REPORT OF PRELIMINARY SURVEY FOR MAEKLONG RIVER BASIN FLOOD FORECASTING PROJECT THAILAND

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JAPAN INTERNATIONAL COOPERATION AGENCY

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CHAPTER I . GENERAL

1-1 Introduction

Upstream area of the Maeklong river is covered by tropical rain forests and farmland is found only along river banks, but area downstream of Kanchanaburi embraces an extensive plain which is densely populated and constitutes an important granary of Thailand. However, the downstream area is often afflicted with flood damages due to heavy rainfall.

Development of a flood forecasting scheme for the Maeklong river basin was initiated by the adoption of a pilot flood forecasting and warning system at the First Meeting of Working Group of Experts on Typhoons of ECAFE/WMO which was held in Bangkok in December 1968. For early implementation of this project, analysis of past floods has been conducted jointly by the Royal Irrigation Department and the Meteorological Department of Thailand.

1-2 Formation and Itinerary of the Team

The Japanese Preliminary Survey Team for the Maeklong River Basin Flood Forecasting Scheme comprised experts in river engineering, hydrology and telecommunication, and was sent to Thailand from February 6 to 19, 1975. Table 1-1 shows the assignment and affiliation of each of the team members.

Table 1-1 - Formation of the Survey Team

Name	Assignment	Affiliation (as at March 1, 75)
Kazusuke NAKAO	Overall control and river engineering	River Councilor, River Division, Kanto Regional Construction Bureau, Ministry of Construction.
Tomomitsu FUJII	Hydrology	Head of Water Management Planning Section, Operation Control Centre for the Tone River Dams, Kanto Regional Construction Bureau, Ministry of Construction.
Kazuhiko TAKAYAMA	Telecommunication	Telecommunication Specialist, Telecommunication Section, Accounting Division, Minister's Secretariat, Ministry of Construction.

During its stay in Thailand, the team conducted the following survey activities for the proposed flood forecasting scheme for the Maeklong river basin with the collaboration of the Thai government. The itinerary of the survey is shown in Table 1-2.

(1) Field Survey

Reconnaissance survey was conducted along the lower reaches of the Maeklong and its tributary, the Khwae Yai, and along the middle and lower reaches of the Khwae Noi, a downstream tributary of the Maeklong in order to study the basin characteristics and the existing condition of the river channel, observation facilities and communication facilities.

(2) Data Collection

The following data were collected during the team's stay in Thailand.

1) Meteorological, hydrological and hydraulic observation data.
2) Data on flooded areas and flood damage.
3) Data on irrigation development and hydropower generation projects and other development schemes.
4) Analytical data relating to flood forecasting and warning.
5) Data on the existing condition of telecommunication system.

Table 1-2 - Itinerary of the Survey Team

Date and Day		Description
Feb	6, Thu	Arrival in Bangkok.
	7, Fri	Courtesy call made on Japanese Embassy and JICA Office; Consultation with the officials of the Meteorological Department, Royal Irrigation Department and Electricty Generating Authority of Thailand at the Meteorological Department.
	8, Sat	Holiday.
	9, Sun	- do -
	10, Mon	Morning: Data collection at RID. Afternoon: Discussion and data collection at EGAT.
	11, Tue	Field survey of Ban Chao Nen dam and Vajiralongkorn dam.
	12, Wed	Sailing on the Kwae Noi by boat from K_{10} to Thong Pha Phum, and inspection of the observation station of the Meteorological Department.
	13, Thu	Survey of Khao Laem dam site now under planning, and sailing down the Kwae Noi to Bangkok.
	14, Fri	Arrangement of data, and intra-team discussion.
	15, Sat	- do -
	16, Sun	Holiday.
	17, Mon	Morning: Discussion at RID. Afternoon: Discussion at the Meteorological Department.
	18, Tue	Discussion at the Meteorological Department, and courtesy call on Japanese Embassy.
	19, Wed	Return to Tokyo.

1-3 Major Findings of the Survey

Surveys for the flood forecasting scheme of the Maeklong river basin have been actively conducted for more than ten years by the Thai government agencies and TCS, and there have been proposed more than four different forecasting systems in the past. Observation stations are not sufficiently installed, but considering the fact that their installation and maintenance entails substantial difficulty because of the basin's geographical condition and sparse population, it may be said that they are fairly well consolidated. Data collection and arrangement at these stations is conducted smoothly, and application of software techniques for run-off analysis and flood routing using the collected data has already entered the stage of practical operation. The team was informed that even trial flood forecasting was actually undertaken using the data of a number of observation stations to which communication means were available.

It appears, however, that this trial forecasting did not produce very good result for want of a well organized observation system and satisfactory communication means and the resultant lack of smooth data transmission. (For these reasons, the Thai government evinced great enthusiasm for the consolidation and improvement of observation equipment and commucation facilities. The present survey was therefore conducted with stress placed on the study of the observation network and communication facilities which are indispensable for flood forecasting and warning)

1-4 Recommendations

On the strength of the findings of the survey, the following recommendations are made.

(1) Responsibility fore ach stage of flood forecasting and warning should be made clear.

(2) There are many districts where observation stations are found close to each other. Determination should be made as to which organization's stations are to be used in such districts.

(3) Decision should be made as to which organization is to exercise control over master station and monitor stations.

(4) An adequate observation network should be planned. For this purpose, basic analysis of the data so far collected should be prompted.

(5) For those stations where observers cannot be promptly assigned at time of a flood, it is advisable that self-recording equipment be installed so that data can be collected by telemetering.

(6) Adequacy of the communication system should be carefully checked by propagation test and other means since the Maeklong basin is mountainous.

(7) Flood forecasting based on run-off calculation and flood routing is made by calculations worked out on a daily basis at present. When recording gagues are installed at most stations, calculations can be made on an hourly basis. In this case, however, the augmented volume of calculation will call for the introduction of a high-speed calculation system.

1-5 Acknowledgement

(1) The kind cooperation of the following Thai officers in the survey is gratefully acknowledged.

Thai Officers concerned participating in the preliminary Survey on the Maeklong Basin Flood Forecasting Project.

I. Meteorological Department

①	Capt. Prasert Soontarotok	Deputy Director-General
②	Dr. Wiroj Sangvaree	Chief, Hydrometeorology Division
③	Mr. Tawatchai Brikshavana	Chief, Hydrological Forecast Sub Division
④	Mr. Smith Tumsaroch	Chief, Telecommunication Division

II. Royal Irrigation Department

①	Mr. Damrong Jaraswathana	Special Grade Engineer and Chief, Hydrology Section, Survey Division
②	Mr. Chaterm Tangtrongchit	Hydrologist, Survey Division

III. Electricity Generating Authority of Thailand

①	Mr. Siri Chitchob	Hydrologist, Survey Division

Notes: Those officers whose names are prefixed by a circle participated in the field survey.

(2) The team wishes to express its deep gratitude to Dr. Charoem Charoem-Rajapak, Director General of the Meteorological Department, forsparing his precious time to interview and discuss with the team.

(3) The team also wishes to express its thanks to Mr. Atsushi Hamamori from the UN Typhoon Committee Secretariat who was kind enough to coordinate the survey itinerary and act as interpreter for the team and also offered many other helpful services.

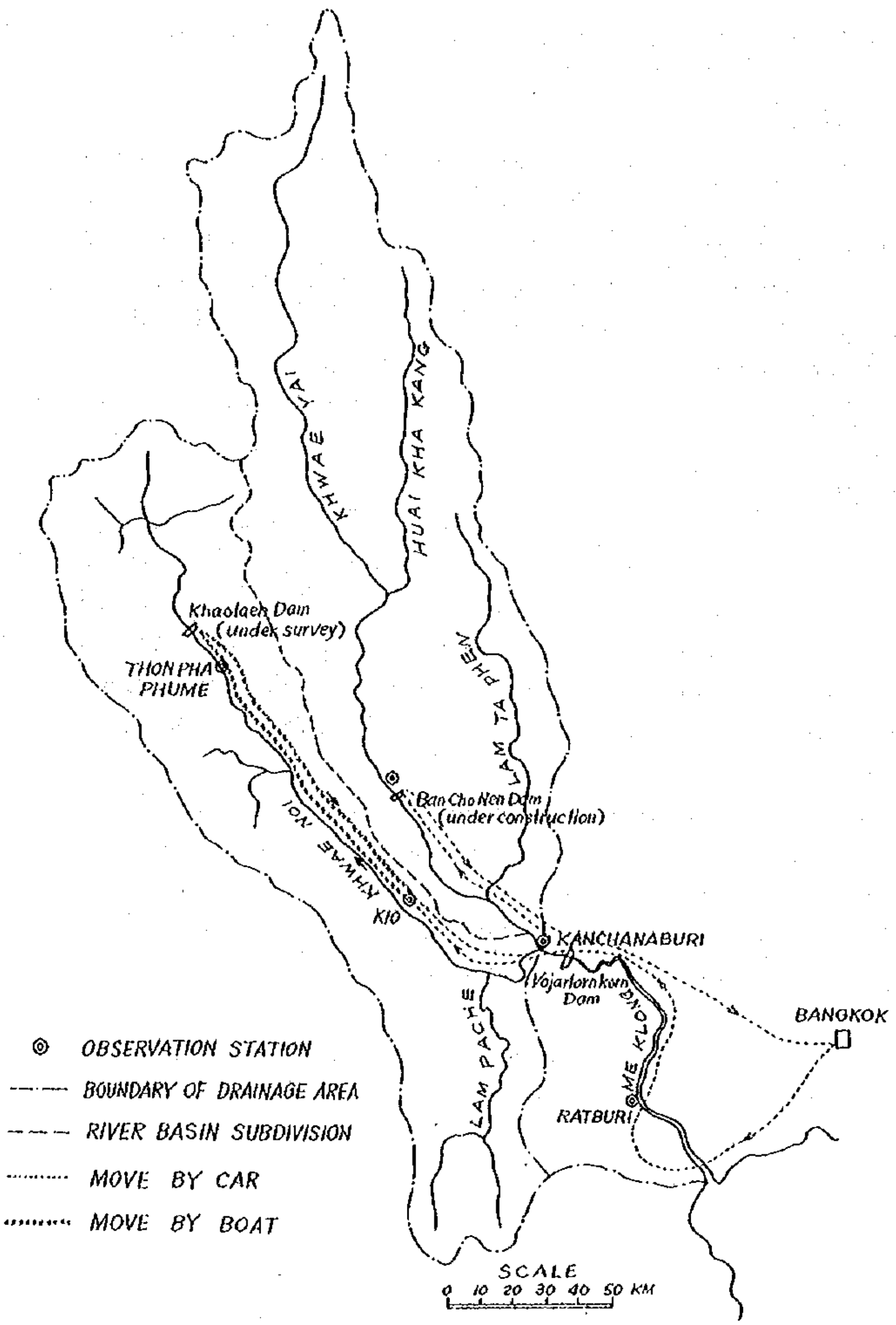


Fig. 2-1 - Outline of River Reconnaissance

CHAPTER II. FIELD SURVEY AND DATA COLLECTION

2-1 Field Survey

During its stay in Thailand, the team conducted a field survey along the lower reaches of the Maeklong and its tributary, the Kwae Yai as well as along the middle and lower reaches of the Kwawe Noi, a downstream tributary of the Maeklong, 'in order to study the characteristics of the Maeklong river basin and graspt the existing condition of the river channel, observation facilities and communication facilities.

(1) Itinerary of Field Survey

The field survey was conducted for three days from February 11 to 13. Details of the field trip are described below.

Feb 11 (Tue)

The team members left Bangkok at 7:00 hrsbythree jeeps provided by the Thai government (one each from the Meteorological Department, RID and EGAT), drove westward on a recently completed highway along the beach, passed by Samut Songkhram and Pak Tho, and arrived at Rat Buri at (9:00 hrs. After the survey of the flood plain, river flow, flood water drain pipe, etc., the team left Phothara at 10:00 hrs and arrived at Kanchanaburi at noon and took a short recess; left Kanchanaburi at 12:30 hrs and arrived at Ban Chao Nen dam at 13:10 hrs.

In the afternoon, the team was given explanation about the Ban Chao Nen dam project and inspected the dam site and diversion tunnel (two under construction).

At 15:30 hrs, theteam left the dam site and inspected the Vajiralongkorn dam (headwork for irrigation and water supply) located about 8 km downstream of Kanchanaburi, and put up near the dam site.

Feb 12 (Wed)

Left Vajiralongkorn dam at 7:00 hrs and proceeded to the Kwae Noi river for survey; arrived at K_{10} station located 80 km upstream at 8:30 hrs. From K_{10}, sailed upstream by a boat (capacity - 10 ~ 12 passengers) to Thong Pha Phum. The time of passing various points between K_{10} and Thong Pha Phum is shown below.

1)	K_{10} Station	8:45 hrs
2)	Sai Yok	9:10 "
3)	Confluence of the Huai Mae Nam Noi	13:00 "
4)	Ban Kui Mang	15:50 "
5)	Thong Pha Phum	17:00 "

After arrival at Thong Pha Phum, the team inspected the rain gauge station and the water stage and discharge station of the Meteorological Department, and put up at a hotel there.

Feb 13 (Thu)

Departure at 7:00 hrs by jeep, and inspected the Khao Laem dam site about 7 ~ 8 km upstream of Thong Pha Phum, where gelogical survey was conducted by an Australian contract with EGAT.

At 8:15 hrs, sailed down from Thong Pha Phum by a boat, passed the confluence of the Huai Mae Nam Noi at 12:00 hrs, and arrived at K_{10} station at 15:00 hrs. Then, proceeded to Bangkok. On the way to Bangkok, the deservair on the left bank was inspected after passing Kanchanaburi.

(2) Transportation

Bangkok and Kanchanaburi are linked by a paved road. From Kanchanaburi to Ban Chao Nan dam, there runs a unpaved road which is well compacted but rough in some sections. There are no roads running upstream from the dam, and boats are the only means of transportation.

The Khwaei Noi river is accessible by train as far as Wang Po, but the team used motorcars for both going and returning. The road leading to the Khwae Noi is not paved and extremely rugged. Road transportationis possible for some distance upstream of K_{10} station, but boats are the only means to go farther upstream.

There are roads linking Thong Pha Phum with Sangkhlaburi and Pilok, but the team was informed that the road leading to Sangkhlaburi is very rugged and boats are the safer means of transportation.

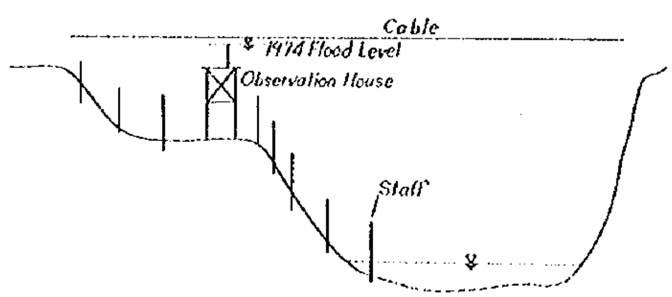
(3) Existing Condition of Stations

The existing condition of the water stage station and the rain gauge station surveyed by the team is described below.

1) K_{10} Station (RID)

a. Water stage is measured by staffs and a bubble gauge.
Eight staffs are used to cover a measuring range of 1 ~ 17 m. The bubble gauge was detached in 1974 when it was submerged under water.

b. Discharge measuring facilities are available, and a cable is stretched across the river.



c. SSB radio telephone is installed at time of a flood.

d. Sketch of the station.

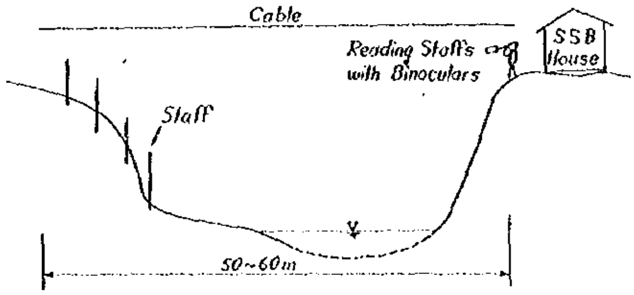
2) Thong Pha Phum Water Stage and Discharge Station (MET)

a. Water stage is measured by staffs.

b. Cable for discharge measurement is stretched, and Price current meter is used.

c. SSB radio telephone is available at all times because the station adjoins the rain gauge station.

d. Sketch of the station



3) Thong Pha Phum Rain Gauge Station

a. The following rain gauges are installed.

- o Ordinary daily rain gauge ..... Approx. 15 cm.
- o Recording rain gauge .... 20 cm.
- o Recording rainfall intensity gauge ... Approx. 75 cm.

b. Evaporating pan is installed.

(4) Town of Thong Pha Phum

Thong Pha Phum has a population of about 5, 000 and is the base of the trip to Pilok mines.

Electricity is generated by an isolated power plant and supplied from the sunset to 23:00 hrs.

It has a hotel and accommodation facilities belonging to the Mining Organization.

Table 2-1 - Itinerary of Field Trip to Khwae Noi - Khwae Yai

(11 - 13 February 1975)

Itinerary

11 Feb. 75

0700	Leave Bangkok
1200	Arrive at Chao Naen Dam
1200	Lunch at the Union of Electricity Generating Authority of Thailand (EGAT)
1300	Observe the Head Work of Chao Naen Dam
1400	Leave Chao Naen Dam
1600	Arrive at Kanchanaburi (on the way to Vajiralongkorn Dam)
1700	Arrive at Vajiralongkorn Dam
	- Dinner at Vajiralongkorn Damsite
	- Stay at Vajiralongkorn Dam

12 Feb. 75

0600	Breakfast at the dam
0700	Leave Vajiralongkorn by car
0830	Arrive K10 (Lum Sum)
0830	Leave K10 (Lum Sum) by boat to Thong Pha Phum - Lunch on board
1500	Arrive at Thong Pha Phum
1530	Seeing topography (on board)
1800	Return to Thong Pha Phum
	- Dinner at the hotel
	- Stay at the hotel in Thong Pha Phum

13 Feb. 75

0700	Leave the hotel
	- Breakfast at the hotel
1200	Arrive at Wang Pho
	- Lunch at Wang Pho
1300	Leave Wang Pho to K10 (Lum Sun)
1400	Arrive at K10 (Lum Sum)
1530	Arrive Vajiralongkorn Dam
1800	Arrive at Bangkok

2-2 Data Collection

The team visited the following organizations a number of times and obtained the reports, drawings and data listed in Table 2-2.

1) Meteorological Department, Ministry of Communications.
2) The Electricity Generating Authority of Thailand (EGAT).
3) Royal Irrigation Department (RID).

Table 2-2 - List of Obtained Data

I. Reports

1. Trial Flood Forecasting in Macklong River (MET, 1973)
2. Preliminary Attempt to Simulate the Streamflow of the River Khwae Noi by Using Recording of Three Standard Raingages (MET, 1969)
3. The Development of Pilot Flood Forecasting in the Mae Klong River Basin (RID, 1974)
4. List of Rainfall Stations in Thailand (RID, 1972)
5. Water Resources Development in Thailand (RID, 1974)
6. The Mae Klong River Basin Development Project (RID,)
7. Development of the River Quae Noi Hydrological Investigations of Monthly Runoff and Sediment (EGAT, 1974)
8. Additional Investigation on the Design Flood of Quae Yai No. 1 Hydro Electric Project (EGAT, 1973)

II. Drawing

1. Locations of Hydrologic Observation Stations (RID, 1968)
2. Map Showing Water Resources Development in Thailand (RID, 1974)
3. Map Showing Flooded Area in October, 1972 (RID, 1972)
4. Map Showing Telecommunication Network (RID)

III. Data

1. Daily Rainfall Data (RID)

1-1	Pilok	1956-67	1970-74
1-2	Sangkhlaburi	1952-74	
1-3	Thong Pha Phum	1952-74	
1-4	Huai Mae Nam Noi	1966-74	
1-5	Wang Pa	1966-74	
1-6	Lum Sum	1965-74	
1-7	Wang Masang	1968-74	
1-8	Lin Thin	1966-74	

2. Hourly Rainfall Data (RID)

2-1	Sangklaburi	October, 1972 and July to October, 1974
2-2	Thong Pha Phum	" "

3. Evaporation

Thong Pha Phum October, 1972 and July to October, 1974

4. Mean Daily gauge height and discharge

4-1	K-6	1952-72
4-2	K-10	1965-74
4-3	K-11	1965-74
4-4	K-13	1965-74
4-5	K-17	1966-74
4-6	K-20	1966-74
4-7	K-22	1966-68
4-8	K-22A	1969-74
4-9	K-27	1968-74

5. Maximum and minimum gauge height

5-1	K-2	1962-66
5-2	K-2A	1967-72

6. Hourly Data

- Hourly gauge readings for: July and August, 1969
  July, 1972
  August and October, 1974
- Rating Table for the Same period of hourly gauge record
- Stations: K10, K11, K13, K17, K20, K22A and K27

IV. Others

Outline of Electricity and Telecommunication concerned.

CHAPTER III. EXISTING CONDITION OF THE MAEKLONG RIVER

3-1 Outline of the Maeklong Basin

The Maeklong is the third largest river in Thailand which flows in the western part of the country and its basin is a steep mountainous area. It flows through deep or narrow valleys and forms a basin of 1 to 1.5 mile diameter in some parts.

The Khwaei Yai and the Khwae Noi, the two major tributaries of the Maeklong, rise in the mountainous district boarding on Burma, flow down southeast almost in parallel with each other, and join to form the Maeklong at Kanchanaburi. The Khwae Yai, the eastern tributary, flows through valleys generally wider than those through which the Khwae Noi, the western tributary, flows. Hence, the Khwae Noi flows much more rapidly than the Khwae Yai. Because of their sharp bed slope and abundant water volume, tributaries of the Khwae Noi are concentrated near the water source and flow through places where the elevation is very close to the highest. As a consequence, new geological configuration can be observed along their uppermost reaches, with a steep and long ridge extending along the Thailand-Burma borders.

The catchment area of the Maeklong is far smaller than those of the other two major rivers in Thailand, the Chao Phya and the Mune, but the mean discharge almost equals that of the Mune and accounts for 50% of the mean discharge of the Chao Phya.

The upper part of the Maeklong basin is covered by tropical rain forests, and farmland can be found only along river banks. However, the downstream area of the basin embraces an extensive and well developed plain which is densely populated. The southern part of the basin, which is covered predominantly by cultivated land, has many important cities such as Ratchaburi and Samut Songkram, and is known as an important granary of Thailand together with the Chao Phya river basin. This area is also known for the frequent occurrence of flood damage.

Table 3-1 - Comparison of Annual Run-off

Basin	Catchment Area Km^2	Mean Discharge m^3/s	Specific Discharge $m^3/s/Km^2$
Chao Phya (at Wad Tha Had)	118,000	920	7.8×10^{-3}
Mune (at Ubon Ratchathani)	107,000	540	5.0×10^{-3}
Maeklong (at Kanchanaburi)	27,000	410	15.0×10^{-3}

Table 3-2 - Statistical Data of Basins

in 2503B. E.

Basin	Total Area Km²	Total Population	Agricultural Population		Acreage of Agricultural Land Holdings		
			Person	%	Total Acreage	Number of Holding	Average of Holding
Khwae Yai River	14, 630	104, 300	83, 700	80. 2	325, 100	14, 452	22. 49
Khwae Noi River	10, 960	63, 400	48, 800	76. 9	154, 825	7, 851	19. 72
Maeklong River plain	7, 019	1, 298, 400	901, 600	69. 4	2, 829, 275	138, 065	20. 49
Total	32, 609	1, 466, 100	1, 034, 100	70. 5	3, 309, 200	160, 368	20. 63

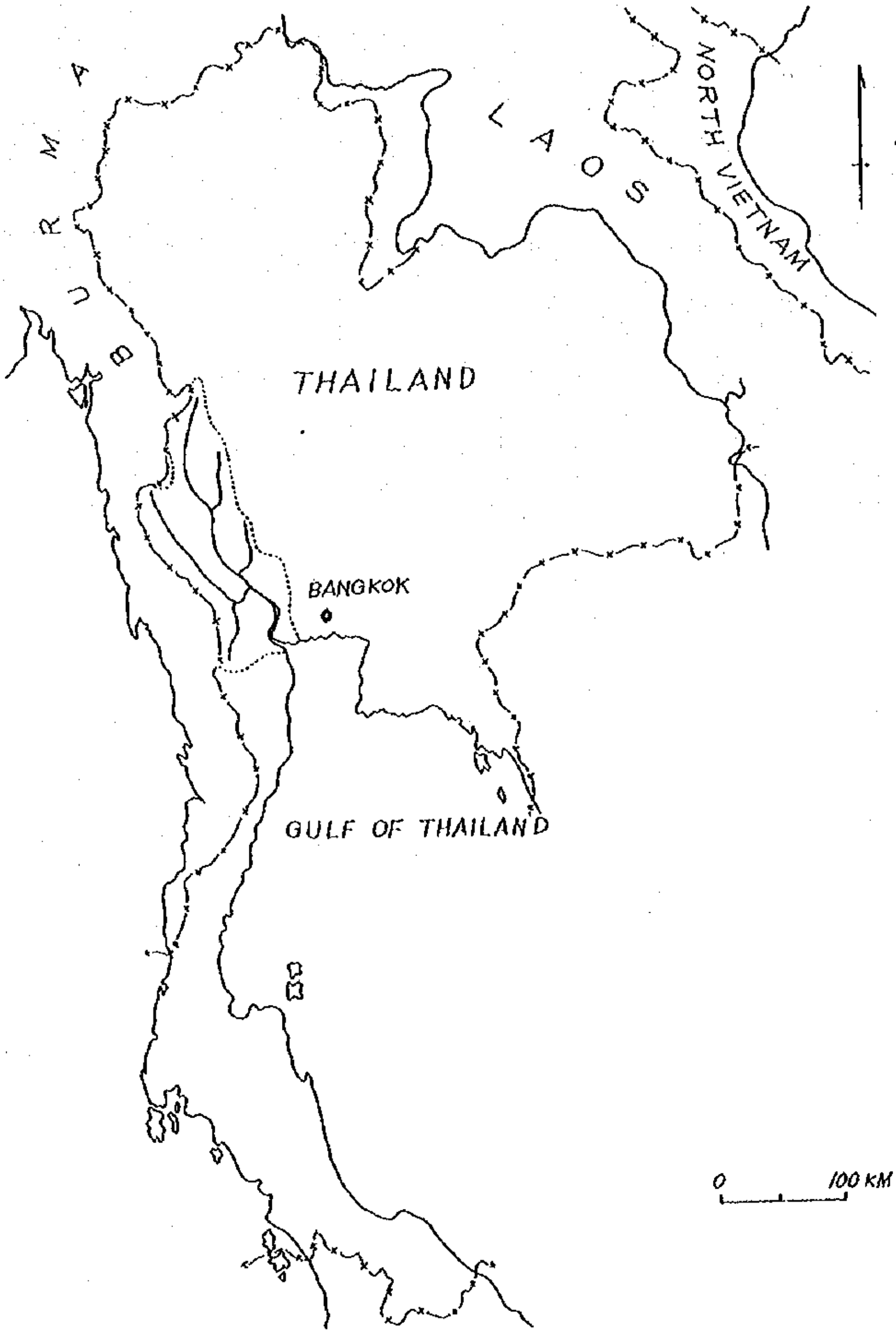


Fig. 3-1 - Location Map of Maeklong River Basin

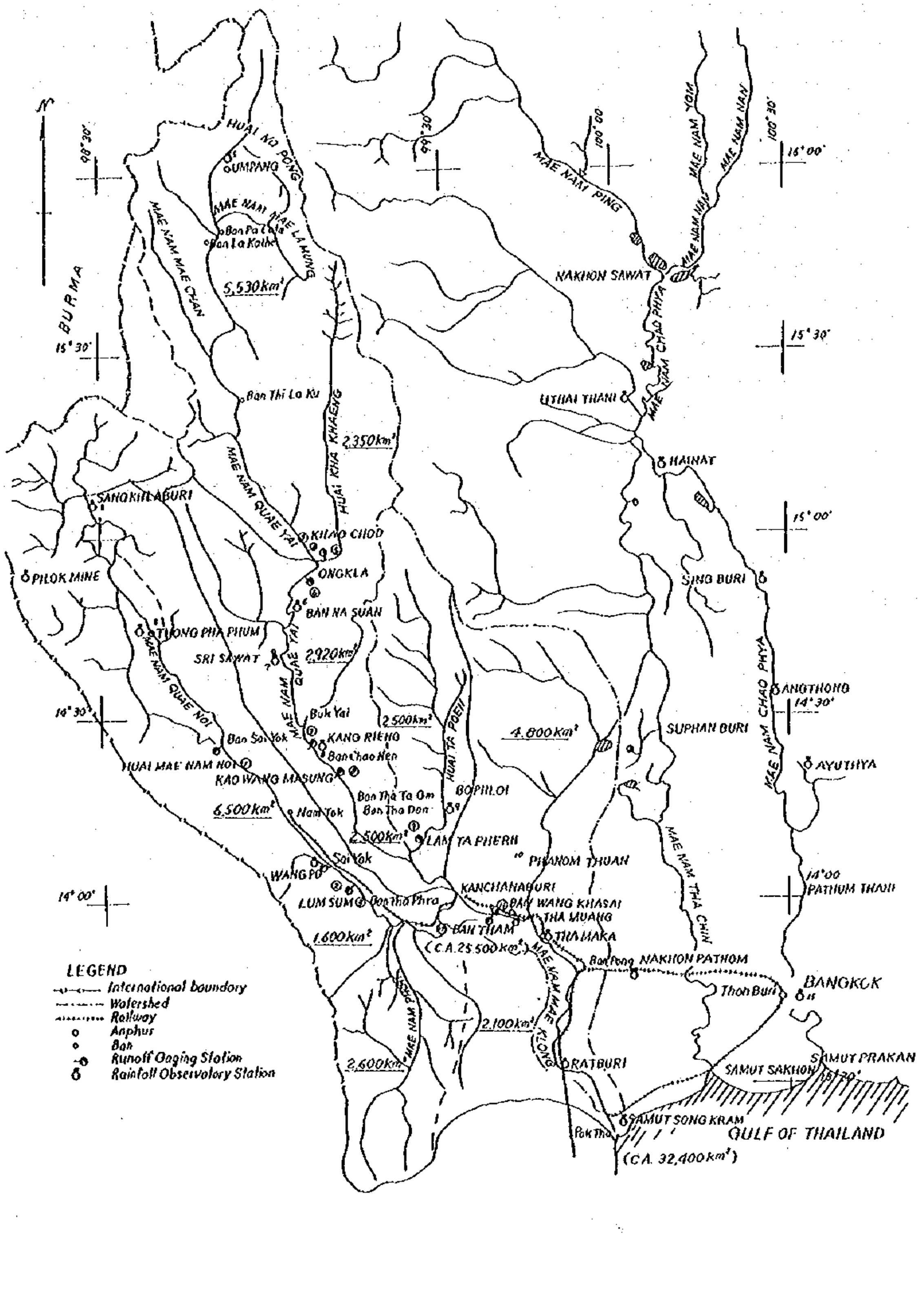


Fig. 3-2 - Location Map of Rainfall and Water Stage Gauging Stations

3-2 Outline of the Maeklong and its Tributaries

In the section downstream of Kanchanaburi, the Macklong has a number of irrigation facilities including Vajaralongkron dam and river improvement is in fair progress. The team was informed, however, that the expansion of river width involves extreme difficulty in urban areas such as Ratchabur and Samut Songkhram because houses are built side by side along both banks.

Upstream of Kanchanaburi, the Macklong is divided into two major tributaries, the Khwae Yai and the Khwae Noi.

The Khwae Yai has two tributies, the Huai Kha Khaeng which joins the Khwae Yai in the upstream section and the Huai Tapoen which flows into the Kwhae Yai in the downstream section. Channel improvement is hardly undertaken except that the construction of Ban Chao Nen dam is under way at a point about 90 km upstream of Kanchanaburi. At present, construction of a diversion tunnel is in progress at the dam site. Ban Chao Nen dam is a multipurpose dam intended for power generation, irrigation water supply, and flood control. It is extremely large in size and expected to have a total storage capacity of about 17. 7 billion tons and an effective storage capacity of about 7. 5 billion tons. It is anticipated that the flood of the Khwae Yai can be almost perfectly controlled after completion of this giant dam.

The Khwae Noi also has two tributaries, the upstream tributary being the Huai Mae Nam Noi and the downstream tributary the Mae Nam Pachi. The team did not observe river improvement work in any part of this river. The Khwae Noi maintains a width of 50 - 70 m as far as Thong Pha Phum which is about 200 km upstream of Kanchanaburi, and abounds in water volume which is far larger than that of the Khwae Yai, and permits navigation by boat even in early Feburary in the dry season. This is due partly to the copious rainfall in the western mountainous district through which the river flows and partly to the geology of the basin which is composed of limestone and therefore provides an extremely large subsurface percolation.

However, the prevelance of limestone is seriously impeding the progress of dam construction at Khao Kwang, Kaeng Puan, Ben Chan De and Khao Laem. Since early dam construction cannot be hoped for, there is great need for establishing a flood forecasting system for the Khwae Noi basin.

Table 3-3 - Catchment Area and Length of Major Rivers

River Name	Primary Tributary	Secondary Tributary	Catchment Area	Length of River Channel	Remarks
			Km^2	Km	
Mae Klong R.			27,200		Catchment area is the value measured at Ban Tham.
	Khwae Yai		14,630		
		Upstream Section of the Khwae Yai	5,530		
		Hvai Kha Khaeng	2,350	130	
		Hvai Tapoen	2,500	140	
		The Khwae Yai down-stream of confluence of the Hvai Taphoen	4,250	--	
	Khwae Noi		10,960		
		Khwae Noi	8,100	300	
		Mae Nam Phachi	2,860	120	
	Maeklong down-stream of Kanchanaburi		1,610	--	

Notes: A deltaic area extends downstream of Ban Tham, so that the basin covers an area of about 32, 600 km^2 in the neighbourhood of the estuary.

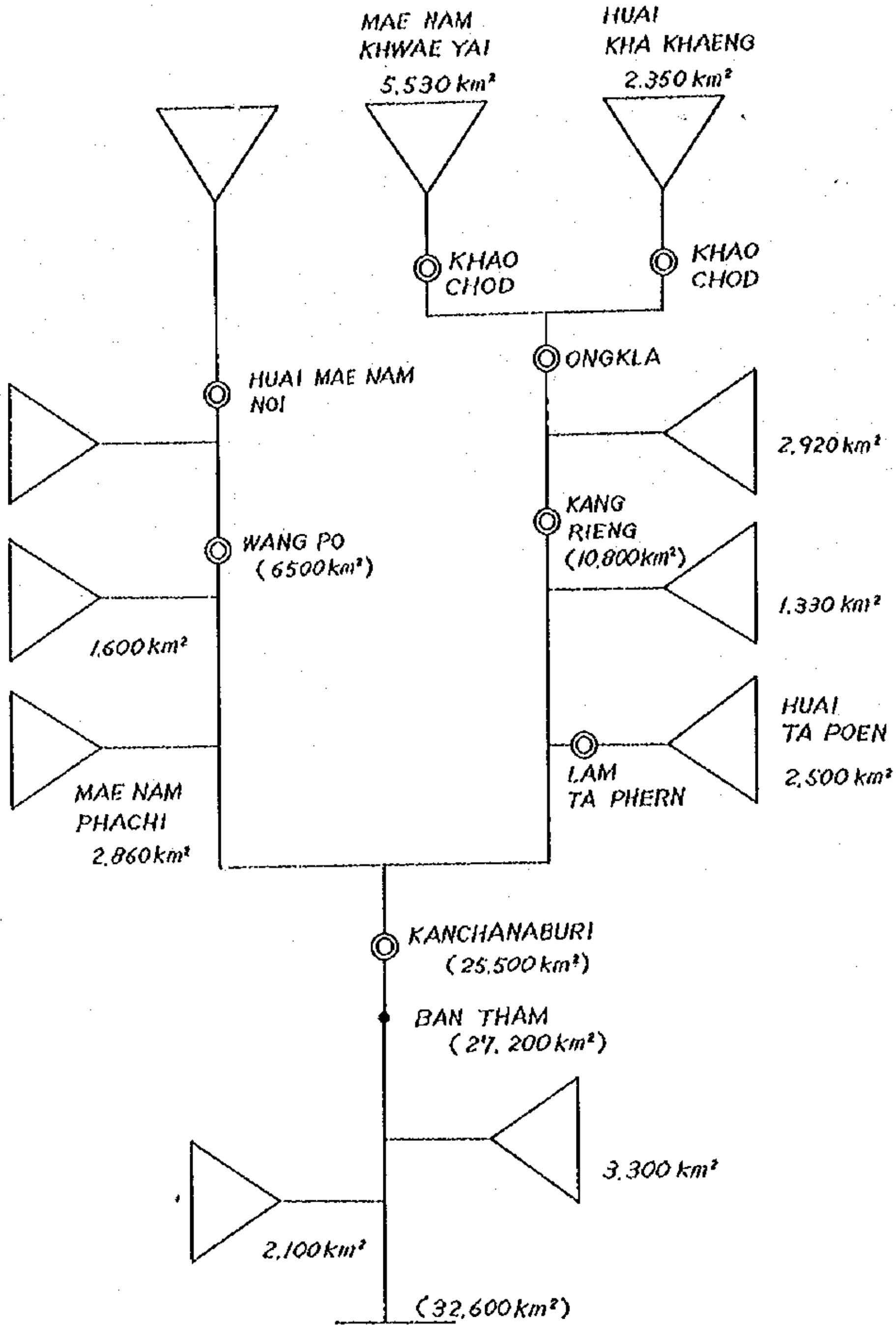


Fig. 3-3 - Basin Model of Mae Nam Mae Klong

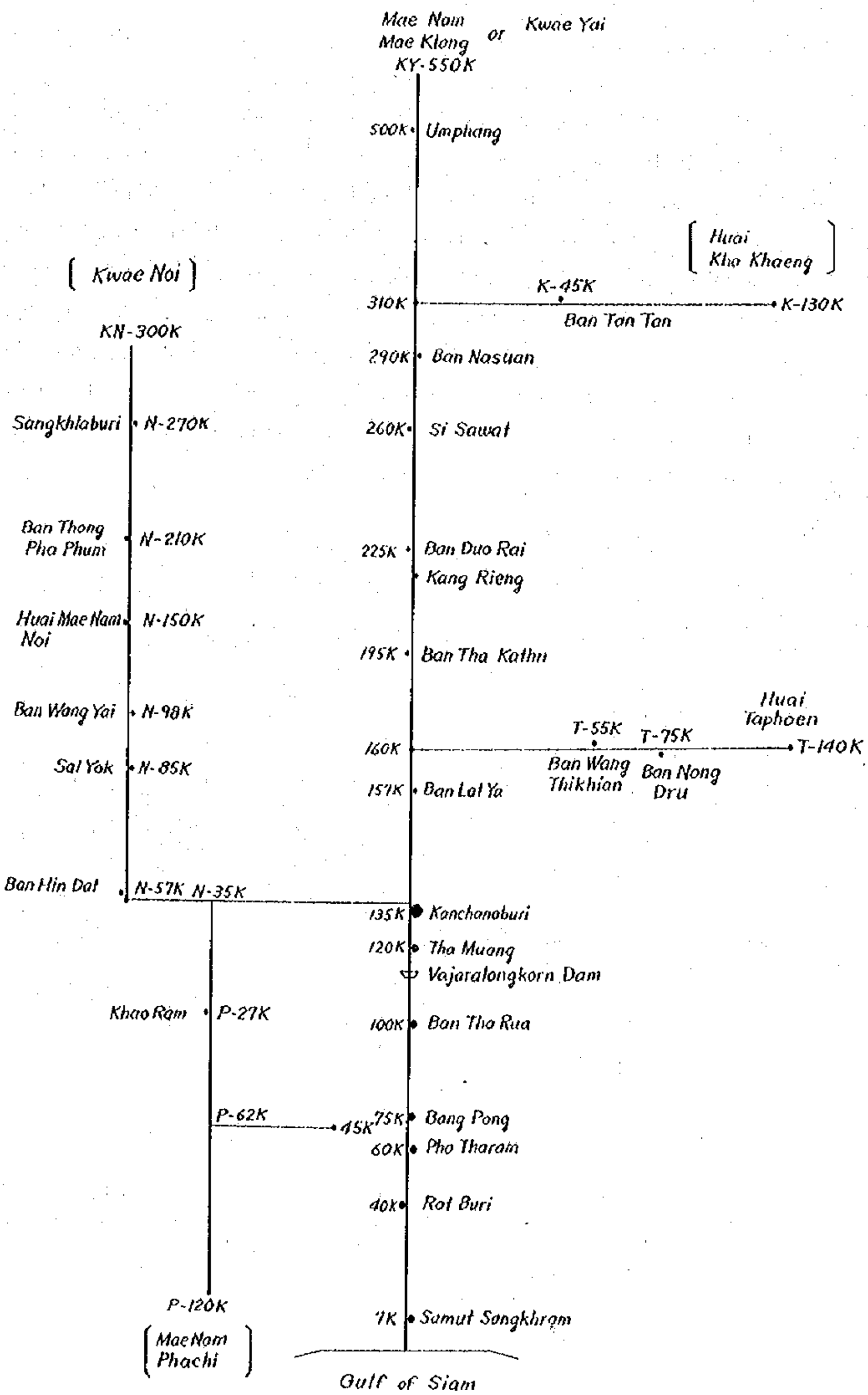


Fig. 3-4 - River Channel Model of Mae Nam Mae Klong

3-3 Climate

The Maeklong is geographically affected by the strong southwesterly monsoon blowing from Bay or Bental and Gulf of Siam.

Generally, the climate of the Maeklong river basin divides itself into three seasons. Winter or the northeasterly monsoon season begins towards the end of October and lasts until the end of February. Summer lasts from mid-February to mid-May. Wet or southwesterly monsoon season begins in mid-May and lasts until the latter half of October.

The water level of the Maeklong usually starts rising from mid-April to early May. It rises gradually with the increase of rainfalls and their intensity, reaching its peak in the August - September period and declining in the October - November period. August records the highest flood occurrence rate, and heavy floods occur in the July - October period by strong rainfalls caused by the effects of strong monsoon, tropical storm, tropical depression, and weather condition in mountainous regions.

Table 3-4 - Annual Rainfall

Station / Year	Sangkhlaburi	Pilok	Ban Pa Tho	Thong Pha Phum	Lin Thin	Hvai Mae Nam Noi	Lum Sum	Wang Masung
1965	2,514	5,083						
66	1,929	3,961	*1,827				936	
67	2,193	5,254	*1,660	994	2,335	2,113	1,110	
68	2,242		1,076	1,615	2,064	1,348	1,162	
69	2,890		*1,586	2,134	*1,670	1,777	1,221	1,216
70	2,183	4,770	781	1,659	1,646	1,528	1,361	956
71	2,367	4,007	*1,285	1,665	2,136	1,563	1,025	907
72	3,104	5,479	1,954	2,174	2,500	2,269	1,390	1,179
73	2,155	5,346	1,379	1,914	1,941	1,720	1,475	1,219
74	(2,086)	(4,287)	(2,369)	(2,164)	(1,985)	(1,839)	(1,596)	(1,413)

Notes:
1. All values indicate the annual rainfall from April to March of the following year.
2. Values for 1974 alone indicate the annual rainfall from April to December.
3. At Ban Pa Tho station, no observation was made in October of 1966 and 1967, November of 1969, and April and November of 1971.
4. At Lin Thin station, no observation was made in April 1969 and in February and March of the following year.

Table 3-5 - Monthly Rainfall in Recent Five Years (1)

Sangkhlaburi

Month / Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	63	291	314	461	418	372	168	22	12	0	23	39
71	102	175	478	657	376	265	158	109	2	0	9	36
72	144	316	605	1, 017	385	409	188	0	29	0	0	0
73	27	217	571	334	479	277	98	5	0	0	13	135
74	248	351	400	428	499	137	*	24				

Pilok Tin Mine

Month / Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	142	555	769	1, 177	1, 033	717	255	70	13	0	0	38
71	40	231	1, 412	1, 174	512	394	189	0	0	0	11	44
72	144	535	1, 118	1, 724	1, 076	489	208	98	0	0	0	88
73	3	312	1, 247	1, 589	1, 295	754	99	10	0	0	6	32
74	179	638	831	632	1, 231	334	401	40	0			

Ban Pa Tho

Month / Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	17	134	68	116	183	199	24	19	21	0	0	0
71	*	56	425	537	165	56	25	*	3	0	9	9
72	28	116	334	745	370	272	22	22	10	0	0	37
73	5	62	301	256	543	164	7	1	0	0	1	38
74	92	427	485	379	904	60	21					

Thong Pha Phum

Month / Year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	146	377	288	303	503	215	212	7	0	0	10	73
71	89	203	204	433	216	264	175	22	26	0	5	21
72	142	228	396	519	289	357	88	66	4	0	0	86
73	3	144	579	386	288	334	77	11	0	0	54	39
74	172	390	347	244	449	211	318	35				

Table 3-6 - Monthly Rainfall in Recent Five Years (2)

Lin Thin

Year \ Month	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	128	134	215	322	223	189	143	97	40	0	76	79
71	285	323	352	422	335	171	129	16	0	0	32	71
72	237	159	297	616	314	471	64	125	102	0	0	116
73	78	171	492	304	295	371	81	21	0	0	32	96
74	99	475	283	281	343	184	286	34	0			

Huai Mae Nam Noi

Year \ Month	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	192	140	162	319	189	239	97	30	17	0	40	104
71	81	165	326	320	172	221	176	5	4	0	14	81
72	220	121	306	633	209	404	151	182	13	0	0	31
73	24	164	506	229	173	388	103	10	0	0	7	116
74	164	315	204	243	365	179	326	44				

Lum Sum

Year \ Month	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	101	149	43	76	71	131	166	62	49	0	46	63
71	97	168	57	75	185	73	99	7	17	0	44	84
72	157	75	199	109	183	251	189	115	28	1	0	82
73	66	222	196	193	126	309	195	64	0	0	3	101
74	117	228	229	138	139	338	355	32	21			

Wang Masung

Year \ Month	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1970	101	149	43	76	71	131	166	62	49	0	46	63
71	97	168	57	75	185	73	99	7	17	0	44	84
72	157	74	95	54	59	349	233	94	40	0	0	23
73	40	184	190	85	173	220	157	38	0	11	2	100
74	78	230	66	72	165	334	468					

Table 3-7 - Daily Evaporation in Millimeters for Calendar Year 1972

Thong Pha Phum

Days	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1										5.4		
2										4.0		
3										3.7		
4										4.9		
5										4.9		
6										4.7		
7										5.2		
8										4.8		
9										3.8		
10										3.8		
11										4.8		
12										3.8		
13										4.2		
14										4.1		
15										5.3		
16										2.1		
17										3.2		
18										3.0		
19										5.0		
20										3.4		
21										2.9		
22										5.2		
23										4.2		
24										4.0		
25										4.5		
26										3.2		
27										4.1		
28										5.2		
29										4.2		
30										4.3		
31										4.0		
Total												
Mean												

Table 3-8 - Daily Evaporation in Millimeters for Calendar Year 1974

Thong Pha Phum

Days	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1							2, 0*	3, 8	2, 7	3, 8		
2							5, 6	5, 5	1, 1	2, 8		
3							1, 2	5, 8	1, 7	3, 0*		
4							3, 3	4, 2	2, 9	4, 2		
5							5, 7	3, 2	3, 8	5, 6		
6							3, 6	4, 4	3, 0	2, 7		
7							1, 0*	3, 0	2, 7	3, 4		
8							3, 0*	4, 7	1, 0*	2, 6		
9							4, 0	3, 6	2, 0	2, 6		
10							4, 5	3, 4	4, 1	2, 5		
11							2, 6	3, 6	3, 0*	1, 0*		
12							3, 2	1, 7	3, 8	1, 0*		
13							2, 7	1, 0*	3, 5	3, 6		
14							2, 9	1, 8	5, 7	3, 0		
15							1, 8	2, 6	2, 6	2, 0*		
16							1, 3	1, 0*	5, 1	2, 0*		
17							3, 5	1, 0*	3, 0*	3, 1		
18							3, 6	1, 0*	3, 4	3, 0		
19							2, 9	1, 2	3, 0*	2, 0		
20							2, 3	1, 6	5, 6	4, 0		
21							1, 8	3, 0*	5, 4	5, 2		
22							3, 0	3, 4	3, 1	3, 0*		
23							3, 4	2, 0	3, 9	5, 4		
24							2, 4	2, 1	5, 0	3, 1		
25							4, 2	2, 9	2, 8	2, 7		
26							2, 8	1, 9	4, 0	3, 7		
27							3, 3	2, 3	1, 9	4, 7		
28							3, 0*	2, 0	4, 4	4, 2		
29							4, 6	2, 9	5, 9	4, 8		
30							3, 6	3, 1	4, 3	3, 0*		
31							4, 7	1, 5		3, 5		
Total							97, 5	85, 2	104, 4	101, 2		
Mean												

Table 3-9 - Duration of Sunshine (1)

Station U-Tong

SUAPN BURI

Month \ Year	1967		1968		1969		1970	
	Total	Mean	Total	Mean	Total	Mean	Total	Mean
Jan.			–	–	–	–	253.8	8.2
Feb.			–	–	–	–	231.9	8.3
Mar.			–	–	272.9	8.8	169.8	9.4
Apr.			–	–	268.2	8.9	251.8	8.4
May			240.2	7.7	213.4	6.9	240.0	7.7
Jun.			182.7	6.1	168.1	5.6	114.8	5.0
Jul.			162.0	5.2	96.6	3.1	134.8	4.4
Aug.			134.1	4.3	148.0	4.8	100.7	3.2
Sep.			163.2	5.4	170.4	5.7	158.2	5.3
Oct.			237.5	7.7	194.1	4.5	188.6	6.1
Nov.			279.4	9.3	226.8	7.6	220.6	7.4
Dec.			280.5	9.0	260.8	8.4	181.0	5.8

Table 3-10 - Duration of Sunshine (2)

Station U-Tong

SUPAN BURI

Month \ Year	1971		1972		1973		1974	
	Total	Mean	Total	Mean	Total	Mean	Total	Mean
Jan.	272.2	8.8	211.2	6.8	270.1	8.7	236.6	7.6
Feb.	191.1	6.8	261.4	9.0	254.9	9.1	226.5	8.1
Mar.	215.2	6.9	235.8	7.6	219.8	7.1	233.4	7.5
Apr.	262.6	8.8	226.2	7.5	263.3	8.8	223.3	7.4
May	191.8	6.2	260.9	8.4	200.1	6.5	170.8	5.5
Jun.	97.8	3.3	126.0	4.2	137.4	4.6	100.4	3.3
Jul.	98.3	3.2	105.7	3.4	116.3	3.7	152.2	4.9
Aug.	141.6	4.6	94.9	3.1	120.6	3.9	121.6	3.9
Sep.	184.4	6.1	153.4	5.1	141.3	4.7	153.8	5.1
Oct.	149.5	3.0	224.6	7.2	221.8	7.2	186.0	6.0
Nov.	249.6	8.3	170.3	5.7	185.1	6.2	203.4	6.8
Dec.	103.0	3.3	190.7	6.2	213.3	6.9	188.8	6.1

Table 3-11 - Duration of Sunshine (3)
Station Kampangsaen
NAKHON PATHON

Year / Month	1973		1974	
	Total	Mean	Total	Mean
Jan.	288. 7	9. 3	252. 2	8. 1
Feb.	261. 4	9. 3	234. 0	8. 4
Mar.	224. 1	7. 2	251. 1	8. 1
Apr.	270. 9	9. 0	211. 3	7. 0
May	227. 6	7. 3	175. 1	5. 6
Jun.	167. 8	5. 6	148. 8	5. 0
Jul.	139. 2	4. 5	186. 2	6. 0
Aug.	138. 9	4. 5	141. 6	4. 6
Sep.	144. 4	4. 8	188. 9	6. 3
Oct.	208. 0	6. 7	181. 9	5. 9
Nov.	184. 2	6. 8	213. 6	7. 1
Dec.	276. 0	8. 9	235. 5	7. 6

3-4 Flood Occurrence Condition

(1) Outline

Rainfall in the Macklong river basin is copious in the May - October period due to the effect of the southwesterly monsoon. The rain brought about by the cyclone from the Bay of Bengal in and around May falls in the Lam Pachi river basin, and in June it falls in the basins of the Khwae Yai and the Khwae Noi.

The strong rain brought about by the typhoon falls in the basins of the Khwae Yai and the Khwae Noin in September, and in the Lam Pachi basin through October and November.

The water level of the Macklong river rises three times a year. The first rise occurs in the May - July period when the level becomes 3 - 4 m higher than in the dry season, with July recording a temporary decline of about 2 m. This is followed by the sharp rise which starts in the beginning of August. The annual highest water level is usually recorded in the August - September period. This second rise is followed by the third rise in some years, and this lasts from October to November but the increment of level is not so large as in the August - September period.

When the discharge of the Khwai Noi or Khwae Yai increases, the Macklong rises almost to the top of its banks. In certain cases where the discharge of both tributaries increases, the Macklong overflows its banks. Accordingly, there always is fear of flooding in August and September. On the left bank side of the Maeklong, there extends a huge lowlying area which forms the natural retarding basin of the Maeklong. The ground elevation of this retarding basin is 3 - 4 m lower than the crown height of banks. Even when the water level does not go beyond the free-board, the river water of ten flows into the retarding basin through the irrigation canal. If the flood occurs at the beginning or end of the irrigation season, a heavy damage is inflicted upon crops.

In Pachaburi province, a railway line and a highway runs on the left bank side of the Maeklong, and a stretch of hills extends on the right bank side. Thus, the flat land on either side of the river is sandwiched in between the river bank and the hilly area. Therefore, the river water overflows into the lowlying land on the left bank side and intrudes into the town area. This part of the basin is known as Thung Khao Nhu where farming is not feasible when the river stage is high. Cultivation in this area is possible only in the non-irrigation season after the river water recedes.

(2) Annual Maximum Discharge

Table 3-12 shows the annual maximum discharges and the time of their occurrence in the last ten years. K_{11} is located in Kanchanaburi, K_{20}, K_6 and K_{27} are located along the Khwae Yai and its tributaries, and K_{10}, K_{13}, K_{22} or K_{22A}, and K_{17} are located along the Khwae Noi and its tributaries. (For exacat locations of these stations, refer to Fig. 3-12)

Discharges recorded before 1964 are shown for reference in Table 3-13.

Records of K_{11} station which are closely related to the floods in downstream area indicate that all annual peak discharges occurred in the period from June to October. The records also indicate that during the 18 year period from 1957 to 1974, the annual maximum discharge occurred in July or August in 12 years. Other months which recorded the annual peak discharge in the same 18 year period are June (once), September (3 times), and October (twice).

Annual peak discharges at K_{11} and K_{10} occurred at about the same time in each year from 1962 to 1974 (1963 exclusive). During the said 18 year period, there were ten floods due to the simultaneous occurrence of annual peak discharges at K_{20} along the Khwae Yai and K_{11} or at K_6 located also along the Khwae Yai and K_{11}.

K_{27} and K_{17} are located along the downstream tributaries of the Khwae Yai and the Khwae Noi. Annual peak discharges at these stations exert little influence upon K_{11} because they occur with a large time lag and are also far smaller than those at K_{11}.

Table 3-12 - Annual Maximum Discharge and Time of Occurrence (1)

Year \ Station	K11	K20	K6	K27	K10	K13	K22 or K22A	K17
65	2,038		791		1,811			
	18^h 30 July		9^h 27 July		24^h 29 July			
66	2,209	766	780		2,263	3,146	143	190
	6^h 14 Sep.	21^h 11 Sep.	18^h 11 Sep.		18^h 12 Sep.	18^h 10 Sep.	28 July	2^h 20 Nov.
67	1,852	615	597		1,680	2,099	119	73
	6^h 22 Aug.	18^h 21 Aug.	15^h 21 Aug.		15^h 20 Aug.	18^h 18 Aug.	3^h 7 Aug.	21^h 8 Oct.
68	1,492	627	618	10	1,106	1,088	K22 54	954
	12^h 18 Aug.	7^h 17 Aug.	7^h 17 Aug.	12^h 19 Mar.	6^h 17 Aug.	11^h 15 Aug.	10^h 16 Aug.	21^h 22 Oct.
69	2,841	1,084	1,079	42	2,375	2,211	207	?
	9^h 14 Aug.	1^h 11 Aug.	22^h 10 Aug.	21^h 4 Nov.	24^h 11 Aug.	7^h 10 Aug.	K22A 24^h 9 Aug.	?
70	1,362	492	481	19	1,182	1,168	167	442
	15^h 19 July	24^h 26 Aug.	21^h 26 Aug.	24^h 5 Nov.	16^h 18 July	21^h 16 July	17^h 16 July	18^h 1 Dec.
71	2,367	876	832	13	1,896	1,887	123	186
	18^h 29 July	19^h 26 July	18^h 26 July	16^h 3 Nov.	19^h 28 July	21^h 26 July	13^h 26 July	23^h 11 Oct.
72	2,990	2,251	2,658	75	3,067	2,860	386	165
	18^h 19 July	19^h 20 Sep.	3^h 20 Sep.	6^h 28 Sep.	1^h 17 July	6^h 14 July	18^h 18 July	22^h 28 Oct.
73	1,982	920		56	1,762	1,846	135	598
	18^h 21 June	6^h 25 Sep.		6^h 10 Oct.	15^h 20 June	24^h 18 June	18 June	24^h 19 Nov.
74	3,561	1,784		380	3,294	3,068	321	355
	21 Aug.	13 Oct.		13 Oct.	6^h 21 Aug.	6^h 19 Aug.	18 Aug.	21^h 16 Oct.

Table 3-13 - Annual Maximum Discharge and Time of Occurrence (2)

	K-11	K-6	K-10		K-11	K-6	K-10
51				58	1, 609	880	
					25 July	6^h 1 Sep.	
52		1, 738		59	2, 853	1, 792	
		6^h 25 Oct.			4 Oct.	6^h 3 Oct.	
53		2, 164		60	1, 434	816	
		15^h 18 Aug.			24 Aug.	18^h 8 Oct.	
54		869		61	4, 330	1, 628	
		9^h 27 Sep.			28 Aug.	18^h 3 Sep.	
55		629		62	3, 416	2, 746	1, 982
		12^h 26 Sep.			22 Sep.	20 Sep.	21 Sep.
56		855		63	2, 939	2, 114	2, 157
		6^h 18 Oct.			5 Oct.	6^h 4 Oct.	12 Aug.
57	2, 799	1, 373		64	2, 251	1, 409	1, 354
	24 Aug.	6^h 4 Oct.			27 Sep.	15^h 26 Sep.	27 Sep.

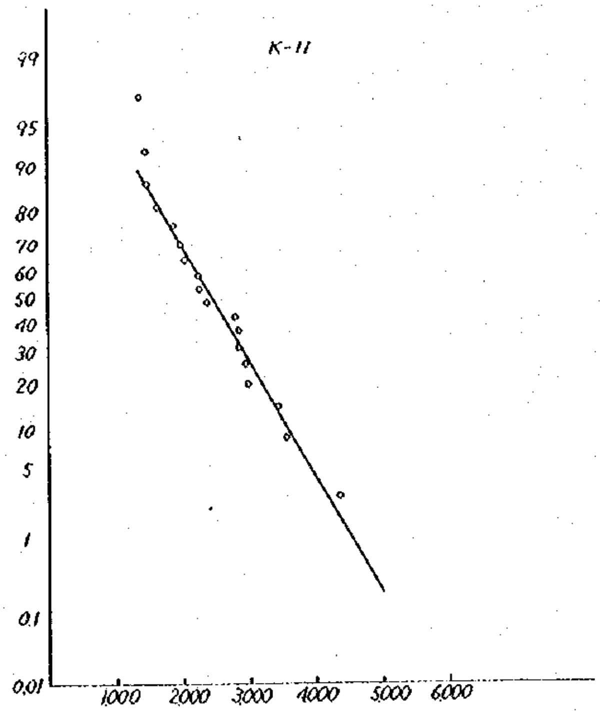


Fig. 3-5 - Exceedance Probability of Annual Maximum Discharge, K-11

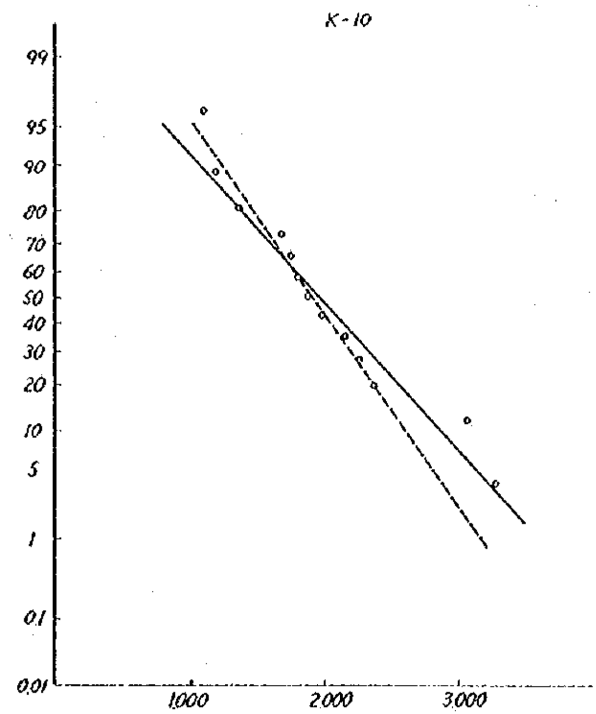


Fig. 3-6 - Exceedance Probability of Annual Maximum Discharge, K-10

Table 3-14 - Highest Water Stage of the Khwae Noi

Year	Month and Day		K13	K13-K10	K10	K10-K11	K11
			MSL m	m	MSL m	m	MSL m
1966	8	1	85.29	42.92	42.37	23.85	18.52
	9	14	90.89	45.28	45.61	25.69	19.92
	9	22	80.21	42.74	37.47	20.28	17.19
67	8	11	87.29	43.40	43.89	25.90	17.99
	8	22	86.65	42.85	43.80	24.58	19.22
	9	5	85.46	43.56	41.90	23.45	18.45
68	8	18	83.90	42.62	41.28	22.93	18.35
	9	17	82.91	42.94	39.97	22.74	17.23
69	8	14	89.21	42.55	46.66	26.01	20.65
70	7	19	84.16	42.55	41.61	23.85	17.76
71	7	29	87.49	42.62	44.87	25.30	19.57
72	7	19	91.84	43.15	48.69	28.23	20.46
	8	2	86.02	42.13	43.89	24.32	19.57
	8	22	82.15	42.10	40.05	22.62	17.43
73	6	21	87.59	43.40	44.19	25.33	18.86
	8	29	84.89	42.02	42.87	24.47	18.40
74	8	21	92.64	43.02	49.62	28.60	21.02
Mean	–		–	42.93	–	24.6	–

Notes: Floods subjected to little influence of the Khwae Yai were selected. Since the distance between K_{13} and K_{10} is about 120 km and that between K_{10} and K_{11} is about 90 km, the gradient of highwater marks can be calculated as follows.

$K_{13} - K_{10}$ 42.93/120,000 ≑ 1/2,800

$K_{10} - K_{11}$ 24.6/90,000 ≑ 1/3,700

(3) Condition of Flooding

Inundation of the Maeklong river basin usually occurs in areas downstream of Vajiralongkorn headwork.

Flooded area can be broadly divided into two. One is the area extend-on both banks of the Maeklong between Ban Pong and Rat Buri. This area is vulnerable to flood damage even by a relatively small increase of discharge. The other is the left bank area between Tha Muang and Tha Maka which is inundated by flood water overflowing the deservoir when the discharge at Vajiralongkorn headwork increases to more than about 2,300 m^3/s.

During the flood which lasted from September to October, 1972, the discharge was about 1,100 - 1,400 m^3/s at K_{11} and an estimated area of about 5,000 ha on both sides of the Maeklong upstream of Rat Buri was flooded. At this time, no flooding was observed in areas further upstream.

During the floods in August and October of 1974, the discharge at Vajiralongkorn ranged from 2,800 - 3,600 m^3/s, which far exceeded the overflow condition of the deservoir. Two areas between Tha Muang and Tha Maka were therefore flooded, producing a flood periphery of about 3,500 ha and in addition, flood water flowed into the Nakhom Chai Si river through Tha Sam channel. In these two floods, an immense inundation occurred in the downstream area, forming a flood periphery of about 13,600 ha on both banks of the river between Ban Pong and Rat Buri.

These floods are illustrated in Figs. 3-7 and 3-10.

Flooded and damaged areas in the period from 1969 to 1974 are shown in Table 3-15.

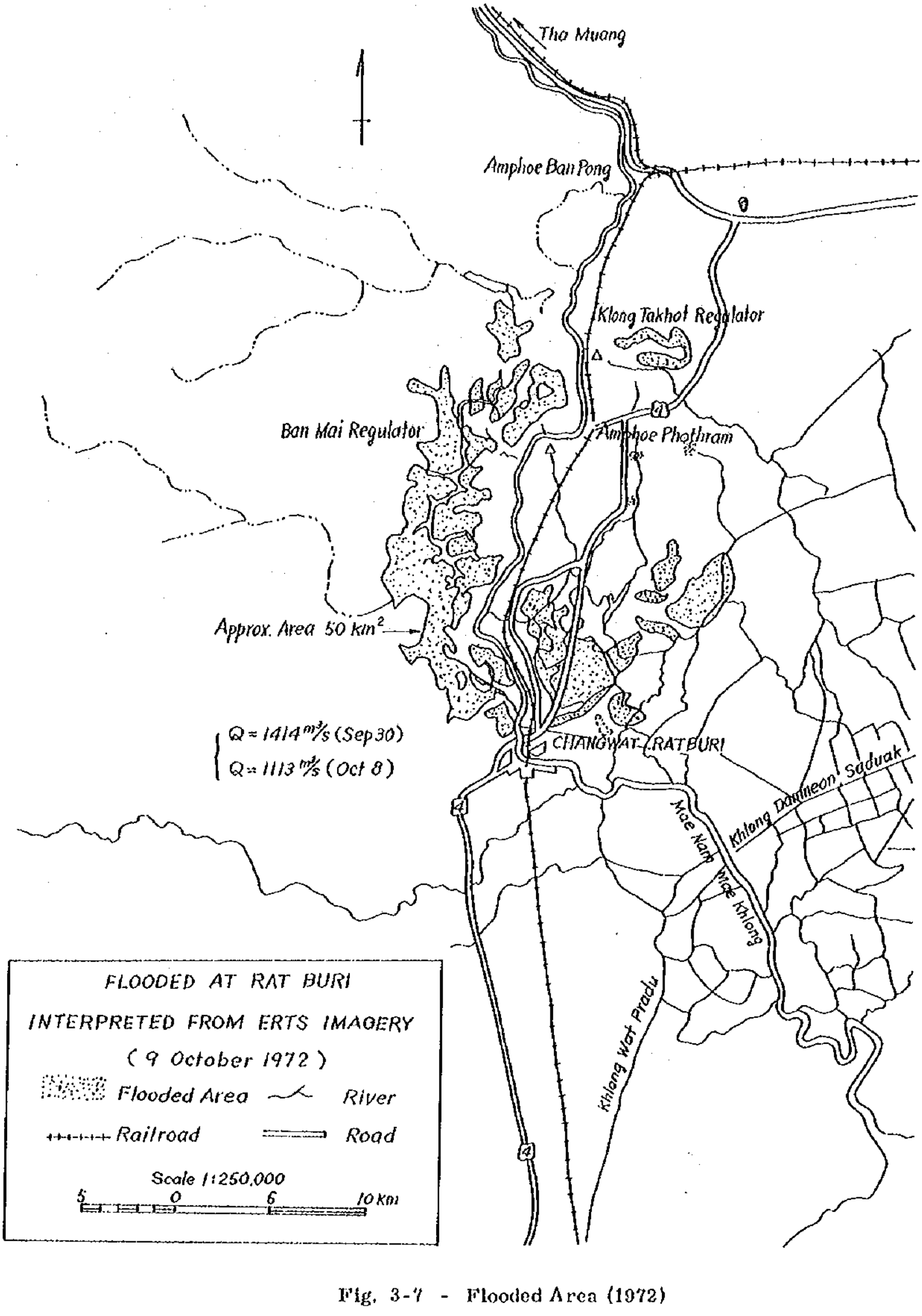


Fig. 3-7 - Flooded Area (1972)

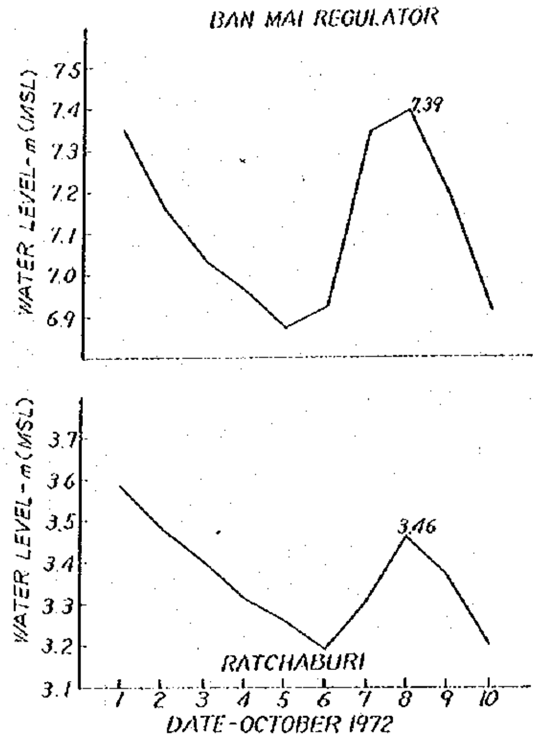


Fig. 3-8 - Water Level of the Maeklong River (1)

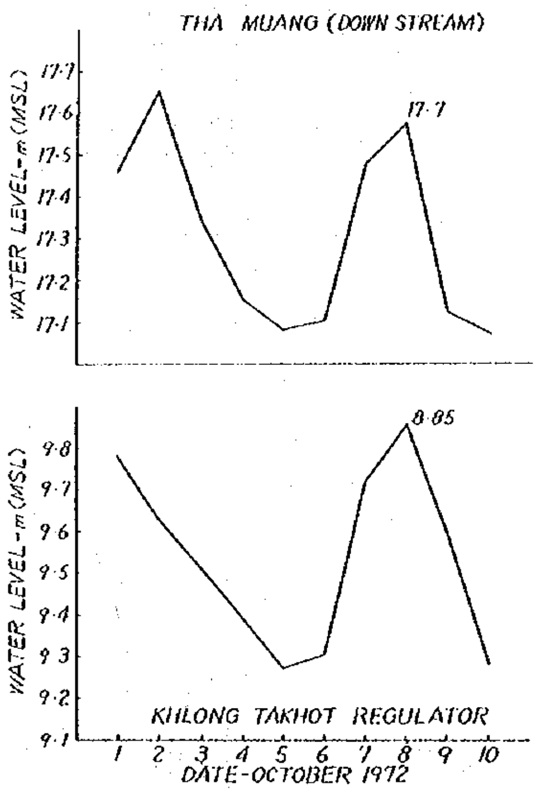


Fig. 3-9 - Water Level of the Maeklong River (2)

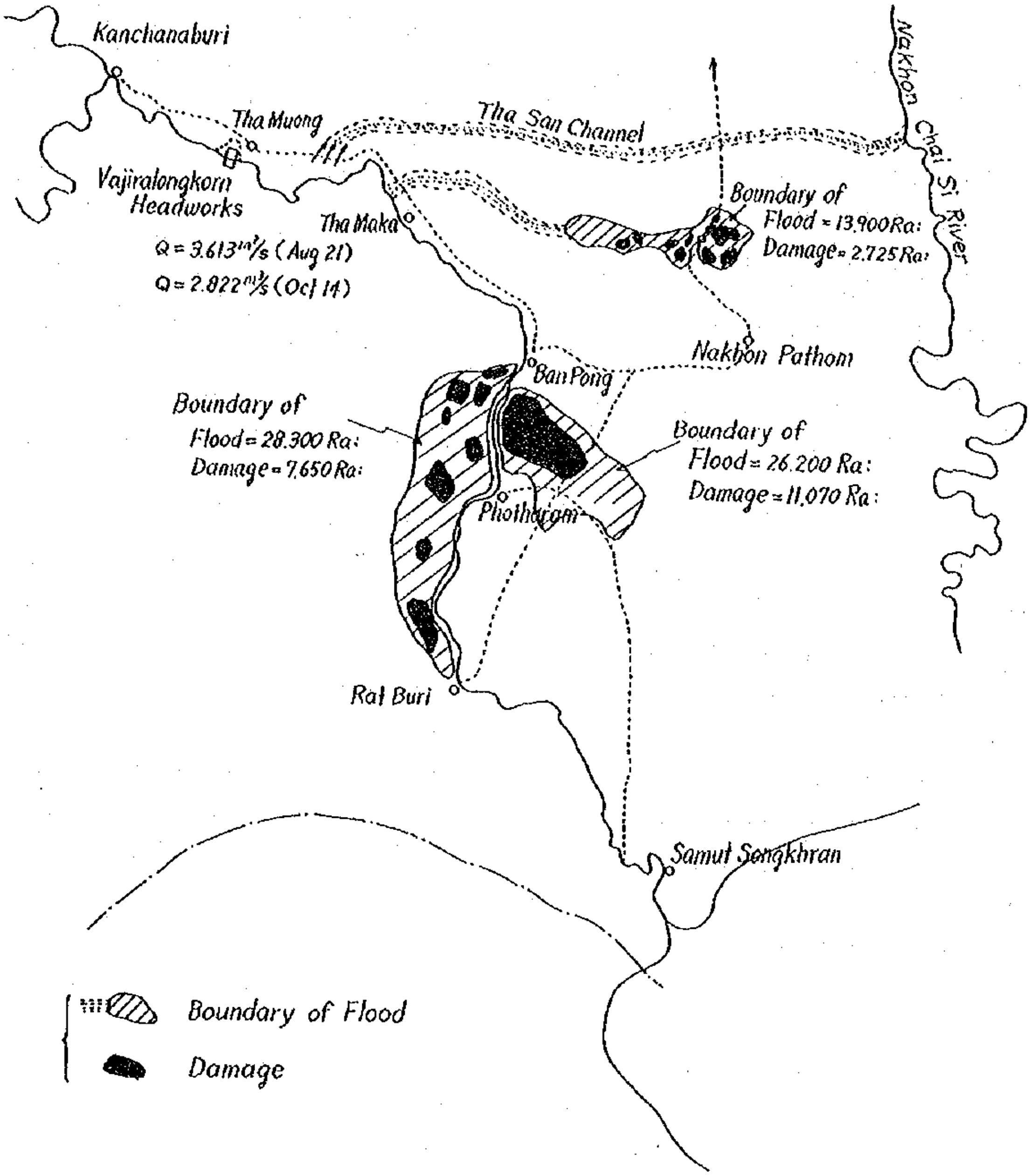


Fig. 3-10 - Flooded Area (1974)

Table 3-15 - Flood of Macklong Project Area

YEAR	PEAK DISCHARGE M^3/SEC	RETURN PERIOD YEAR	BOUNDARY OF FLOOD RAI	DAMAGE RAI
1969	2,841 (12 Aug.)	3	350,000	NO RECORD
1971	2,367 (29 Jul.)	2	1,500	1,500
1972	2,990 (19 Jul.) 2,370 (2 Aug.)	4 2	173,750	12,520
1974	3,613 (21 Aug.) 2,822 (14 Oct.)	8 3	68,744	21,819

*Diversion of Mae Klong Project began in Sept., 1970.

3-5 Ban Chao Nen Hydropower Generation Programme

(1) Outline

Under the Ban Chao Nen Hydropower Generation Programme, it is planned that a dam and power plant will be constructed on the Khwae Yai at a point about 150 km to the northwest of Bangkok.

The dam is planned to be of the rockfill type with an impermeable core, having a height of 135 above the foundation rock, a total storage capacity of 17,745 million m^3 and an effective storage capacity of 7,470 million m^3. It will have a catchment area of 10,880 km^2, and be used for year-round storage of flood water and supply of irrigation water in the dry season.

Five generators to be installed at Ban Chao Nen power plant are expected to exhibit a total installed capacity of 720,000 kW. The generators are planned to be installed in two stages. In the first stage, three generators will be installed to provide an installed capacity of 360,000 kW, which is to be augmented by another 360,000 kW by the second stage installation of two additional generators. The two generators to be installed in the second stage are planned to be provided with a reversible turbine to pump up water.

Completion of this power plant will make it possible to generate an annual average of 1,160 million KWH of electric energy whichis to be transmitted to the substation in Bangkok by the transmission line having a total length of about 165 km.

The dam is intended to be used for multipuporse operation such as supply of irrigation water and flood control besides power generation.

(2) Basic Data of Ban Chao Nen Power Generation Programme

1) Location — Ban Chao Nem on the Khwae Yai river.

2) Catchment area — 10,880 km^2.

3) Annual inflow — 4, 600 MCM.

4) Maximum possible discharge — 7, 100 m^3/s.

5) Basic data of reservoir

a. Normal water surface level — El 180. 0 m.

b. Ponding area — 419 km^2

c. Total storage capacity — 17, 745 MCM.

d. Effective storage capacity — 7, 470 MCM.

e. Maximum level of ponding area — 182. 4 m

(3) Basic Data of the Dam

1) Type — Rockfill dam with an impermeable core.

2) Dam site geology — Quartzite, sandstone, and limestone.

3) Crest height — 185. 0 m.

4) Dam height — 135. 0 m.

5) Crest length — 610. 0 m.

6) Dam volume — 12, 300, 000 m^3.

(4) Basic Data of Spillway

1) Type — Open chute type.

2) Gate — Radial gate, 10 m x 9. 5 m x 3.

3) Maximum discharge — 2, 420 m^3/s.

(5) Power Generation

1) Maximum turbine discharge

First stage — 133 m^3/s x 3 generators = 399 m^3/s.

Second stage — 199. 5 m^3/s x 2 generators = 399 m^3/s.

Total — 798 m^3/s.

2) Maximum output

360, 000 kW in both the first and second stages, totalling 720, 000 kW.

3) Annual generated electric energy

1, 160 x 10^6 KWH.

3-6 Existing State of Observation Stations and Avilability of Data

There are many organizations engaged in observation activities along the Maeklong river and in its basin in order to collect meteorological data as well as data for flood control and water utilization. Accordingly, the existing observation networks, belonging mostly to the following four organizations, present an extreme complexity.

1) Meteorological Department, Ministry of Communications.

2) The Electricity Generating Authority of Thailand (EGAT).

3) National Energy Authority (NEA).

4) Royal Irrigation Department (RID).

While these four organizations are carrying out observation for different purposes, it was found that their stations are established close to each other in some areas. Due to the lack of sufficient coordination and cooperation between the four organizations, the team found it impossible to conduct a systematic survey of all stations whose activities are indispensable for flood forecasting. In the present survey, observation stations could not be satisfactorily classified and inter-related even with the drawings and data provided to the team.

An attempt was made, however, to classify the stations in order using the reports of TCS and NEA and drawings provided by RID. The following tables and drawings show the results of this attempt.

Table 3-16 - List of Rain Gauge Stations (Existing)

No.	Name of Station	River Basin		Classification	Location	Managed by	Duration of observation	Remarks
		Main	Tributary					
1	Umphang	Khwae Yai	Huai No Pong	Ordinary		Met.	1952	
2	Ban Naswan	Khwae Yai	Khwae Yai	Ordinary		Met.	1957	
3	Ban Naswan (K-19)	Khwae Yai	Khwae Yai	Ordinary		RID	1968	Incomplete
4	Si Sawat	Khwae Yai	Khwae Yai	Ordinary		Met.	1955	
5	Kang Rieng (K-6)	Khwae Yai	Khwae Yai	Ordinary		RID	1952	
6	Kanchanaburi	Meklong	Meklong	Radio Linked		Met.	1911	
7	Kanchanaburi (K-8)	Meklong	Meklong			RID	1957	
8	Bophloi (K-12)	Khwae Yai	Taphoen	Ordinary		RID	1956	Incomplete
9	Panom Tuan	Meklong					1952	
10	Sangkhlaburi	Khwae Noi	Khwae Noi	Ordinary		Met.	1952	
11	Pilok	Khwae Noi		Ordinary		Met.	1959	
12	Thong Pha Phum	Khwae Noi	Khwae Noi	Radio Linked		Met.	1952	Incomplete
13	Thong Pha Phum (K-13)	Khwae Noi	Khwae Noi			RID	1966	Incomplete
14	Lum Sum Sai Yok (K-10)	Khwae Noi	Khwae Noi			RID	1955	Incomplete
15	Suan Phung (K-17)	Khwae Noi	Phachi	Ordinary		RID	1966	Incompleted
16	Tha Muang	Meklong	Meklong				1952	
17	Tha Maka	Meklong	Meklong				1952	
18	Bangkok						1911	
19	HUAI MAE NAM NOI K22	Khwae Noi	Khwae Noi					

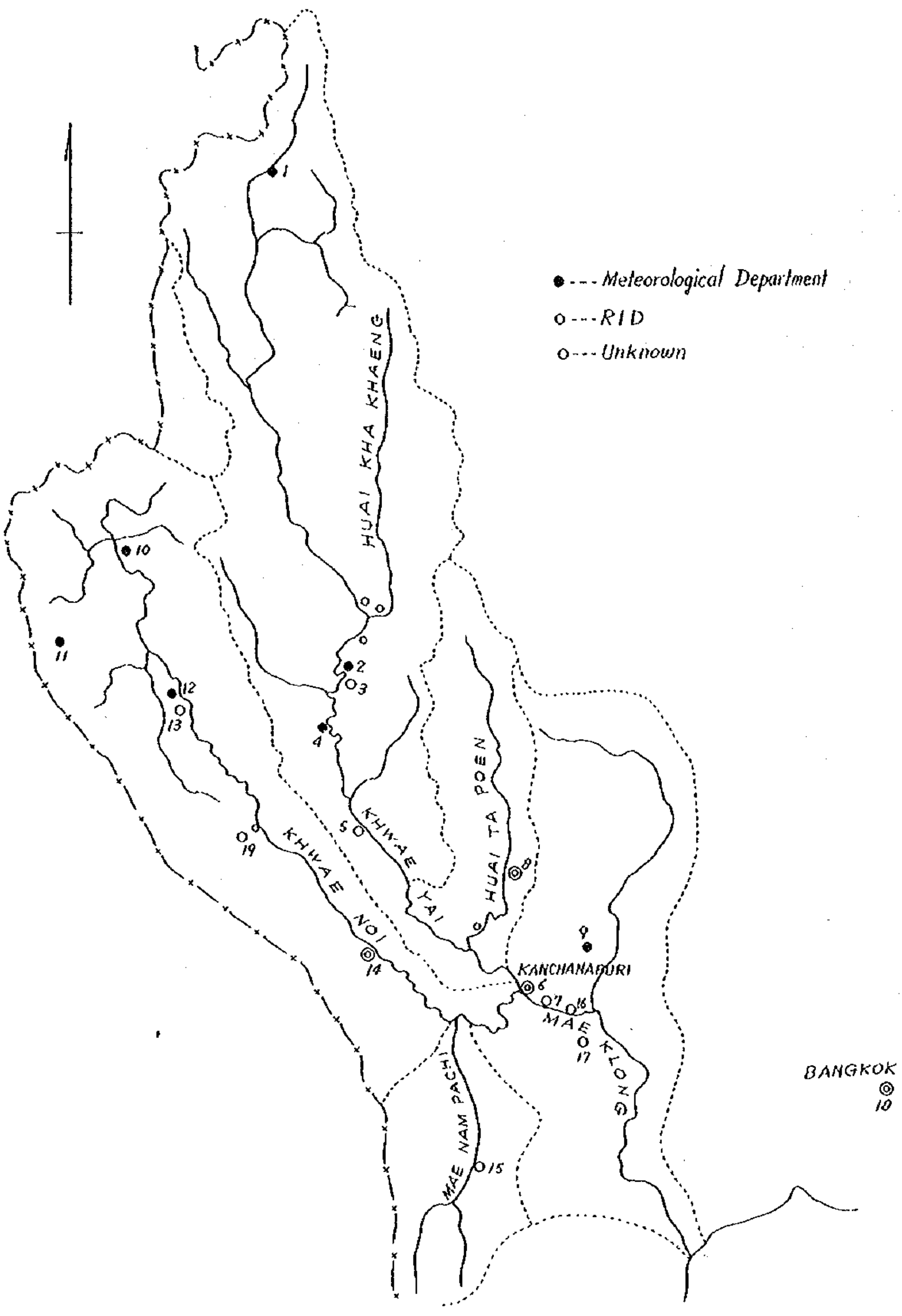


Fig. 3-11 - Locations and Affiliation of Rain Gauge Stations

Table 3-17 - List of Collected Rainfall Data

Upper Column -- Data of TCS
Middle Column -- Data of EGAT (monthly and annual rainfalls)
Lower Column -- Data of EGAT (daily rainfall)

No.	Name of Station	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
1.	Umphang	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O X X	O O O	O O O	O O O	O O O	O O O	O O O	O	O	O					
2	Ban Naswan						O O	O O	O O	O O O	O O O	X O O	O O O	O O O	O O O	O O O	O	O						
3	Ban Naswan K-19																	X	X					
4	Si Sawat				O O	O O	O O	O O	O O	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O	O	O					
5	Kang Rieng K-6	O O	O O	O	O O O	O	O	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O O O	O	X						
6	Kanchanaburi	O O	O O	O	O	O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O	O	O					
7	Kanchanaburi K-8						O	O	O	O	O	X												
8	Bophloi K-12				O	O	O	O	O	O	O	O	O	O	O	O	X	O	X					
9	Panom Tuan	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								
10	Sangkhlaburi	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O X	O O	O O	O O	O	O	O					
11	Pilok								O O	O O	O O	O O	O O	O O	O O	O	O	O	O					
12	Thong Pha Phum	O	O	O O	O O	X X	O O	X X				O O		X X	X X		O	O						
13	Thong Pha Phum K-13														X	X	O	O	O					
14	(Wang Po) Sai Yok K-10				O	O	O	O	O	O	O	O	O	O	X O	X O	O	O	X					
15	Suan Phung K-17															X	O	O	X					
16	Tha Muang	O	O	O	O	O	O	O	O	O	O	O	O	X	X									
17	Tha Maka	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								
18	Bang Kok	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O								

Table 3-18 - List of Water Stage Stations (Existing)

No.	Name of Station	Name of River		Classification	Duration of Observation	Managed by	Zero Point	Remarks
		Main	Tributary					
1	Khao Chod	Khwae Yai	Khwae Yai	staff	1965			
2	Khao Chod	Khwae Yai	Hvai Kha Khaeng	staff	1965			
3	Ongkla (K-19)	Khwae Yai	Khwae Yai	staff	1966	RID		
4	Kang Rieng (K-6)	Khwae Yai	Khwae Yai	staff	1952	RID		
5	Kao Wang Masung (K-20)	Khwae Yai	Khwae Yai	staff	1965	RID		Incompleted Data
6	Lam Ta Phern (K-12)	Khwae Yai	Hvai Ta Poen	staff	1965	RID		
7	Hvai Mae Nam Noi (K-22)	Khwae Noi	Khwae Noi	staff	1966	RID		
8	Wang Po (K-9)	Khwae Noi	Khwae Noi	staff	1962	RID		
9	Lum Sum K-10	Khwae Noi	Khwae Noi	staff	1965			Incomplete Data
10	Kanchanaburi K-8	Mae Klong	Mae Klong	self recording	1957	RID		Distinction between Kanchanaburi and Ban Tham stations not clear
11	Ban Tham	Mae Klong	Mae Klong		1957			
12	Ban Wang Khasai	Mae Klong	Mae Klong		1965			
13	Ban Thong Pha Phum (K-13)	Khwae Noi	Khwae Noi	staff	1965	RID		Incomplete Data
14	K-10	Khwae Noi	Khwae Noi	staff	1965	RID		
15	Ban Suan Phung (K-17)	Khwae Noi	Phachi	staff	1966	RID		
16	K-4					RID		locations unknown
17	K-11					RID		"
18	K-27					RID		"

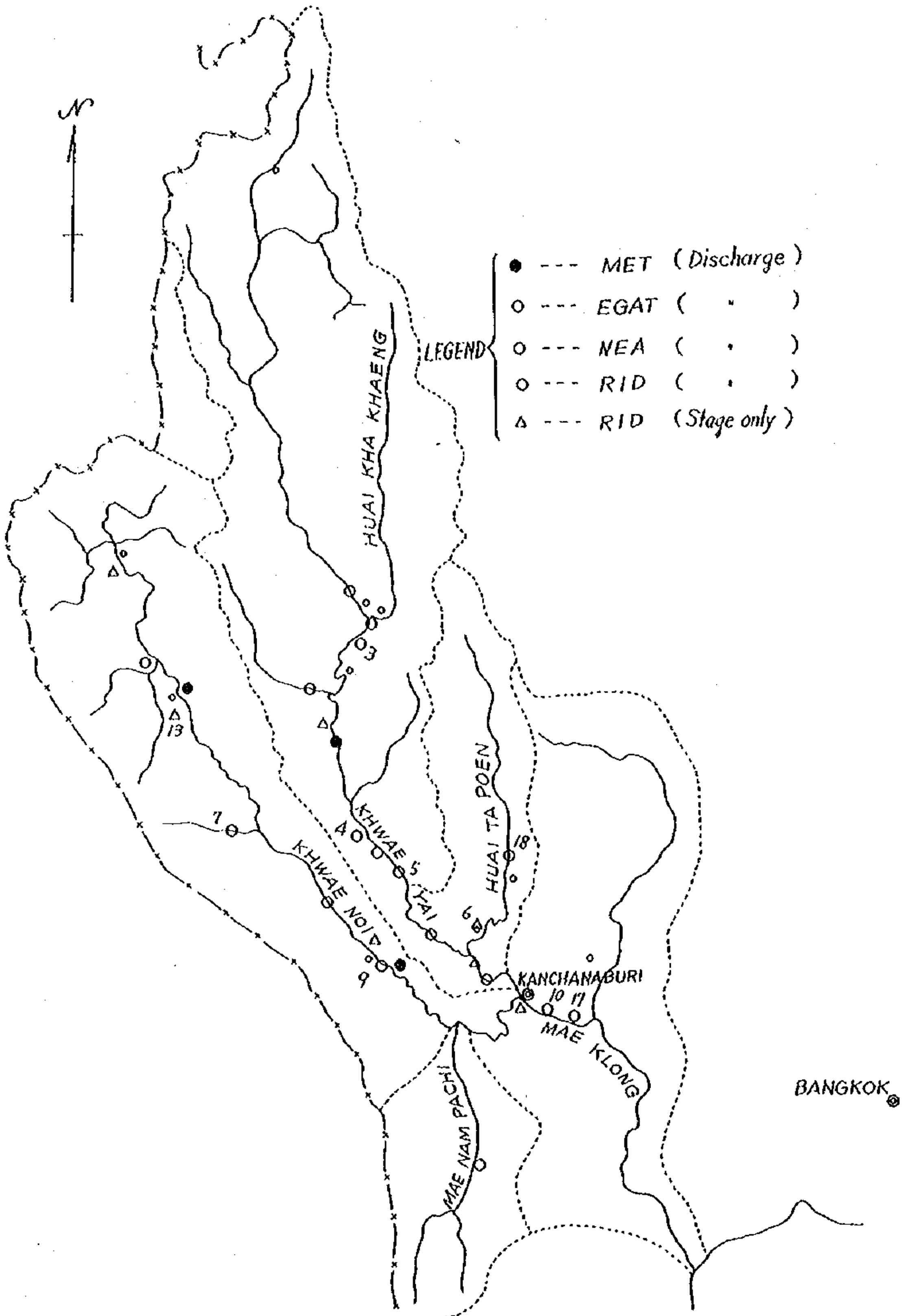


Fig. 3-12 - Locations and Affiliation of Stage and Discharge Stations

Table 3-19 - List of Collected Water Stage Data

Upper column - Data of TCS
Lower column - Data of EGAT

No.	Name of Station	52 and 53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
1	Khao Chod (Main)													O	O								
2	Khao Chod (Tributary)													X	X								
3	Ongkla K-19														O								
4	Kang Rieng K-6	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O O	O	O	O					
5	Kao Wang Masung (K-20)														 O	O							
6	Lam Ta Phern K-12													 X	O	O							
7	Hvai Mae Nam Noi K-22														X O	O							
8	Wang Po K-9										X O	O O	O O	X	O	X	X	X					
9	Lum Sum K-10													O O	O O	O	O	O					
10	Kanchanaburi K-8					O	O	O	O	O	O	O	O	O	O	X	O						
11	Ban Tham					O	O	O	O	O	O	O	O	O	O	X							
12	Ban Wang Khasai													O									
13	Ban Thong Pha Phum (K-13)													X	O	O							
14	K-10																						
15	Ban Suan Phung K-17														O	O							
16	K-4											O	O										
17	K-11													O	O	O	O	O					
18	K-27																X						

3-7 Hydrological and Hydraulic Data Collected in the Survey

Since it is expected that the flood of the Khawe Yai river will be controlled almost perfectly after completion of Ban Chao Nen dam, the data of the areas downstream of the dam were collected, with prime effort directed towards collecting data of the Khwae Noi river.

Due to the great diversity and enormous quantity of past data, the team collected data for the last ten years so as to avoid any confusion that may arise from excessive collection.

Collected data and the locations of stations from which they were obtained are shown in the following tables and maps.

Table 3-20 Collected Hydraulic Data

O ...... Complete Φ ...... Incomplete

No.	Name of Rivwe	Name of Station	Code	Data of Daily Water Stage and Discharge											Data of Hourly Water Stage				
				Observation period before 1964	65	66	67	68	69	70	71	72	73	74	69 Jul.	69 Aug.	72 Jul.	74 Aug.	74 Oct.
1	Mae Klong	Wat Tha Khlong	K2A			(Stage only)	O	O	Φ	Φ	O	O	O	O					
2	〃	Ratchaburi	K2	62~64	O	O	(Stage only)												
3	〃	Wang Khanai	K11		O	O	O	O	O	O	O	O	O	O	O	O	Measurement made every three hours O	O	O
4	Khwae Yai	Khao Wang Masang	K20			O	O	O	O	O	O	O	O	O	O	O	O	O	O
5	〃	Kaeng Rieng	K6	53~64	O	O	O	O	O	O	O	O							
6	(〃 Tributary) Lam Taphoen	Ban Wang Yai	K27					O	O	O	O	O	O	O				O	O
7	Khwae Noi	Ban Lum Sum	K10		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
8	〃	Ban Tha Khanun	K13		Φ	O	O	O	O	O	O	O	O	O	O	⊙	O	O	O
9	(〃 Tributary) Hvai Mae Nam Na'	Tambou Tha Thung Na Ban Sai Yok	K22A						O	O	O	O	O	O	O	O	O	O	O
10	(〃) 〃	Ban Sai Yok Ban Tha Thung Na Noi	K22			O	O	O											
11	(〃 Tributary) Lam Phachi	Frontier Police Station	K17			O	O	O	O	O	O	O	O	O	O	O	O	O	O

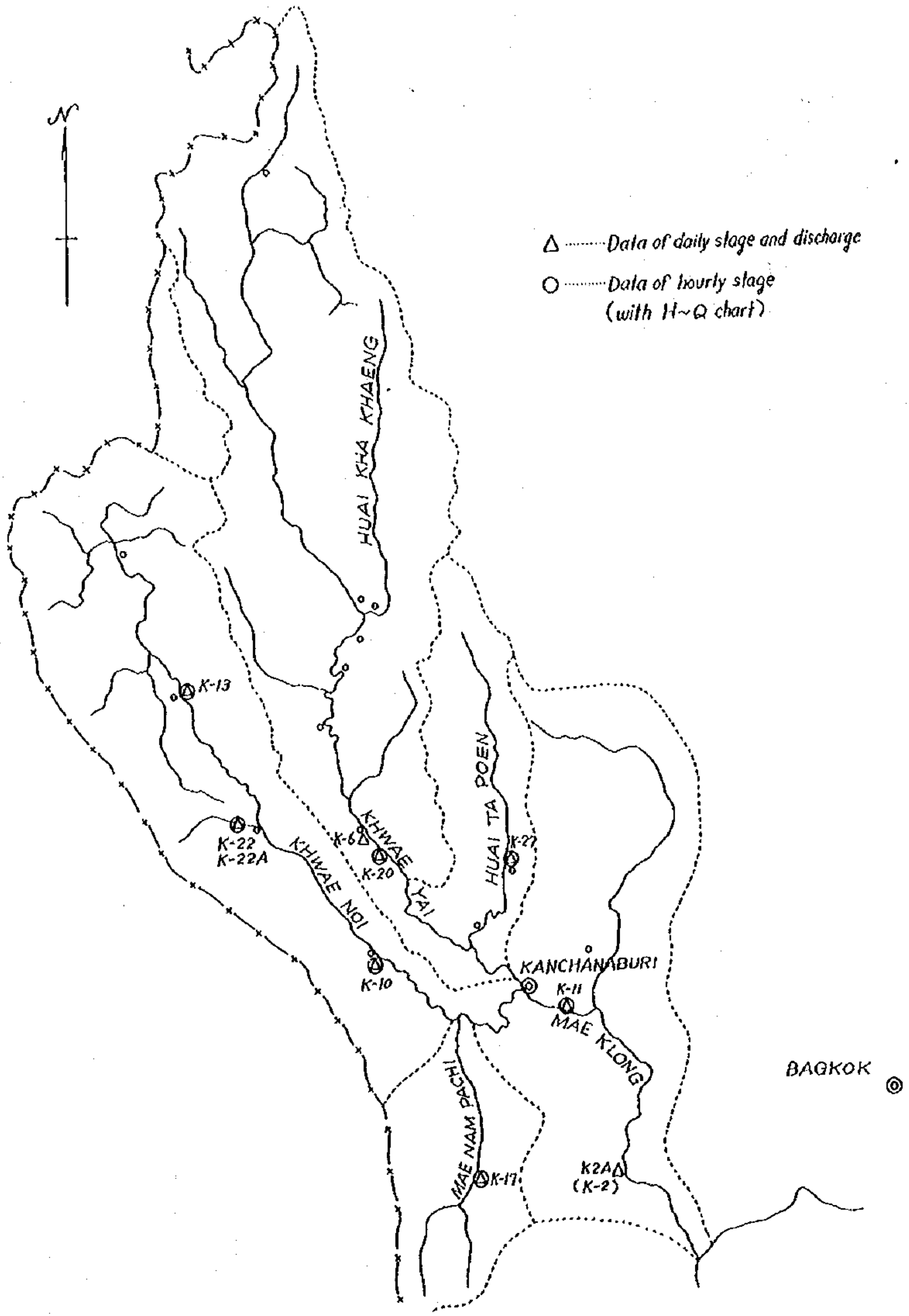


Fig. 3-13-1 - Locations of Stations Providing Hydraulic Data

Table 3-21 - Collected Rainfall Data

○ ...... Complete ⦶ ...... Incomplete – ...... No observation made

Name of River Basin	Name of Station (Code)	Daily Rainfall Data																							Hourly rainfall data	
		52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	72 Sep.–Oct.	74 Jul.–Sep.
Khwae Noi	Sangkhlaburi (13063)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	Pilok Tin Mine (13092)					○	⦶	–	○	○	○	○	○	○	○	○	○			○	○	○	○	○		
	Ban Pa Tho (13152)															⦶	⦶	○	⦶	○	⦶	○	○	○		
	Thong Pha Phum (13053)	○	○	○	○	⦶	○	⦶	–	–	–	○	–	⦶	⦶	–	○	○	○	○	○	○	○	○	○	
	Lin Thin (13142)															⦶	○	○	○	○	○	○	○	○		
	Hvai Mae Nam Noi (K-22, 13221)															⦶	○	○	○	○	○	○	○	○		
	Lum Sum (K-10, 13211)														⦶	○	○	○	○	○	○	○	○	○		
Khwae Yai	Wang Masung (K-20, 13281)																		○	○	○	○	○	○		

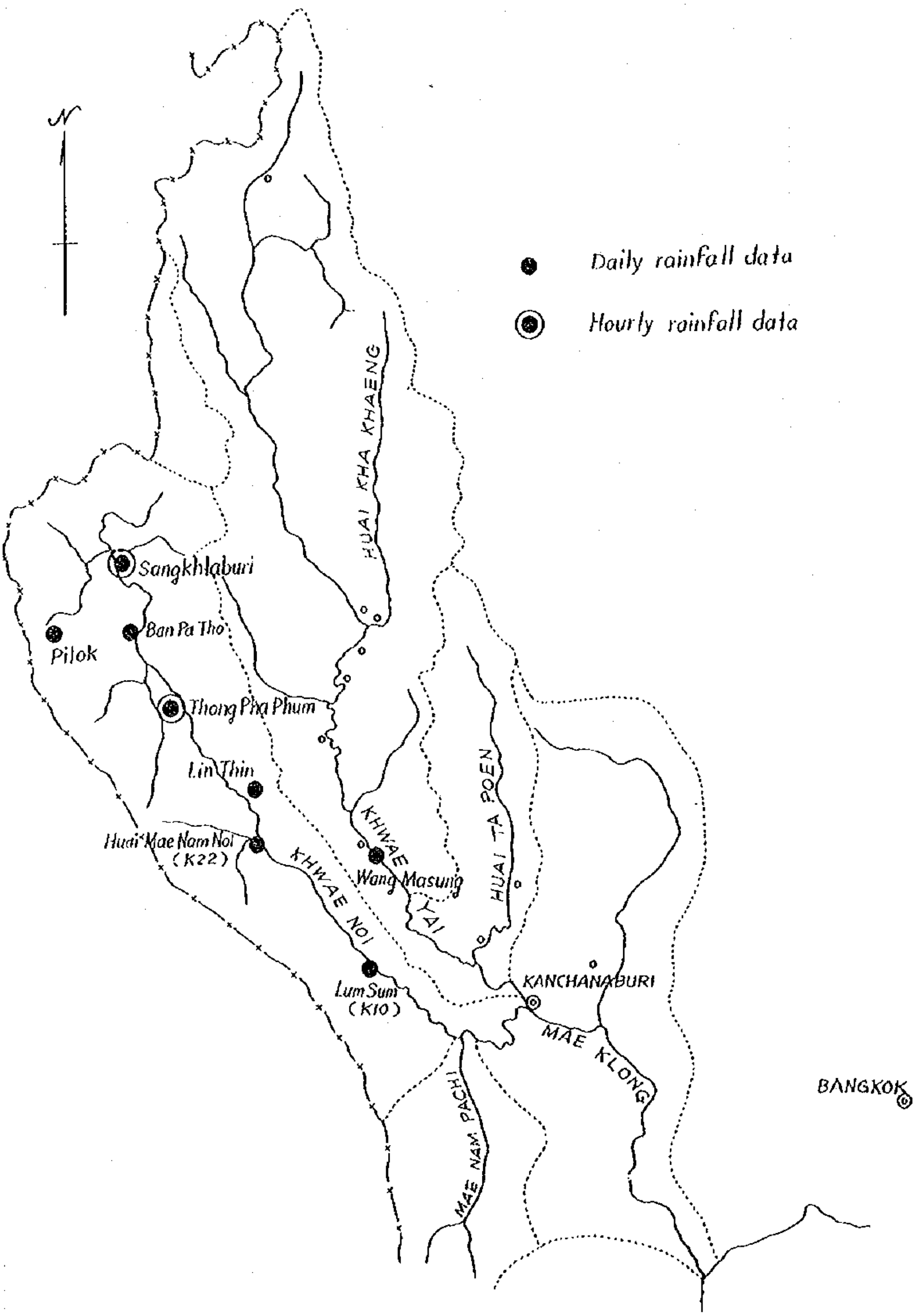


Fig. 3-13-2 - Locations of Stations Providing Rainfall Data

3-8 Existing State of Communication Facilities

(1) General Condition

- o SSB radio telephone is very widely used so that new frequency allocation entails substantial difficulty.
- o Introduction of VHF is planned by many stations. Frequency allocation is realtively easy because VHF is hardly used at present except for military purposes.
- o In mountainous areas where the avilability of commercial power source is often limited, introduction of solar battery is advisable.
- o Shortage of communication engineers is observed. SSB radio telephones are mostly operated by female operators.
- o Annual number of thunder-bolts in the Maeklong basin is 63 (recorded at Kanchanaburi during the 1951 - 1970 period).

(2) Communication Facilities of the Meteorological Department

- o Existing telecommunication network is as illustrated in Fig. 3-14-1.

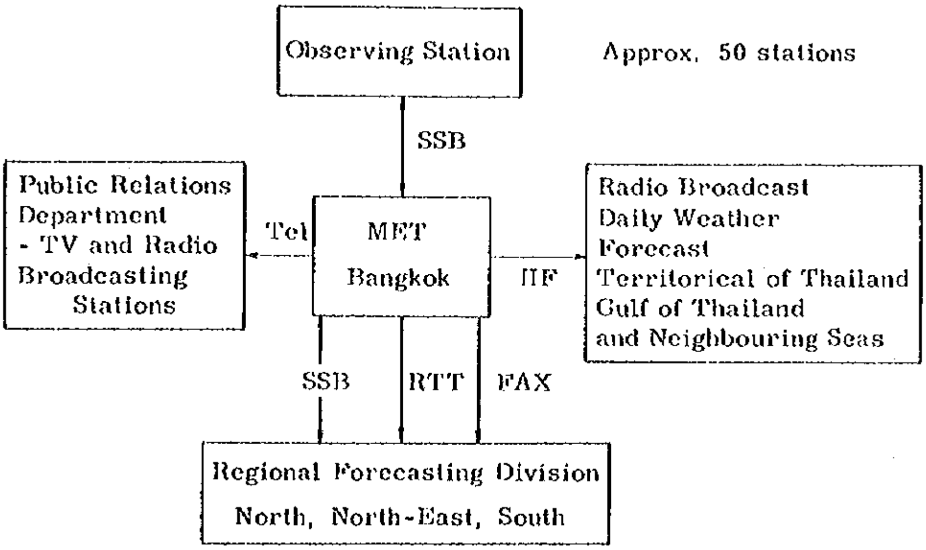


Fig. 3-14-1 - Existing Telecommunication Network

- o Local observing stations, numbering about 50, are linked with MET Bangkok by the SSB network.
- o SSB is also used to link the three Regional Forecasting Divisions (North, Northeast and South) with MET Bangkok.
- o TV and radio broadcasting stations are connected with MET Bangkok by telephone line to broadcast weather forecast covering the Thai territory, Gulf of Siam and neighbouring seas (short wave).

- Thong Pha Phum station in the Macklong basin is equipped with an SSB set which is used for fixed time communication with MET Bangkok. When the propagation condition is not favourable, Chumphon station in the south is used for relaying. This set is a 1967 product of Motrola using four frequencies, i.e., 6550, 6660, 8070 and 8660 KHz.

  Thong Pha Phum station is not constantly supplied by electricity. A 2 KVA isolated diesel power plant is used to supply electricity from the sunset to 23:00 hrs for lighting and telecommunication.
- A telemetering system consisting of one control station and three reporting stations (maker: Japan Radio Co., Ltd.) is established in the Ping river basin in the upstream area of the Chao Phray, with Chieng Mai station serving as control station. Fig. 3-14-2 shows the outline of this telemetering system.

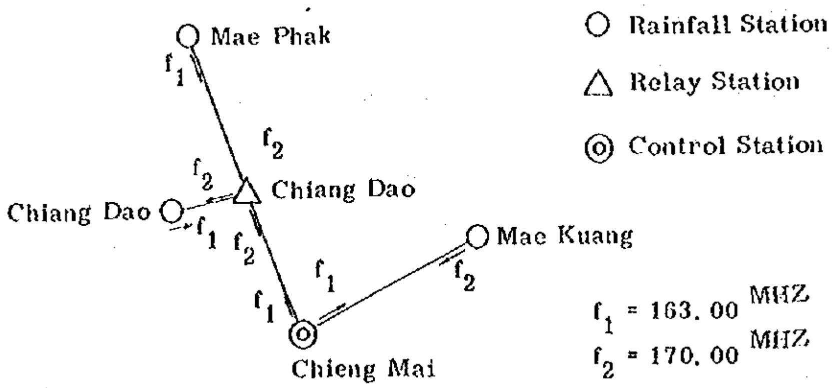


Fig. 3-14-2 - Schematic Drawing of Chieng Mai Telemetering Network

Equipment used in this system are identical in design to the standard equipment designated by the Japanese Ministry of Construction.

(3) Communication Facilities of the Royal Irrigation Department

- RID has an SSB network connected with its local offices. The network is composed of eight local bases and has a total of 169 SSB sets.
- An RID base is established at Kanchanaburi, which is linked with RID Bangkok by VHF.
- 26 frequencies are used for SSB communication and six for VHF communication. For communication between Bangkok and Kanchanaburi, 136 MHz is used.
- Portable SSB set can be installed at major water stage stations including K_{10} located along the Khwae Noi whenever it becomes necessary to establish a communication circuit with RID Bangkok.
- RID Bangkok has five SSB sets and one VHF set (for communication with Kanchanaburi) which are set up in their respective operation boxes and operated by exclusive operators for communication with local stations.

- o RID has a total of about 600 mechanics and operators distributed to respective local offices. RID Bangkok is staffed by about 30 personnel engaged in communication with these local offices. Automatic telemetering system is not introduced yet.

3-9 Survey of Dam Sites on the Maeklong

The Maeklong is known as a river system in the mountainous area abounding in water volume. In order to make effective use of its abundant water volume, dam construction is planned at various places besides Ban Chao Nen dam on the Khwae Yai river which is now under construction. Proposed dam sites include the two in the upstream section of the Khwae Yai, the one on the Huai Ta Poen which is a tributary of the Khwae Yai, and the four on the Khwae Noi.

Survey of these dam sites is conducted chiefly by EGAT for electric power development. However, since downstream dams are planned to be also used for irrigation, RID is carrying survey of their sites.

Upstream area of the Khwae Yai is very sparsely populated and difficult of access due to the lack of roads. These drawbacks are also observed in the upstream area of the Khwae Noi. In addition, the whole Maeklong basin is geologically composed of limestone, and this poses a serious problem in the construction of dams.

It must also be noted that the Ban Chao Nen dam programme has not yet entered the stage of full-scale construction and is likely to face the financial problem.

From these facts, it can be readily imagined that it will take a considerably long period of time for all the planned dams to be completed.

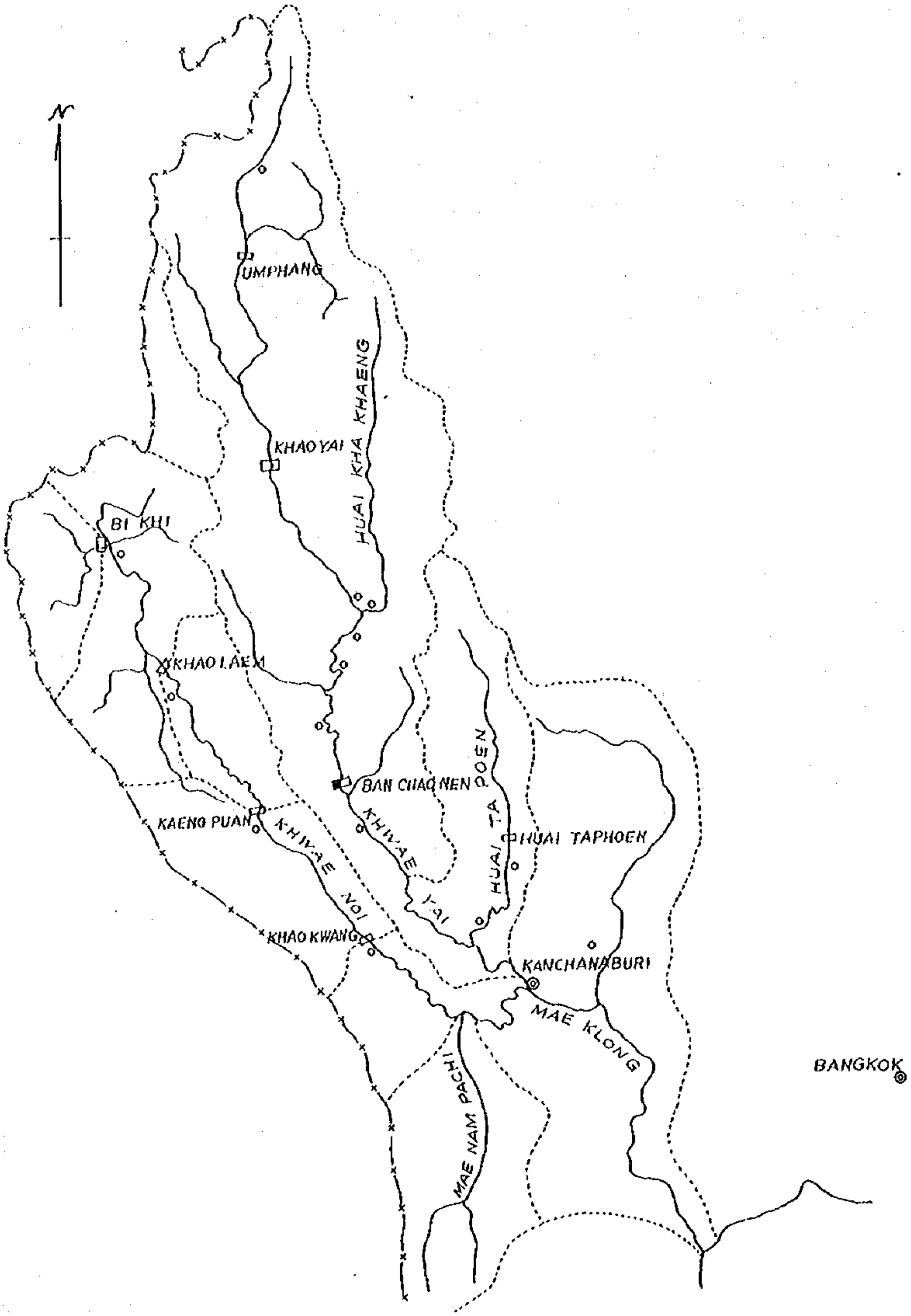


Fig. 3-15 - Proposed Dam Sites on the Maeklong River

CHAPTER IV. ANALYSIS OF THE FLOOD FORECASTING SYSTEM

4-1 Past Progress of Activities for Establishing a Flood Forecasting System

(1) Proposal of ECAFE/WMO Preparatory Mission on Typhoons

Background

In pursuance of the recommendation made at the meeting of the Working Group of Experts on typhoons in Manila, 1965, the ECAFE and WMO jointly organized an expert mission comprising of three members namely Dr. F. W. Reichelderfer as the team leader, Dr. S. N. Sen as Synoptic Meteorologist and Dr. T. Takenouchi as Hydrologist and Flood Control Expert.

One of the objective of the mission was to select a key river basin for establishment of a pilot flood forecasting and warning system in each of the typhoon - affected countries including Thailand. The mission visited Thailand during February - March 1967 and, as a result of the exchange of views with the Thai officials concerned, selected the Maeklong river basin for that purpose. Further, on the basis of the information obtained and data readily available during the visit, the mission proposed a simple flood forecasting scheme indicating a tentative network system together with equipment, personnel and other requirements for its implementation (vide publication 1 under Reference).

(2) Development of Pilot Flood Forecasting in the Basin

(Proposal of a method for flood forecasting by TCS)

Background

The ECAFE/WMO Joint Unit on Typhoons (later designated as TCS) was actively engaged in developing a comprehensive plan for a pilot flood forecasting for the Maeklong river basin in collaboration with the Meteorological Department and the Royal Irrigation Department of Thailand. As for the basis for planning a flood forecasting sheeme, the Joint Unit carried out an extensive hydrological study with a view to evolving an appropriate flood forecasting method for the basin.

Considering the availability of rainfall and streamflow data, the study was based on data for the period from 1962 to 1966. It was found that flood forecasting one day in advance for K_8 (Kanchanaburi) would be practicable on the basis of a stage correlation between K_8 and K_9 or K_{10} on the Khwae Noi and between K_8 and K_6 on the Khwae Yai. Further, it was revealed that the runoff at K_9 or K_{10} and K_6 could be estimated from rainfall data of each catchment area and thereby two to three days forecasting time could be obtained if desired.

The results of the study is summarized in the following paragraphs (vide Note 2 under Reference).

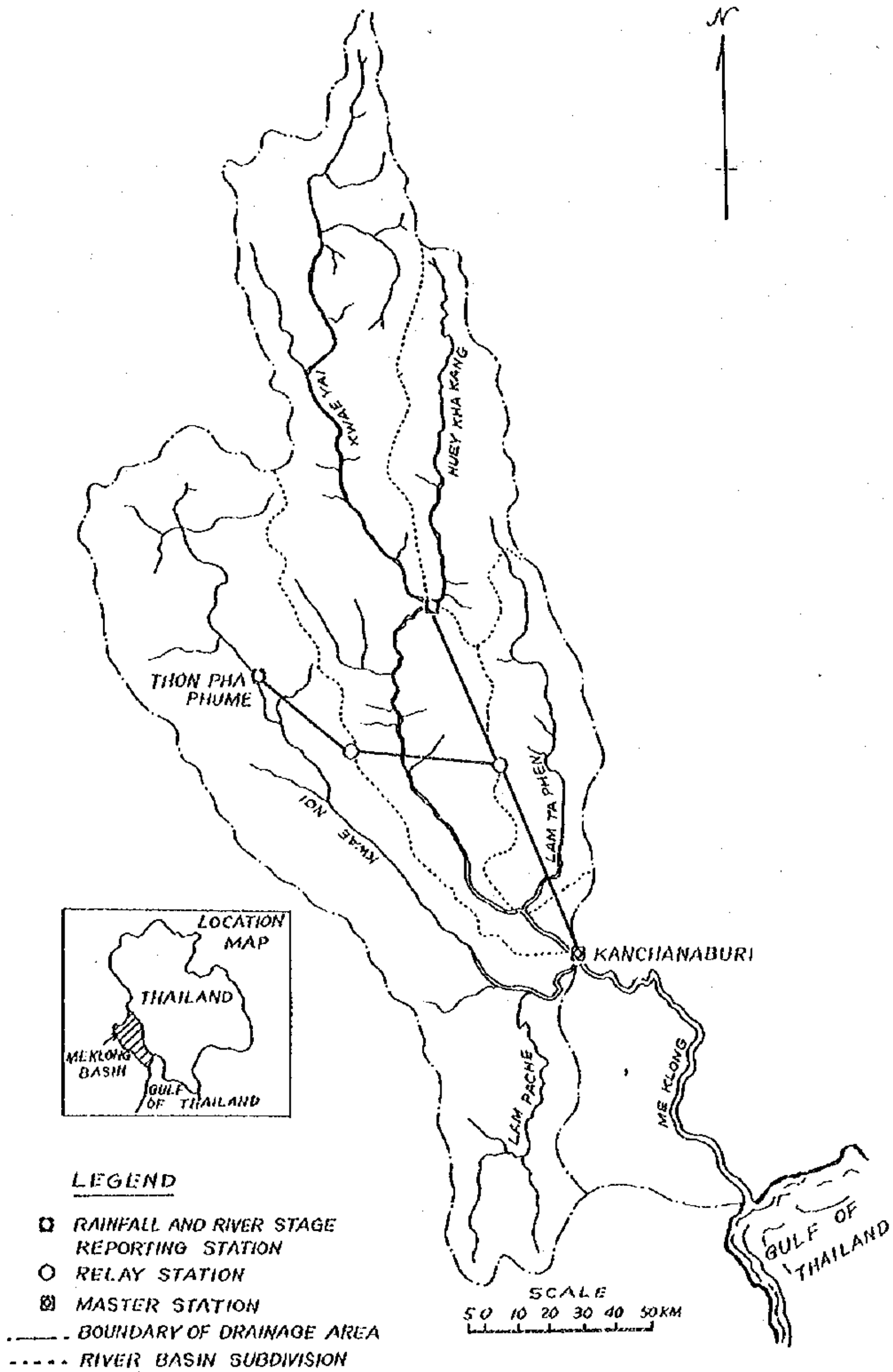


Fig. 4-1 - Flood Forecasting Scheme for the Maeklong Riber Basin Proposed by ECAFE/WMO Preparatory Mission on Typhoons

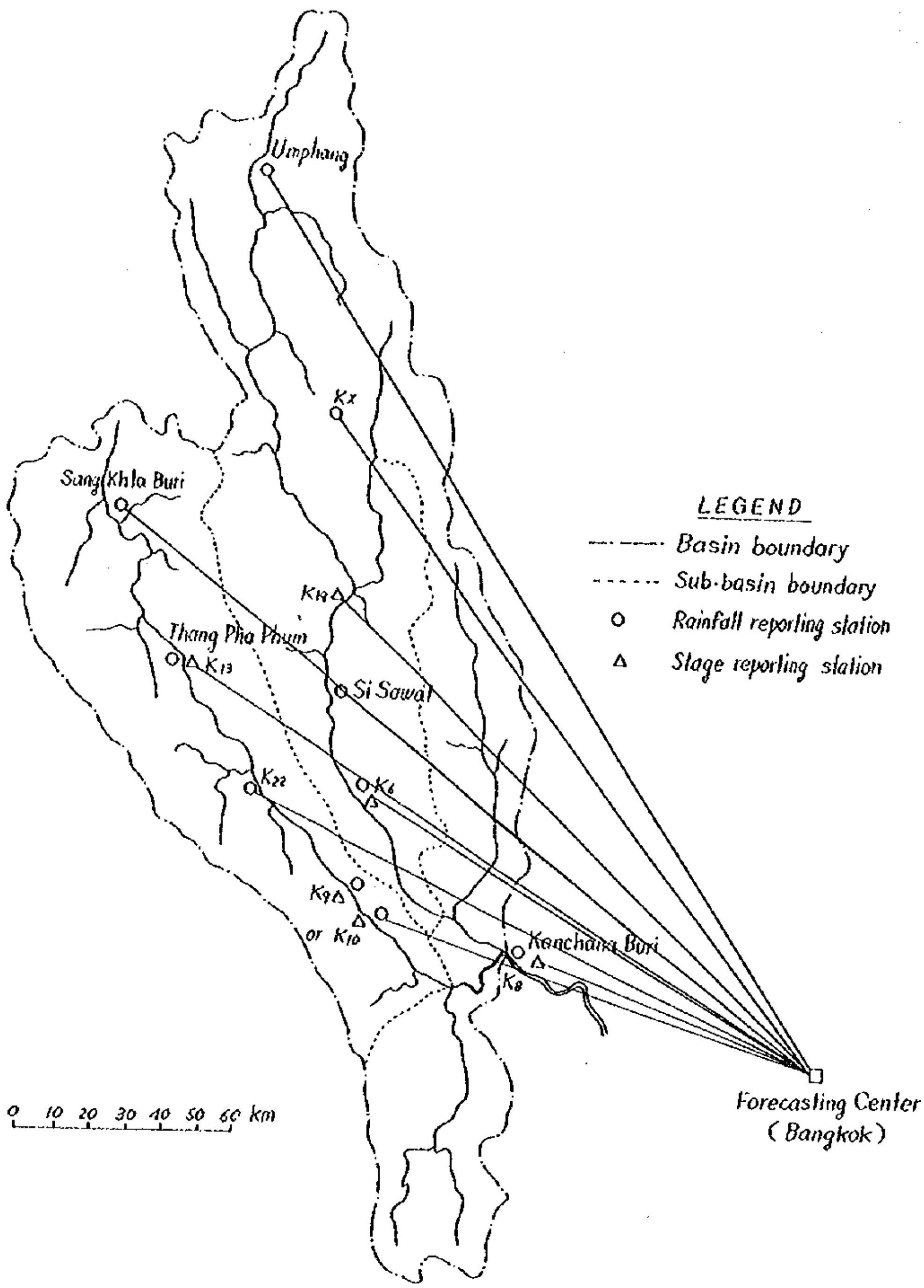


Fig. 4-2 - Maeklong River Basin and Proposed Flood Forecasting System

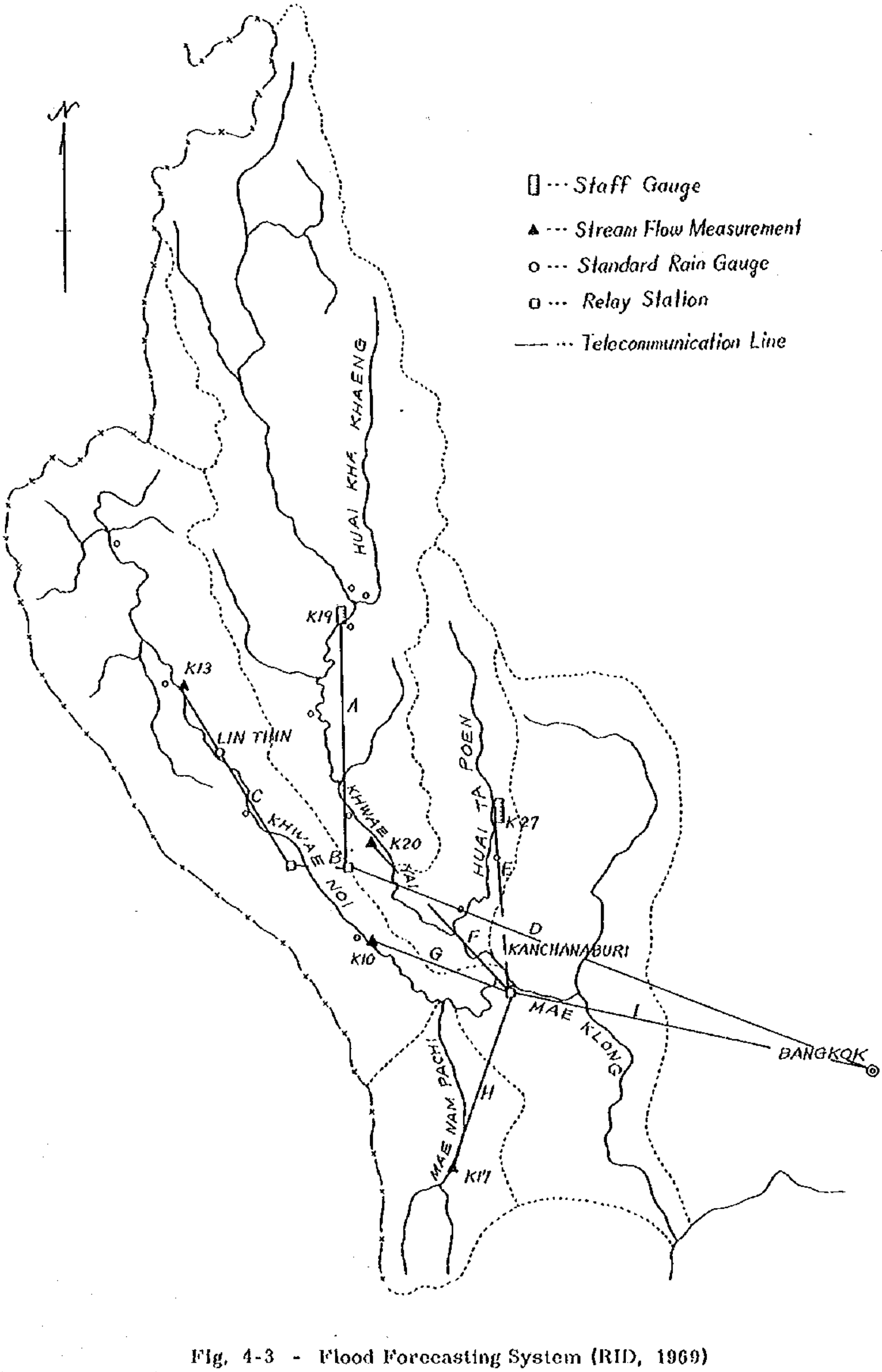


Fig. 4-3 - Flood Forecasting System (RID, 1969)

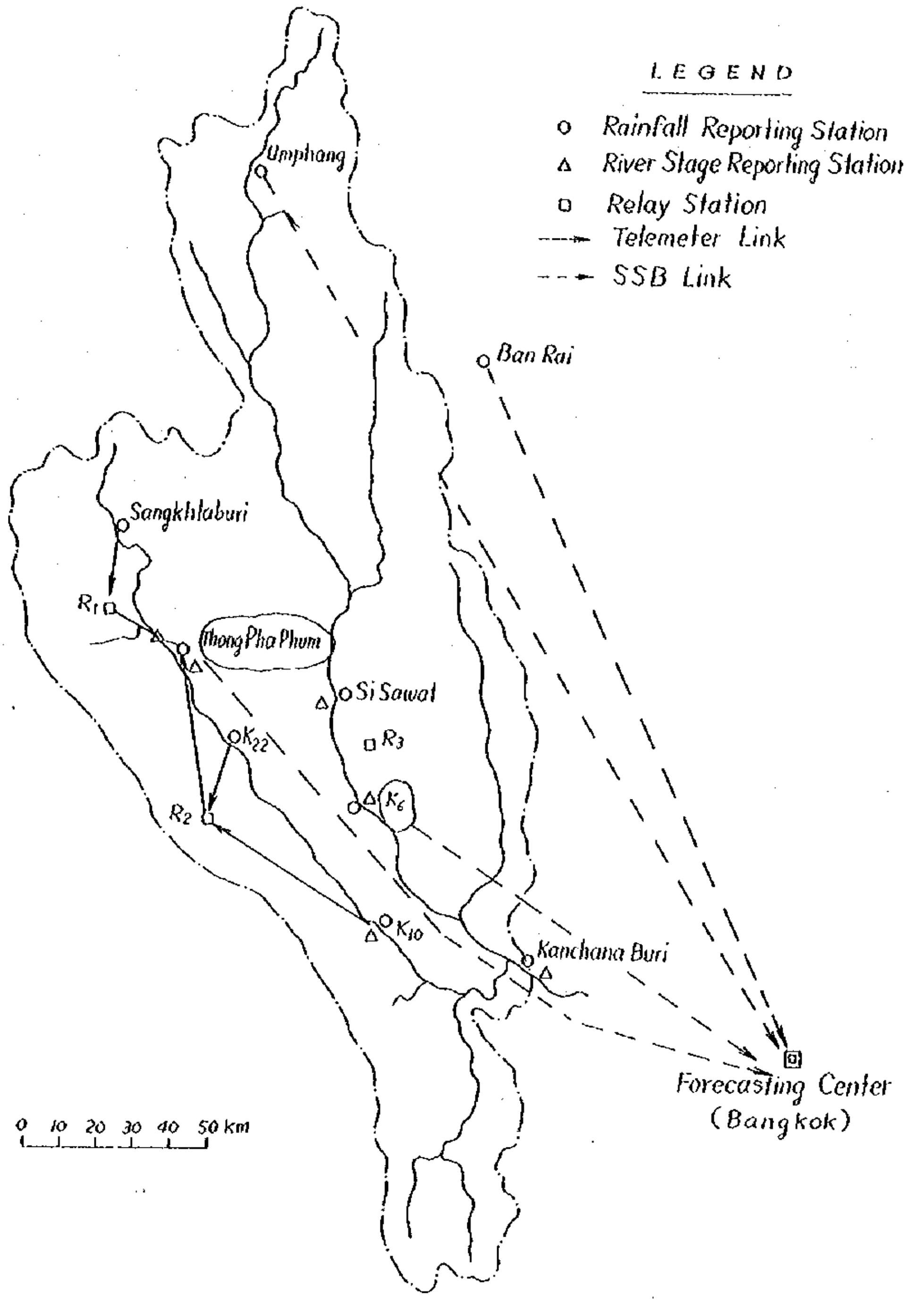


Fig. 4-4 - Flood Forecasting Network Proposed by TCS in Connection with Draft Request to UNDP

(3) Study on the Meteorological Conditions Associated with Floods

A preliminary study of the meteorological conditions associated with past floods in Macklong river basin was carried out by the ECAFE/WMO Joint Unit on Typhoon in 1970 in collaboration with the Meteorological Department of Thailand. Because of limited data available at that time, more detailed analysis could not be undertakên. However, the preliminary study revealed several important features and the need for such study in planning a flood forecasting system. The result of this preliminary study was summarized in a Note entitled "A Note on Meteorological Conditions Associated with Floods in Mae Klong river basin (Thailand)" which is reproduced in the Appendix attached to this Note.

(4) Network Proposed in Connection with the Draft Request to UNDP

In connection with the preparation of a draft request to UNDP for assistance in 1972, TCS had planned to include as UNDP input the cost of equipment needed for the implementation of the Maeklong river forecasting system. However, because of the limited fund expected for such equipment, an attempt was made to draw up a simple network, so that cost of equipment would not exceed US$100, 000. The following criteria were accordingly considered for drawing up the forecasting network.

1) Reporting stations should be selected from existing ones as much as possible (avoid new station in remote areas).
2) SSB radio telephone should be used wherever possible.
3) Telemetering equipment may be considered for a limited number of stations in remote or uninhabited areas.
4) Forecasting center should be located in Bangkok.

After consultation with the Departments concerned, the network shown in Fig. 4 was drawn up. Type of stations and cost of the equipment as estimated in 1972 under this scheme are shown in Table 1 below:

Table 4-1 - Estimated Construction Cost

Location	Type of Station	Cost of US$
(Telemetering station)		
Thong Pha Phum	Collection centre	20,000
Sangkhla Buri	Rainfall	7,000
K_{22}	Rainfall	7,000
K_{10}	Rainfall and Stage	10,000
R_1	Relay	10,000
R_2	Relay	10,000
K_6	Collection centre	10,000
Si Sawat	Rainfall and stage	10,000
R_3	Relay	10,000
	Total	94,000
(SSB Station)		
Thong Pha Phum	Collection centre & rainfall	1,500
Umphang	Rainfall	1,500
K_6	Collection centre & rainfall	1,500
Banrai	Rainfall	1,500
	Total	6,000

(Total)

94,000 + 6,000 = 100,000

(5) Trial Flood Forecasting

There had been 17 river gauging stations in the Maeklong river basin and about 50 rain gauging stations in and around the basin when the Maeklong was selected for the establishment of a pilot flood forecasting system in 1968. Pending the establishment of a comprehensive flood forecasting system, it was thought worthwhile undertaking trial flood forecasting on the basis of the method proposed by the ECAFE/WMO Joint Unit (described under section 2 of the Note). For this purpose arrangement was made for collection of data at Bangkok from selected stations by suitable communication facilities.

The government of Thailand has made continuous effort to establish communication links between Bangkok and selected stations. During the flood season in every year since 1969, the Meteorological Department has set up and maintained data transmission by SSB radio telephone from selected rain gauging stations. The Royal

Irrigation Department also provided similar arrangement for the transmission of data from selected river gauging stations. Existing telecommunication circuits of other organizations were utilized in case of some remote stations. By these arrangements, all the data of daily rainfall and river stage were transmitted to Bangkok and eventually gathered at the Meteorological Department and the Royal Irrigation Department. The network has been gradually improved in the recent years and by 1973, it included seven stations as shown in Table 2.

The target of the trial flood forecasting was to estimate primarily the peak stage or discharged and its time of occurence at K_8 station near Kanchanaburi. The Meteorological Department mainly applied the method proposed by the Typhoon Committee Secretariat in calculating the forecast discharge at K_8 from the basin rainfall computed on the basis of the rainfall data transmitted by the temporary communication system. The Royal Irrigation Department applied mainly a stage correlation between the upstream stations and K_8.

The result of the trial operation of the flood forecasting was not always satisfactory owing to the following reasons.

1) Inadequate distribution of raingauging stations.
2) Irregular and/or delayed data transmission through the telecommunication circuits which belong to the organizations other than the Meteorological and Royal Irrigation Departments.
3) Inconsistent reporting of data by the voluntary observers engaged in some gauging stations.
4) Breakdown of the telecommunication equipment.

It should however be pointed out that the officials engaged in the trial forecasting accumulated their experience and knowledge that would be utilized in the establishment and operation of the comprehensive flood forecasting system in the future. A comprehensive report on the trial flood forecasting (Trial Flood Forecasting in Mae Klong River by Dr. Wiroj Sangvares and Mr. Amon Chantanavivate, Meteorological Department Bangkok, Thailand, November 1973) was prepared and distributed by the Thai delegation at the 6th session of Typhoon Committee in 1973.

Table 4-2 - Reporting Stations Included in the Trial Flood Forecasting System for the Maeklong River

Name of station	Data observed	Department by which communication is provided
Thong Pha Phum	R and S	Meteorological Department
Sangkh la Buri	R and S	Meteorological Department
K_{10}	R and S	Royal Irrigation Department
K_{20}	R and S	Royal Irrigation Department
Umphang	R	Local Administration Department
Si Sawat	R	Local Administration Department
Pilok	R	Department of Mineral Resources

(Note) R: Rainfall
S: River Stage

(6) Case study of past floods

Background

Pending the establishment of a new flood forecasting system in the Maeklong river basin, it was proposed by TCS to undertake case study of past floods by applying the method of flood forecasting as developed by TCS. The study was undertaken with the following purposes in view:

1) To examine the fitness of the proposed method, which was developed on the basis of the data obtained mainly during 1962 - 1966, with the data obtained in recent years, and to improve the method as necessary.
2) To examine the adequacy of the proposed network of reporting stations and consider improvements as necessary.
3) To offer an opportunity for the concerning Thai officials to familiarize with the calculation and other procedures included in the operation of the proposed method.

The study was undertaken by the Meteorological Department and the Royal Irrigation Department in consultation with TCS. The Meteorological Department completed two trial computations of runoff at K_6, K_{10} and K_8 stations for 1971 and 1972. Whereas, the Royal Irrigation Department concentrated its effort on the Kwae Noi and complated three trial computations of runoff at K_{10} for seven (7) years from 1967 to 1973. The work by both Departments are summarized in the following paragraphs.

References

① Report of the ESCAP/WMO Preparatory Mission on Typhoon: WMO-RP. TC. 11, ECAFE-WRDP/TYPM/1. May 1967.

② Development of Pilot Flood Forecasting in Maeklong River Basin in Thailand (a preliminary report by the ECAFE/WMO Joint Unit on Typhoons), November 1970.

③ Trial Flood Forecasting in Maeklong River by Dr. Wiroj Sanvaree and Mr. Amon Chantanavivate, Meteorological Department, Bangkok, Thailand, November 1973.

④ The Maeklong Pilot Flood Forecasting: Case Study on Past Flood of the Kwae Noi (Second Revision, 1974): Royal Irrigation Department.

4-2 Analysis of the Flood Forecasting System

4-2-1 Target Area and Target Point of Flood Forecasting

The target area of flood forecasting for the Maeklong river basin can be delineated clearly without any difficulty for the following reason.

The area upstream of Kanchanaburi is hilly, thinly populated and devoid of any districts where flood could become a knotty problem, whereas the area extending down-stream of the confluence is an important granary of the country and embraces cities like Ban Pong, Rat Buri and Samut Songkhlam along rivers where the population is concentrated and heavy floods poses a serious social problem.

Thus, it is justifable to designate the flooded area downstream of Kanchanaburi as the target area of flood forecasting.

As regards the target point at which floods are to be forecast, selection must be made with account taken of the need for classifying floods by scale.

For the upstream area which is prone to be inundated by heavy floods, it will suffice to forecast the discharge at Vajiralongkorn headwork because of its proximity, provided that the correlation between discharge and overflow depth at this point can be made clear.

For the vicinities of Rat Buri where damages are caused even by relatively small floods, it will be necessary to forecast the water stage at Bang Pong and Rat Buri.

Accordingly, it will be necessary to include Vajiralongkorn headwork and Rat Buri in the selected target points, and it is preferable to add Ban Pong and Photharm as target points for water stage forecasting.

4-2-2 Pattern of Flood Occurrence and Discharge Correlation

When the discharge at K_{11} reaches 2,300 m^3/s, flood water overflows the deservoir on the left bank and causes a large inundation. However, since this is preceded by small scale inundation, attention must be directed to discharges larger than 2,000 m^3/s at K_{11}.

During the 13 year period from 1962 to 1974, there occurred 14 floods all recording discharges larger than 2,000 m^3/s at K_{11}. Of these 14 floods, four are considered to have been caused by the Khwae Yai, eight by the Khwae Noi, and the remaining two by the combined discharges of the two tributaries.

Between K_{20} and K_{11}, there flows a large tributary, the Huai Ta Poen, but its discharge is very small and its influence upon the Khwae Yai is negligible. Between K_{10} and K_{11}, there also flows a large tributary, the Mae Nam Phachi, but its influence on the Khwae Noi can be disregarded because of the Large time lag of the flood season and the small flood discharge.

It follows, therefore, that the flood discharge at K_{11} is determined by that at K_{20} and K_{10}.

Ban Chao Nen dam now under construction on the Khwae Yai at a point upstream of K_{20} is expected to exhibit an almost complete flood control capacity upon its completion. This means that the discharge relationship between K_{10} and K_{11} on the Khwae Noi bears closely upon the inundation of the Maeklong basin. Fig. 4-5 showing the discharge correlation between $K_{20} + K_{10}$ and K_{11} indicates that there can be expected 10 to 20% of gradual discharge decrease in between. However, when the relationship between K_{10} and K_{11} is reexamined on the basis of the above correlation chart with the said gradual decrease taken into consideration, it becomes clear that in no cases will the discharges at K_{10} and K_{11} become almost equivalent, and that the peak discharge at K_{11} is caused by the Khwae Yai even when the discharge of the Khwae Noi is dominant.

Assuming that the discharge at K_{10} alone need to be considered and that there could be a gradual decrease of discharge, the discharge at K_{11} increases to the dangerous degree every two or three years (as actually recorded in 1963, 1966, 1969, 1972 and 1974).

This means that even after completion of Ban Chao Nen dam, inundation of the area downstream of K_{11} cannot be eliminated and there will still be great need for flood forecasting. Further, the influence of the Khwae Yai on the peak flood discharge at K_{11} can never be disregarded and it is necessary to pay careful attention to the run-off condition of the Khwae Noi before discharging water from Ban Chao Nen dam.

The above discussion leads to the conclusion that the flood forecasting system for the Maeklong basin should be established with particular emphasis placed on the basin of the Khwae Yai downstream of Ban Chao Nen dam and on the entire basin of the Khwae Noi.

Planning of a forecasting system meeting the above requirements will be largely facilitated by Figs. 4-5 and 4-6 which show the good flood discharge correlation between $K_{20} + K_{10}$ and K_{11}, good correlation between flood discharges at K_{10} and K_{11} which are relatively less subject to the influence of the Khwae Yai, and good correlation between K_{13} and K_{10}.

Table 4-3 - Comparison of Peak Discharge (1)

(Unit: m^3/s)

Year	Month and Day		K6 or K20	K10	K6 or K20 + K10	K11	Difference
			(K6)				
62	8	8	615	1,872	2,487	○ ● 2,321	166
	9	22	2,749	1,982	4,728	△ ● 3,416	1,312
63	8	14	742	2,157	2,899	○ ● 2,218	681
	10	5	2,114	1,250	3,364	△ ● 2,939	425
64	9	27	1,409	1,354	2,763	⊙ ● 2,251	512
65	6	22	431	1,643	2,074	○ 1,799	275
	7	30	791	1,811	2,602	○ 1,811	791
			(K20)				
	10	1	340	658	998	○ 1,107	-109
66	8	1	522	1,352	1,874	○ 1,604	270
	9	14	766	2,263	3,029	○ ● 2,209	820
	9	22	577	538	1,115	○ 1,100	15
67	8	11	347	1,239	1,586	○ 1,354	232
	8	22	615	1,680	2,295	○ 1,852	443
	9	5	566	1,257	1,823	○ 1,551	272
	10	5	559	727	1,286	⊙ 1,168	118
68	8	18	627	1,106	1,733	○ 1,492	241
	9	17	324	879	1,207	○ 1,175	32
69	8	14	1,084	2,375	3,459	○ ● 2,841	618
	9	24	861	964	1,825	⊙ 1,584	241
	10	5	659	635	1,294	⊙ 1,195	99
70	7	19	411	1,182	1,593	○ 1,362	231
	8	27	470	625	1,095	⊙ 1,117	-22
71	7	29	876	1,896	2,772	○ ● 2,367	405
72	7	19	654	3,067	3,721	○ ● 2,990	831
	8	2	679	1,709	2,388	○ ● 2,367	21
	8	22	484	887	1,371	○ 1,308	63
	9	10	* 69H-Q 1,300	1,041	2,341	⊙ ● 2,142	199
	9	21	* 69H-Q 1,900	850	2,750	△ ● 2,355	395
73	6	21	590	1,762	2,352	○ 1,982	370
	8	29	594	1,465	2,059	○ 1,780	279
	9	26	900	872	1,772	⊙ 1,626	146
74	8	21	1,131	3,294	4,425	○ ● 3,561	864
	10	14	* 74H-Q 2,500	696	3,196	△ ● 2,904	292

○ K10 ≫ K20　　⊙ K10 ≒ K20　　△ K10 ≪ K20　　● K11 ≫ 2,000

Table 4-4 - Comparison of Peak Discharge (2)

(Unit: m^3/s)

Year	Month and Day		K6	K13	K27	K17	K22
62	9	22	2,746	–			
63	10	5	2,114	–			
64	9	27	1,409	–			
65	6	22	431	–			
	7	30	791	–			
	10	1	340	560			
66	8	1	513	1,566		5	101
	9	14	780	* 74H-Q 2,600		6	97
	9	22	588	482		3	23
67	8	11	351	1,262		7	75
	8	22	597	2,099		40	87
	9	5	563	1,534		6	68
	10	5	551	717		18	21
68	8	18	618	1,088	0	5	48
	9	17	329	904	0	1	27
69	8	14	1,079	2,211	0	7	166
	9	24	787	930	3	21	38
	10	5	630	551	7	9	27
70	7	19	398	1,168	0	29	117
	8	27	456	619	0	2	25
71	7	29	832	1,887	0	21	100
72	7	19	687	2,860	0	5	193
	8	2	753	1,536	0	13	118
	8	22	534	793	0	5	59
	9	10	1,368	732	6	9	115
	9	21	2,287	759	22	9	46
73	6	21	–	1,846	1	43	135
	8	29	–	1,310	0	9	79
	9	26	–	716	2	36	–
74	8	21	–	3,068	1	69	321
	10	14	–	407	139	160	42

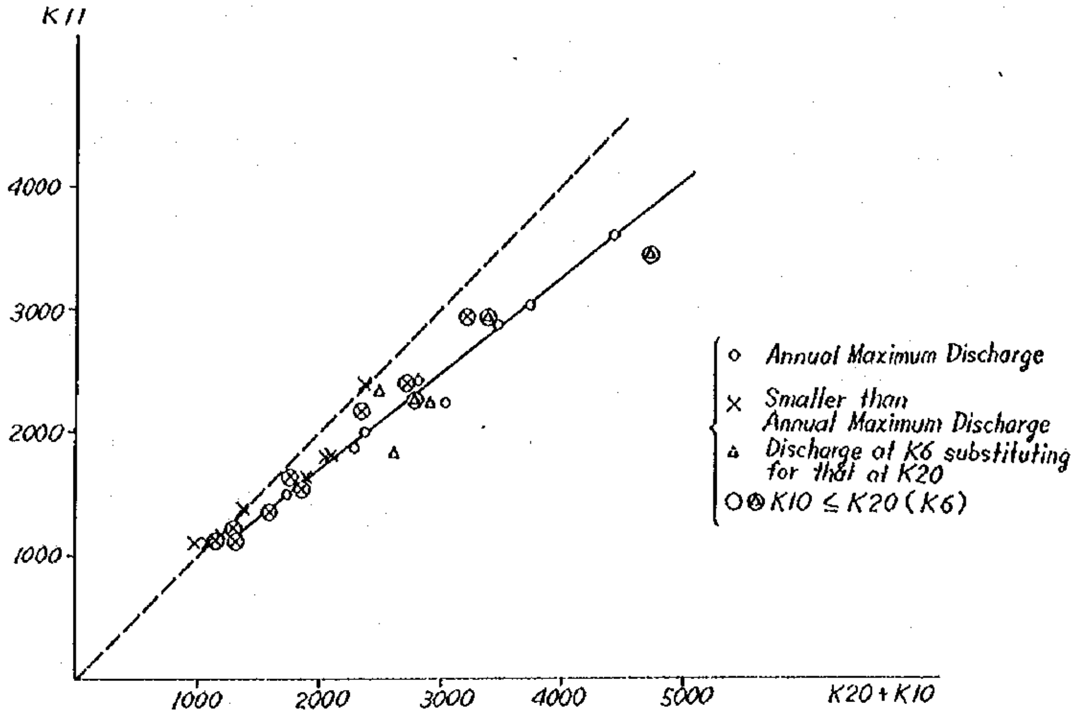
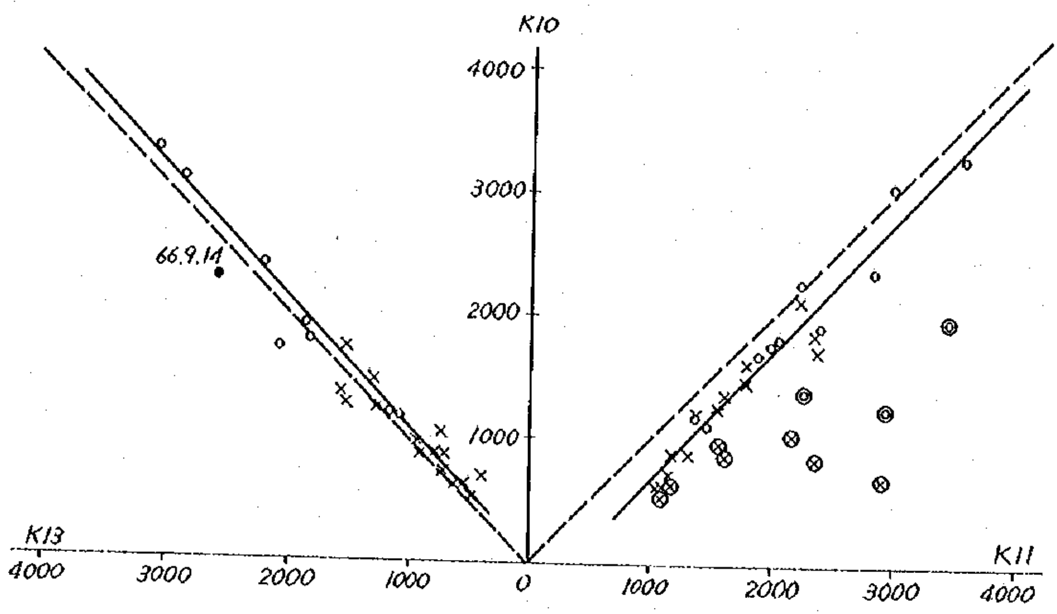


Fig. 4-5 - Discharge Correlation Chart (1)



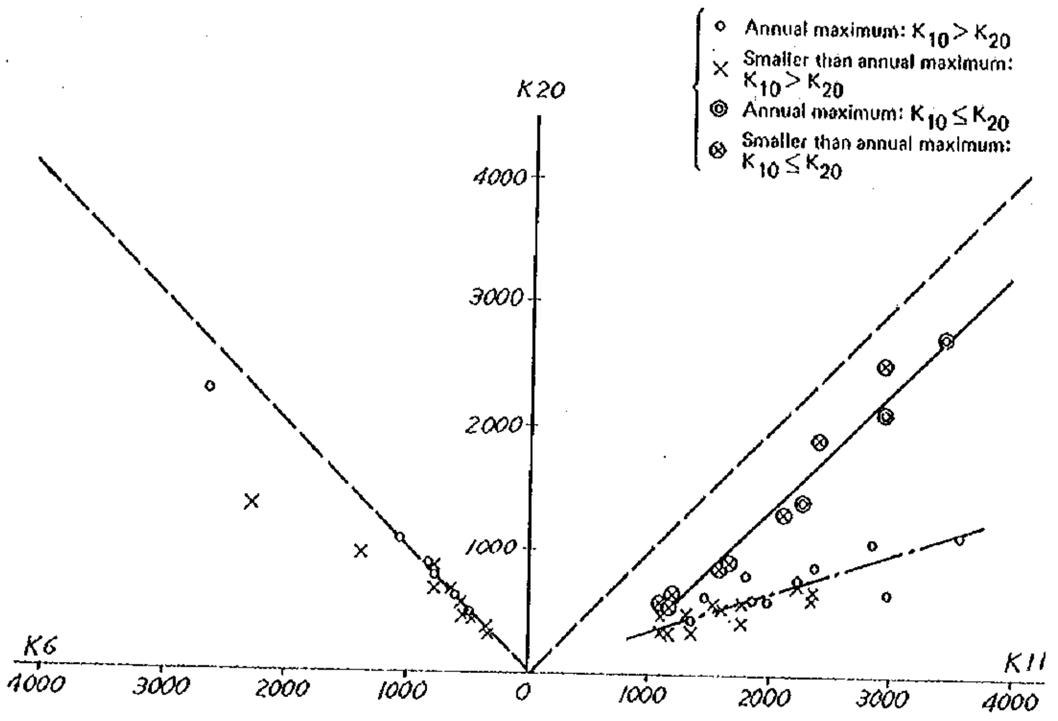


Fig. 4-6 - Discharge Correlation Chart (2)

4-2-3 Propagation and Duration of Flood

Propagation of flood wave of the Khwae Noi from K_{13} to K_{10} and from K_{10} to K_{11} and that of the Khwae Noi from K_{20} to K_{11} were picked up from the flood record for ten years from 1965 to 1974 which contained the time of occurrence of peak flood level. The results are shownin Table 4-5. Although there were a few dubious values, it was found that the propagation ranges from 40 to 48 hours and averages 2 days between K_{13} and K_{10}, ranges from 20 to 40 hours and averages 30 hours between K_{10} and K_{11}, and averages about one day between K_{20} and K_{11}.

Completion of Ban Chao Nen dam will make it possible to stabilize the discharge at K_{20} to a substatial extent. Hence, considering the good discharge correlation between K_{13} and K_{10} and between $K_{10} + K_{20}$ and K_{11}, it seems that fairly accurate flood forecasting two days in advance is practicable by the observation made at these stations alone.

However, the above discussion holds true only in the case where the propagation of flood wave is considered without regard to the duration of flood which is another very important factor of flood forecasting. Study of this factor discloses the following facts.

As is clear in Figs. 4-7 - 4-11 showing discharge curves, the flood discharge at K_{11} maintains itself close to the peak value for a long time, and this can be deduced in some degree only after the temporal transition of discharge is observed at K_{10} and K_{20}, so that forecasting can be made only one day or so in advance. If the peak flood and its duration are to be forecast by estimating the change in discharge, then forecasting calculations must be worked out in some way or other.

Table 4-5 - Propagation of Flood Wave

Year	Month and Day	K13 → K10	K10 → K11	K20 → K11	Remarks
1965	Jul. 30		18 hrs (18 hrs)		
66	Sept. 14	2 days (48 hrs)	1 day and 12 hrs (36 hrs)		
67	Aug. 22	1 day and 21 hrs (45 hrs)	1 day and 15 hrs (39 hrs)		
68	Aug. 18	1 day and 19 hrs (43 hrs)	1 day and 6 hrs (30 hrs)		
69	Aug. 14	1 day and 17 hrs (41 hrs)	(uncollect)	1 day and 6 hrs (30 hrs) 1 day (24 hrs)	double peak
70	Jul. 19	1 day and 19 hrs (43 hrs)	23 hrs (23 hrs)		
71	Jul. 29	1 day and 22 hrs (46 hrs)	23 hrs (23 hrs)		
72	Jul. 19	2 days and 19 hrs (67 hrs)	2 days and 6 hrs (54 hrs)		Calculation of Average propagation from K10 to K11 was omitted
73	Jun. 21	1 day and 15 hrs (39 hrs)	1 day and 3 hrs (27 hrs)		
74	Aug. 21	2 days (48 hrs)	1 day and 18 hrs (42 hrs)	1 day (24 hrs)	
* Note 2 〃	Oct. 14		1 day (24 hrs)	1 day (24 hrs)	
Average		1 day and 23 hrs (47 hrs)	1 day and 5 hrs (29 hrs)	1 day and 2 hrs (26 hrs)	

Notes: 1. Date indicates the time when the peak discharge was recorded.

2. All values indicate the propagation at the peak discharge subjected to relatively small influence of the Khwae Yai except that measured on October 14, 1974 when the Khwae Yai's flood discharge was dominant.

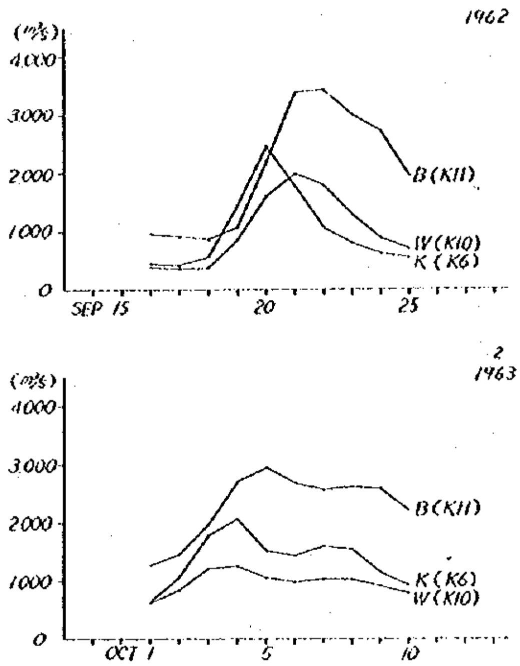


Fig. 4-7 - Discharge Transition (1)

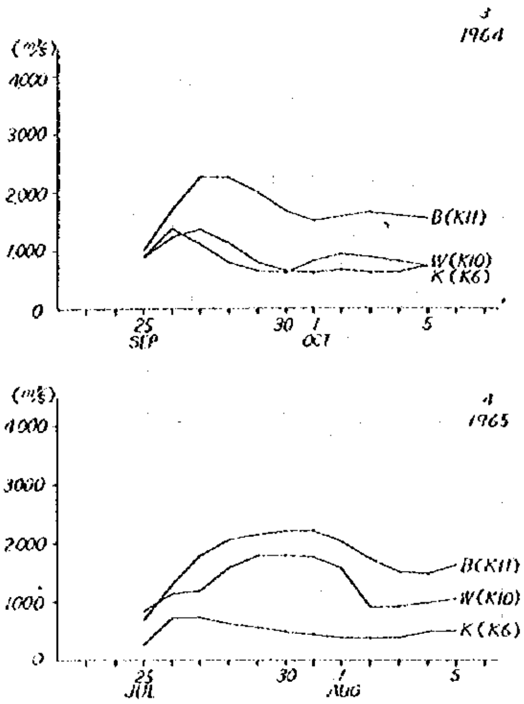


Fig. 4-8 - Discharge Transition (2)

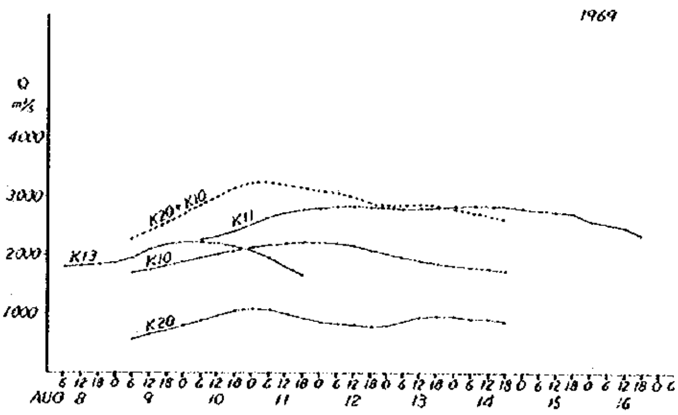


Fig. 4-9 - Discharge Transition (3)

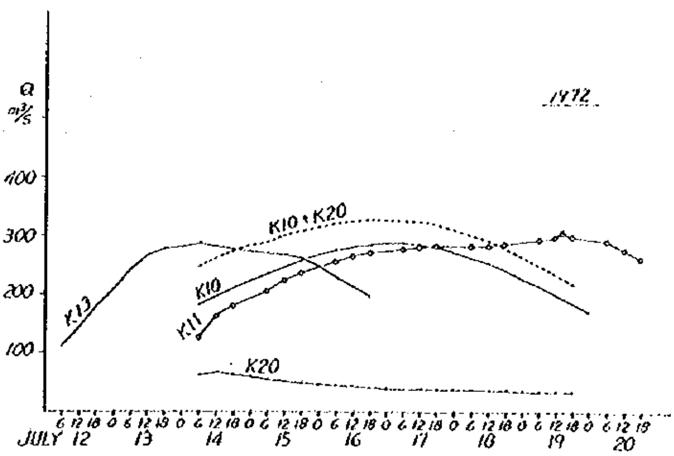


Fig. 4-10 - Discharge Transition (4)

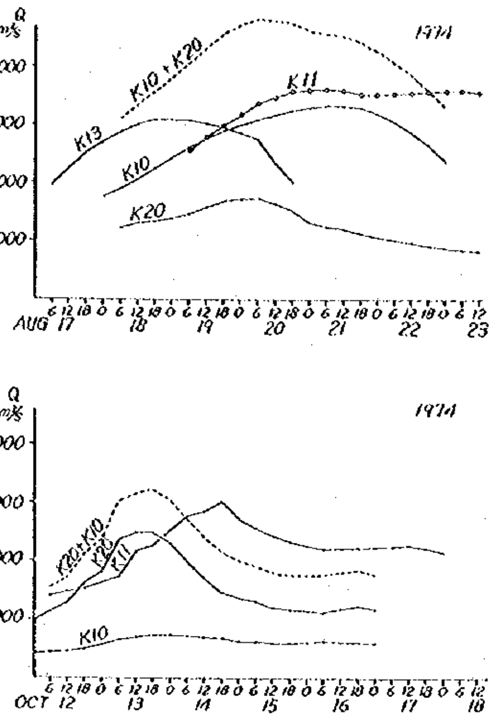


Fig. 4-11 - Discharge Transition (5)

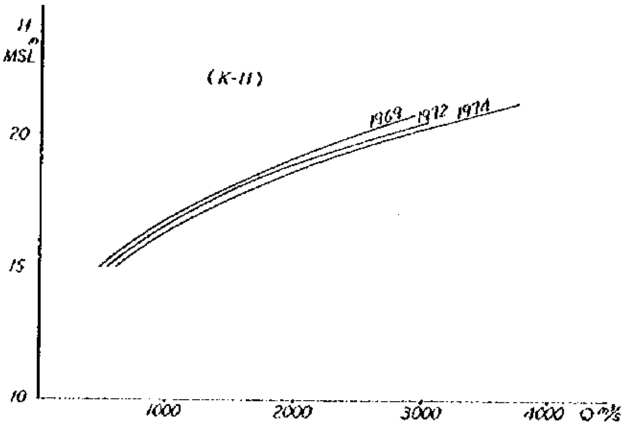


Fig. 4-12 - Stage-Discharge Curve (1)

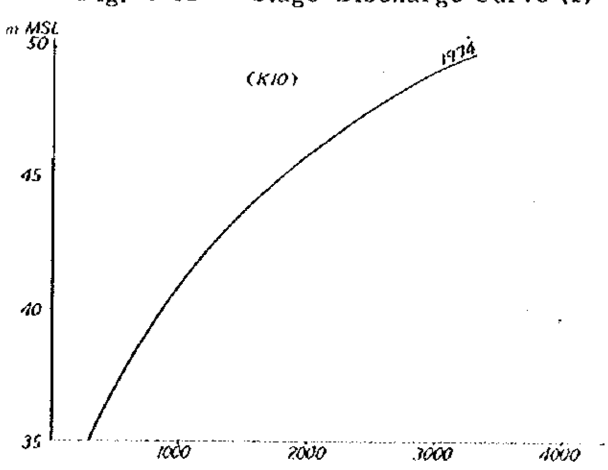


Fig. 4-13 - Stage-Discharge Curve (2)

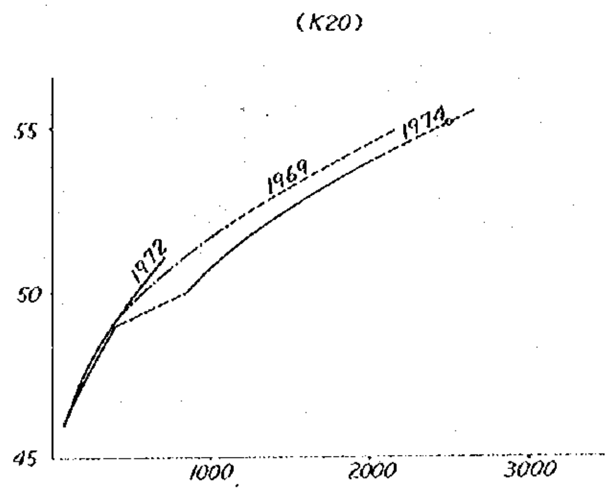


Fig. 4-14 - Stage-Discharge Curve (3)

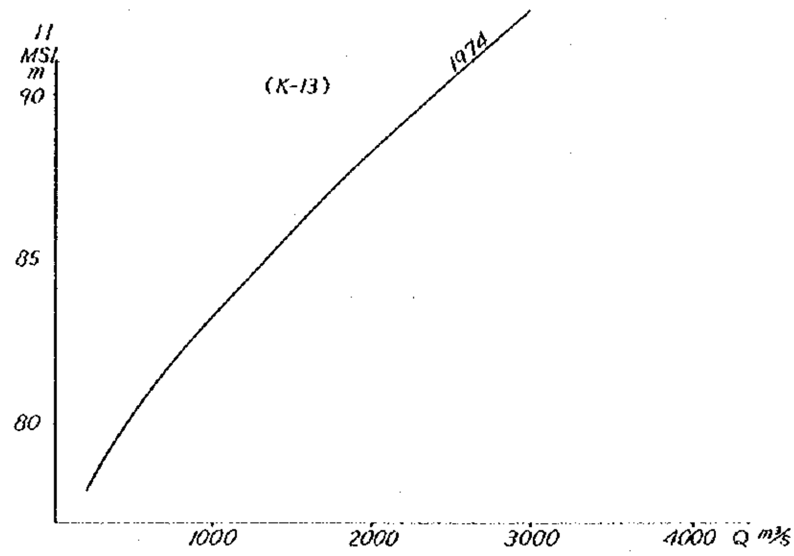


Fig. 4-15 - Stage-Discharge Curve (4)

4-2-4 Outline of Calculation Method Adopted for Flood Forecasting

The method proposed by the Hydrologist of the ECAFE/WMO Joint Unit on Typhoon (Mr. Mizuno) in November 1970 is adopted by both the Meteorological Department and the Royal Irrigation Department with improvements effected to it.

Both departments employ the unit hydrograph prepared from the daily rainfall data so that the flow of calculations is bascially the same. However, improvements have been made in the method of obtaining the base-flow discharge and effective rainfall as well as in the method of separating the direct run-off and interflow.

Fig. 4-16 is the flow chart of calculations. Details of the calculation method are described in the following data.

1) Development of Pilot Flood Forecasting in Maeklong River Basin in Thailand, November 1970.
2) Trial Flood Forecasting in Maeklong River, Dr. Wrij Sangvaree, Meteorological Department, November 1973.
3) The Development of Pilot Flood Forecasting in the Maeklong River Basin, Hydrological Section, RID, 1974.

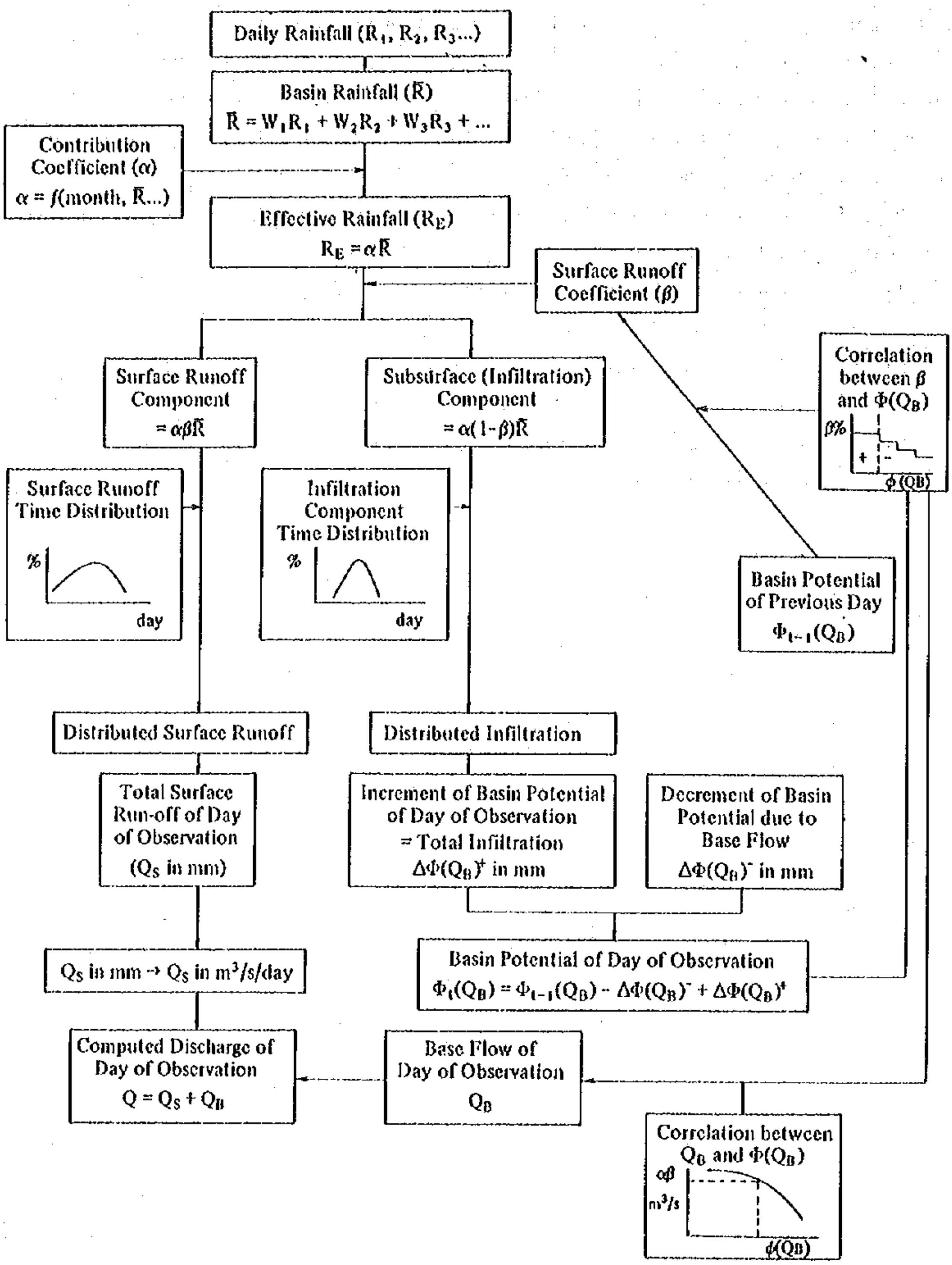


Fig. 4-16 - Flow Chart of Run-off Analysis of the Maeklong

The following description was quoted from the above reports to deal in some more detail with the observation system.

The Meteorological Departments adopts the system proposed by Mr. Mizuno, in which the Khwae Noi and the Khwae Yai are aligned with the following stations established for forecasting calculation.

The Khwae Noi : Rain gauge station (Sangkhla Buri, Thong Pha Phum, K_{22})
Stage and discharge station (K_{10})

The Khwae Yai : Rain gauge stations (Umphang, Si Sawat, K_6)
Stage and discharge station (K_6)

The Maeklong : Stage and discharge station (K_8)

Discharges at K_{13} (Khwae Noi) and K_{19} (Khwae Yai) are used as reference data, and rainfall data at K_{10}, K_x and Kanchanaburi are incorporated in the forecasting procedure. Relationships between respective stations are shown in Fig. 4-17

The Royal Irrigation Department attaches weight to the Khwae Noi, and forecasts the stage and discharge at K_{10} using the rainfall data at eight stations (Sankhla Buri, Pilok, Ban Pa Tho, Thong Pha Phum, Ban Lin Thin, K_{22}, K_{20} ((located outside the basin)) and Lum Sun ((K_{10}))). Location of these stations are shown in Fig. 4-18.

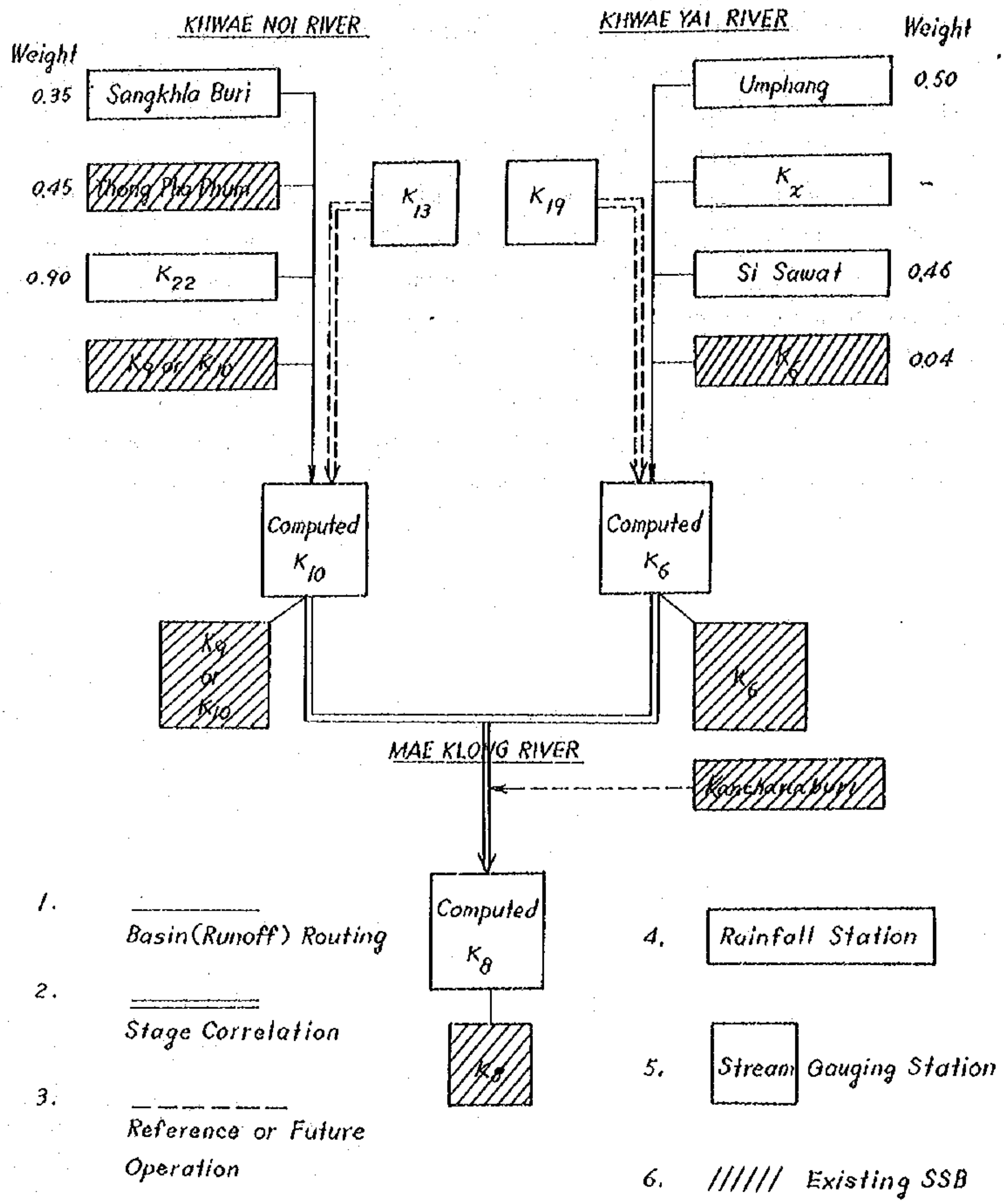
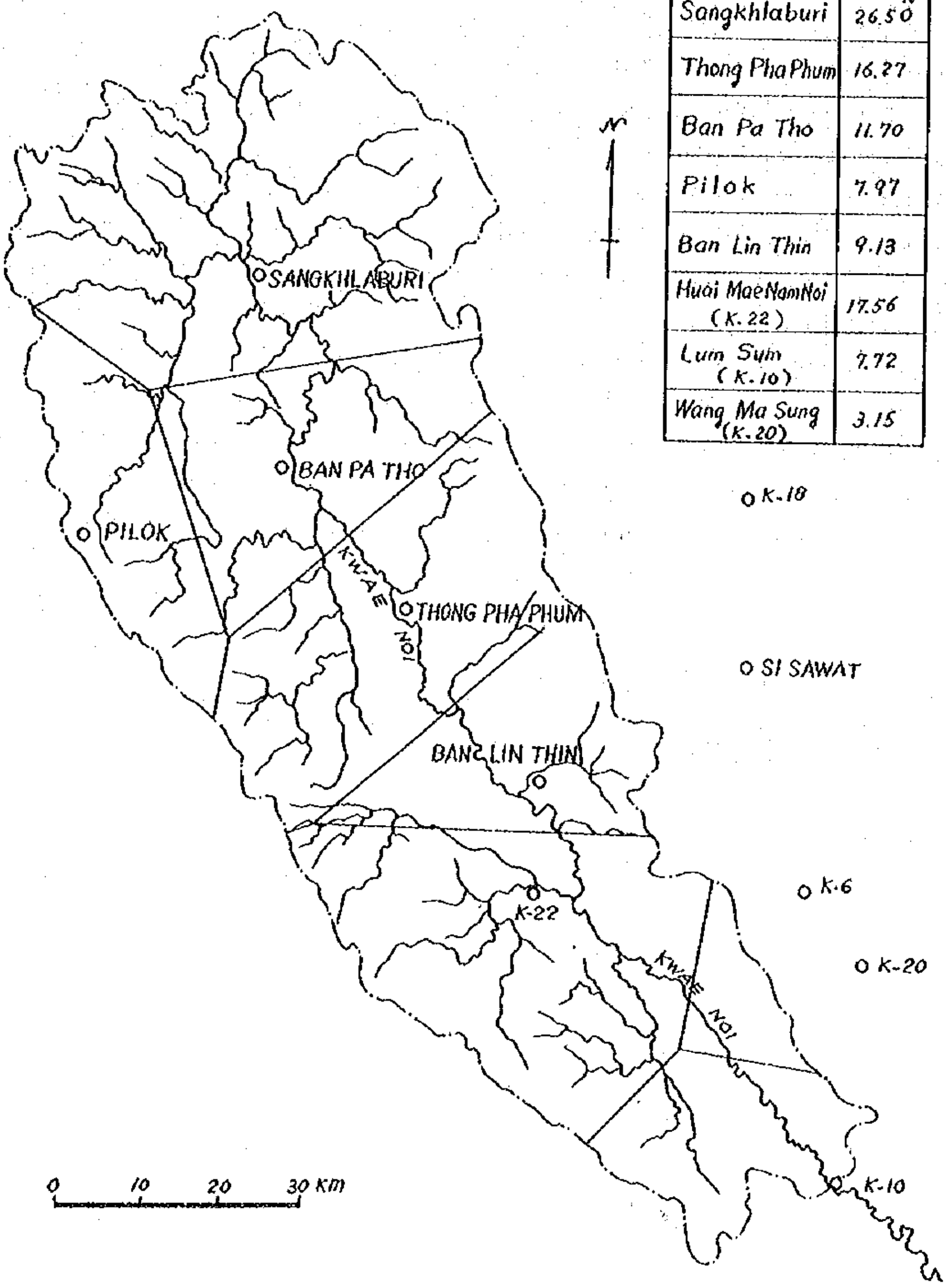


Fig. 4-17 - Flood Forecasting Procedure Flow Chart



Thiessen Weight

Rainfall Station	Weight
Sangkhlaburi	26.50 %
Thong Pha Phum	16.27
Ban Pa Tho	11.70
Pilok	7.97
Ban Lin Thin	9.13
Huai Mae Nam Noi (K.22)	17.56
Lum Sum (K.10)	7.72
Wang Ma Sung (K.20)	3.15

Fig. 4-18 - Network of Rain Gauge Stations above K_{10}

4-2-5 Rainfall Analysis

(1) Time of Occurrence of Peak Rainfall

Study of the time elapsed from the day of peak rainfall to the day when the discharge at K_{10} reaches its peak disclosed that frequencies of daily peak rainfall, 2-day peak rainfall, 3-day peak rainfall and 4-day peak rainfall are as shown in Table 4-6. As seen in the table, the peak rainfall caused by continuous rain recorded three days before the discharge at K_{10} reaches its peak accounts for as large as 40% of all peak rainfalls. In the case of daily peak rainfall, two-thirds are caused by continuous rain recorded three or four days before the peak discharge at K_{10}. In the case of 2- to 4-day peak rainfall, nearly two thirds are also caused by continuous rain recorded two or three days before the peak discharge at K_{10}. Insofar as the daily, 2-day and 3-day peak rainfalls are concerned, over 90% can be known more than two days before the discharge at K_{10} reaches its peak. Therefore, if the flood discharge at K_{10} is estimated from the peak rainfall occurring more than two days before, it will serve as useful forecasting data together with the discharge measured at K_{13}.

Tables 4-7 and 4-8 show the 2-day and 3-day peak rainfalls at the rain gauge stations in the Khwae Noi basin. These tables indicate that the rainfall at Lum Sum and Wang Ma Sung is smaller than at other stations, and that Wang Ma Sung which is in the Khwae Yai basin is not very important for calculation of the Khwae Noi's flood discharge.

Table 4-6 - Occurrence Time Frequency of Peak Rainfall

2-day Peak Rainfall			3-day Peak Rainfall			4-day Peak Rainfall		
Number of days before Peak Discharge at K10	Frequency	(%)	Number of days before Peak Discharge at K10	Frequency	(%)	Number of days before Peak Discharge at K10	Frequency	(%)
1 ~ 2	3	3	1 ~ 3	11	9	1 ~ 4	25	21
2 ~ 3	23	19	2 ~ 4	30	23	2 ~ 5	31	26
3 ~ 4	49	(41)	3 ~ 5	52	(41)	3 ~ 6	48	(40)
4 ~ 5	20	17	4 ~ 6	25	19	4 ~ 7	9	8
5 ~ 6	19	16	5 ~ 7	7	5.5	5 ~ 8	4	3
6 ~ 7	4	3	6 ~ 8	2	1.5	6 ~ 9	1	1
7 ~ 8	1	1	7 ~ 9	–	–	7 ~ 10	1	1
8 ~ 9	–	–	8 ~ 10	1	1	8 ~ 11	–	–

Daily Peak Rainfall		
Number of days before Peak Discharge at K10	Frequency	(%)
1	4	3
2	8	6.5
3	47	(39)
4	32	26.5
5	19	16
6	8	7
7	1	1
8	1	1

Table 4-7 - 2-day Peak Rainfall

	Sangkhla Buri	Pilok	Ban Pa Tho	Thong Pha Phum	Lin Tin	Huai Mae Nam Noi	Wang Ma Sung	Lum Sun
1	188.8	204.2	137.5					38.9
2	138.2	461.8	130.3			143.8		27.9
3	(55.8)	252.0	81.7	(32.7)	44.5	135.6		10.8
4	81.0	381.6	84.7	41.7	58.9	93.2		8.4
5	60.7		59.9	0	38.9	96.3		7.9
6	(64.8)		46.7	79.5	26.4	41.7		6.0
7	115.8		49.6	50.9	34.8	93.9	13.7	9.6
8	102.9		58.0	59.7	46.6	49.6	8.5	1.2
9	(145.9)		41.1	88.8	126.0	102.1	19.6	14.6
10	109.0	313.0	17.9	148.2	83.1	106.2	22.7	57.2
11	145.2	221.6	122.3	64.3	52.6	85.1	26.0	49.1
12	147.1	280.8	51.8	125.6	101.0	81.2	20.5	20.3
13	283.5	362.0	177.3	176.6	143.2	187.3	27.6	52.9
14	114.2	162.0	106.5	78.2	49.5	101.5	4.3	4.0
15	215.5	294.8	106.7	165.4	121.0	213.3	65.1	45.0
16	71.1	190.2	128.0	75.1	44.5	43.1	20.9	24.5
17	140.9	290.0	178.3	158.8	46.9	91.3	26.9	18.6

Table 4-8 - 3-day Peak Rainfall

	Sangkhla Buri	Pilok	Ban Pa Tho	Thong Pha Phum	Lin Tin	Huai Mae Nam Noi	Wang Ma Sung	Lum Sum
1	239.2	273.2	154.5					46.9
2	177.5	562.4	152.4			150.6		29.1
3		320.2	120.2		64.0	159.3		17.7
4	110.1	504.8	123.9	55.1	77.5	107.8		12.0
5	75.4		90.0		75.1	112.5		8.5
6	91.1		62.8	114.5	39.2	59.4		6.9
7	130.2		70.3	76.2	49.6	122.3	17.7	17.9
8	137.1		67.1	83.5	60.8	63.6	9.3	1.6
9	178.5		67.6	118.1	162.4	135.8	26.0	17.9
10	151.5	427.2	23.1	179.0	100.3	140.7	31.5	65.2
11	210.1	308.6	170.5	91.5	69.9	107.9	28.3	50.6
12	196.0	247.2	59.2	139.5	117.2	95.3	22.9	24.2
13	388.9	441.5	242.4	210.8	191.6	198.5	27.8	59.3
14	162.6	220.0	123.1	89.2	89.7	121.1	7.8	6.1
15	264.3	399.3	132.6	211.7	144.9	262.3	72.3	68.4
16	111.2	315.4	168.5	96.3	66.9	61.4	28.7	35.5
17	186.4	390.5	254.2	193.9	70.6	131.6	34.6	27.7

(2) Rainfall Correlation

Rainfall correlation during several days before the peak discharge is recorded at K_{11} was studied for the following eight rain gauge stations whose rainfall data bear closely upon the Khwae Noi's discharge.

Songkhla Buri, Pilok, Ban Pa Tho, Thon Pha Phum, Lin Tin,
Huai Mae Nam Noi (K_{22}), Lum Sum, and Wang Ma Sung.

The results of this study are shown in Tables 4-9 - 4-12 for daily, 2-day, 3-day, 5-day and 7-day rainfalls.

As is clear in these tables, the correlation is extremely poor, with the highest correlation coefficient being 0.85 of the 7-day rainfall between Lum Sum and Wang Ma Sung and the next highest not exceeding 0.7. It cannot therefore be justified to decrease the number of rain gauge stations according to the correlation coefficient. In the basin divided by Thiessen method, one station must cover an area of 500 to 2,000 km^2 which is mountainous, and this well explains the low correlation coefficient.

Correlation of 3-day peak rainfall was also studied (See Figs. 4-19 and 4-20), but the results were not satisfactory either. Hence, the correlation coefficient cannot be used for examining the number of stations.

Table 4-9 - SOUKAN KEISU (1 DAY)

Kansokujo	Sangkhla	Piloktin	Wangpath	Thongcha	Lin Thin	Huaimaen	Lum Sun	Wangmasu	K10
Sangkhal	1.00000	0.41437	-0.01824	-0.45740	-0.24454	-0.09846	0.23443	-0.21089	-0.11723
Piloktin	0.41437	1.00000	-0.15713	-0.25241	0.65451	0.21291	0.12346	-0.21500	0.43788
Wangpath	-0.01824	-0.15713	1.00000	0.01887	-0.09040	0.26511	0.02197	-0.58370	0.04347
Thongcha	-0.45740	-0.25241	0.01887	1.00000	0.39085	0.59979	0.35347	0.64560	0.03105
Lin Thin	-0.24454	0.65451	-0.09040	0.39085	1.00000	0.58549	0.41842	-0.22755	-0.18252
Huaimaen	-0.09846	0.21291	0.26511	0.59979	0.58549	1.00000	0.64953	-0.21349	-0.09333
Lum Sun	0.23443	0.12346	0.02197	0.35347	0.41842	0.64953	1.00000	-0.25056	-0.27613
Wangmasu	-0.21089	-0.21500	-0.58370	0.64560	-0.22755	-0.21349	-0.25056	1.00000	0.09453
K10	-0.11723	0.43788	0.04347	0.03105	-0.18252	-0.09333	-0.27613	0.09453	1.00000

Table 4-10 - SOUKAN KEISU (3 DAY)

Kansokujo	Sangkhla	Piloktin	Wangpath	Thongrha	Lin Thin	Huaimaen	Lum Sun	Wangmasu	K10
Sangkhla	1.00000	0.55096	0.33648	0.11682	0.03656	0.11515	0.12165	-0.17489	0.31913
Piloktin	0.55096	1.00000	0.43304	0.38172	-0.26026	0.26468	0.08790	-0.54398	0.52798
Wangpath	0.33648	0.43304	1.00000	-0.16526	-0.08132	-0.07928	-0.27767	-0.50539	0.07050
Thongrha	0.11682	0.38172	-0.16526	1.00000	-0.00971	0.29002	0.33972	0.62130	0.39833
Lin Thin	0.03656	-0.26026	-0.08132	-0.00971	1.00000	0.38527	0.09461	0.38208	-0.03023
Huaimaen	0.11515	0.26468	-0.07928	0.29002	0.38527	1.00000	0.48689	0.10018	-0.11495
Lum Sun	0.12165	0.08790	-0.27767	0.33972	0.09461	0.48689	1.00000	0.35951	-0.28693
Wangmasu	-0.17489	-0.54398	-0.50539	0.62130	0.38208	0.10018	0.35951	1.00000	-0.09647
K10	0.31913	0.52798	0.07050	0.39833	-0.03023	-0.11495	-0.28693	-0.09647	1.00000

Table 4-11 - SOUKAN KEISU (5 DAY)

Kansokujo	Sangkhla	Piloktin	Wangpath	Thongrha	Lin Thin	Huaimaen	Lum Sun	Wangmasu	K10
Sangkhla	1.00000	0.49705	0.31692	0.44551	-0.09933	0.23924	0.29362	-0.09359	0.20656
Piloktin	0.49705	1.00000	0.56870	0.28915	0.14722	0.33762	-0.07266	-0.51379	0.33850
Wangpath	0.31692	0.56870	1.00000	-0.18812	0.03422	0.11780	-0.22450	-0.38730	0.36093
Thongrha	0.44551	0.28915	-0.18812	1.00000	0.05835	0.44535	0.38171	0.39694	0.18037
Lin Thin	-0.09933	0.14722	0.03422	0.05835	1.00000	0.17479	0.35864	0.73128	0.18184
Huaimaen	0.23924	0.33762	0.11780	0.44535	0.17479	1.00000	0.54860	0.47583	-0.02585
Lum Sun	0.29362	-0.07266	-0.22450	0.38171	0.35864	0.54860	1.00000	0.82704	-0.21478
Wangmasu	-0.09359	-0.51379	-0.38730	0.39694	0.73128	0.47583	0.82704	1.00000	-0.30670
K10	0.20656	0.33850	0.36093	0.18037	0.18184	-0.02595	-0.21478	-0.30670	1.00000

Table 4-12 - SOUKAN KEISU (7 DAY)

Kansokujo	Sangkhla	Piloktin	Wangpath	Thongrha	Lin Thin	Huaimaen	Lum Sun	Wangmasu	K10
Sangkhla	1.00000	0.34740	0.10330	0.45505	-0.15706	-0.01256	0.03900	-0.08149	0.34230
Piloktin	0.34740	1.00000	0.55379	0.45226	0.61235	0.46868	-0.18491	-0.41743	0.47767
Wangpath	0.10330	0.55379	1.00000	0.17401	0.12814	0.21528	-0.19099	-0.22174	0.46071
Thongrha	0.45505	0.45226	0.17401	1.00000	0.37542	0.35285	0.17554	0.18811	0.42113
Lin Thin	-0.15706	0.61235	0.12814	0.37542	1.00000	0.71009	0.29242	0.33268	0.34735
Huaimaen	-0.01256	0.46868	0.21528	0.35285	0.71009	1.00000	0.15642	0.26258	0.25541
Lum Sun	0.03900	-0.18491	-0.19099	0.17554	0.29242	0.15642	1.00000	0.85233	-0.24998
Wangmasu	-0.08149	-0.41743	-0.22174	0.18811	0.33268	0.26258	0.85233	1.00000	-0.28681
K10	0.34230	0.47767	0.46071	0.42113	0.34735	0.25541	-0.24998	-0.28681	1.00000

Table 4-13 - 5-Day Rainfall Data

No.	Year	Month	Day	Sangkhla	Pilokin	Wangpath	Thongtha	Lin Thin	Huaimaen	Lan Sun	Wangmasa	K10
1	1965	6	22	128.8	301.0	0.	87.9	0.	0.	0.	0.	16
2	1965	7	30	158.1	198.8	0.	77.4	0.	0.	0.	0.	18
3	1965	10	1	72.2	145.8	0.	0.	0.	0.	20.6	0.	6
4	1966	8	1	21.4	56.2	19.1	0.	15.6	0.	1.8	0.	13
5	1966	9	14	25.4	67.4	8.7	0.	0.	18.7	9.4	0.	22
6	1966	9	22	36.7	38.8	41.5	0.	0.	38.7	17.6	0.	5
7	1967	8	11	38.2	309.6	127.3	15.6	124.2	59.1	9.5	0.	12
8	1967	8	22	45.6	165.8	92.8	17.8	167.0	59.7	15.6	0.	16
9	1967	9	5	83.7	216.4	123.3	16.4	59.3	115.0	11.6	0.	12
10	1967	10	5	7.5	154.0	0.	23.3	49.1	140.5	35.5	0.	7
11	1968	8	18	80.0	0.	72.0	83.4	75.1	63.3	5.5	0.	11
12	1968	9	17	65.3	0.	22.3	58.9	96.6	53.9	47.9	0.	8
13	1969	8	14	104.6	0.	48.2	119.8	94.9	28.9	24.8	64.5	23
14	1969	9	24	97.5	0.	57.5	56.7	32.9	58.0	4.1	6.3	9
15	1969	10	5	52.4	0.	39.5	129.6	64.6	44.2	27.8	48.5	6
16	1970	7	19	136.3	305.8	1.1	154.4	64.4	142.3	72.4	32.9	11
17	1970	8	27	84.8	239.8	63.4	41.9	57.0	42.3	49.3	16.7	6
18	1971	7	29	145.5	168.0	189.8	53.6	50.2	87.7	45.9	20.5	18
19	1972	7	19	67.5	164.5	46.3	39.3	96.2	41.6	15.6	6.4	30
20	1972	8	2	68.1	166.0	74.5	92.1	68.6	75.3	50.6	44.7	17
21	1972	8	22	68.2	175.3	64.9	34.3	50.3	11.6	2.2	2.9	8
22	1972	9	10	78.7	149.6	62.5	109.8	124.5	146.9	166.5	171.5	10
23	1972	9	21	95.2	107.0	59.7	113.8	84.9	105.9	32.5	84.1	8
24	1973	6	21	0.	356.0	101.5	155.7	100.8	169.5	36.7	45.4	17
25	1973	8	29	0.	273.9	214.0	57.7	60.5	24.8	4.8	1.6	14
26	1973	9	26	0.	114.7	0.9	51.2	40.3	24.1	20.6	48.2	8
27	1974	3	21	0.	341.1	182.8	146.1	74.3	109.4	12.1	23.9	32
28	1974	10	14	0.	73.1	2.7	115.5	114.2	111.5	110.3	204.3	6

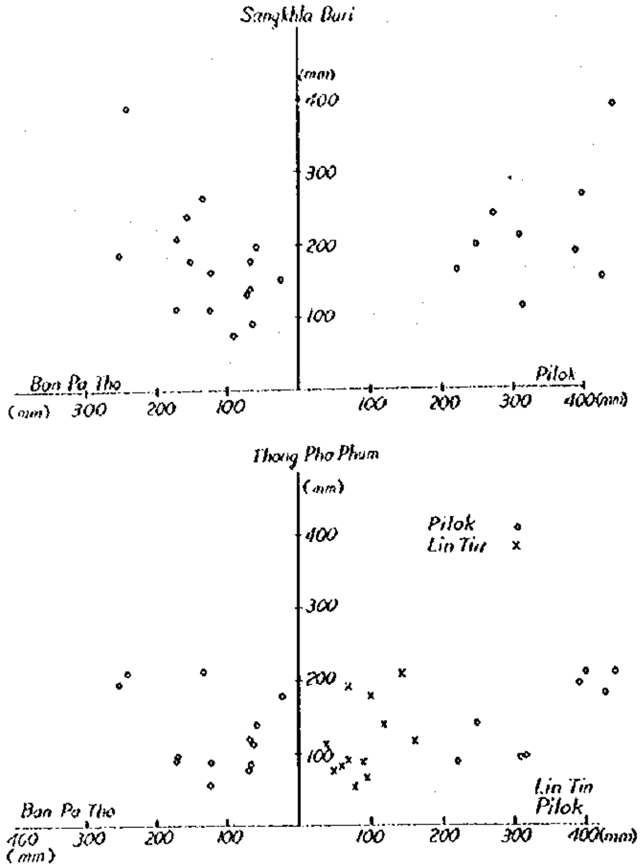


Fig. 4-19 - Correlation Chart of 3-day Peak Rainfall (1)

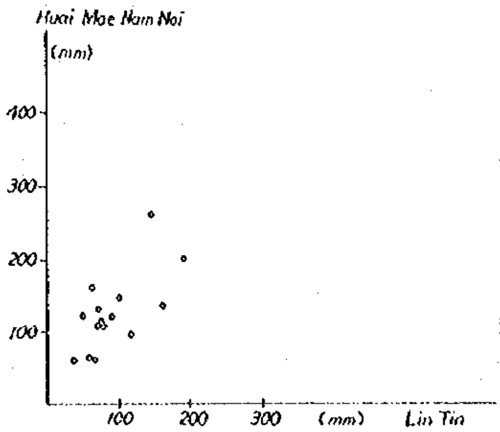


Fig. 4-20 - Correlation Chart of 3-day Peak Rainfall (2)

(3) Relationship between Catchment Area and Number of Rain Gauge Stations

On the basis of the study on the planimetric dispersion of rainfall, the relationship between the catchment area and the number of rain gauge stations has been determined tentatively by calculations in which the computation accuracy of average rainfall of basin is employed as parameter.

At present, Muskingum method developed in the United States is most widely used. In Japan, the method recently developed by the Public Works Research Institute of the Ministry of Construction is also used for flood forecasting. Since these two methods produce almost the same results which can be simply read from a graph, the team employed them to obtain the required number of rain gauge stations without regard to their validity in the Maeklong basin.

K_{10} on the Khwae Noi covers a catchment area of 7, 008 km^2. When a number of relative errors in the calculation of average rainfall in the catchment area are assumed, the required number of stations as produced by the two methods turns out to be as shown below.

Table 4-14 - Required Number of Rain Gauge Stations

Relative Error	Muskingum	Method of Public Works Research Institute
5 %		83
10	22	20
15	10	10
20	6	6

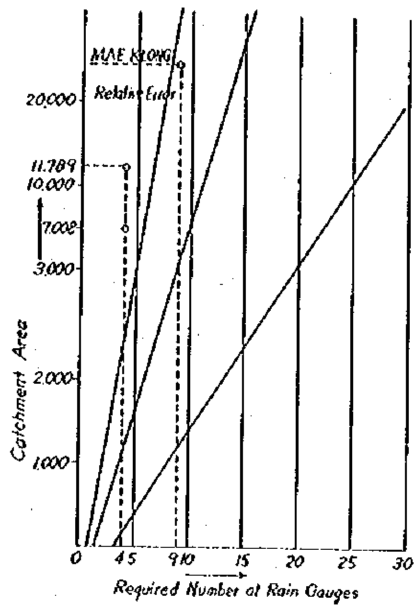


Fig. 4-21 - Catchment Area and Number of Rain Gauge Stations (Muskingum)

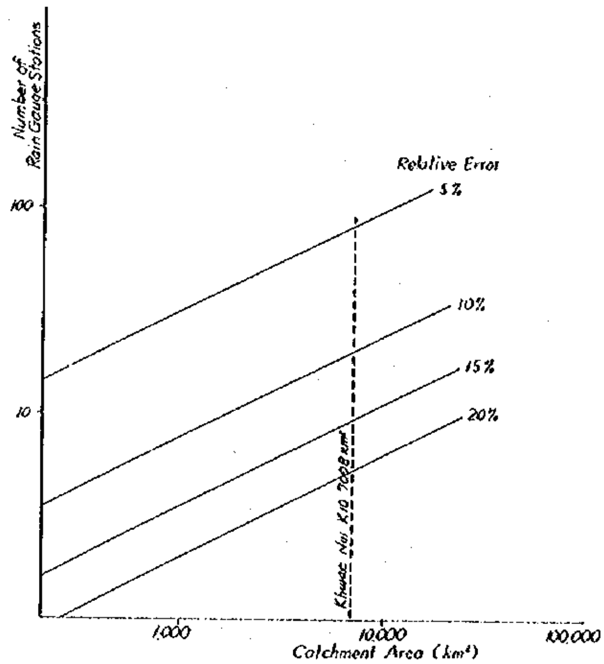


Fig. 4-22 - Catchment Area and Number of Rain Gauge Stations for Accuracies at a Significance Level of 50% (Method of Public Works Research Institute)

(4) Relationship between Average Daily Rainfall of Catchment Area and Number of Rain Gauge Stations

The flood discharge estimation for the Maeklong river is largely affected by the calculation accuracy of average daily rainfall of catchment area because it is based on the daily rainfall data at present.

Hence, the number of stations was decreased one by one by assuming that the weighted average rainfall (Thieseen method) recorded during the selected flood periods (Table 4-15) at the seven stations in the Khwae Noi basin represents the correct average rainfall was expressed in relative error to obtain its frequency.

Table 4-15 - Selected Flood Periods

No.	Year of occurrence	Duration of Flood
1	1967	Jul. 31 - Aug. 9
2		Aug. 10 - Aug. 19
3	1970	Jul. 8 - Jul. 17
4	1971	Jul. 18 - Jul. 27
5	1972	Jun. 1 - Jun. 10
6		Jul. 7 - Jul. 16
7		Jul. 17 - Jul. 26
8	1973	Jun. 10 - Jun. 19
9		Aug. 17 - Aug. 26
10	1974	Aug. 11 - Aug. 20

As to the weight of each station which varies with the decrease of the number of stations, an approximate value was obtained by Thiessen method. Table 4-16 shows the selected cases and the Thissen weight in each case, and Table 4-17 shows the frequency of relative errors in the average daily rainfall of catchment area.

The relationship between the occurrence frequency of each relative error and the number of stations is illustrated in Fig. 4-23.

Fig. 4-23 indicates that if the relative error is smaller than 5%, its cumulative occurrence frequency is small for six stations, and if it increases to 5 - 10%, about 90% of daily rainfall is covered in Case 6-1. However, up to an error of 10% and 15%, there exists a large gap between six stations and five stations, and it appears that five stations will not suffice. If the error is held within 20% and 30%, the difference between six stations and five stations and five stations becomes much smaller and could be reduced to zero depending on the distribution of stations. With an error of 40 - 50%, there exists virtually no difference among four stations, five stations and six stations, and even three stations produce no great difference if they are suitably located.

Thus, the number of stations depends on the relative error. Although nothing definite can be said before clarifying the influence of rainfall variation on the flood discharge, it is desirable to maintain as high an accuracy as possible because the relative error is based on the average value of only seven stations. It is therefore considered that the allowable range of relative error would be from 10 to 15% and the suitable number of stations would be six. In this case, the following are the stations to be selected.

1. Sangkhal Buri
2. Ban Pa Tho
3. Pilok
4. Thong Pha Phum
5. Ban Lin Thin
6. Huai Mae Nam Noi (Ban Sai Yok - K_{22})

Table 4-16 - Thiessen Weight (Approximate Value)

Case / Rainfall Gauge Station	7-Stations	6-Stations			5-Stations		
	7-1	6-1	6-2	6-3	5-1	5-2	5-3
Sangkhla Buri	0. 265	0. 265	0. 265	0. 3118	0. 265	0. 3118	0. 3118
Thong Pha Phum	0. 1627	0. 1627	0. 1931	0. 2095	0. 1931	0. 2399	0. 2095
Ban Pa Tho	0. 1170	0. 1170	0. 1170	–	0. 1170	–	–
Pilok	0. 0797	0. 0797	0. 0797	0. 1031	0. 0797	0. 1031	0. 1031
Ban Lin Thin	0. 0913	0. 0913	–	0. 0913	–	–	0. 0913
Huai Mae Nam Noi	0. 1913	0. 2842	0. 2522	0. 1913	0. 3452	0. 2523	0. 2842
Lum Sum	0. 0929	–	0. 0929	0. 0929	–	0. 0929	–

Case / Rainfall Gauge Station	4-Stations			3-Stations			
	4-1	4-2	4-3	3-1	3-2	3-3	
Sangkhla Buri	0. 3118	0. 3634	0. 265	0. 3634	0. 3118	0. 3634	
Thong Pha Phum	0. 2399	0. 2914	0. 1627	0. 2914	0. 5851	0. 4480	
Ban Pa Tho	–	–	0. 1967	–	–	–	
Pilok	0. 1031	–	–	–	0. 1031	–	
Ban Lin Thin	–	–	0. 3755	–	–	–	
Huai Mae Nam Noi	0. 3452	0. 2523	–	0. 3452	–	–	
Lum Sum	–	0. 0929	–	–	–	0. 1886	

Table 4-17 - Frequency of Relative Error in Average Daily Basin Rainfall

(Unit: %)

Case / Relative Error %	6-1	6-2	6-3	5-1	5-2	5-3	4-1	4-2	4-3	3-1	3-2	3-3
0 - 5	58	35	28	26	18	26	13	7	21	7	1	4
5 - 10	32	46	33	24	18	14	21	10	20	11	1	5
10 - 15	8	13	17	26	19	16	12	14	12	4	7	6
15 - 20	2	4	12	15	20	28	11	14	6	13	4	6
20 - 30		2	8	8	18	14	31	26	18	25	4	10
30 - 40			1	1	4	2	9	17	9	24	7	10
40 - 50			1		2		3	7	8	11	3	13
50					1			5	6	5	73	43

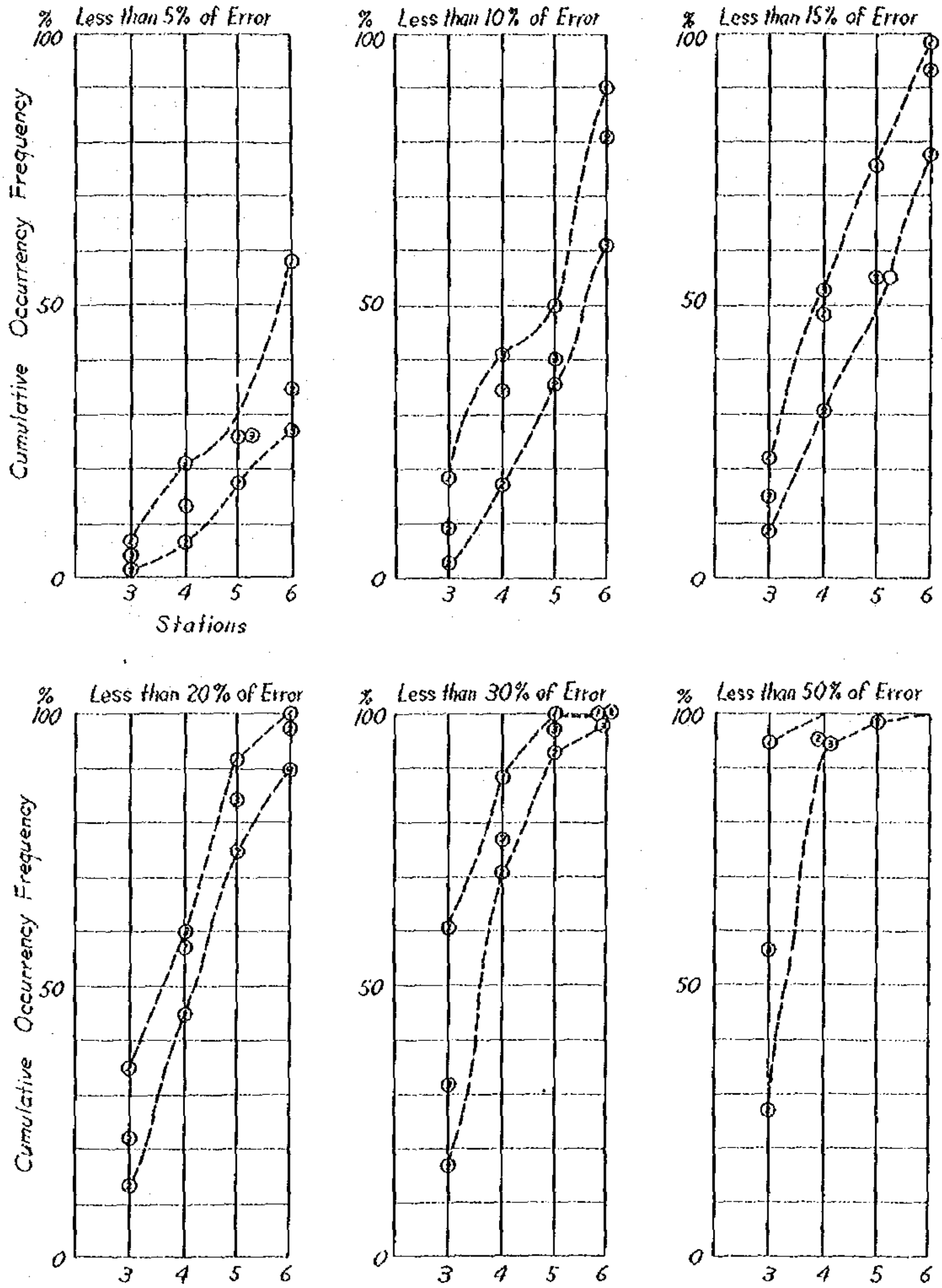


Fig. 4-23 - Relationship between Number of Stations and Occurrence Frequency of Error

4-3 Telemetering System Planned for Macklong Basin Flood Forecasting

(1) Outline

A number of plans have been drawn up and examined for establishment of a flood forecasting and warning system for the Macklong river basin. These plans, shown in Fig. , include those studied by the Meteorological Department and the Royal Irrigation Department and the one drafted by the Typhoon Committee after a survey.

By the initiation of the construction work of Ban Chao Nen dam, need arose to revise these plans to cope with the new condition in the upstream area of the Khwae Yai. With this new condition in mind, the team reexamined the telemetering system with account taken of the following points.

1. VHF should be used for radio circuits for stabilized communication.
2. All equipment should allow for easy maintenance and inspection after installation.
3. Number and locations of relay stations should be determined with special care.

The planned system is composed of four stage reporting stations, six rainfall reporting stations (of which one is stage and rainfall reporting station), two relay stations and the master stations in Bangkok. (Location of the master station must be determined by future study. For the purpose of the circuit design, however, it was assumed that the master station would be set up at the Meteorological Department and the monitor station at RID).

It is to be noted that this is just a rough desk plan and its details must be determined by propagation test and field surveys to be conducted in future.

(2) Telemetering System and Circuit Design

The system will comprise of the following stations.

1)	Master control station	Bangkok (Meteorological Department).
2)	Monitor station	" (RID).
3)	Relay station	Rep_1 and Rep_2.
4)	Rainfall reporting station	Sangkhla Buri, Ban Pa Tho, Pilok, Ban Lim Thin, and Ban Sai Yok (K22).
5)	Stage reporting station	Ban Lum Sum (K_{10}), Wang Khanai (K_{11}), and Khao Wang Masang (K_{20}).
	Rainfall and stage reporting station	Thong Pha Phum.

Fig.4-24 shows the network of telemetering system for automatic transmission of data collected at respective observation stations.

Table 1 shows the circuit design of each span. S/N ratio of more than 30 db can be assured for all spans excepting one. However, this must be confirmed by tests because the span loss is likely to change by the effect of city noise in Bangkok and the location of the reporting station.

(3) Outline of Equipment and Estimated Cost

Equipment configuration of each station is shown in Fig.4-25 and the approximate cost in Table 4-19.

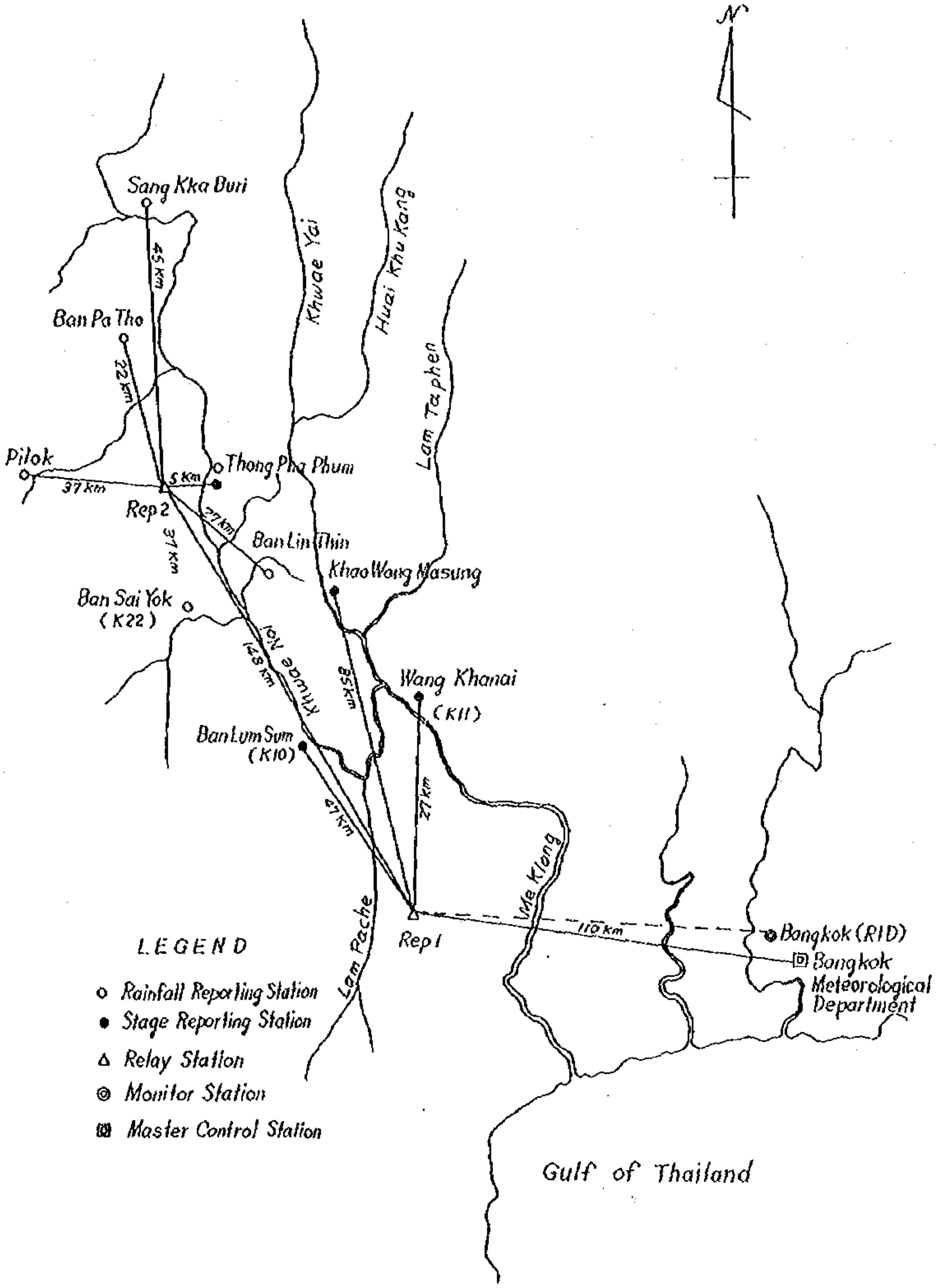


Fig. 4-24 - Network of Telemetering System

Table 4-18 - Table of Circuit Design

Item	Unit	Rep 1 – Rep 2 Relay Station	Rep 1 – Bang Kok Relay Station	Rep 1 – Khao Wang Masang (K20) Stage Reporting Station	Rep 2 – Thong Pha Phum Rainfall and Stage Reporting Station	Rep 2 – Sang Kha Buri Rainfall Reporting Station	Rep 2 – Ban Lim Thim Rainfall Reporting Station	Rep 1 – Ban Lum Sum (K10) Stage Reporting Station	Rep 1 – Wang Khanai (K11) Stage Reporting Station	Rep 2 – Ban Pa Tho Rainfall Reporting Station	Rep 2 – Ban Sai Yok (K22) Rainfall Reporting Station	Rep 2 – Pilok Rainfall Reporting Station
Span Length	Km	148	110	85	5	45	27	47	27	22	37	37
Antenna Power	dBm	+40	+40	+40	+40	+40	+40	+40	+40	+40	+40	+40
Free Space Loss	dB	-118.5	-116	-113.6	-89	-108.4	-103.6	-108.5	-103.6	-102	-106.3	-106.3
Ground Constant	〃	-20	-20	-10	-10	-10	-10	-10	-10	-10	-10	-10
Additional Loss	〃			-26	-22	-6			-6		-18	-14
Feeder Loss	〃	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Antenna Gain (transmitter)	〃	+8	+8	+8	+8	+8	+8	+8	+8	+8	+8	+8
〃 (receiver)	〃	+8	+8	+8	+8	+8	+8	+8	+8	+8	+8	+8
Received Power	dBm	-90.5	-88	-101.6	-73	-76.4	-65.6	-70.5	-71.6	-64	-86.3	-82.3
Received Noise Power	〃	-106	-106	-106	-106	-106	-106	-106	-106	-106	-106	-106
High Frequency S/N	dB	+15.5	+18	+4.4	+33	+29.6	+40.4	+35.5	+34.4	+42	+19.7	+23.7
S/N Improvement Factor	〃	+14	+14	+14	+14	+14	+14	+14	+14	+14	+14	+14
S/N in Standard Condition	〃	29.5	32	18.4	47	43.6	54.4	49.5	48.4	56	33.7	37.7

Antenna Power 10W

Antenna–Yagi three element antenna (T&R)

S/N improvement factor I = 14 dB ($fm = 3^{KHZ}$, $fd : 5^{KHZ}$, $B : 20^{KHZ}$)

External noise field intensity (15dBuV) Receiver Noise Power -121 dBm ($F : 10^{dB}$ $B : 20^{KHZ}$)

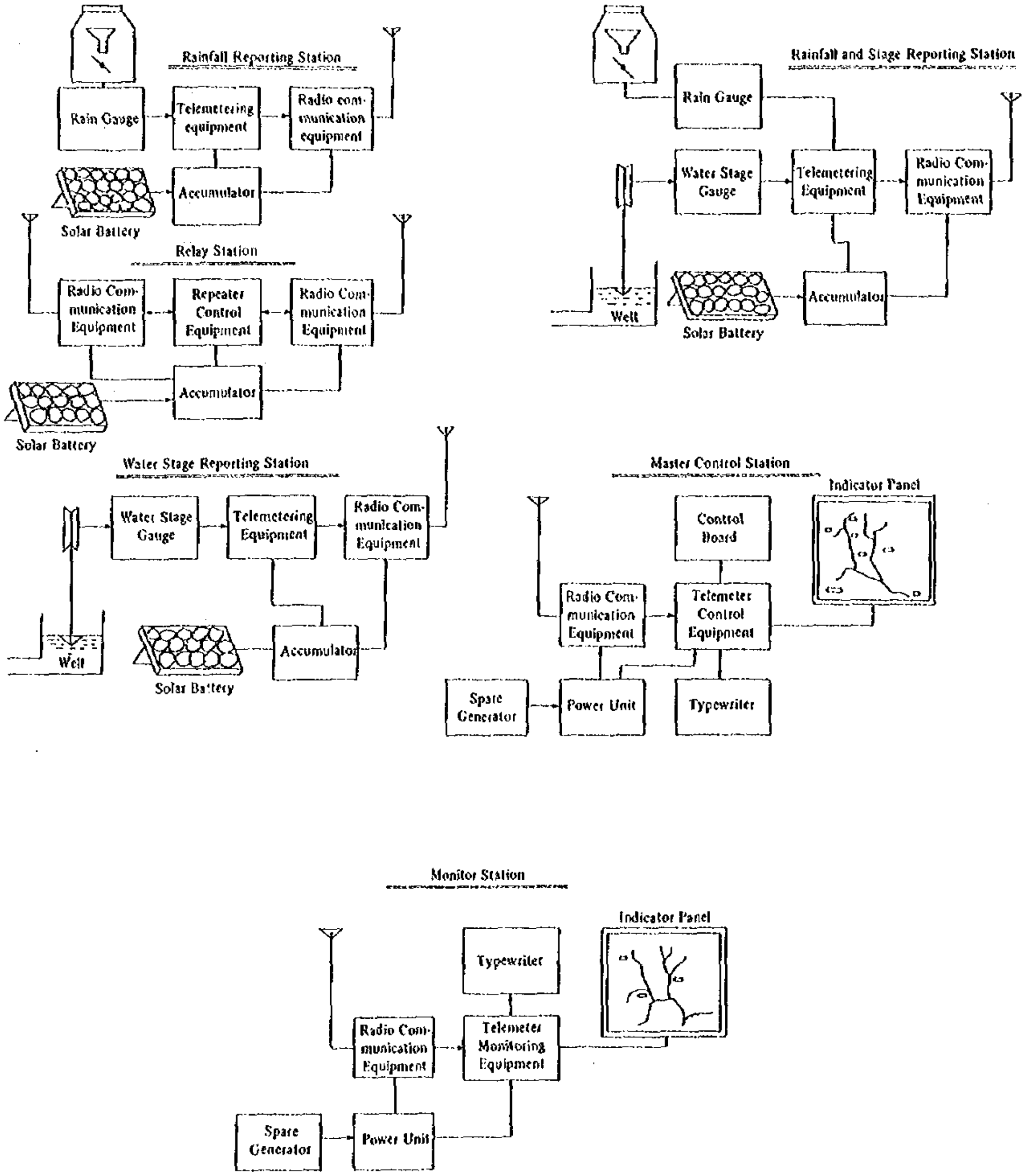


Fig. 4-25 - Equipment Configuration

(4) Approximate Construction Cost

Construction costs of telecommunication facilities, observation stations, etc. are shown in Tables 4-19 - 4-21. These tables show only rough costs which are subject to fluctuation by detailed field survey and include the transportation and installation costs which can be determined only at site.

Insofar as can be seen in Tables 4-19 - 4-21, the cost of telecommunication equipment is by far the greatest and the observation facilities and others combined account for about 40% of the cost of the telecommunication equipment. The total cost is estimated to be about 190 million yen.

Table 4-19 - Approximate Construction Cost of Telecommunication Facilities

Unit: Thousand Yen

Station	Number	Unit Cost	Total Cost	Remarks
Master Control Station	1		39,000	Bangkok (Meteorological Department)
Monitor Station	1		20,000	Bangkok (RID)
Repeater Station	2	10,500	21,000	
Rainfall Reporting Station	5	6,000	30,000	
Stage Reporting Station	3	6,000	18,000	
Rainfall and Water Stage Reporting Station	1		7,000	
Total			135,000	

Notes: 1. Construction costs of buildings and steel towers are not included.

2. CIF Thia port is adopted.

Table 4-20 - Approximate Cost of Observation Facilities and Building Construction

Station	Number	Equipment		Installation Work and Station Building		Remarks
		Unit Cost	Total Cost	Unit Cost	Total Cost	
		thousand yen	thousand yen	thousand yen	thousand yen	
Rainfall Reporting Station	5	800	4,000	2,500	12,500	Station Area – 10 m²
Stage Reporting Station	3	2,200	6,600	3,500	10,500	Station Area – 10 m²
Rainfall and Stage Reporting Station	1	3,000	3,000	4,000	4,000	Thong Pha Phum
Total			13,600		27,000	

Table 4-21 - Approximate Cost of other Construction Cost

Item	Quantity	Cost		Remarks
		Unit Cost	Total Cost	
		Thousand yen	Thousand yen	
Remodelling of master control station	1 set		5,000	Steel tower inclusive
Remodelling of monitor station	1 set		5,000	Steel tower inclusive
Repeater station	2	2,000	4,000	Station area -- 10 m²
Total			14,000	

List of Obtained Data

I. Reports

1. Trial Flood Forecasting in Maeklong River (MET, 1973)
2. Preliminery Attempt to Simulate the Streamflow of the River Khwae Noi by Using Recording of Three Standard Raingages (MET, 1969)
3. The Development of Pilot Flood Forecasting in the Mae Klong River Basin (RID, 1974)
4. List of Rainfall Stations in Thailand (RID, 1972)
5. Water Resources Development in Thailand (RID, 1974)
6. The Maeklong River Basin Development Project (RID,)
7. Development of the River Quae Noi
   Hydrological Investigations of Monthly Runoff and Sediment (EGAT, 1974)
8. Additional Investigation on the Design Flood of Quae Uai No. 1 Hydro-Electric Project (EGAT, 1973)

II. Drawing

1. Locations of Hydrologic Observation Stations (RID, 1968)
2. Map Showing Water Resources Development in Thailand (RID, 1974)
3. Map Showing Flooded Area in October, 1972 (RID, 1972)
4. Map Showing Telecommunication Network (RID).

III. Data

1. Daily Rainfall Data (RID)

1-1	Pilok	1956 - 67	1970 - 74
1-2	Sangkhlaburi	1952 - 74	
1-3	Thong Pha Phum	1952 - 74	
1-4	Huai Mae Nam Noi	1966 - 74	
1-5	Wang Pa	1966 - 74	
1-6	Lum Sum	1965 - 74	
1-7	Wang Masang	1968 - 74	
1-8	Lin Thin	1966 - 74	

2. Hourly Rainfall Data (RID)

2-1	Sangkhlaburi	October, 1972 and July to October, 1974
2-2	Thong Pna Phum	" "

3. Evaporation

Thong Pha Phum	October, 1972 and July to October, 1974

4. Mean Daily gauge height and discharge

4-1	K-6	1952 - 72
4-2	K-10	1965 - 74
4-3	K-11	1965 - 74
4-4	K-13	1965 - 74
4-5	K-17	1966 - 74
4-6	K-20	1966 - 74
4-7	K-22	1966 - 68
4-8	K-22A	1969 - 74
4-9	K-27	1968 - 74

5. Maximum and minimum gauge height

5-1	K-2	1962 - 66
5-2	K-2A	1967 - 72

6. Hourly Data

- Hourly gauge readings for: July and August, 1969
  July, 1972
  August and October, 1974
- Rating Table for the Same period of hourly gauge record
- Stations: K10, K11, K13, K17, K20, K22A and K27

IV. Others

Outline of Electricity and Telecommunication concerned.

Experts participating in the Preliminary Survey
on the Maeklong Basin Flood Forecasting

I. Japanese Mission

1.	Mr. Kazusuke Nakao	Chief
2.	Mr. Tomomitsu Fujii	Hydrologist
3.	Mr. Kazuhiko Takayama	Telecommunication Expert

II. Typhoon Committee Secretariat

1.	Mr. Atsushi Hamamori	Hydrologist and Flood Forecasting Expert

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Flood Forecasting Project

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2.	Dr. Wiroj Sangvaree	Chief, Hydrometeorology Division
3.	Mr. Tawatchai Brikshavana	Chief, Hydrological Forecast Sub-Division

II. Royal Irrigation Department

1.	Mr. Damrong Jaraswathana	Special Grade Engineer and Chief, Hydrology Section, Survey Division
2.	Mr. Chalerm Tangtrongchit	Hydrologist, Survey Division

III. Electricity Generating Authority of Thailand

1.	Mr. Siri Chitchob	Hydrologist, Survey Division