3.3 Telecommunication Network and Facilities

Agencies related to this Study such as RID, EGAT, BMA and MD have telecommunication networks in the Chao Phraya River Basin. The telecommunication system of RID which is the major agency for flood protection works is mainly discussed in this section.

The public telecommunication systems operated by the Telecommunication Organization of Thailand (TOT), the Communication Authority of Thailand (CAT), and the Post and Telegraph Department (PTD) are considered to be useful to the flood forecasting system. Therefore, the condition of the telecommunication systems of these agencies are also briefly discussed.

RID

RID has 12 regional offices all over the country, and the Chao Phraya River Basin administratively belongs to Region Nos. 1, 2, 3, 7 and 8. Each regional office is divided into project offices which, in principle, have control over the gauging stations (refer to Fig. 3-8).

Communication between the head office in Bangkok and regional offices is made by voice communication link of one-way HF/SSB, while that between regional offices and project offices is dependent on the one-way HF/SSB radio link and/or the one-way VHF link. Radio and magneto telephones are used for the communication between project offices and some of the gauging stations (refer to Fig. 3-9). Aside from the above, TOT's public dial telephone system is also installed at the RID Head Office, its regional offices, project offices and important gauging stations.

The telecommunication network is shown in Figs. 3-8. The frequencies of 4810, 5830, 7855 and 7990 KHz are allocated for HF/SSB and those of 139.050, 139.100 and 141.000 MHz are for VHF. The power output of the radio equipment is 100 watts for HF/SSB and 100 watts or 60 watts for VHF.

Some communication by magneto telephone is not clear because the lines are superannuated and sometimes involve interference and noise due to bad weather. In general, voice communication through the VHF radio link can be heard clearly in case of short distance communication. As for the HF/SSB link connecting the head office with the regional offices, talking condition is practically good, though interference and noise are sometimes involved in communication in-between.

MD

The telecommunication network of MD is illustrated in Fig. 3-10. It consists of HF/SSB radio links among the head office, regional offices, gauging stations and radar stations. The system is used to collect meteorological data from the gauging and radar stations.

The number of observatories are 26 in the northern part, 19 in the middle part and 27 in the southern part. The meteorological data from observatories are collected by means of one-way HF/SSB radio telephone with frequencies of 6.550 KHz and 6.660 KHz. The power output of the HF/SSB equipment is 130 or 150 watts and its talking condition is good.

EGAT

The telecommunication system of EGAT which consists of microwave radio links and powerline carrier telephone links is used for the maintenance of power facilities, control of power distribution, data collection and communication of administrative matters. The network links the head office, the hydropower station, and the substation, as shown in Fig. 3-11.

Hydrological data are transmitted by the system mentioned above from the gauging stations at Bhumibol Dam, Sirikit Dam, and so on, to the head office in Bangkok. The microwave radio presently in use utilizes the 900 MHz band and the talking condition is good. Communication is kept in good condition even in flood time.

Since there is no definite connection line between EGAT and RID, data to the RID head office are forwarded by TOT telephone cable or delivered by hand. EGAT has a plan to expand its microwave system to cope with the present shortage of connection channel.

BMA

Bangkok Metropolitan Administration (BMA) has pumping stations for flood protection works. Communication between pumping station and the BMA head office is carried out by means of one-way VHF radio network (150 MHz band, 4 channels), but this is restricted to Bangkok. The condition of communication between pumping station and the BMA head office is good even in flood time.

Besides the above, BMA has a TOT line system with RID and MD. To upgrade the communication condition among offices concerned, improvement of the telecommunication system has been formulated by JICA and is presently being planned to be implemented.

LAD

The Local Administration Department (LAD) of the Ministry of Interior has a function to take countermeasures against natural disasters and others. It has various means of communication with provincial offices in emergency situations.

The present telecommunication facilities between LAD and provincial offices are the TOT telephone line (exclusive use of its channel), the one-way VHF radio for communication within 100 km in distance, and the one-way HF/SSB radio for long distance communication. The telecommunication network is not revealed for security reasons. At present, the communication between the RID head office and LAD is carried out by the TOT telephone.

TOT

TOT has a long distance microwave radio network and a telephone cable network covering the whole country. It installs the telecommunication network for commercial use. The microwave network in the Chao Phraya River Basin is as shown in Fig. 3-12.

In general, the microwave and telephone cables of TOT can be rented. Sometimes, some portions of the telephone cable in Bangkok is inoperable due to inundation in the rainy season, especially during a big flood lasting for several days.

CAT

CAT utilizes a satellite earth station network of INTELSAT, as shown in Fig. 3-13. Satellite earth stations on the Chao Phraya River Basin are located in Bangkok as master station, and at Nakhon Sawan, Phitsanulok, Lampang and Chiang Mai as substations.

CAT maintains a commercial telecommunication system for telephone services and data transmission by means of satellite communication and a UHF radio network. The satellite channel is rented for public use and so far, it is used by private and public firms located where the TOT line is not installed. The talking condition is good even in flood time.

PTD

PTD has a Domestic Satellite Communication Center (DSCC) in Bangkok, and the satellite channel is rented for communication among government offices.

Satellite communication uses transponders rented from PALAPA of Indonesia. Transponders of 1-3/4 (700 voice channels) are already being used by TV stations, the army and other agencies, and additional transponders of 1/4 (100 voice channels) are scheduled to be rented. However, it is necessary for the user of a PTD satellite channel to install a satellite earth station (SES) by itself.

3.4 Data Management System and Facilities

A data management system is composed of data collection system, data processing system and data dissemination system. The data management system of the agencies related to flood protection works such as RID, MD, EGAT, BMA and PAT have been investigated. These systems are presented in Fig. 3-14 and the details are described hereinafter.

3.4.1 Data Collection System

RID

Hydrological data have been collected for the management of irrigation facilities by the O&M Division and for hydrological analysis by the Hydrology Division, as shown in Fig. 3-18.

(1) Data Collection by the O&M Division

Data collected by the O&M Division are mainly from irrigation areas. According to the Report on Water Management System of Chao Phraya and Meklong Basins in April 1985, the data were collected from 212 rainfall stations and 100 water level/regulator stations. Besides the above, data of 84 rainfall stations observed by MD from April to November were also collected by the O&M Division.

Data are observed at 3-hour intervals starting from 6:00 o'clock in the morning to 9:00 o'clock at night. The data at 6:00 o'clock in the morning are usually reported the next morning between 8:00 and 10:00

o'clock through the Communications Division to the O&M Division.

During flood time, data at important stations for water management are reported promptly by radio on the basis of the request of the O&M Division. Data collection using personal computers between Regional Office No. 7 and the head office is being tried by the O&M Division under the guidance of the IEC Project.

(2) Data Collection by the Hydrology Division

Data collected in the Chao Phraya River Basin are rainfall (251 stations); water level (179 stations); meteorological data such as air temperature, relative humidity, atmospheric pressure, evaporation, etc. (33 stations); stream flow (96 stations) and sediment (18 stations).

These data are sent monthly by mail to the Hydrology Division in the RID Head Office from hydrological offices under the control of this division. Data from a few remote gauging stations are sent directly to the Head Office, and the data observed by other agencies such as MD, EGAT, and so on, are sent to the Hydrology Division by hand or mail irregularly.

MD

Weather and climatic conditions, as well as water level of major rivers, are observed by MD. MD operates 10 meteorological gauging stations and 4 water level gauging stations in the Chao Phraya River Basin. All water level gauging stations are located on the Pasak River and discharge measurement is carried out at two of these stations. Most of the data are collected at 3-hour interval (8 times a day) from observatories to the weather station at the Head Office of MD in Bangkok.

Rainfall condition over Thailand is monitored by eight (8) meteorological radars. The radars are used to know the rainfall area and the direction of its movement. Rainfall condition in the Chao Phraya River Basin is monitored at Chiang Mai and Bangkok radar stations.

EGAT

There are 20 meteo-hydrological gauging stations set up by EGAT in the middle and upper reaches of the Chao Phraya River. Meteo-hydrological data are collected by the EGAT Head Office through its branch offices. Out of the above data, hydrological data at dams are collected and transmitted daily to the EGAT Head Office.

BMA

Drainage control in Bangkok is managed by DDS of BMA. Water level data on the drainage channel and inundation area are observed and reported three times a day to DDS for the effective operation of flood mitigation facilities such as drainage pumps and gates. Other hydrological data related to flood protection works such as water level/discharge and tide in the main Chao Phraya River, as well as rainfall in the basin, are collected through the related agencies such as RID, MD and so on. The predicted flood water level of the main river estimated by EGAT is also collected.

PAT

Tidal water level is observed by PAT. Seven (7) automatic gauging stations are installed on the Chao Phraya lower reaches and estuary. The paper recordings are sent weekly to the head office by mail.

3.4.2 Data Processing System

Data processing for flood forecasting study will be executed by RID. Therefore, the existing data processing system of RID has been studied.

RID

Collected data are processed and stored by computer. Data processing for hydrological analysis is made by the Hydrology Division, while the simulation model of water management for irrigation is carried out by the O&M Division by using the daily data.

Outputs of the flood data processed consist of the flood scale, the rating curves at the gauging stations, hydrographs, etc. Data such as rainfall, water level, discharge, plantation condition of crops in the agricultural area and so on are compiled on the weekly basis, and the hydrological report which describes the flooding and inundation condition of the area, damaged condition of assets and properties, etc., is prepared as well.

Publications on data processing are prepared by the Hydrology Division and the O&M Division. The Hydrology Division prepares the Hydrological Yearbook, List of Rainfall Stations in Thailand, List of Water Level/Discharge Gauging Stations under RID, and the Monthly Runoff Report. The List of Structures under Operation of Irrigation Projects in Thailand, 1985, was prepared by the O&M Division.

Hydrological database as shown in Table 3-5 is being developed by the IEC Project. A computer system is installed at the Data Processing Division and terminals are provided in other divisions.

One super-minicomputer and two super-microcomputers were introduced in the Data Processing Division by the IEC Project. Some personal computers are used as stand-alone or work station of the minicomputer.

The super-minicomputer is actually utilized for multiple purposes, i.e., administrative and technical calculation, by multi-users. One of the super-microcomputers is used as data input machine. Another super-microcomputer is installed in the IEC Project Office for research.

According to the interview with the Data Processing Division, the computers are fully utilized and two more computers are planned to be installed in the near future. Personal computers are being installed in every regional office.

3.4.3 Data Dissemination System

Among the agencies concerned, EGAT is the only agency executing flood prediction works covering the whole Chao Phraya River Basin. RID sends the hydrological data needed for this purpose to EGAT by hand. Flood prediction results by EGAT are disseminated by hand to RID and BMA in the form of weekly reports.

3.5 Flood Forecasting Practice

Since 1979, flood forecasting in the Chao Phraya River Basin has been conducted by EGAT for use in dam operation, and the flood information is transmitted to RID and other agencies concerned. MD has been conducting the flood forecasting for the basins of tributaries of the Chao Phraya River, Pasak and Nan rivers, to provide information for flood fighting. In this portion of the report, the description is focused on the flood forecasting system of EGAT which has many points of similarity.

In the flood forecasting system of EGAT, the flood prediction model used is based on that developed by AIT in 1978. The model consists of sub-models, namely, Streamflow Synthesis and Reservoir Regulation, Empirical Runoff Calculation, Grid Model and Harmonic Model.

By using the sub-models mentioned above, future water stage is predicted seven days in advance at the Memorial Bridge point in Bangkok, together with the inflow volume to the Bhumibol and the Sirikit dams and the discharge at Nakhon Sawan Station.

3.6 Organization

The organizational set up of the Government of the Kingdom of Thailand is presented in Fig. 3-15. So far, there is no institution and legal framework carrying out integrated and comprehensive flood control, including flood forecasting and flood fighting. However, a few committees are concerned in flood fighting, and several agencies independently execute related activities in the Chao Phraya River Basin such as hydrological observation, flood forecasting, flood fighting, water flow control of the main stream and drainage works, as shown in Table 3-6.

With regard to flood forecasting, RID, MD, EGAT, BMA, HD, PAT, etc., mainly execute hydrological observation for their respective purposes. MD executes flood forecasting as part of its meteorological information services and EGAT also executes it in relation to the discharge of major dams on the tributaries of the Chao Phraya River.

In relation to flood fighting and flood damage mitigation, policy decisions and planning are tasked to the Civil Defence Committee. The LAD's responsibility as Secretariat of the Committee is flood fighting, especially in provincial areas.

In consideration of the serious flood damages in Bangkok Metropolitan Region (BMR) consisting of Bangkok and the five provinces of Nonthanburi, Samut Prakan, Nakhon Pathom, Pathum Thani and Samut Sakhon, the Bangkok Metropolitan Region Dvelopment Committee was created in 1986 by the order of the Prime Minister. The Committee is in charge of policy determination and planning of solutions to flooding problems; while the DDS of BMA executes flood fighting, river improvement and drainage works in Bangkok as the Secretariat of this Committee.

As for the flood mitigation in agricultural areas, RID executes water flow control, drainage works and flood fighting in the Chao Phraya River Basin. Flood fighting and drainage works for provincial urban areas are carried out by the respective provincial governments in cooperation with LAD, RID and the Department of Public Works (DPW) which carries out consulting services for public drainage works.

The organizational setup of the foregoing committees and agencies are described in the Supporting Report on Organization. Fig. 3-16 presents the organizational chart of RID which is tasked with a rather comprehensive flood control of the Chao Phraya River Basin compared to the other agencies.

Table 3-1. PRINCIPAL FEATURES OF BHUMIBOL AND SIRIKIT DAMS

Particulars		Features	
		Bhumibol Dam	Sirikit Dam
General Data	° River System and River Name	Chao Phraya Basin; Ping River	Chao Phraya Basin; Mae Nan River
	° Year of Completion	1964	1972
	° Purpose	I; P; F	I; P; F
	° Catchment Area	26,386 km^2	13,130 km^2
Dam	° Type	Concrete Arch Gravity Type	Earthfill Dam
	° Height	154.0 m	113.6 m
	° Crest Elevation	261.0 m (MSL)	169.0 m (MSL)
	° Crest Length	486.0 m	800.0 m
Reservoir	° Maximum High Water Level (HWL)	262.2 m (MSL)	166.0 m (MSL)
	° Normal HWL	260.0 m (MSL)	162.0 m (MSL)
	° Minimum HWL	213.0 m (MSL)	128.0 m (MSL)
	° Available Drawdown	47.0 m	34.0 m
	° Storage at Normal HWL	13,462 x 10^6 m^3	9,510 x 10^6 m^3
	° Storage at Minimum HWL	3,800 x 10^6 m^3	2,850 x 10^6 m^3
	° Effective Storage	8,600 x 10^6 m^3	8,800 x 10^6 m^3
	° Minimum Water Level for Power Operation	213.0 m (MSL)	128.0 m (MSL)
	° Minimum Water Level for Irrigation	202.5 m (MSL)	105.75m (MSL)
Spillway	° Type	Tunnel Type	2 Tunnels, horse shoe section
	° Crest Elevation	242.9 m (MSL)	150.5 m (MSL)
	° Control Gate	Radial Gate (11.0m wide x 17.4 m high x 4)	Radial Gate (11.85m wide x 15.00 m high x 2)
Intake Structure	° Intake Gate	7 Fixed Wheel Gates	1 Fixed Wheel Gate
	° Gate Size	4.2m x 6.7m	6.0m wide x 8.5m high
	° Base Elevation of Inlet	201.0 m (MSL)	105.75m (MSL)
Discharge	° Design Flood Discharge	6,000 m^3/s	8,000 m^3/s
	° Maximum Flood Recorded	4,500 m^3/s (1975)	/1
	° Discharge Capacity of Spillway	6,000 m^3/s	3,250 m^3/s
	° Discharge Capacity of River Outlet	200 m^3/s (Use No. 8 Penstock)	400 m^3/s
	° Discharge for Maximum Power Output Per Unit	No. of Turbines: 7 units	No. of Turbines: 3 units
	- At Max. Head	when 123.2m, 75.8 m^3/s	when 84.3m, 194.3 m^3/s
	- At Nor. Head	when 100.0m, 79.5 m^3/s	when 75.4m, 183.0 m^3/s
	- At Min. Head	when 71.8m, 61.0 m^3/s	/1

Note: I = Irrigation; P = Power Generation; F = Flood Control

/1 = Data not available

Table 3-2. MAJOR RIVER STRUCTURES IN THE LOWER REACHES FROM NAKHON SAWAN

Water Course	Name of Structure	Location (Province)	Structural Features				Full Supply Level (m MSL)		Flood Level (m MSL)		Design Flow (m^3/s)
			Gate			Sill Elevation (m MSL)	Upper	Lower	Upper	Lower	
			Type	Number	Width (m)						
Chao Phraya River	Chao Phraya Dam (Barrage)	Chai Nat	° Radial Gate ° Miter Gate	16 1	12.50 14.00	+9.00 +9.00	+16:50	+7.50	+18.00	+16.00	3,300.0
Suphan River	Phonlatep Head Regulator	Chai Nat	Slide Gate	4	6.50	+7.50	+16.50	+13.90	+19.40	+15.86	320.0
	Ban Thabot Regulator	Chai Nat	Radial Gate	4	6.00	+8.75	+13.50	+9.80	+13.73	+13.68	318.0
	Sam Chook Regulator	Suphan Buri	Slide Gate	2	12.50	+2.50	+9.15	+6.30	+9.52	+9.31	318.0
	Pho Phraya Regulator	Suphan Buri	Slide Gate	2	12.50	+0.20	+6.00	+0.75	+5.91	+5.82	318.0
Noi River	Boromma-that Head Regulator	Chai Nat	Radial Gate	4	6.00	+9.60	+16.00	+15.10	+18.24	+16.20	260.0
	Channasut Regulator	Sing Buri	Radial Gate	4	6.00	+5.72	+11.60	+9.73	+11.84	+11.40	260.0
	Yang Mani Regulator	Sing Buri	Radial Gate	4	6.00	+2.32	+7.74	+6.16	+7.74	+7.30	260.0
	Phak Hai Regulator	Ayutthaya	Radial Gate	3	6.00	-2.00	+3.50	+3.30	+3.50	+3.30	150.0
Chai Nat-Pasak . Canal	Manorom Head Regulator	Chai Nat	Radial Gate	6	6.00	+12.80	+16.472	+16.142	+20.00	+16.142	210.0
	Chongkae Regulator	Chai Nat	Radial Gate	6	6.00	+9.50	+13.390	+13.150	-	-	207.0
	Koke Kathiem Regulator	Lop Buri	Radial Gate	4	6.00	+6.29	+10.79	+10.59	-	-	174.1
	Reong Rang Regulator	Saraburi	Radial Gate	3	6.00	+3.97	+8.53	+8.27	+9.810	+9.810	131.0
Chai Nat-Ayutthaya Canal	Maharaj Head Regulator	Chai Nat	Radial Gate	3	4.00	+11.60	+16.00	+15.50	+18.00	-	75.0
Makamthao-Uthong Canal	Makamthao-Uthong Head Regulator	Chai Nat	Slide Gate	6	1.75	+13.75	+16.10	+15.95	-	-	35.0
Pasak River	Rama VI Barrage	Saraburi	Slide Gate	6	12.50	+0.10	+7.50	-	+9.81	-	Unknown

Table 3-3. MAJOR RIVER STRUCTURES IN THE UPPER REACHES FROM NAKHON SAWAN

Water Course	Name of Structure	Location (Province)	Structural Features					Retention Level (m MSL)	Flood Level (m MSL)		Design Flow (m^3/s)
			Type	Number	Width (m)	Height (m)	Sill Elevation (m MSL)		Upper	Lower	
Yom River	Mae Yom Weir	Phrae	Fixed Weir & Rubber Dam	5	68.80	3.50	+178.00	+181.50	+183.75	+183.00	3,000
Nan River	Phitsanulok Diversion Weir (Naresuan Dam)	Phitsa-nulok	Movable Radial Gate	5	12.50	7.60	+40.20	+47.80	+50.35	+49.75	1,600
Thap Salao River	Thap Salao Diversion Weir	Uthai Thani	Fixed Weir	6 2 2	8.0 9.9 3.0	3.00	+71.00	+74.00	+77.25	+76.40	700
Yom to Nan River (Curtain Canal)	Control Regulator	Phitsa-nulok	Radial Gate	2	6.0	4.00	+33.975	/1	+37.675	+36.750	85
Yom to Nan River (DR 15.8 Canal)	Control Regulator No. 1	Phitsa-nulok	/1	/1	/1	/1	/1	/1	/1	/1	60
	Control Regulator No. 2	Phitsa-nulok	/1	/1	/1	/1	/1	/1	/1	/1	60

Note: /1 Data not available yet.

Table 3-4. MAXIMUM RELEASED WATER FROM DIVERSION STRUCTURES

(Unit: m^3/s)

Water Course and River Structure	Design Flow	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Chao Phraya River		1975	345	220	85	115	245	470	560	990	3,000	3,980	2,330	905
		1978	359	200	91	77	140	149	1,629	1,468	2,240	3,769	1,782	395
° Chao Phraya Dam	3,300	1980	131	73	121	73	723	1,005	1,075	1,195	2,210	3,825	2,195	440
		1983	140	115	130	113	120	245	120	800	1,000	3,370	2,625	1,530
Chainat-Pasak Canal		1975	64	100	106	171	171	165	214	232	280	266	273	80
		1978	49	102	117	118	103	92	150	210	238	153	245	161
° Manorom Regulator	210	1980	147	52	54	43	210	192	213	225	192	376	207	121
		1983	148	144	150	152	155	150	145	184	182	205	210	95
Noi River		1975	33	70	76	81	86	71	105	253	231	250	251	130
		1978	40	62	80	71	86	102	61	180	251	200	240	200
° Borommathat	260	1980	161	140	102	51	111	70	151	241	262	263	151	102
Regulator		1983	51	108	141	141	131	97	61	186	271	251	61	46
Suphan River		1975	22	92	124	142	143	80	103	125	107	318	286	82
		1978	74	55	102	153	114	111	90	146	225	292	280	102
° Phonlatep Regulator	320	1980	54	36	66	56	126	91	127	126	176	318	61	12
		1983	81	131	151	151	161	101	71	81	191	191	16	5
Chainat-Ayutthaya Canal		1975	-	-	-	-	-	-	-	-	-	-	-	-
		1978	-	-	-	-	-	-	-	-	-	-	-	-
° Maharaja Regulator	75	1980	20	25	25	20	26	20	54	76	78	68	54	20
		1983	0	25	27	39	38	16	56	63	70	70	70	39

Table 3-5. DATA BASE BY IEC PROJECT

1. General Information

   1.1 D River and Province
   1.2 D Administration
   1.3 D Map Information

2. River Flow Information

   2.1 F Rating Curve and Stage-Discharge Conversion
   2.2 D Hourly Gauge Height
   2.3 F Cross Section
   2.4 F Sedimentation
   2.5 C Water Quality

3. Weather Information

   3.1 F Daily Rainfall
   3.2 C Hourly Rainfall
   3.3 D Meteorological Data
   3.4 C Annual Heaviest Rainfall and Its Duration

4. Irrigation Water

   4.1 D Daily High and Low Discharge
   4.2 C Discharge Calculation Formula or Coefficient
   4.3 C Facilities Cross Section

5. Reservoir

   5.1 C Daily (Volume), Water Level, Inflow, Release, Evaporation and Rainfall

   5.2 C Water Level and Volume

6. Crop

   6.1 D Rice
   6.2 D Field Crop
   6.3 D Sugarcane
   6.4 D Vegetables
   6.5 D Perennials
   6.6 D Fishponds

Note: F = existing file system; D = under development; C = under consideration

Table 3-6. AGENCIES EXECUTING FLOOD CONTROL AND FORECASTING IN THE CHAO PHRAYA RIVER BASIN

Agencies	Hydrological Observation & Analysis	Flood Forecasting	Flood Fighting	River Improvement & Water Flow Control of Mainstream	Drainage Works
Royal Irrigation Department	⬤		•	⬤	⬤
Meteorological Department	⬤	•			
Electricity Generating Authority of Thailand	•	•			
Bangkok Metropolitan Administration	•		•	•	•
Harbour Department	•				
Port Authority of Thailand	•				
Local Administration Department			•		
Department of Public Works					•
Provincial Government			•		•

Note: ⬤ Major Activity, • Minor Activity

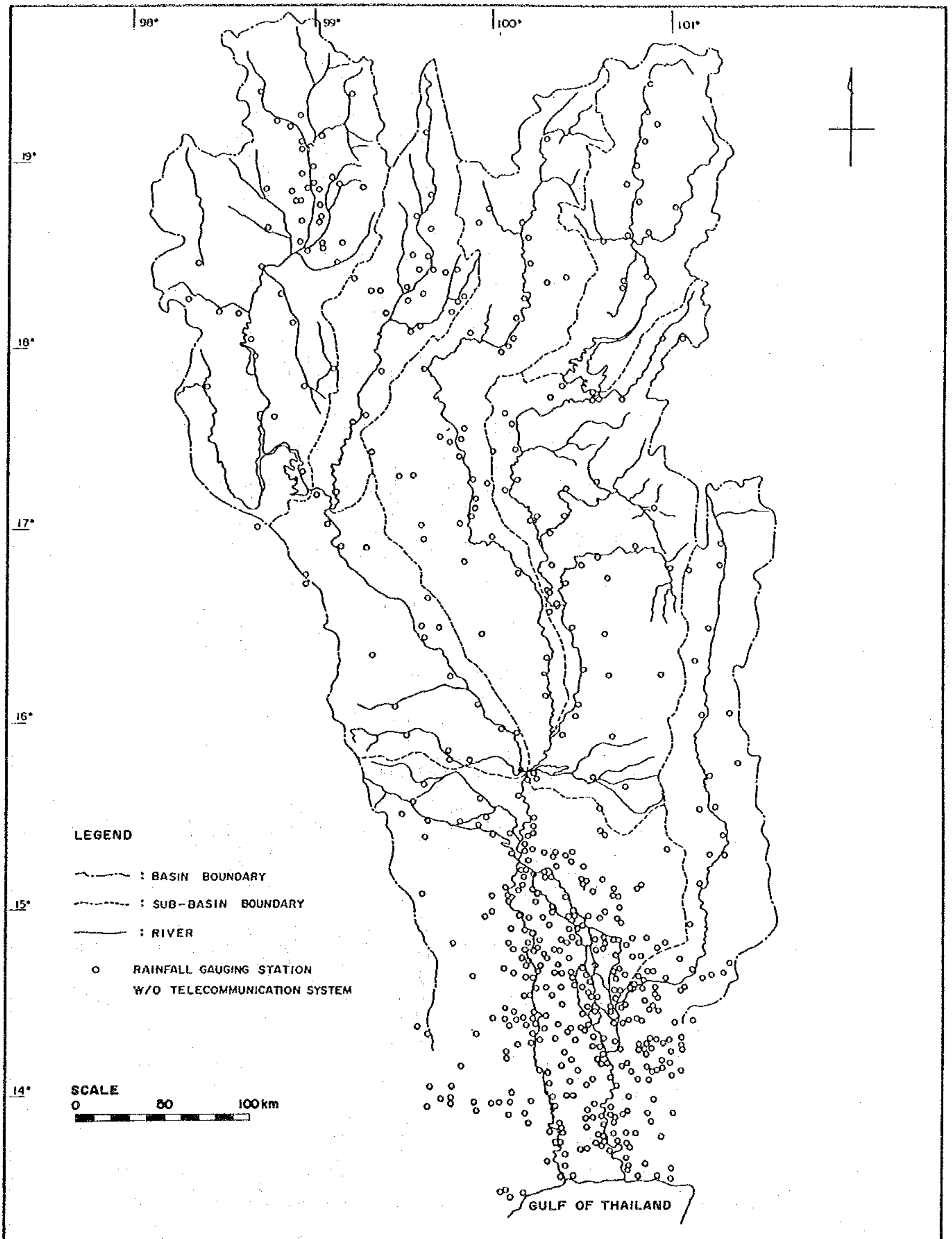


Fig. 3-1 LOCATION MAP OF EXISTING RAINFALL GAUGING STATIONS

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

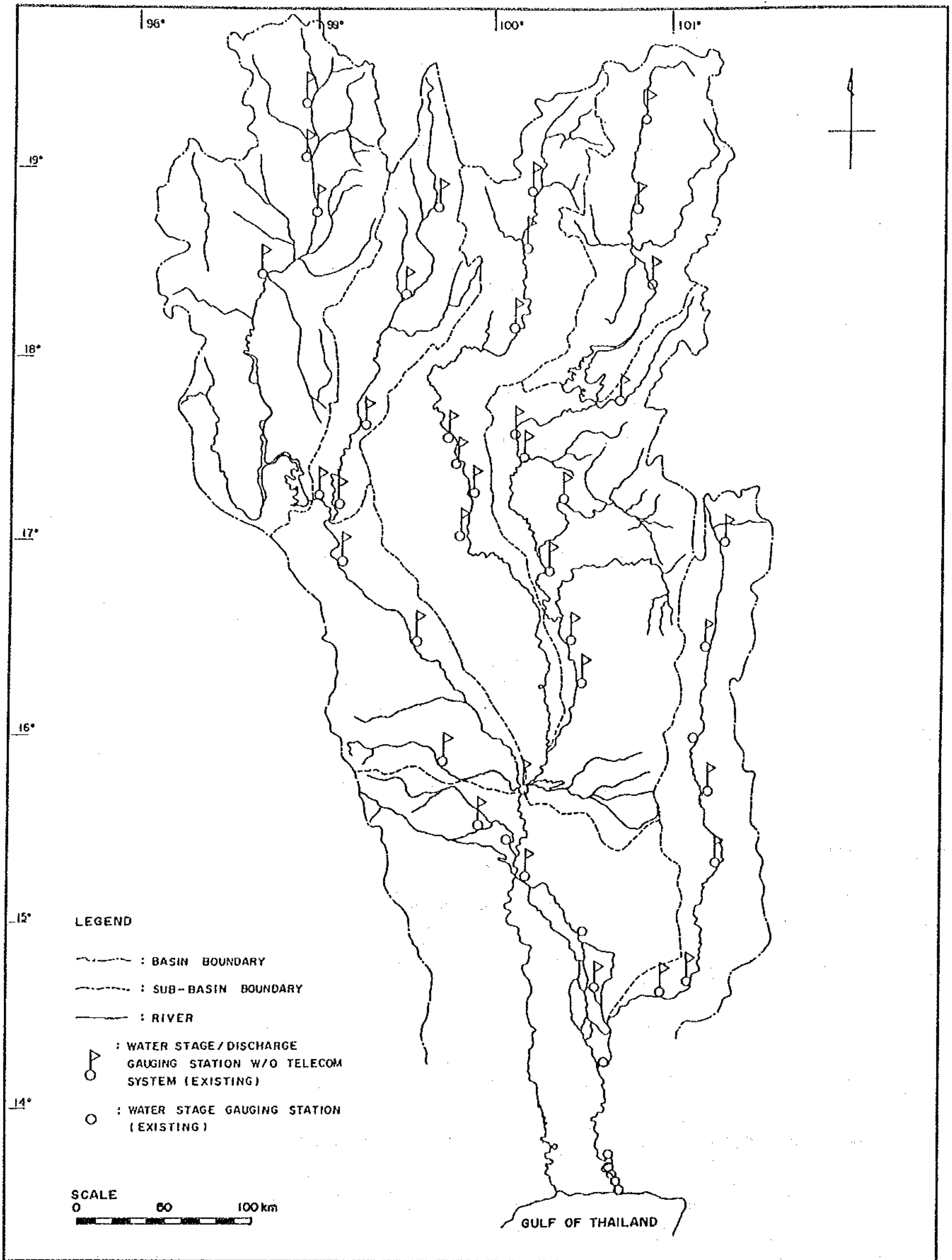


Fig. 3-2. LOCATION MAP OF EXISTING KEY WATER STAGE AND DISCHARGE GAUGING STATIONS	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

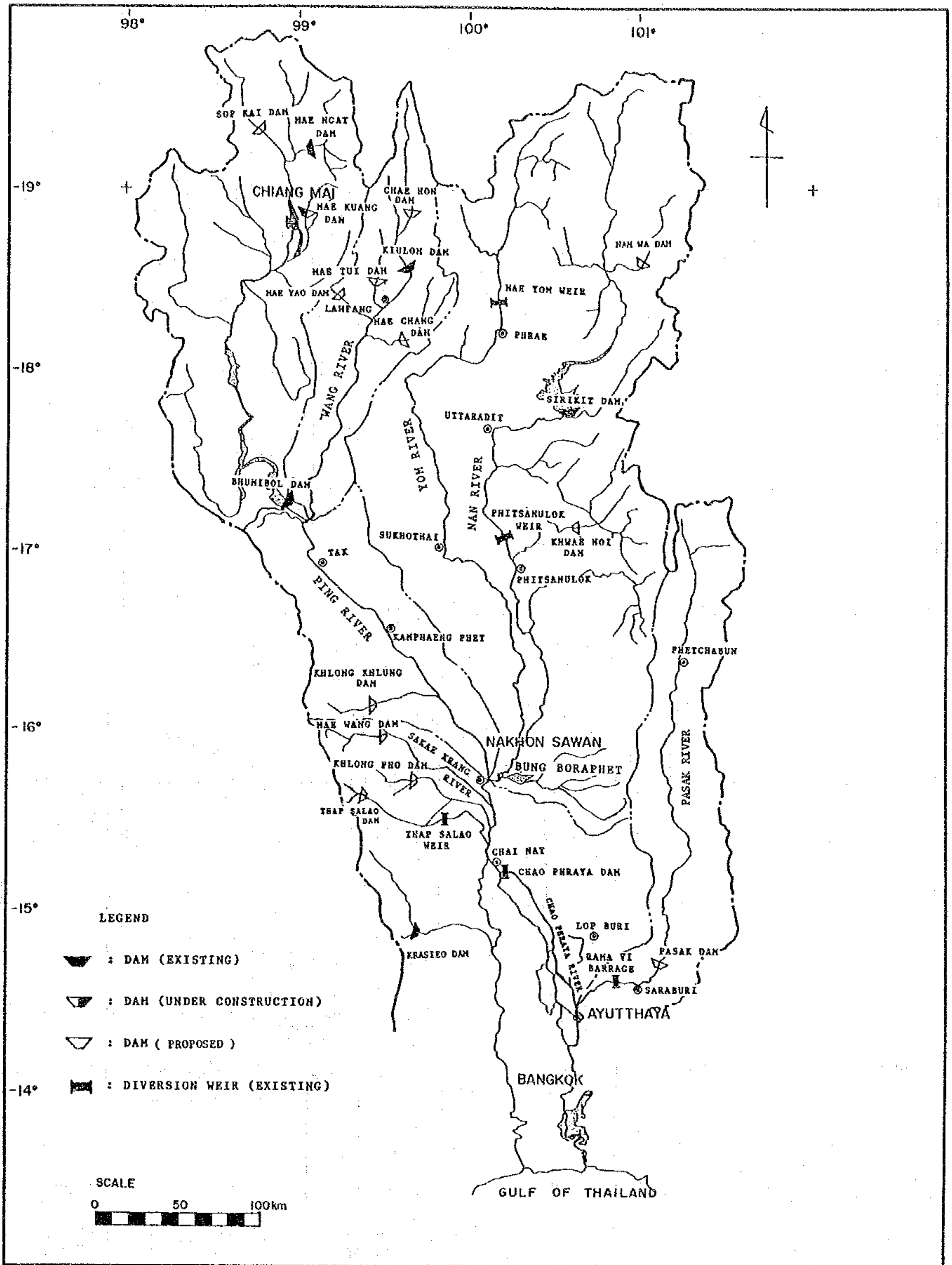


Fig. 3-3. LOCATION OF DAMS AND DIVERSION WEIRS/BARRAGES

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

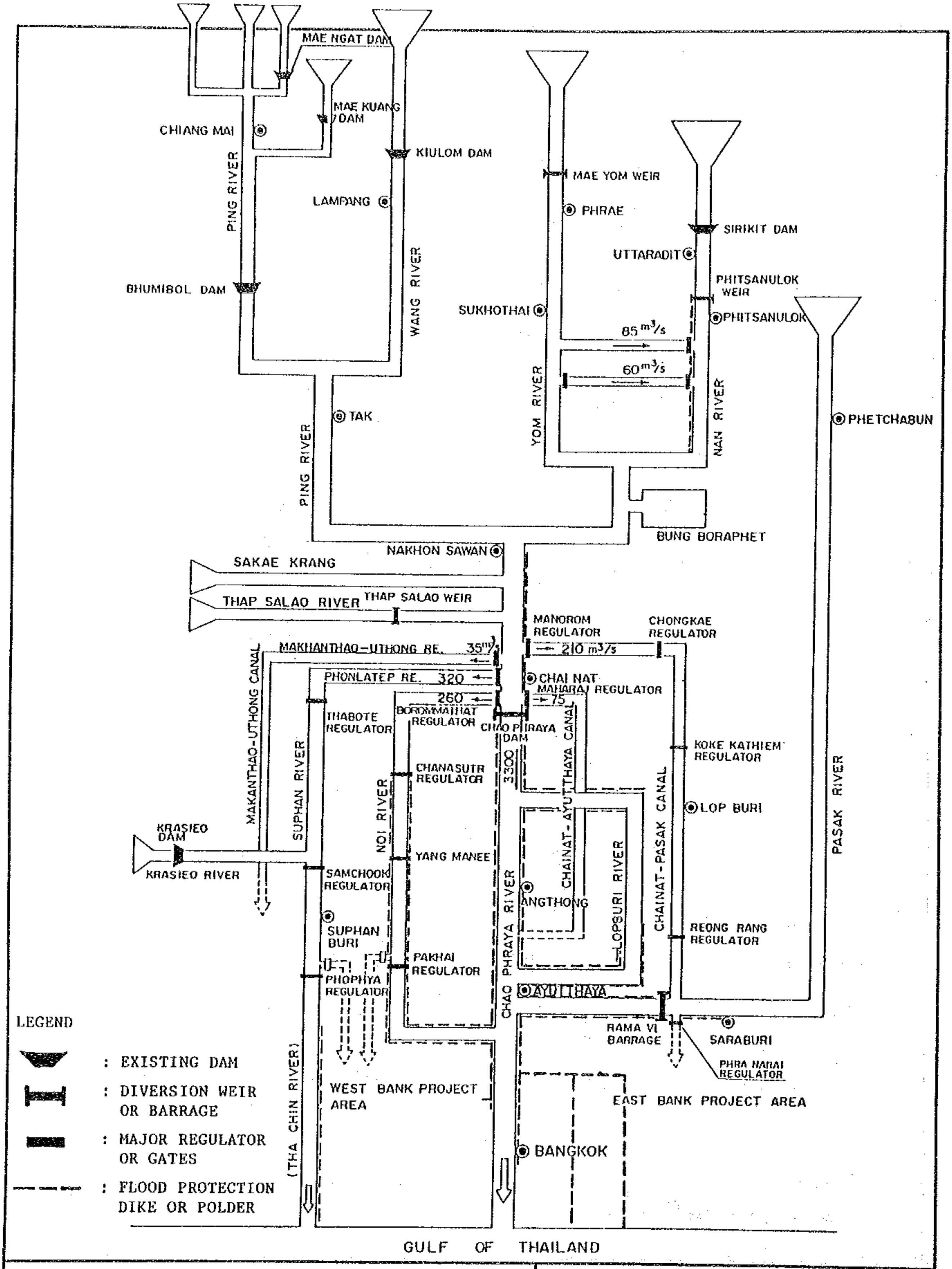
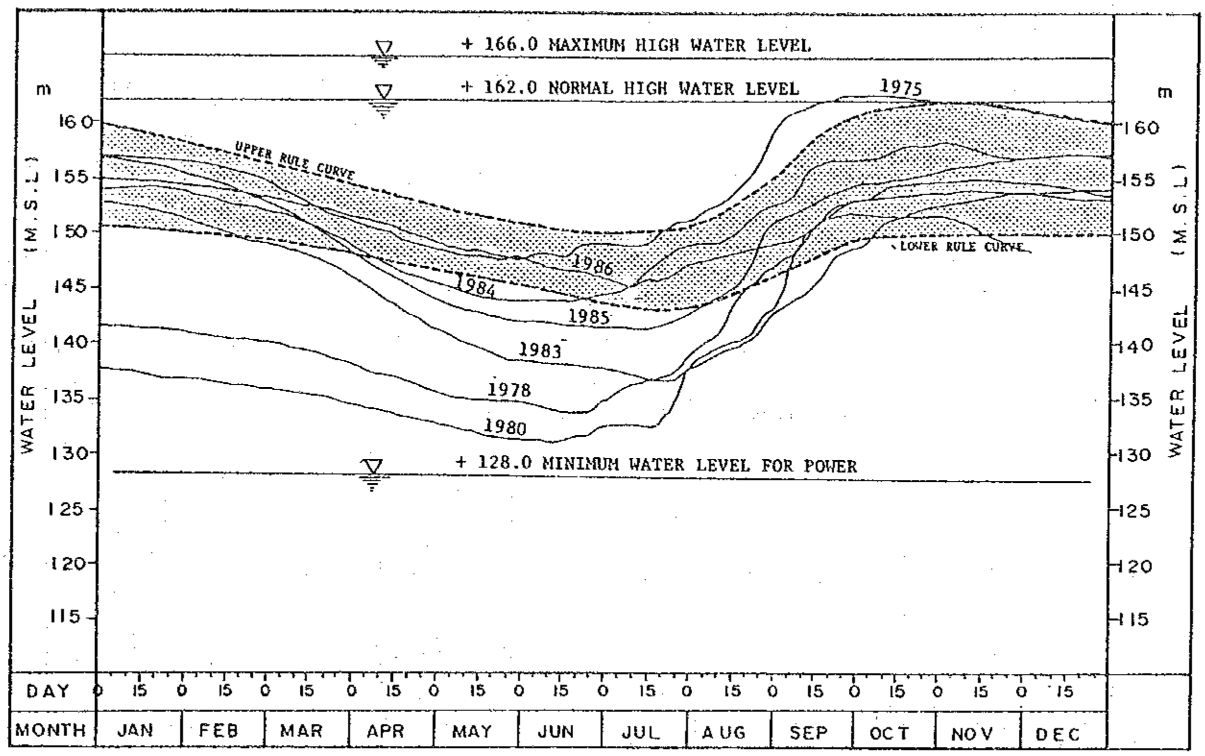


Fig. 3-4. MAJOR RIVER STRUCTURES

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

SIRIKIT DAM



BHUMIBOL DAM

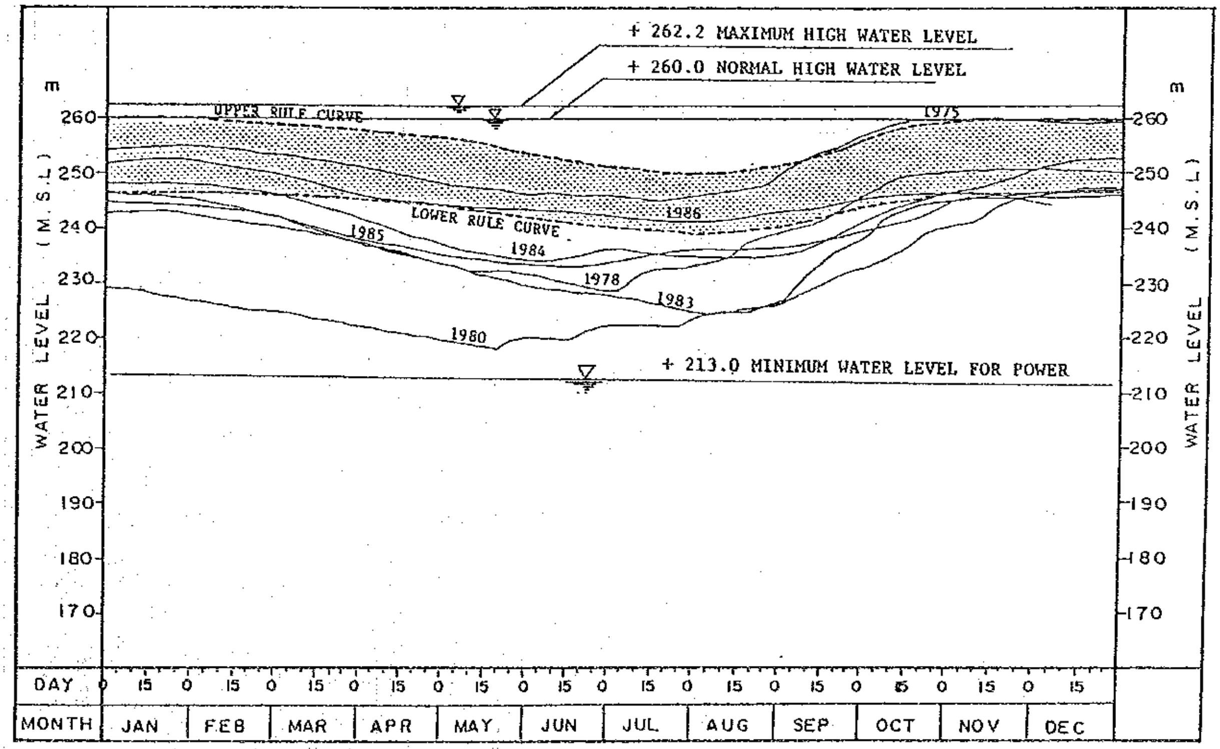


Fig. 3-5. RESERVOIR WATER LEVEL OF SIRIKIT AND BHUMIBOL DAMS

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

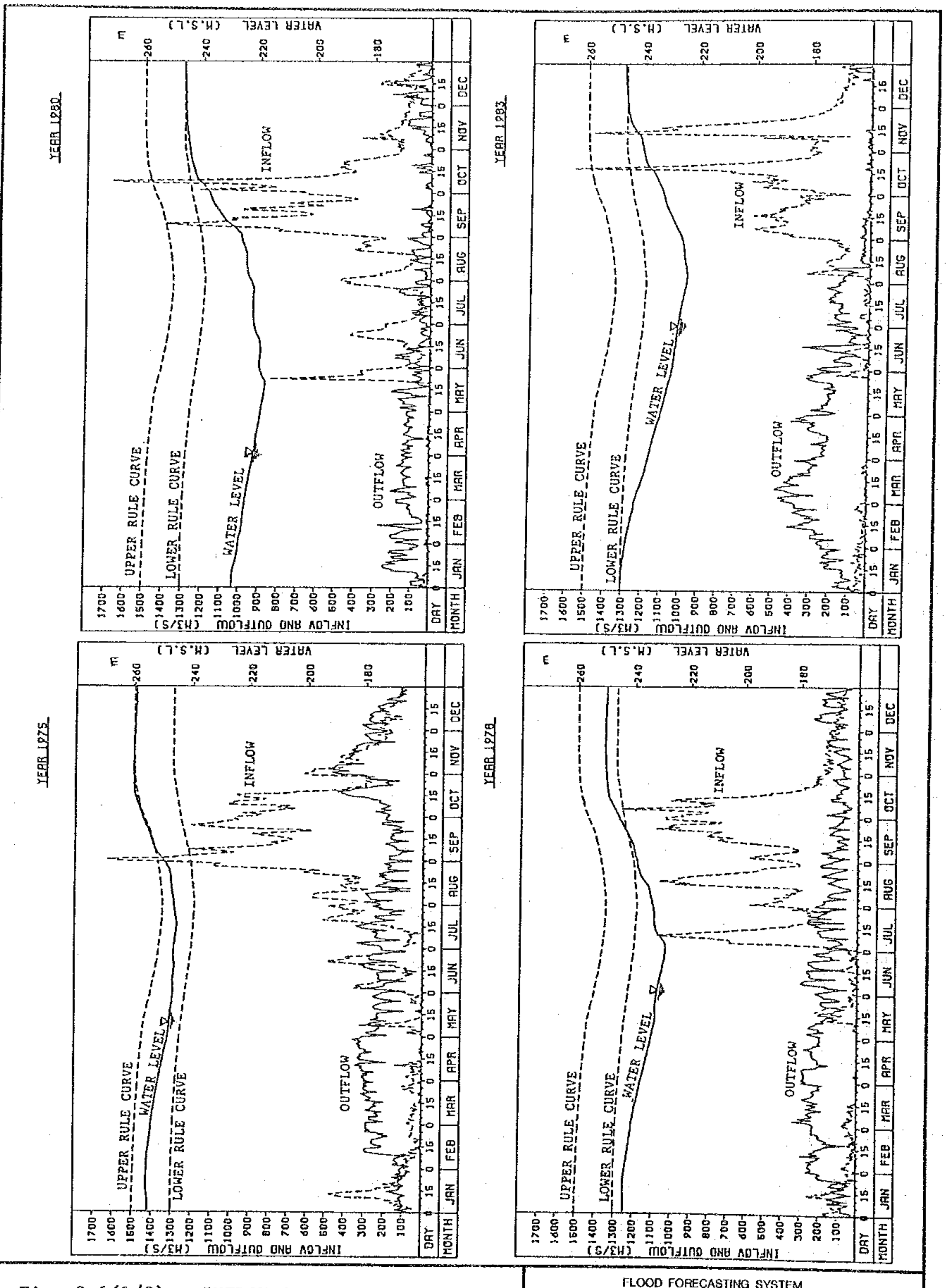


Fig. 3-6(1/2). INFLOW AND OUTFLOW OF RESERVOIRS (BHUMIBOL DAM)

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

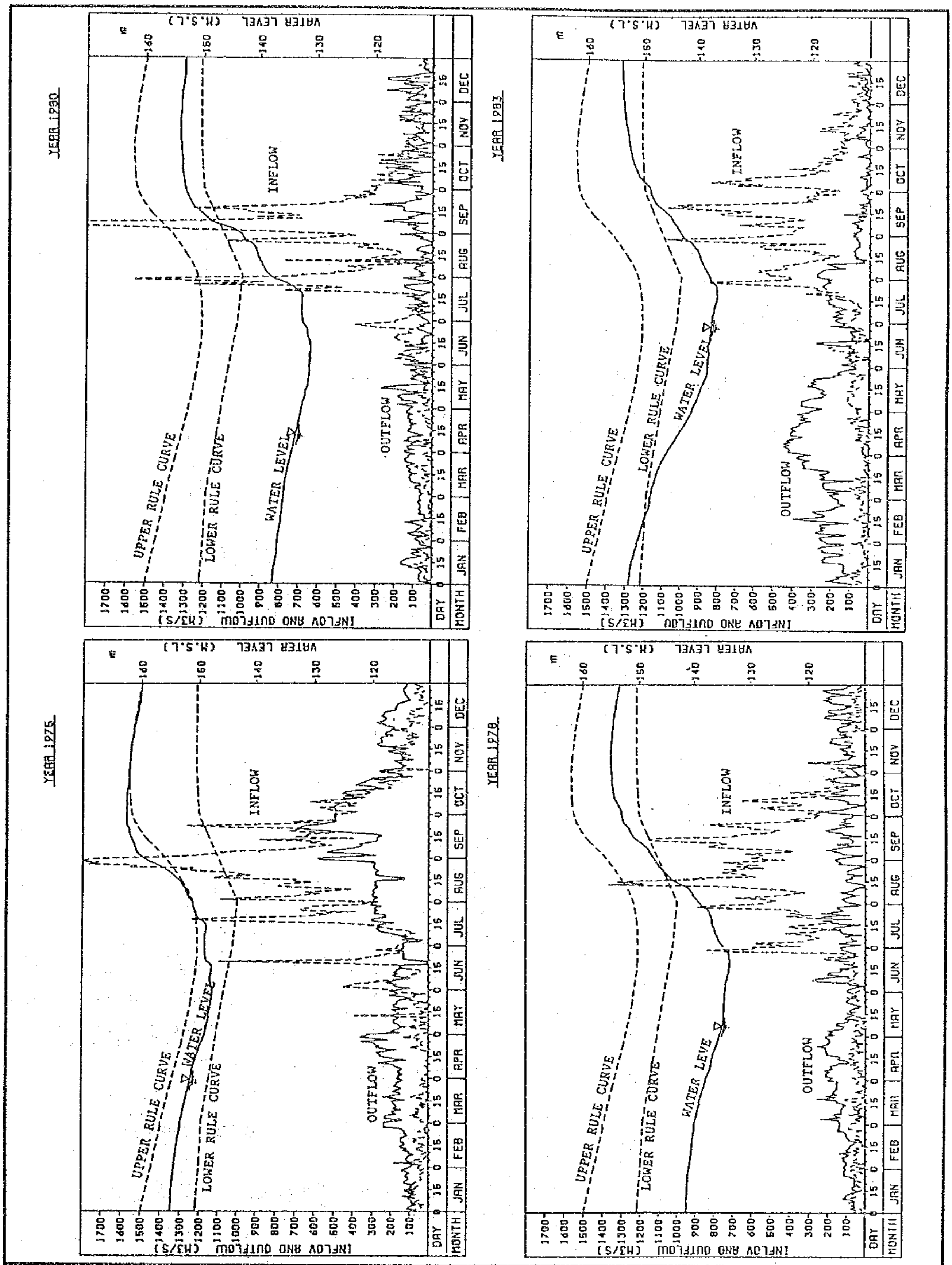


Fig. 3-6(2/2). INFLOW AND OUTFLOW OF RESERVOIRS (SIRIKIT DAM)

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

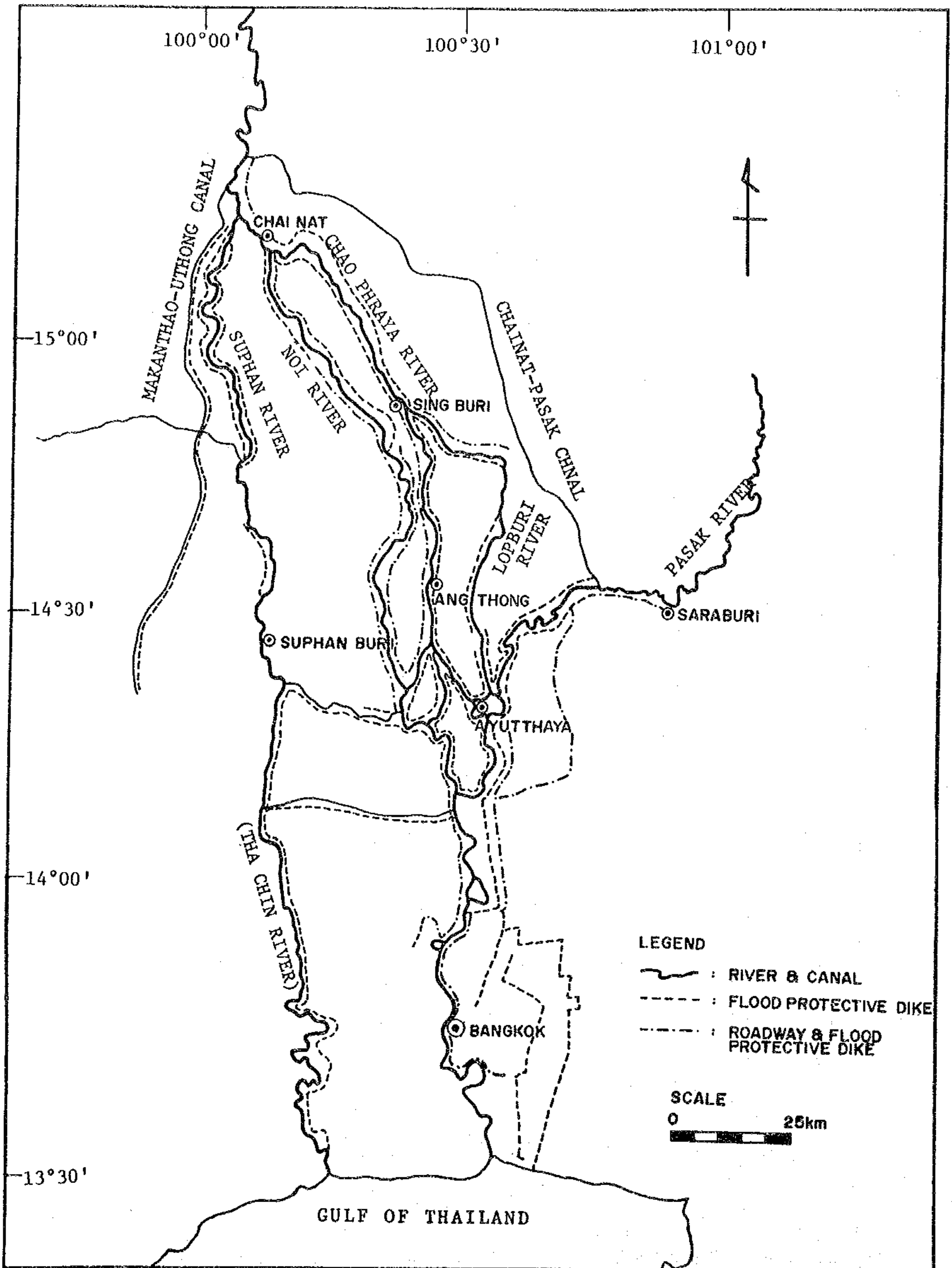


Fig. 3-7. EXISTING DIKE ALIGNMENT IN THE LOWER REACHES FROM NAKHON SAWAN

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

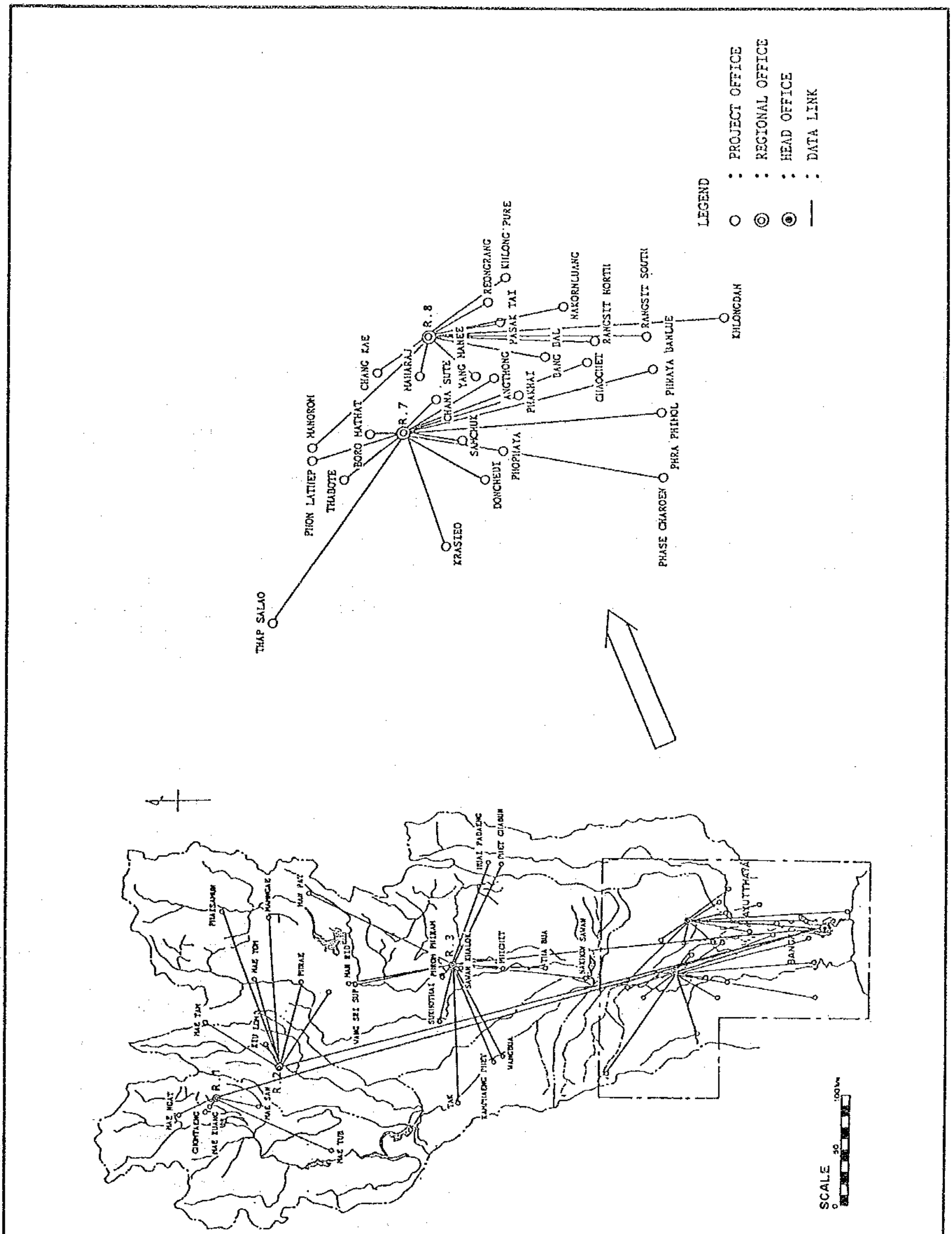


Fig. 3-8. RID TELECOMMUNICATION NETWORK

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

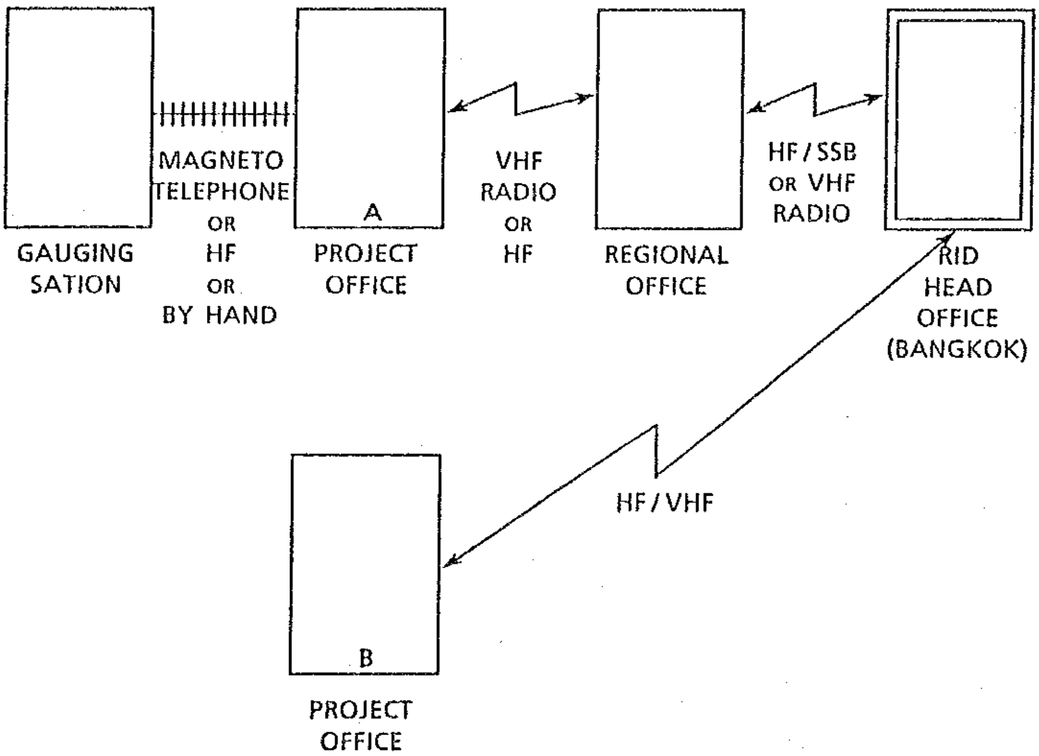


Fig. 3-9. CONFIGURATION OF RID TELECOMMUNICATION SYSTEM

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

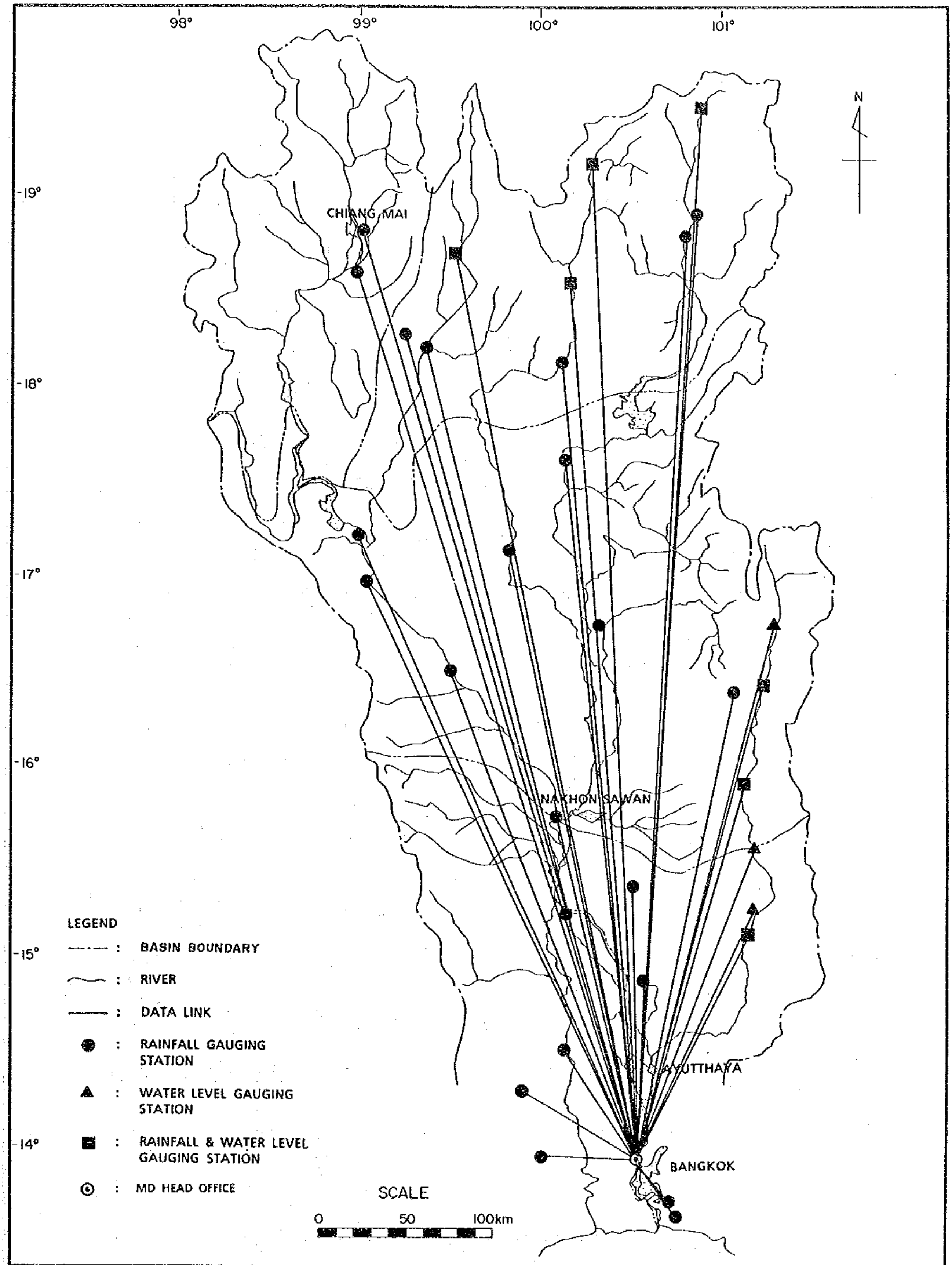


Fig. 3-10. MD TELECOMMUNICATION NETWORK

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

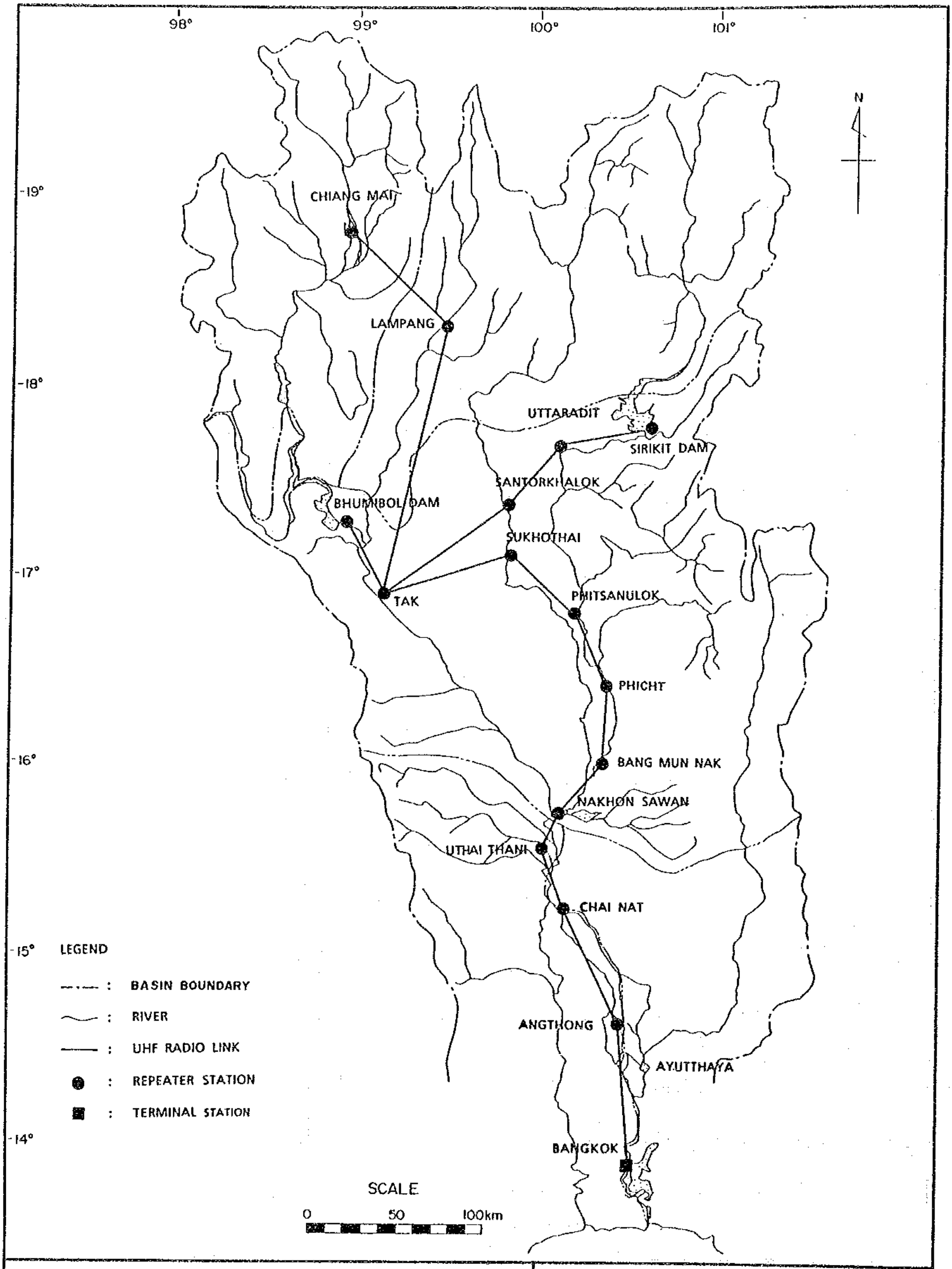


Fig. 3-11. EGAT MICROWAVE NETWORK

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

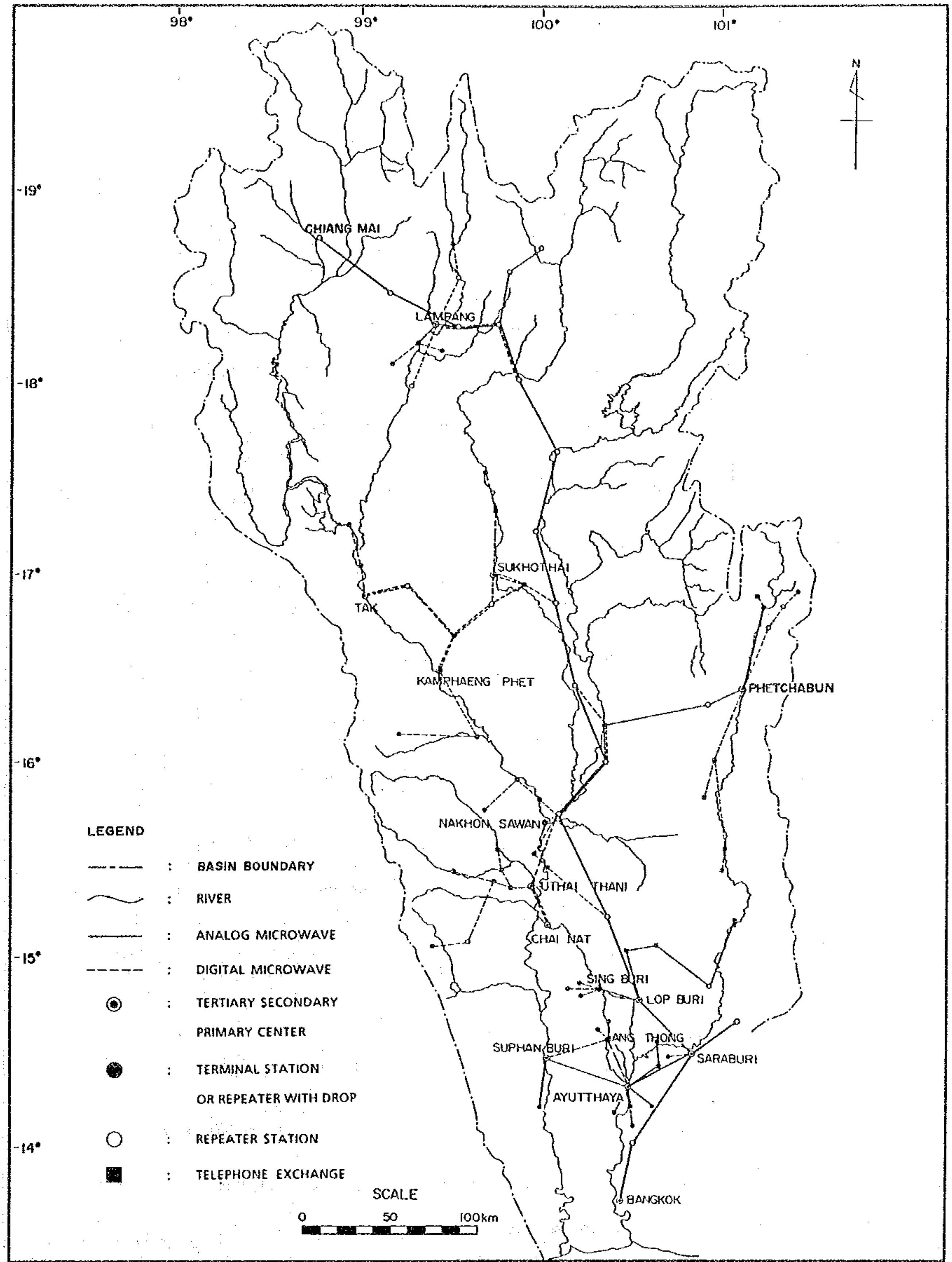


Fig. 3-12. TOT MICROWAVE NETWORK

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

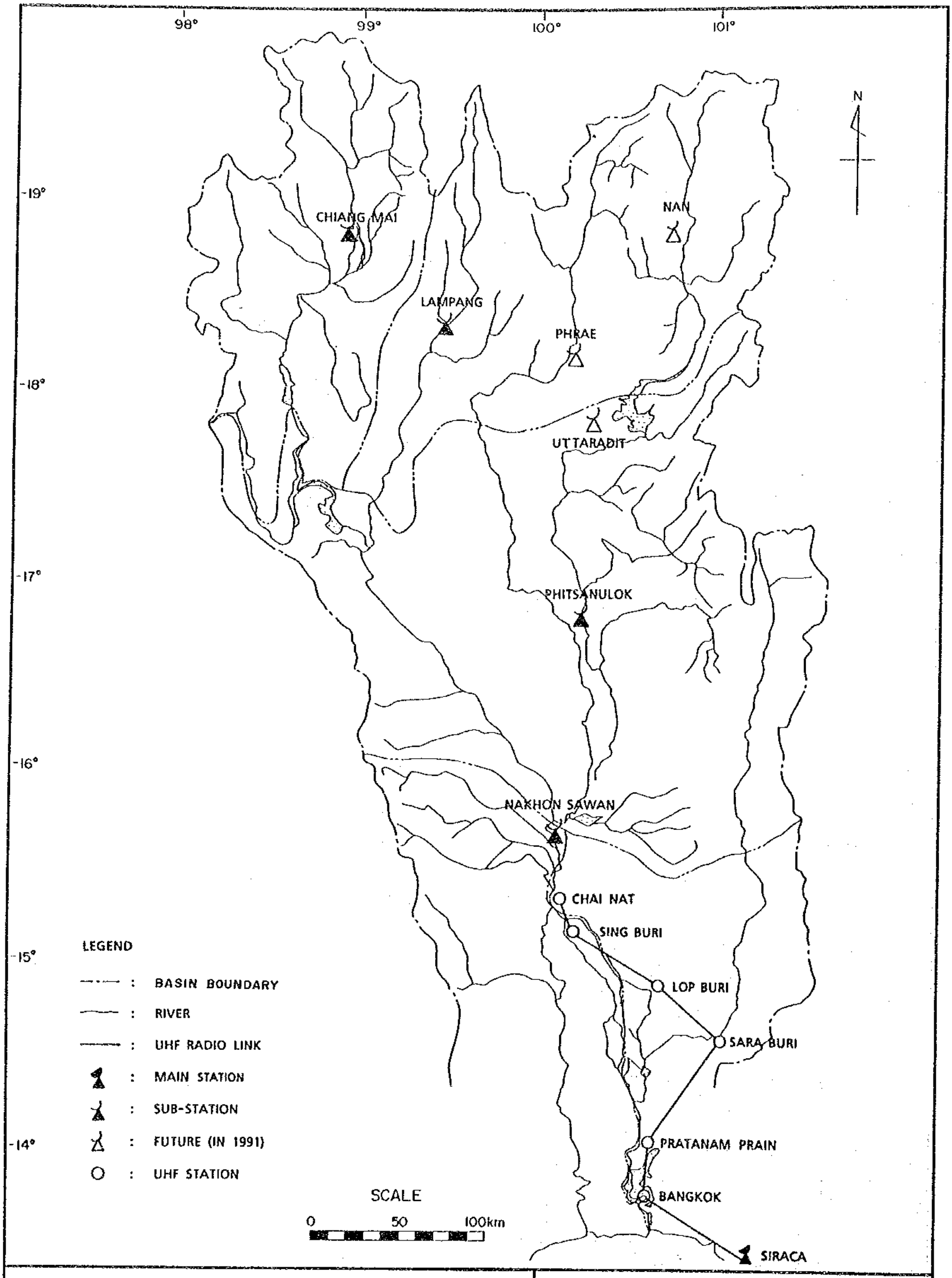


Fig. 3-13. CAT TELECOMMUNICATION NETWORK

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

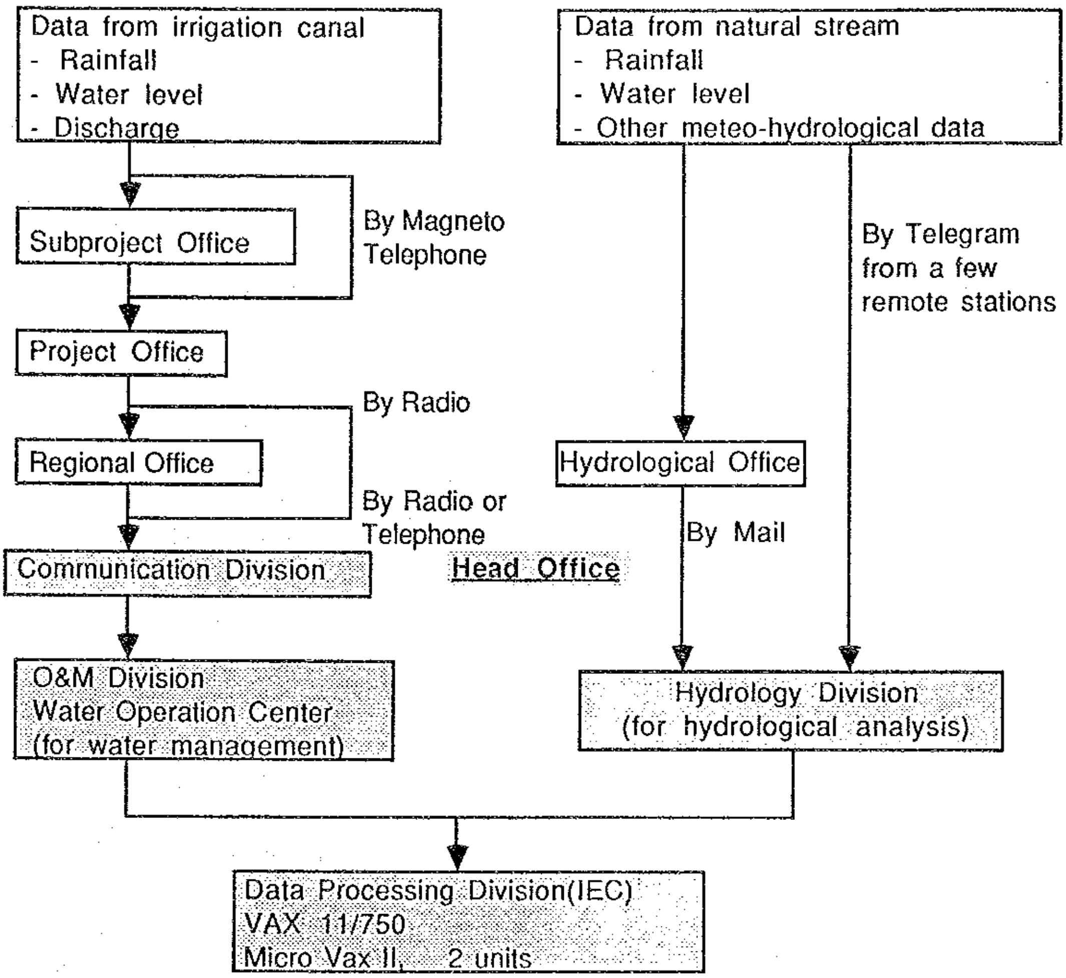


Fig. 3-14. DATA MANAGEMENT SYSTEM OF RID	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

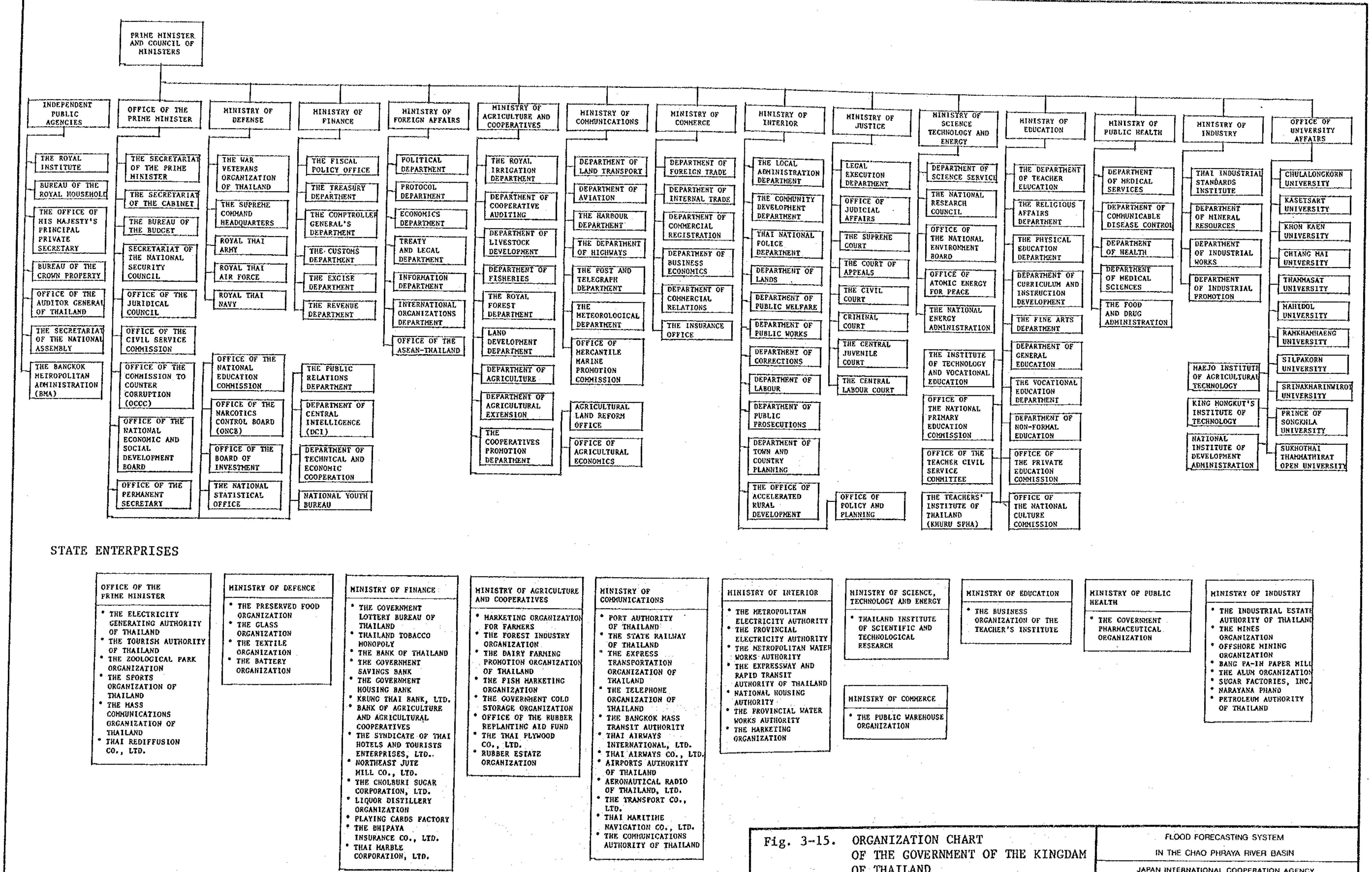


Fig. 3-15. ORGANIZATION CHART OF THE GOVERNMENT OF THE KINGDAM OF THAILAND

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

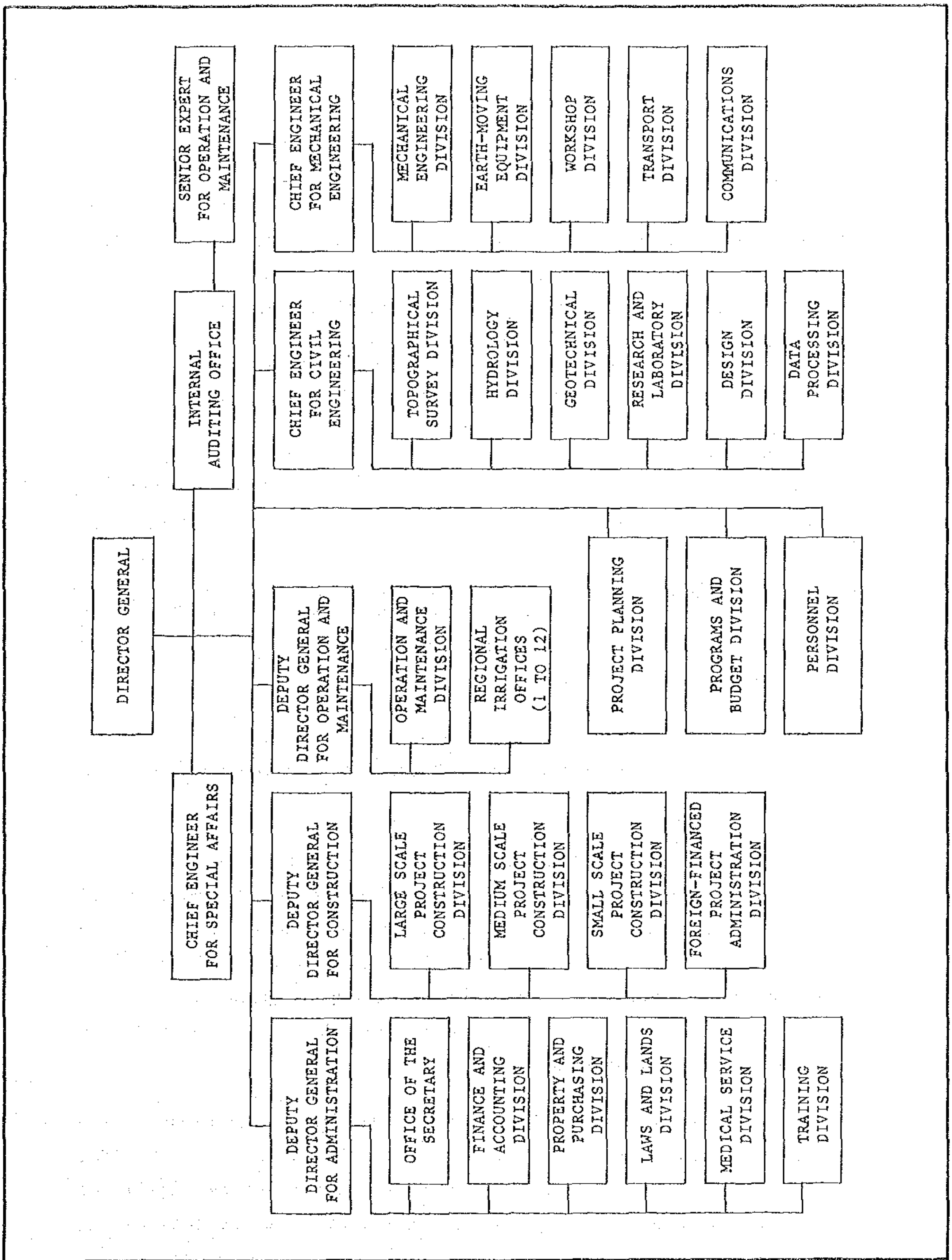


Fig. 3-16. ORGANIZATION CHART OF THE ROYAL IRRIGATION DEPARTMENT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 4. CONCEPT OF PROJECT FORMULATION

The Flood Forecasting System in the Chao Phraya River Basin aims to mitigate flood damage through the effective control by river structures, the execution of flood fighting works, etc., based on advance information on flooding water in the Target Area. To predict the future flood discharge on the area precisely at the necessary flood prediction time, the flood forecasting system should be established with the following considerations:

(1) To install hydrological observation stations that can grasp the flood condition precisely;

(2) To set up a telecommunication network that can operate with the least manual intervention which may cause incidental error in the transmission of data;

(3) To provide a computerized data management system that can process the numerous flood data promptly and prevent the occurrence of error; and

(4) To set up a data dissemination system to the agencies concerned that can operate with the least manual intervention and avoid the occurrence of error.

Since the updating of telecommunication facilities and computer systems is required, together with quite a number of hydrological observation facilities, it may take a long time and a lot of fund to attain the above considerations and realize a new system. It may also be necessary to conduct an extensive training of personnel on the operation and maintenance of the new system, while the flood damage problem has to be resolved urgently.

At present, hydrological observation networks, telecommunication networks and data management systems exist under RID, MD, EGAT, BMA, etc., for their own purposes. By employing the existing facilities with the introduction of supplemental equipment, a flood forecasting system in the Chao Phraya River Basin can be realized at a lesser cost and within a shorter period of time, but the reliability of flood prediction results may not be so high compared with those of an updated system.

Under the above circumstances, the flood forecasting system is formulated in two steps, namely, Step 1 and Step 2, as follows:

Step 1: Flood forecasting system utilizing the existing facilities with the introduction of supplemental equipment and with lesser emphasis on the accuracy of flood prediction results.

Step 2: Flood forecasting system with updated facilities having a high reliability of flood prediction results.

Among those currently executing related works, several agencies may be proposed as the executing agency for the flood forecasting system. However, the flood forecasting system project is an essential prerequisite to the comprehensive flood control project in the Chao Phraya River Basin, so that it is desirable that the agency presently responsible for flood control in the basin be also held responsible in managing the flood forecasting system.

In view of the above, this study is made on the premise that the Royal Irrigation Department (RID), which is considered as the agency responsible for flood control in the Chao Phraya River Basin, will manage the flood forecasting system for the Basin.

CHAPTER 5. BASIC STUDY AND ANALYSIS

5.1 Selection of Target Areas and Flood Prediction Points

Target Areas

The target areas were selected from the lower reaches of Nakhon Sawan where flood damage has frequently and widely occurred and thus require a flood forecasting system to mitigate the damage through flood prevention activities. The conditions for selection are as follows:

(1) Areas that suffer from damage caused by flood from the Chao Phraya River and its main tributaries, because the damage is generally more serious than that caused by local rainfall inundation.

(2) Urbanized and populated areas where serious damage by inundation due to flood discharge from the Chao Phraya River is highly anticipated, and the agricultural areas that habitually suffer from flood damage.

Based on the above considerations, the target areas have been decided to cover the following (refer to Fig. 5-1):

(1) Bangkok Metropolis and urban areas in Nakhon Sawan, Chai Nat, Sing Buri, Lop Buri, Ang Thong and Ayutthaya; and

(2) Agricultural areas along the Chao Phraya River between Ang Thong and Ayutthaya, and along the Pasak River between Ayutthaya and Rama VI Dam.

Among these areas, top priority for the establishment of a flood forecasting system was given to Bangkok Metropolis in view of the following reasons. The next priority was given to other target areas which will be dealt with equally.

(1) Bangkok Metropolis with a large population of about 30% of the whole basin population (refer to Table 5-1) is

the core of the nation's various activities. It is also very vulnerable to flood damage, as presented in Table 2-7.

(2) Flood damage potential in Bangkok Metropolis increases as the river embankment along the Chao Phraya river course is developed, because flood discharge tends to increase more than ever; and,

(3) Flood prevention effects can be maximized in this area through the prediction of the discharge from the Chao Phraya River.

Flood Prediction Points

It is necessary to predict the flood discharge and/or water stage to provide enough time for the carrying out of the required actions for flood damage prevention in the target area. Thus, several flood prediction points were selected where the flooding conditions on the target area can be well defined.

In principle, one flood prediction point has to be selected for each target area. However, three (3) flood prediction points were selected for Bangkok Metropolis, since this target area covers a wide stretch that is influenced by the tidal fluctuation along the Chao Phraya River, and the maximum water stage along the wide stretch may occur at different times with different heights depending upon the points observed.

The flood prediction points that have been selected are the following points at which water stage has been observed by the existing gauging stations. (Refer to Fig. 5-1.)

(1) Bangkok Metropolis : Bangkok Memorial Bridge, RID Samsen and Pakred Station

(2)	Ayutthaya	:	Confluence point of Chao Phraya River with Pasak River
(3)	Agricultural area in the upper reaches from Ayutthaya along the Chao Phraya River and Ang Thong	:	Ang Thong Station
(4)	Agricultural area along the Pasak River near Ayutthaya	:	Rama VI Barrage Station
(5)	Sing Buri	:	Sing Buri Station
(6)	Lop Buri	:	Lop Buri Station
(7)	Chai Nat	:	Chai Nat Station
(8)	Nakhon Sawan	:	Nakhon Sawan Station

5.2 Flood Prediction Time

In this study, flood prediction time is defined as the period from which hydrological data are observed up to the time the flood discharge is predicted (refer to Fig. 5-2).

The flood prediction time for the flood prediction model has been studied in two cases according to objective, as follows:

(1) Short Term Flood Prediction Time

A shorter flood prediction time has been considered for the urgent flood protection works on the target area.

(2) Long Term Flood Prediction Time

A longer flood prediction time has been applied in cases where integrated flood protection works are required to effectively operate the water control river structures in the basin.

5.2.1 Short Term Flood Prediction Time

Activities During Flood Prediction Time

During the flood prediction time, the following items of work are performed mainly after hydrological observations:

(1) Data collecting, processing, filing and calculating for flood prediction.

(2) Dissemination of flood prediction results to agencies concerned.

(3) Deliberation on the necessary countermeasures.

(4) Dissemination of the necessary countermeasures to agencies involved.

(5) Execution of the necessary countermeasures.

Among the above items of work, execution procedures for items (1) and (2) will change according to the type and kind of system employed, while that of items (3), (4) and (5) which are involved in flood warning and flood fighting are basically unchangeable even in the introduction of a new system. In this connection, the short term flood prediction time has been studied in two cases, Step 1 and Step 2, on the basis of the necessary flood prediction time presumed under the present activities of the agencies concerned.

Necessary Time Presumed Under the Present Activities

Among the agencies involved in flood forecasting and flood protection works, RID, BMA and EGAT undertake the above items of work according to the time allotted by them for the purpose. Judging from the activities of these agencies, the necessary flood prediction time under the present activities has been estimated at 5.5 days, as shown in Table 5-2.

Minimum Flood Prediction Time Required For Step 1 System

The Step 1 Flood Forecasting System has been formulated with the upmost utilization of existing facilities. Therefore, the minimum flood prediction time required for the items of work, except item (2), will not become shorter even if some facilities are newly installed, because the required time for item (1) is subject to the activity of the existing facilities. In item (2), the time could be made shorter to 0.3 day by the newly installed telecommunication line connecting the RID Head Office to the related agencies. Therefore, the minimum flood prediction time required for the Step 1 system has been estimated at 5.3 days, as shown in Table 5-2.

Minimum Flood Prediction Time Required For Step 2 System

The Step 2 Flood Forecasting System has been formulated on the basis of updated facilities, i.e., on-line telemetering system. It is, therefore, expected that the minimum flood prediction time required can be made remarkably shorter for items (1) and (2), as discussed below.

(1) Data Collection, Processing, Filing and Calculation of Flood Prediction

The necessary time for collecting, processing, filing and calculating flood prediction, which is presently estimated at 2.5 days, can be made shorter to 0.2 days by the introduction of an on-line telemetering system.

This system will enable real-time data collection, processing, filing and calculation of flood prediction. Only a supplemental operation manual for data check, data input, etc., may be needed from time to time.

(2) Dissemination of Flood Prediction Results to Agencies Concerned

Since the flood prediction results can be easily disseminated through the use of a facsimile equipment, the necessary time for this work is expected to be 0.2 days.

From the above considerations, the necessary flood prediction time for the Step 2 system is estimated at 2.9 days, as shown in Table 5-2.

5.2.2 Long Term Flood Prediction Time

Flood prediction is based on the observed hydrological data, sometimes using additionally the estimated future rainfall to make the prediction period longer. A longer term of flood prediction enables a more effective operation of the flood control structures because flood protection activities can be undertaken much in advance of the flood occurrence. However, this also involves a question of prediction reliability, i.e., accuracy becomes lower in proportion to the length of prediction time.

Long term flood prediction is also made by using the observed rainfall data to maintain accuracy to the allowable extent. The period of prediction may correspond to the flood lag time, which consist of the concentration of intensive daily rainfall and the traveling time of the peak flood discharge to the target area.

Flood runoff of the Chao Phraya River is subject to the characteristics of flood runoff of the Ping River where peak discharges due to intensive daily rainfall unexpectedly appear and are directly propagated to Nakhon Sawan. Hence, it may be impossible to predict floods covering a long period with an allowable accuracy by means of predicting future rainfall, unless the future rainfall can be predicted with an allowable accuracy.

In view of the foregoing, the long term flood prediction time is estimated on the basis of the flood lag time.

5.3 Time Interval to Update Flood Prediction Results

Flood prediction results, especially short term flood prediction results which are immediately disseminated to the agencies concerned in flood fighting works, should be updated to cope with the abrupt change in flood water stage by the collection of newly observed data. Thus, it is necessary to set the time interval for the updating of flood prediction results, considering the flooding condition in the target area and the possible time interval for data collection.

Time Interval Based on Flood Condition

Flooding conditions in the target area differ between the upper and the lower reaches from Bang Sai, and the time intervals for updating of flood prediction results can be set as follows:

(1) Upper Reaches from Bang Sai

The flood water stage in this stretch continuously rises up for one week or more due to heavy rainfall in the upper basin. Although it is very difficult to define the abrupt change with the definitive flood water stage rise, this should be set from the aspect of flood fighting works. According to the observed data of the 1978, 1980 and 1983 floods, the maximum daily change of the flood water stage at Nakhon Sawan, Chai Nat and Ang Thong reaches about 50 cm.

In the foregoing case, the water stage of 15 cm, which nearly corresponds to the thickness of one layer of sandbag or concrete block piled up on the bank to prevent overtopping water, was applied to the abrupt change, assuming that the water stage of 15 cm is within the possible extent to be coped with through one time flood fighting works. In this connection, the time interval to update the flood prediction results will come to 6 hours, i.e., four times a day, which is derived by dividing the maximum daily water stage change of 50 cm by the said 15 cm.

(2) Lower Reaches from Bang Sai

Since the lower reaches from Bang Sai is affected by tidal fluctuation, the change of water stage in the stretch sometimes comes to 15 cm or more even on the hourly basis. However, since the peak tidal stage in this stretch emerges periodically, it is possible to know the time of occurrence of the peak water stage precisely in advance, together with the water stage, and the appropriate flood fighting works can be taken by the time of the peak water stage. Therefore, updating of flood prediction results on the hourly basis is not so necessary. As for the execution of flood fighting works, updating of the flood prediction results is proposed in accordance with the time interval of the peak tidal stage of approx. 10 hours.

Possible Time Interval For Data Collection

It is desirable to collect the data within the same time frame as the updating of flood prediction results. However, the possible time interval for data collection depends on the method of data collection which differs between the Step 1 and the Step 2 systems.

In the Step 1 system, it is proposed that data collection is performed once a day by manual operation on the basis of the currently used system, while it is based on the telemetering system in Step 2 where the data can be collected on real time with no time interval. In this connection, the possible time interval for data collection is one day in the Step 1 system, while any time interval can be applied in the Step 2 system.

Under the above situations, the interval to update the flood prediction results are set at one day for the Step 1 system, and six hours for the upper reaches from Bang Sai and ten hours for the lower reaches from Bang Sai for the Step 2 system. To uniformly operate the flood forecasting system for all the target areas, it is recommended to adopt the six hours interval for both the upper reaches and the lower reaches for convenience.

5.4 Flood Prediction Model

5.4.1 Flood Prediction Model as a Whole

The flood prediction model as a whole is composed of four basic mathematical models, namely, the Basin Runoff Prediction Model, the River Channel Routing Model, the Flood Plain Routing Model and the Unsteady Flow Prediction Model. The purposes of the four models are as follows:

(1) Basin Runoff Prediction Model

The model is used to predict runoff discharge generated by rainfall in the respective catchment areas.

(2) River Channel Routing Model

The model is used to simulate the channel flow discharge along the river stretches where the channel storage function and tidal influences are regarded as nil.

(3) Flood Plain Routing Model

The model is used to simulate flow discharge in the offstream flood plain areas, and to predict outflow discharge returning to the river channel.

(4) Unsteady Flow Prediction Model

The model is used to predict hourly water level along the estuary influenced by tidal fluctuations. The model further attaches the function of tidal prediction at the Gulf which is given through the Harmonic Analysis and used as a downstream boundary condition for the model calculation.

In consideration of flood runoff conditions in the Chao Phraya River Basin, the objectives of the Basin Runoff Prediction Model have been arranged to be the 14 subbasins in the Ping, Wang, Yom, Nan, Pasak and Sakae Krang river basins (refer to Fig. 5-3). As the objectives of the Flood Plain Routing Prediction Model, four major flood plains were selected around (1) the downstream of Yom River from Sukhothai (Sta. Y4) to Sam Ngam (Sta. Y17), (2) the vicinity of Phitchit (Sta. N10) along the Nan River, (3) confluence of Ping and Nan rivers, and (4) the downstream of the Chao Phraya River from the Chao Phraya Dam (Sta. C13) to Bang Sai (Sta. C29) (refer to Fig. 5-4). With regard to the Unsteady Flow Prediction Model, the objective is the estuary of the Chao Phraya River from the river mouth to Bang Sai (refer to Fig. 5-4).

The systematic diagram of the flood prediction model as a whole, corresponding to the above arrangement of basic models, is shown in Figs. 5-5 and 5-6. In the flood prediction model as a whole, runoff discharges predicted by the Basin Runoff Prediction Model have been fed as the input of inflow discharges for the River Channel and Flood Plain Routing Model. Subsequently, the outflow discharges simulated through the River Channel and Flood Plain Routing Models were used as the boundary condition of the Unsteady Flow Prediction Model.

The water levels along the estuary have been finally predicted by the Unsteady Flow Prediction Model with the use of another boundary condition in terms of the predicted tidal fluctuation at the Gulf.

The theoretical concepts and governing equations of the above basic mathematical models are described in Subsections 5.4.2 up to 5.4.5, together with the assumptions made and solution methods.

5.4.2 Basin Runoff Prediction Model

Theoretical Concepts and Governing Equations

The Four-Serial Storage Tank Model has been adopted to predict the runoff discharge generated by rainfall in the basin. In the model, the catchment of the basin was simulated by storage tanks having several outlet holes at their sides and bottoms, as shown in Fig. 5-7.

Rainfall firstly enters into the upmost tank, and either runs off through the side holes or infiltrates through the bottom holes into the lower tank. This runoff and infiltration process is subsequently repeated in the lower tanks.

Water assumed to be lost through evapo-transpiration is subtracted from the stored water in the tanks. The subtraction is firstly done from the storage in the upmost tank, but if the stored water is insufficient for the subtraction, the deficit is subtracted from the storage in the second tank. This process is repeated in the lower tanks until the assumed loss through evapo-transpiration is fully deducted from the storage in the tanks.

In the model, the size of outlet holes was made smaller as the tank is located in a lower position on the assumption that speed of runoff and infiltration decreases as the location of the aquifer in the basin becomes lower. Thus, the serial tanks were arranged so as the runoff from the upmost tank corresponds approximately to the surface flow discharge, while the runoffs from the second, third and fourth tanks correspond to either the intermediate or the base flow discharge.

The discharges from each runoff and infiltration hole are expressed in the following equations:

$$q(t) = (h(t)-H) \cdot a_1$$
$$i(t) = h(t) \cdot a_0 \qquad (5.1)$$

where, $q(t)$: Discharge from the runoff hole (mm/day)
$h(t)$: Storage depth in the tank (mm)
H : Constant for the runoff hole height (mm)
a_1 : Constant for the runoff multiplier (day^{-1})
$i(t)$: Discharge from the infiltration hole (mm/day)
a_0 : Constant for the infiltration multiplier (day^{-1})

The equation of continuity is also assumed as below:

$$r(t) - q(t) - i(t) = \frac{dh(t)}{dt} \qquad (5.2)$$

where, $r(t)$: Effective precipitation (mm)
(= Actual Precipitation - Evapo-transpiration)

Features of the Model

Since the aforesaid model has non-linear characteristics, a large number of trial and error simulations were required to determine the model constants such as multiplier and height of runoff and infiltration holes. However, the model has the specific features mentioned hereunder which are advantageous to express the runoff mechanism of the Chao Phraya River Basin. Accordingly, as far as the structure of the model is properly determined, the results of model simulation coincide well with the observed values.

(1) Due to the arrangement of the multiplier and height of runoff and infiltration holes in the upmost tank, the model can well express the phenomenon of initial runoff loss which is variable in compliance with rainfall hystenesis.

(2) The model contains plural runoff holes. Due to this mechanism, the model can well express the sensitive non-linear phenomena such as the increment of runoff discharges accelerated by the increment of rainfall and the demission of runoff discharges during non-rainy days.

(3) Due to the large catchment area, the major subbasins such as Ping, Yom, Nan and Pasak river basins cause different occasional peak discharge flows. Hence, the flood discharges on the Chao Phraya River are attributed to not only surface flow but also the intermediate and base flow in each subbasin. The said intermediate and base flow are well expressed by the arrangement of serial storage tanks in the model.

(4) The calculations in the model can be made only by simple arithmetic operations such as addition, subtraction and multiplication. Besides, the main parameter for calculations is set on only the storage depth in each tank. Accordingly, the feedback can be easily made by adjusting the storage depth corresponding to the observed value.

Verification of the Model

The constant parameters for the model equations were determined by trial simulations using the past hydrological records. The periods of trial simulation are the typical flood years of 1978, 1980 and 1983. Hydrological records for the simulations include items such as daily average rainfall and evapo-transpiration as the input data, and runoff discharges for the verification of the results of simulation.

Numerous trial simulations were made assuming various values of constants until the simulated hydrographs of runoff discharges were well fitted to the observed hydrographs. The simulation results are shown in Fig. 5-8, while the constants listed in Table 5-3 are the final values adopted to the model.

By using the constants adopted, the flood discharges were also simulated and compared with the observed values as shown in Table 5-4. Thus, a good coincidence was also given in the comparison.

5.4.3 River Channel Routing Model

The model has been applied to the river stretches where the storage function of river channels and the tidal influences are regarded as nil. Thereby, the model is to express the transition of the river channel discharges simply by the following two elements, namely, (1) the traveling time of channel flow discharges, and (2) the relationship of channel flow discharges before and after overbanking.

Traveling Time of Channel Flow Discharge

According to the simulation results of the Basin Runoff Prediction Model, it has been identified in several river stretches that the simulated flood peak discharges are propagated toward the downstream observation point subject to the negligible influence of channel storage function, and the propagation takes a rather constant traveling time regardless of the flood occasion (refer to Table 5-4). From the above viewpoints, 17 river stretches were selected through trial simulation to arrive at a constant traveling time. The location of the river stretches and the traveling time assumed for each river stretch are as shown in Figs. 5-5 and 5-6 and Table 5-5, respectively.

Relationship of Channel Flow Discharges Before and After Overbanking

On the basis of the trial simulation, 11 overbanking points were assumed to the model (refer to Figs. 5-5 and 5-6. Thereby, the channel flow discharges before and after overbanking can be expressed simply by the linear relationships, as shown in Fig. 5-9. The overbanking discharges are herein assumed to be either the pondage or the offstream flood plain flow which has been simulated by the Flood Plain Routing Model mentioned in Subsection 5.4.4.

5.4.4 Flood Plain Routing Model

Theoretical Concepts and Governing Equations

There is a non-linear type characteristic in the runoff phenomena to be influenced by the retarding effects. To express the characteristics, the objective section is divided into several storage containers, and the outflow discharges from each container are assumed to have the following relationship with their corresponding storage volumes.

$$S(t) = K \cdot Q\,(t + T1)^{p} \qquad (5.3)$$

where, S(t) : Storage volume in one container at time t

k, p : Constants

Q(t+T1): Outflow discharge from the container at time (t + T1)

T1 : Lag time

The equation of continuity in each storage container is also expressed as below:

$$dS(t)/dt = I(t) - Q(t + T1 + T1z) \qquad (5.4)$$

where, I(t) : Inflow discharge to the container at time t

dS(t)/dt: Differential of storage volume by time

Tlz : Apparent lag time

The outflow discharges from the container were calculated through the above equations from the known quantities of inflow discharges, using a storage volume as the medium function. The objective sections applied to the model were divided into several storage containers, which were expressed by the river stretch assuming storage function as shown in Figs. 5-5 and 5-6.

The inflow discharges at the upmost stream container were given as the boundary conditions by the runoff discharges simulated by the Basin Runoff Prediction Model and the River Channel Routing Model. On the basis of the boundary conditions, the outflow discharges from the upmost stream container were calculated through the above equations and input to the next downstream container as the inflow discharges. Thus, the outflow discharges have been repeatedly calculated in the downward containers on the basis of the outflow discharges calculated from the upward container.

The section of the Chao Phraya River between the Chao Phraya Dam and Bang Sai has the river channel network composed of several diversion channels. To know the diversion ratio of the calculated outflow discharges from the upper container, the non-uniform calculation was made on the basis of the river channel survey results obtained in this study period. As the results, the diversion discharges to each channel have been given, as shown in Fig. 5-10.

The constant parameters of "k", "p", "Tl" and "Tlz" in equations (5.3) and (5.4), as shown in Table 5-6, were determined for each storage container on the basis of the hydrological relationship between the outflow discharge and its corresponding storage volume. The said relationship was derived from either the observed discharge hydrographs or the river channel survey results and the topographic map.

Features of the Model

Among the various calculation models, the Flood Plain Routing Model (conventionally called Storage Function Model) has been applied due to the following advantages:

(1) The calculation method is not complicated.

(2) The method can easily deal with changes in runoff condition due to river improvement through the modification of parameters.

(3) In case that there is much difference between the calculated value and the observed value at the prediction and calibration points, modification of the calculated value to correspond with the observed one is easily performed.

Verification of the Model

Simulations of the past flood phenomena were made through the proposed Flood Plain Routing Model, together with the Basin Runoff Prediction Model and the River Channel Routing Model, as shown in Fig. 5-11 and Table 5-7, so as to verify the adequacy of the model and its parameters. Judging from the good coincidences between the simulated and observed discharge hydrographs in all simulations, it has been evaluated that the proposed model is applicable to the prediction.

5.4.5 Unsteady Flow Prediction Model

Theoretical Concepts and Governing Equations

The model has been developed to express the fluctuations of water level along the estuary which are governed by the propagation of tidal waves in the Gulf. The hydraulic propagation can be conventionally calculated by the following unsteady free surface equations:

Equation of Continuity:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (5.5)$$

Equation of Motion:

$$\frac{1}{gA}\frac{\partial Q}{\partial t} - \frac{2QB}{gA^2}\frac{\partial H}{\partial t} - \frac{Q^2B}{gA^2}\left(i + \frac{\partial H}{\partial x}\right) + \frac{\partial H}{\partial x} + n^2\frac{|Q|Q}{A^2R^{4/3}} = 0 \qquad (5.6)$$

where, Q : Flow discharge
H : Water level
g : Gravity acceleration
A : Discharge flow area
B : Width of water surface
t : Time
i : Channel slope
x : Distance
R : Hydraulic radius
n : Manning's Roughness Coefficient

The momental water level (H) has been successively calculated through the above equations from time to time and from the downstream point upwards. In the selection of equations, it was necessary to set up various given conditions such as the hydraulic dimensions of river channel, the appropriate Manning's Roughness Coefficient, the initial condition of water level profile, and the boundary conditions. The contents of the above conditions are as below.

(1) The hydraulic dimensions of river channel is used to correlate the water level and its corresponding hydraulic values such as discharge flow area (A), width of water surface (B) and hydraulic radius (R). The hydraulic dimensions were provided with the results of the river channel survey in 1980.

(2) In the equations, the Manning's Roughness Coefficient is the controlling parameter of the computed water levels along the estuary. In this connection, the appropriate value of Manning's Roughness Coefficient has been determined by simulations using the previous hydrological records.

(3) The initial condition has been given as the water level profile at the time before starting calculations for the river stretch from the river mouth to Bang Sai. The water level profile has to be consecutively provided from the hourly water levels observed at the stations along the estuary, so that the water level prediction in the model can be calibrated.

(4) One of the boundary conditions has been given in terms of daily average runoff discharge predicted at Bang Sai by the Basin Runoff Prediction Model, the River Channel Routing Model and the Flood Plain Routing Model.

(5) Another boundary condition has been given in terms of hourly average tidal level predicted at the Gulf by the Harmonic Analysis.

In the Harmonic Analysis, it was assumed that tidal fluctuations periodically occur due to attracting forces by the sun and the moon. On the basis of the assumption, the hourly tidal levels were predicted by the following equation which is subject to a tidal composition of 61 harmonic constituents:

$$h(t) = \sum_{i=1}^{60} Hi \sin(\frac{2 \cdot \pi}{Ti} \cdot t + Ri) + H_{61} \qquad (5.7)$$

where, $h(t)$: Tidal level at time t starting from the specified standard time (m)

H_i : Amplitude of the ith constituent (m)

T_i : Cycle of the ith constituent (hour)

R_i : Phase (delay of angle) of the ith constituent at the specified standard time (radian)

The cycle of each constituent (T_i) is a known quantity which is given from astronomical phenomena. The constants of the amplitude (H_i) and the phase (R_i) can be determined for each corresponding (T_i) by using the previous tidal records of a fairly long period.

Verification of the Model

Verifications were made on the effects of the Manning's Roughness Coefficient in the aforesaid unsteady free surface equations, and also on the applicability of the tidal prediction achieved by the Harmonic Analysis.

(1) Effects of Manning's Roughness Coefficient

Through the tidal simulation assuming various Manning's Roughness Coefficients, the following matters were verified:

(a) The proposed unsteady flow calculation model will enable prediction of one-day maximum water level and its occurrence time by using the roughness coefficient of 0.024, at least for the river stretch from the river mouth to Pakred (located about 70 km from the river mouth) which covers the Bangkok target area (refer to Fig. 5-12 and Table 5-8).

(b) The roughness coefficient of 0.024 will also enable prediction of the water level hydrograph for the river stretch around Memorial Bridge (located about 50 km from the river mouth). Thereby, better accuracy is expected in the prediction for the ascent limb of hydrograph (refer to Figs. 5-13(1/3) and 5-13(2/3)).

(c) The results of the simulation of Bang Sai (located about 110 km from the river mouth) suggest that the roughness coefficient of more than 0.024 will be required for the prediction along the upper stream from the Bangkok target area (refer to Fig. 5-13(3/3) and Table 5-8).

(2) Effects of Tidal Prediction

Table 5-9 shows the constants of the amplitude and the phase for each corresponding cycle of constituents. The constants were determined through Harmonic Analysis on the basis of the tidal records at Fort Phra Chul in 1977, 1979 and 1982, and used to predict the hourly tidal levels in the following years of tidal recording, namely, 1978, 1980 and 1983.

By using the constants determined, the hourly tidal level hydrographs were predicted for the days in either the month of rainy season (October) or the month of dry season (January), as shown in Fig. 5-14. The one-day maximum and minimum tidal levels through a year are also predicted, as shown in Fig. 5-15 and Table 5-10.

As the results of the above prediction, it is concluded that there are still about 60 days in a year having the difference of more than 30 cm in the observed and predicted one-day maximum water level (refer to Table 5-11).

One of the reasons for the above difference is attributed to the meteorological tidal deviations governed by the wind and air pressure. In this connection, it was attempted to reduce the difference through the correlation analysis based on the following equation:

$$dH(t) = Ka \cdot dP + Kb \cdot W^2 \cdot COS^2 x \qquad (5.8)$$

where, dH(t): Difference of tidal levels observed and predicted by the Harmonic Analysis at time t

dp : Drop in atmospheric pressure (mb)

W : Wind velocity (m/s)

x : Angle between wind direction and coastline

Ka,Kb: Constant parameter

The definite values of constant parameters "Ka" and "Kb" were, however, not obtained during this study period due to the following conditions:

(a) The data of atmospheric pressure and wind were collected from the records in 1978, 1980 and 1983. However, these data contained rather small variations of the drop in atmospheric pressure and wind velocity.

(b) The study was done by using the data of wind velocity which was recorded at Bangkok Meteorological Office. However, the wind condition in the gulf may be rather different from that at the office.

From the above viewpoints, it is desirable to have a further study on the matter of meteorological tide deviations by using the data recorded at the river mouth for a longer period.

Table 5-1. POPULATION DENSITY BY PROVINCE

Item No.	Name of Province	Area of Province (km^2)	Population in 1984 (person)	Population Density ($person/km^2$)
Upper Reaches from Nakhon Sawan				
1	Chiang Mai	20,107	1,252,241	62.3
2	Lampang	12,534	730,057	58.2
3	Lamphun	4,506	392,588	87.1
4	Phrea	6,539	471,101	72.0
5	Nan	11,472	410,484	35.8
6	Tak	16,407	311,767	19.0
7	Sukhothai	6,596	560,219	84.9
8	Phitsanulok	10,816	722,475	66.8
9	Uttaradit	7,839	437,853	55.9
10	Kamphaeng Phet	8,608	628,789	73.0
11	Phichit	4,531	558,236	123.2
	Sub-Total	109,955	6,475,810	58.9
Lower Reaches from Nakhon Sawan				
1	Nakhon Sawan	9,598	1,031,924	107.5
2	Phetchabun	12,668	893,940	70.6
3	Uthai Thani	6,730	280,184	41.6
4	Chai Nat	2,470	332,412	134.6
5	Kanchanaburi	19,483	607,171	31.2
6	Suphan Buri	5,358	751,875	140.3
7	Singburi	822	208,838	253.5
8	Lopburi	6,200	671,823	108.4
9	Angthong	968	466,195	481.6
10	Saraburi	3,576	469,064	131.2
11	Ayutthaya	2,557	637,845	249.5
12	Nakhon Pathom	2,168	596,157	275.0
13	Nonthaburi	622	478,199	768.8
14	Pathom Thani	1,526	366,767	240.3
15	Samut Sakorn	872	301,631	345.9
16	Bangkok	1,565	5,174,682	3,306.5
17	Samut Prakarn	1,004	640,316	637.8
18	Ratchaburi	5,196	675,148	129.9
	Sub-Total	83,383	14,584,171	174.9
	Total	193,383	21,059,984	108.9

Table 5-2. REQUIRED FLOOD PREDICTION TIME

Particulars	Necessary Time Presumed under the Present Activities (Day)	Minimum Flood Prediction Time Required (Day)	
		Step 1	Step 2
1. Data collection, processing, filing and calculation of flood prediction	2.5	2.5	0.2
2. Dissemination of flood prediction results to agencies concerned	0.5	0.3	0.2
3. Deliberation on the necessary countermeasures	0.3	0.3	0.3
4. Dissemination of the instructions on countermeasures	0.2	0.2	0.2
5. Execution of the countermeasures	2.0	2.0	2.0
	5.5	5.3	2.9

Note: One day is assumed to be ten hours from 8 a.m. to 6 p.m. which is regarded as the possible working hours for the activities.

Table 5-3(1/2). CONSTANT PARAMETERS FOR BASIN RUNOFF CALCULATION

Parameter Items	Symbol	Basin No. BS-1 Ping River (20,031 km^2)	Basin No. BS-2 Wang River (6,187 km^2)	Basin No. BS-3 Ping River (5,797 km^2)	Basin No. BS-4 Ping River (5,162 km^2)	Basin No. BS-5 Yom River (6,721 km^2)	Basin No. BS-6 Yom River (4,320 km^2)	Basin No. BS-7 Nan River (8,521 km^2)
A. Multiplier								
1. 1st Tank								
- Runoff Hole (upper)	a1	0.111	0.200	0.060	-	0.120	-	-
- Runoff Hole (middle)	a2	0.022	0.040	0.040	0.040	0.040	0.034	0.031
- Runoff Hole (lower)	a3	0.020	0.035	0.035	0.040	0.035	0.030	0.027
- Infiltration Hole	ao	0.014	0.025	0.025	0.034	0.025	0.021	0.019
2. 2nd Tank								
- Runoff Hole	b1	0.006	0.010	0.010	0.014	0.010	0.009	0.007
- Infiltration Hole	bo	0.011	0.020	0.020	0.027	0.020	0.017	0.016
3. 3rd Tank								
- Runoff Hole	c1	0.002	0.002	0.002	0.003	0.002	0.002	0.002
- Infiltration Hole	co	0.001	0.004	0.004	0.005	0.004	0.003	0.003
4. 4th Tank								
- Runoff Hole	d1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B. Height of Runoff Hole (mm)								
1. 1st Tank								
- Upper	A1	130	130	130	-	130	-	130
- Middle	A2	100	100	100	100	100	100	100
- Lower	A3	80	80	80	80	80	80	80
2. 2nd Tank	B	60	60	60	60	60	60	60
3. 3rd Tank	C	50	50	50	50	50	50	50
4. 4th Tank	D	20	20	20	20	20	20	20
C. Initial Storage Height (mm)								
1. 1st Tank	X1	0	0	0	0	0	0	0
2. 2nd Tank	X2	0	0	0	0	0	0	0
3. 3rd Tank	X3	0	0	0	0	0	0	0
4. 4th Tank	X4	20	20	20	20	20	20	20

Table 5-3(2/2). CONSTANT PARAMETERS FOR BASIN RUNOFF CALCULATION

Parameter Items	Symbol	Basin No. BS-8 Nan River (9,568 km^2)	Basin No. BS-9 Nan River (5,478 km^2)	Basin No. BS-10 Nan/Yom River (15,488 km^2)	Basin No. BS-11 Sakae Krang River (5,775 km^2)	Basin No. BS-12 Tha Pla Pai River (4,349 km^2)	Basin No. BS-13 Pasak River (5,180 km^2)	Basin No. BS-14 Pasak River (8,124 km^2)
A. Multiplier								
1. 1st Tank								
- Runoff Hole (upper)	a1	-	-	-	0.060	-	-	0.110
- Runoff Hole (middle)	a2	0.034	0.044	0.026	0.050	0.040	0.018	0.036
- Runoff Hole (lower)	a3	0.029	0.039	0.023	0.050	0.040	0.007	0.014
- Infiltration Hole	ao	0.021	0.028	0.017	0.010	0.034	0.007	0.014
2. 2nd Tank								
- Runoff Hole	b1	0.008	0.011	0.007	0.010	0.014	0.004	0.009
- Infiltration Hole	bo	0.017	0.022	0.013	0.020	0.027	0.004	0.009
3. 3rd Tank								
- Runoff Hole	c1	0.002	0.002	0.001	0.002	0.003	0.002	0.002
- Infiltration Hole	co	0.003	0.004	0.002	0.004	0.005	0.002	0.002
4. 4th Tank								
- Runoff Hole	d1	0.001	0.001	0.001	0.001	0.001	0.0009	0.0009
B. Height of Runoff Hole (mm)								
1. 1st Tank								
- Upper	A1	-	-	-	200	130	-	200
- Middle	A2	100	100	100	80	100	100	100
- Lower	A3	80	80	80	60	80	80	80
2. 2nd Tank	B	60	60	60	40	60	60	60
3. 3rd Tank	C	50	50	50	30	50	50	50
4. 4th Tank	D	20	20	20	10	20	20	20
C. Initial Storage Height (mm)								
1. 1st Tank	X1	0	0	0	0	0	0	0
2. 2nd Tank	X2	0	0	0	0	0	0	0
3. 3rd Tank	X3	0	0	0	0	0	0	0
4. 4th Tank	X4	20	20	20	20	20	20	20

Table 5-4. COMPARISON OF EXTREME VALUES BETWEEN OBSERVED AND SIMULATED BASIN RUNOFF DISCHARGES

Subbasin Code No.	Upstream Discharge Observation Point	Downstream Discharge Observation Point	Year	Observed at Downstream Point		Simulated for Downstream Point		Lag Time
				Date	(m^3/s)	Date	(m^3/s)	(days)
BS-1 (Ping River)	Chiang Mai (P1)	Bhumibol Dam (Inflow)	1978	Jul.09	1,080	Jul.08	1,030	1.0
			1978	Aug.17	1,070	Aug.14	1,080	3.0
			1978	Oct.06	1,270	Oct.04	1,330	2.0
			1980	Sep.09	1,380	Sep.07	1,410	2.0
			1980	Oct.08	1,660	Oct.07	1,550	1.0
			1983	Oct.19	1,570	Oct.18	1,590	1.0
			1983	Nov.13	1,470	Nov.12	1,520	1.0
BS-2 (Wang River)	Chae Hom (W10A)	Thaen (W3A)	1978	Aug.15	640	Aug.14	650	1.0
			1980	Sep.07	420	Sep.06	430	1.0
			1983	Sep.16	350	Sep.14	350	2.0
BS-3 (Ping River)	Wang Kra Chai (P12) and Wang Khrai (W4A)	Kamphaeng Phet (P7A)	1978	Jul.12	780	Jul.10	770	2.0
			1978	Oct.02	1,180	Sep.29	1,190	3.0
			1978	Oct.15	630	Oct.13	770	2.0
			1980	May 23	1,530	May 22	1,540	1.0
			1980	Oct.04	910	Oct.02	920	2.0
BS-5 (Yom River)	Ngao Sak (Y20)	Si Satchanalai (Y14)	1978	Aug.15	1,550	Aug.13	1,550	2.0
			1978	Sep.26	1,000	Sep.23	1,180	3.0
			1980	Sep.02	990	Sep.01	970	1.0
			1980	Sep.08	2,170	Sep.07	2,150	1.0
			1983	Sep.16	710	Sep.14	860	2.0
BS-7 (Nan River)	Nan (N1)	Sirikit Dam (Inflow)	1978	Aug.15	1,320	Aug.14	1,020	1.0
			1978	Sep.14	1,150	Sep.13	960	1.0
			1980	Aug.25	1,070	Aug.25	1,000	0.0
			1980	Sep.06	2,260	Sep.05	2,330	1.0
			1983	Sep.19	1,070	Sep.18	1,020	1.0
BS-8 (Nan River)	Tha Pla (N12A)	Phitsanulok (N5A)	1978	Aug.16	1,410	Aug.13	1,320	3.0
			1978	Sep.25	1,210	Sep.23	1,210	2.0
			1980	Aug.01	1,240	Jul.30	1,280	2.0
			1980	Sep.09	1,520	Sep.07	1,530	2.0
			1980	Sep.20	1,230	Sep.18	1,220	2.0
			1983	Sep.09	660	Sep.07	780	2.0
BS-14 (Pasak River)	Wichian Buri	Saraburi (S9)	1978	Oct.03	3,210	Sep.30	3,260	3.0
			1980	Oct.05	890	Oct.01	850	4.0

Table 5-5. CONSTANT PARAMETERS ASSUMED AS FLOOD TRAVELLING TIME

River Stretch Code No.	River System	Travelling Time (days)
R1	Ping (Chiang Mai to Bhumibol Dam)	2.0
R2	Wang (Chae Hom (W10A) to Thoen (W3A))	1.0
R3	Wang (Thoen (W3A) to Wang Krai (W4A))	1.0
R4	Ping (Bhumibol Dam to Kamphaeng Phet (P7A))	2.0
R5	Ping (Downstream from Kamphaeng Phet (P7A))	1.0
R6	Yom (Ngao Sak (Y20) to Si Satchanalai (Y14))	2.0
R7	Yom (Downstream from Sam Ngam (Y17))	3.0
R8	Nan (Nan (N1) to Sirikit Dam)	1.0
R9	Nan (Sirikit Dam to Phitsanulok (N5A))	2.0
R10	Nan	1.0
R11	Yom/Nan	1.0
R12	Chao Phraya	1.0
R13	Tha Pla Pai	8.0
R14	Sakae Krang	6.0
R15	Chao Phraya	3.0
R16	Pasak (Lom Sak to Wichian Buri)	2.0
R17	Pasak (Wichian Buri to Rama VI Dam)	3.0

Table 5-6. CONSTANT PARAMETERS OF STORAGE FUNCTION FOR SUBDIVIDED RIVER STRETCH

(1) Upper Reaches from Nakhon Sawan

River Stretch Code No.	Constant Parameters			
	K	P	Tl	Tlz
S1	80.0	0.800	0.0	4.0
S2	80.0	0.800	0.0	0.0
S3	80.0	0.600	0.0	7.0
S4	80.0	0.800	0.0	0.0
S5	210.8	0.615	2.0	0.0

(2) Lower Reaches from Nakhon Sawan

River Stretch Code No.	Flow Capacity (m^3/s)	Constant Parameters /1 Less Than Flow Capacity		Constant Parameters /1 More Than Flow Capacity	
		K	P	K	P
S6	2,700	17.1	0.6	4.6×10^{-5}	2.2
S7	2,000	12.1	0.6	1.2×10^{-5}	2.4
S8	1,200	5.8	0.6	1.3×10^{-7}	3.1
S9	700	1.0	0.6	4.6×10^{-15}	5.6
S10	700	3.3	0.6	1.5×10^{-8}	3.5
S11	200	2.1	0.6	1.1×10^{-5}	3.0
S12	700	4.6	0.6	2.4×10^{-6}	2.8
S13	250	3.3	0.6	1.4×10^{-5}	2.8
S14	900	5.8	0.6	5.8×10^{-7}	3.0
S15	200	3.3	0.6	5.0×10^{-6}	3.1
S16	200	4.2	0.6	7.1×10^{-5}	2.7
S17	150	2.9	0.6	6.3×10^{-6}	3.1
S18	200	2.1	0.6	1.1×10^{-5}	3.0
S19	900	2.9	0.6	3.1×10^{-10}	4.0
S20	1,800	4.8	0.6	8.8×10^{-8}	3.0
S21	3,000	4.6	0.6	1.4×10^{-6}	2.5
S22		120.0	0.8	120.0	0.8

Note: /1 Zero value is assumed as parameters of "Tl" and "Tlz" for all river stretches in the lower reaches from Nakhon Sawan.

Table 5-7. COMPARISON OF OBSERVED AND SIMULATED ANNUAL PEAK DISCHARGES AND ANNUAL DISCHARGE VOLUME

Verification Point	Simulation Starting From	Year	Annual Peak Discharge				Annual Discharge Volume	
			Observed		Simulated		Observed	Simulated
			(m^3/s)	Date	(m^3/s)	Date	($10^6 m^3$)	($10^6 m^3$)
(1) Nakhon Sawan (C2)	Downstream points of Ping, Yom and Nan River /1	1978	3,540	Oct. 7	3,553	Oct. 7	31,215	31,779
		1980	4,320	Oct. 9	4,352	Oct. 9	29,709	30,255
		1983	2,290	Oct. 23	-	- /2	23,945	- /2
(2) Chai Nat (C13)	Nakhon Sawan (C2)	1978	3,741	Oct. 11	3,739	Oct. 7	19,727	23,370
		1980	3,795	Oct. 10	3,796	Oct. 10	20,725	22,036
		1983	3,290	Oct. 25	3,097	Oct. 27	16,889	18,560
(3) Angthong (C7A)	Chai Nat (C13)	1978	2,550	Oct. 12	2,967	Oct. 12	11,966	13,756
		1980	3,115	Oct. 13	3,024	Oct. 13	13,639	14,780
		1983	2,482	Oct. 25	2,604	Oct. 26	11,815	10,852

Note: /1 Kamphaeng Phet (P7A) of Ping River, San Ngam (Y17) of Yom River and Thaphan Hin (N10A).

/2 Simulation was not made due to the missing discharge data at Y17.

Table 5-8. EFFECTS OF MANNING'S ROUGHNESS COEFFICIENT ON COMPUTED STAGE FOR TIDAL COMPARTMENT

Date of Flood	Objective Point	Distance from River Mouth (km)	Observed and Computed Maximum Water Stage (m above MSL)					
			Observed	Computed by Varied Manning's (n)				
				n=0.03	n=0.028	n=0.026	n=0.024	n=0.02
Oct 21 '78	Pak Nan	7	1.75	1.78	1.77	1.76	1.75	1.73
	Bangkok Port	27	1.73	1.92	1.87	1.83	1.80	1.75
	Satha Pradit	40	1.77	2.07	1.95	1.84	1.75	1.62
	Memorial Bridge	48	1.89	2.26	2.14	2.04	1.92	1.76
	RID Samsen	54	2.03	2.30	2.21	2.11	2.04	1.88
	Pakred	70	2.15	2.67	2.49	2.31	2.16	2.00
	Bang Sai	110	3.25	3.41	3.18	2.97	2.79	2.49
Oct 27 '80	Pak Nan	7	1.68	1.71	1.70	1.70	1.69	1.66
	Bangkok Port	27	1.77	1.78	1.73	1.70	1.66	1.61
	Satha Pradit	40	-	1.88	1.77	1.68	1.60	1.47
	Memorial Bridge	48	1.92	2.32	2.20	2.10	2.03	1.93
	RID Samsen	54	2.01	2.33	2.22	2.12	2.04	1.93
	Pakred	70	2.21	2.68	2.51	2.36	2.22	1.98
	Bang Sai	110	3.16	3.23	3.02	2.82	2.66	2.34
Oct 31 '83	Pak Nan	7	1.93	2.04	2.03	2.02	2.01	2.00
	Bangkok Port	27	1.97	2.14	2.11	2.10	2.08	2.06
	Satha Pradit	40	1.87	2.15	2.07	2.00	1.94	1.86
	Memorial Bridge	48	1.82	2.07	1.99	1.93	1.90	1.88
	RID Samsen	54	1.94	2.27	2.19	2.12	2.06	1.98
	Pakred	70	2.05	2.41	2.28	2.15	2.05	1.89
	Bang Sai	110	3.09	3.35	3.19	3.04	2.92	2.77

Table 5-9. CONSTANTS FOR TIDAL PREDICTION FORMULA AT FORT PHRA CHUL

CONSTITUENTS		CONSTANTS FOR 1978		CONSTANTS FOR 1980		CONSTANTS FOR 1983	
i	CYCLE Ti (HR)	AMPLETUDE Hi (M)	PHASE Ri (RAD)	AMPLETUDE Hi (M)	PHASE Ri (RAD)	AMPLETUDE Hi (M)	PHASE Ri (RAD)
1	8765.82422	0.16590	3.31894	0.12731	3.23874	0.14736	3.39769
2	4382.90625	0.04730	2.65788	0.04737	4.06928	0.04585	4.69960
3	661.30933	0.02141	0.32317	0.01360	3.20360	0.00880	0.04215
4	354.36694	0.00723	4.46429	0.01630	0.19595	0.00840	0.91319
5	327.85889	0.00299	0.64732	0.02234	3.32207	0.02680	2.51708
6	24.00000	0.02461	1.88119	0.03550	2.06727	0.04019	2.88921
7	23.93446	0.59835	2.72694	0.58481	2.85820	0.64441	2.88899
8	24.06589	0.19438	3.01946	0.18809	3.03100	0.17455	3.11989
9	24.13214	0.01141	-0.95539	0.01393	-0.51029	0.01045	-1.24002
10	23.86929	0.00591	0.25081	0.01776	-0.64174	0.05371	-0.73148
11	23.80447	0.01746	-1.06281	0.01929	-1.12477	0.01382	4.23182
12	24.84120	0.02206	3.21864	0.03302	-1.02316	0.01406	-1.00772
13	23.20695	0.00779	-0.77349	0.00973	3.99981	0.00100	4.53057
14	23.09848	0.02145	4.07350	0.01971	0.79343	0.02515	2.23615
15	24.70906	0.01022	0.20434	0.01322	4.22073	0.00653	3.49912
16	25.81934	0.35621	1.05281	0.30833	3.72591	0.40380	-1.40323
17	25.66812	0.03516	2.72095	0.07083	-1.26044	0.02798	0.27381
18	22.42018	0.04566	1.27614	0.03241	4.64898	0.04240	3.53555
19	22.30608	0.02352	1.18994	0.02426	-1.35951	0.03457	3.90042
20	26.72305	0.00890	-0.35848	0.01972	1.51319	0.01024	-0.49557
21	26.86836	0.05941	0.59283	0.06496	0.02463	0.06769	-0.14711
22	27.84839	0.00800	0.96843	0.01590	-0.41371	0.01236	2.50667
23	28.00623	0.00622	-0.45591	0.00432	4.16998	0.01114	1.17468
24	12.00000	0.28765	3.73524	0.28537	3.77340	0.27866	3.53473
25	12.01645	0.02955	-0.63727	0.02235	-0.53788	0.04117	4.26908
26	11.98360	0.02425	-0.59707	0.02011	0.23727	0.06404	-0.00376
27	11.96724	0.09187	-0.17670	0.09782	-0.04354	0.09812	-0.14813
28	12.19162	0.04106	4.70062	0.01659	-1.19211	0.03616	1.37229
29	12.22177	0.01581	-0.75972	0.01714	2.80822	0.01923	1.94738
30	11.78613	0.01372	1.01489	0.00444	0.22124	0.01305	-0.81790
31	11.75452	0.00604	0.68521	0.01733	-1.56307	0.00819	4.40608
32	12.42060	0.59429	1.25708	0.53392	4.13625	0.54115	-0.93723
33	11.60695	0.01450	2.57281	0.01649	-0.08596	0.01556	4.54853
34	12.45590	0.03833	3.60376	0.09276	1.32671	0.08650	1.42424
35	12.38551	0.02671	4.44754	0.06180	-0.81181	0.01146	-0.05445
36	12.65835	0.09054	0.62571	0.10215	0.29416	0.09382	0.03481
37	12.62600	0.01350	-0.91633	0.02769	1.87212	0.02491	-0.23624
38	12.87176	0.03148	1.09054	0.02000	0.19207	0.02200	3.02702
39	12.90538	0.02112	1.51821	0.02138	0.72540	0.01367	3.66487
40	13.12727	0.00623	0.83623	0.00482	0.76748	0.01129	4.53338
41	13.16671	0.00958	1.21399	0.01020	1.86399	0.01281	4.69037
42	7.99271	0.01554	-0.79450	0.01200	-0.74522	0.01399	-0.64518
43	8.17714	0.02026	2.74135	0.01452	-0.44397	0.01862	0.90648
44	8.19243	0.01452	3.92204	0.01286	0.41700	0.02110	1.80928
45	8.28041	0.00715	2.66405	0.00301	2.58846	0.00633	1.93824
46	8.38631	0.01964	1.88989	0.01600	0.79556	0.01699	3.67781
47	6.00001	0.00705	-0.78628	0.00761	-0.55556	0.00419	-0.47131
48	5.99180	0.00360	-0.28940	0.00290	0.71030	0.00494	0.04127
49	6.10334	0.02503	3.11459	0.02443	-0.27790	0.01928	0.98670
50	6.09485	0.00285	-1.20417	0.00662	1.25713	0.00317	1.04141
51	6.16020	0.00400	2.61011	0.00418	2.61111	0.00278	2.73232
52	6.21031	0.02853	0.85495	0.02442	0.03211	0.02392	2.74803
53	6.26918	0.01131	0.12316	0.00703	2.66009	0.00771	3.78920
54	4.04567	0.00313	4.15684	0.00465	1.34230	0.00688	2.35685
55	4.04194	0.00168	1.19847	0.00274	3.24459	0.00336	3.78235
56	4.09239	0.00994	1.85561	0.00836	1.28528	0.00554	3.81168
57	4.08857	0.00261	-1.46789	0.00343	3.56286	0.00053	-0.66542
58	4.11787	0.00395	1.65096	0.00184	3.64339	0.00135	-1.35679
59	4.14020	0.00741	-0.34896	0.00606	1.80641	0.00439	-0.71555
60	4.16628	0.00328	-0.65571	0.00305	3.52702	0.00297	0.16230
61	0.0	0.41679		0.47845		0.63102	

Note: /1 Constants for each year are estimated in the basin of tidal levels recorded for 357 days (1 Jan. to 23 Dec.) in the preceding year.

/2 Constant of 'Phase' is subject to the standard time at 0:00 AM on either 27th May in a non-leap year or 28th May in a leap year.

Table 5-10. MONTHLY AND ANNUAL EXTREME VALUES OF TIDAL LEVEL

Year	Month	Observed		Predicted	
		Maximum	Minimum	Maximum	Minimum
1978	JAN	1.95	-1.23	1.86	-1.32
	FEB	1.74	-1.16	1.81	-1.15
	MAR	1.69	-1.05	1.64	-0.99
	APR	1.75	-1.27	1.68	-1.30
	MAY	1.97	-1.51	1.63	-1.51
	JUN	2.04	-1.37	1.57	-1.59
	JUL	1.90	-1.34	1.55	-1.53
	AUG	1.72	-1.27	1.51	-1.26
	SEP	1.81	-1.10	1.48	-0.98
	OCT	2.04	-0.97	1.63	-1.07
	NOV	1.85	-1.11	1.73	-1.19
	DEC	1.83	-1.18	1.82	-1.28
	ANNUAL	2.04	-1.51	1.86	-1.59
1980	JAN	1.93	-1.22	1.85	-1.31
	FEB	1.78	-1.11	1.83	-1.22
	MAR	1.72	-1.01	1.71	-0.84
	APR	1.82	-1.15	1.66	-0.99
	MAY	1.70	-1.46	1.59	-1.12
	JUN	1.60	-1.50	1.52	-1.28
	JUL	1.75	-1.50	1.63	-1.45
	AUG	1.77	-1.30	1.69	-1.29
	SEP	1.75	-0.99	1.65	-0.94
	OCT	1.75	-0.94	1.69	-0.93
	NOV	1.94	-1.05	1.73	-1.02
	DEC	2.08	-1.06	1.77	-1.20
	ANNUAL	2.08	-1.50	1.85	-1.45
1983	JAN	2.12	-1.15	2.13	-1.14
	FEB	2.05	-1.03	1.96	-0.96
	MAR	1.90	-0.83	1.82	-0.81
	APR	1.90	-1.01	1.88	-0.88
	MAY	1.93	-1.19	1.86	-1.03
	JUN	2.17	-1.37	1.81	-1.31
	JUL	1.94	-1.32	1.75	-1.45
	AUG	2.09	-1.13	1.65	-1.33
	SEP	2.03	-1.05	1.62	-1.03
	OCT	2.13	-0.89	1.79	-0.87
	NOV	2.19	-0.65	2.00	-0.96
	DEC	2.25	-0.81	2.14	-1.07
	ANNUAL	2.25	-1.37	2.14	-1.45

Table 5-11. DIFFERENCES BETWEEN OBSERVED AND PREDICTED DAILY MAXIMUM TIDAL LEVEL (PREDICTED ONE YEAR IN ADVANCE)

Subject Year	Season	Maximum Difference (m)	Average Difference (m)	Occurrence of Difference in Daily Maximum Tidal Level in One Year					
				Less than 0.1 m (day)	Less than 0.2 m (day)	Less than 0.3 m (day)	Less than 0.4 m (day)	Less than 0.5 m (day)	More than 0.5 m (day)
1978	Rainy Season	0.58	0.16	63	131	162	177	182	184
	Dry Season	0.32	0.09	128	165	180	181		
	Annual	0.58	0.12	191	296	342	358	363	365
1980	Rainy Season	0.38	0.11	97	158	178	184		
	Dry Season	0.45	0.13	83	141	171	179	182	
	Annual	0.45	0.12	180	299	349	363	366	
1983	Rainy Season	0.49	0.16	72	124	159	172	184	
	Dry Season	0.36	0.11	96	156	177	181		
	Annual	0.49	0.13	168	280	336	353	365	

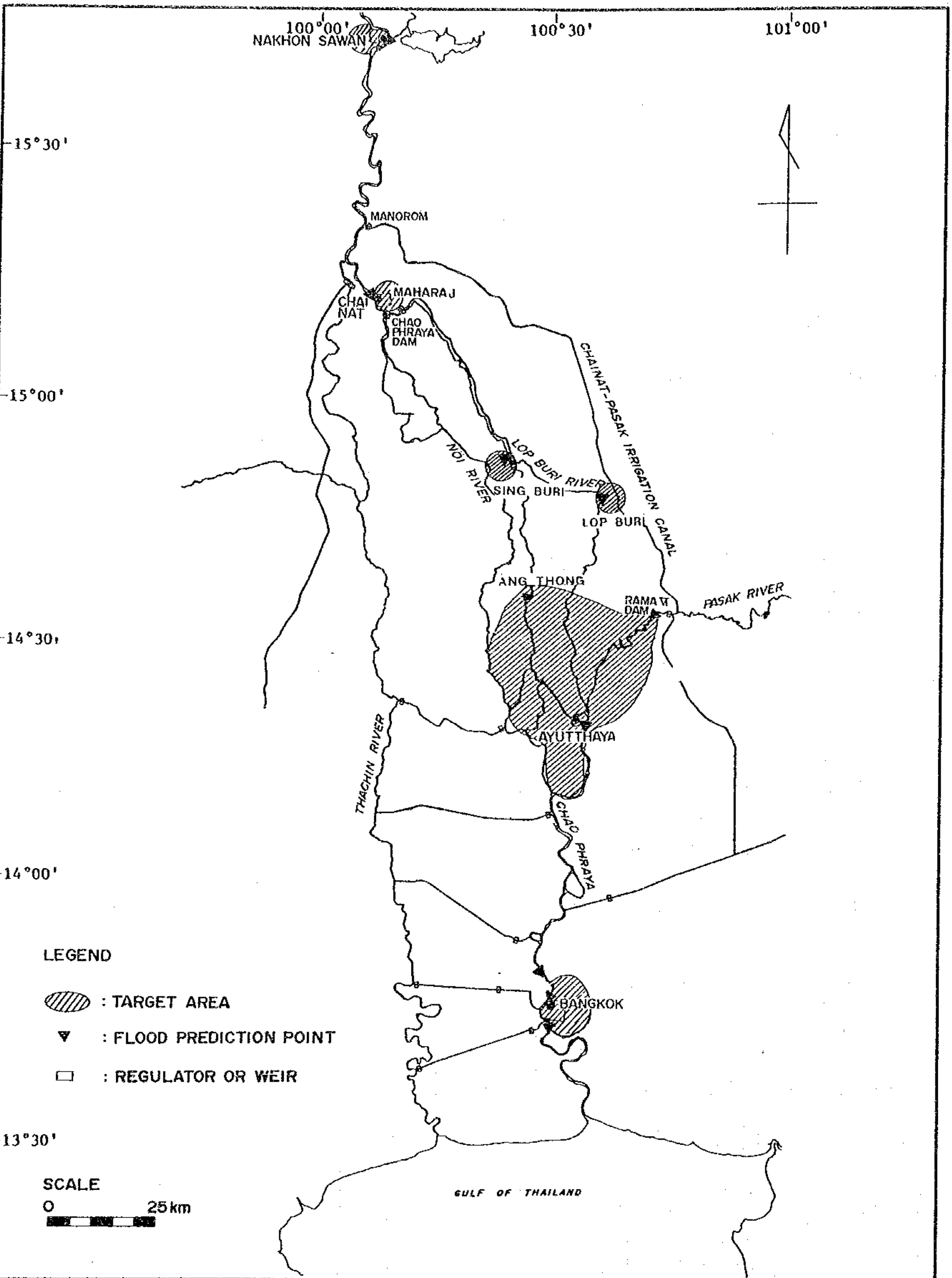


Fig. 5-1. TARGET AREA AND FLOOD PREDICTION POINT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

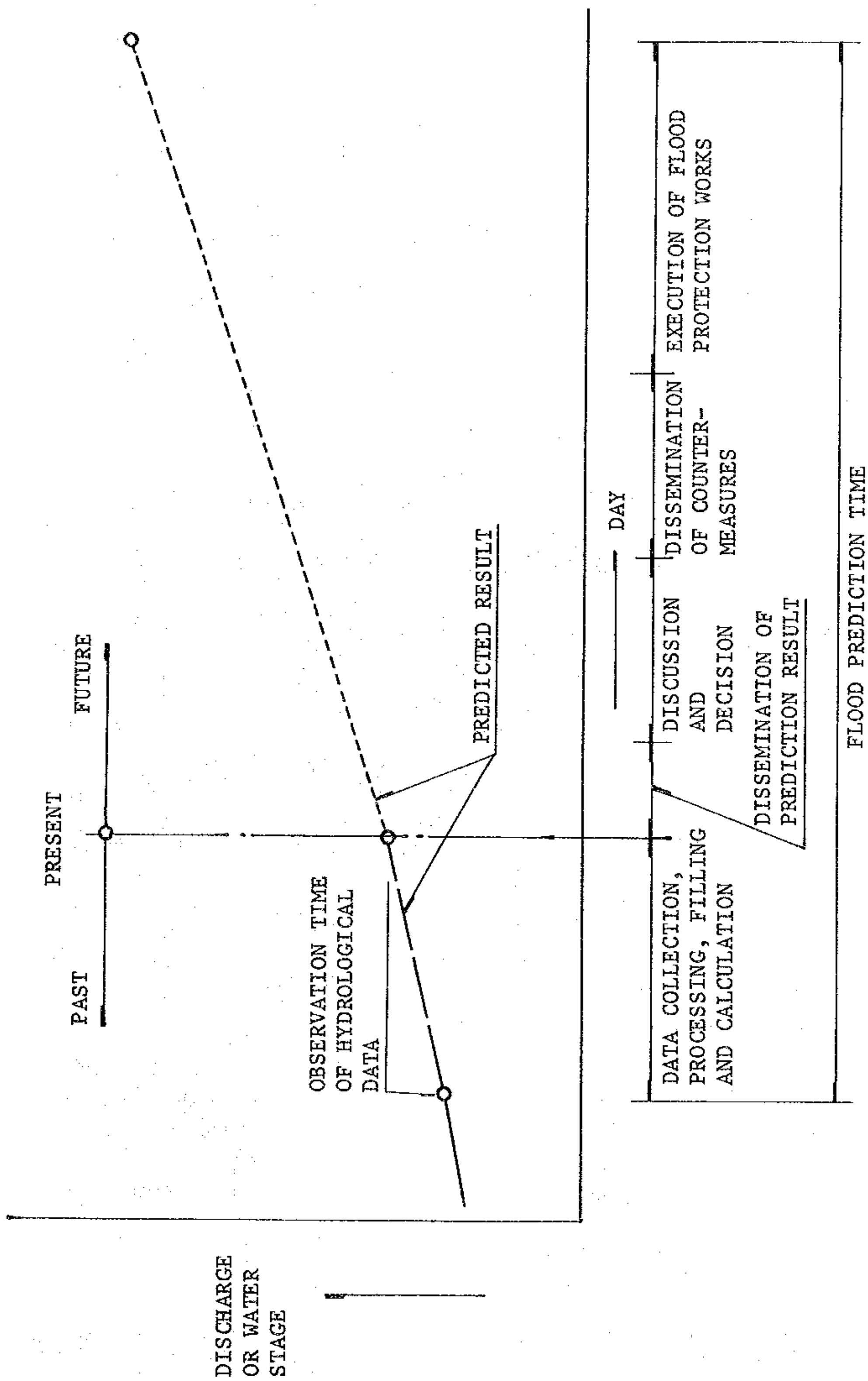


Fig. 5-2. WORKS TAKEN DURING FLOOD PREDICTION TIME

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

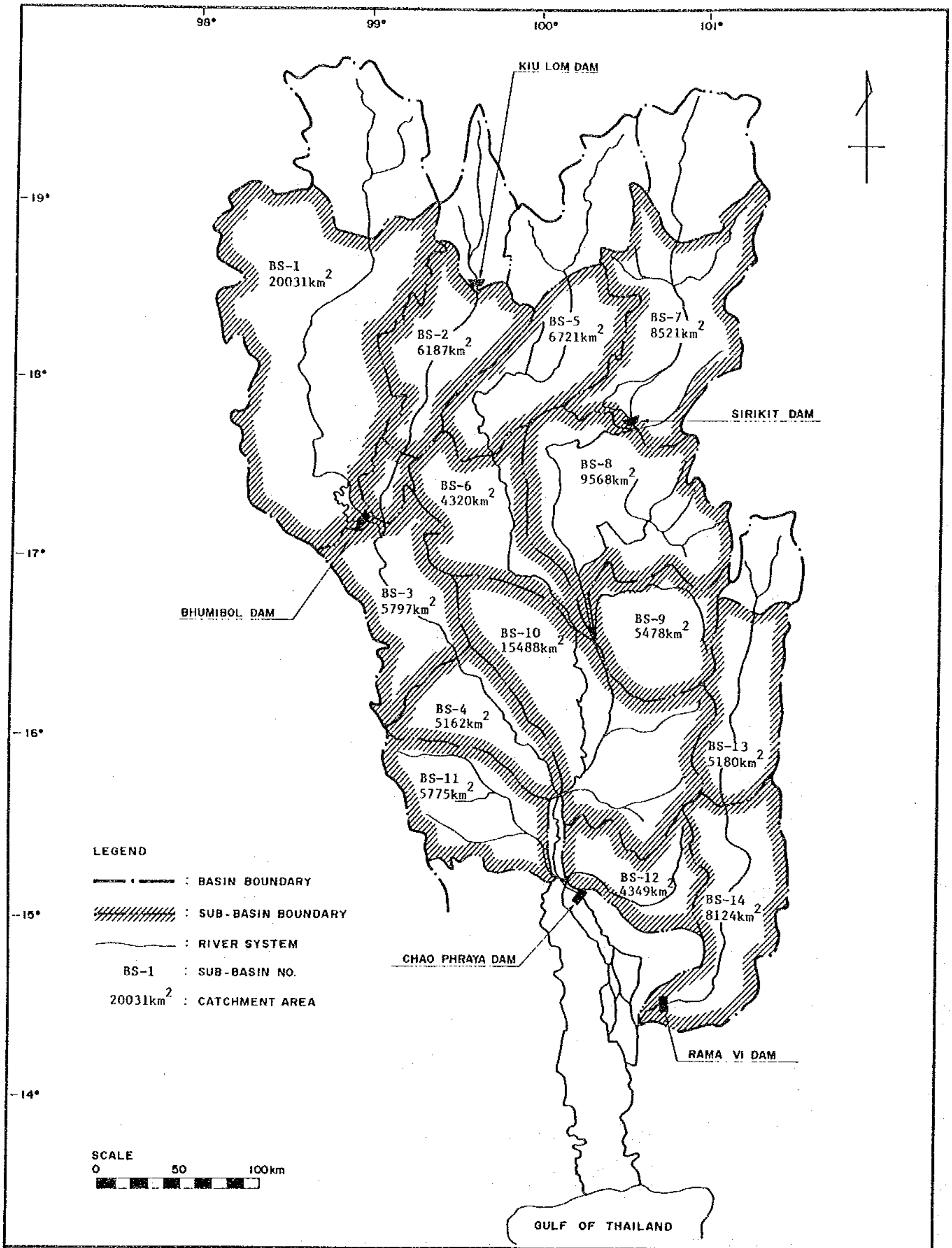


Fig. 5-3. SUB-BASIN BOUNDARY ASSUMED FOR FLOOD PREDICTION MODEL	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

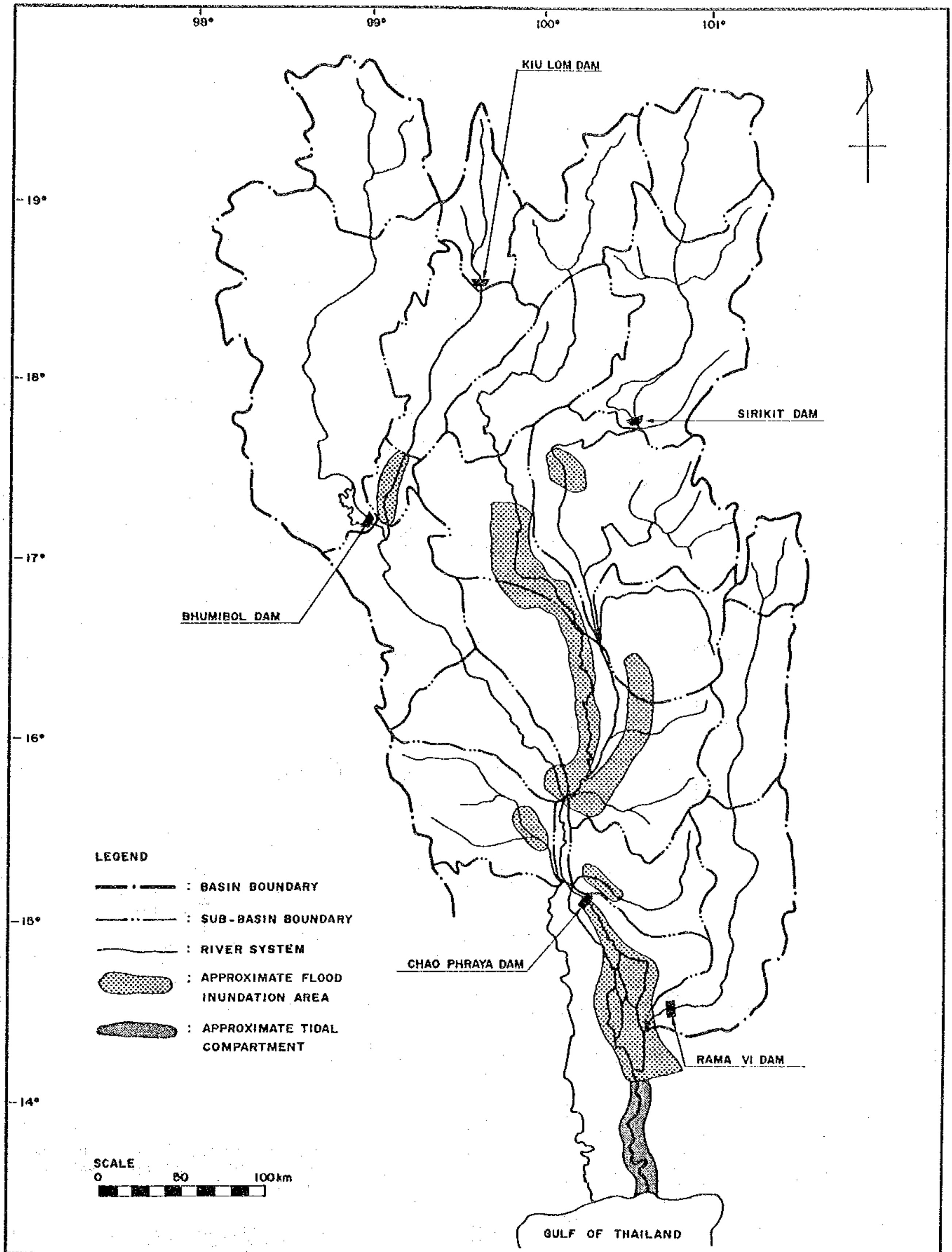


Fig. 5-4. FLOOD INUNDATION AREA AND TIDAL COMPARTMENT ASSUMED FOR FLOOD PREDICTION MODEL	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

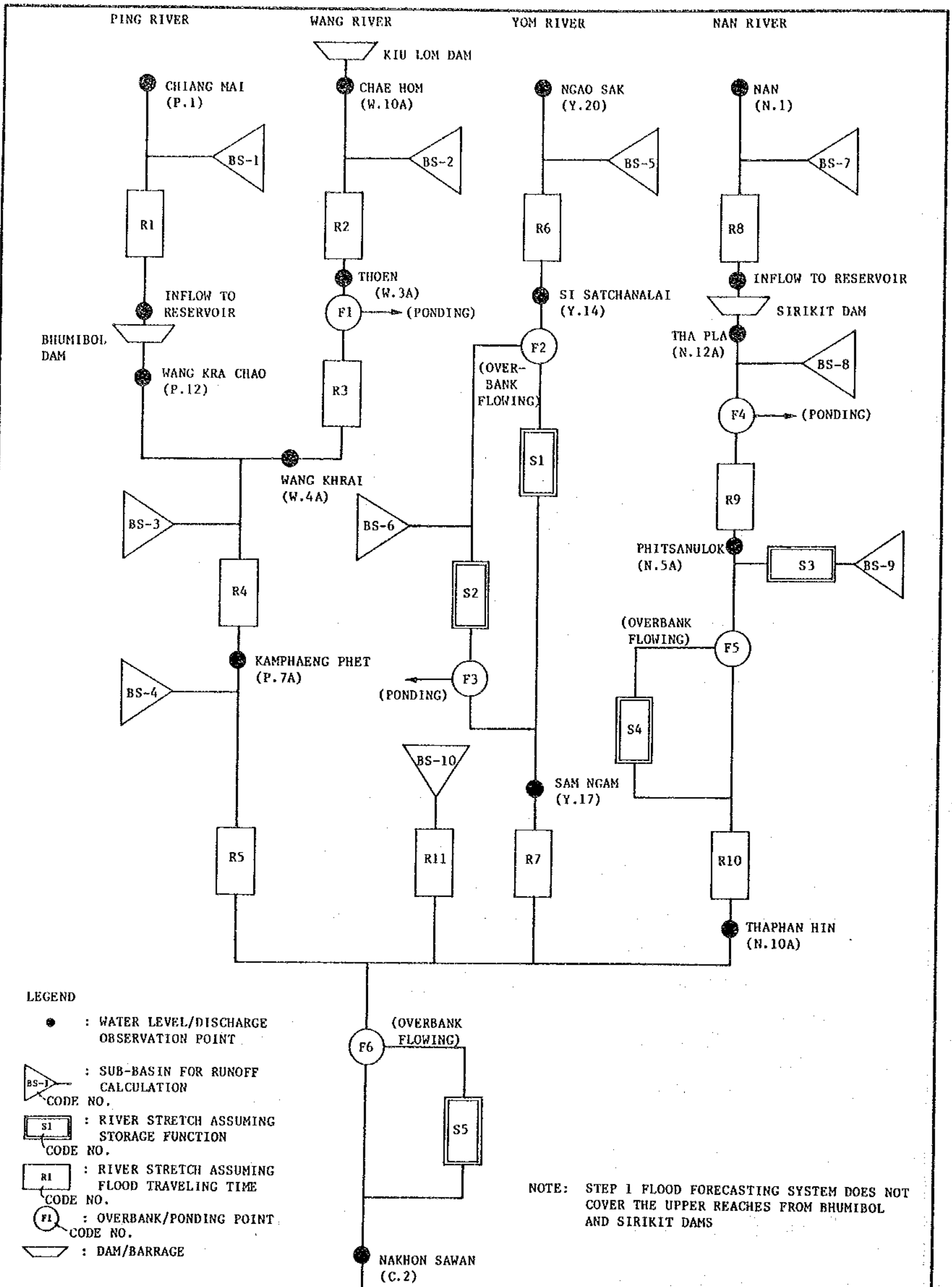


Fig. 5-5. FLOOD PREDICTION MODEL FOR UPPER REACHES FROM NAKHON SAWAN

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

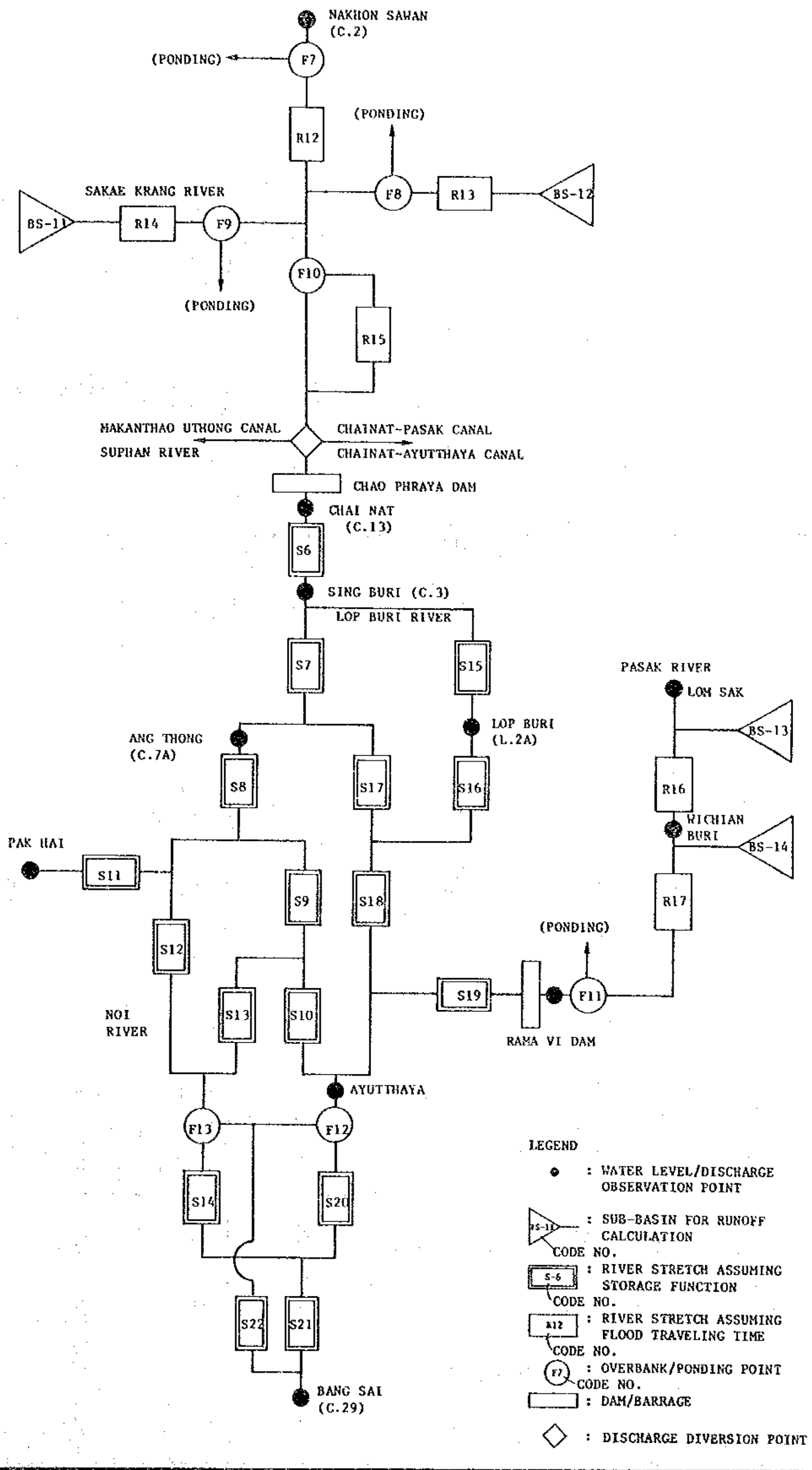


Fig. 5-6. FLOOD PREDICTION MODEL FROM NAKHON SAWAN TO BANG SAI

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

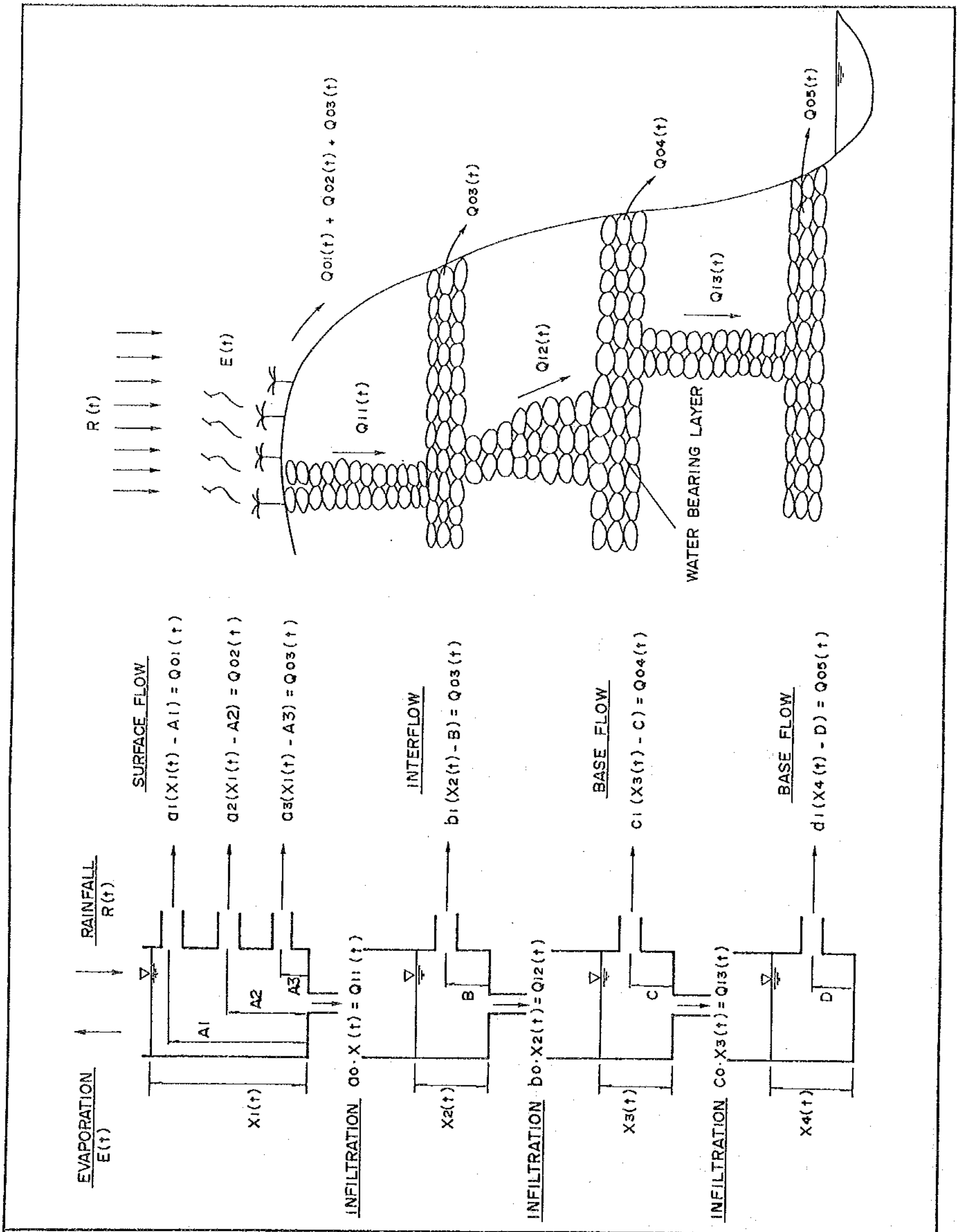
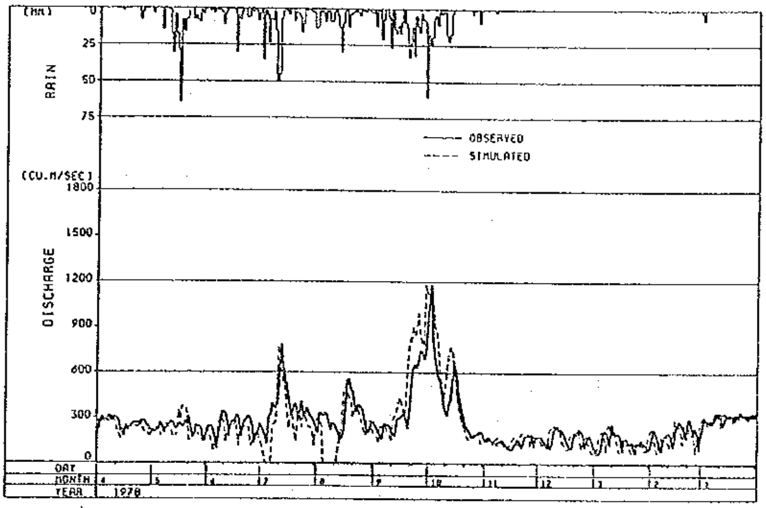
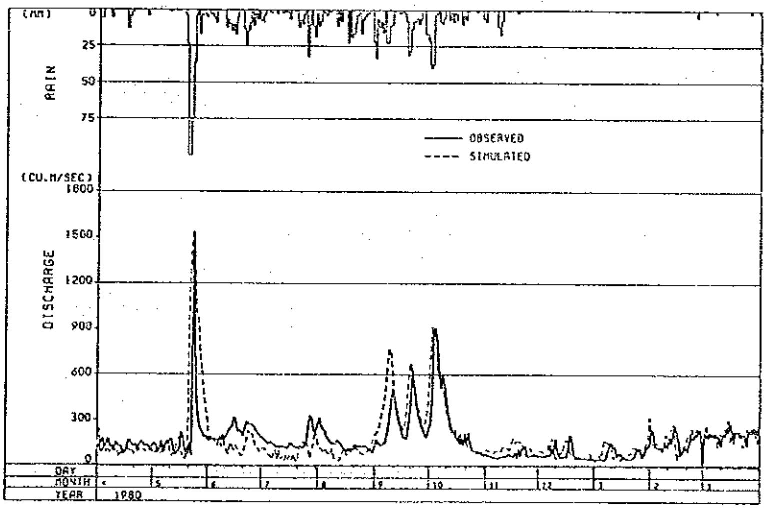


Fig. 5-7. SCHEMATIC DIAGRAM OF BASIN RUNOFF PREDICTION MODEL

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

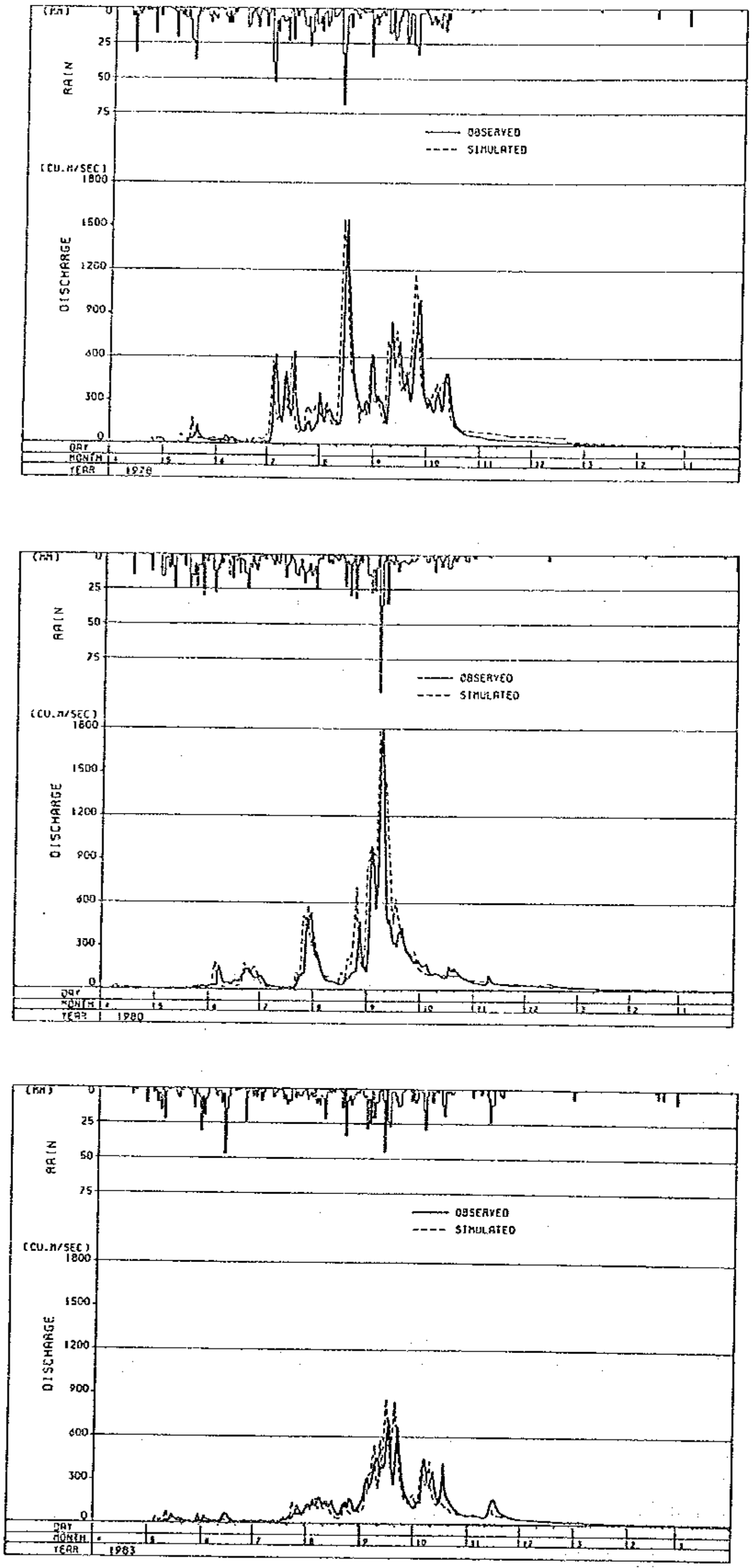
JAPAN INTERNATIONAL COOPERATION AGENCY





STA. P7A IN PING RIVER BASIN

Fig. 5-8(1/4). DISCHARGE HYDROGRAPH SIMULATED BY BASIN RUNOFF PREDICTION MODEL	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

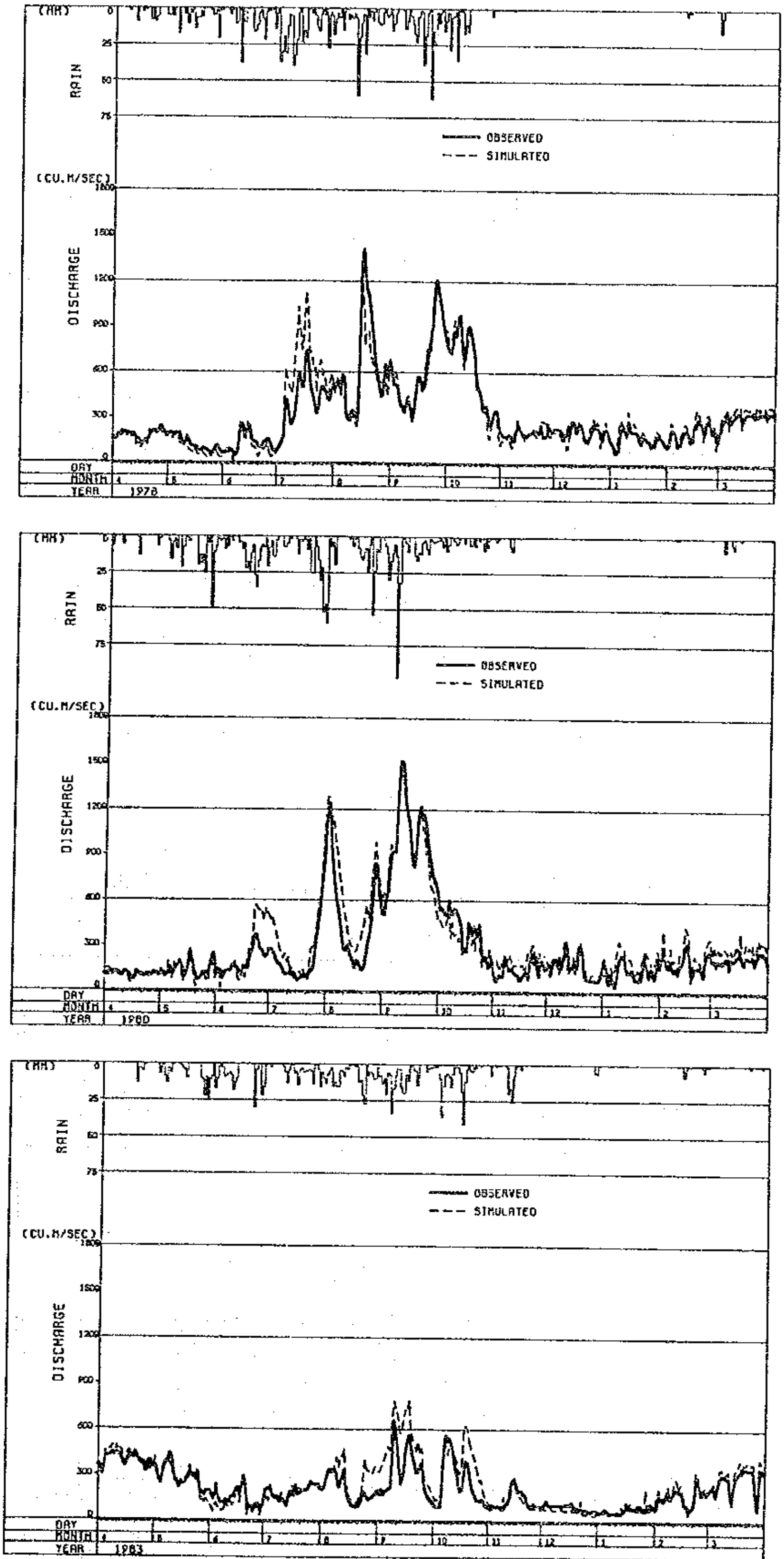


STA. Y14 IN YOM RIVER BASIN

Fig. 5-8(2/4). DISCHARGE HYDROGRAPH SIMULATED BY BASIN RUNOFF PREDICTION MODEL

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

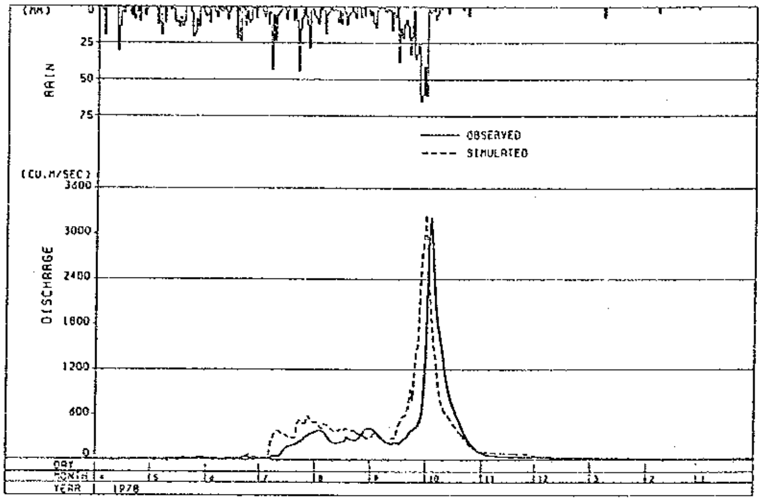


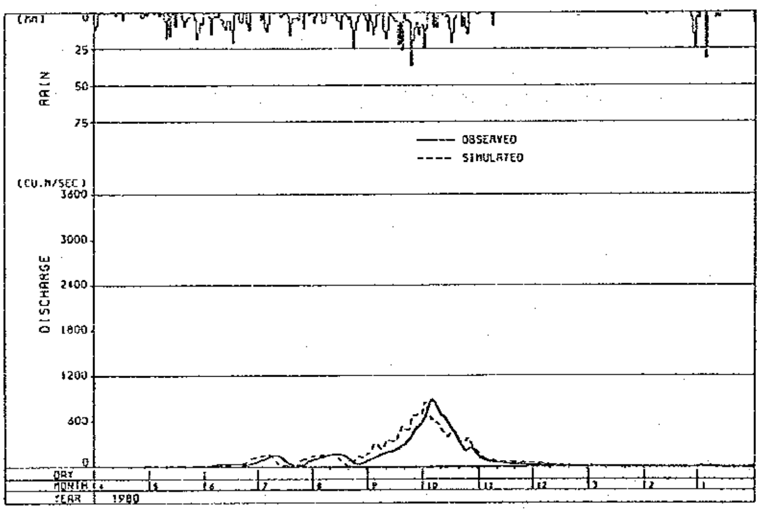
STA. N5A IN NAN RIVER BASIN

Fig. 5-8(3/4). DISCHARGE HYDROGRAPH SIMULATED BY BASIN RUNOFF PREDICTION MODEL

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY





STA. S9 IN PASAK RIVER BASIN

Fig. 5-8(4/4). DISCHARGE HYDROGRAPH SIMULATED BY BASIN RUNOFF PREDICTION MODEL	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

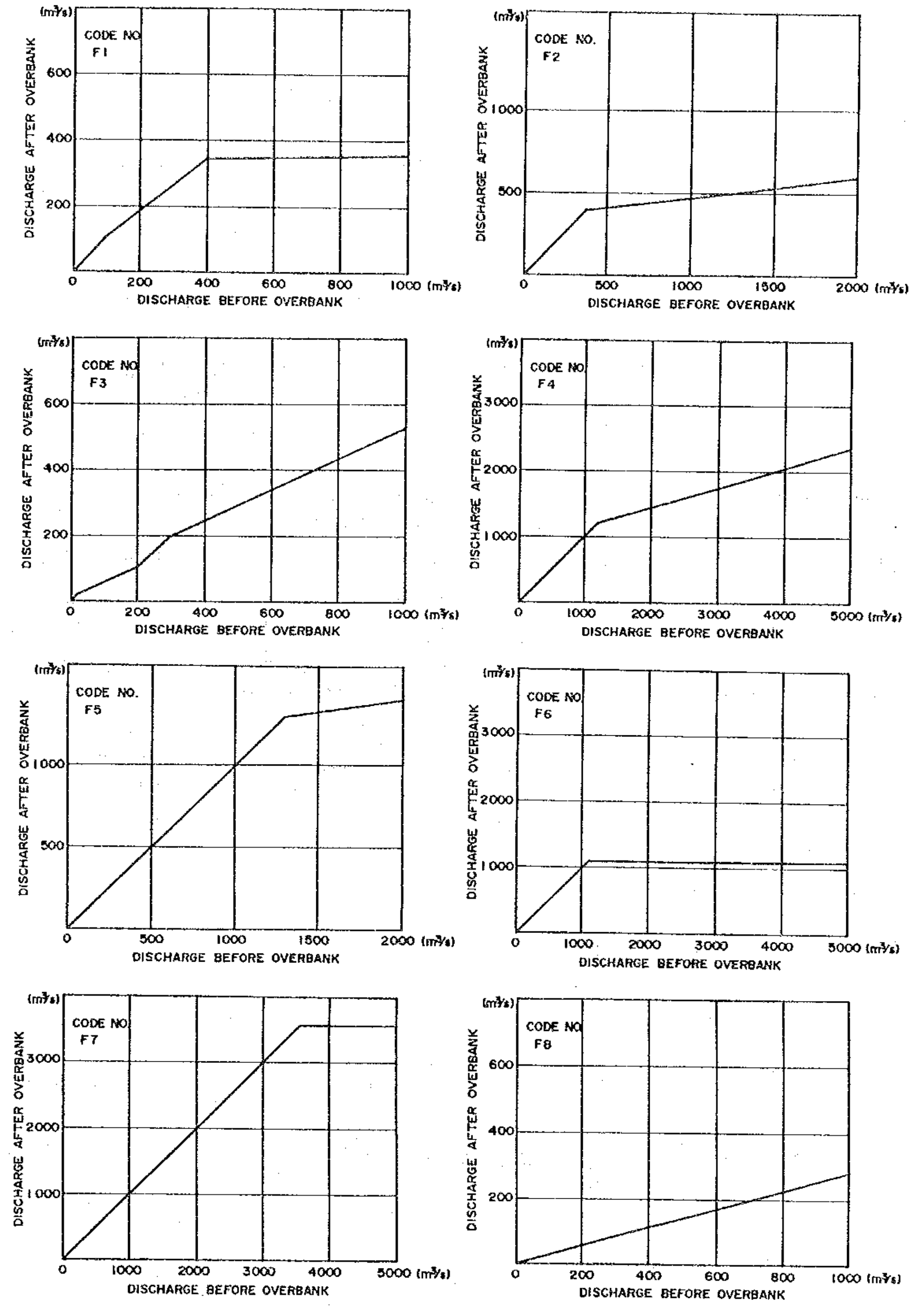


Fig. 5-9(1/2). RELATIONSHIP OF RIVER CHANNEL FLOW DISCHARGES BEFORE AND AFTER OVERBANK

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

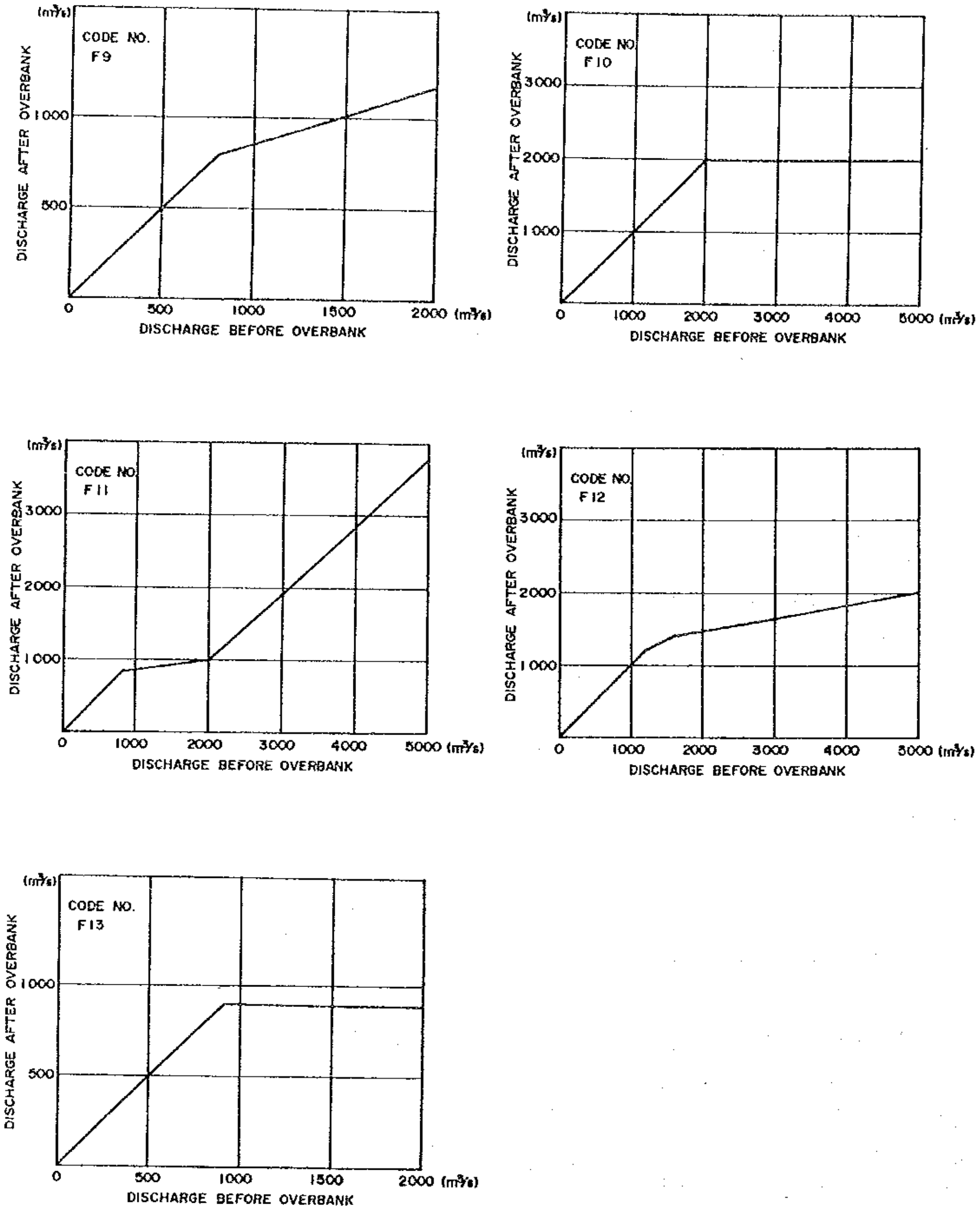


Fig. 5-9(2/2). RELATIONSHIP OF RIVER CHANNEL FLOW DIXCHARGES BEFORE AND AFTER OVERBANK	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

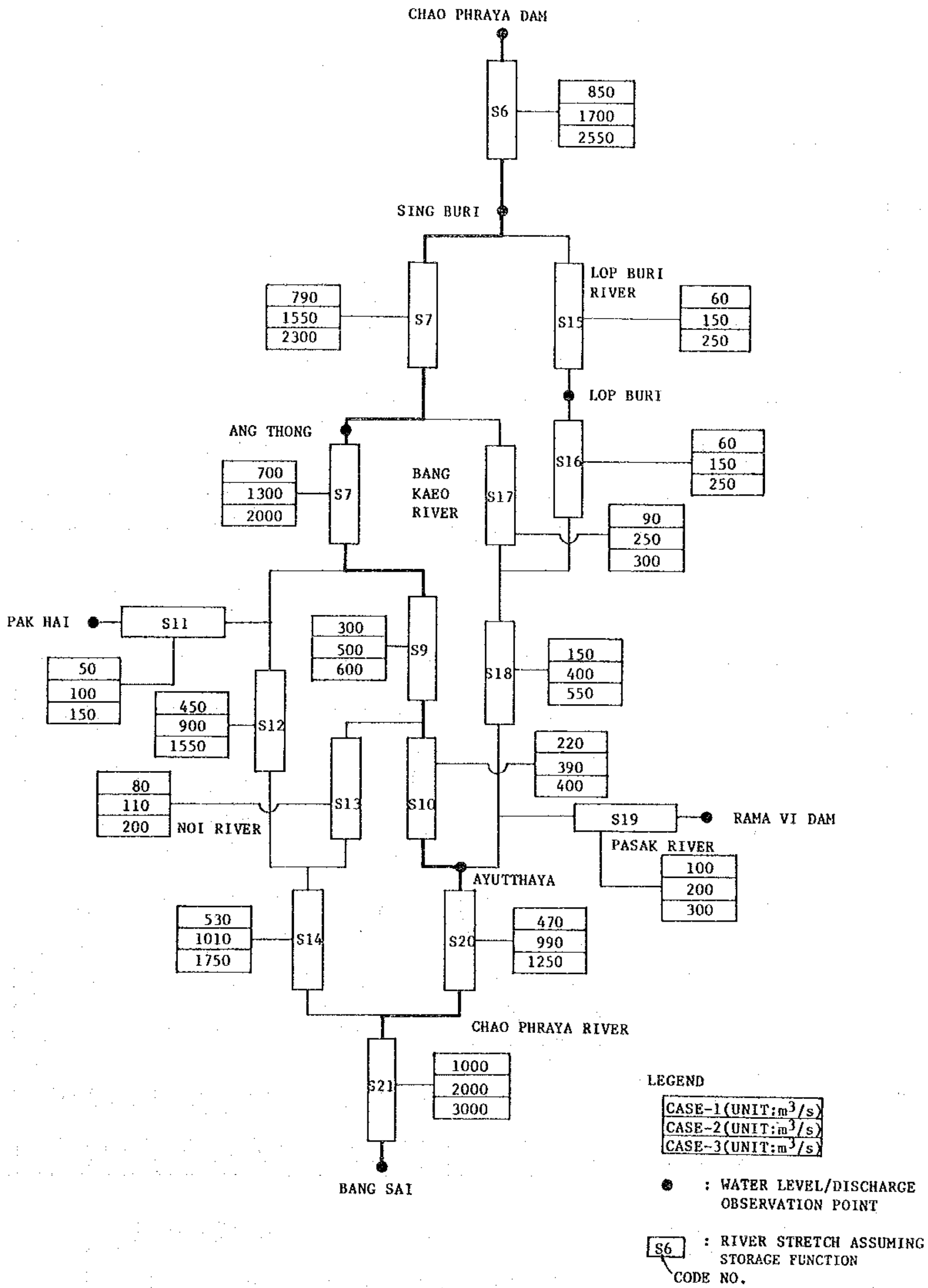
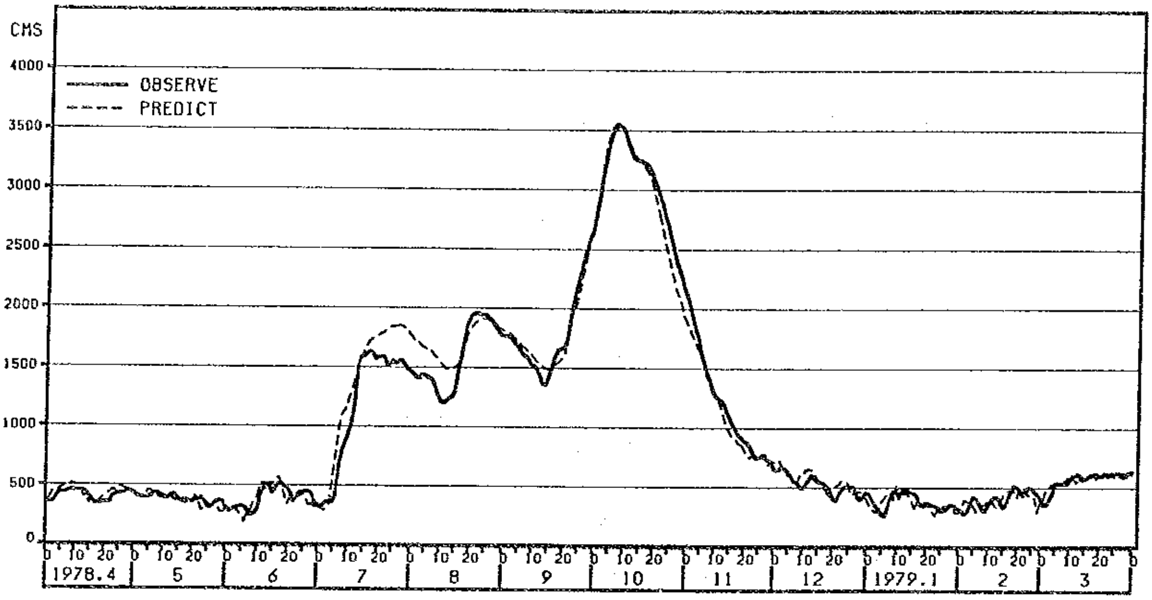


Fig. 5-10. DIVERSION RATIO OF FLOOD DISCHARGE AMONG SUBDIVIDED CHANNEL

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY



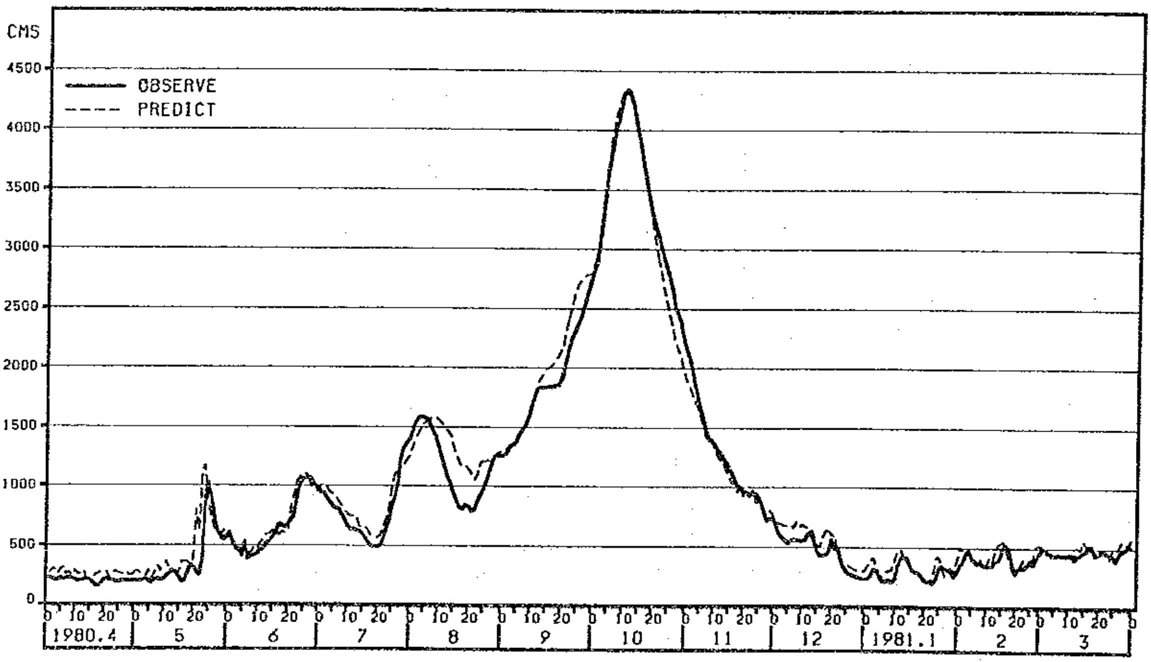


Fig. 5-11(1/4). DISCHARGE HYDROGRAPH SIMULATED AT NAKHON SAWAN

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

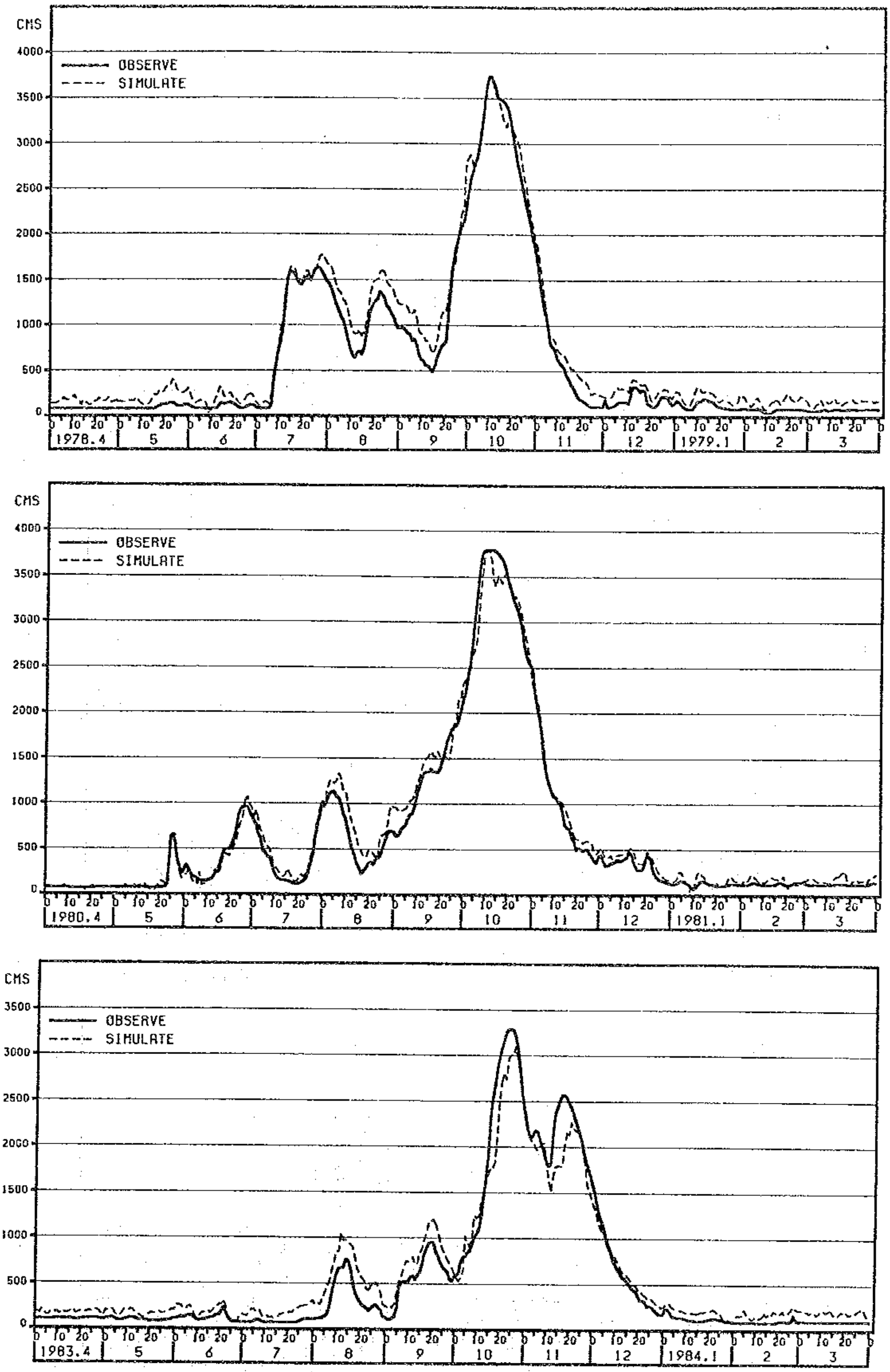


Fig. 5-11(2/4). DISCHARGE HYDROGRAPH SIMULATED AT CHAI NAT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

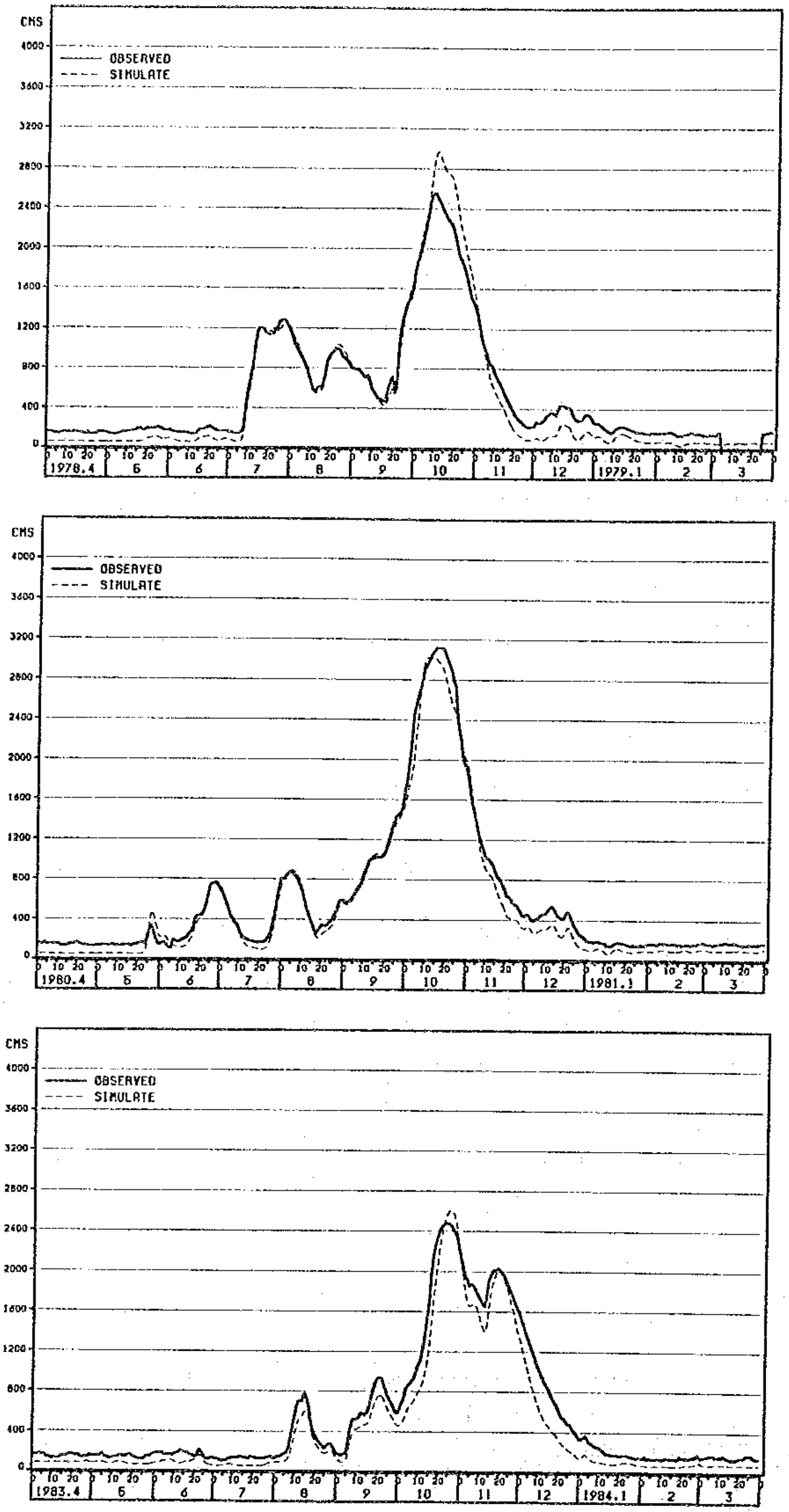
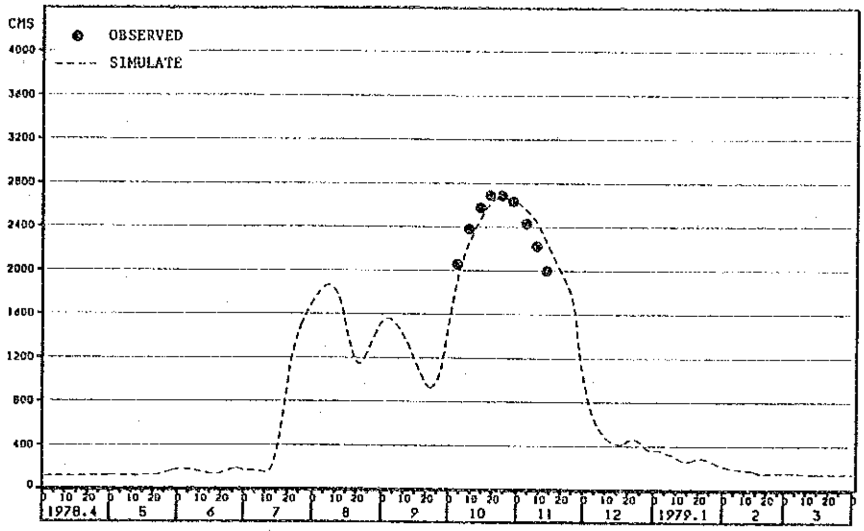
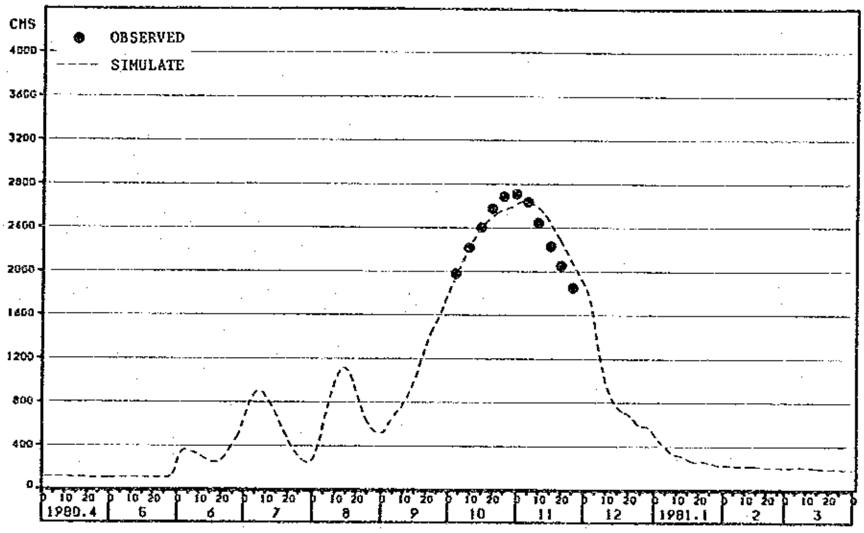


Fig. 5-11(3/4). DISCHARGE HYDROGRAPH SIMULATED AT ANG THONG	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY





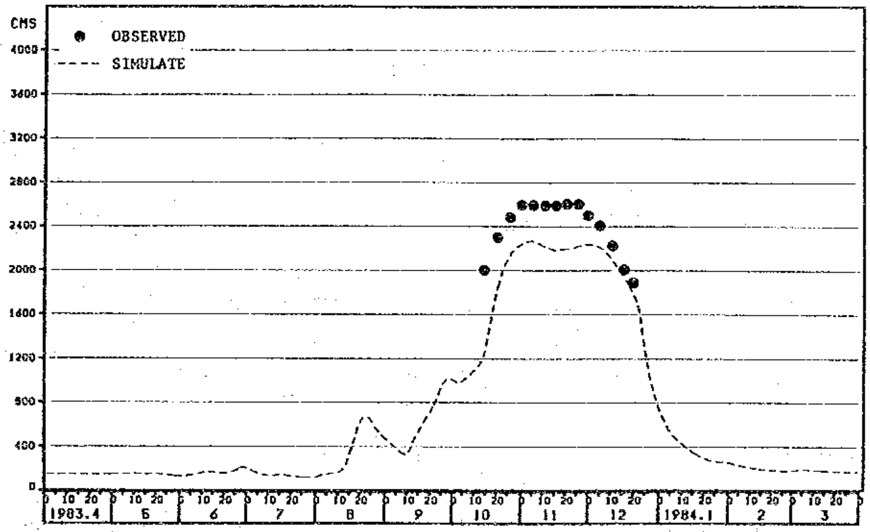


Fig. 5-11(4/4). DISCHARGE HYDROGRAPH SIMULATED AT BANG SAI

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

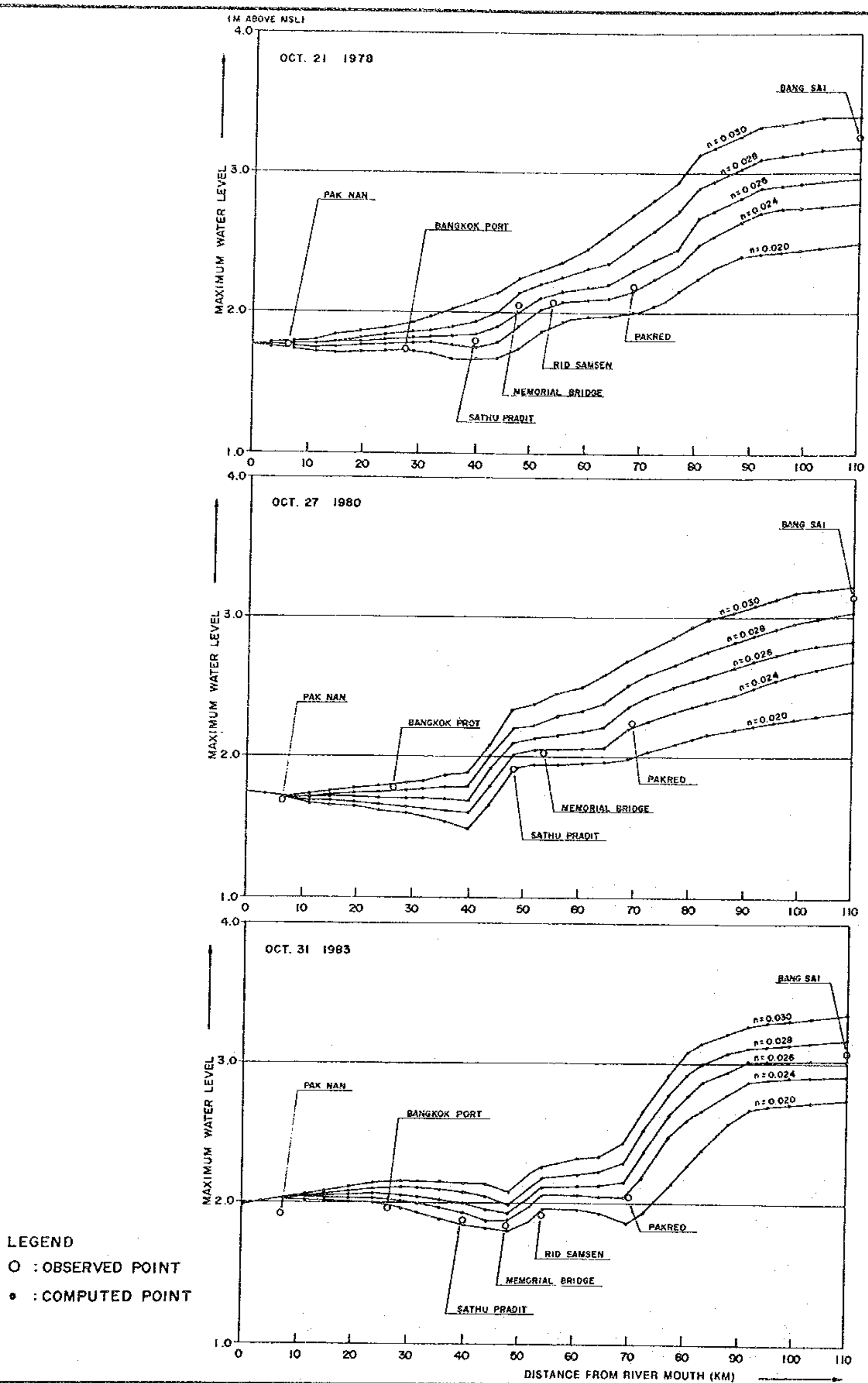


Fig. 5-12. EFFECTS OF MANNING ROUGHNESS COEFFICIENTS ON COMPUTED MAXIMUM WATER STAGE	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN
	JAPAN INTERNATIONAL COOPERATION AGENCY

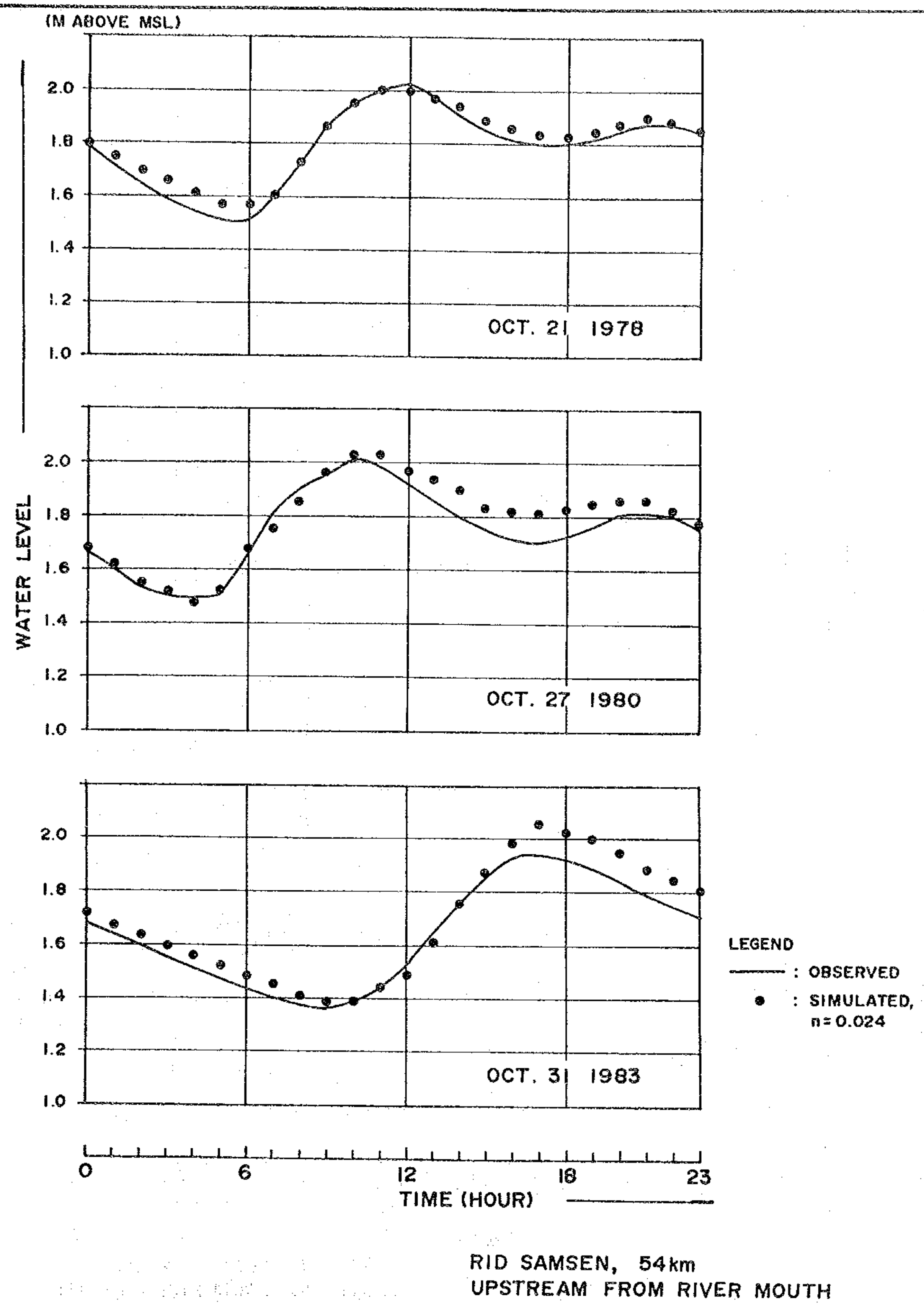


Fig. 5-13(1/3). OBSERVED AND SIMULATED WATER LEVEL HYDROGRAPH FOR TIDAL COMPARTMENT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

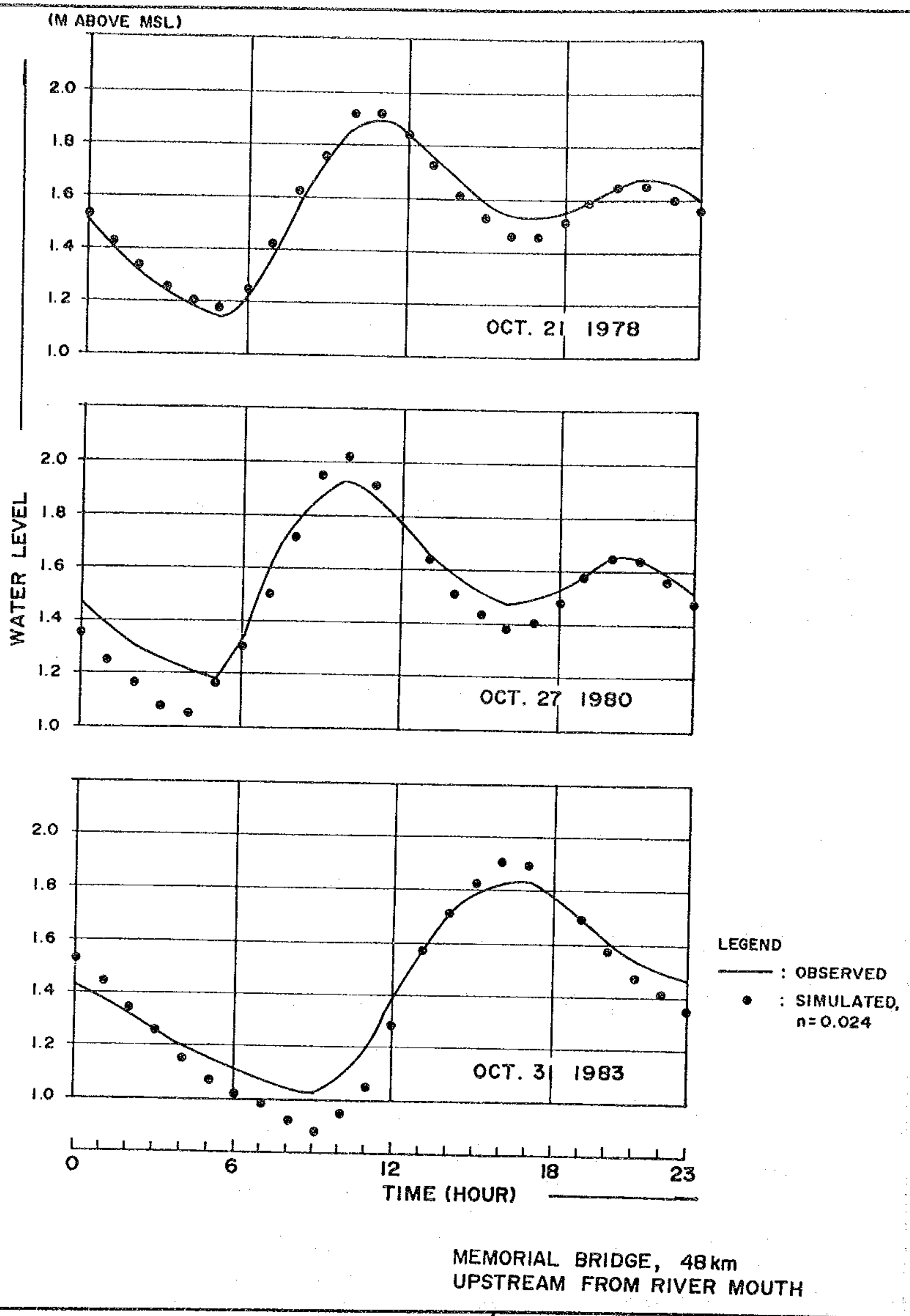


Fig. 5-13(2/3). OBSERVED AND SIMULATED WATER LEVEL HYDROGRAPH FOR TIDAL COMPARTMENT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

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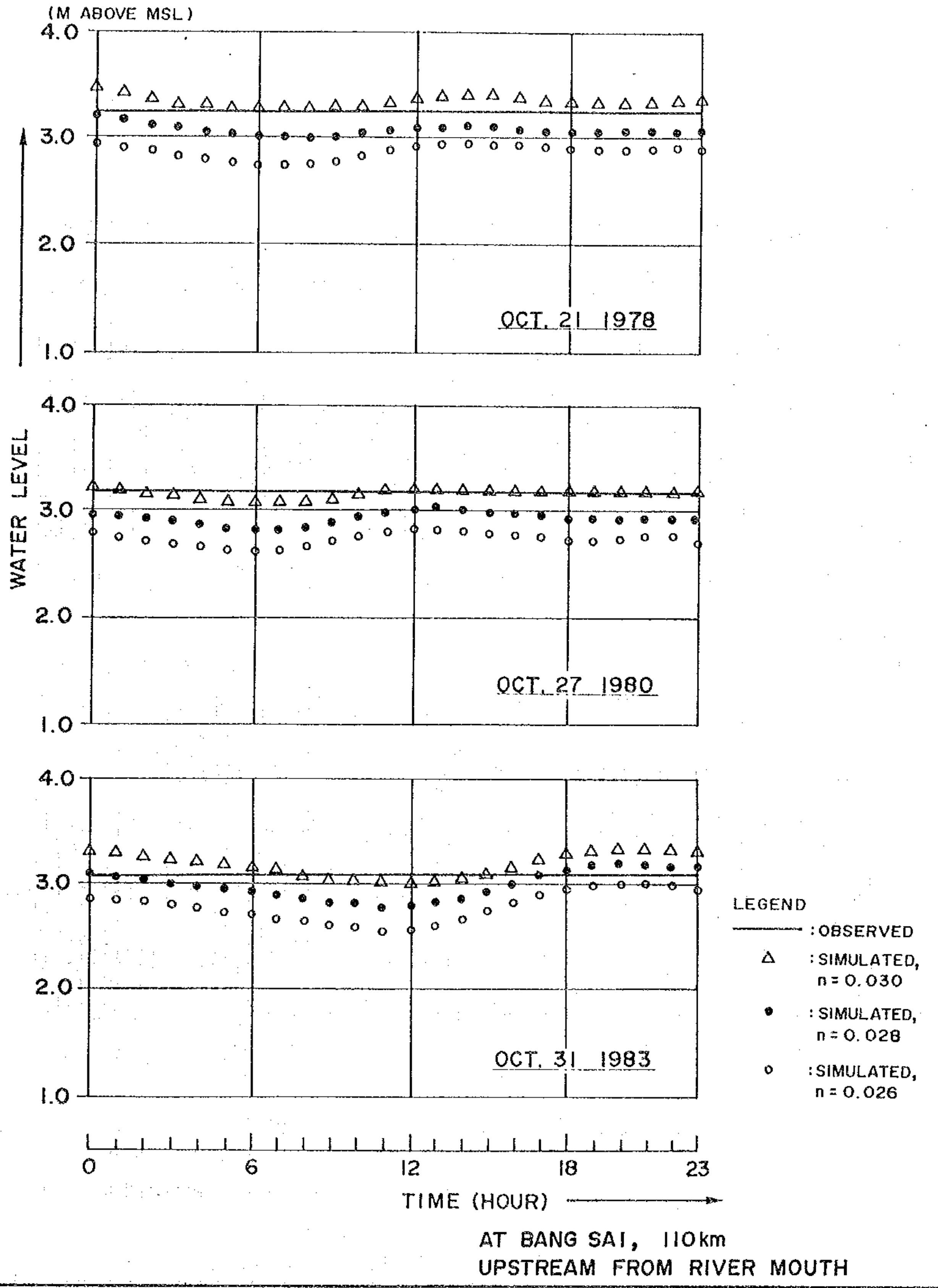
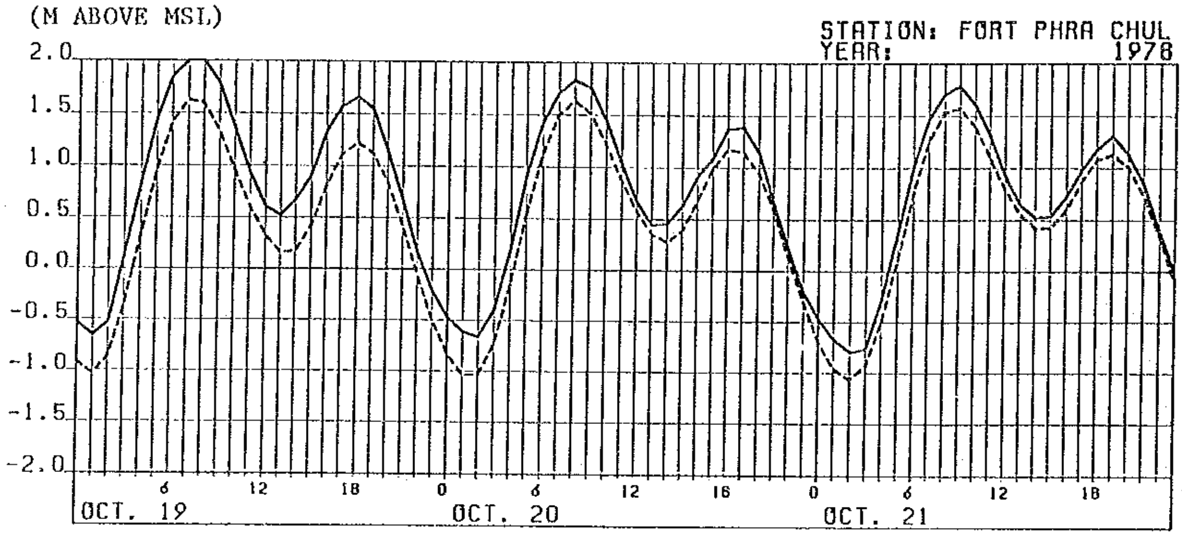
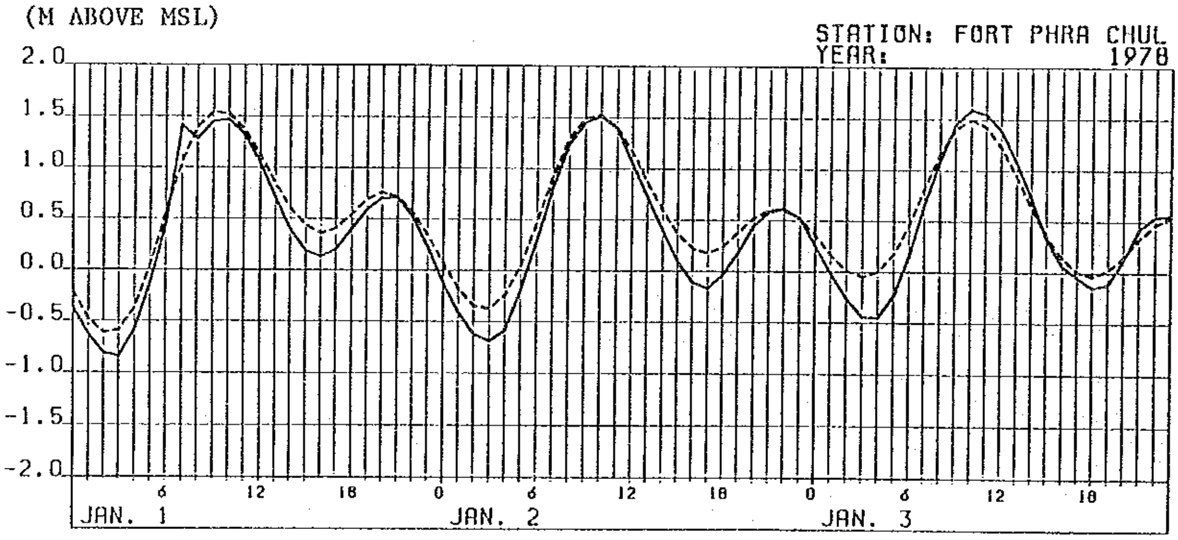


Fig. 5-13(3/3). OBSERVED AND SIMULATED WATER LEVEL HYDROGRAPH FOR TIDAL COMPARTMENT

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY



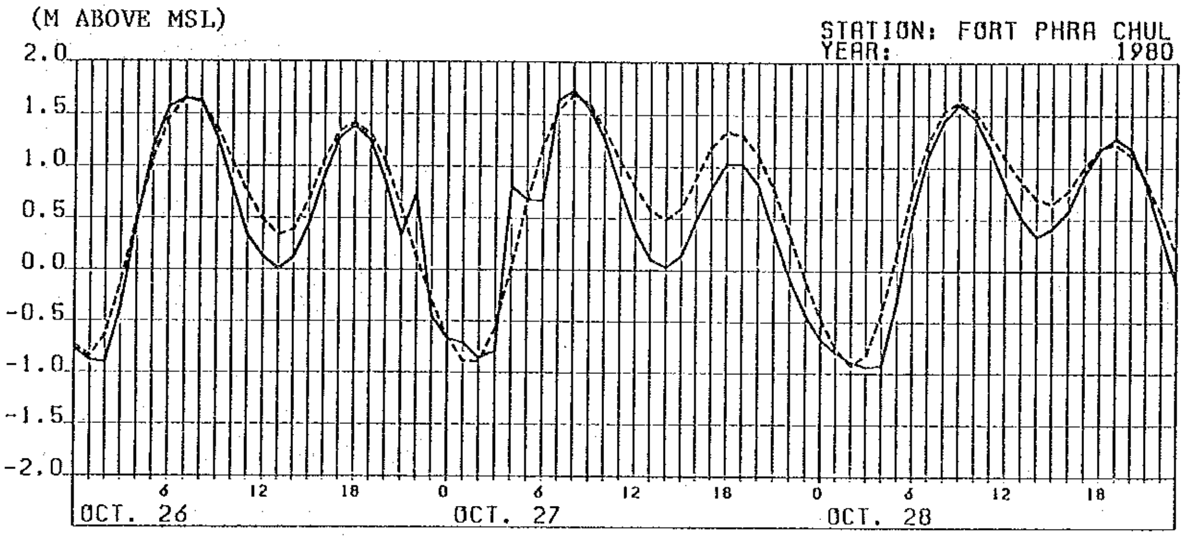


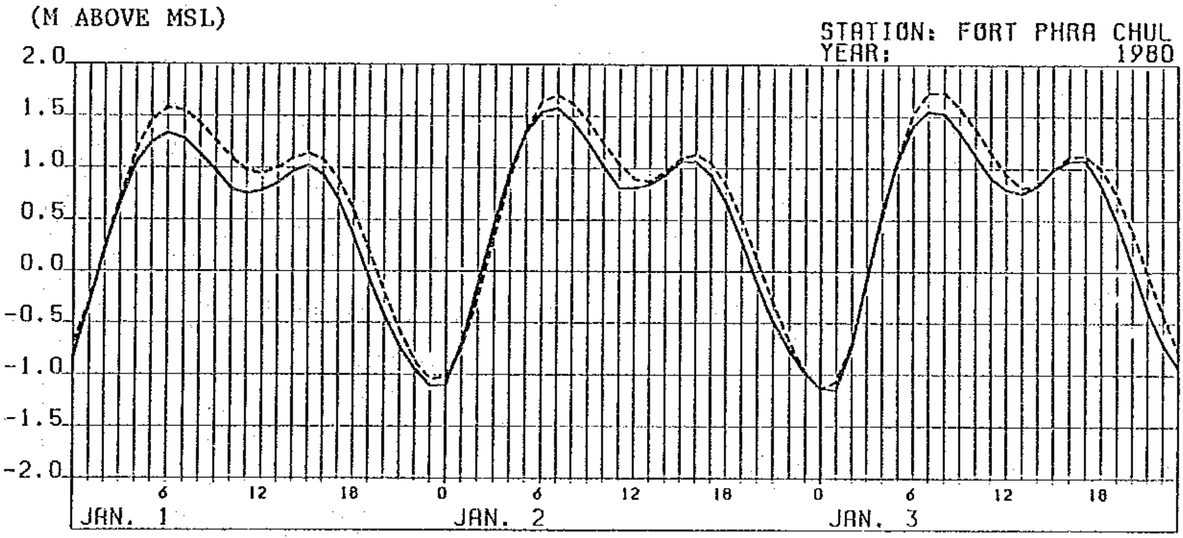
LEGEND

——— : OBSERVED

------ : PREDICTED

Fig. 5-14(1/3). HOURLY VARIATION OF TIDAL LEVEL (IN 1978)



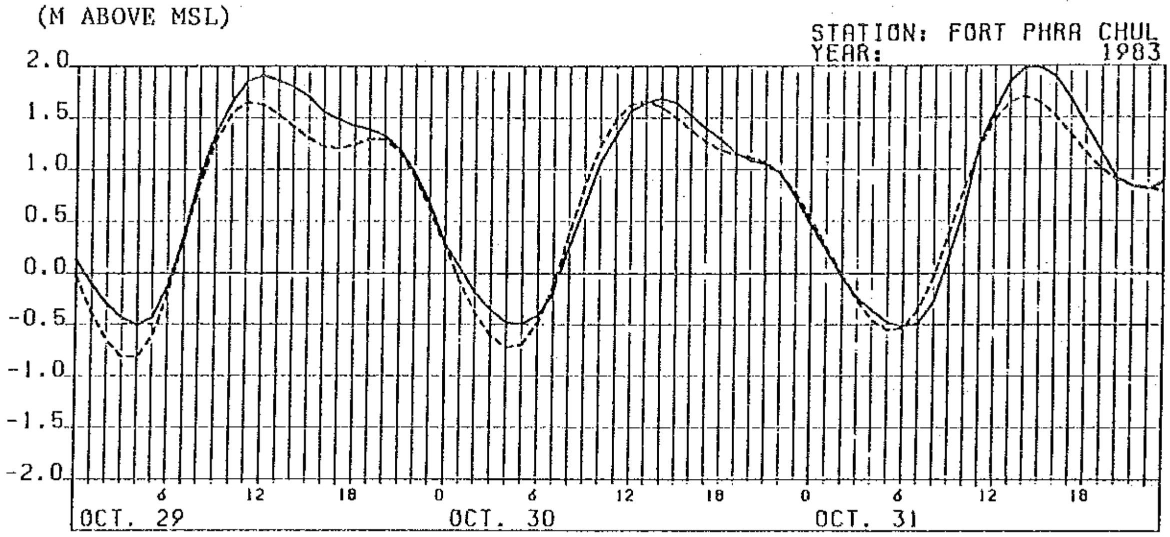


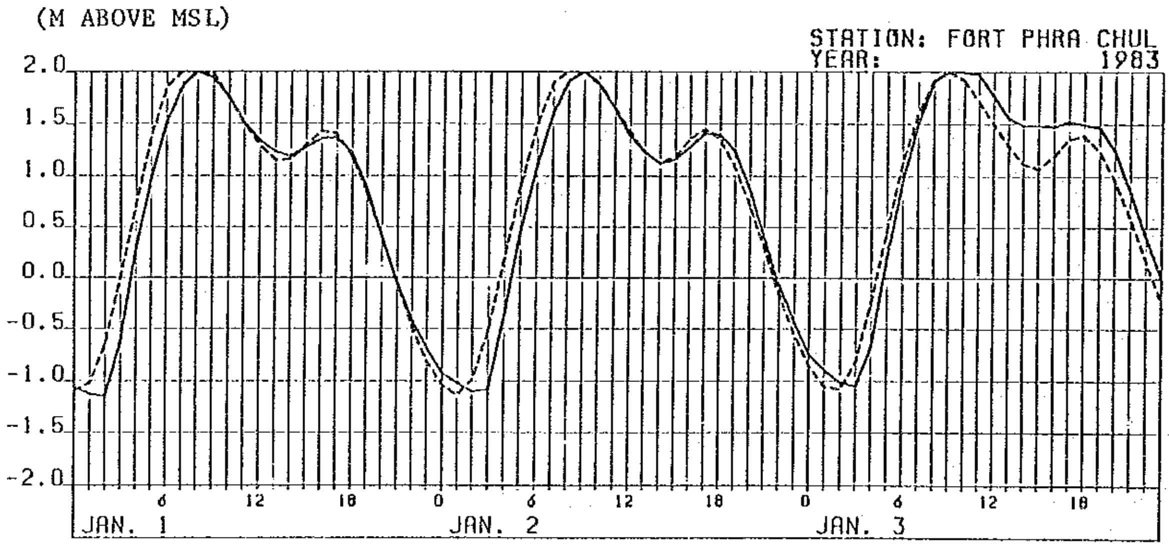
LEGEND

——— : OBSERVED

----- : PREDICTED

Fig. 5-14(2/3). HOURLY VARIATION OF TIDAL LEVEL (IN 1980)	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY





LEGEND

——— : OBSERVED

- - - - - : PREDICTED

Fig. 5-14(3/3). HOURLY VARIATION OF TIDAL LEVEL (IN 1983)

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

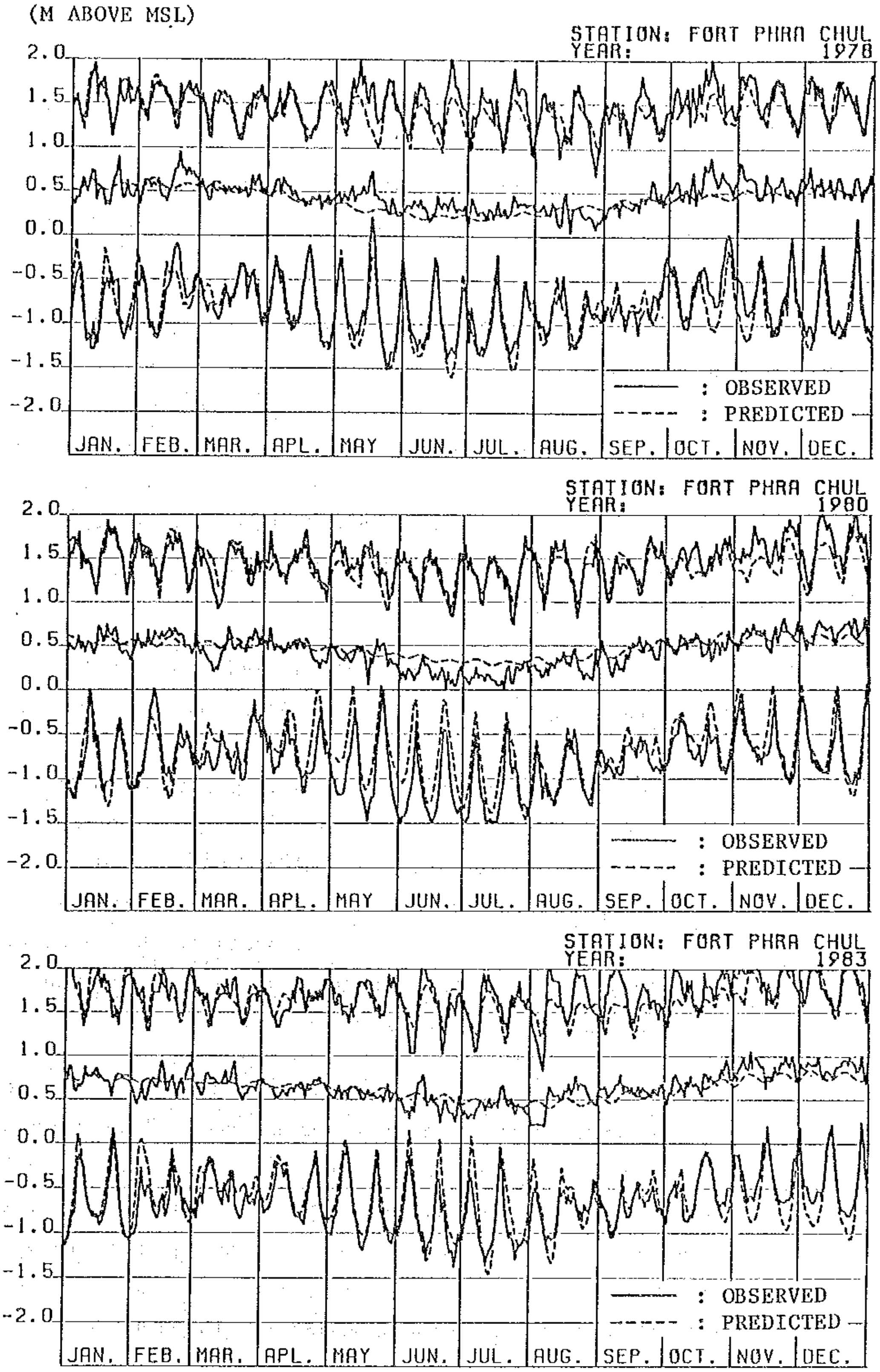


Fig. 5-15. DAILY VARIATION OF ONE-DAY MAXIMUM, AVERAGE AND MINIMUM TIDAL LEVEL	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 6. FLOOD FORECASTING SYSTEM BASED ON EXISTING FACILITIES (STEP 1)

6.1 Principles of Formulation

In accordance with the concept of project formulation in Chapter 4, the principles of formulation are stipulated as follows:

(1) Hydrological gauging stations for the Step 1 Flood Forecasting System are selected from the existing stations located at essential points to predict runoff condition in the target area. Supplemental stations will be installed only in areas with no available station and where flood runoff discharge is expected to drastically influence the flooding condition at the target area.

(2) The selected stations are classified into two groups from the viewpoint of available telecommunication network, namely, the stations with telecommunication network and those without telecommunication network. In the former group, the currently used telecommunication network will be applied with minor rehabilitation, if necessary. As for the latter group, the telecommunication system will be set up on the basis of the currently used facilities so as to establish the most convenient and effective system of communication.

(3) Although RID has been operating a computer system for use in irrigation water management and is planning to introduce additional computer systems, their availability for use in this flood forecasting system is expected to be limited. Therefore, the study is made on the premise that the said computer system is not applicable to this flood forecasting system.

(4) The flood prediction results will be disseminated to agencies concerned such as BMA, EGAT and LAD by using

the appropriate method based on the currently used facilities.

6.2 Formulation of Proposed Flood Forecasting System

6.2.1 Data Collection

Hydrological data are to be collected by water level and rainfall gauging stations. Hydrological observation points for use in the proposed flood prediction models are to be selected in consideration of their strategic locations. Special attention is to be paid to the selection so as to immediately set up the Step 1 Flood Forecasting System and maintain it until the proposed Step 2 Flood Forecasting System has been established. In this connection, the following conditions have been taken into account:

(1) Availability for immediate and effective use of existing gauging facilities and their existing data transmission facilities with least rehabilitation or modification; and

(2) Applicability of the organization operating the existing gauging facilities.

Correspondingly, 31 water level gauging stations which include a tidal gauging station and 34 rainfall gauging stations have been selected from the gauging stations operated by RID, the Meteorological Department (MD) and the Port Authority of Thailand (PAT). The details of the proposed gauging stations are described hereinafter, and their inventory and location are in Tables 6-1 and 6-2, and in Fig. 6-1.

<u>Selection of Water Level Gauging Stations</u>

The water level gauging points were selected in view of the following necessities of their gauging data:

(1) To calibrate the initial conditions for the simulations in the flood prediction models (refer to Table 6-3).

(2) To input the boundary condition in terms of runoff discharges observed in the upper reaches (refer to Table 6-4);

(3) To accommodate the basic data for the tidal prediction in the Gulf of Thailand; and

(4) To monitor the water level/discharges at the respective prediction points (refer to Table 6-3).

In the selection, the availability of the existing gauging stations has been considered. Priority was given to the existing gauging stations operated by the Hydrology Division of RID, since most of the necessary gauging points are located at these stations. The water levels gauged by the Division are, however, presently transmitted by mail to the RID Head Office in Bangkok which needs to be replaced by a more suitable and quicker data transmission method useful for the flood prediction purpose. Furthermore, the existing hydrological observation of the Hydrology Division contains blind spot areas in the Pasak and the Sakae Krang river basins.

In view of the blind spot areas, the two existing gauging stations operated by the Meteorological Department have been selected for gauging in the middle reaches of the Pasak River Basin. As for the Sakae Krang River Basin, it is proposed to resume the water level gauging and discharge measurement at Sta. Ct8 previously operated by the Hydrology Division of RID, the gauging works of which were suspended since 1980. In addition to the river flow gauging, the tidal level in the Gulf of Thailand is further proposed to be gauged at Fort Phra Chul which is operated by the Port Authority of Thailand.

Selection of Rainfall Gauging Stations

Rainfall gauging stations will be used to estimate the areal average rainfall for the 12 subbasins where the Basin Runoff Prediction Model is applied. It is herein noted that 14 subbasins are finally proposed as the objectives of the model calculation in the Step 2 Flood Forecasting System, while 2 subbasins covering the catchment areas of the Bhumibol and Sirikit dams (Basin Code No. BS-1 and BS-7) are excluded from the objectives in the Step 1 Flood Forecasting System assuming that the discharge released from the dams are given to the model calculation as boundary conditions.

In the selection of the proposed gauging stations, priority has been given to the availability of the existing gauging facilities, as well as the data transmission facilities. Correspondingly, the stations have been selected as follows (refer to Table 6-5):

(1) The 10 rainfall gauging stations located nearby the water level gauging stations selected in the foregoing, considering that the data transmission facilities employed by the water level gauging stations can be used in common with these rainfall gauging stations; and

(2) The 18 rainfall gauging stations attached to either the Meteorological Department or the regional offices of RID which are presently able to transmit the gauged data to their head offices in Bangkok within one day through their own existing data transmission facilities.

In the selection made above, the rainfall gauging points could be rather uniformly distributed in the respective subbasins, except the Sakae Krang River Basin. To make up for the lack of gauging stations in the Sakae Krang River Basin, six (6) gauging points have been additionally selected from the existing gauging stations operated by the Hydrology Division of RID, which solely exist in the basin but do not possess the available data transmission system. Therefore, the selected