fig.5-13(1) Double Mass Curve
(Mae Hong Son - Mae Sariang)

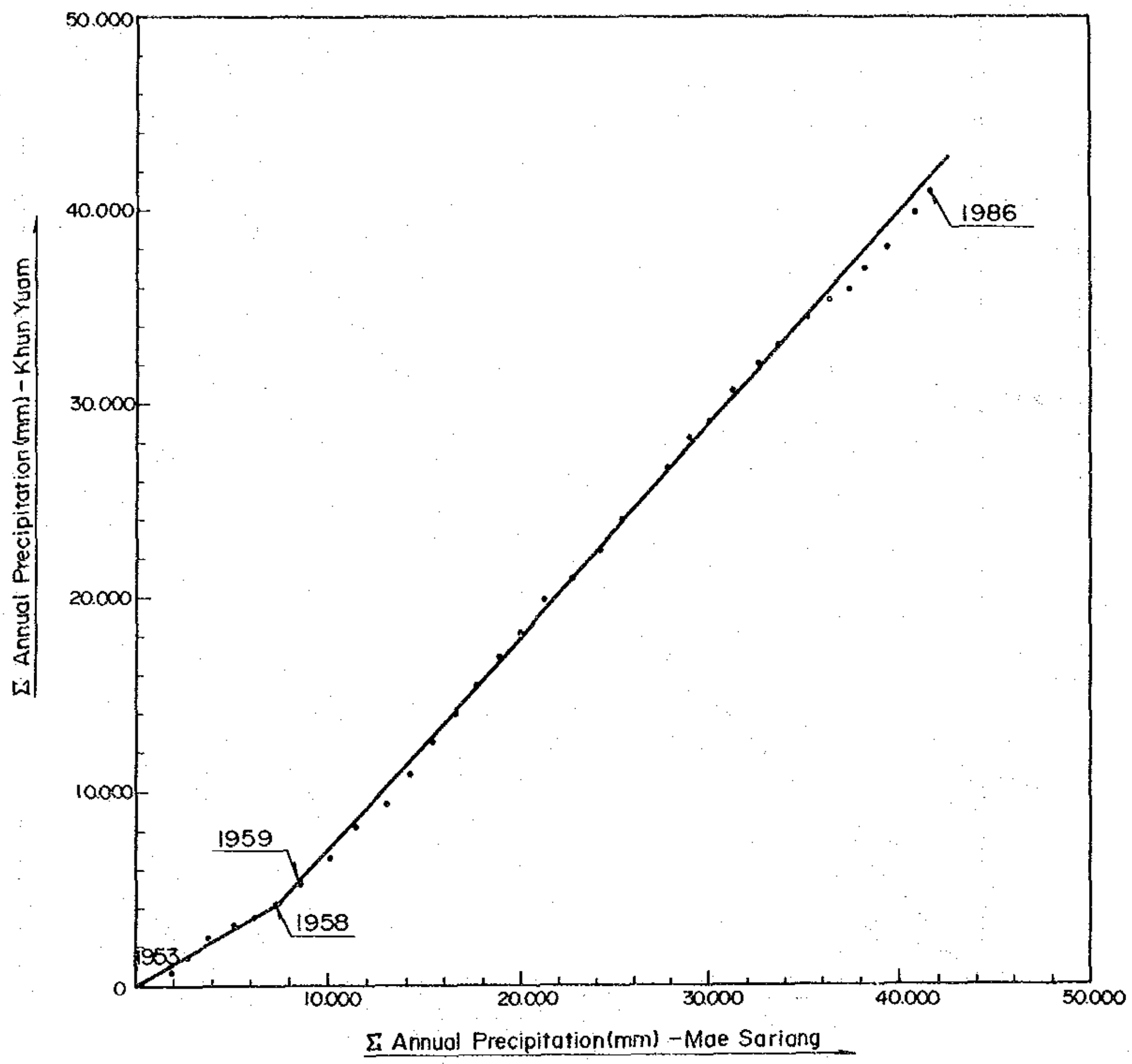
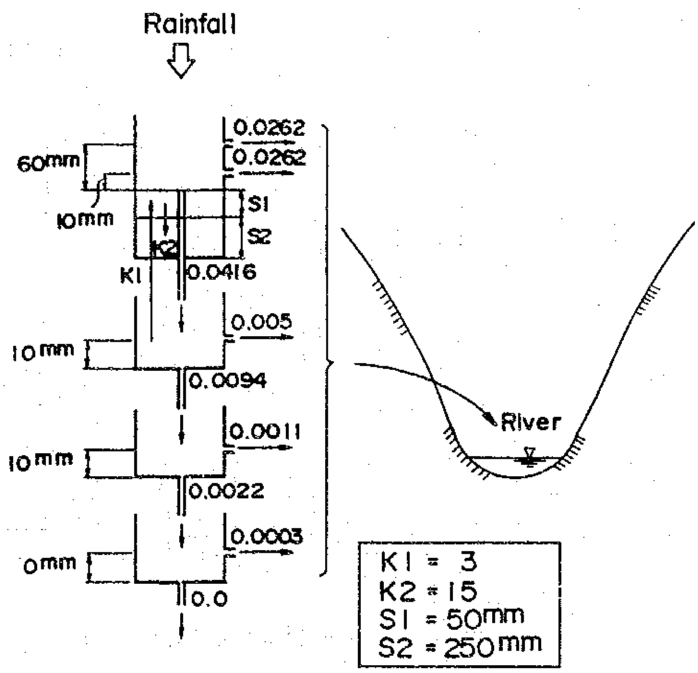


Fig.5-13(2) Double Mass Curve
(Khun Yuam - Mae Sariang)

for Ban Tha Rua



for Sop Han

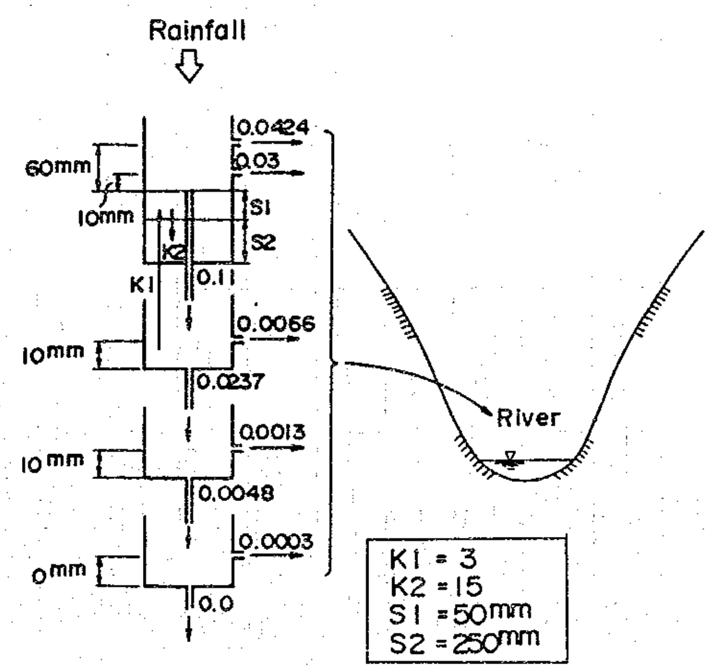


Fig. 5 — 14 Adopted Tank Model and Coefficients

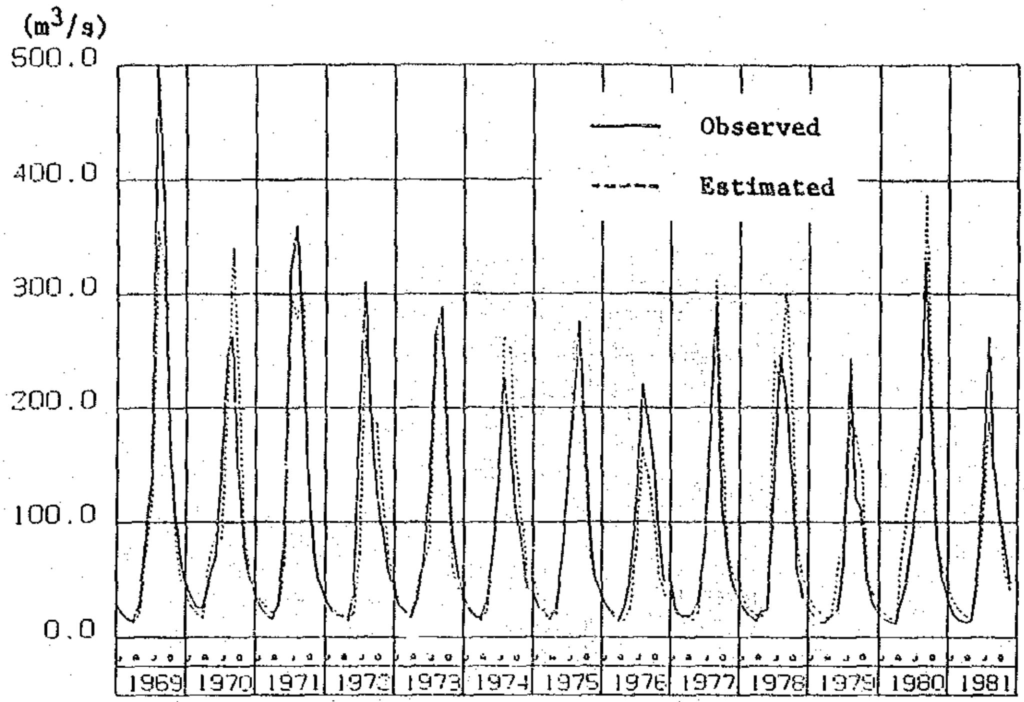


Fig. 5 −15　　Observed and Estimated Runoff at Ban Tha Rua Gauging Station

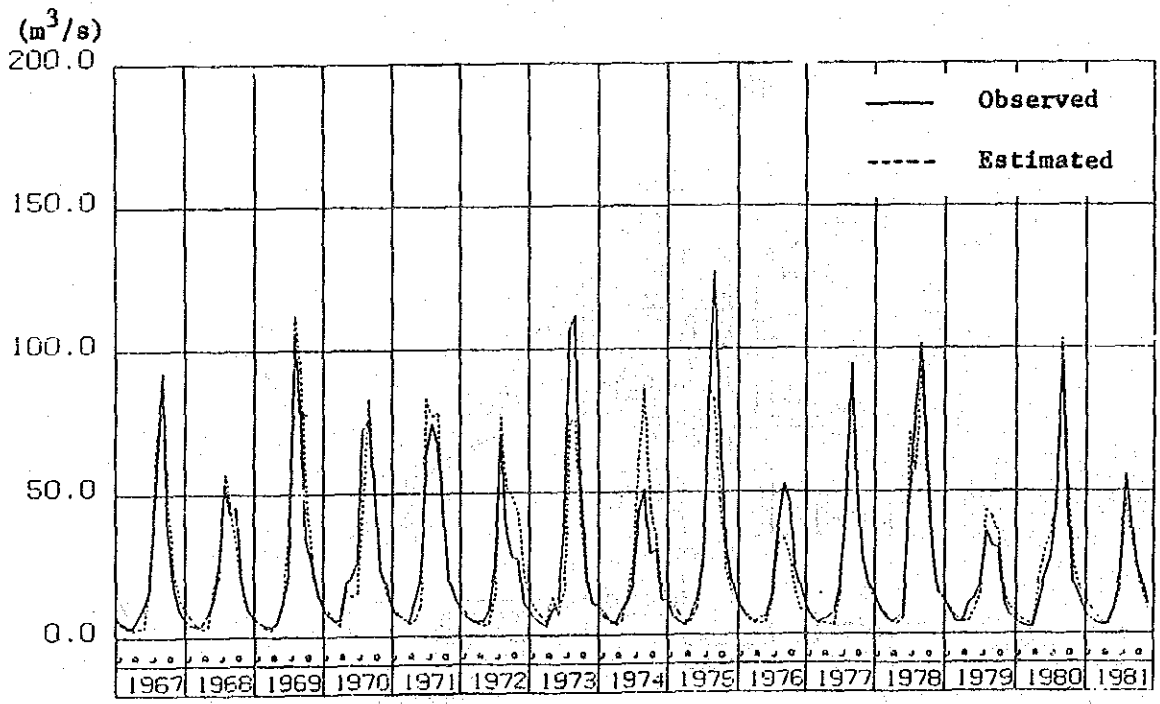


Fig. 5 −16　　Observed and Estimated Runoff at Sop Han Gauging Station

5.5 Flood Analysis

5.5.1 Methodology

In the flood analysis the following different methods were tried to evaluate the magnitude of the floods at the Mae Lama Luang dam and the Nam Ngao dam.

The first paragraph presents an empirical approach based on envelope curves.

Next, a statistical approach is performed on the available flood records.

The third section presents the results of tank model analysis and unit hydrograph analysis. The thus obtained tank models and unit hydrographs are used for the study devoted to the probable maximum flood.

Finally, all results are summarized and discussed, and the design flood values for further studies are estimated.

5.5.2 Experimental Curves

Fig. 5-17 presents the envelope curves of maximum recorded discharges and PMF estimates of various projects in Thailand.

Using the envelope curve of PMF estimates the following values are obtained:

PMF Estimates Using Envelope Curve

	Drainage Area (km^2)	Specific Yield ($m^3/sec/km^2$)	Q (m^3/sec)
Mae Lama Luang dam	6,030	1.1	6,900
Nam Ngao dam	835	2.4	2,000

5.5.3 Statistical Analysis

(1) Flood Records

The station at Ban Tha Rua, situated about 20 km upstream of the Mae Lama Luang dam, and the station at Ban Mae Ngao, situated about 15 km downstream of the Nam Ngao dam have been in operation since 1968 and 1984 respectively.

Annual flood peaks at these two stations are listed in Tables 5-18 and 5-19.

According to these data, the floods are recorded to occur mainly in August. The recorded maximum flood peak of 1,180 m^3/sec occurred at Ban Tha Rua on August 1, 1969, and 770 m^3/sec (estimated value) at Ban Mae Ngao on August 30, 1971.

(2) Flood Frequency Analysis

A frequency analysis was done at the both sites of the Mae Lama Luang dam and the Nam Ngao dam, followed by the estimation of flood peaks at both damsites using the data presented in Tables 5-18 and 5-19.

Two methods, Gumbel distribution and lognormal distribution, were applied to the flood series at both sites.

The results of flood magnitudes at various return periods are tabulated in Tables 5-20 and 5-21.

Figs. 5-18 and 5-19 show the 95% confidence limits established on both sides of the fitted lognormal distribution curve of the flood peaks.

5.5.4 Probable Maximum Flood

(1) Methodology

The probable maximum flood at each site is determined by the following steps.

In a first step the whole drainage area is divided into five sub-basins as shown in Fig. 5-20.

Next, various parameters for each sub-basin are derived by the Tank Model method or Snyder's method.

The third step is to estimate the probable maximum precipitation (PMP) for each sub-basin.

Finally the probable maximum flood at each site is obtained by applying the PMP to a tank model or a unit hydrograph for each basin.

(2) Basin Parameter

The following table shows how various parameters are estimated for each basin.

For sub-basins No.1, 3 and 4, parameters of the tanks are derived by simulating several floods' data; precipitation and river flow discharge recorded at the relevant stations.

For sub-basins No.2 and 5, unit hydrographs are established based on topographic maps (scale 1:250,000).

Figs. 5-21 and 5-22 illustrate the tank configuration for sub-basins No.1, 3 and 4, and unit hydrographs for sub-basins No.2 and 5.

Methods of Estimation of Basin Parameters

No. of sub-basin	Drainage Area (km^2)	Estimating Method	Data Used for Estimation	
			Precipitation	River Discharge
1	2,496	Tank Model	Khun Yuam St. (daily)* Mae La Luang St. (daily)* Sop Han St. (daily)*	Sop Han St. (hourly)
2	378	Snyder's Synthetic Unit Hydrograph	---	---
3	1,376	Tank Model	Mae Suat St. (daily)*	Mae Suat St. (hourly)
4	935	Tank Model	Ngao St. (hourly)	Ngao St. (hourly)
5	845	Snyder's Synthetic Unit Hydrograph	---	---
Total	6,030			

Note *: In order to perform flood simulation, hourly precipitation patterns are prepared from daily precipitation by applying the hourly pattern at Salawin St. to each station.

(3) Probable Maximum Precipitation

The historical storm with the highest amount of precipitation recorded has been sought among the existing records during the rainy season from May to October in the Yuam river basin.

The storm of May 22-24, 1980 proved to produce the maximum rainfall amount over a period of three days. Therefore, this historical storm is selected for the calculation of the PMP.

A table below presents the daily rainfall during the above storm recorded at the stations in the basin.

Storm Rainfall Recorded at Stations

(Unit: mm)

St.Name / Date	Khun Yuam	Mae La Luang	Sop Han	Chom Chaeng	Mae Sariang	Ban Tha Rua
May 22nd	8.0	10.5	19.0	24.0	18.0	16.5
May 23rd	70.5	85.5	125.4	80.7	131.0	124.3
May 24th	7.0	56.2	65.1	70.3	68.4	63.0
Total	85.5	152.2	209.5	175.0	217.4	203.8

Adjustment factors for moisture charge and topographic barriers were applied to maximize the above historical storm and a maximizing factor of 1.48 was derived (see Appendix).

Hence, the maximum rainfalls over the 3-day period are calculated and presented in a table below.

Daily PMP Values at Stations

(Unit: mm)

Day \ Name	Khun Yuam	Mae La Luang	Sop Han	Chom Chaeng	Mae Sariang	Ban Tha Rua
1	11.8	15.5	28.1	35.5	26.6	24.4
2	104.3	126.5	185.6	119.4	193.9	184.0
3	10.4	83.2	96.3	104.0	101.2	93.2
Total	126.5	225.2	310.0	258.9	321.7	301.6

To obtain the PMF hydrographs for the sub-basins, the net PMP depths applied to unit hydrographs or tanks are evaluated as follows.

Net PMP Depths of Sub-Basins

No. of Sub-basin	Net PMP Depth
1	Tank Model: $PMP_1 = (P_{KY}, P_{ML}, (P_{SH} + P_{CC} + P_{MS})/3)$
2	Unit Hydrograph: $PMP_2 = ((P_{SH} + P_{CC} + P_{MS})/3) * (1-R)$
3	Tank Model: $PMP_3 = 1/2 (P_{BT} + (P_{SH} + P_{CC} + P_{MS})/3)$
4	Tank Model: $PMP_4 = P_{BT}$
5	Unit Hydrograph: $PMP_5 = 1/2 (P_{BT} + (P_{SH} + P_{CC} + P_{MS})/3)*(1-R)$

Note 1) PMP_i = Net PMP depth for sub-basin No. i
P_{KY} = Net PMP values at Khun Yuam st.
P_{ML} = " Mae La Luang
P_{SH} = " Sop Han
P_{CC} = " Chom Chaeng
P_{MS} = " Mae Sariang
P_{BT} = " Ban Tha Rua

2) The PMP depth over middle reaches of the Yuam river is estimated to be the average of P_{SH}, P_{CC} and P_{MS}, since these three stations are located nearby.

3) R = Retention loss (= 0.20)
The retention loss of the PMP depth for the Tank Model is one of parameters in a flood simulation and is already derived.

The time-intensity pattern of the most rainy day (the second day) during the PMP storm was determined by making reference to the time distribution of storm rainfall recorded at the Ban Mae Ngao station. Percentages of the 6-hour period for the second day are 25%, 50%, 15% and 10% successively.

The time-intensity patterns of the first and the third day are represented by an average value (25%) for each 6-hour period.

(4) Probable Maximum Floods

- Mae Lama Luang dam

Synthesizing the five PMF hydrographs for sub-basins and base flow, the consequent PMF hydrograph was obtained with a peak of 5,200 m^3/sec at the Mae Lama Luang dam as shown in Fig. 5-23.

Base flow corresponds to the recession curve of the maximum historical flood on August 1, 1969, which is assumed to occur 3 days before the PMP storm.

- Nam Ngao dam

It is highly expected that the PMP values of 321.7 mm at the Ban Tha Rua station, which is the highest among those of 6 stations, occurs in the sub-basin No. 4 corresponding to the Nam Ngao dam site. Applying the PMP (321.7 mm) to the tank for the sub-basin No. 4, the PMF hydrograph was established.

Adding the PMF hydrograph for sub-basin No.4 to base flow, and multiplying the ratio of the catchment area of the Nam Ngao dam to that of the Ban Mae Ngao station, the consequent PMF hydrograph was obtained with a peak of 2,100 m^3/sec at the Nam Ngao dam as shown in Fig. 5-24.

Base flow corresponds to the recession curve of the maximum historical flood on August 30, 1971, which is assumed to occur 3 days before the PMP storm.

5.5.5 Design Flood

All results of flood analysis are summarized in a table below.

Summary of Flood Analysis

(Unit: m^3/sec)

Method	Mae Lama Luang Dam	Nam Ngao Dam
PMF envelope curve	6,900	2,000
Statistic analysis (return period: 10,000-year)	3,118 (2,200 - 5,200)*	1,615 (1,400 - 2,100)*
Probable maximum flood	5,200	2,100

* 95% confidence limits

Flood values obtained by statistical analysis are less reliable for high return periods because of the small number of samples (short observation period), so it is reasonable to evaluate the 95% confidence bands of flood values for a high return period.

PMF values at the both dam sites, 5,200 m^3/sec and 2,100 m^3/sec, stand inside the 95% confidence bands of flood values for a 10,000-year return period, and have almost the same magnitudes as the flood values obtained with PMF envelope curve.

Therefore, these PMF values are proposed for further use in this study.

Table 5－18 Annual Flood Peaks at Ban Tha Rua

Year	Date of Occurrence	Peak Flood (m^3/sec.)
1968	August 15	820
1969	August 1	1,180
1970	August 20	810
1971	August 30	1,130
1972	August 26	770
1973	August 29	650
1974	August 13	780
1975	August 30	480
1976	October 22	530
1977	September 8	540
1978	August 15	640
1979	August 15	430
1980	September 8	1,070
1981	August 12	700
1982	July 31	730
1983	October 16	240
1985	September 12	480
1986	July 12	280

Note : Flood peak in 1984 is not available.

Table 5－19 Annual Flood Peaks at Ban Mae Ngao

Year	Date of Occurrence	Peak Flood (m^3/sec.)
1968	August 14	(230)
1969	August 1	(700)
1970	August 20	(700)
1971	August 30	(770)
1972	August 26	(480)
1973	August 29	(270)
1974	August 13	(500)
1975	September 19	(220)
1976	August 11	(220)
1977	September 6	(310)
1978	August 15	(420)
1979	August 15	(280)
1980	September 9	(470)
1981	August 12	(510)
1982	July 31	(520)
1983	August 24	(500)
1984	August 16	460
1985	August 29	350
1986	August 13	190
1987	August 26	440

Note : ( ) values are estimated from the generated daily discharges.

Table 5－20 Results of Frequency Analysis at Nam Yuam Dam

Return Period (year)	Flood Peak (m³/sec.)		
	Gumbel	Lognormal	Average
5	969	944	957
10	1,160	1,144	1,152
20	1,343	1,339	1,341
50	1,581	1,600	1,591
100	1,759	1,802	1,781
1,000	2,346	2,512	2,429
10,000	2,933	3,303	3,118

Table 5－21 Results of Frequency Analysis at Nam Ngao Dam

Return Period (year)	Flood Peak (m³/sec.)		
	Gumbel	Lognormal	Average
5	519	500	510
10	622	601	612
20	721	698	710
50	848	828	838
100	944	927	936
1,000	1,260	1,274	1,267
10,000	1,575	1,655	1,615

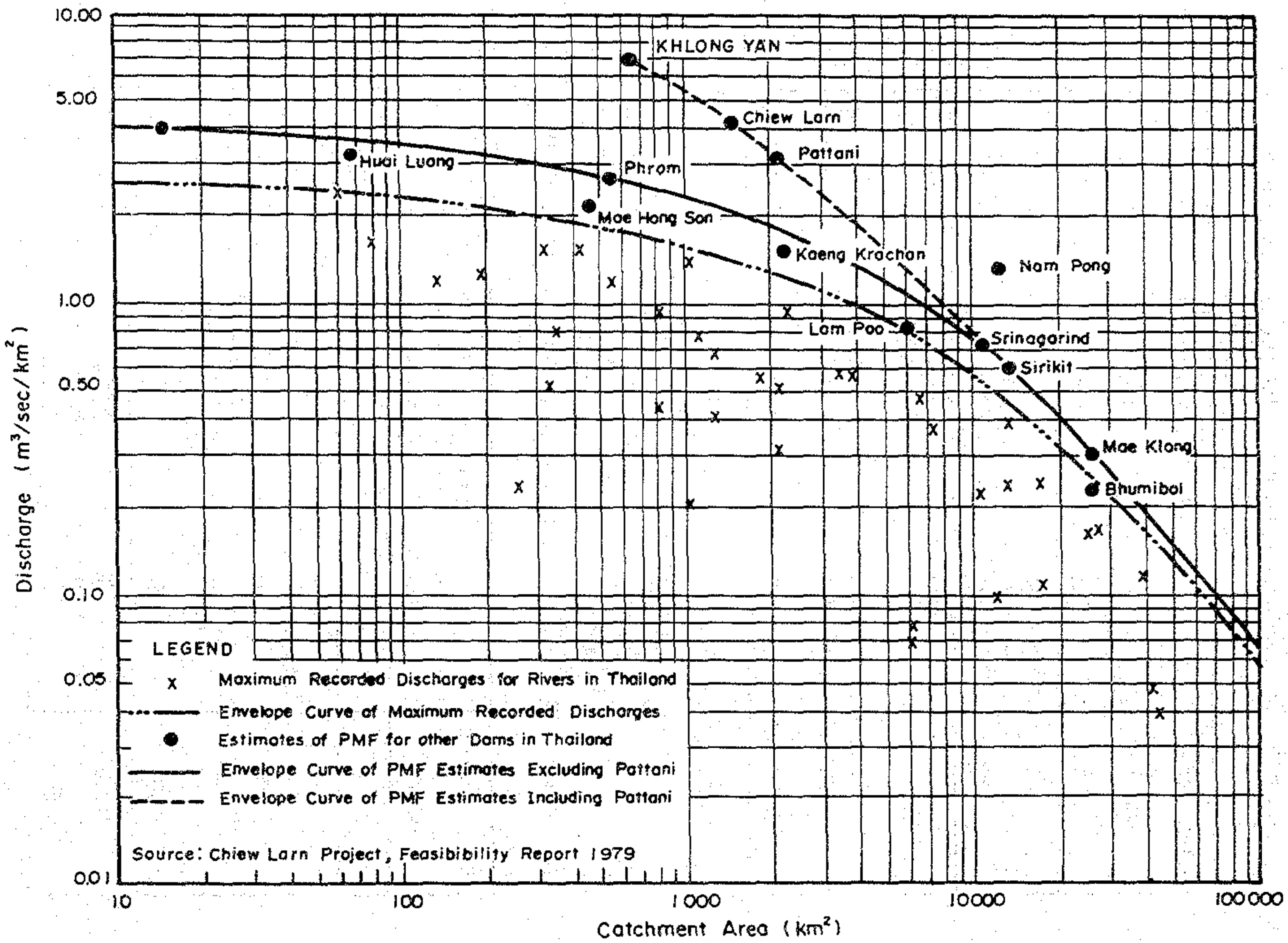


Fig.5-17 Comparison of Peak Flow from Flood Hydrographs of Various Projects

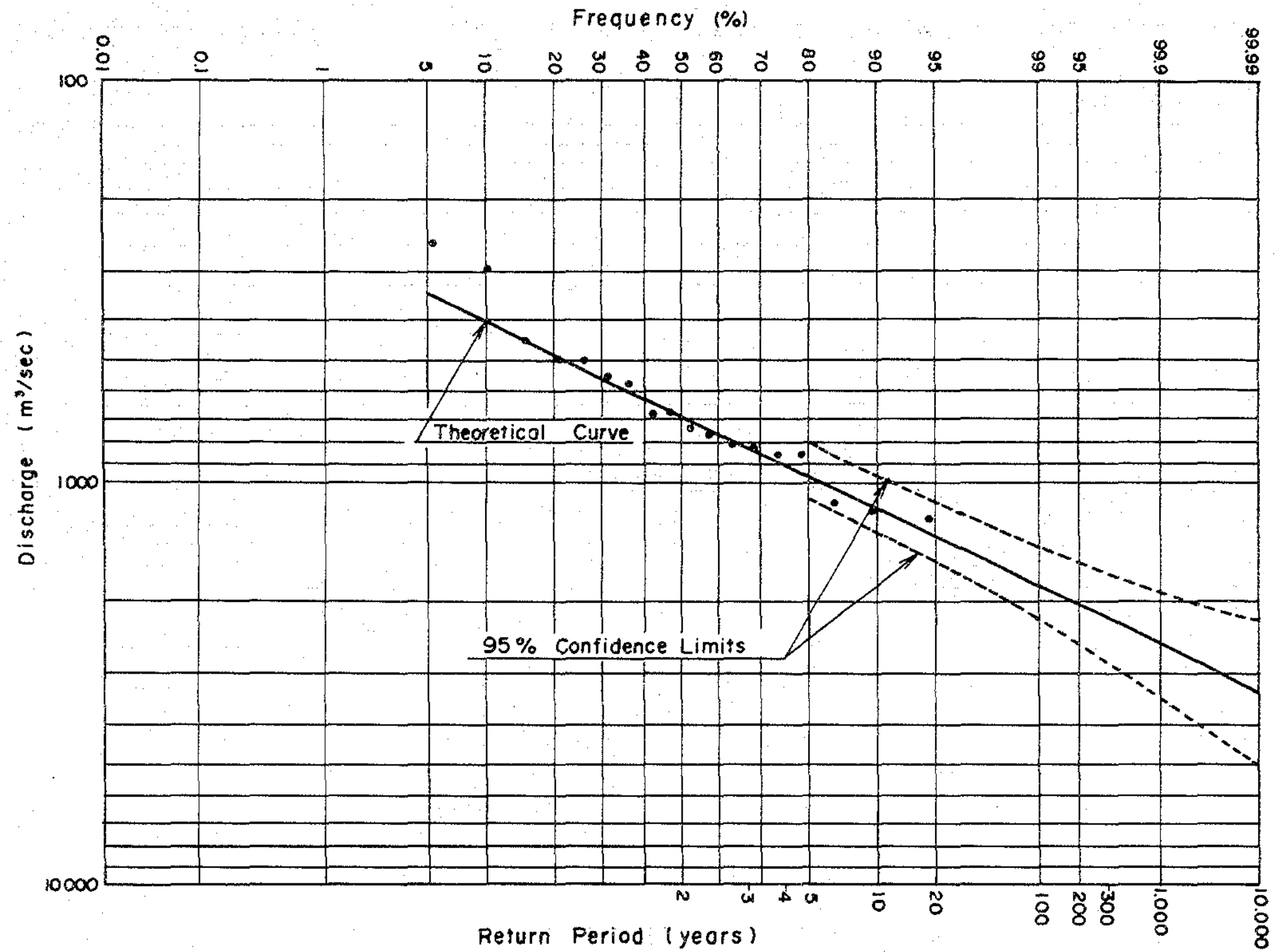


Fig.5 – 18 Reliability of the Results of Frequency Analysis at Nam Yuam Dam

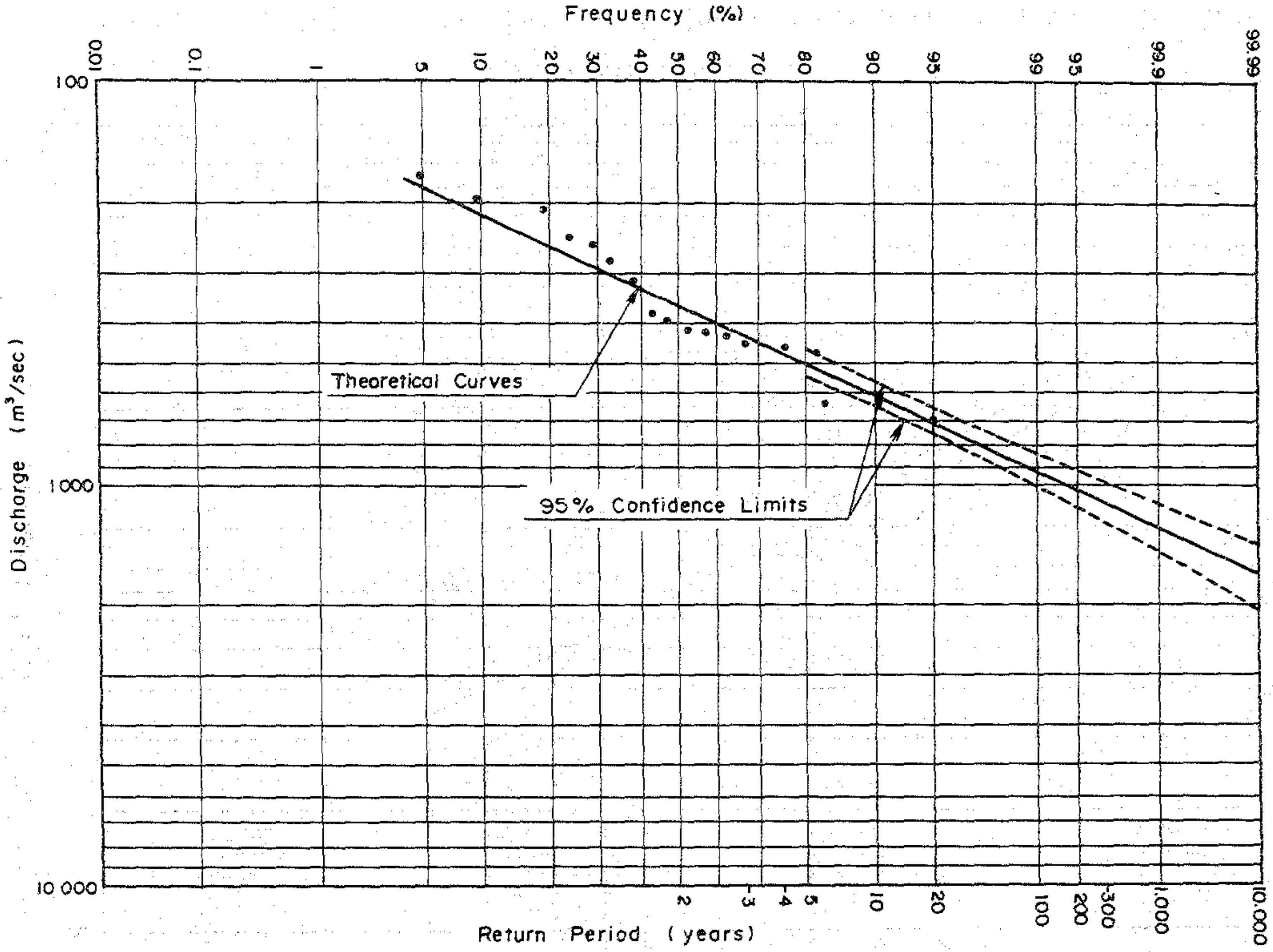


Fig.5-19 Reliability of the Results of Frequency Analysis at Mae Ngao Dam

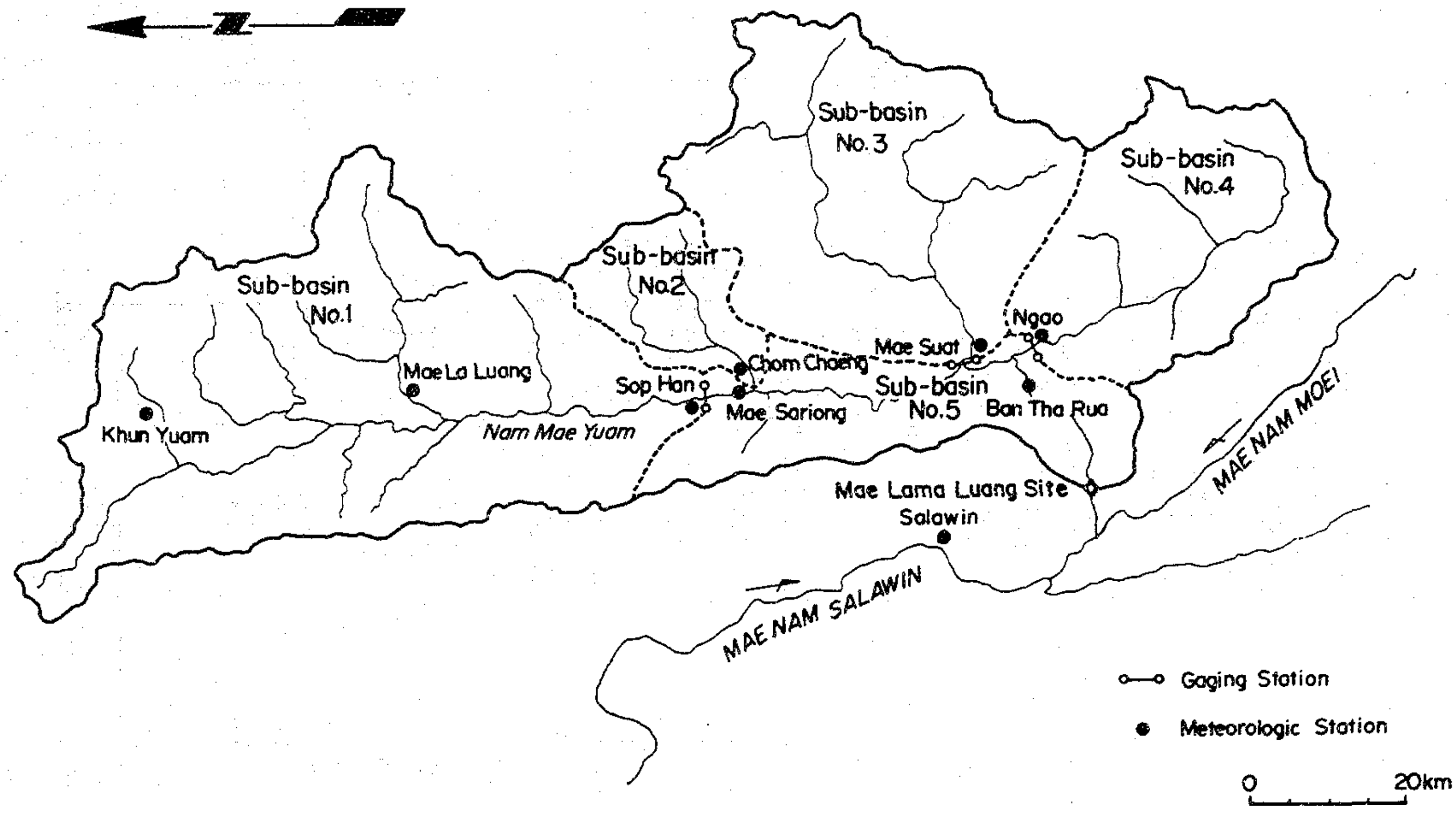


Fig.5-20 Division of Nam Yuam River Basin into 5 Sub-basins

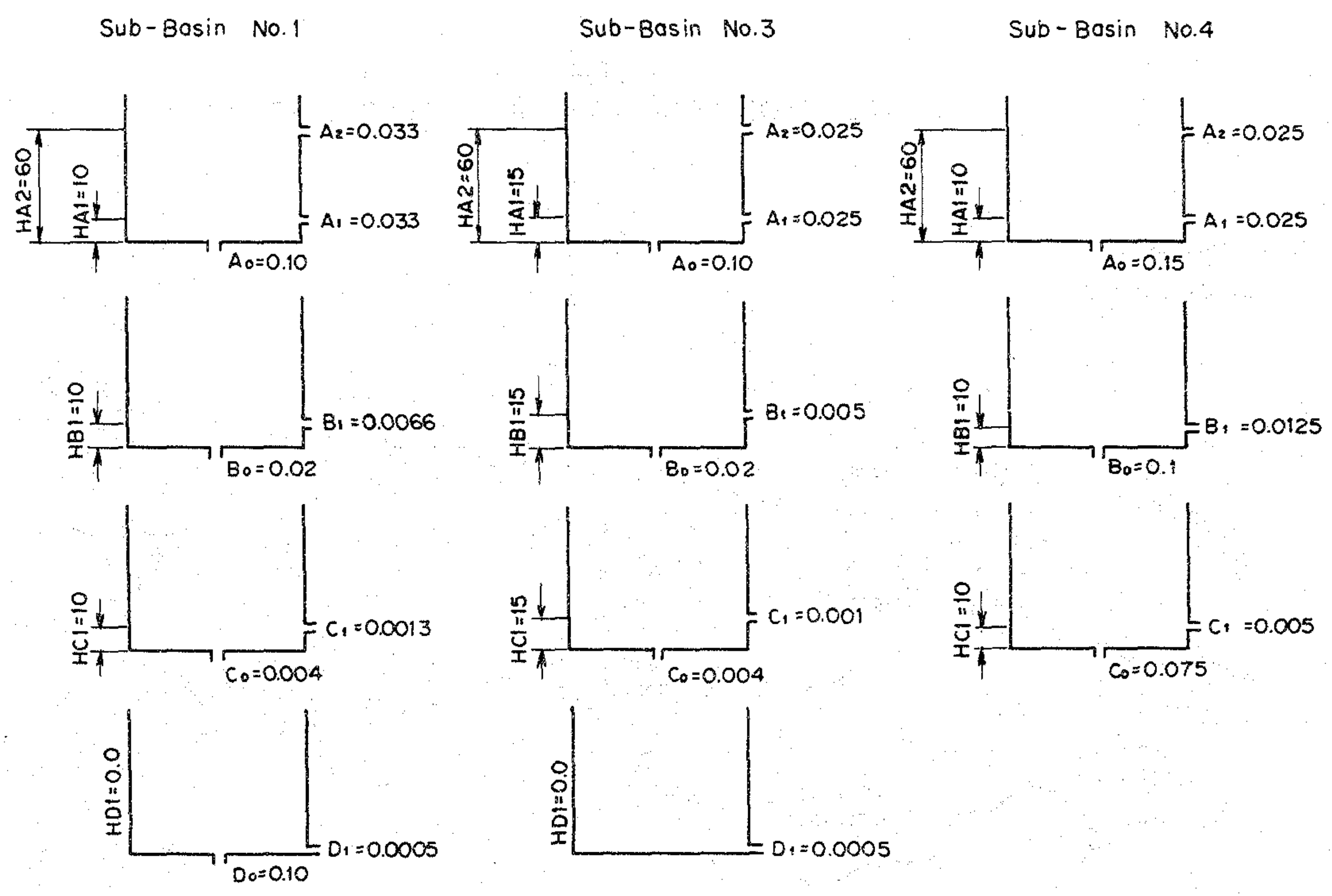
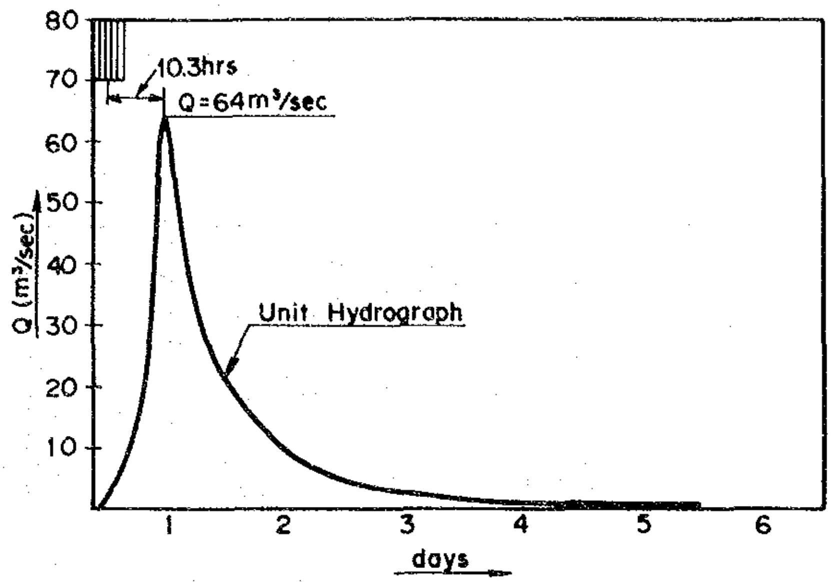
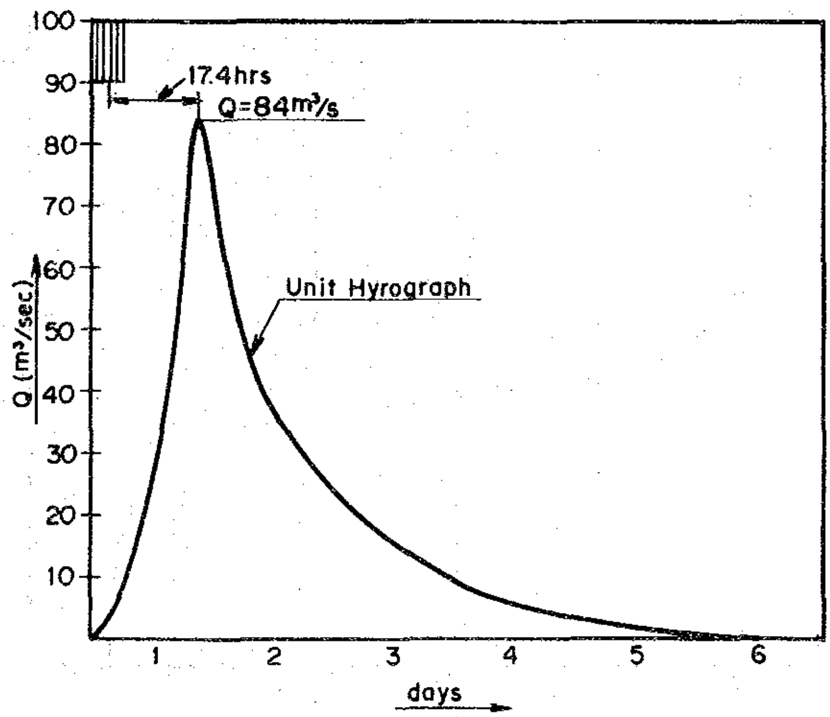


Fig.5-21 Configuration of Tanks for Sub-Basin Nos. 1, 3 and 4



Sub - Basin No. 2



Sub - Basin No. 5

Fig. 5-22 Unit Hydrographs for Sub-basins Nos. 2 and 5 (Snyder's Method)

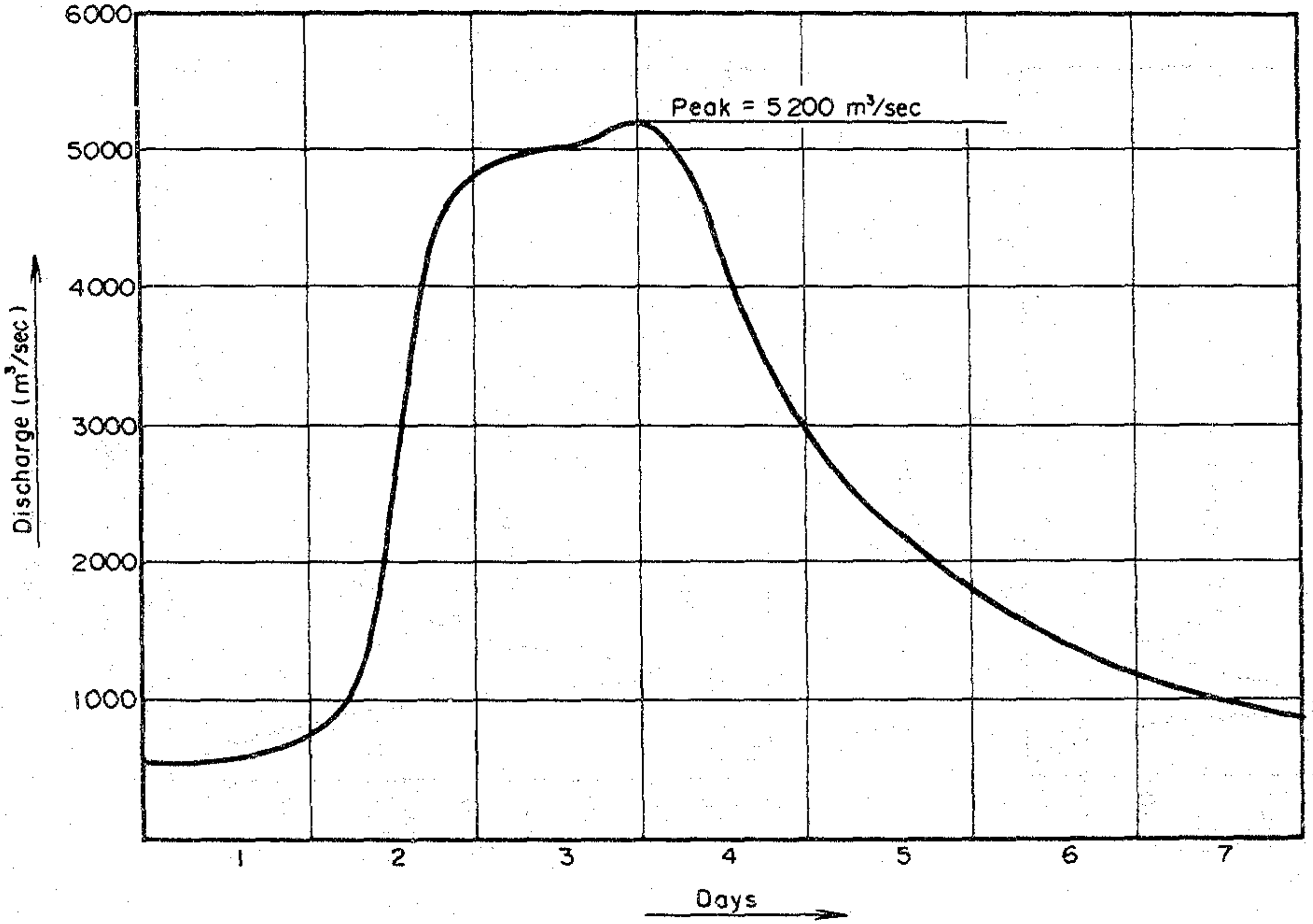


Fig. 5-23 PMF Hydrograph at Mae Lama Luang Dam

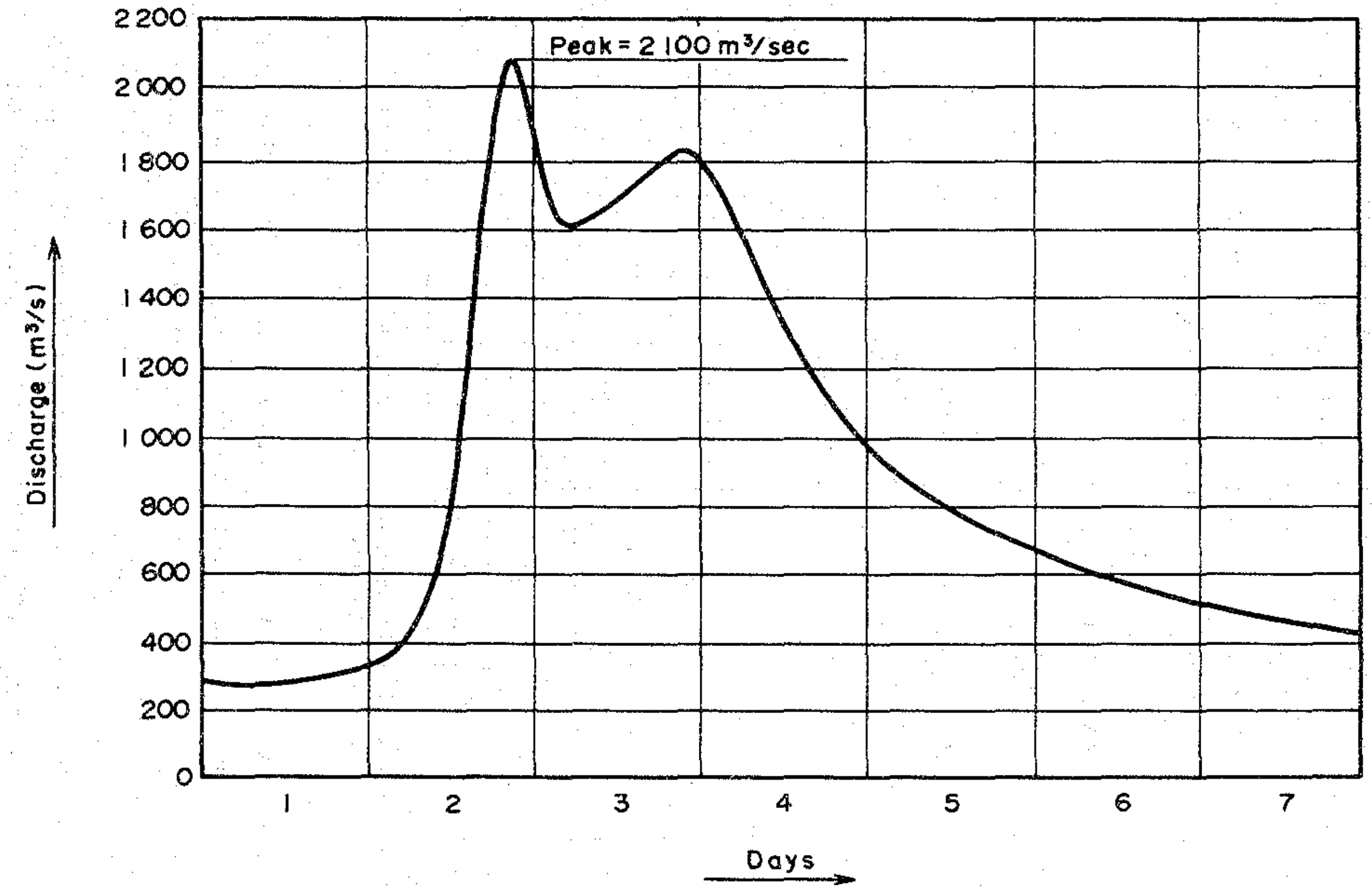


Fig.5-24 PMF Hydrograph at Nam Ngao Dam

5.6 Sedimentation

5.6.1 Methodology

In this study, reference is made to data of suspended sediments recorded at stations of Sop Han, Ban Tha Rua and Tha Song Yang. The specific yields of these relevant stations were determined by anticipating a bed load equal to 20 percent of the suspended sediment load. The obtained specific yield is 205 m^3/km^2/year. This figure was applied to the Yuam and Ngao rivers.

5.6.2 Reservoir Sedimentation

(1) Quantity of Sediment Inflow

The required information together with specific yields at selected stations are tabulated below:

Specific Yields at Relevant Stations

Station	Annual Suspended Load (ton)	Total Annual Load (ton)	Drainage Area (km^2)	Depth of Erosion (mm)	Specific Yields (m^3/km^2)	Available Record Period
Sop Han	308,000	369,600	2,496	0.114	114	1971-1985
Ban Tha Rua	1,281,000	1,537,200	5,770	0.205	205	1971-1986
Tha Song Yang	1,599,000	1,918,800	8,360	0.177	177	1972-1986

Notes: Assumed bed load = 20 percent of suspended sediment load
Assumed in-situ soil density = 1.30 ton/m^3

Considering the depths of erosion of various rivers in the whole Thailand as shown in Fig. 5-25, the depth of erosion value of 0.205 mm at the Ban Tha Rua station is conservative and reasonable.

Therefore applying the specific yield of 205 m^3/km^2/year and soil density of 1.30 ton/m^3, the total annual sediment load at the Mae Lama Luang and Nam Ngao damsites are computed as tabulated below:

Damsites	Drainage Area (km^2)	Total Annual Sediment (ton)
Mae Lama Luang	6,030	1,607,000
Nam Ngao	835	222,500

(2) Reservoir Trap Efficiency

Trap efficiency is expressed in terms of percentage of incoming sediment retained in a reservoir. Trap efficiency curves by Brune show the relationship between the reservoir trap efficiency and the ratio of reservoir capacity to mean annual inflow.

According to the relationship represented by Brune's curve, the trap efficiency of these two reservoirs are about 90% for the Mae Lama Luang dam and 95% for the Nam Ngao dam.

(3) Sediment Volume

Normally the unit weight of sediment increases with the time it remains in the reservoir. With a time of impoundment of 100 years, the unit weight of the trapped sediment was calculated as 1.342 ton/m^3.

Therefore the accumulated sediment volume for these two reservoirs are evaluated and shown in a table below:

Damsite	Sediment Volume for 100 years (10^6 m^3)	Sediment Level (EL. m)
Mae Lama Luang	93.6	118.7
Nam Ngao	15.8	185.8

Note 1) : Mae Lama Luang dam

(1,607,000 - 222,500 x 0.95) x 0.90 ton x 100 years/1.342 ton/m^3

= 93,600,000 m^3

2) Sediment level is assumed horizontal in the reservoir.

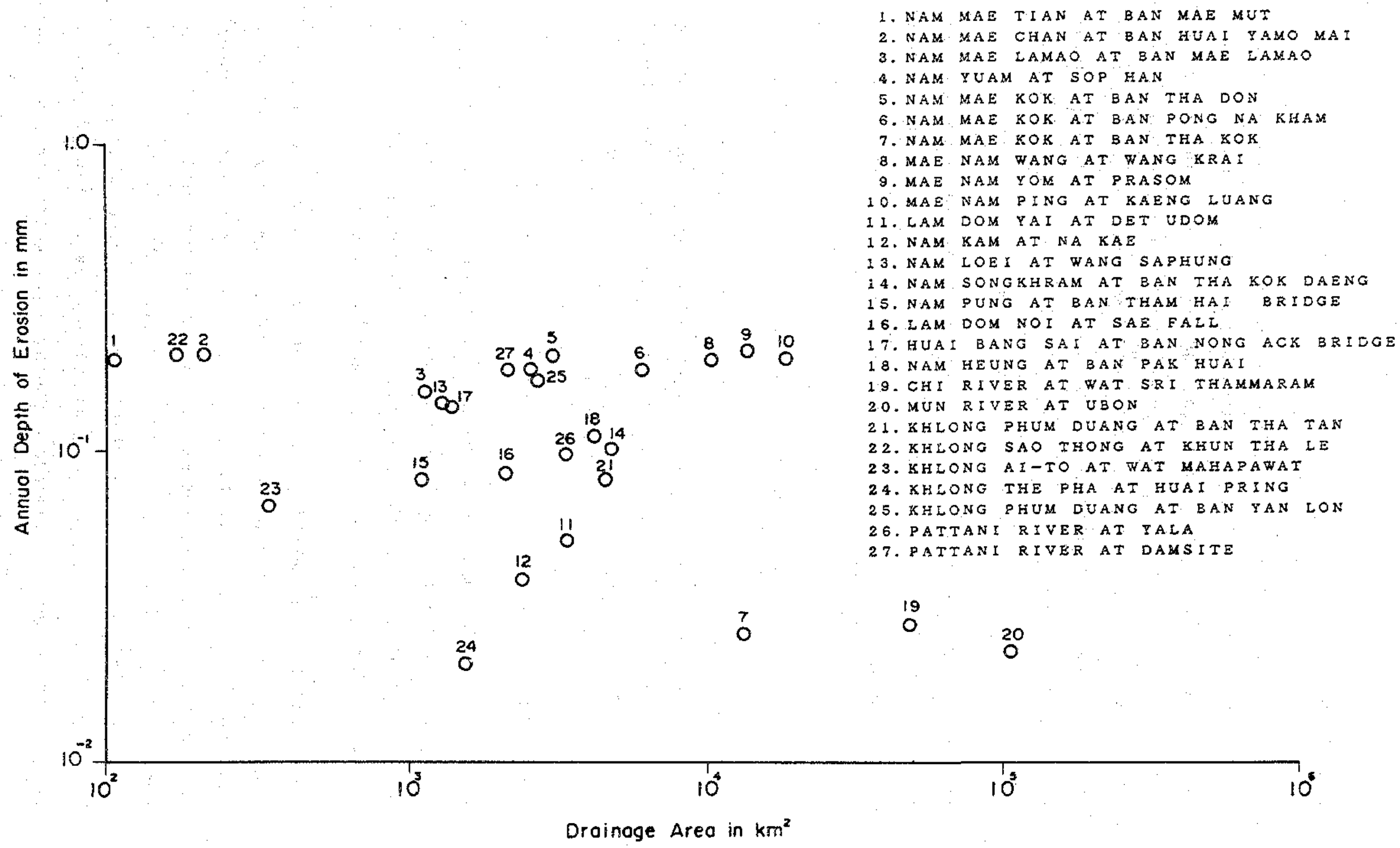


Fig. 5-25 Annual Depth of Erosion in Thailand

5.7 Dam Breach Analysis

5.7.1 Scope of Analysis

Dam failures are caused by sudden or unpredictable events (e.g. adverse hydrological conditions, gate malfunction, seismic action, etc.). Most of the damages caused by the rupture of a large dam are due to a flood resulting from sudden emptying of the reservoir. So, it is highly advisable to develop flood emergency plans including innundation maps, evacuation plans and a knowledge of flood propagation characteristics before the occurrence of such a catastrophic event.

Considering the above background, hydrological analyses on dam breaches of the Nam Ngao dam and/or Mae Lama Luang dam were carried out to guide for emergency preparedness plans on the following two cases.

(1) The Mae Lama Luang dam breaches at its full capacity.

(2) The Nam Ngao dam breaches while the Mae Lama Luang reservoir is at full capacity. The wave front which may probably overtop the Mae Lama Luang dam will be checked and the further breach is to be analysed.

5.7.2 Methodology

There have been a number of studies on mathematical models suitable for dam breach analyses performed by various institutes, e.g., the U.S. Geological Survey, the U.S. Corps of Engineers, the Illinois State Water Survey, the U.S. National Weather Service.

In this study the DAMBRK model developed by the U.S. National Weather Service is chosen to simulate and evaluate the routing of flood waves due to dam breach. The model consists of two conceptual parts, namely: (1) description of the dam failure mode, i.e., the geometrical description of the breach; and (2) a hydraulic computational algorithm for determining the time history (hydrograph) of the outflow through the breach as affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows and downstream tailwater elevations; and for routing of the outflow hydrograph through the downstream valley. The model also determines the resulting water surface elevations (stages) and flood-wave travel times.

The governing hydraulic equations of the model are the complete one-dimensional Saint-Venant equations of unsteady flow which are coupled with internal boundary equations representing the rapidly varied (broad-crested weir) flow through structures such as dams which may develop a time-dependent breach.

The system of equations is solved by a non-linear weighted 4-point implicit finite difference method. The hydrograph to be routed can be developed by the geometrical model using specified breach parameters (size, shape, time of development). Breach parameters are explained illustratively in Fig. 5-26.

5.7.3 Breach of Mae Lama Luang Dam

(1) Analytical Condition

The initial outflow hydrograph due to dam breach is governed by size and form of the breach and time required for its formation. The actual dam breach mechanics are not well understood, and it is said that historical dam failures show that almost anything can happen.

Froelich derived a predictor for time of failure (T) statistically by investigating properties of more than 40 historical dam breaches ranging in height from 15 to 285 ft as follows:

$$T = 0.8\ (Vr/Hd^2)^{0.50}$$

where, T : time of failure (hrs)
Vr: reservoir volume (acre - ft)
Hd: dam height (ft)

The height of the Mae Lama Luang dam is 119 m (390 ft) and the total reservoir volume is 502×10^6 m^3 (0.407 million acre-ft), and the time of failure is predicted 1.3 hrs. The standard error of estimate for T is ± 0.9 hr. Hence, to investigate the impact of the breach time assumptions, an erosion time of 0.5, 1, 2, 4, 8 hrs was assumed.

As for the breach size, some classification was tried out by Vogel, showing that 5 - 100% of the area of an embankment dam can be eroded. On the other hand, Fread gives a range of the fully developed breach of one to three times the dam height. Hence to study the influence of the breach size, it is assumed that the bottom width of the breach is varied from 20 m to 80 m and side slopes of the trapezoidal breach are 45°. Elevation of breach bottom is assumed to correspond to the elevation of reservoir bottom.

Analytical conditions for case studies on the breach of the Mae Lama Luang dam are summarized in the following table.

The routing of the dam-break floods is computed through the 6 km downstream valley until the conjunction of the Yuam River and the Moei River.

Study Cases on Breach of the Mae Lama Luang Dam

Item / Case No.	Width of Breach Bottom (m)	Breach Time (Hrs.)	Manning n
1	80	0.5	0.04
2	80	1.0	0.04
3	80	2.0	0.04
4	80	4.0	0.04
5	80	8.0	0.04
6	20	1.0	0.04
7	40	1.0	0.04
8	20	1.0	0.06
9	20	1.0	0.08

Elevation of water when breached: 165 m
Elevation of breach bottom : 62 m
(corresponding to an elevation of reservoir bottom)
Side slope of breach : 45°
Reservoir inflow : 250 m^3/sec
Initial downstream flow : 330 m^3/sec

(2) Results of Analysis

- Influence of Breach Time

The time until the breach is fully developed can only be estimated. Instantaneous failure causes the maximum outflows at the damsite, however, peaks are attenuated along the river course. To study the influence of the breach time assumptions, an fully breaching time of 0.5, 1, 2, 4 and 8 hrs was assumed for the Mae Lama Luang dam. Breach width was assumed to be 80 m, and a coefficient of roughness 0.04 according to Manning's formula.

Breach hydrographs at the dam site are shown in Fig. 5-27, and a breach formation (reservoir elevation, width and elevation of breach bottom, for a case of 1-hour breaching time is shown in Fig. 5-28. The breach of the Mae Lama Luang dam is assumed to progress at a linear formation rate in terms of both the width and the elevation of the breach bottom over a breach time as shown in Fig. 5-28. At the time of beginning of breach formation, the reservoir water level is assumed to be EL. 165 m which corresponds to the normal high water level of the reservoir.

Maximum outflows from the dam and times when maximum outflows occur, are summarized below.

Maximum Outflow from Mae Lama Luang Dam

Item	Case 1	Case 2	Case 3	Case 4	Case 5
Breach time (hours)	0.5	1.0	2.0	4.0	8.0
Max. Outflow (m^3/sec)	224,000	177,900	118,200	66,800	36,700
Time of Max. Q (hours)	0.50	0.96	1.72	2.96	4.80

The above table shows that the maximum outflow occurs before the dam breach is fully developed except in the case of breach time of 0.5 hour, also indicating that the breach time assumptions can significantly influence maximum breach outflows.

The results of the routing of breach outflows through the downstream reach of the Mae Lama Luang dam is summarized in the following table, Fig. 5-29 and Fig. 5-30.

The routing of the downstream valley was carried out until the conjunction of the Yuam and Moei rivers. The attenuation rate ranges from 93% to 99% at 6 km depending on breach time. A shorter breach time causes a larger breach outflow and a stronger attenuation along the river course (see Fig. 5-29). However, here the initial differences of river water levels are too large to be compensated for in the relatively short routing reach of 6 km (see Fig. 5-30).

Effect of Varying Breach Time

Distance	Item	Breach Time	0.5 hrs.	1.0	2.0	4.0	8.0
0.5 km	Q	m^3/sec	221,300	176,000	117,200	66,550	36,660
	H	m	108.53	103.79	97.94	98.46	93.93
	V	m/sec	32.38	30.78	28.51	24.71	10.05
	T	hrs	0.50	0.95	1.15	2.60	4.80
3 km	Q	m^3/sec	215,400	174,600	116,900	66,300	36,560
	H	m	105.35	103.90	101.16	94.75	89.06
	V	m/sec	20.19	17.55	13.01	9.93	7.62
	T	hrs	0.53	0.85	1.80	3.00	4.80
6 km	Q	m^3/sec	209,000	171,100	115,500	65,550	36,280
	H	m	101.30	99.38	95.04	89.08	83.88
	V	m/sec	13.81	11.98	9.80	7.57	5.89
	T	hrs	0.58	1.00	1.80	3.00	5.20

Note: Q = maximum discharge
H = maximum elevation
V = maximum velocity
T = time to maximum elevation
Bottom width of breach = 80 m
Coefficient of roughness = 0.04

- Influence of Breach Size

To investigate the impact of breach size, a trapezoidal breach of side walls of 45° inclination and bottom width varying from 20 m to 80 m was assumed. Breach time was assumed to be 1.0 hour, and an elevation of breach bottom EL. 62 m. The results are summarized below.

The results indicate that the width of breach bottom does not give large differences of breach outflows or river water levels. The reason might be concluded that the breach area of 80 m wide breach bottom is only 1.48 times the breach area of 20 m wide breach bottom.

Effect of Varying Breach Size

Distance	Item	Breach Width	20 m	40 m	80 m
0.5 km	Q	m^3/sec	143,200	161,400	176,000
	H	m	99.67	101.98	103.79
	V	m/sec	29.79	30.35	30.78
	T	hrs	1.03	1.00	0.95
3 km	Q	m^3/sec	141,200	158,700	174,600
	H	m	104.30	104.00	103.90
	V	m/sec	14.05	16.06	17.55
	T	hrs	0.98	0.98	0.85
6 km	Q	m^3/sec	136,500	154,500	171,100
	H	m	96.30	97.97	99.38
	V	m/sec	11.01	11.55	11.98
	T	hrs	1.10	1.05	1.00

Note: Q = maximum discharge
H = maximum elevation
V = maximum velocity
T = time to maximum elevation
Breach time = 1.0 hr
Coefficient of roughness = 0.04

- Influence of Coefficient of Roughness

Selection of coefficient of roughness (the Manning n) should reflect the influence of river bank and bed materials, channel obstructions, irregularity of the river banks, and especially vegetation.

The flow observations used in developing the Manning n predictive methods have been confined to floods originating from rainfall. The much greater magnitude of a dam-break flood produces greater velocities and results in the innundation of portions of the floodplain never before innundated. The dam break flood is much more capable of creating and transporting large amounts of debris (unrooted trees, demolished houses, vehicles, etc.) than the lesser rainfall-generated flood. Therefore, the Manning n values often need to be increased in order to account for the additional energy losses associated with the dam-break floods. To study the impact of the Manning n, the Manning n values of 0.04, 0.06 and 0.08 for the downstream river course of the Mae Lama Luang dam were assumed. The width of the breach bottom was assumed to be 20 m, and the breach time 1.0 hour. The results are summarized in the following table, Fig. 5-31 and Fig. 5-32.

The increased Manning n causes peak discharges to be decreased through the downstream valley and also causes flood water level to be rised. In case of the Manning n values of 0.06 and 0.08 all the flow is subcritical, while in case of the Manning n value of 0.04 the flow is supercritical at certain times. This results in a considerable difference of peak flood elevations until 3 km downstream.

Effect of Varying Coefficient of Roughness

Distance	Item (n)		0.04	0.06	0.08
0.5 km	Q	m^3/sec	143,200	140,000	121,300
	H	m	99.67	118.99	124.20
	V	m/sec	29.79	14.65	11.15
	T	hrs	1.03	1.00	1.00
3 km	Q	m^3/sec	141,200	135,900	117,400
	H	m	104.30	110.44	113.54
	V	m/sec	14.05	10.65	8.46
	T	hrs	0.98	1.05	1.10
6 km	Q	m^3/sec	136,500	129,000	110,300
	H	m	96.30	101.66	103.87
	V	m/sec	11.01	8.45	6.82
	T	hrs	1.10	1.15	1.20

Note: Q = maximum discharge
H = maximum elevation
V = maximum velocity
T = time to maximum elevation
Breach time = 1.0 hr
Bottom width of breach = 20 m

5.7.4 Breach of Nam Ngao Dam

(1) Analytical Condition

The breach analysis of the Nam Ngao dam was carried out on the following conditions:

<u>Nam Ngao Dam</u>

Reservoir water level when breached:	270 m (N.H.W.L.)
Elevation of breach bottom :	160 m
Side slope of breach :	45°
Width of breach bottom :	80 m
Breach time :	1 h, 8 h

<u>Mae Lama Luang Dam</u>

Initial reservoir water level :	165 m
Reservoir water level when breached:	168.5 m
Elevation of breach bottom :	62 m
Side slope of breach :	45°
Width of breach bottom :	80 m
Breach time :	1 h, 8 h

The Froelich's equation ($T = 0.8 (Vr/Hd^2)^{0.5}$) cited before was used to select a breach time of the Nam Ngao dam, and T was derived to be 1.8 hrs. Taking into consideration the standard error of ± 0.9 hr, a breach time of 1 and 8 hrs was assumed to produce maximum and minimum breach outflow.

Elevation of breach bottom was assumed to be 160 m which corresponds to an elevation of the reservoir bottom of the Nam Ngao dam. By the study of the Mae Lama Luang dam breach it was found that width of breach bottom does not significantly affect breach magnitude, so width of breach bottom was fixed to be 80 m. Study cases are summarized below.

Study Cases on Breach of the Nam Ngao Dam

Item / Case	Nam Ngao Dam		Mae Lama Luang Dam		Manning n
	Width of Breach Bottom (m)	Breach Time (hrs)	Width of Breach Bottom (m)	Breach Time (hrs)	
1 (Max. breach)	80	1.0	80	1.0	0.04
2 (Min. breach)	80	8.0	80	8.0	0.04

A flood wave due to a breach of the Nam Ngao dam flows down through the Ngao river to the conjunction of the Yuam and Ngao rivers, and propagates both upstream and downstream. The flood wave propagating downstream arrives the Mae Lama Luang dam site and may overtop the dam crest, which may cause a breach of the Mae Lama Luang dam. Therefore, a flood routing of the Nam Ngao dam breach was carried out through about 90 km river course as follows:

- Ngao River

  Nam Ngao dam - Conjunction of Yuam and Ngao Rivers — 12 km

- Yuam River

  Conjunction of Yuam and Ngao Rivers - Mae Sariang — 45 km

  Conjunction of Yuam and Ngao Rivers - Mae Lama Luang dam — 28 km

Mae Lama Luang dam - Conjunction of Yuam and Moei Rivers		6 km
Total		91 km

(2) Results of Analysis

- Propagation of Flood along Ngao River

Maximum outflows at the Nam Ngao dam site and at the conjunction of the Yuam and Ngao rivers are summarized below and shown in Fig. 5-33.

Maximum Outflows Due to Nam Ngao Dam Breach

Item	Max. Breach Case	Min. Breach Case
Breach time (hrs)	1.0	8.0
At Nam Ngao dam site		
Max. outflow (m^3/sec)	260,300	65,450
Time (hrs)	1.0	5.9
At conjunction		
Max. outflow (m^3/sec)	217,500	64,750
Time (hrs)	1.2	6.4

In the maximum breach case, the peak discharge at the conjunction of the Yuam and Ngao rivers is attenuated to the extent of 84% of the peak discharge at the Nam Ngao dam site, and a travel time of the flood wave is 0.2 hour (12 minutes). On the other hand, in the minimum breach case the peak discharge at the conjunction is not so much strongly attenuated, and a travel time is 0.5 hour (30 minutes) which is longer than in the maximum breach case.

- Propagation of Flood Along Yuam River

A flood wave due to the breach of the Nam Ngao dam propagates further both upstream and downstream reaches of the Yuam river. Routing results of the flood wave are shown in Fig. 5-34 and Fig. 5-35.

Fig. 5-34 indicates profiles of maximum discharge along the Yuam river from Mae Sariang to the conjunction of the Yuam and Moei rivers. The Mae Lama Luang dam fails in both maximum and minimum breach cases due to overtopping.

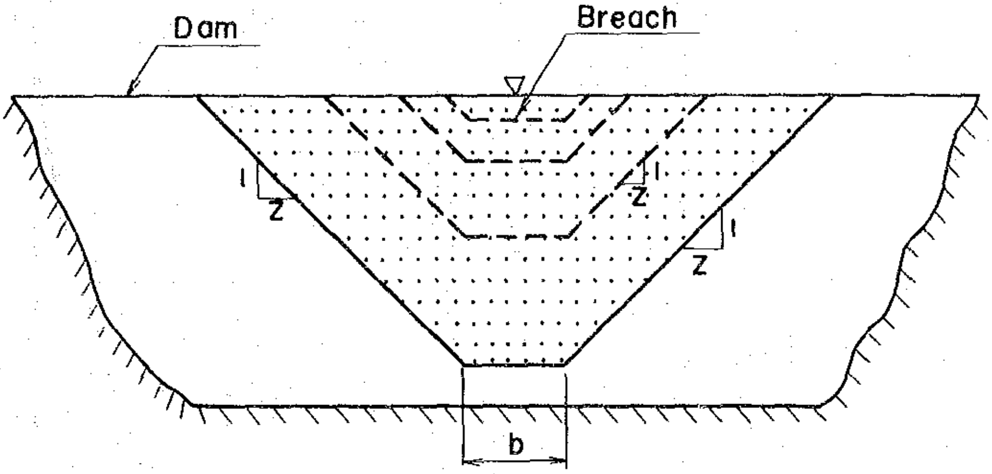
Fig. 5-35 indicates profiles of maximum water level of the Yuam river. In the maximum breach case the water level at the conjunction of the Yuam and Ngao rivers rises by more than 50 m, even in the minimum case by about 25 m.

However, the flood wave is damped out along the river, and at far remote locations, that is 35 km upstream of the conjunction of the Yuam and Ngao rivers (around Ban Huai Sai), there is no rise of water level due to the dam breach. Discharge and river stage hydrographs at two different locations, 8 km and 21 km upstream of the conjunction of the Yuam and Ngao rivers, are shown in Fig. 5-36. Peaks of discharge and river stage occur at different times each other, and a peak of river stage occurs earlier than a peak of discharge. A travel time of river stage from the Nam Ngao dam site is 0.85 hour (51 minutes) 8 km upstream of the conjunction of the Yuam and Ngao rivers, and 2.96 hours 21 km upstream (around Ban Huai Mae Ko).

- Breach Formation of Mae Lama Luang Dam

As is described before, the Mae Lama Luang dam is overtopped by the flood wave and fails. It is assumed that the dam starts to breach when the dam is overtopped by 0.5 m.

Breach formation and outflow in the maximum and minimum breach case are shown in Fig. 5-37 and Fig. 5-38. Routing results of the downstream valley of the Mae Lama Luang dam are shown in Fig. 5-39.



b : width of breach bottom

Z : side slope of breach

⬚ : breach formation

Fig. 5-26 Front View of Dam Showing Formation of Breach

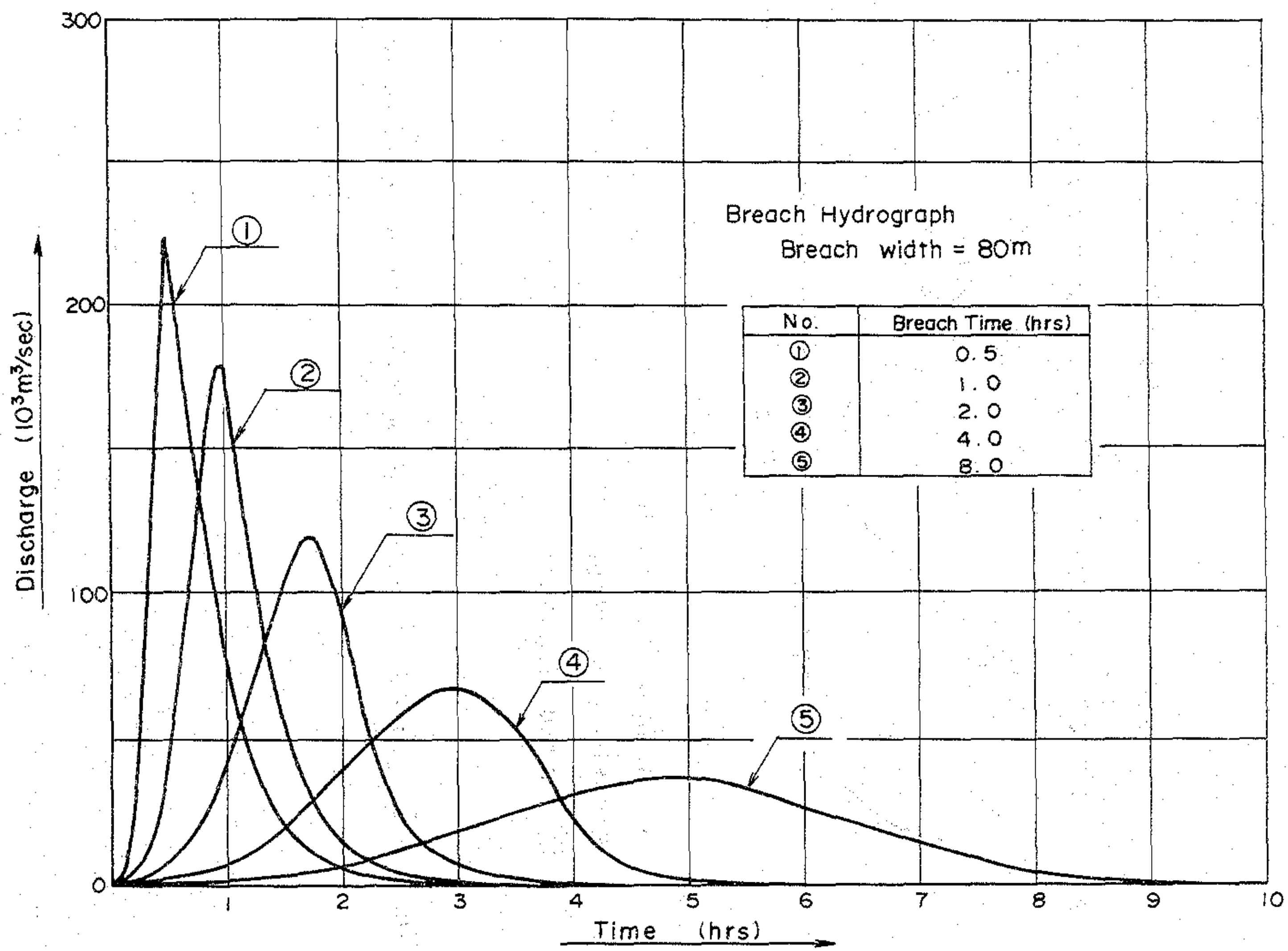


Fig. 5-27 Breach Hydrographs with Various Breach Time

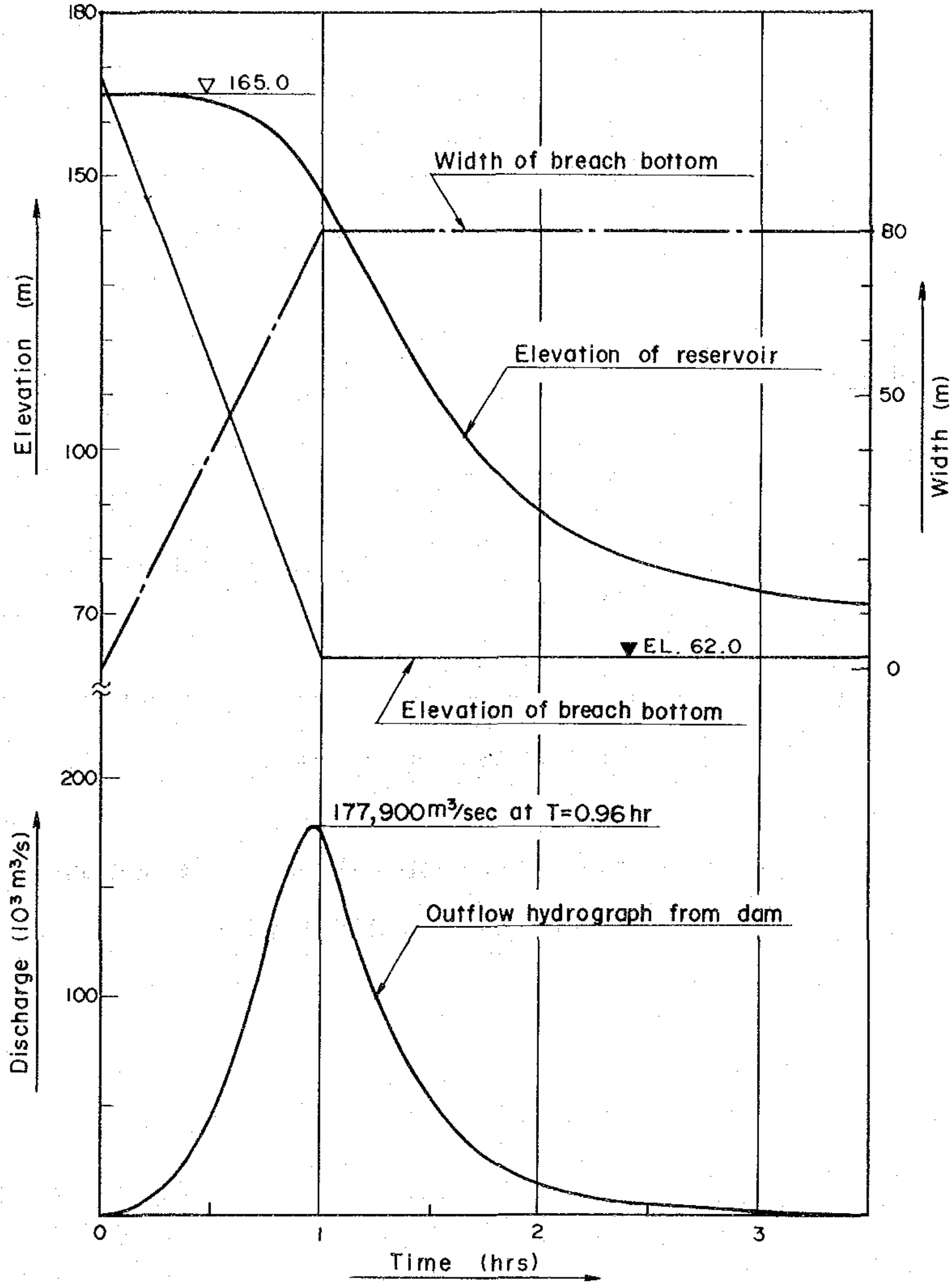


Fig. 5-28 Breach Formation and Outflow of Mae Lama Luang Dam

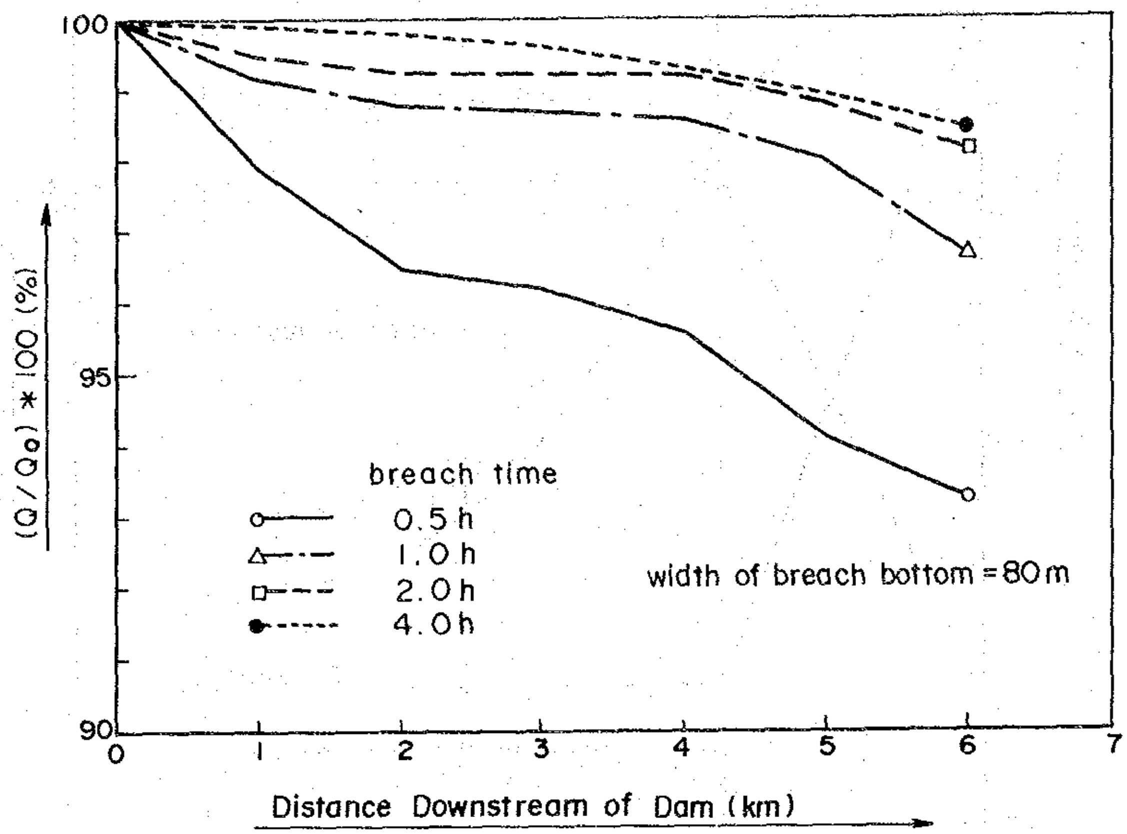


Fig. 5-29 Peak Discharge (Q) as a Percentage of Maximum Outflow (Qo)

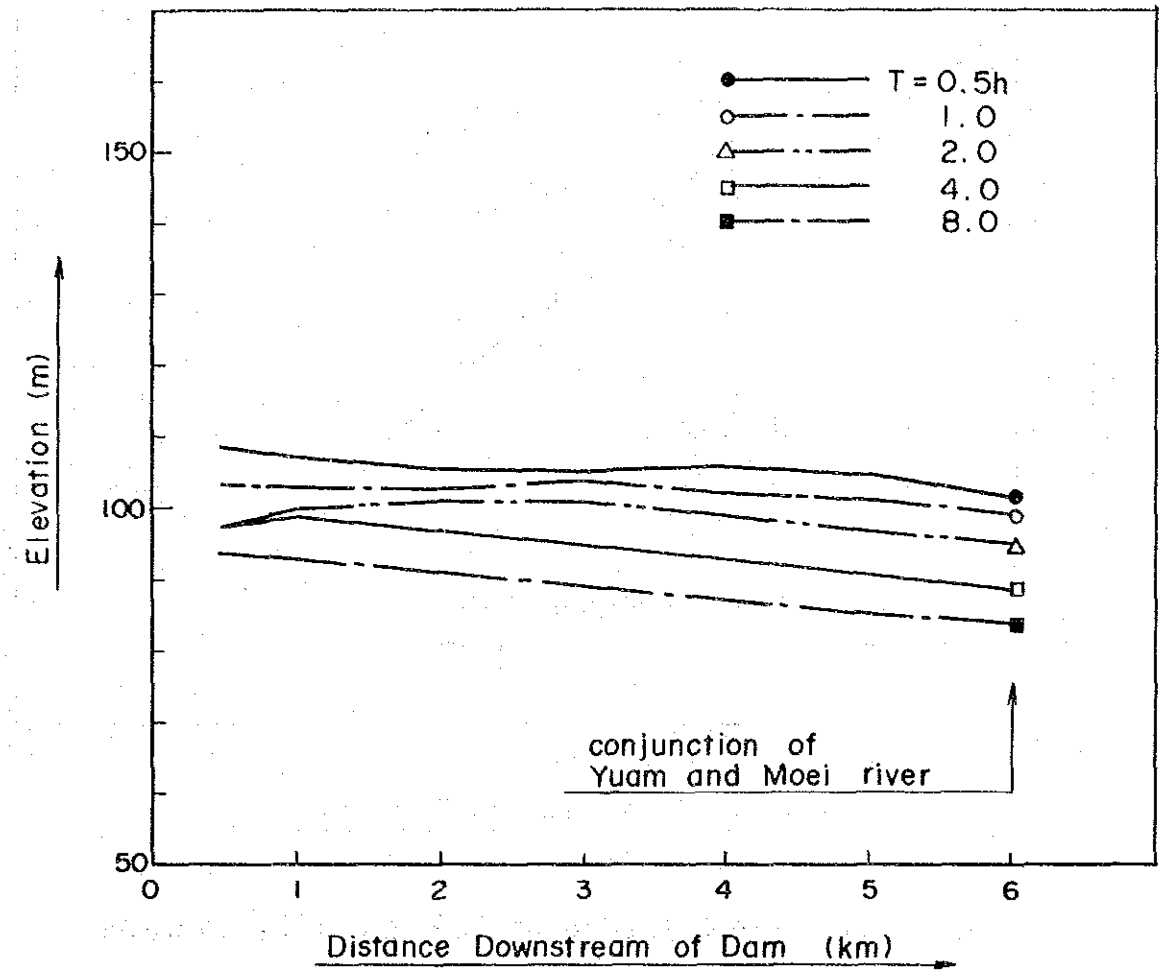


Fig. 5-30 Profile of Peak Flood Elevation
Due to Mae Lama Luang Dam Breach

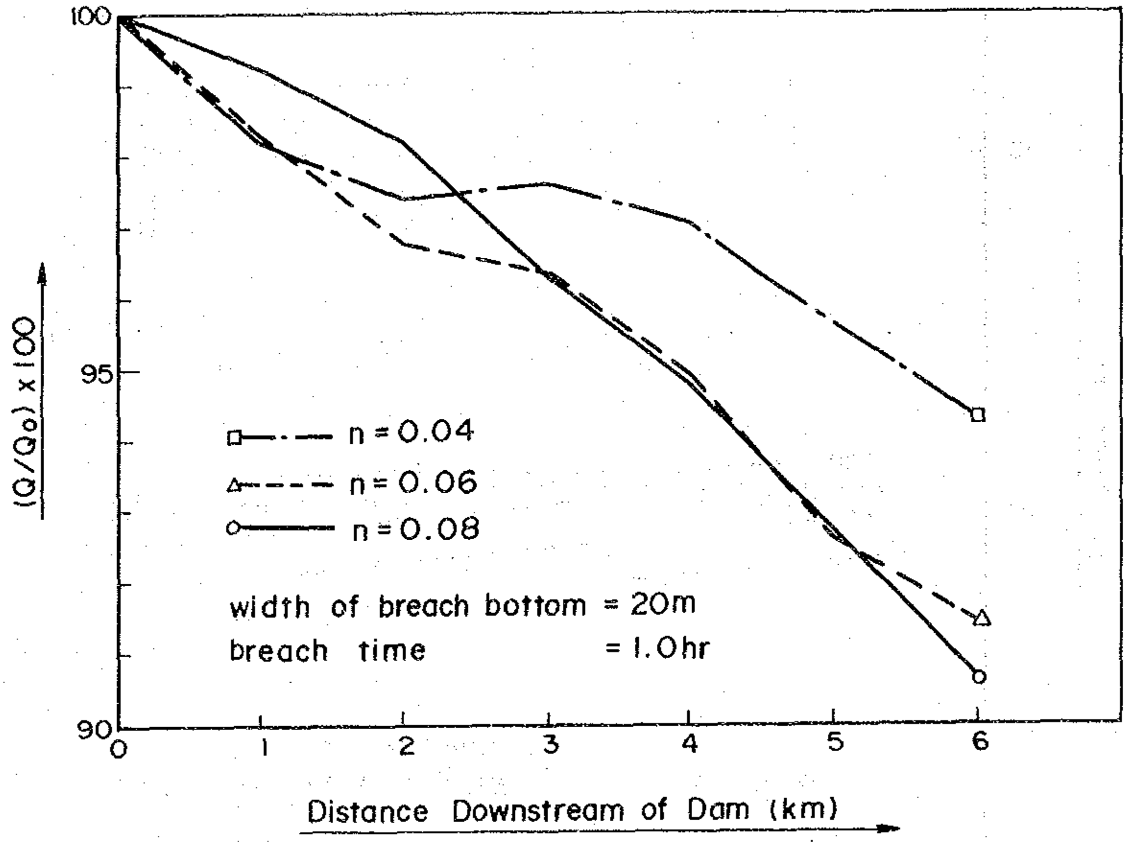


Fig. 5-31 Peak Discharge (Q) as a Percentage of Maximum Outflow (Qo)

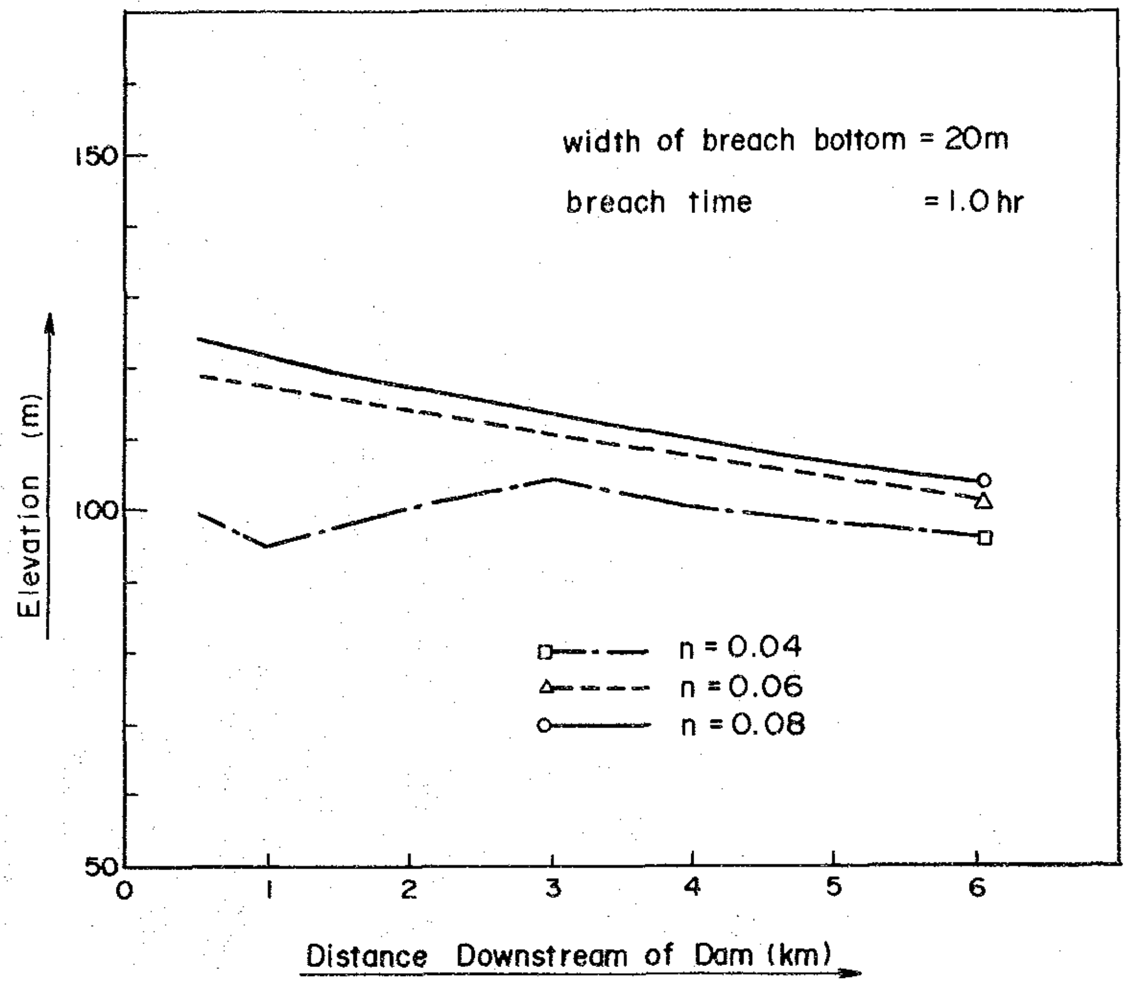


Fig. 5-32 Profile of Peak Flood Elevation Due to Mae Lama Luang Dam Breach

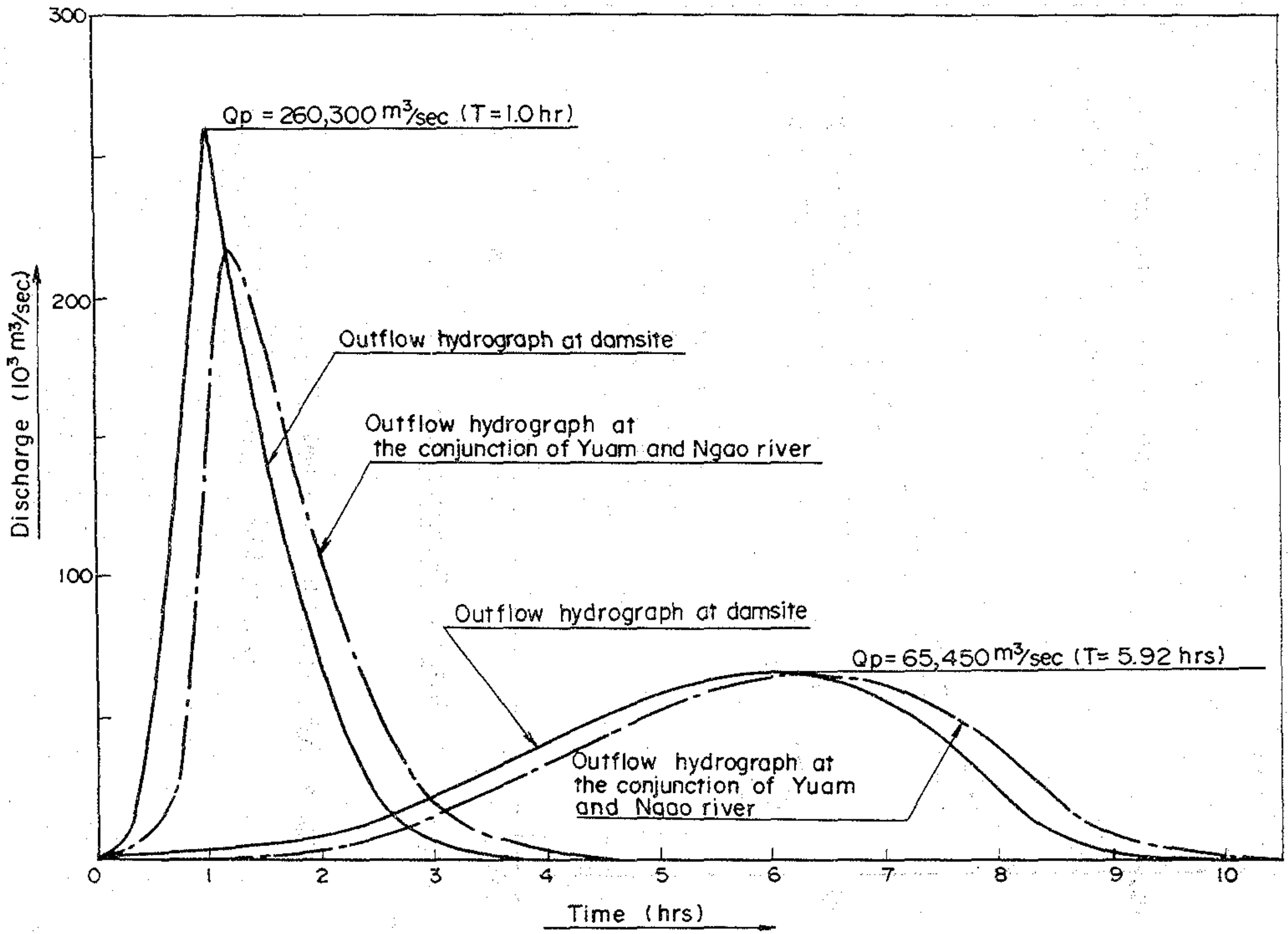


Fig. 5-33 Flood Attenuation Along Ngao River

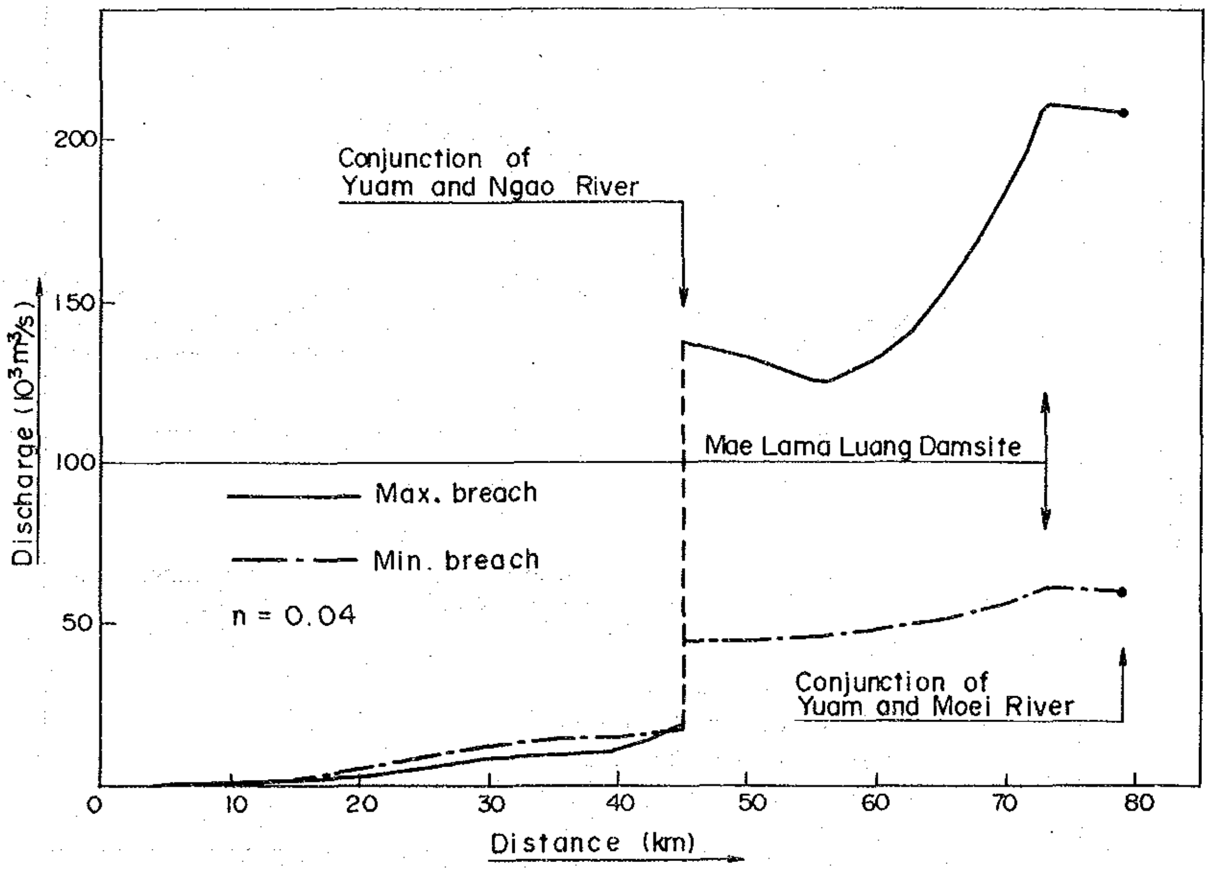


Fig. 5-34 Profile of Maximum Discharge Due to Breach of Nam Ngao Dam